

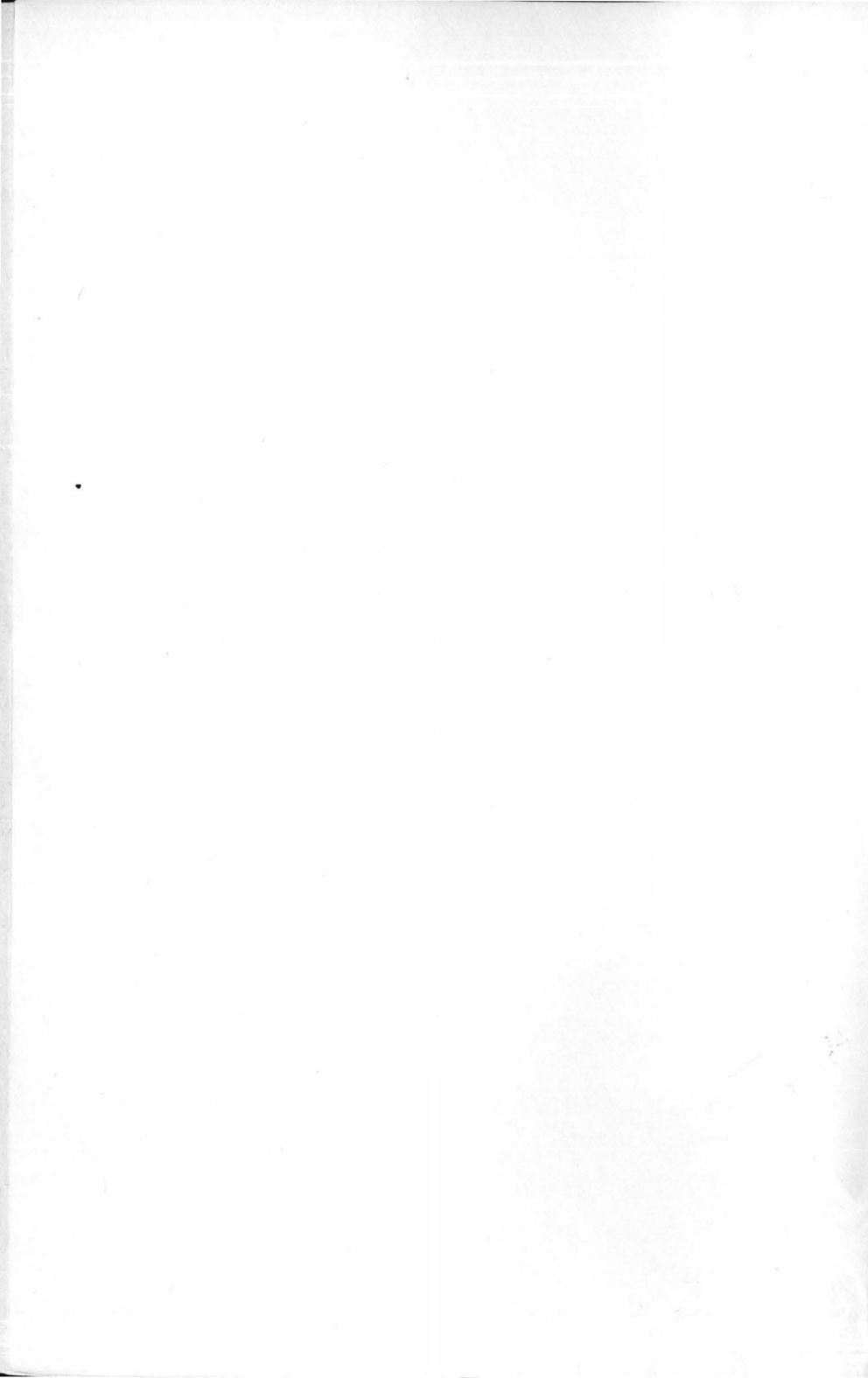
CONCRETE PRACTICE IN IRELAND 1975

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SEPTEMBER 1975



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CONCRETE PRACTICE IN IN IRELAND 1975



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held at University College Dublin
in September 1975**

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FOREWORD

PROFESSOR J. C. I. DOOGE, M.E., M.SC., F.I.E.I., F.I.C.E.,
F.A.S.C.E.

Professor of Civil Engineering, University College, Dublin.

The Proceedings in this volume relate to the second Symposium held in University College, Dublin on the subject of "Concrete Practice in Ireland". The success of the first Symposium held in 1965 was a major factor in the decision to organise the second Symposium which was held from the 11th - 13th September, 1975. Those who attended the second Symposium, or who read the proceedings in this volume, will surely agree with the opinion that the series launched in 1965 successfully passed its sea trials in 1975.

A comparison of the topics covered in the 1975 Symposium reported in this volume and those covered in the earlier 1965 Symposium reveals a judicious blend of continuity and variation on which the Organising Committee should be congratulated. The arrangement whereby the authors of the 1965 Symposium chaired the meetings at which a new panel of speakers reviewed Concrete Practice in 1975 not only ensured fresh viewpoints but was a welcome recognition that expertise in Ireland in this important branch of Civil Engineering is not confined to a few. The Symposium attracted an attendance of 247 and of these over 50 contributed to the discussion of the papers. Copies have been made of all the slides shown during the presentation of the papers at the Symposium and these copies are available in the Department of Civil Engineering for reference by anyone interested. During the Symposium an exhibition of some 30 photographs was mounted illustrating concrete work over the previous ten years, and current literature, including the new Irish Building Specification, was placed on display by An Foras Forbartha and Cement Limited.

Through the medium of a questionnaire circulated during the Symposium a wide range of topics were suggested by the participants for further study. Since this listing was a valuable outcome of the Symposium it has been appended to the present proceedings not merely as a matter of record but in the hope that it may serve as a stimulus to members of the profession in Ireland and lead to work which will be part of the progress reported in the next symposium in 1985.

The Department of Civil Engineering at University College Dublin and the whole of the engineering profession in Ireland are indebted to the Organising Committee of the Symposium, and in particular to Professor J. W. de Courcy, to the authors of the papers and to all who participated in the Symposium proceedings.

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SESSION A

SPECIFICATIONS CODES OF PRACTICE AND REGULATIONS FOR STRUCTURAL CONCRETE

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Summary

This paper provides information on the current practice which prevails amongst engineers in this country in respect of design and construction in structural concrete. The author endeavours to present a view which conforms with that of the majority of those engaged in such work. The standards used in Ireland are mainly British Standards and the relevant publications are mentioned and discussed. Where recently issued codes of practice require the adoption of new methods in design, a short review is given of the position prior to the introduction of these standards. The methods of specifying and the regulations governing concrete construction are described and it is recommended that the introduction of Irish Building Specifications and National Building Regulations should be arranged at the earliest possible time.

General

It is a considerable time since the introduction of any standard relating to concrete construction or structural design has caused such a volume of comment and controversy as has the introduction of the two British Standard Codes issued in 1972 namely CP 3 : Chapter V — Part 2 and CP 110 — Part 1. Each of these documents has received extensive study by designers because of the considerable changes which their implementation requires in design work. It is inevitable therefore that a considerable part of this paper should relate to the appraisal of the requirements contained in these two publications.

Specification of structural concrete has been the concern of the engineer from the earliest days of concrete production. A specification

is required for almost every project constructed in concrete and the issue of a number of different specifications to any one contractor during any one year for the production of a basically similar material is not helpful in creating efficiency within the construction industry. New data has become available in recent years and while this does not require major changes in the approach of the engineer to specification writing, it is nevertheless necessary to modify the requirements of existing specifications in order to take it into account. It is therefore opportune to suggest the adoption of an agreed specification which sufficiently covers all aspects of concrete production and leaves the specifier with sufficient flexibility to select clauses appropriate to the quality and form of the construction envisaged. It is appropriate to mention the Irish Building Specification Draft which has been prepared by An Foras Forbartha and which would fulfil the requirements of an agreed specification for concrete construction.

There has been a deficiency in the area of legal regulations governing the control of the construction of buildings in this country. The instruments by which such control is exercised at present are the Public Health (Ireland) Act 1878, Public Health Acts Amendment Acts 1890 and 1907 and the Local Government (Planning and Development) Act 1963. Local Authorities are empowered under the Public Health Acts to make Bye-Laws and the Minister for Local Government may make regulations to be known as Building Regulations under the Local Government (Planning and Development) Act. Bye-Laws made by Local Authorities stipulate standards and other requirements which must be complied with by any person intending to construct a building within the area under the control of a Local Authority. Building regulations may prescribe standards expressed in terms of performance, types of materials, methods of construction or otherwise in relation to buildings intended to be constructed in any part of the country. Bye-Laws have been prepared by only a small number of Local Authorities and those which exist are not now entirely suitable for the present methods and materials applied to construction. There is a need for regulations which are appropriate and this has been recognised by successive Ministers for Local Government. Building regulations have not yet been issued but Draft Building Regulations have been prepared by An Foras Forbartha and issued for private comment. It is now suggested that the need is sufficiently great to require the issue of National Building Regulations at the earliest possible time.

Standards

In this country construction projects for all forms of buildings, bridges, marine works, road and motorways, dams, tunnels and water retaining structures, using structural concrete as a medium are generally designed to the requirements of the following appropriate codes of practice, standards or memoranda :

Loading :

- BSI CP 3 : Chapter V : Part 1 : Dead and Imposed Loads (1).*
- BSI CP 3 : Chapter V : Part 2 : Wind Loads (2).
- BS 153 : Steel Girder Bridges : Part 3A : Loads (3).
- BS 648 : Schedule of weights of building materials (4).
- Road Note 29 : A guide to the structural design of flexible and rigid pavements for new works (5).
- BS 2655 : Lifts : Part 6 : Building construction requirements (6).
- Civil Engineering CP 2 : Earth retaining structures (7).
- MOT Memorandum 771 — Standard Highway Loading (8).
- DOE BE 5/73 — Standard Highway Loading (9).

Design :

- BSI CP 110 : The structural use of concrete (10).
 - Part 1 : Design, materials and workmanship.
 - Part 2 : Design Charts.
 - Part 3 : Design Charts.
- BSI CP 114 : Structural use of reinforced concrete in buildings (11).
- BSI CP 115 : The structural use of prestressed concrete in buildings (12).
- BSI CP 116 : The structural use of precast concrete (13).
- BSI CP 117 : Composite construction in structural steel and concrete (14).
- BSI CP 2004: Foundations (15).
- BSI CP 2007: Design and construction of reinforced and prestressed concrete structures for the storage of water and other aqueous liquids (16).
- BSI CP 111 : Structural recommendations for loadbearing walls (17).
- DOE : Various memoranda on bridges (18).
- ACI Standard 318-71 : Building code requirements for reinforced concrete (19).

Loading

The basis for assessing dead and imposed loads for the design of buildings is British Standard Code of Practice CP 3 : Chapter V : Part 1. The latest edition of this document was issued in 1967 and it contains considerable information concerning the imposed loading which should be applied to floors, classified in terms of functional use. The requirements for loading on ceilings, skylights, roofs, parapets and balustrades are also given. Imposed floor loadings are listed in comprehensive tabular form for the different uses of a building and this information removes the criticism which had been made concerning the previous 1952 issue of the document where lack of data of sufficient detail resulted in the necessity to depart from the stipulated loading under certain circumstances. The first amendment AMD 141, published in November 1968, indicated that the requirements in respect of dynamic loadings applied only to single crane operation and to

*Numbers in parentheses refer to the references given at the end of the paper.

simple forms of crane gantry. Special arrangements were required for heavy cranes, high speed operation or multiple cranes on a single gantry. It also indicated alterations in the loading intensity for library floors subject to stacking, giving incremental loading intensity for each metre of height. The second amendment AMD 587, issued in September 1970, dealt with alterations in the requirement for flat and sloped roof loading, introducing a requirement for concentrated loads. Amendment AMD 1024 of September 1972 introduced a requirement for assessing forces on vehicle barriers in car parks, indicating separate formulae for barriers designed for vehicles less than and greater than 2500 kg. This amendment also altered the requirements for loading on roofs at ceiling supports and on skylights and similar structures. The code refers to British Standard 648 which provides information on a schedule of weights of building materials. It does not give data on loading on structures subjected to internal pressures from contents, loading due to machinery vibration other than for gantry cranes, loads incidental to construction and test loads. The code applies to loading on new buildings and new structures, alterations and additions to existing buildings and existing structures, and to existing construction on change of use. Part 6 of BS 2655 specifies the structural and fire resistant requirements in respect of building construction for lifts and escalators.

British Standard 153 : Part 3A indicates the loading which should be taken in the design of steel girder bridges and this information is applied in the design of all road or rail bridges constructed in concrete. Main road bridges are usually designed for HA loading with 35 units HB loading as given in the Standard. In special circumstances, such as for large city bridges HA loading and 45 units of HB loading are used. Bridges on roads other than main roads are designed for HA loading only. Information given in MOT memoranda 771 and DOE publication BE 5/73 is also applied in assessing bridge loading. Civil Engineering Code of Practice Number 2 contains information on the various forms of earth pressures and other forces exerted on earth retaining structures. Guidance given in Ministry of Transport Road Note 29 is the basis for the structural design of concrete road pavements. Roads are classified in terms of functional use and traffic density in that publication.

Wind loading

The design of structures to resist wind loading is based on information given in British Standard Code of Practice CP 3 : Chapter V : Part 2. A satisfactory assessment of wind loading has frequently presented a problem for the designer and the matter is not entirely resolved at present. It is therefore appropriate to examine briefly the development of the present approach to the estimation of wind loading. The first British Standard Code of Practice for wind loading was issued in 1944. Basic wind speeds were given for different parts of Britain and these were modified depending on the degree of expos-

ure. A unit equivalent static pressure was specified for application in respect of each wind speed and coefficients were applied to that value to determine pressures on windward, leeward, internal and roof surfaces of buildings or structures and also to obtain local pressure on cladding units. Wind speeds ranged from 24.587 metres per second to 37.998 metres per second and unit pressures from 0.335 kN per sq metre at ground level for the lower speed to 2.083 kN per sq metre at a height of 60.960 metres for the higher value. The code was revised in 1952 and it defined four different categories of exposure each related to a maximum wind speed averaged over one minute these being 20.117, 24.140, 28.164 and 32.187 metres per second. Equivalent static pressures were again stipulated in respect of the wind speed and thus a range was given from 0.192 kN per sq metre at ground level for a speed of 20.117 metres per second to 1.484 kN per sq metre at a height of 60.960 metres for a speed of 32.187 metres per second. Coefficients were again applied to the equivalent pressures to obtain various surface pressures but the effective height to be used for calculation of wind pressure was taken from a datum of ground level whereas previously provision had been made to allow for the shelter provided by any permanent obstacle.

In the period following the publication of the 1952 code a considerable amount of research and investigation was undertaken on the behaviour and effects of wind. The concept of dynamic pressure of the wind became accepted by scientists and a statistical basis was developed for the assessment of the maximum probable wind speed at any selected site. The significance of gust action became apparent and it was accepted that there could be differences between the results of model tests under smooth flow conditions and the actual magnitudes and distribution of pressures on structures. Data concerning the actual pressures exerted by wind on buildings was however, minimal. In 1969 a draft for a new code was issued for comment. Prior to the issue of the Report of the Ronan Point Tribunal (33) in November 1968 there had been no serious criticism of the 1952 code, although designers had found that the requirements for particular areas such as coastal locations, high ground situations, and tall buildings were not adequately dealt with in the code. The Ronan Point Report was however critical of the requirements of the code particularly in relation to wind loading on tall buildings. It was inevitable that the provisions in the draft code should in some way reflect the concern expressed about inadequate wind pressures in the Ronan Point Tribunal Report. However, discussions on the document and the comments made on it, following limited circulation, showed very considerable opposition to the introduction of some of the requirements, particularly in the case of wind pressures on low rise buildings. When the new code, CP 3 : Chapter V : Part 2 : Wind Loads, was issued in 1970 it contained substantial modifications to the earlier draft document. A revised edition was published in 1972 and this contained an extended range of pressure coefficients for all building shapes for which there was sufficient information available. It

also included force coefficients for unclad structures and additional information on ice formation and wind forces on circular sections.

In this country the collection, quality control, and publication of wind data is undertaken by the Department of Transport and Power through the Meteorological Service. The availability of information on wind speeds is attributable to the use of anemometers in various selected sites throughout Ireland and Britain. This instrument has the capacity to measure wind speed and to record the mean hourly speed and direction of the wind for each clock hour of the day; it also records the highest gust speed of the day together with its direction and time of occurrence. The anemograms developed by the instrument show rapid fluctuations of wind speed and direction relative to time and indicate gusts at the maximum ordinates and lulls at the minimum ordinates on the trace. The recorded gusts are averaged over two to five seconds depending on the response time of the anemometer. Gusts are conventionally referred to as three second gusts and the highest value can be read directly from the anemogram. The average hourly speed can be estimated by visual examination. Maximum gust speed and maximum hourly speed can be determined for each year at each station. It is possible to obtain information on the maximum gust speeds which are likely to be exceeded only once in a period of any specific number of years, by means of the statistical theory of extreme values developed by Gumbel (20). Lines of equal wind speed known as isolines can be drawn for an entire area or country from the data obtained at a number of anemometer stations in suitable locations. Isolines for this country at interval speeds of two metres per second are shown in Fig. A1 which has been reproduced from Technical Note Number 35 published by the Irish Meteorological Service (21). The lines represent the maximum gust speed in open level country, at a height of 10 metres above ground, likely to be exceeded only once in fifty years. A second map, from the same source, shows, in Fig. A2, isolines for the mean hourly wind speed, in open level country, at a height of 10 metres above ground, likely to be exceeded only once in 120 years. The basic wind speed for any location is taken as the value given for the isoline passing through that area. Interpolation to one metre per second is possible. The basic wind speed referred to in the new code is derived from information similar to that given in Fig. A1, but applicable to Britain. While particular local conditions frequently result in there being a prevailing direction of wind, the maximum wind force used in design can be applied from any direction.

Design wind speed

The difference in the present approach to wind loading is the replacement of a wind speed averaged over one minute by a wind speed based on a three second gust, thus resulting in the use of a higher basic speed in design. The four different categories of exposure have been replaced by isolines for the assessment of the basic wind speed and this is required to be adjusted by the application of three

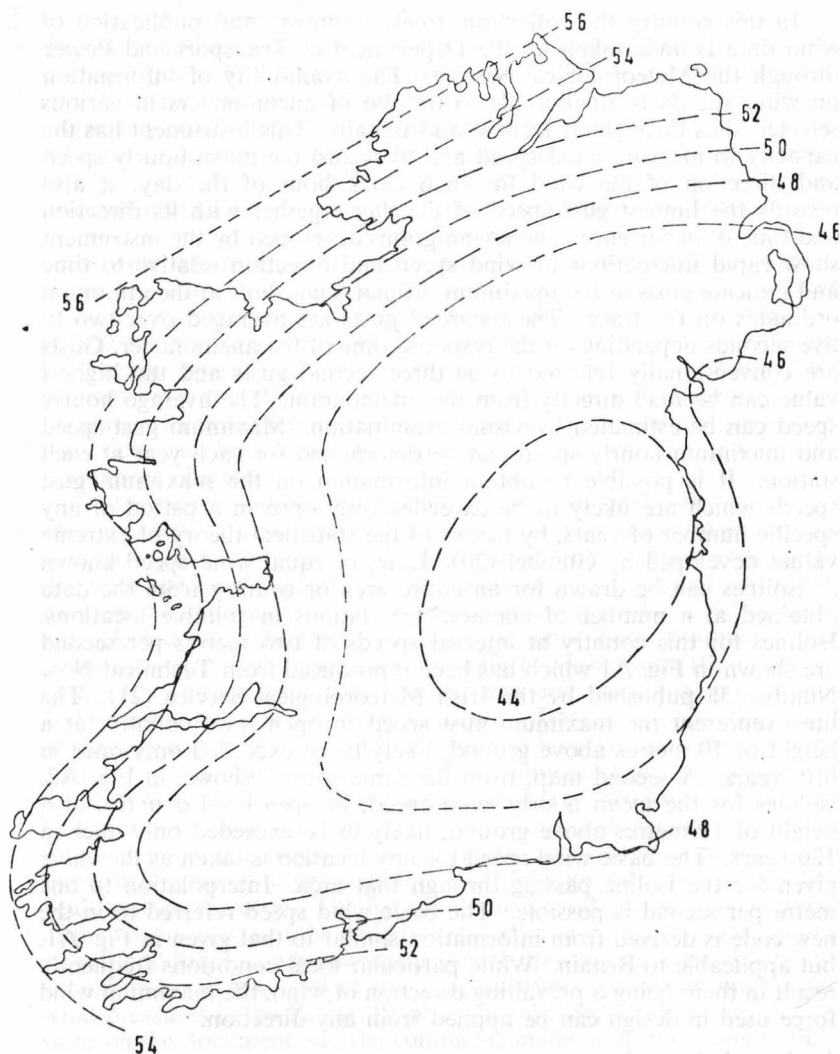


FIG. A1

GUST WIND SPEED IN METRES PER SECOND AT A HEIGHT OF 10 METRES ABOVE GROUND IN OPEN LEVEL COUNTRY LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS.

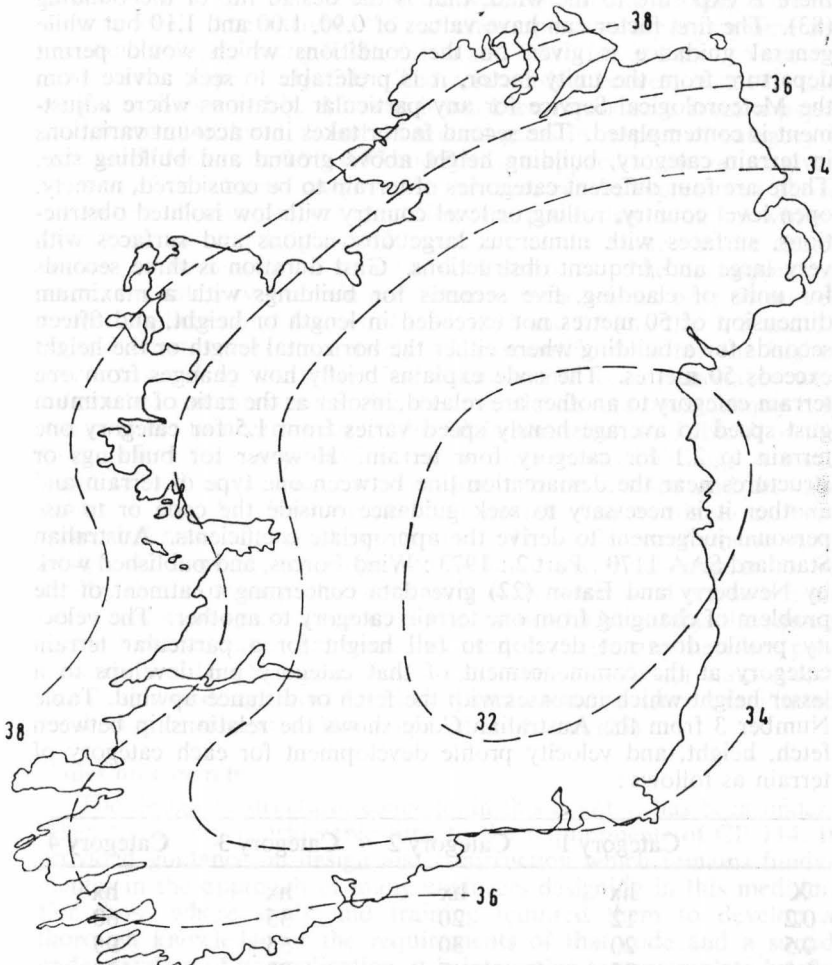


FIG. A2

MEAN HOURLY WIND SPEED IN METRES PER SECOND AT A HEIGHT OF 10 METRES ABOVE GROUND IN OPEN LEVEL COUNTRY LIKELY TO BE EXCEEDED ONLY ONCE IN 120 YEARS

factors to give the design wind speed. These factors take into account local topographical influences (S1), surface roughness, gust duration and height above ground level (S2), and the period of years over which there is exposure to the wind, that is the design life of the building (S3). The first factor can have values of 0.90, 1.00 and 1.10 but while general guidance is given on the conditions which would permit departure from the unity factor, it is preferable to seek advice from the Meteorological Service for any particular locations where adjustment is contemplated. The second factor takes into account variations in terrain category, building height above ground and building size. There are four different categories of terrain to be considered, namely, open level country, rolling or level country with low isolated obstructions, surfaces with numerous large obstructions and surfaces with very large and frequent obstructions. Gust duration is three seconds for units of cladding, five seconds for buildings with a maximum dimension of 50 metres not exceeded in length or height, and fifteen seconds for a building where either the horizontal length or the height exceeds 50 metres. The code explains briefly how changes from one terrain category to another are related, insofar as the ratio of maximum gust speed to average hourly speed varies from 1.5 for category one terrain to 2.1 for category four terrain. However for buildings or structures near the demarcation line between one type of terrain and another it is necessary to seek guidance outside the code or to use personal judgement to derive the appropriate coefficients. Australian Standard SAA 1170 : Part 2 : 1973 : Wind Forces, and published work by Newberry and Eaton (22) give data concerning treatment of the problem of changing from one terrain category to another. The velocity profile does not develop to full height for a particular terrain category at the commencement of that category but develops to a lesser height which increases with the fetch or distance upwind. Table Number 3 from the Australian Code shows the relationship between fetch, height, and velocity profile development for each category of terrain as follows :

	Category 1	Category 2	Category 3	Category 4
X	hx	hx	hx	hx
0.2	12	20	35	60
0.5	20	30	55	95
1.0	25	45	80	130
2.0	35	65	110	190
5.0	60	100	170	300
10.0	80	140	250	450

x = fetch = distance downwind from a change in terrain category in kilometres.

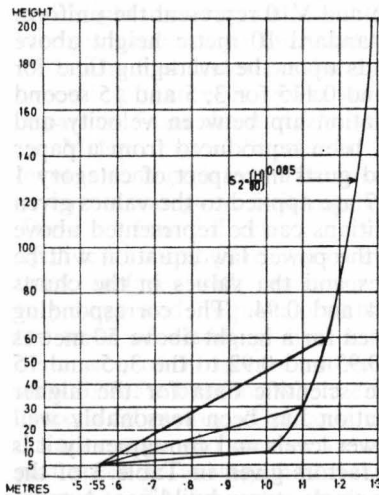
hx = the height in metres of development of a velocity profile at a distance x downwind from a change in terrain category.

Variation of wind speed with height for a strong wind condition can be represented by the power law equation $V_h/V_{10} = h^a/10$ where h is the height in metres and V_h and V_{10} represent the uniform speeds at a height of h and at the standard 10 metre height above ground level. The variable " a " depends upon the averaging time for the wind velocity, being 0.085, 0.100 and 0.115 for 3, 5 and 15 second gust values respectively (23). The relationship between velocity and height is shown in Fig. A3, which has been reproduced from a paper by Mason (24), for 3, 5 and 15 second gusts in respect of category 1 terrain. If factors of 0.98, 0.97 and 0.97 are applied to the values given in each of the charts, category 2 conditions can be represented above 10 metres. For category 3 conditions the power law equation will be operative above a height of 20 metres and the values in the charts require to be multiplied by 0.96, 0.94 and 0.94. The corresponding values for category 4 terrain are obtained for a height above 50 metres by the application of factors of 0.94, 0.93 and 0.92 to the 3, 5 and 15 second chart values respectively. The scientific data for the higher levels covered by the power law equation has been reasonably well established but this is not so for the lower levels and consequently it is not possible to accept entirely the S2 factors given in Table 3 of the Code, where these apply to low rise or single storey buildings. A more rapid fall off in the factor would appear to be justified and the diagrams in Fig. A3 show the effect of straight line terminations from three different heights above ground. The code requirements give design wind speeds for single storey buildings which appear to be greater than necessary. The derivation of dynamic wind pressure from the design wind speed is based on a formula which contains the square of the wind velocity. The pressures used in design are therefore particularly sensitive to a relatively small increase in design wind speed. Conversion of design wind speed to dynamic wind pressure is facilitated by the use of tabulated data prepared by Eaton (25).

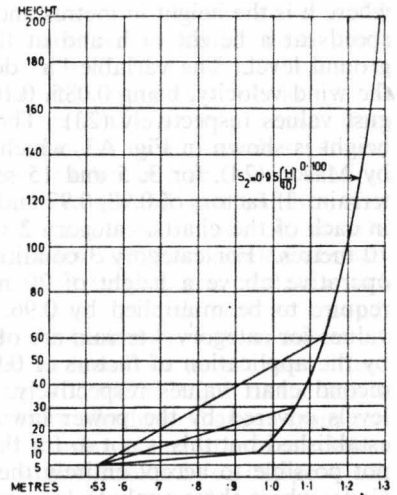
Codes on concrete

The design of structural concrete, in this country, has been undertaken for a very considerable time to the requirements of CP 114. It provided guidance on design and construction which remains fundamental in the approach of many engineers designing in this medium. For those whose study and training required them to develop a thorough knowledge of the requirements of that code and a sound understanding of its application, it is interesting to contemplate briefly the historical background to the codification of structural concrete. The regulations for concrete design in the early days of its use can be attributed to Moersch in Germany and date back to 1902, the Building Code of the Borough of Manhattan of 1903, the French Government Regulations of 1906, the RIBA Joint Committee Report of 1907, its Second Report of 1911, and the London County Council Regulations of 1916. It is pertinent to recall that the issue of the LCC Regulations of 1916 was possible only after considerable discussion, amendment,

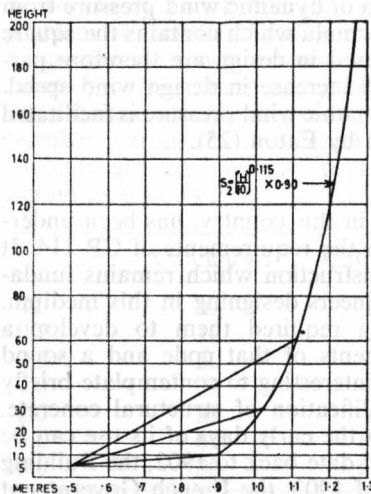
SESSION A



S₂ FACTORS: THREE SECOND GUST.



S₂ FACTORS: FIVE SECOND GUST.



S₂ FACTORS: 15 SECOND GUST.

FIG A3

**RELATIONSHIP BETWEEN
WIND VELOCITY AT ANY
HEIGHT 'H' AND VELOCITY
AT STANDARD 10 METRE
HEIGHT ABOVE GROUND
LEVEL.**

revision, legal argument, and negotiations between the Council, The Concrete Institute, The Institution of Civil Engineers, The RIBA and The Surveyors Institute. The document when issued contained the now familiar sequence of headings, dealing with loading, beams, columns, walls, foundations, reinforcement cover, materials, testing, formwork, and workmanship. The Building Research Board of the London County Council issued a report embodying Regulations on design in 1933 and this became the basis adopted by designers at that time. It indicated a treatment of axially loaded columns based on inelastic properties of concrete but it received considerable criticism because of difficulty in use arising from the large amount of academic content. In 1938 London County Council issued a publication entitled "Construction of Buildings in London". This generally adopted the recommendations given in the 1933 Regulations and was issued in December 1939 as a Code of Practice for the use of Reinforced Concrete in Buildings by the Building Industries National Council in Britain.

In September 1942 a Committee convened by the Institution of Structural Engineers made a recommendation that a new code should be prepared for issue and operation on a national basis in Britain. The code issued by the Building Industries National Council was to be the basis for the new code. A report of the Committee published in 1943 was accepted by the British Ministry of Works and at the request of the Ministry, the Institution of Structural Engineers established a Code Drafting Committee to prepare a revised code entitled "The Structural use of Normal Reinforced Concrete in Buildings"—reference CP 114. This Code was first published in April 1948. It indicated a permissible stress in bending of 6.895 N/sq mm for 1:2:4 concrete and a permissible tensile stress of 124.106 N/sq mm for mild steel. There had been no issue in draft form prior to publication and consequently a minimum time elapsed between initiation and implementation. The responsibility for preparation of codes was transferred subsequently to the British Standards Institution and therefore when the code was being reviewed it was necessary to issue a draft form for general and specific comment. Specific comment was sought from professional and trade organisations who were concerned. All comments expressed were considered in the preparation of the final document.

A revision of CP 114 was published in June 1957. Special mix grades were introduced in addition to the nominal mix classification in order to facilitate the specification of concrete for prestressed construction. Permissible compressive concrete stresses could be increased above 6.895 N/sq mm by 25% for a similar rate of increase in cube strength. Difficulty in achieving the required cube strengths could be taken into account by accepting a reduction of 25% maximum with a corresponding reduction in permissible stresses. Increase in strength with age at loading was recognised and appropriate permissible stress increases were allowed. The permissible shear stress of 0.689 N/sq mm

for 1:2:4 concrete had not apparently caused any critical comment to indicate the future concern which was to be expressed about that requirement. The permissible tensile stress in mild steel bars up to 40 mm diameter was increased to 137.895 N/sq mm. Works cubes were to be taken as considered necessary. Three test cubes were required for each age at which tests were taken. Strength requirement could be considered satisfied if all three cubes exceeded the specified strength or if the average of the three exceeded the specified strength and the difference or if the average of the three exceeded the specified strength and the difference between the greatest and the least was not more than 20%. For special concrete mixes, quality control and checking was to be provided during the progress of the works by taking a minimum of six cubes per batch, at least once per week, three for testing at 7 days and three at 28 days. The cube strength was required to reach the specified value. Limitation of deflexion was required and span/depth ratios were given. The load factor method of design was introduced but elastic theory methods were permitted.

The first British Standards Institution code on prestressed concrete, namely CP 115, was issued in 1959. This was, in effect, the first limit state design code published by the BSI. It has been largely incorporated in the unified code currently in use. When the 1957 edition of CP 114 was under review it was apparent that a code for precast concrete was needed. The preparation of such a code was then undertaken and CP 116 was issued in February 1965. It contained many of the design clauses of CP 114 and clauses from CP 115 for prestressed precast members. The code dealt in considerable detail with concrete materials, workmanship, inspection, testing and durability. Information was also given on the specification of concrete surfaces, structural connexions and composite in-situ and precast construction. Increases in permissible stresses of up to ten per cent were allowed because of the greater control under conditions of factory production and a maximum limiting shear stress of 0.9 N/sq mm was introduced. New information on high alumina cement concrete relative to the problem of conversion of that material was given and requirements on tolerances were included. An amendment to CP 114 was issued at the same time, bringing that code into conformity with the precast concrete code in matters which were common to the two, including the allowable increase in permissible stresses. PD 6151 for CP 114 and PD 6152 for CP 116 issued in 1967 related to restrictions concerning shear requirements. There were other modifications introduced subsequent to the collapse of a section of Ronan Point Flats, through addendum No. 1 to CP 116 in 1970. Subsequent amendments to CP 114, CP 115 and CP 116 dealt with the provision of horizontal ties in all forms of construction other than those mentioned in addendum No 1 to CP 116.

The Unified Code

The introduction of British Standard Code of Practice CP 110 in November 1972 initiated a new era in the design of structural concrete.

It is a unified code for in-situ reinforced concrete, precast concrete and prestressed concrete. It is intended that after a period, during which the three existing codes and the unified code would remain in force, the older codes will be withdrawn. At present it is possible to base design either on the New Code, or on the other three documents. In Britain the code was received with considerable resistance by many engineers and its reception was reminiscent of the difficulties and objections which occurred on the introduction of the 1916 London County Council Regulations and the 1933 Regulations of the Building Building Research Board of London County Council. In this country the introduction of the unified code into design office practice has been a gradual process, and while more than seventy per cent of designers now use CP 110, some proportion of them also use CP 114 and CP 116. There was some reluctance initially to use the new code because of the fundamental departure from existing practice and the increase in design office costs which result in implementing the change. The design costs were not considered to be justified by some engineers because of the virtual unchanged result in the overall structural design. The early experience in using the code creates the impression of very considerable involvement in the application of formulae, but these exercises become less burdensome with the passage of time and experience shows that following an introduction to the design process a number of the checks required in the code are not needed in design of repetitive elements.

The unified code is based upon the limit state philosophy of design. It was inevitable that this design concept should be adopted because it has been the basis for design in many countries for a number of years. The method is a logical one for the evaluation of element sizes and reinforcement requirements. There are three limit states to be considered in design, namely, the limit state of ultimate strength, the limit state of serviceability in respect of deflexion, and the limit state of serviceability in relation to cracking under service loads. The aim is to ensure that the probability of each limit state being reached, is more or less constant for all members in a structure, and that it is appropriate to that limit state, and that in addition an adequate degree of safety is provided against the structure becoming unfit for use. The Code is issued in three parts—Part 1 deals with design, materials and workmanship, Part 2 contains design charts for singly reinforced beams, doubly reinforced beams and rectangular columns and Part 3 contains design charts for circular columns and prestressed beams. There are many areas where differences occur when comparison is made with the requirements of the three preceding concrete codes. The overall factor of safety is derived by the application of partial factors to loading and materials, and a further partial factor is introduced for combination of dead, live and wind loads. It is difficult to say what precise result the various combinations of factors have on the overall safety factor, but the intention is that structures designed in accordance with CP 110 should have virtually the same degree of safety and

serviceability as structures designed in accordance with CP 114, CP 115 and CP 116. The global factors involving strength and load lie between 1.61 for a total dead load condition and 1.84 for an entirely live load condition.

In view of the absence of sufficient information on behaviour of floors under partition loading, the code requirement acknowledges that careful attention should be given to the problem of deflexion for partition loading. The suggested value of $1/250$ of the span with a maximum of 20 mm for deflexion produced by imposed loads would not however appear to be sufficiently restrictive to prevent damage to particular forms of partition construction. It is essential to select the maximum value of deflexion which is to be permitted, relative to the form of construction of partition and its capability to accommodate the deflexion of the structural element. The American Concrete Institute Building Code 318-71 gives a deflexion/span ratio of $1/480$. The unified code stipulates special restrictions for spans in excess of 10 metres and allowance is made for the effects of reinforcement depending on whether it is tensile or compressive. The modifications made for reinforcement content are related to the inelastic behaviour and creep of concrete. Under special conditions, or where the designer considers it necessary to apply limits other than those for which the tables have been prepared, it is possible to apply a simple multiplier to the tabulated data in the tables to obtain the corresponding information for the altered limits. It should hardly be necessary to prepare detailed deflexion calculations on the basis given in Appendix A of the code, except in very unusual circumstances and then only when precise information is available on the restraint and loading conditions on the member. The argument can be made that the use of the tables to assess the deflexion limit is a little tedious, but the ease of adaptability of the procedure for other selected limits of deflexion is a significant advantage.

The problem of shear resistance is treated less restrictively than in CP 114. The analysis of the stress pattern within the beam is based on the familiar truss analogy method and the values of ultimate shear stress which have been given in table 5 are based on the results of test data. Higher average shear stresses than previously are permitted on the concrete section before the introduction of calculated shear reinforcement. Nominal shear reinforcement is therefore required more frequently and it is of slightly greater quantity than previously required. The maximum spacing requirement should be subject to further examination based on an extensive test programme. The code incorporates clauses on torsion for the first time in a BSI publication. It has been assumed that torsional shear stress is based on plastic stress distribution and while this is a progressive approach, the data given in table 7 of the code are extremely conservative. Corresponding values given in the current American Code are more than twice as great. It has been argued by Marshall (26) that the ultimate torsional resistance is significantly greater than that appropriate to the values for permis-

sible stress given in the code and that consequently the provisions result in excessive reinforcement for torsion resistance.

Section 4 gives the requirements in respect of the design and detailing of prestressed concrete. The information is almost identical to that contained in CP 115 in which the concept of limit state was introduced. It is now necessary to give consideration to the effects of the development of bursting tensile forces and the spacing of tendons in the end blocks of pretensioned members, in order to provide an arrangement in the transmission zone which does not lead to possible longitudinal splitting at the surfaces. More specific guidance however is required concerning the arrangements of reinforcement necessary to prevent the adverse effects of cracking. Requirements should be given indicating the methods to be used to prevent end splitting at the bearings of pretensioned members where small diameter wire is used in high strength concrete.

The requirement for bearing width for precast units is very likely to lead to problems where tolerances produce a reduction in actual bearing width below the recommended value. Serious stability problems can arise where the placement of the reinforcement within either the supporting or supported elements is such that an increase in cover results. The difficulty is compounded by the stipulation in the Code which allows a further reduction in the width to below 75 mm. It is suggested that a minimum bearing width of 100 mm should apply for any unit, with the possible exception of a unit bearing on structural steel when a minimum of 75 mm could be permitted at the discretion of the designer.

The clauses in the new code dealing with inspection and testing of concrete are a considerable improvement on previous requirements. Non-destructive testing in the form of rebound hammer tests, gamma radiography, ultrasonic pulse velocity testing and electromagnetic cover measuring devices are permitted. It is essential that the operator of any of the instruments should be experienced in the method of testing because otherwise results can be unreliable. While the three methods of testing concrete strength would not be sufficiently precise or consistent for use in a programme intended as a substitute for tests taken during production of the concrete, they can be used with core testing and covermeter readings to establish whether results, which are below requirements, are properly indicative of poor quality concrete construction, or, whether visible signs of sub-standard workmanship actually represent inferior quality concrete. There is very little use made in Ireland of these testing methods but core cutting and rebound hammer testing are undertaken on a limited scale.

Fire resistance of concrete

The information available on fire resistance of structural concrete is limited and there is a considerable need for further data to be provided through research and testing. The lack of sufficient informa-

tion has tended to precipitate a conservative approach to requirements which have been confined to guidance on the minimum cross-sectional depth of members and the thickness of cover to reinforcement. Code requirements have been stipulated on the basis of fire tests on elements under laboratory conditions and on a small amount of practical information derived from fires in buildings. It is necessary to examine the present requirements in the context of the limited data available. The resistance of a member in a structure is influenced by such factors as the restraining action of reinforcement, the influence of adjacent structural members and the type of aggregate used in the concrete. The rate of expansion of concrete subjected to temperature rise is affected in an ascending order, depending on whether the aggregate is limestone, igneous or siliceous material. The temperature rise within the concrete is influenced by the amount of water which is held within the pores of the material, and initially internal temperature can be retained at 100°C while evaporation takes place at the surface of the member. When shrinkage subsequently takes place, the available water dries off and differential stresses cause cracking in the tensile zone and this produces an increase in the rate of drying. The resulting higher temperature causes a release of chemically bonded water and at this stage fragmentation of the concrete is noticeable. The pattern of the fragmentation is again dependent upon the type of aggregate and a dimensionally unstable material like flint causes early spalling, while more stable aggregates such as limestone and sintered material cause very little spalling. The thermal conductivity of the concrete influences the rate of temperature rise and concrete made with lightweight aggregate behaves more favourably in this respect. The loss of compressive strength does not become significant until a temperature of 250°C is reached. The reduction is more rapid at higher temperature and the following table indicates the approximate values which show the relationship between the crushing strength at any given temperature and that at 18°C. The rate of loss in the table is for concrete using siliceous aggregates.

T	0	100	200	300	400	500	600	700
R	100	99	95	88	65	45	40	35

where T = temperature in degrees celsius

and R = ratio of crushing strength at the given temperature to that at 18°C.

The yield stress of cold worked mild steel reinforcing is affected by temperature increase in the manner shown by the following approximate figures :

T	0	100	200	300	400	500	600	700
R	100	110	115	105	99	75	50	25

where T = temperature in degrees celsius

and R = ratio of yield strength at the given temperature to that at 18°C.

It is evident that initially there is no loss of yield strength up to a temperature of 400°C but at 600°C the loss is approximately 50 per cent. It has been usual practice to consider 600°C as the critical temperature for the fire resistance of slabs and beams because of the factor of safety requirement of two given in CP 114 : 1948, but the critical temperature is now possibly 35°C less because the global factor for limit state design is less than 2. The temperature effects on hot rolled high yield reinforcement cause less reduction in yield strength up to about 600°C but beyond this value there is not much difference between the two types of steel. Prestressing steels consisting of wire, strand, and alloy bar are more adversely affected by high temperature than the mild steel quality. For wire and strand a loss of 50 per cent in tensile strength is reached at about 400°C but for high tensile alloy bar this loss does not occur until a temperature of about 530°C . The fire resistance for reinforced and prestressed concrete is based on their behaviour at critical temperatures of 550° and 400°C respectively.

The Unified Code gives considerable data on the requirements for different types of floor constructions for durations of fire resistance between half an hour and four hours. The necessity to use "average" concrete cover instead of "minimum" concrete cover increases the design time because of the extra computation required and seems an unnecessary departure from the previous method of stipulating minimum cover. The requirements for ribbed floor construction are exceptionally harsh and it would be preferable to use data based on the results of tests on this type of floor construction when assessing the resistance. Acknowledgement is given in the code that resistance of concrete having limestone or sintered aggregates is greater than that for concrete made with siliceous material, but no information on reduction in cover to reinforcement for concrete made with these aggregates is given. The necessity to introduce supplementary reinforcement to retain cover in place when siliceous aggregate is used is not a requirement which can be considered favourable when efficiency and cost of placing reinforcement are measured.

Specification of concrete

Specification of concrete has been the concern of engineers since concrete was first produced and from the earliest days clauses have developed to the form which is now well known, and cover such matters as cement, aggregates, water, additives, methods of measurement, mix proportions, transport, placing, compaction, joints, cold weather working, reinforcement, formwork, curing, surface finishes, minimum strength, quality control and testing. Standard Specifications are in use by many engineers, that is, standard in relation to each particular office, firm or organisation. There is a modification made to this 'standard' by many in respect of each job specification and in some instances an abbreviated form is used for small works. It is evident that all of these documents have a considerable amount of data in common although the descriptions and clause reference are not

necessarily identical. The method which has been in general use for specifying concrete is that which is now known as the "prescribed mix" method. When this method is now used in accordance with the stipulations in CP 110 the specifier selects the mix proportions and the concrete produced on this basis is not subject to rejection unless it can be shown that the producer or contractor has not complied with the requirements of the specification. It is not possible to claim non-compliance because of the failure of test cubes to attain adequate strength, but nevertheless the designer is obliged to satisfy himself that the concrete strength in the structure is adequate. It is stated in CP 110 that if specification is by prescribed mix method then compliance should be judged on the basis of the specified mix proportions and required workability. Therefore it is necessary to rely on clauses dealing with production and quality control, involving minimum standards of supervision and accuracy of batching plant, for this purpose.

The concept of "designed mix" as distinct from prescribed mix was first introduced in the 1965 edition of CP 114 under the description of 'standard mixes'. This is a specification based on performance standards where the responsibility for achieving a particular strength of concrete is placed with the producer or contractor and where only the minimum cement content, the maximum nominal size of aggregate and the type of cement are specified. Compliance with the specification is judged on the basis of the crushing strengths of test cubes for 28 day testing, or such shorter period provided the relationship with the 28 day strength is established. It is a disadvantage to await 28 days for cube test results and there is a need for the development of an acceptable accelerated test procedure. At present accelerated test results are not sufficiently reliable to provide an alternative to 28 day tests.

Additives are not used extensively by engineers in Ireland, but when used, specifiers require to have detailed information about the ingredients in the admixture. The use of calcium chloride is not generally permitted. Provision is made in specifications for the use of special cements, lightweight aggregates, and special aggregates for use in surface finishes. Clauses dealing with the use of high alumina cement concrete were deleted from current concrete codes of practice in August 1974.

The present situation about the manner of specifying concrete is not entirely satisfactory. The number of specifications which is placed before producers and contractors during any one twelve month period is considerable and since these are for basically the same product, it is unnecessary to argue the case for the existence of an agreed specification which would be suitable for use by all those concerned with specifying concrete. The Final Draft of an Irish Building Specification (27) has been circulated for comment by An Foras Forbartha and the issue of the final document is expected shortly. This Building Specification has been arranged in a series of work sections coded under the

SfB classification. The work sections deal generally with a construction form and sub-divisions relate to the different constituent materials. The order of the work sections roughly reflects the order in which construction is undertaken and each section deals separately with materials and workmanship. Clauses in each section or sub-section are coded in a consistent manner throughout the document. Additional clauses may be introduced without interrupting the sequence. It is intended that the Irish Building Specification should be used as a library of clauses from which selected ones can be taken for the preparation of project specifications.

The document has been prepared in close collaboration with experts on the different aspects covered by the specification. Consultation with representatives of all interested parties and invited comment from individuals and organisations involved in the industry preceded the preparation of the draft document. The Specification is set out in performance terms. The basis for specifying concrete mixes is in conformity with the methods given in CP 110 and the testing programme for compliance is identical to the unified code requirements. The approach therefore is based on probability and it would be necessary to take cognisance of this element when considering acceptance. It can be argued that if a producer wishes to reduce the risk of rejection, because of non-compliance with the testing plan, it is necessary to set higher design strength targets than the characteristic strengths specified. This however would be in conflict with the view of many users of ready-mixed concrete who claim that actual strengths frequently exceed design strengths and consequently the risk element is thereby reduced. The proposed testing plan is based on a group of four consecutive test cube results and it does have the following disadvantages :

- (a) The difficulty of implementing the programme on small contracts and on contracts where supply is intermittent.
- (b) The omission of a requirement to specifically exclude the inclusion of any one test result in more than one group, otherwise it would be possible to assign different average strengths to the same volume of finished concrete.

The specification in relation to surface finish requires the provision of sample panels incorporating any special features, but allows specification by means of descriptive clauses for fair faced and board marked finish. In contrast it is suggested in CP 110 that the term 'fair faced' should be avoided. The author believes that specification based on large size sample panels is preferable. Clauses on tolerances are included but this is an aspect of concrete construction to which there is a need for designers and contractors to give more attention. There is a lack of information on the degree of accuracy which can be attained and the cost implications of attaining a particular level of accuracy. It is noted that a reference to the standard for the manufacture of supersulphated cement is given and although the use of this

type of cement in Ireland is very unlikely it should be noted that very many of its chemical compounds are also contained in high alumina cement, and therefore care should be exercised if its use is contemplated.

Ready-mixed concrete

The use of ready-mixed concrete in this country has increased very significantly in recent years and although statistical data on the proportion of all concrete production using a ready-mixed source of supply is not available, it is estimated that the volume is now about 26 per cent of all concrete produced in this country. Engineers do not stipulate directly the use of ready-mixed concrete but accept this method of production when approval is sought. Apart from reference to BS 1926 : 1962 : Ready-mixed concrete (28), special clauses are not generally given in specifications relating to its use. Specifiers rely on limited works inspection, and site testing involving cube sampling and slump measurement to check compliance with the specification. Many engineers now consider that an Irish Standard for ready-mixed concrete is required. A final draft of such a document has been circulated by the Institute for Industrial Research and Standards and it believed that issue of this Standard would fulfil the need of specifiers. The draft Irish Standard deals with the requirements for the production and supply of concrete delivered at the site or into the purchaser's vehicles, in a plastic condition. It specifies the types of materials for use, accuracy of measurement, time and rate of mixing, tests for establishing suitability of mixing equipment, transporting requirements, delivery conditions, types of mix specification, methods of inspection, sampling, and testing, compliance requirements, and delivery records.

Irish Standards

The only Irish Standards in use for the specification of concrete production are IS 1 on Portland cement (29) and IS 5 on aggregates for concrete (30). Engineers do not consider that other Irish Standards are required except in the case of ready-mixed concrete where a very significant number of designers consider that an Irish Standard should be available. Information on standard profiles for in-situ ribbed and waffle slabs have been prepared and published by An Foras Forbartha in a document title "Modular Components 7 : In-situ ribbed and waffle waffle slabs" (31). A range of sizes is given and it is intended that these be adopted for use on a national basis.

Regulations and approvals

Present practice requires the design and construction of structural concrete works to be in accordance with the appropriate provisions of the building bye-laws of the particular Local Authority for the area in which the building lies. Design in accordance with the various Codes of Practice or other Standards generally in use, is normally accepted by Local Authorities as fulfilling the bye-law requirements.

It is seldom that a Planning Authority seeks the submission of calculations to show structural adequacy, although in a small number of special circumstances submission of calculations has been necessary. It is usual for a Local Authority to accept a certificate from a consulting engineer indicating the basis for the structural design rather than seek the submission of calculations.

Approval of projects which benefit from State financial grants is required from the particular Government Department responsible. Projects involving railway and canal bridges or bridges across navigable or tidal waters are required to be approved by the Department of Transport and Power. The requirement in respect of span, bed level and soffit level for river bridges require to be approved by the Office of Public Works. Bridge Orders may be necessary under the Local Government Act 1946 for large bridge projects especially if changes in navigation conditions are envisaged. For large bridges or for bridge projects in which an unusual design concept is used, it is normal to submit calculations on design to the Department of Local Government.

Reference has previously been made to the less than satisfactory situation which exists in respect of building regulations. The draft Building Regulations prepared by an Foras Forbartha contain fifteen parts, two of which are particularly relevant to structural design. Part 4 of the regulations is on structural strength and stability and Part 9 covers structural fire precautions. Compliance with Part 4 requires the following :

- (a) Foundations and and building structure to be designed and constructed in accordance with the requirements of the relevant current building codes.
- (b) Design to be undertaken in accordance with the loading stipulations of CP 3 : Chapter V.
- (c) Loading notices to be provided in buildings.
- (d) Record drawings to be furnished to the Planning Authority, indicating a schedule of imposed loads relating to the completed building, and such calculations as necessary to indicate clearly the principles of structural design. Each set of these documents to be accompanied by a declaration signed by a qualified engineer, architect or surveyor, stating that the drawings are the final design drawings.

Part 9 indicates the regulations concerning fire resistance periods which are to be applied to each building purpose group depending on the floor area and cubic capacity. It also indicates the resistance requirements for elements such as floors, walls, protected shafts, stairways and roofs.

Recommendations on structural design in relation to progressive collapse due to accidental damage to buildings are contained in a Report on Accidental Damage to Buildings (32) issued by the Institu-

of Engineers of Ireland in October 1972 and in a revision to sections 4.2 and 4.3 of that report in March 1974. The design proposals apply to buildings of five or more storeys. The recommendations relating to concrete construction require the incorporation of ventilating systems within the building, vent panels on external walls and compliance with the stability requirements of CP 110.

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Discussion

MR. HARRINGTON introduced his paper.

He said that very significant changes had occurred in Ireland since 1965 in the design and construction of structural concrete. These had been due, in the main, to the introduction in Britain of the unified code of practice for the structural use of concrete and the new code of practice for wind loading. He felt that, as Irish designers had had little opportunity to participate in the preparation of these codes, there should be an opportunity to discuss them, particularly on matters of

possible disagreement, and he considered the present symposium to be a suitable forum. It was, of course, not possible to offer comprehensive coverage of all new data relevant to Irish practice within the constraints of a single paper.

He reported that information used in the preparation of the paper had been obtained by means of three forms of enquiry. The first was a questionnaire issued to consulting engineers and state-sponsored organizations. The response to this had been 57 per cent. The second was a questionnaire sent to Local Authorities and this had drawn a 68 per cent response. The third form had consisted of telephoning contracting firms and this had produced almost 100 per cent response. It was not claimed that the coverage had been complete, but he believed that results obtained through processing the information received provided a reliable indication of current opinion in Ireland.

Referring to the specification of concrete, Mr. Harrington recalled that a case had been stated and accepted in principle at the 1965 symposium for the introduction of an Irish standard specification for making concrete; and he said that one might confidently hold now that the issue of a standard specification would be universally acceptable to those concerned with the design and production of structural concrete as a material. The draft for the Irish Building Specification prepared by An Foras Forbartha contained appropriate sections and was arranged in such a way that there was sufficient flexibility to select clauses appropriate to the quality and form of construction envisaged. It appeared from information he had received that specifiers in Ireland now selected either "designed" mixes or "prescribed" mixes in a 1 : 1 ratio, and that about one in three designers specified "special structural concrete" as described in the Unified Code.

Generally, additives were not used, but slightly less than 50 per cent of designers had permitted their use on occasions.

The testing of concrete had provided many problems and the requirements now stipulated in CP110 required considerably greater site control to comply with the procedure laid down. Facilities now available enabled the smallest contractor to have testing undertaken at a suitably equipped laboratory, but the manner in which cubes were prepared was not always satisfactory on every site. Mr. Harrington felt it would be a considerable improvement if facilities could be provided by a mobile unit to assist the less-experienced firms in the extremely important technique involved. The position about rejection for non-compliance was set out clearly in CP110 and the procedure could be seen as a reasonable one. However, it was very important that a specifier distinguish between the two forms of mix specification in relation to the establishment of non-compliance.

Mr. Harrington pointed out, in passing, that it was difficult to specify concrete for water-retaining structures strictly in accordance with CP110.

From his survey of opinion, he found that the provision of an Irish Standard for ready-mixed concrete was considered to be necessary by

68 per cent of those in private practice and state-sponsored organisations, and by 88 per cent of Local Authority engineers. Approximately 50 per cent of contractors would favour the introduction of such a Standard.

In the general matter of this compliance of building with statutory requirements, Mr. Harrington underlined the importance of a single set of common regulations applicable throughout the country. The draft Building Regulations prepared by An Foras Forbartha (not to be confused with the Specification mentioned earlier) provided such a solution to present difficulties and would be acceptable to the engineering profession. The requirements in respect of structural design were, in his opinion, comprehensive and he realised that implementation would place an additional work load on the building control divisions of Local Authorities. At present, most Local Authorities did not have Building Bye-laws and requirements which properly related to building regulations were imposed through conditions attached to planning permission. It was seldom that the submission of design calculations was required by Local Authorities.

The publication of CP110, the Unified Code, in 1972 was the most important development of the decade in the present context, with very wide-ranging effect. The intention in Britain was that while the separate codes, CP114, CP115 and CP116 did remain in force temporarily, in parallel with CP110, these would eventually be phased out in favour of CP110.

Notwithstanding the large amount of information contained in the Unified Code, it did not, he felt, satisfy the needs of designers in a number of aspects. There was disagreement with the requirements particularly in respect of shear, torsion, deflexion, crack control, and fire resistance. He believed that the deflexion limits permitted were excessive, and that a maximum value of 1:350 of the span for the shorter spans should be the upper limit with a value of 1:480 being used generally. The amount of reinforcement required to resist torsion was considerable and a case could be made for less stringent treatment. The provisions for shear resistance were conflicting insofar as acknowledgment had been made of the contribution of concrete in shear resistance, but the spacing of nominal link reinforcement was reduced.

The resistance of concrete in shear required further consideration and this should involve extensive test programmes. Recent work by Desayi (Magazine of Concrete Research: Vol. 26:No. 86:March 1974, pp. 29-38) supported the case for an increase, rather than a decrease, in the maximum spacing of nominal shear reinforcement.

The problem of reinforcement at anchorages in pre-tensioned and post-tensioned units required more attention than given in CP110 so that a more effective prevention of end splitting could be achieved.

Bearing widths permitted for precast units were a potential source of danger, and Mr. Harrington felt that the minimum value should be increased to 100 mm in all instances except possibly for bearings on structural steel members.

Turning to the problem of fire resistance, Mr. Harrington said that it was acknowledged that the code clauses in that area were based on limited data, which had involved some testing. He believed that some of the provisions, particularly for resistance in excess of two hours were very conservative. It was significant also that the section on fire resistance in CP110 was not in accord with the overall concept of the code because its requirements were not based on limit state philosophy.

Mr. Harrington then referred to a very recent publication which had reached him only two days earlier, namely a Report issued jointly by the Institution of Structural Engineers and the Concrete Society and entitled "Fire resistance of concrete structures". The main objective of the committee who produced it had been to examine the possibility of developing methods of designing structures for a specified fire resistance in a more rational manner than those now in use. The Report outlined research and testing laboratory experience in Britain and other European countries and in the U.S.A., and compared the results of fire tests on structures with experience from real fire situations, using detailed case histories. A more rational design method was described, emphasizing the advantages of careful detailing, and differentiating between the requirements of sections where either shear or flexure predominated. The approach was based on limit state principles and the Report proposed details of good structural arrangements and suggested lines for future development.

Mr. Harrington next developed some of the topics relating to wind loading which his paper had given. He said that, in contrast to the 1952 edition of CP3 Chapter 5: Wind Loading, the 1970 version with its subsequent revisions contained a very large amount of data for wind loading on structures and so was of increased assistance for designers. Nevertheless this Code in its 1970 version had been the most controversial document issued by the British Standards Institution, in the context of this Symposium, during the period under review. The loading requirements were very much greater than those given in 1952, and required, inter alia, that the majority of buildings should be designed for wind pressures of magnitudes attributable to five-second gusts. There was, however, no scientific information available to confirm that that order of pressure was attained on structures below a height of 30 metres. There was, therefore, a basis for disagreement with the current code, but it was, in his opinion, essential to be specific about the reason for disagreement. There could be no dispute with the established scientific data shown on the isolines illustrated in Figures A1 and A2 in this paper, and these could provide a basis for design. The classification of terrain types was also entirely acceptable. The determination of wind velocity above a height of 10 metres was, however, based on a mathematical concept, the application of which could be accepted above a particular level but not below that level. The difficulty lay in its application to low rise structures up to a height of 30 metres. He felt therefore that the values of the S2 factors given in the Code for heights up to 30 metres were questionable in relation to ter-

rains of types 1, 2 and 3, and he suggested that reductions should be made in the values of those factors in the particular types of terrain mentioned, for increments of height up to 30 metres. Suitable values might be given, in his opinion, by the use of appropriate straight line terminations from the power law curves shown in Figure A3. The suitability of the dynamic pressures required by the Code in relation to the design of fixings for cladding panels or glazing units was not questioned.

Consideration of design pressures in a change-of-terrain situation was probably best dealt with by the preparation of velocity profile lines from the table relating to fetch, which was given in the text. The design category could then be determined from the relationship between the fetch and the height of the building.

Mr. Harrington illustrated his introduction with eleven slides which showed:

- types and changes of terrain;
- wind pressures related, in accordance with CP3 (1952 and 1970 versions), to terrain category, height of building, and basic wind speed;
- a table of gust speeds (m. per sec.) likely to be exceeded only once in 10, 20, 50, 100 years at 10 metres above ground level at various Irish stations;
- a table of gust speeds and mean hourly wind speeds (m. per sec.) likely to be exceeded only once in 120 years at 10 metres above ground level at various Irish stations;
- a set of curves showing the fetch: height: velocity profile relationship for the four code terrain categories;
- a typical Irish building, constructed in 1957, as an example for discussion on wind pressures applicable prior to and subsequent to the time of the 1970 code.

DR. D. ORR opened the discussion. He congratulated the author for his thoroughness in reviewing and assessing such a diverse body of material. The clear expression of complex concepts within the compressed space of a Code was always difficult, and interpretation had to be preceded by careful personal study. He himself had been working in Australia when new wind loading codes were introduced there in 1971, and a frequent comment about them had been very similar to that now being made about CP110, namely that their provisions were far too theoretical to be useful in a design office. Mr. Harrington's remarks on terrain-change treatment in the new CP3 indicated one case in point.

The care needed when using, in one country, codes which had been prepared for another had been mentioned by the author. He endorsed that opinion and offered three reasons. Firstly, he showed three slides of typical dwelling houses in Northern Australia, demonstrating the effect of cyclone on low-rise structures. A very high proportion of wind

damage in Northern Australia, and he mentioned the recent Darwin hurricane in that context, had been to low-rise dwellings. One would therefore expect an Australian code to be conservative in that aspect of design, whereas such a code might in fact be very much too conservative for conditions in other countries. Secondly, a code tended to be coloured by calamities in the country of its origin. In that context, one might sense an over-reaction in Britain to Ronan Point and high alumina cement, and possibly should compensate accordingly when using Codes reflecting that over-reaction. Thirdly, a code from a country of high industrial development with, for instance, a high level of building mechanisation, might require adjustment for use in a less-developed country.

Speaking about the education of engineers, Dr. Orr questioned whether he should be trying to teach Codes to undergraduates or simply helping them to develop their minds so that they would themselves be able to master Codes while in practice. He gave as an instance the difficulty for engineers of simultaneously absorbing the new design philosophy of CP110 and interpreting the condensed Code clauses in which it was presented. He felt that a comment from the profession would be useful on that topic.

Discussing on-going technological problems, and he singled out time-dependent deflexion and structural stability as just two examples, Dr. Orr raised the issue of the increasing necessity for continuing education for engineers to keep them abreast of new developments. He wondered how far it was desirable for universities to become involved in that work, and whether in fact they were the best institutions for refreshing the minds and memories of practising engineers. If they had a function in that field, then the profession should recognise that staff: student ratios in Ireland were deplorably low, and lagging seriously behind other countries, and should bring pressure to bear in appropriate quarters to have those ratios improved. At present, the small-group tutorial type of instruction, so necessary to explore design techniques, was not possible even at undergraduate level, and it was hard to see how extensive participation in continuing education could be serviced.

MR. J. GWYNN questioned Mr. Harrington's statement that accelerated cube tests were not yet sufficiently reliable to provide an alternative to 28-day tests. He wondered whether that statement was a personal opinion or a result of the survey made in preparation of the paper. He quoted Mr. Mescal's finding, in his paper for the Symposium, that some ready-mixed concrete suppliers were now using accelerated cube tests in their control programme. He mentioned a recent lecture to the Irish Concrete Society in which the lecturer, discussing 24-hour accelerated tests, had reported finding the coefficient of variation for a series of tests less in fact than that for a series of testing machines!

Referring to the new wind loading Code, Mr. Gwynn quoted Mr. Harrington as saying that "the scientific results (used in the Code) should be accepted without question". Regretfully, he had to say that he did question them, because he did not consider them scientific. He was sure that wind speeds had been correctly observed, but the correlation of wind speed and wind pressure was another matter. Results based on wind tunnel experiments had definite limitations. The Code was generally so based, as witness the article "British Standard Code of Practice for load: Wind Loads" by Mason (24) also the admission in the Code itself that it lacked data on all but simple cases, and the consequent recommendations contained in it suggesting the necessity of wind tunnel tests in complex cases. A paper by Baines some years ago indicated the high significance of changes in terrain, and in Mr. Gwynn's opinion, that had to cast doubts on the application of wind tunnel experimentation conducted in steady flow conditions. He was impressed by the work of Mackey, who had established near Hong Kong a test site involving a purpose-built and fully instrumented multi-storey steel building and freestanding towers for wind speed measurements, and was recording actual wind speeds, and the loads, pressures, and strains resulting from them over a period of many years. Professor Mackey was taking a very forthright approach, in trying to see what was actually happening under real site conditions. The inauguration of a similar direct observation study in Ireland would be very valuable.

MR. M. O'CALLAGHAN supported Mr. Harrington's call for uniformity in the specification of concrete in Ireland. CP110 had, fortunately, dismissed the "nominal mix", and we now had only designed and prescribed mixes to handle. This was an improvement, but nevertheless he, as a ready-mixed concrete producer, regrettably had to report that he had recently to contend with a specification for concrete, allegedly in accordance with CP110 but containing also a pre-1965 compliance demand for an absolute minimum for cube test results.

He noticed that most specifications in Ireland still insisted on the explicit approval of the specifier for the use of ready-mixed concrete and he felt, with 26 per cent of all concrete in Ireland now being ready-mixed, to quote Mr. Harrington's figure, that the restraint on contractors should be reviewed. He also argued that it was unduly restrictive to insist on the full arbitrary current margin of 15N per mm² for ready-mixed concrete, as no allowance was made in that figure for the expertise of the producer, working in a continuous production situation. He would like to remark to Mr. Gwynn, who had mentioned accelerated testing, that his company had been using that method in quality control for some time and was finding it fairly successful. On concrete testing, generally, it was remarkable how much more testing was in progress now than in 1965. He was not sure whether that represented a greater availability of test facilities, or was a result of the considerable increase in ready-mixed concrete deliveries during that period. He did urge, however, that a greater sense of uniformity should inform

the profession in that matter. He felt that there were far too many personal variations to BS 1881 (Methods of Testing Concrete) being practised by individual specifiers.

Regarding procedures in the event of non-compliance, Mr. O'Callaghan pointed out that it was always necessary first to establish the validity of the results in question, and CP110 had emphasized this. On actual proving tests, the main reliance in Ireland seemed to be on core-testing, and this test method had a considerable volume of research work in Britain to support it, although little in Ireland. We should realise however that the acceptance criteria for cores had become more rigid since 1965, because whereas in 1965 the conversion factor from core-crushing tests to equivalent cube strength was taken as 1.3, it was now, in 1975, taken as 1.25.

On the relationship between cube tests and the strength of the corresponding placed concrete, Mr. O'Callaghan said that some recent published figures had caused alarm to specifiers, viz. concrete in situ slabs with a strength of 42 per cent of the test cubes, and in walls and columns, 60-70 per cent of the test cubes. He drew attention to the partial load factor for concrete in CP110 which proposed 0.67 as the ratio of the strength of placed concrete to the strength of cubes representing that concrete, and suggested viewing the figures quoted earlier, in that context.

MR. J. McCULLOUGH referring to the I.E.I. Report on Accidental Damage (32) drew attention to an important point of difference between that document and its British counterpart. The Irish document provided for the possible removal by accident of two contiguous panels at right angles in a building. This was significantly different to the requirements of the British regulations.

Speaking about the certification of design calculations, he said that whereas it had traditionally been normal for Local Authorities to accept the certificate of a consulting engineer, there had been instances in the last twelve months where various consultants had been asked for calculations, and some of these, he understood had been sent forward by Local Authorities to the Institute for Industrial Research and Standards for checking. He deprecated the possible duplication of scarce labour implied in that process, and considered that it would be better that a way be found to satisfy a Local Authority about the competence of a designer who was issuing a certificate, than that reliance should have to be placed on re-checking, possibly by people who did not have all the information available to the designer.

MR. P. T. PIGOTT thanked Mr. Harrington for his reference to the Irish Building Specification. Its preparation would not have been possible without the full cooperation of the building industry. An Foras Forbartha was very grateful for that cooperation and looked forward to its continuance, which would be essential if the Specifica-

tion were to be kept properly updated. A point of particular difficulty in phrasing the Specification had lain in its need to cater both for large sophisticated constructional projects and simpler small contracts. The best guidance available to the drafters on concrete quality control had been CP110. The provisions of that Code were very complex for small contracts, and he would urge that prescribed mixes, as defined in CP110, be used in any contract where it was not feasible to implement a full cube testing programme.

Referring to the proposed National Building Regulations, he would point out that the draft for these had been completed by An Foras Forbartha and had been submitted to the Department of Local Government where they were now under consideration.

Mr. Piggot mentioned, for inclusion in the list of working documents given by Mr. Harrington, the "Recommendations for Site Development Work for Housing Areas" published in 1974 by An Foras Forbartha. He felt that document could usefully be added to the bibliography as it contained a great deal of information on concrete for roadways and footpaths.

MR. A. R. BROWETT, in a written contribution, referred to Figure A1 in Mr. Harrington's paper, reproduced from Technical Note Number 35 (21). He commented that a comparison of that Figure with figures given in a recent publication of the British Department of Energy, "Guidance on the design and construction of offshore installations", would show that the map contained in the British documents indicated lower wind speeds than its Irish counterpart for the west and south-west coast but higher speeds for the south-east part of the country. The variation was up to 3 metres per second in parts of the south-west coast.

MR. P. KWIK, in a written contribution, gave his opinion firmly that if every design office had to produce calculations for checking, safer and perhaps more economical structures would result. His firm had, in the last twelve years, been responsible for the design, generally in reinforced concrete and on difficult sites, of a number of structures, including buildings up to 30 metres in height, jetties, foundations, and cooling tower basins. The designs had been part of "design and construct" contracts, and design calculations had been submitted to the clients for checking in all instances.

It was not necessarily true that a design produced by a reputable firm had to be sound, since in many instances the design was the product of a single individual rather than of a team. All designers were different, and human, and he felt quite sure that structures had been designed and built from time to time with less than adequate calculations and not in compliance with codes of practice. On the other hand, when design calculations had to be submitted for checking, compliance was more probable.

As an example of deliberate non-compliance, he understood that in the design of continuous beams and frame works, some consulting engineers ignored the Codes and based the quantities of reinforcement required on midspan bending moments of $1/8$ or $1/10$ WL, with anti-crack steel over the supports. He was strongly opposed to that practice which, while possibly acceptable for the ultimate limit state, was not satisfactory for the serviceability limit states.

Mr. Kwik recognised that the production of calculations for checking did require a little more time and effort, but questioned whether that was not a proper part of the consultants's work and responsibility. (Mr. Kwik sent, with his remarks, a specimen set of design calculations.)

MR. N. RYAN, in a written contribution, referred to Mr. Harrington's proposal that the minimum bearing for precast units should be increased from 75 mm to 100 mm. He personally, from a study he had been making on tolerance and fit, would not like to see deviations in the dimensions of components and space dealt with by an arbitrary increase in nominal bearing dimensions. He would like to develop that point in the discussion on Session C.

MR. N. MONTGOMERY, in a written contribution, expressed the hope that Mr. Harrington's call for the earliest possible issue of the National Building Regulations would be endorsed in an authoritative request from the Symposium to the Government for this to be done. It seemed clear that by 1965 the Minister for Local Government had been convinced of the need for national Building Regulations and had thereupon instructed An Foras Forbartha to set about preparing them. An Foras Forbartha had, in accordance with its normal policy, sought the help of the professions and of the industry in that work. It was clear, from the whole-hearted response which that request evoked, from the hours spent without remuneration on working parties and deliberating committees, that professions serving the industry had been equally convinced of the imperative need, for the industry as a whole, for the early promulgation of authoritative national Building Regulations.

Mr. Montgomery pointed out that it was now some years since the completed draft of the Regulations had gone from the Foras to the Custom House. One had the impression that the failure to complete the work was not just a matter of Local Government tradition, but was aggravated, by a reduction to a minimum in the name of the national economy, of the staff engaged in the work. He felt that the Minister should be advised that in the true perspective of national economy, there was no real saving involved in delaying still further the completion of a set of National Regulations started in 1965.

He had been associated with the drafting of those portions of the Regulations which dealt with fire precautions and means of escape.

It would be no secret that those clauses would be found to have been based not on original research but rather on adaptation to Irish conditions of the applicable portions of the English and Scottish Regulations. The Draft, on a preliminary restricted circulation, had been seen by the Royal Institute of the Architects of Ireland, amongst others, and had elicited protests on various grounds, the principal objection perhaps being an anticipated increase in building cost involved in the satisfaction of the new requirements. It was of value to consider that and other such protests in the context of Mr. Harrington's remarks. He noted Mr. Harrington's call for further research into the fire resistance of concrete and for more realistic testing and hoped that call should be heeded in such areas of authority and influence as the Institute for Industrial Research and Standards.

The problem of fire precautions was complicated by a dichotomy of interest, into life and property. Protection of property was obviously a concern of the insurance companies, and they, as for instance in England through their Fires Officers' Committee, demanded high standards in the construction and protection of the property they covered. Protection of human life, on the other hand, was the concern of the State, and that concern was expressed in Building Regulations. The complication referred to earlier was that those interests were separate. The training, skill, and experience of experts in life and experts in property were differently oriented. Sometimes they overlapped, sometimes they conflicted, but both interests combined, in their demands, to increase the cost of building.

Mr. Montgomery supported Mr. Harrington in seeking that new fire research and testing for concrete be established on a more truly scientific basis than existed at present. He regarded the work of the British Fire Research Station at Borehamwood as pragmatic rather than scientific in the sense indicated by Mr. Harrington. He would like to see the dichotomy resolved and a unified set of recommendations, governing both life and property, offered to the authorities concerned.

MR. P. AUNGIER, in a written contribution, said that it appeared to him that modifications to codes sometimes arose from a sense of panic magnified by the media of information. He felt, for instance, that the stricter requirements of the new Wind Code reflected that attitude. A similar conservatism also marked the recently increased demands for shear reinforcement, the proposal in CP101 (Foundations and sub-structures for non-industrial buildings of not more than four storeys) that reinforcement should be provided in all foundations, and several features in the newer bridge design publications of the British Department of the Environment. He felt that the whole area of concrete bridge design was rather chaotic, and criticised in particular, BE 1/73 (18) which, declaring itself mandatory, had reduced permissible shear stresses, outlawed the load factor method of design, and virtually

excluded the use of high yield reinforcement. He looked forward to a new Code on bridge design, which he understood was pending, and which he hoped would halt the current rush to conservatism.

Mr. Aungier concurred with a speaker at the final session in regretting the small representation from Northern Ireland and hoped the position would be rectified at the next Symposium. He referred to an important paper by Rhodes on "The structural assessment of buildings subjected to bomb damage" (J.I. Struct. E. Vol. 52, No. 9, September 1974) and said that there were recommendations in that paper for the detailing of reinforcement which might properly influence future codes of practice.

MR. T. BOLAND, in a written contribution, pointed out that the development of an accelerated cube testing process did not in fact answer the problem of dealing with cast concrete of inferior quality. He would have welcomed a reference to the fresh concrete testing methods of the Cement and Concrete Association, and considered that the incorporation of that test as a specified control would be useful.

MR. HARRINGTON replied to the discussion.

He accepted Dr. Orr's valuable comments on the Australian wind code and on the dangers of using codes outside their regional context. He personally had felt that the drafters of the British code had been considerably influenced by the Australian text, and inappropriately so, because the disaster situation recognised as a high risk in parts of Australia occurred very rarely, if at all, in Britain and Ireland. He remained of the opinion that the pressures recommended in British codes were far higher than necessary, particularly those relating to low-rise buildings.

He would agree with Mr. Gwynn about the value of accelerated testing for concrete where this was feasible. Suppliers of ready-mixed concrete were using the technique and he would in fact consider it a necessity for such organizations. It was not being used at all in Ireland however for testing site-made concrete. There were too many real difficulties. Furthermore, where ready-mixed concrete was concerned, it would not be justifiable to accept the suppliers' accelerated test results in lieu of 7-day or 28-day tests. Needless to say, that comment was in no way a reflection on the suppliers.

Mr. Gwynn had taken him to task about his attitude to scientific data in the field of wind pressure. The science which he queried lay wholly in the validity of the basic power-law relationship principles on which the formulae were based, and in that, he did not feel there would be any disagreement between them. He concurred with Mr. Gwynn in not accepting extrapolation from wind-tunnel experiment to real site conditions, and in fact it was that very viewpoint which had led to his suggestion that the pressures given for low-rise buildings were unreal. There was no doubt that the profession urgently needed practical information on wind pressures in real conditions.

Mr. Harrington welcomed Mr. O'Callaghan's comments. The generally high expertise of ready-mixed concrete suppliers was now an accepted fact. He, with Mr. O'Callaghan, would certainly hope that no order to demolish completed work would ever be based solely on the evidence of low cube test results. It was reasonable to expect that examination of the concrete in the suspect structure would always precede such an order. He felt that the 42 per cent and 70 per cent ratios which Mr. O'Callaghan had quoted related more to poor compaction than to anything else. The lesser figure referred to slabs and the greater to columns and this represented for him a reasonable observation on the relative qualities of the compaction often found to be achieved in these two elements. He felt that Mr. O'Callaghan's plea for a reduced current margin was in general justified, as most ready-mixed concrete did amply exceed its specified characteristic strength. There was one supplier however who kept quite close to current margin requirements, and while that was of course in order, the discussions generally would have convinced his listeners of just how embarrassing to everybody low results were. The current margin was the buffer against that situation.

Mr. McCullough and Mr. Pigott had made important points. He agreed that duplication of work, as for instance in the checking of structural calculations, should be monitored carefully. It was noteworthy however that the situation in Britain was one of far greater duplication than we experienced here. He was glad that Mr. Pigott had referred to the Report on development work in housing areas. It was an important document and members should be made aware of it.

Mr. Harrington later provided replies to the written contributions made to his paper.

In reply to Mr. Kwik, he said that the production, by design offices, of calculations for checking would not in his view cause any change either in the degree of safety or the overall economy of structures designed by reputable firms. It could in a number of cases result in a change of format for the presentation of such calculations. He doubted that, in a reputable firm, a design for any significant project would be the work of one individual only and he would expect the overall design to be the result of a team effort involving the necessary checking stages. He would not envisage difficulties for consulting engineers in providing calculations for checking but the point made in the paper was that this would involve an increased workload for local authorities and this problem would require solution before the check system could be effectively implemented.

He was grateful to Mr. Montgomery for his endorsement of the call made in the paper for the early issue of the National Building Regulations and for his support for the request made that further research be undertaken on the fire resistance of structural concrete construction. Hopefully, the obvious need for answering these calls would be recognised and the results would include economic benefits for the construction industry, and through it, progress for our country.

Mr. Harrington said he would be glad to study the contribution made by Mr. Ryan in Session C when this was published. He would like however to emphasize that, in his view, a minimum nominal bearing width of 75 mm was too low for concrete-to-concrete bearings in order to produce good construction.

He would support Mr. Aungier in his view concerning the need for a new code dealing with bridge design.

In reply to Mr. Browett, he believed that the information given in the British DOE publication could be used to deduce that extreme 50 year gust speeds for the west and south west coasts should be about 2 m/s less than the values given in the paper. However, it was to be noted that in October 1975 the Irish Meteorological Service had published Technical Note No. 41 (Logue) and it contained revisions of data previously given in Technical Note No. 35. In the later publication, annual maximum gust and mean wind speeds had been extracted from the autographic wind records of a number of stations for periods up to and including 1974. The information given in Technical Note No. 35 was based on data recorded up to 1970. The gust wind speeds given in the later note shows a reduction of about 4 m/s for west and south west coastal areas, a reduction of 1 m/s for south east coast and an increase of from 1 to 2 m/s for midland and eastern areas respectively.

In reply to Mr. Boland, Mr. Harrington observed that there had been some demand in Britain for the use of the fresh concrete testing method for acceptance tests, but he believed that there was not yet available sufficient data on the influence of machine performance and sampling techniques on the accuracy of the result, to consider specifying this form of test in terms of an acceptance test. The use of the method as a quality control aid by contractors, laboratories and ready-mixed concrete producers was likely to increase in this country during the next few years.

He would agree with Mr. Boland on his observation concerning IS 5. In that respect it should be noted that draft proposals for amendments to clauses 6.2.2.1 and 6.2.2.3 of CP110:Part 1 had been circulated. These dealt with the chloride salt content of marine aggregates.

THE SUPPLY AND HANDLING OF CONCRETE

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Introduction

The supply of concrete and its subsequent placement on site is primarily the area of the builder or contractor and in certain cases that of the ready-mixed concrete manufacturer. There have been changes over the last 10 years in the methods of supply and handling, some significant and considerable, others perhaps surprisingly have only been slight.

The author has endeavoured, through discussions with contracting firms both big and small, ready-mixed concrete producers, plant providers and other groups associated with the building industry to establish the extent of these changes and what is current practice with respect to mixing and placing.

The paper examines the topics under the following headings:—

- (1) Raw materials for concrete.
- (2) Mixing of concrete and supply.
- (3) Handling, vibration, and curing.
- (4) Some treatments of unhardened concrete.

(1) Raw materials for concrete

Cement

A major indicator of the growth of the concrete industry over the last 10 years has been the increased production of Cement Limited. In 1965 its capacity was 1.3M tonnes per year, the Limerick plant having the larger capacity of the two then in operation, with 760,000 tonnes per year.

In 1972 the newly completed Platin Works went into production with a possible annual output of 420,000 tonnes, so bringing the present total capacity to 1.75M tonnes per year. It is worth noting that the work has commenced this year on the construction of Platin II, which will further increase capacity by some 1M tonnes.

An analysis of current cement sales show bulk sales running at 52% of the total. This indicates a surprisingly high demand for bagged cement.

A further breakdown of bulk sales which is approximate, but reasonably accurate, yields the following information:

User:	% of Bulk Sales:
Ready-mixed Concrete Manufacturers:	52%
Pre-Cast Concrete:	42%
Site Mixed Concrete:	6%

The delivery of bulk cement is carried out mainly by C.I.E. in containers with a delivery capacity of 15/16 tonnes or 20/22 tonnes. An interesting development in recent years has been the use of private bulk carriers by a number of companies. At present, approximately 35% of all bulk dispatches is collected by customers using their own vehicles.

The sizes of cement silos used by ready-mixed concrete producers vary considerably depending on company policy. The 30 tonne silo tends to be most commonly used for site-produced concrete. While there has been considerable progress in the development of certain concreting plant, a suitable and reliable method of measuring cement content of on-site silos has not yet been devised. The mixer operator invariably has to climb to the top inspection hatch and, based on experience, roughly estimate the contents. Where critical pours are involved, it may often be essential to know to the nearest tonne or so the current contents. Most contractors provide for errors in this respect by maintaining a store of bagged cement, the use of which delays the pour and considerably reduces cost efficiency.

The types of cements presently manufactured in the Republic of Ireland are:—

- (a) Normal Portland cement (bulk & bagged)
- (b) Rapid hardening cement (bulk & bagged)
- (c) Sulphate-resisting cement (bulk)

In the early 1970's Cement Limited manufactured a slag cement specifically for the E.S.B. Project in Turlough Hill.

Aggregates

Ireland continues to be blessed in this respect. There does not appear to be any shortage of aggregates, unlike the U.K. where the use of sea-dredged aggregate has now become a reality. Not only are our aggregates generally of excellent quality for concrete manufacture, many of them also possess considerable possibilities in terms of architectural concrete.

Aggregates for concrete manufacture are mainly supplied by specialist providers in either batched form or in single sizes, i.e., 20 mm—10 mm; 10 mm—3 mm; sand. Opinion is divided on the merits or demerits of using batched aggregate. It is argued that where consistently high quality concrete is required, the single sized batching is preferable as the mixing on site can be continuously monitored by the

interested parties. On the other hand the suppliers argue, reasonably, that their factory-controlled methods are more accurate and reliable than those on site. Where durability and strength are the sole requirement for a concrete, the author has found that all-in batching gives most satisfactory results. Perhaps if a further requirement in respect of finish pertains, then it is possible that on-site single sized batching with responsible supervision may be more desirable.

The majority of aggregate suppliers are aware of the importance to the industry of a product produced to comply with Irish and British standards. This has led to the installation of modern crushing, grading and washing equipment, even on small to medium-sized plants. The resultant product has done much in the last 10 years to eliminate an aspect of concrete control which was once a considerable worry on building sites.

Present day deliveries can be effected in containers up to 30 tonnes. The old practice of delivering aggregate in bulk consignments would now appear to be almost extinct.

Water

This commodity is, as always, in plentiful supply throughout the country and its quality rarely poses problems with respect to the concrete quality. However, the author has heard recently of a case where water, which had been contaminated by industrial waste, was used with resultant sub-quality concrete. It is possible that this may increasingly become an area of concern.

The introduction of water to the mix on site is usually mechanically controlled and adjustments are made where necessary to allow for moisture content of the sand. An experienced mixer operator will normally have little difficulty in gauging correct water content after the first two batches of the day have been discharged.

In the case of ready-mixed concrete, water is added at the batching plant (except where dry batching is used) and a further quantity may be added by the truck operator from a tank located on the truck. This latter possibility is normally only required where the client specifically requests that the water content be increased.

Additives

There is, at present, a wide range of additives on the market, most of which are manufactured abroad. These are generally added to the mix in liquid form, during the mixing process. Opinion is somewhat opposed to their usage, for two main reasons:

- (1) They introduce a further ingredient to the mix which requires accurate controlling.
- (2) Many of the claims attributed to additives have not been adequately substantiated in practice.

However, based on information received from suppliers and builders, it would appear that additives are becoming more accepted and widely used. Certainly the following results of a recent survey in the

U.K., show a high usage of air entrainers, accelerators, and retarder/workability agents.

Additives	% of Concrete placed in the U.K.
pigments:	0.75%
waterproofers:	0.3%
air entrainers:	5%
accelerators:	5%
retarder/workability agents:	7%

(2) Mixing of concrete and supply

Site-mixed concrete

The methods of manufacture of site-made concrete have not changed significantly over the last 10 years. The types of mixers generally in use cover the range from 5/3½ to 21/14. These can be either mechanically or electrically driven.

On small contracts or perhaps housing projects the smaller 5/3½ and 7/5 mixers are adequate, while on the medium to large jobs the 21/14 is now in general use with maybe a 5/3½ as a stand-by for mortar mixes during the blockwork, paving phases.

Present-day claims suggest an output of ½ cu. yd. per 3 mins. for the 21/14 but in practice, due to slightly less than maximum charging, 8 cu. yds. per hour is reasonable. It is possible to achieve this output with two operatives at the mixer, one operating the mechanical shovel and the other the cement, water and discharge controls. The use of batched aggregates helps to improve this cycle and reduce errors.

Mixers

There has not been any significant development in the design and output of the drum type mixers though they are still by far the most commonly used on sites. They are robust, mobile and adequately meet the demands of their users.

There has been considerable innovation by British and Continental Designers on the pan-type or turbo-mixers. Their manufacturers claim:

- Higher output achieved by a higher mixing intensity and a shorter discharge period.
- Greatly improved mixing ability yielding higher strength concrete for a given cement content compared with drum-type mixers.

Both of these claims have been substantiated. The ready-mixed concrete and precast concrete producers are the main users of such Plant. There are models available for site use, claiming outputs of 15

cu. yds. to 24 cu. yds. for a batch output of a $\frac{1}{2}$ cu. yd. Such outputs are, of course, entirely dependent upon the rate of charging materials to the mixer.

Ready-mixed concrete

In 1965 ready-mixed concrete was essentially confined to the Dublin area and used about 7 - 8% of all cement produced. This compares with a 1974 figure of approximately 25 - 26%. Looking at the growth of the ready-mixed concrete industry in other countries, this trend was entirely predictable. Sales of ready-mixed concrete in the U.K. are approximately 43% of the total concrete used, while the similar 1973 figure for the U.S.A. is 63 - 65%. It is likely therefore, that the next decade will see a further increase in Ireland in ready-mixed concrete sales.

At the moment, there are some 22 separate companies supplying ready-mixed concrete in the Republic. This includes firms having a large number of separate plants and is limited to firms whose major activity consists of producing ready-mixed concrete. In addition it is estimated that there are twenty or so companies who supply ready-mixed concrete as a minor aspect of their total business. In recent years the smaller companies are succumbing to takeover bids by some of the larger firms. This should lead to a greater standardization of the product and hopefully to a wider range of mixes with high standards of control becoming available to consumers in all locations.

A number of factors have contributed to the growth of the industry, as follows:

- (a) Improved methods of production and quality control have increased the purchasers confidence in the product.
- (b) Ability to meet the clients delivery requirements which are proving more and more exacting, both in quantity and specification.
- (c) As a result of (a) and due to increased competition, the price of ready-mixed concrete has become an increasingly more attractive economic proposition to the builder.

It is worth examining the first two points in some detail:

- (a) Batching of ready-mixed concrete is generally carried out by weighing the quantities of cement, sand and aggregate and by metering of water. Weighing equipment is of a high order of accuracy (less than 1% with some recent equipment). Cement weighing systems generally operate to an accuracy of 5 kg. divisions and the aggregate system to 10 or 20 kg. divisions. Present weighing of cement, i.e. pre-selection of the batch weight by cement, reduces inaccuracies and decreases the batching time required. Addition of water is still the key to consistency of batching. Flow meters in present times are most commonly used with visual checks by the experienced batcher. There are also available, electronic methods of gauging the moisture content of the sand and aggregate to ensure correct specified water content.

The quality control of ready-mixed concrete can be broken into three areas:

(i) Materials:

Aggregates—Regular grading and moisture tests.

Sand—Regular grading, moisture and silt tests. Grading and moisture content of sand are carefully scrutinised to determine trends and variations.

Cement—I.I.R.S. and Cement Limited carry out their testing on cements and ready-mixed concrete manufacturers tend to rely completely on data supplied.

(ii) Mixed Concrete:

While in the plastic state workability tests (slump) are normally carried out. Regular plastic density determinations are made to check yields. In some plants use is made of accelerated testing of concrete cubes.

This is the Grant Method which consists of heating covered cubes in moulds for approximately 16 hours, stripping and testing. Correlation charts are then used to estimate 7 and 28 day results. This method allows for 28 days results to be known within a day or so and remedial action, if required, can be promptly undertaken.

(iii) Analysis of Results:

The Cusum Method tends to be used on most up to date plants to ensure that corrective measures are taken when small variations in day to day results might have a cumulatively adverse effect. This method consists of plotting mean strength, standard deviation and various correlations on specially prepared sheets. The plottings are examined daily, using envelopes which indicate trends and the actions to be taken by either increasing or decreasing the cement content if necessary.

(b) In the earlier days of ready-mixed concrete the customer's confidence in the industry was rarely complete due to the occasional plant breakdowns and lack of co-ordination in deliveries. It is only fair to note that in certain cases, problems arising from the latter were of the customer's own making, though he often failed to realise this. However, such situations are now, happily, less frequent.

Because of the number of plants operating, particularly in urban areas, breakdowns no longer pose a serious problem. It is generally possible for the supplier to switch to another plant for deliveries with little disruption in the concreting programme. Unfortunately the same cannot be said for less well developed areas and the writer has heard of a number of unsatisfactory incidents arising from mechanical failure at the plant. In anticipation of such events most contractors make provision by installing a small mixer on site.

The co-ordination of deliveries to sites has improved somewhat. The level of control tends to be more satisfactory, the larger the pour in question. Deliveries are co-ordinated by an office based supervisor

who maintains direct telephone contact with the sites. Nevertheless, the author feels that there is room for improvement in this area even allowing for the occasional misdirections by the purchaser.

The arguments regarding the economics of ready-mixed concrete and site-mixed concrete are hotly debated. Certainly the ready-mixed industry has succeeded in recent years in making the unit cost of its product most competitive. Ready-mixed concrete appears to have captured a large section of the site placed concrete market, while the sale of bulk cement directly to sites would indicate a definite decline in site production. In the final analysis, each job or contract must be assessed on its merits and the decision to use site-mixed or ready-mixed concrete will depend on many variables. These include:

- (i) Availability and suitability of plant for site-mixing. It may prove economic to use ready-mixed concrete in the initial stages of a contract.
- (ii) Access problems for site-mixing plant, e.g. confined urban sites.
- (iii) Size and frequency of pours.
- (iv) Is the bulk of the concrete to be placed below/at or above ground level?
- (v) Crane and on-site mixer locations may entail excessive slewing times so ready-mixed concrete may be economically more feasible.

(3) Handling, vibration and curing

Handling

The methods of handling concrete on building sites have not changed significantly over the past 10 years. However, the organisation of sites and increased sophistication in machinery design has led to considerable improvement both in the technique and rate of handling of large contracts. Many factors will dictate the type of handling to be used depending on the nature and size of the job in hand. Concrete is handled in Ireland in one of the following ways:

- (a) Wheelbarrows.
- (b) Dumpers.
- (c) Hoists.
- (d) Conveyors.
- (e) Crane/Skips.
- (f) Pumps.
- (g) Monorails.

(a) The use of wheelbarrows as a means of handling is obviously limited to contracts where small quantities only are required to be placed. They are used on large jobs in sections inaccessible to crane skips and where small quantities are to be poured. It is obviously not a very sophisticated way of placing, but nevertheless there are few sites without their wheelbarrows. Small hand-operated power driven barrows can be effective, particularly on elevated pours to transport

concrete to points beyond the radius of the crane. These machines have a capacity of approximately $\frac{1}{2}$ m³ and can be used in conjunction with a hoist.

(b) The variation in design of dumpers and tipper trucks presently available is evidence of the wide use of this type of plant for on-site handling. Their capacity runs from 1 m³ to 3 m³ and many of them have the ability to rotate their tip bucket through 90° which facilitates pouring. They are generally robust and capable of taking considerable punishment if properly maintained and serviced. It is equally important to ensure, where possible, that site roads are reasonably level thus reducing wear and tear on travelling plant.

Normally the dumper will pick the concrete up directly at the mixer and travel to the point of placement. On projects where the bulk of the concrete is to be placed at or below ground level, this can be an efficient method of handling.

For work above ground level their use is obviously limited as the concrete must be placed in a skip to be elevated by crane or hoist to the required level. A number of dumper manufacturers now utilise detachable skips in place of the standard gravity discharge bucket.

This method, to be efficient, involves the use of two skips per dumper. The first skip is placed on the dumper and takes the discharge from the mixer. This is subsequently picked up by the crane, off the dumper. The second skip is then placed on the dumper to take the next discharge of concrete. It is delivered to the crane which has already placed the first skip on transfer cradle whence the dumper picks it up and so the cycle carries on.

(c) Hoists are used extensively for placing concrete above ground level where small quantities only require to be placed at any given time. There is, naturally, a limitation on the quantities they can handle but they tend to be used where expenditure on a permanent or mobile crane is not warranted. Recent models present a wide range in lifting capacity and offer advantages in mobility both from site to site and around the site itself. They require regular and thorough maintenance and can prove troublesome if this is not attended to.

(d) Mechanical belt conveyors are rarely used in this country for placing concrete. It is interesting to note that they appear to be popular in the U.S.A., largely because of:

- (i) Efficiency—few breakdowns.
- (ii) Low capital cost.
- (iii) Adaptability to most site situations in that they are capable of being directed through 90° and can be used on soft surfaces. However, it is perhaps significant that their use is mainly confined to the warmer states where climate is less likely to pose serious problems.

(e) The overall nature and shape of cranes has altered only slightly over the last ten years. The tower crane is most commonly used on medium to large-sized contracts while the luffing jib type appears to be losing popularity.

The lifting, reaching and slewing capacity of tower cranes has resulted in a situation where cranes presently available are suited to certain particular aspects of a building contract, more than others. The choice of a crane to lift heavy precast concrete units at full jib may not be the ideal one for concrete placing and so the contractor is occasionally faced with a compromise decision.

The tower crane, because of its ability to travel on tracks and rise to considerable heights, as required, is used regularly on building construction and civil engineering contracts. Obviously much thought must go into the placing of cranes on site to ensure maximum efficiency and use. It is also important to reduce to a minimum the number of occasions on which the crane has to be taken down and re-erected, as the cost of this operation can be most expensive.

Mobile cranes of the telescopic and strut type are also used for placing concrete. While expensive to hire, they are well suited to contractors requiring only a limited number of large pours and having otherwise little use for a crane. A number of large contractors have purchased their own mobile cranes. On heavy industrial building they can be effective, offering both mobility and the capacity to handle large pours. Most of the concrete on this type of work tends to be below ground level and not always accessible to dumper trucks.

The shape and capacity of concrete skips has altered very little in the last decade. However, improved designs of the side chute has facilitated placing concrete in narrow sections and walls.

(f) The most significant development in terms of handling has been the growth in popularity of the concrete pump. There are at present 9 mobile 3" - 4" diameter piston-type pumps in the Republic, six of which are operated by ready-mixed concrete manufacturers and the balance by private contractors. There were no mobile hydraulic pumps in use in 1965. The trend in the U.K. and on the Continent has indicated a similar growth.

Because of the higher rate of placing, the effect of pumping has been to have larger single concrete pours than was heretofore possible. This ideally entails more detailed planning and programming between the builder and designer in advance of concreting. It leads to a reduction in last minute panic situations where, for instance, a floor might be poured section by section with information being fed to a builder in a piecemeal manner.

The majority of pumps in use can be cab-operated or console-operated by the operative standing adjacent to the work thus eliminating the use of a bankman. The smaller diameter pipes are capable of delivering horizontal distances of approximately 100 metres and vertical distances of 75 metres. The pump may be set up on site in 5 minutes if the boom only is required for placing. However, where long distances are involved, setting up times of approximately $\frac{1}{2}$ to 1 hour are required depending on the pipe length.

The design of the mix and consistent mixing are essential to a good pumping operation. A cohesive mix is required with a minimum

cement content of 250 kg/m³, extra sand content approx. 5% and a slump of 50 - 70 mm. Gap grading is to be avoided and where possible rounded aggregates should be used, as this results in less wear to the pipeline. Plasticisers and air entraining agents have been used successfully to ensure cohesion and reduce pipe friction.

The rate of pumping depends entirely on the rate of placing. Pump manufacturers claim rates of the order of 60 m³ per hour where little placing is involved. On narrow sections and where pipe lengths have to be removed, rates of 10 - 15 m³/hr. can be expected. Irish figures indicate a discharge rate of 25 m³/hr. where few obstructions and delays are involved. The British Building Research Station did some work on pump output in the early days and found the discharge rate in practice to be 33% of rated output.

The cost of hiring pumps will vary with the size of pour involved and is generally subject to negotiations with the ready-mix providers. There are three basic charges involved, a fixed daily charge, a rate per m³ pumped and an additional charge for extra cement per m³ pumped. The present day fixed charge is of the order of £60 per day. An analysis of 1973 placing charges where pumps were hired from ready-mixed concrete suppliers gave an average charge of £1.29/m³ pumped.

(g) Monorails—this arrangement is generally used by Civil Works particularly where water has to be traversed. The wagons with a half-metre capacity are carried on the rails which are easily erected and adjusted as required.

(h) Other methods—the most commonly used underwater methods of placing are the tremie or the underwater concrete bucket both of which are being used successfully in this country. It is also worth noting that concrete has been placed using a helicopter and skip.

Vibration

Satisfactory quality and finishes can only be achieved by adequate vibration of the concrete. This fact is now widely accepted throughout the industry. The use of vibrators on medium to large size contracts is automatic while vibration or compaction of some form is attempted on many small "do it yourself" jobs.

The most common type of vibrator in use is the internal or poker type which is inserted in the concrete and powered by petrol/diesel, electricity or air. External vibration is not usual except where quality finishes are essential or where the influence of the internal vibrator cannot be effective.

A significant development has been the increased use of vibrating screeds on ground floor slabs. Here the screed can be either timber or steel with a vibrating motor mounted in the centre. Beams up to six to seven metres long are available and can be cambered by stressing wires to ensure that the motor causes no deflection in the centre with a resultant slab depression. The concrete is placed ahead of the screed which is manually operated and is vibrated as the screed travels along the

forms. The section of concrete close to the forms is normally poked-vibrated as the influence of the screed is not effective in these areas.

Curing of concrete

While the Irish climate may have a lot going for it, it is not a satisfactory curing agent. The curing of concrete is an area which has and can still be neglected even on large contracts, with unfortunate results. In the case of floor slabs the concrete must be protected soon after final placing which is often late in the evening and so this is forgotten or not thoroughly executed.

Curing in Ireland is carried out in the following ways:

(1) Covering the concrete with damp hessian soon after placing and maintaining the hessian in a damp state for the curing period specified. Maintaining the hessian in a damp state may not always be the easiest of tasks.

(2) Covering the concrete with light gauge polythene soon after placing. This has the effect of retaining the moisture on the surface of the concrete and so ensuring adequate curing. However, windy conditions will tend to lift the cover unless it is well weighted down. In the author's experience it is difficult to get many covering uses out of polythene and so it can in practice be somewhat expensive.

(3) Covering of concrete after it has hardened with sand. The sand is maintained in a damp condition—this method has obvious limitations.

(4) Use of curing agents which are applied by spraying over the concrete surface soon after placing or immediately after stripping. These can be supplied with a colourising tint which indicates clearly the areas covered. The sprays, once applied, need no further maintenance and are effective curing agents. It is important to note whether the sprayed surface will in the future have an applied finish requiring maximum bonding, such as a screed or plaster. If this is the case it is essential to check that the curing agent is self-destructing within an acceptable period or will not affect the bonding capabilities of the surface.

(4) Some treatments of unhardened concrete

It is worth commenting on the present state of the art of floor finishing techniques applied while the concrete is still plastic or fully hardened. Floors have been traditionally finished by successive trowelling with steel trowels with much depending on the skill of the operative. The process tended to be lengthy and expensive.

The introduction of the power float has had a significant effect on the quality and performance of floor slabs. The float, which is petrol driven, can have discs and trowels fitted as required. However, as many builders have found to their cost, it is essential that the floating and trowelling operation be carried out at the correct time.

Floating should not be started until the surface moisture has evaporated and the concrete is stiff enough to take the weight of the machine. Its primary function is to regulate and close in the concrete surface. The power trowelling operation then follows on and successive trowellings with floats will produce a hard wearing surface. It is, of course, imperative that the operatives using this equipment are fully experienced if maximum benefits are to be obtained.

Vacuum dewatering

The timing problems of power trowelling can in some instances be overcome by the use of the vacuum dewatering process. This technique, discovered in the early 1930's has only recently achieved popularity on a commercial scale in the U.K. It has also been used in Ireland, apparently with some success.

The surface of the compacted concrete is covered by a rigid or flexible suction mat, incorporating filter layers. The mat is connected to a vacuum generator. The vacuum is applied at a rate of 2 to 3 minutes per 25 mm of concrete depth. A considerable quantity of water is withdrawn from the concrete, the filter ensuring that no cement is removed. The operation has no adverse effect on the concrete as the volume of water used in production of concrete is well in excess of that required for the chemical hydration of the cement. The concrete stiffens rapidly after application of the vacuum with the result that the surface may be power-floated within an hour or so after placing.

Some further advantages claimed for the process are:

- (1) Increased compressive strength due to reduction of the w/c ratio.
- (2) Improved wear resistance.
- (3) Reduced shrinkage.

Summary

To summarise developments in the last ten years of concrete supply and handling in Ireland, it is reasonable to say that in most respects our methods and techniques are comparable with those presently pertaining in the U.K. and Europe.

There is a wide range of machinery available for mixing concrete. On small sites the 5/3½ of 7/5 mixers are still most popular and functional, while the 21/14 tends to dominate on the middle to large contracts. However, the considerable development in the size and output of pan mixers may see a trend towards their use particularly on large contracts. It is perhaps worth noting that at the very opposite end of the scale there is now available, a manually powered and operated "do it yourself" mixer, called simply "Stroll-A-Mix".

In the area of handling the use and growing popularity of the concrete pump has been significant. If we are to develop along similar lines to the U.K. and Germany, it is likely that this method will achieve more widespread use. There has not been a noticeable change in the

use and design of cranes for handling concrete. Developments in this respect have been to improve design to cope with various other site situations as the crane is a multi-purpose site machine.

An increased awareness that proper mix design and quality control can result in improved site efficiency with resultant site economies is evident. Suppliers of concreting materials and ready-mixed concrete have noted a significant increase in the number and nature of enquiries regarding the characteristics of their products in relation to mix design and content.

Within the Construction Industry, the science of daily and long-term-planning of concreting operations has been given more recognition. Formerly the exclusive field of the General Foreman, it is now analysed in depth during the pre-contract stage and further examined and refined during the contract period. A further impetus to this improved planning has resulted from the increased number of large and single pours which require a great deal of pre-planning and programming.

There is, in the opinion of the author, one particular area where there is room for improvement. The skills of the designers, builders, programmers and controllers have improved and been recognised. There are courses and training programmes available which adequately meet the requirements of the Industry as far as personnel are concerned. While all of these skills are considerable, indeed, formidable, in the final analysis we are dependent on the man who mixes, transports, places and vibrates the concrete.

If the operative has little knowledge of the technology of concrete then we, the planners, can only go part of the way towards achieving a near optimum result. At present we tend to depend on experience gained over many years and minor disasters to ensure that the concrete mixed and placed meets the specification. Perhaps suitably designed training courses for concrete operatives would result in considerably fewer minor disasters and consistently good quality concrete, achieved through improved site efficiency.

The practice on the Continent has been to give greater recognition to the skill of the concrete operative. Perhaps we, in Ireland, should follow suit.

Discussion

MR. MESCAL introduced his paper.

He had recognised the impossibility of treating in detail all the developments of the last ten years which might be considered to lie within the scope of his paper. He had tried to deal with some particularly significant points in detail, but in general had had to confine himself to comments on the trends of the period with some look towards the future. In preparing his paper, he had sought the help of

consulting engineers, contractors, ready-mixed concrete suppliers, and suppliers of plant and equipment, and indeed members in every part of the concrete building industry, not only in the offices but also on the sites, at the mixers and in the casting teams. There were too many sources to acknowledge individually, but he was extremely grateful to all who had helped him.

The paper dealt with the materials for concrete, their supply and processing, and the handling and placing of concrete.

Regarding materials, there had been two significant developments in the decade. These related to cement and to additives. In 1972, Cement Limited had opened their Platin works (their first dry process plant), thereby increasing their manufacturing capacity by 420,000 tonnes per year. They would in the near future be increasing the capacity at Platin by a further 1,000,000 tonnes per year. The company had also commenced the manufacture of sulphate-resisting cement. Mr. Mescal thought that that was probably prompted by the fact that a number of British consultants working in Ireland had specified its use. He felt that in future years, there would be need also for an extra-rapid-hardening cement, more akin to the ultra-rapid-hardening cement now available to Britain than to the rapid-hardening cement we now had. The recent history of high alumina cement would underline the necessity for the new material.

There might also be a need for a locally-manufactured white cement. He did of course appreciate the difficulty that existed of finding suitable raw materials, but, on the other hand, those who had used British white cement knew just how costly a commodity that material was in our market.

Regarding additives, there had, in recent times, been a considerable growth in their use. Up to two or three years ago, they had not been popular in the Republic. Mr. Mescal had found in his survey however that since then, contractors were giving them far more attention and a consensus was emerging that they did work, provided they were intelligently used. Figures relating to their use in the Republic were not available, but he had quoted figures for the British use of accelerators, retarders, and workability agents in his paper and the Irish industry should recognise the significance of those figures. His survey of Irish practice showed that the possible saving in cement and consequently in cost, resulting from the use of an additive, was an important factor for the industry. It was also clear that suppliers were aware of our increasing interest in the use of additives, that was if one could judge from the great influx of new additives to the Irish market, and the promotion efforts of their sales teams. In a recent experience of his own, Mr. Mescal had found that, following several phases of experimental trial and error, which involved direct communication with the suppliers, a particular additive which at first had been a decided failure had come around to making a valuable and economically sound contribution to work which he was doing. He

could not leave the subject of additives however without recording that there did at present exist in Ireland a large body of opinion utterly opposed to their use.

Turning to the manufacture and supply of concrete, the major development of the decade had been the increase in the use of ready-mixed concrete. In 1965, about 7% of the concrete used in buildings in the Republic had been ready-mixed concrete. The figure now was about 26%; and the upward trend would continue, if one were to judge by Britain and the U.S.A. where the current levels were now approximately 45% and 66%. It was clear that the suppliers of ready-mixed concrete had gained the confidence of the builders, and this was largely because suppliers were providing concrete of consistently high quality at a competitive cost. Mr. Mescal attributed their achievement to their high level of quality control and their sophisticated management techniques. He mentioned particularly the Grant method of accelerated testing and the Cusum method for monitoring concrete strength.

The only area in which the feed-back from his survey suggested a weakness in the organization of the suppliers lay in their co-ordination of deliveries to sites; and some feeling clearly existed that the bigger customers got preferential treatment. It was not necessary, he felt, to remind anyone how inadequacies in concrete supply, however arising, could damage site relationships between, on the one hand, designers and their resident staffs, and, on the other, contractors and their suppliers. There could of course be faults on both sides. Contractors did not always give their suppliers the detailed information and notice required to maintain the flow of concrete needed. One important question, however, had been raised through his survey. Why did the suppliers of ready-mixed concrete not use radio control for their trucks? It was a fact that he had not come across any supplier so equipped, and it seemed to him a curious lack against the background of so much sophistication in other aspects. On the matter of cost, the consensus today would seem to be, in very general terms, that for large pours or large contracts, site mixing was generally more economical, provided there were no site restriction problems, whereas, for small to medium-sized contracts, ready-mixed concrete might well be cheaper.

Speaking on concrete handling generally, Mr. Mescal considered that our work in Ireland was still too labour-intensive. He would of course accept Dr. Orr's observation at the earlier session that Irish industry was less plant-oriented than say the industry in Britain or Germany or the U.S.A. He himself had observed, however, particularly in Germany, that the men engaged in concreting operations had a far greater appreciation of the work they were doing in the placing and compacting of concrete than their Irish counterparts. Education could, in his opinion, play a large part in increasing the efficiency of labour, and thereby reducing its cost.

The most significant development of the decade in the handling of concrete had been the concrete pump. In 1965, there had been no

mobile hydraulic pumps in the Republic. Now, there were nine, six belonging to ready-mixed concrete suppliers and three to contractors. The concrete pump offered three main advantages. Firstly, there was a reduction in the cost of placing where large pours were involved; secondly, pumps could be used to overcome difficult access problems; and thirdly, they could be used to place concrete under water. He felt he should stress two points about pumping concrete. Firstly, the construction sequence had to be planned carefully, with particular attention to suitable pump locations, and, secondly, the concrete mix had to be designed with pumping in view. The matter of mix design was critical. Those in his audience who had experience of delivery pipes becoming filled with immovable concrete would know the depths to which the character of the contractors engineer might be plumbed, merely from observing his reactions at such a juncture.

Very large volumes of concrete could be placed as single casts, if pumps were used. Single pumps could work at rates of 20-25 cubic metres per hour, even in locations difficult of access. A single 24-hour cast of 1100 cubic metres, using three pumps, had been achieved in the Irish Life development in Abbey Street in Dublin, while, in Britain, a quantity of nearly 3000 cubic metres had been placed in 22 hours. It seemed quite clear that the use of concrete pumps would increase significantly in the Republic in the coming years, as their use in Britain and elsewhere was already extensive.

Generally it would be agreed that the level of concrete technology in Ireland had risen substantially in the last ten years, and Irish technologists now had an expertise well on a par with most other countries. The courses and lectures which had been provided during the period had been extremely valuable. The concrete technologist had, in his opinion, grown in stature during the decade and his linked achievements of higher standards and reduction in real cost were now well recognised by the industry. The development in style of the concrete specification during that time echoed the advances made, and his final comment would be a suggestion that specifiers should thenceforth recognise even more the change which had been occurring, and should draft their future specifications so as to enable contractors and technologists generally to use their increasing expertise to the full.

Mr. Mescal illustrated his introduction with seven slides showing the delivery and pumping of ready-mixed concrete, and the appearance of concrete suitable for pumping.

MR. M. SWEENEY opened the discussion. Mr. Mescal and he shared the common bond of being engaged in civil engineering construction, and this added to his pleasure of speaking to the paper.

He had to say that he saw the developments of the past ten years in the supply and handling concrete not so much as changes, but rather as improvements in certain aspects of the concrete industry. As improvements, they could be classified under two headings. Firstly, the methods of production, reliability of transport, and quality control

of ready-mixed concrete had improved considerably. Secondly, a major improvement in handling and placing had been the construction of the more efficient and economic piston-type concrete pump instead of the pneumatic placer which had been used successfully for many years, although on a limited scale in this country. In that context, he referred his listeners to the particular information given by Mr. Wallace in the discussion on the paper "Mixing, placing, and curing methods" at the 1965 symposium.

He found Mr. Mescal's statistics on the increased production of cement and the analysis of current cement sales very informative. Based on the information given, the following facts emerged :

sale of bulk cement	:	52% of total
sale of bagged cement	:	48% of total

Taking the breakdown figures of the bulk cement sales into account, Mr. Sweeney arrived at the following :

ready-mixed concrete	:	27% of total cement sales
precast concrete	:	22% do.
site-mixed concrete		
(bulk cement)	:	3% do.
site-mixed concrete		
(bagged cement)	:	48% do.

This gives a total of 51% for site-mixed concrete, assuming that the bagged cement was used entirely on site-mixed concrete. He recognised of course that a comparatively small quantity of bagged cement was used also in pipe jointing and in making mortar and grout. He found the relative figures interesting and was surprised that ready-mixed concrete accounted for only 27% of the market compared with the figures of 45% and 66% for Britain and the U.S.A. The sales of bagged cement at 48% were to him surprisingly high, considering that the current market price of bagged cement was £24.17 per tonne, compared with £18.87 per tonne for bulk cement, delivered within a radius of six miles from the GPO Dublin, i.e. a difference of £5.30 per tonne. The increase in production in ready-mixed concrete as given in the paper had been 18% in the decade since 1965, or 1.8% per annum. He wondered how that rate of increase might compare with other European countries. One would have to remember of course that density of population, and ours was relatively small, was a factor which might limit the economical expansion of the use of ready-mixed concrete. He would like to know from Mr. Mescal if the sales figure of 48% for bagged cement was for domestic sales only, or whether it included any export sales by Cement Limited, to Northern Ireland or elsewhere.

Mr. Sweeney agreed with Mr. Mescal about the difficulty of keeping a check on the contents of a 30-tonne silo and on the timing of cement deliveries for major pours of concrete. In his own experience on some sites, two 30-tonne silos had been used. Then, if the job also warranted

the use of two 21/14 mixers* in tandem for occasional large pours, the difficulties of timing of deliveries of the bulk trucks and the dangers of running out of cement were considerably reduced.

For site-mixed concrete, he agreed that the use of batched aggregates simplified the mixing arrangements on the site considerably, and from his own experience he had found the resulting concrete satisfactory both as to quality and finish. As regards the mixing process, the tendency, following the introduction of high-capacity piston type concrete pumps, was to use pan-type or turbo-type mixers giving outputs of 15 to 24 cubic yards (11.5 to 18.3 m³) per hour to match the output of the pumps. Another quite successful arrangement had been the use of two 21/14 mixers discharging directly into the hopper of the concrete pump and giving an average output of 16 cubic yards (12.2 m³) per hour.

Regarding the economics of using ready-mixed or site-mixed concrete, the arguments, as Mr. Mescal had pointed out, were still being debated as hotly as they had been in the 1965 Symposium. The matter of choice was essentially one of economics as specified requirements could be met as well on the site with proper supervision as they could with ready-mixed concrete. However, he would make one important exception, namely that he would prefer to use site-mixed concrete where a structure was designed on a post-tensioned basis. The following reasons governed his choice. Firstly, appreciating the high strengths and general quality required in the concrete, the contractor's supervisory staff, as well as the consulting engineer's staff, would ensure that the strictest control was exercised, as otherwise the results could be disastrous, economically for the contractor and perhaps prestige-wise for the consulting engineer. Secondly, the volumes of the pours were usually small, and the site staff was unlikely to plan for a fast pouring rate, bearing in mind the necessity of ensuring highly efficient vibration of the concrete in the structural sections which were relatively small in volume, with the added difficulties of keeping sheathing, ducts, anchors, and the like, in their correct positions, and of placing concrete in areas where reinforcement was highly concentrated.

One might ask what these problems had to do with not using ready-mixed concrete. His reply would be that by using site-mixed concrete, the rate of pouring could be controlled and altered, and the danger of a hold-up of the transport of the ready-mixed concrete, especially in cities due to unforeseen traffic jams and bomb scares, could be avoided. Another pertinent factor in using ready-mixed concrete that was to be post-tensioned was that, unless strict supervision was exercised at suppliers works, a lower grade concrete intended for another site might possibly be delivered and placed. In fairness to the manufacturers of ready-mixed concrete, he should say

*The 21/14 concrete mixer is known in SI terminology as a 600/400 litre mixer, the volume of 600 litres being approximately equivalent to 21 cubic feet, namely the volume of loose materials which the mixer can accept. It is not a common size in the new SI range of mixer. (Ed.).

at once that, to his knowledge, that had never happened, but personally after many years of experience on sites, he would prefer to use site-mixed rather than ready-mixed concrete for post-tensioned structures.

Getting back to economic considerations, Mr. Mescal stated that ready-mixed concrete appeared to have captured a large section of the market. However, taking into consideration, as already mentioned, that bagged cement accounted for 48% of the total cement sales, there were obviously many contractors using site-mixed concrete who strangely, from the economic point of view, were not using the cheaper bulk cement. Contractors, like any other business men, were economic in their outlook and must have their own good reasons for using bagged cement and site-mixed concrete.

He hoped it might be of interest to compare the cost factors involved in using site-mixed and ready-mixed concrete, in 1965 and also in the present day.

In 1965, ready-mixed concrete containing 525 lb of cement per cubic yard (312 kg per m³) cost £4.00 per cubic yard (£5.22 per m³) delivered in Dublin. The present price for the same mix was £10.50 per cubic yard (£13.80 per m³) which was £6.50 per cubic yard dearer than in 1965, an increase of 162%.

Regarding site-mixed concrete, washed and graded aggregates had cost £0.75 per tonne in 1965. The present-day price was £2.80 per tonne which was £2.05 per tonne higher than in 1965, an increase of 273%. Bulk cement delivered in Dublin in 1965 had cost £7.61 per tonne. The current price today was £18.87 per tonne. This was £11.26 per tonne higher than in 1965, an increase of 148%. The basic rate per hour for labourers in 1965 had been 5/6 or £0.28, per hour. The present day basic rate was £0.98. This was £0.70 higher than in 1965, an increase of 250%. In 1965, the capital cost of a 21/14 mixer, complete with weighing apparatus, handscraper, and 30 tonne silo, had been approximately £3000, and the present-day cost for the same equipment was approximately twice that, namely £6000. Based on various cost factors involved, and allowing a straight line depreciation period of four years for plant, and adding an allowance for spare parts and maintenance, Mr. Sweeney had calculated the unit costs of producing a cubic yard of site-mixed concrete in 1965 and in 1975, and a comparison of those with corresponding costs for ready-mixed concrete suggested to him that the gap in price between site-mixed and ready-mixed concrete had been reduced considerably during the decade.

In that context, and assuming that his calculations were correct, he hoped he has repaid the ready-mixed concrete manufacturers for some of his previous criticism. He would add that, apart from the relative costs of making concrete in the two modes, the ready-mixed trucks could considerably reduce the labour costs incurred in placing concrete below ground level and on road and floor slabs. In general,

he trusted he had added sufficient fuel to keep that particular argument hot. Perhaps more would be added by later speakers.

Turning to plant, Mr. Sweeney agreed with Mr. Mescal that the most significant improvement of the decade in placing concrete had been the introduction of piston-type concrete pumps. They could be either truck-mounted complete with placing booms, or they could be placed directly under the discharge points of mixers, the concrete then being pumped through 3" or 4" diameter pipes (75mm or 100mm) to wherever required.

To the best of his knowledge, that type of pump had been used in the Republic for the first time in 1968, on the construction of the offshore jetty in Bantry Bay. Speaking as the contractors' construction manager on that project, he said that they had had (apart from some minor troubles with stormy weather) many difficult and unique technical problems to overcome. One of these had been how to place underwater concrete in 40" diameter (1.01m) cylinder piles 220 feet (67m) long which had been driven to rock, some at a rake of 1 in 3. They decided they would try to pump the concrete as that seemed the only feasible method; and after many consultations with manufacturers of concrete pumps in Britain and in Germany, they had had an offer from a German company that their pumps would do the job, and that if they failed there would be no charge, a type of guarantee, he might add, seldom offered to contractors! According to the manufacturers, concrete had never before been pumped to such a depth; and it would be appreciated that pumping concrete vertically downwards was in fact more difficult than upwards, due to air locks, segregation of the concrete, and the like. They had used 5" diameter (125mm) discharge pipe lines and had had sufficient pipes, bends, and fittings generally, for two piles, the approximate volume of concrete being 65m³ per pile.

To overcome the difficulty of having the concrete falling at a very rapid rate through the vertical pipeline, they had inserted a specially made tight-fitting ball into the pipeline ahead of the concrete, and this had been sufficient to prevent the concrete from falling too freely. When the ball reached the bottom of the pile, it floated to the surface indicating that the concrete had reached the toe of the pile; and they had at all times kept a sufficient head of concrete in the pile to allow for continuous placing while the sections of the pipeline were being removed.

The method had proved very successful and they had been able to complete the pumping of two piles per day. They had also used the pumps for the concreting of the superstructure. From experience gained on that project, the pumping of concrete to underwater locations had since been used on many structures.

Mr. Sweeney concluded by looking forward with pleasure to the further discussions which he hoped would take place in 1985.

MR. T. M. DUGGAN felt he would like to comment on the statistics given by Mr. Mescal and developed by Mr. Sweeney. The figure of 52% given in the paper for bulk cement sales as a proportion of total sales was slightly low. The proportion was in fact about 58%. This change would alter Mr. Sweeney's very significant analysis to some degree, but, as had been pointed out, there remained the surprising fact that extremely little cement had been going in bulk to building sites. Furthermore, a very significant quantity of cement was still being supplied in 50 kg bags. In 1975 approximately 600,000 tonnes of bagged cement were used on the home market. The cement industry was most interested in collecting statistics on the end uses of cement, but the gathering of information of that kind for bagged cement was extremely tedious and expensive and in many countries had proved unreliable.

Speaking about the difference in overall cost between bulk cement and bagged cement, the margin undoubtedly favoured bulk cement, but he was horrified to learn, if he had understood Mr. Sweeney correctly, that a differential of £5 per tonne existed between the two materials ordered in the same quantities in the Dublin area. He would have felt that the margin should only be about one third of that sum.

There had been a reference to the use of contaminated mixing water as a problem possibly of increasing significance in concrete quality. His recollection however was that a recent study made in University College Dublin, where a large number of water sources, including some very doubtful ones, had been examined in that context, the only water that gave a clearly unsatisfactory result had been the effluent from a sweet factory!

Mr. Duggan supported Mr. Mescal's attitude towards the use of admixtures. He felt it necessary to emphasise that the significant cost was the cost per cubic metre of concrete placed rather than the cost of constituents in isolation. Consequently the increase in cement cost due to the dramatic rise in energy costs and the considerable expansion in knowledge and development of admixtures combined to alter the economic picture fundamentally. In the mid-70's there was little doubt that the controlled use of admixtures allowed reduction in cost without sacrificing performance.

The home manufacture of special cements had been mentioned. This had to be considered in the context of the Irish market, and any decision to manufacture locally must rest largely on the economics of selling locally, of having an Irish market of adequate size. If one accepted that an extra rapid hardening cement, for instance, might be required in 2% to 3% of the concrete work of a given country, then it became clear that what might be an economical manufacturing venture in a country having, say, twenty five times our total annual consumption of cement, might be quite uneconomical in Ireland. Of course, if concrete users could demonstrate an overall economy in concrete cost, even at the expense of an uneconomical and therefore

costly cement, that situation would demand its own investigation. It was not possible to make white cement in Ireland as the raw materials were not available.

Concerning the range of concrete mixes, Mr. Mescal seemed to be advocating a wider range of mixes in his paper. Perhaps Mr. Duggan had not fully understood what the author was saying, but he personally looked forward to a reduction, rather than an increase, in the number of mixes used. He envied, in some ways, the simple technology of the anonymous small builder who had told him that he could build any building with just three mixes, the first used generally for building the job, the second with a little more sand in it for the tricky bits, and the third for making the cubes.

MR. C. BRUCE, noting Mr. Mescal's use of Britain and Western Europe as yardsticks for progress in Irish technology, deplored the apparent break-down in communication between Irish engineers and their colleagues in the U.S.A. and Canada. We could, in many of the intriguing developments mentioned by Mr. Mescal, benefit from examining American experience. Regarding tinted concretes for instance, it had been found far better to place reliance on coloured aggregates than on coloured cements, and he would like to see the Irish aggregate resources explored in that context. There were some very attractive colours available, and he considered that the possibility existed for basing a new industry on their development.

He could not consider the vacuum process as a promising development for the future. It had originally been developed in the U.S.A., but the building industry there had now largely abandoned it, on the ground that it was illogical to add surplus water to concrete for the sole purpose of compaction. It was more sensible to examine means of compacting dry mixes and that was one direction in which American practice was now moving. They were finding it possible and appropriate to use very small sized aggregates, with the resulting concretes down almost to the consistency of mortar; and the applicability of such a material to thin shapes and to curved shapes was clear.

Mr. Bruce was sorry that no reference had been made to re-vibration techniques or to the Shotcrete or Gunite processes for placing concrete. The sprayed application of concrete represented by those processes was to him an interesting study in development. It had been introduced first in Europe, but had had to go to the U.S.A. for full development, and it was now being developed there in a very professional way.

MR. M. O'CALLAGHAN took up Mr. Mescal's point about weaknesses in the delivery process for ready-mixed concrete. From the suppliers' point of view, the site team was sometimes liable to be at fault, firstly in badly-timed ordering, and secondly in holding up trucks on site through not being ready to accept deliveries at times priorly appointed.

MR. N. LOONEY said that while he was primarily interested in precast concrete, he was becoming increasingly involved in concrete technology, and would like to say something about additives, an area in which he felt extreme caution was necessary. More and more additives, increasingly sophisticated in composition, were coming on the market, and one could not avoid the suspicion that their manufacturers, or some of them, were having cause, one way or another, to use basic commercial chemicals which were doubtful possibly both in quality and in consistency. Research work in Britain had revealed various undesirable side effects in the use of some additives and the need was clearly emerging for a formal standard for additives, with due compliance provisions. He personally would be slow to use a proprietary additive coming from a manufacturer who did not demonstrably have the resources or the scientific or chemical ability to carry out the necessary checks to ensure the sound quality of his products. He would be particularly cautious in that regard about additives based on vinsol resins, which were coming more and more into use.

MR. M. DONNELLAN questioned the effect of, as it were, replacing cement with additives upon the durability of the resulting concrete, particularly in the context of water-retaining structures. It was necessary to remain insistent on a proper level for minimum cement contents. In that context, the need for rapid analysis of fresh concrete was growing and he wondered whether the work pioneered by Messrs John Laing in that field some years ago had yet reached the stage of having an apparatus commercially available for that purpose.

MR. K. M. HALLORAN in a written contribution, described the Rapid Analysis Machine (RAM) recently developed by the Cement and Concrete Association in Britain for the determination of the cement content of fresh concrete. The machine weighed approximately 160 kg and was 900 mm x 800 mm in plan area and 1400 mm high. It operated on the principle of a separator which removed and measured all material of size less than 150 microns from a sample of fresh concrete. That quantity represented the cement content plus any silt in the aggregate, and it was of course possible to make a correction for the actual silt content, if a sample of the aggregate being used was available. The manufacturers claimed accuracy of the following order for concrete having a wet density of 2500 kg per cubic metre :

- a) for silt-free aggregates, a standard deviation of 6.4 kg for cement content in a cubic metre of concrete;
- b) for aggregates with a silt content in excess of 3% of the combined weight of aggregates, a standard deviation of 9.7 kg for the cement content in a cubic metre of concrete.

The Institute for Industrial Research and Standards had acquired one of these machines and it was at present being evaluated for possible use in the Institute's quality control service.

MR. R. A. DUGGAN in a written contribution agreed with Mr. Mescal that the placing of concrete on Irish sites was still too labour-intensive. He felt that one reason was that too often the contractor expected all members of the concrete gang to be capable of placing, compacting, and finishing the concrete, three distinct operations which did not necessarily involve the same skills. The end result was that the men did not become adept at any operation—the old adage of jack-of-all-trades seemed to apply—with the consequence that the work was carried out inefficiently and involved an excess number of operatives. The answer obviously lay in specialisation and, as Mr. Mescal had said, in educating the members of the team in the meaning of what they were doing.

One advantage of specialisation could be illustrated by considering the finishing of concrete slabs. The practice in Ireland was to tamp and finish with long screed boards from pre-located edges formed with timber runners or scaffold poles. In the U.S.A. and Australia a very different technique, not normally seen in Ireland, was widely used. There, the concrete was first placed and compacted, usually with a poker vibrator, to the approximate finished level, using nails on the side forms or height over reinforcement as a guide. Immediately that was finished, a separate finishing crew started. They first took a series of spot levels and formed a number of mounds about 300 mm square and 3 to 4 m apart, bringing them to the correct finished level by hand trowelling. They could do that work in a matter of minutes. The concrete between the mounds was then screeded to the correct level with a timber plank operated by one man using the mounds as reference points. Minor irregularities were then smoothed out with a long-handled float operated from outside the area of the pour and the area was then left for steel trowelling or other finishing process. The technique did obviously call for skill, but it had the advantages that it was quick and did not involve the placing and removing of special screeding runners. Furthermore, it removed all dimensional restrictions on the size of the pour, leaving it to be determined solely by structural considerations and the contractor's facilities.

Mr. Duggan also commented on the use of curing compounds. He considered that when an area to be cured was to be subject to a lot of traffic from men and materials at a very early age, possibly within twenty-four hours of casting, the surface of the compound should be covered to prevent its premature disintegration. Another important aspect of curing was the curing of slab soffits and there he considered curing compounds to be invaluable. Although soffits were not usually remembered in curing programmes, early stripping combined with drying winds could head to distress, and he himself had experienced a disturbing shrinkage crack in the soffit of a slab where the top surface was being very carefully cured.

MR. P. J. DUGGAN in a written contribution drew attention to the sharp contrast which could exist between controlled laboratory testing

and site testing. Difficult working conditions, relatively untrained personnel, too often a lack of motivation or understanding of the purpose of the test, sometimes a cynical attitude that the test was an empty formality to pay lip service to a specification, all were factors that militated against meaningful site testing. He instanced as examples the occasionally appalling handling of cubes before test and the ineffectual use of slump tests. He realised that it might be argued that any testing was better than nothing, but he would very much like to see consideration being given which would improve the quality and therefore the authority of site testing.

MR. MESCAL replied to the discussion.

He thanked Mr. Tom Duggan for his correction on the bulk cement quantities, 58% instead of 52%, and observed that the figures given in the paper had been obtained from Cement Limited.

On the matter of deliveries of ready-mixed concrete, it did appear to him that there was need for a higher level of co-ordination between suppliers and their delivery teams, and between suppliers and customers. By using radio control, a driver could advise his office that for instance he was stuck in a traffic jam, and the supplier could then maintain delivery to the site by sending out a second truck to bypass the jam.

Regarding contaminated mixing water, his concern was that builders should be alert to the danger of working in areas where the water was liable to be polluted, and could usefully be warned of that danger if it was not already clearly evident. The case he had cited did relate to the use of water contaminated with an industrial effluent.

Some problems had been raised about the range of mixes to be made available. Frankly, contractors would like to see only one mix for all work, but of course, it was the engineer's function to specify the mix, and the contractor's to meet that specification. For coloured concretes, he, too, felt that coloured aggregates were more satisfactory than coloured cement (white cement had been particularly in his mind), and he agreed with the importance of developing our knowledge of Irish coloured aggregates.

Mr. Mescal had no experience of re-vibration of concrete, nor had any contractor who had been consulted by him in preparing his paper. It was an interesting area, and did clearly merit examination. He was aware of Shotcrete and similar processes. They were very important but he had considered them too specialised to be treated by him in his section on placing concrete.

One could never be complacent about additives. They could be inconsistent in quality. In his own experience after several drums of additive delivered to a site had been sampled for use in trial mixes and extraordinary results had been obtained, it was found on investigation that the drums concerned had been filled during a labour dispute at the factory and the material was substandard. Additives should

not be purchased and simply added to the concrete following the manufacturer's instructions. It is essential to make trial mixes and analyse the results before proceeding to use the additives in site concrete.

He recommended, as a useful publication the report of a British Committee ("Admixtures for Concrete": Report of the sub-committee on admixtures set up within The Concrete Society: Technical Report TRCS 1: December 1967).

There was a standard document from France which he would not recommend due to its complexity.

The matter of testing the composition of fresh concrete had been raised. There was a tester on the market but he had no personal experience of it and did not think that it was being commonly used in Ireland.

THE CURRENT USE OF PRECAST CONCRETE

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Summary

Trends in the use of precast concrete components are examined. Developments in design and manufacture are considered. The performance aspects are outlined and the future of precast concrete is discussed.

1. Introduction

This paper examines the principal developments in the use of precast concrete in Ireland over the period 1965-1975 and discusses these developments in terms of their economic and technical significance.

The term precast concrete has a variety of meanings and in its wider sense implies all concrete products cast on or off site before incorporation into a building or structure. However, this paper is limited to the consideration of the use of large precast concrete structural components in this manner. The development of precast concrete in these terms has had a conspicuous influence on the design and construction of buildings and structures and has led to important developments in many aspects of the construction industry. At its simplest level it has given contractors the opportunity of avoiding some of the worst effects of building under inclement weather and of reducing the time taken to erect buildings and structures, while at a more sophisticated level it has provided an exciting new medium for the expression of design concepts. Precast concrete has been in the forefront of industrialisation in the construction industry and the associated technology is both complex and challenging. A view of precast concrete in economic and technological terms solely would be inadequate and it is hoped that environmental and other aspects will be considered in the discussion of the subject.

2. Precast concrete production

2.1 It is difficult to establish the full extent of precast concrete component production in Ireland. This is true for many materials and components used in the construction industry and makes the forecasting of future prospects from an analysis of past trends a hazardous occupation. The data has been compiled from the limited published data and supplemented by information obtained from the Central Statistics Office. Table C1 shows published data on the value of precast concrete buildings and sections manufactured and of imports of precast concrete components. The production information in this Table is available only to 1971 when there was a change in the form of enquiry. The classification of imports was changed from 1973, but an attempt has been made to establish consistency over the period. Import figures for 1974 are available only for eleven months and have been grossed up for the twelve month period.

TABLE C1—Production and Imports of Precast Concrete Units
1965 - 1974

Year	Precast Buildings and Sections £	Imports £	Total £
1965	N.A.	46,565	—
1966	459,000	49,142	508,142
1967	740,000	14,349	754,349
1968	937,000	16,640	953,640
1969	840,000	47,393	887,393
1970	929,000	147,538	1,076,538
1971	1,297,000	77,960	1,374,960
1972	N.A.	32,133	—
1973	N.A.	225,937	—
1974	N.A.	637,438	—

Sources : C.S.O. Census of Industrial Production
C.S.O. External Trade Statistics

Table C2 shows production data and the tonnage of imports also prepared by the Central Statistics Office. The production data probably underestimates the true situation because of the type of enquiry and the failure of some firms to provide returns. However, both tables show some interesting general trends.

TABLE C2—Tonnage of Production and Imports of Precast Concrete Units, 1965 - 1974

Year	Precast Buildings and Sections Tonnes	Imports Tonnes	Total Tonnes
1965	N.A.	48	
1966	50,810	2,365	53,175
1967	83,509	446	83,955
1968	95,259	1,003	96,262
1969	57,100	5,590	62,690
1970	55,800	11,392	67,192
1971	89,100	11,891	100,991
1972	51,600*	5,609	57,209
1973	61,600*	16,146	77,746
1974	62,600*	24,078	86,678

* estimate

Source : C.S.O. External Trade Statistics

It is clear from these tables that the production and use of precast concrete components has fluctuated considerably over the period reaching peaks in 1968 and 1971. Figure C1 shows the relationship between the usage of precast concrete components and the gross output of the construction industry.

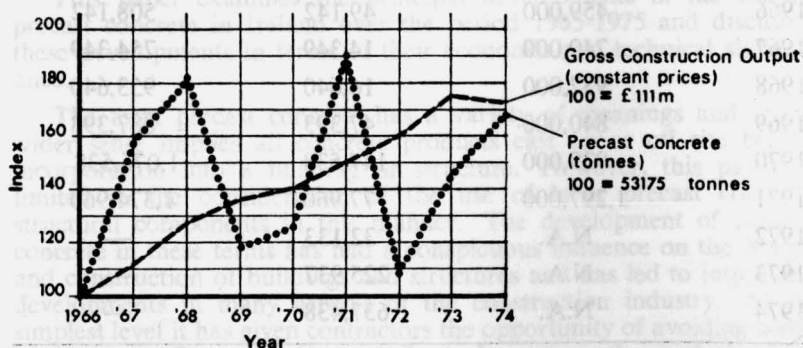


FIG C1

INDICES OF USAGE OF PRECAST CONCRETE COMPONENTS AND GROSS OUTPUT OF CONSTRUCTION 1966 - 1974.

This shows that usage has not matched or kept pace with the growth of the construction industry. It is not possible to draw any conclusion from available data that usage of precast concrete has fluctuated in line with the growth or otherwise of particular sectors of the industry. Indeed, from the figures available, it is more likely that

the fluctuations were associated with individual large projects such as the Ballymun housing project and the Regional Technical Colleges project than with the development of the industry as a whole. It is likely that such fluctuations that occurred put a considerable strain on the resources of the precast concrete industry at some periods and led to serious underutilisation of resources and investment at other periods. There is some evidence from a limited survey by the author that the production of single and multi-storey systems has been increasing to 1974, while floor and roof units and wall cladding units has remained static after reaching a peak in 1970/71.

2.2. A striking feature of the data is the growth of imports of precast concrete units. They have risen fairly consistently from a modest 48 tonnes in 1965 to 24,078 tonnes in 1974. The latter figure is almost 28% of current usage. Table C3 shows the origin of these imports.

TABLE C3—Origin of Imports of Precast Concrete Units.

Year	Origin		
	Great Britain	Northern Ireland	Other
1965	45%	53%	2%
1966	84%	16%	—
1967	80%	20%	—
1968	91%	8%	1%
1969	32%	68%	—
1970	12%	86%	2%
1971	8%	92%	—
1972	8%	92%	—
1973	10%	90%	—
1974	6.5%	93.5%	—

Source : C.S.O. External Trade Statistics

It can be seen that Northern Ireland manufacturers have captured an increasing share of the market in recent years to the point where the bulk of imports now come from this source. In contrast, production by Irish manufacturers has, apart from two years, remained relatively static. There may be a number of reasons for the increased penetration by Northern Irish manufacturers. One contributing factor is certainly the lower cost of materials. For example, in March 1975 normal Portland cement was quoted at £21.35 per tonne ex rail head Dublin, compared with £15.56 per tonne delivered site Belfast. Rough white deal, 100 mm x 75 mm, was quoted at £86.70 per 100 m in Dublin, compared with £52 per 100 m in Belfast. The difference in trade union labour rates between both areas is marginal. It appears that Northern Ireland manufacturers can offset the extra cost of delivery to sites in the Republic by lower prices for some materials. In an era of free

trade, with progressive reduction of customs duties, this obviously represents a serious challenge to our precast concrete industry.

3. Developments in design

3. 1. Precast concrete design has undergone considerable change over the period. A number of factors can be identified as contributing to this change among which has been an increasing awareness on the part of designers of the potential of precast concrete. The industrialised construction inherent in the use of precast concrete is generally considered to have three advantages over traditional in situ construction :

- (i) Factory produced components reduce some of the risks involved in on-site construction. These risks stem from variables such as weather, operational performance and organisation of work. Consequently the quality of construction should be improved.
- (ii) The use of larger components requires increased mechanisation of site processes. This may present limitations to the use of precast concrete in certain circumstances. Where this mechanisation is available the speed with which construction can be executed, particularly on restricted sites, is enhanced.
- (iii) The production and use of standard components should give some cost advantage by virtue of the degree of repetition involved.

Designers have responded to these advantages with some enthusiasm and imagination. The period has witnessed the extension of the use of precast concrete into many new types of building. The alternative techniques to in situ concrete floor construction such as precast reinforced and prestressed floor and roof units have been followed by an increasing range of structural systems comprising beams and columns in addition to these units. There has been an increase in the range of portal frame systems available, together with increased spans and stanchion spacing. While in many earlier systems the beam and column type construction was associated with non load bearing precast concrete wall panels there has been a steady progression to the use of load bearing cladding panels incorporating windows. This latter type of construction was used on the Ballymun housing project and first used in a commercial building in Ireland in Lansdowne House, Dublin, in 1965 (1)* A feature of the use of load bearing precast concrete cladding panels and of systems with deep spandrel beams was the provision of large glazed areas and the introduction of air conditioning in commercial buildings. This was prevalent to 1973 when the energy crisis called into question the advantages claimed for large glazed areas. Figure C2 illustrates how the shape and glazed areas of precast concrete cladding panels have changed in chronological order over the period 1965-1973 for six office blocks designed by the same firm of architects. There is some evidence that the use of precast concrete cladding panels for commercial buildings in Dublin, at least, has not been as extensive in recent years as when they were first introduced

*Numbers in parentheses refer to the references given at the end of the paper.

and that brick facades have come back in favour. The use of precast concrete in low rise buildings has been concentrated on industrial and agricultural buildings and on the housing sector. In the latter case systems have been developed for detached single storey houses.

3.2. A brief review of some interesting examples of precast concrete construction illustrates an increasing awareness of some features of its use during the period. The first time large scale production featured in the housing programme was the Ballymun Housing Project which commenced in 1965. The Balency system used on the medium rise and high rise flats combined precast wall panels with in situ concrete floor and roof slabs and has been described in detail elsewhere (2). The system has been used for other medium rise schemes in the Dublin and Galway area. However, it appears that for sociological reasons, if not for other reasons, the provision of medium and high rise flats for mass housing has lost favour. Another example of the combination of load bearing precast cladding units with in situ floor concrete construction is Lansdowne House, Dublin. In this instance the contractor chose to precast the cladding units on site and a casting shed was specially built for this purpose. Only eleven moulds were used, ten for the rectangular units, each weighing about 1.6 tonnes, and one for the quoin units.

The new university buildings at Belfield also provide an interesting contrast between the use of in situ and precast concrete. In general, precast concrete is reserved for the cladding units, but in the Restaurant Building two independent structures, one in situ and the other precast, are used. Floors and stairs are in in situ natural colour reinforced concrete with a smooth finish from close boarded shuttering and the roof structure including the perimeter columns, consists of precast concrete components. The long span components are post-tensioned and the finish is acid etched white exposed aggregate. The new Passenger Terminal at Dublin Airport, also described in detail elsewhere (3), was completed in 1972 and was constructed to a very tight time schedule. In this case a structural steel framework was chosen on the basis of speed in fabrication and erection, but precast concrete was used for the floors, roof and vertical fins of the main building and for the bridge beams for the elevated roadway. Because of the tight construction schedule, it was considered that there was too much work for a single precast concrete manufacturer and three were used in the work.

In the civil engineering field, precast concrete construction was used extensively where speed of construction as well as cost was important. In the case of the renewal of the Malahide viaduct (4), believed to be the largest precast superstructure in Ireland, over 2000 tonnes of concrete were erected during the winters of 1966-1968. The hollow core prestressed sections weighing from 20 to 38 tonnes were manufactured in the CIE Works, Inchicore. In general, bridge renewals by CIE are composite precast concrete and steel beams or

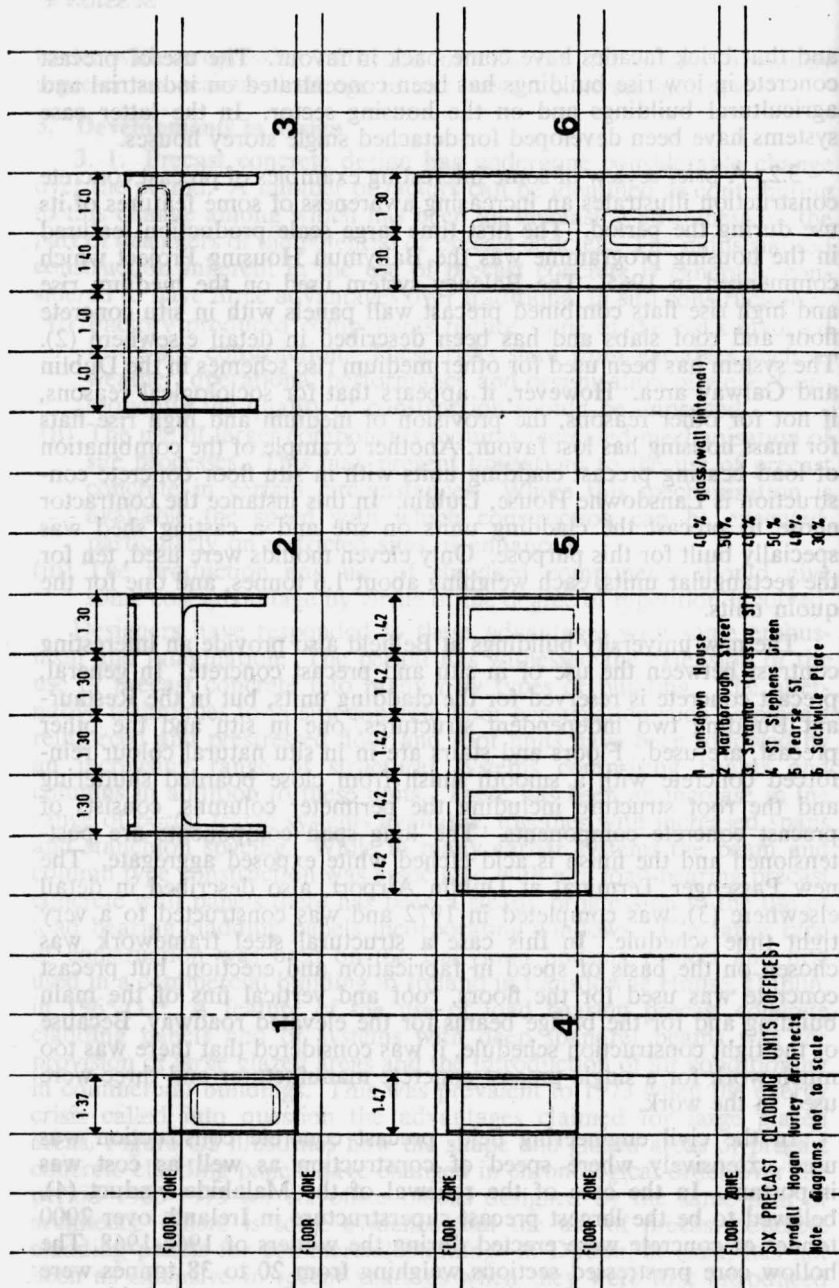


FIG C2
PRECAST CLADDING UNITS

sloping leg portals and are lifted into position on Sundays to avoid interruption to traffic. The recently completed footbridge at Booters-town, Co. Dublin is an interesting example of precast construction.

Perhaps the most novel form of precast concrete construction is that currently being undertaken at the Central Bank building in Dame St., Dublin. Work on the building, which was for some time the centre of heated controversy over the implementation of planning requirements, was delayed after completion of the twin service towers and roof structure. The floors which consist of an in situ concrete flat slab on a framework of lattice steel girders are currently being cast at ground level. The fascia and exposed soffit cladding panels are fixed to the floors before the entire floor construction is hoisted on a series of steel bars and fixed at the required level. This is an interesting extension of the concept of structural precast concrete.

3.3. With the extension of the range of precast concrete there has been considerable discussion on the advantages or otherwise of open and closed systems of construction. Closed systems are characterised by the use of components that are unique to a particular system and by the linking of the functions of design and construction in an integrated operation. The basic competition, in terms of cost, is among systems, not among designers. In contrast, open systems are characterised by the acceptance of a common set of standards, particularly in regard to the co-ordination of dimensions, and the functions of building design and construction are usually handled separately. Designers may use predesigned components for a variety of buildings and this interchangeability of components is a key feature of such systems. The size of the market in Ireland for precast concrete components is relatively small, approximately 0.5% of the gross output of the construction industry, and it would appear that open systems would have considerable advantages including increased standardisation, the optimisation of the production investment and the provision of variety usually required by designers.

The co-ordination of the dimensions of buildings is the key to the efficient development of such systems and the need for such a technique has been recognised in all countries where technical development of the building industry has reached a certain stage, irrespective of the country's economic, social and technical policy in other fields (5). Work has been progressing in An Foras Forbartha on a programme of research on dimensional co-ordination. In 1969, the Government accepted a recommendation of An Foras Forbartha that the basic module to be used in dimensional co-ordination should be 100 mm and dimensional co-ordination is included as an integral part of the change to metric in the building industry (6). Research work has proceeded on two major aspects. In order to create a demand for dimensionally co-ordinated products, An Foras, in consultation with a committee representative of the principal government client departments, is preparing a framework of controlling dimensions for different

building categories. Recommendations have been prepared for housing, schools and factories and it is hoped to complete proposals for offices and hospitals before the end of 1975. This framework will initially be applicable to projects in the public sector and it is hoped that the private sector will adopt them in due course. The second aspect is the sizing of products. An Foras, in consultation with Product Group Committees, representative of manufacturers and designers, has prepared recommendations for the sizing of components within the framework of controlling dimensions. Thus, for the first time, manufacturers and designers have an opportunity of determining the dimensions of components for use in the building industry on a systematic basis. In the context of precast concrete, recommendations have been published on sills and lintels and work is currently proceeding on the floor and roof units. Figure C3 shows the dimensions of the range of precast concrete floor and roof units currently manufactured here and it is clear that a rationalisation of this range is urgently required to facilitate the use of dimensionally co-ordinated construction. An important ingredient in the promotion of dimensional co-ordination is the inclusion of the Standards Division of I.I.R.S. in the work of the Product Group Committees. Thus, it is expected that the dimensional characteristics of components as agreed by these committees will be included in future Irish Standards.

3.4. Two major areas of concern in the design of precast concrete components and buildings are tolerances and jointing. Tolerances are an important ingredient related to quality control in building and to how components fit together. Difficulties are encountered because of the combination of tolerances for setting out, manufacture and assembly of components to the inherent variations such as thermal or moisture variations and deflexions. Techniques have been developed recently for estimating the risk of misfit of components subject to these conditions. Recent work by the British Building Research Establishment in this area is of interest (7). They have developed a technique which, with the aid of a series of graphs, predicts the risk of misfit of components by combining statistically the following variables:

- Manufacturing variability.

- Permissible joint size.

- Positive and negative reversible deviations.

- Number of components in a space.

- Variability of the size of space to contain components.

The approach is dependent on the theory that actual component sizes and the spaces into which they fit are subject to the statistical normal distribution. There could be some doubt about this for precast concrete components and further investigation may be required to provide the proof. The application of the technique requires that components be positioned within a given space by distributing the joint sizes over the space available.

mm		WIDTH																		
mm	mm	400	422	457	533	600	610	625	650	675	686	700	762	914	1016	1200	1219	1800	2400	2700
THICKNESS	100	●																		
	114																			
	125	●																		
	127		●																	
	146		●																	
	150	●																		
	152		●	●	●	●	●	●	●	●	●	●	●							
	171			●																
	175	●																		
	178		●	●	●			●				●								
	197		●																	
	200	●																		
	203		●		●	●	●	●	●	●	●	●	●		●	●				
	205																			
	223		●																	
	225	●																		
	229		●					●												
	240																			
	248		●																	
	250	●																		
	254					●	●		●	●	●	●	●							
	275	●																		
	300	●																		
	305				●	●	●	●	●	●	●	●	●							
	355																			
375	●																			
406																				
457																				
500																				
508																				
600																				
610																				
700																				

FIG C3
RANGE OF PRECAST CONCRETE FLOOR
UNITS CURRENTLY AVAILABLE.

However, another problem which remains is what tolerances should be specified and what tolerances are actually achieved on site. In an examination made by the author (8) of recommended tolerances by eight international authorities for the linear and cross sectional dimensions of concrete structural beams and columns (including precast components) there was evidence of very little agreement on how tolerances should be specified or on what tolerances should be specified. Table C4, from this study, shows the range of tolerances recommended for three typical dimensions for normal or medium quality work.

TABLE C4—Range of Tolerances for Selected Dimensions.

Dimension	Minimum Tolerance mm	Maximum Tolerance mm
600 mm	4.5	20
1.5 m	5	36
5.0 m	8	60

This presents a dilemma to the designer which is compounded by the fact that the limited number of field studies of tolerances actually achieved on site indicate that figures nearer the maxima listed in the recommendations and well in excess of those normally specified, are usual. This problem concerns designers, manufacturers and contractors and research is urgently required to ensure that the full benefits of prefabrication and standardisation can be achieved.

Joints in precast concrete components and in particular in cladding units have been the subject of much consideration in recent years. The structural requirements for joints will be discussed later but the weathering properties are of particular concern in buildings with precast concrete cladding panels. There are two basic approaches to the treatment of these joints, the sealed joint and the open drained joint. The argument in favour of sealed joints is based on the provision of a positive seal against water penetration together with flexibility to accept movement in adjacent components. Problems exist, however, in respect of the durability and consequent maintenance of the joint and in determining responsibility in the event of failure. The open drained joint is designed to resist water penetration by providing a drainage path for such water combined with a protected baffle. The argument in its favour is based on minimum maintenance. The use of open drained joints has increased considerably in recent years and there is a considerable body of opinion among designers and manufacturers that, with increased usage, confidence has been gained in the techniques and they offer a better performance than sealed joints.

3.6. No discussion on the current use of precast concrete would be complete without reference to two well publicised crises in recent years which have important consequences for the construction industry and for precast concrete design in particular. One is the collapse of multi-storey flats at Ronan Point, London, in May 1968 and the other is the problem associated with the use of high alumina cement. While both problems developed in Great Britain, their consequences have had considerable impact here. In the case of the Ronan Point collapse, the subsequent public enquiry recommended that the British Building Regulations be amended to include provisions dealing with progressive collapse (9). Effect is given to this recommendation by the Building (Fifth Amendment) Regulations, 1970, subsequently modified

by the Building (Seventh Amendment) Regulations, 1971. A special committee of the Institution of Engineers of Ireland was set up in 1972 to report on a proposal that "in regard to any future Irish building regulations recommendations relating to the design of buildings against accidental damage should be more flexible and less arbitrary than the corresponding clauses of the British Regulations appear to be". The report (10) of this committee was circulated in October 1972 and subsequently revised in May 1974 following a study of C.P. 110 : 1972. Other papers will cover the detailed recommendations in this report. The emphasis on the provision of alternative load paths for all load bearing members to guard against progressive collapse arising from the accidental removal of any one of them has led to a re-appraisal of the structural design of highrise buildings in general and of the joints between components in particular. There is an increased emphasis on mechanical joints between components supplemented as required by welding. Undoubtedly, the design of completely precast structures in accordance with the Building Regulations (Seventh Amendment) 1971 is now considerably more difficult.

The problems associated with the use of high alumina cement have been well publicised. Indeed, it could be contended that the publicity has been hysterical and in some cases designed to strike terror into an unsuspecting public. Fortunately, the problem is not as severe here as in Great Britain where high alumina cement precast concrete components were more extensively used. In August 1974 the Department of Local Government circularised (11) local authorities, following the BRE report on the failure of roof beams at a school in Stepney, London, advising them that in considering building bye-law and planning applications, they should ensure that as far as practicable, h.a.c. was not used for structural work. Local authorities were also requested to endeavour to identify any buildings in their functional area which had incorporated any quantity of h.a.c. in their structure and to advise owners to have the need for remedial action investigated without delay. Thus, responsibility for the structural safety of these buildings has been placed firmly in the hands of the owners. To date, I.I.R.S. have examined some seventy buildings, determining the extent of conversion using differential thermal analysis.

4. Developments in manufacture

4.1. There has been a steady increase in the variety of precast concrete components and systems available in Ireland and the following is a brief outline of the current range.

Floor and roof units : Basically three types of floor and roof units are available :

- a) Double Tee beams, reinforced and prestressed, which with a structural screed can span up to 21 metres. To prevent differential vertical movement between units, welded connections between adjacent flanges are usually provided.

- b) Flat slab units either with a formed core as in the Rocrete and Arrow units or extruded using a very low slump concrete as in the Breton Spiroll units.
- c) Composite constructions which also provide a flat soffit. There are two basic types. The Omnia wide slab is a partly precast unit to which is added a structural concrete topping. Hollow block slabs such as Lyncrete, Spancrete and Omnia differ in the shape of the hollow block and of the precast member. Composite construction of this type relies on in situ concrete for flexural strength and accidents have occurred due to overloading of the precast member before the in situ concrete was cured.

Cladding panels : Composite cladding panels such as Erbest, Roh-Fab and Panelite panels are 30 - 50 mm thick, returned at the edges for fixing and incorporating a cavity and insulation. They have a variety of exposed aggregate finishes. Fixing may be by bolting and the joints between panels are open drained.

Systems : There is a wide range of portal frame systems available. Sitecast portal frames have a maximum span of 22.8 m and a maximum eave height of 7.6 m. Atcost frames have a shorter maximum span of 21 m and a maximum eave height of 9 m. Galway Concrete produce, in addition to standard portal frames, the Crendon Metric 4 System which has a 4° pitch, a maximum clear height of 12 m and provision for dividing the structure into two floors by a system of beams and slabs. Multi-storey framed systems such as Structurapid, Rocrete and Bantile M.S. 67 differ essentially in the treatment of individual components and in joint details. In addition Rocrete manufacture H.P. shells for use either independently or with the system. System built housing such as Roh-Fab, McPlan and Erbest combine precast concrete wall panels with other prefabricated components.

4.2. Recent technical developments have been assessed on the basis of a survey of precast concrete manufacturers who were asked to list significant developments during the period 1965 - 1975. They are as follows :

- | | |
|------------------------------|--|
| Casting methods : | <ul style="list-style-type: none"> Improved handling for larger units, i.e. overhead cranes, clamps, etc. Improved high frequency vibration. Improved mould design incorporating hinges. Use of tilting tables. Long line prestressing. Extrusion process. |
| Concrete production : | <ul style="list-style-type: none"> Use of lightweight structural precast concrete. Use of high speed pan mixer and load cells. More efficient batching methods. |

Curing :	Introduction of hot mixing water in winter. Use of steam pipes under casting beds. Heating of moulds using hot water. Steam curing.
Finishes :	Exposed aggregate using retarders, acid etching and brushing.
Site assembly methods :	Development of column to beam joints. Handling of units of mass of up to 15 tonnes. Site welding of panel joints. Self levelling dowel bars for structural units.
Jointing methods :	Open drained joints. Shear key between floor slabs.
Transport :	Maximum length : 24 m Maximum size : 6 m x 3 m Mass : 18 tonnes Distance : 280 - 300 miles

4.3. An important feature of precast concrete is the variety of finishes that can be achieved. In addition to finishes for internal surfaces that require no applied rendering, all the finishes for in situ concrete are appropriate and additional finishes involving specialised techniques give a wide range of possibilities. The publication of an authoritative handbook on exposed concrete finishes (12) in 1970 was a welcome addition to the literature and went some way towards dispelling some of the mystery surrounding these techniques.

Designers and manufacturers have collaborated to provide a good standard of finish and to explore further the colour and durability potential of Irish aggregates. The sand bed method used in earlier examples of exposed aggregate finishes has now been replaced by techniques using surface retarders, surface washing, acid etching and surface tooling (13). However, there is little general information on the availability of suitable Irish aggregates for this purpose. Table C5, giving sources of coarse aggregate used recently or considered suitable for use, has been prepared from a survey of precast concrete manufacturers, discussions with aggregate suppliers and examination of recent literature.

The listing is not exhaustive and there may not be general agreement on the suitability of all the sources. Aggregates should be tested before use, particularly for impurities, which may cause staining. However, it is hoped that it will stimulate interest in an extended list supported by sample panels and test results.

4.4. The method of specifying finishes for precast and in situ concrete has been a source of conflict between designers, contractors and manufacturers. Contractors and manufacturers have found diffi-

TABLE C5—Sources of Coarse Aggregates for Exposed Aggregate Finishes.

Aggregate	Colour	Source
Old red sandstone	Red/Brown	Ballincollig, Co. Cork
Granite	Grey/White	Ballybrew, Co. Wicklow
Granite	Blue	Arklow, Co. Wicklow
Basalt	Dark grey	Ballinleeny, Co. Limerick
Marble	Green	Spiddal, Co. Galway
Marble	White	Letterfrack, Co. Galway
Limestone	White/Black	Glenarm, Co. Antrim
Limestone	Brown	Dungannon, Co. Armagh
Limestone	Grey	Naas, Co. Kildare
Limestone	Grey/White	Feltrim, Co. Dublin
Limestone	Dark grey	Belgard, Co. Dublin
Limestone	Grey	Ballyneety, Co. Limerick
Limestone	Dark grey	Bunratty, Co. Clare
Gravel	Fawn	Toomebridge, Co. Antrim
Gravel	Pink	Lough Gall, Co. Armagh
Whinstone	Grey	Ballyclare, Co. Antrim
Gritstone	Green	Arva, Co. Cavan
Gritstone	Dark red	Arva, Co. Cavan
Gritstone	Grey	Castleblayney, Co. Monaghan
Gritstone	Red	Greywood, Co. Kilkenny
Quartz	White/off white	Coolkenno, Co. Carlow
Ennis spar	White	Labane, Co. Galway
Andesite	Green/blue/grey	Slane, Co. Meath
Andesite	Dark green/brown/ grey	Allen, Co. Kildare
Granodiorite	Dull grey	Brownswood, Co. Wexford
Syenite	Brown/red	Proudstown, Navan, Co. Meath
Volcanic ash	Green	Dungarvan, Co. Waterford
Felsite	Brown	Gorey, Co. Wexford

culty in pricing, with reasonable accuracy, the finishes specified. The Irish Building Specification, currently being prepared by An Foras Forbartha, has adopted a basic approach of linking specification requirements for concrete finishes with samples. Alternative methods are offered for specifying the finish for the samples, either by a method or a performance specification, and the finished work must conform with the approved sample. An interesting alternative method of specification has been developed by the Norwegian Building Research Institute (14) which attempts to express the quality of finish in quantitative terms. In some cases limits are given on the magnitude of the blemishes and in others a limit is set on the variations between different

parts of the surface. Reference photographs of blemishes and a colour scale are used to check the quality of the finish. This method may well improve on traditional methods by providing more satisfactory criteria.

5. Performance of precast concrete

5.1. An assessment of the use of precast concrete should consider the performance of the product in buildings and structures. It is difficult to get a comprehensive picture without a detailed survey of structures in use. To date there is little experience of the use of performance specification for the elements of a structure and consequently methods of evaluating performance are at an early stage of development. However, to get some idea of the problems encountered and the nature of performance testing and evaluation which has been undertaken, the experience of the Building Industry Division of IIRS was examined. This Division has provided a field testing and technical development service for over a decade. In the case of precast concrete work the types of investigation may be classified as follows: Performance in use, testing of structural components, testing of materials and development work.

5.2. Performance in use: The more significant problems encountered in the performance of components in use were as follows:

- a) Cracking of precast concrete components due to misplacement of reinforcement. Cracks appeared in components and tests indicated that, although sufficient reinforcement was usually provided, it had been given excessive cover or had been misaligned and unacceptable cracking had occurred.
- b) Problems associated with excessive prestressing or eccentricity in components.
- c) Surface blemishes on components. Generally the problems arose from rust stains or crazing. Suitable solvents were recommended for stains and crazing was attributable to inadequate curing.
- d) Water penetration of joints in precast concrete cladding. The water penetration was generally attributable to inadequate joint design of workmanship.

5.3. Testing of structural components: Structural components were tested to establish either performance or conformity with specification. These tests consisted of:

- a) Load/deflection tests and tests to destruction. In general these tests gave satisfactory results and no significant failures were recorded.
- b) Core testing and ultrasonic testing. In general these tests also gave satisfactory results.
- c) Investigation of failure of components during site handling. It was difficult to establish with confidence the causes of these failures, but they were believed to be due to the handling after casting before delivery to sites.
- d) Identification of non flexible techniques in composite construction leading to sudden shear failure.

5.4. Testing of material : The testing for compliance of materials with specification is essential to quality control of components. The significant tests were as follows :

- a) Testing of aggregates for suitability for exposed finishes. Important ingredients of these tests were water absorption and chemical composition.
- b) Testing of techniques for finishes such as acid etching and use of pigments.
- c) Testing of aggregates, including lightweight aggregates.

5.5. Development work : Significant items of development work are as follows :

- a) The Bantile M.S. 67 Building System. In addition to advice on the design, a full scale structural test was carried out on a single bay of the system. This test indicated that some aspects of the structural behaviour of the system needed further attention, particularly the behaviour of the edge beam.
- b) Verification of load/span tables for precast concrete components.
- c) Developments of electrical curing method for precast prestressed components.
- d) Development of technical specifications (Technopaks) covering design, production, use and quality control for the following components :
 - Prestressed lintels and portal frames
 - Precast r.c. portal frames
 - Medium span precast prestressed floor and roof units
 - Tapered precast roof beam.

6. The future for precast concrete

6.1. As has been indicated earlier, the precast concrete industry has had a chequered pattern of development over the past ten years. There is evidence of a high quality of work and a keen response to the demand for high and medium rise housing, industrial structures, bridgework and commercial buildings. The use is evident of on site prefabrication techniques by contractors in instances where this was considered economical and appropriate to production schedules.

For any sector of an industry to advance and develop it must create its own imperative. Advantages such as speed, lower cost and better quality control may prove illusory unless backed by innovative products and techniques that make a unique contribution to performance rather than simply change the methods of producing traditional products. The key to the development of such products and techniques lies in a rigorous analysis of the performance requirements of components and in meeting these requirements better than traditional products within certain limitations of cost. It must be possible to demonstrate clearly how these improvements are achieved. To achieve this end the sector must face a substantial investment in technological research. It also requires a response from designers that indicates an appreciation of the production techniques and capabilities of the

industry. If these two requirements are realised they may well imply a fundamental re-appraisal of attitudes in the industry and the gap between design and construction could be narrowed.

It is perhaps significant that the impact of the precast concrete sector, excluding manufacturers of small components such as blocks, roof tiles, lintels, sills, etc., on the housing programme has been largely in terms of medium and high rise structures. There has been very little impact on the low rise mass housing market which is now the largest single element in the output of the construction industry. This is an area where a fundamental re-appraisal of performance requirements is being made in the light of the high cost of energy. It may well be that the precast concrete industry should re-assess its role in this sector with a view to developing products, perhaps of a lightweight nature, that meet these new requirements better than traditional products. Any such assessment, however, must be complete and include the total process from manufacture to performance in use. Likewise in the second largest sector, industrial buildings and structures, a similar re-assessment may be useful. Both these areas would provide a sound base which could support research and development in other areas.

Finally, the efficient use of industrial technology requires substantial changes in the traditional relationships between designers, contractors and component manufacturers. It requires a better understanding of that technology by all those concerned. It may also require a re-appraisal of the skill mix of the labour force employed in the construction industry. It also requires the full exploitation of the investment in plant, equipment, personnel, research and development. The professions, trade unions and the industry have an important role to play to ensure that the economic potential of an important indigenous resource is fully realised.

Acknowledgments

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Discussion

MR. PIGOTT introduced his paper.

Firstly, there was an addition he wished to make to the text. Reference should be included in Section 4.1 to a Roocrete portal frame system which utilized a 4° pitch and was available in spans up to 30 m.

In preparing his paper, he realised the huge range of the precast concrete industry and had felt it prudent to limit his study to large-element work. All of his references would be to that part of the industry. He did of course regret having to eliminate the important small-element section of the industry, items such as blocks, tiles, sills, and the like, but the whole spread would have been too large to deal with in any useful detail in one paper.

Figure C1 of the paper compared the usage of precast concrete components to the gross output of construction in each of the nine years up to 1974. He felt that the fluctuation in usage, which that

figure demonstrated, was the important factor, rather than the size of the usage. Production rates ranging significantly from under-loading to over-loading of manufacturing capacity could not fail to be damaging to an industry having a heavy commitment both in technological expertise and forward planning. He would submit that under-utilization of the national resource in this field was a serious disadvantage to the Irish economy. The situation was not being improved by the increasing level of importation of finished components indicated in Table C3 of the paper; and it could not be regarded as a happy one, particularly in view of the difficulties which were known to have faced at least two firms during the previous year.

Turning to the topic of standardisation, there had been a strong call in the 1965 Symposium for a rationalization of the sizes and dimensions of precast concrete in components and in whole structures. An Foras Forbartha in its work on dimensional co-ordination had made a good start since then. A series of modular frameworks had been established and recommended to the industry, and they in their turn formed a sound basis for standardization of component sizes. Designers and manufacturers were co-operating actively in the programme, although Figure C3 of the paper might suggest to some that there was still lots of room for rationalizing the range of slabbing units at present available. Any comment on standardization should include a reference to the perennial problems of precast concrete, accuracy and tolerances.

The report by Bonshor and Eldridge (7) gave useful guidance regarding the fit of components. Possibly more significantly, work was now under way in Britain on actual measurements of precast concrete work as built; and some parallel work was in progress in An Foras Forbartha. The results of extensive case studies properly analysed would, he felt, be of great value to the industry.

Another area of interest in precast concrete was the question of finish, and in this area we did not have enough information on what was available in Ireland. He had tried in the paper and in his slides to draw together as much as he could about finishes, but he recognised the incompleteness of his findings and he would welcome all further information. If precast concrete was to be treated seriously, the matter of finish clearly required more attention, by way of some agreed classification of available materials and techniques; and that might usefully be illustrated by an on-going display of sample panels.

Finally there was the essential matter of performance. The Institute for Industrial Research and Standards was tackling this problem as his paper showed, and it was encouraging to see designers and manufacturers coming together under the aegis of the Institute, amongst others, to examine their mutual problems in the pre-production stages of research and development. He was not sure however that all the relevant problems were being tabled for study. In any questioning as to where the Irish precast concrete industry was heading and what its future was, the matter of performance would, in his opinion, have to

be central. It was not sufficient for a structural medium merely to do something just as well as another medium could do it, with the two being used in generally similar manners. A medium had to develop its own imperative. To achieve this, he considered that there should be a complete re-assessment of the role of precasting in Irish construction; and this would involve, as a prerequisite, a clear identification of performance requirements and a rigorous examination of the ability of precast concrete to meet them.

He suggested three questions for discussion, all relating to the future of the industry. These were:

- (a) what were the most significant parameters in assessing the performance of precast concrete building structures?
- (b) could the precast concrete industry survive without any investment in technological research, and how could such research be directed into a well balanced co-ordinated programme?
- (c) how successfully could low rise housing be used as a basis for research and development?

Mr. Pigott illustrated his introduction with seventy six slides showing Irish precast concrete work of the last ten years. He had divided the building shown into five groups, namely housing; education; hospitals; commercial buildings and offices; industry; and miscellaneous, including civil engineering. The buildings shown included the following:

Housing:

- High rise development at Ballymun
- High rise development at Keogh Square, Inchicore
- A detached house (The Erbest system)
- A detached house

Educational:

- Ballymun Comprehensive School, (a)
- King's Hospital School, Palmerstown, (the Bantile MS 67 system)
- St. Andrew's College, Booterstown
- The Royal College of Surgeons in Ireland, Dublin
- University College Dublin—Restaurant
- University College Dublin—Library
- University College, Dublin—Arts and Administration buildings
- College of Technology, Kevin Street, Dublin (the G80 system)

Hospitals, commercial buildings and offices:

- County Offices, Cork
- Lansdowne House, Ballsbridge
- Office Block, Shelbourne Road, Ballsbridge
- Fitzwilton House, Dublin, (b)
- Texaco House, Ballsbridge
- Offices for the Department of Posts and Telegraphs, Dublin
- Offices for the Department of Agriculture, Dublin, (c)
- Setanta House, Dublin

ACC House, Dublin
 Altergo House, Dublin
 Departure Building and Car Park at Dublin Airport, (d)
 Astral House, Dublin
 The Central Bank, Dublin

Industry :

*IDA Factory at Carlow for Messrs. Braun
 Workshop, laboratory, and control building at Platin for
 Cement Limited
 Gantry supports at Platin for Cement Limited, (f)
 Warner Lambert Limited, Blackrock, Dublin, (g)

Miscellaneous, including civil engineering :

Footbridge at Maynooth College
 Footbridge at Booterstown for C.I.E.
 Grandstand at Leopardstown
 Pedestrian subway units for Dublin Corporation
 Tunnel segments, Grand Canal Drainage Scheme, Dublin
 Stairway at Convent, Athlone
 Extension, St. Mary's Priory Church, Tallaght

In showing the slides, Mr. Pigott included the following observations. The letters relate to the corresponding references in parentheses in the list above :

- (a) the exposed aggregate is Arva gritstone;
- (b) the vertical fins are the precast elements;
- (c) the aggregate were Dungannon limestone and Wicklow sand. They were used with white cement. The 720 units used in the building were cast from five moulds;
- (d) the precast concrete work for this project was divided between three manufacturers;
- (e) the aggregate was Coolkenno quartz. It was used with white cement. The glass was set in neoprene gaskets which were placed directly in a groove in the precast concrete;
- (f) the gantry supports were prestressed hollow column supports weighing 16 tonnes;
- (g) the wall units in this project were the largest precast wall units so far made in the Republic, being 7 m high x 4 m wide and weighing 8.7 tonnes. As such, they amended the information given in the author's printed paper. The aggregate is a brown felsite from Gorey.

MR. F. LYDON, opening the discussion, said it was fitting to review one's whole attitude to a medium such as precast concrete from time to time. The ten year period was suitable, and he agreed with Mr. Pigott that the new forms and expressions of design which had emerged in the medium in that time were making it an exciting medium to work

*(This building is described in a paper "The planning, design and construction of a factory building" given by W. J. Kearney to IEI in October 1975. Ed.)

in. The organization of the building industry in its precast concrete sector could, however, clearly be improved at the national level, and Mr. Pigott was to be complimented for stating the issues for debate so explicitly in his paper and introduction.

The annual fluctuation in production was disturbing. One realised of course that with the size of our market, the impact of a single large project, as, for instance, Ballymun or the Regional Technical Colleges programme, would distort the graph of annual production considerably, but it remained a fact that a stop/start industry with no long production runs could not readily attract large capital investment. The question of imports into the Republic, mainly from Northern Ireland, also raised issues which might be stated very simply. Why was it that cement was costing £6 per ton more in Dublin than in Belfast, and why was rough white deal timber over 60% dearer here? If we knew how to overcome such price differences for the raw materials for the industry, it would help our competitiveness.

Looking at the slides which Mr. Pigott had shown, and comparing Irish work with works which had been seen and read about in other countries, Mr. Lydon said that we should be very satisfied with our ability to design and manufacture precast concrete in Ireland. We did however have to rationalize our work in the context of our domestic market; and in that connexion, the subject of systems was very significant. Versatility in a system was desirable and, in our limited market conditions, was of primary importance. Starting from the absurd limit of the most versatile of all precast concrete elements, the concrete block, we should be examining the possibility of an open "kit of parts" type system of wide applicability, based on small elements which could be produced with not too sophisticated mechanization. Consideration should then be given to the extension of that basic system into a number of systems suitable for particular building categories as established by Mr. Pigott, housing, schools, perhaps industry. By those means, we might, at least in the areas where a fairly continuous throughput of work could be ensured, foster longer production runs, and give the industry the incentive it needed to develop its plant and to finance further research and development.

The small market did give us one considerable advantage which we should use to the full. That was the facility of communication between the various parts of the industry. Designers, manufacturers, and erectors could get to know one another very well in our small community, and that acquaintanceship did demonstrably lead to an understanding closer than might be possible in larger countries.

Mr. Lydon felt that the Regional Technical Colleges project might have been included in Mr. Pigott's review. It was probably the largest precast concrete project of the decade in the schools sector. Colleges had been built to a single unified constructional system in seven towns, namely Letterkenny, Sligo, Galway, Athlone, Waterford, Carlow and Cork, and a programme of extensions using the same system, but with

a different form of cladding had recently started. The project was of special interest in that the brief for the schools had been for a building system rather than for a structural system; and there was an enormous difference between the two. A structural system could be fairly easily designed and brought to a high level of refinement, provided one's sole concern was the structure. A building system however which had to be designed to cater for all the complex needs of the building was far more intractable and created many more problems for the structural engineer if the end product was to be a satisfactorily integrated whole, and one which worked. The colleges project had possibly been the first attempt to achieve this in the Irish context. In that connexion, he suggested that a valuable research study could be undertaken at each of the colleges, by way of an appraisal of just how the building system in service was in fact meeting the requirements of the original brief.

Dimensional co-ordination was essential in any process of rationalization, and An Foras Forbartha was to be congratulated for its work in that field. On the associated topic of tolerances, his philosophy was simple. The more tightly drawn the specification the more costly would be the work. One should recognise how reasonable it was that this should be so when one considered the extra cost involved in making the very accurate moulds required for small tolerances, probably from steel, and the cost of maintaining them properly throughout the production run.

He had been interested in the references made in the paper and in the introduction to the problems associated with progressive collapse, and high alumina cement. Mr. Pigott had not mentioned the topic of woodwool slabs where some problems were now developing. Engineers faced with difficulties, which the media liked to treat hysterically, should not lose their sense of judgment in facing them. The media should not be permitted to exaggerate difficulties, and reporters in all media should be compelled to produce real evidence instead of drafting headlines with no substantial knowledge of what they were talking about.

MR. T. M. DUGGAN said that the price of cement was clearly a matter of interest in the Symposium. He could not give the precise selling figures for cement, because final selling prices in the Republic were controlled by merchants rather than by manufacturers. There were several points however which should be made. Firstly, the price of bulk cement in Northern Ireland was based on a global strategy for the whole of the United Kingdom, and not on the cost of production at the Magheramorne and Cookstown factories. Secondly, the cement industry of the United Kingdom was based largely on the use of coal which was being supplied to it on a three-year fixed price contract, not due to expire until 1976. During that three years the oil crisis had occurred and as a result the cost of fuel to the cement industry in the Republic had increased from £1.7 million per year to £7 million per

year, and this rise had influenced the cost of cement in the Republic. The cost ratio between North and South would change considerably when the U.K. industry came to negotiate their next contract for fuel in 1976. In the meantime, North-South cement transactions contained an anomaly in that Northern Ireland which imported our cement to supplement its own production actually had to sell that cement cheaper in Northern Ireland than it bought it in the Republic, so as to maintain the global U.K. strategy.

Another difference between the cement industries in the Republic and the U.K., and one which would have a bearing on price differentials, was that, in the Republic, bagged cement and bulk cement were priced ex factory at rates which reflected strictly their own respective costs of production and handling, whereas in the U.K., the difference between the two overall costs was not fully reflected in the prices charged. It was the opinion of our cement industry in the Republic that bulk cement represented the most efficient way of using cement, and that this manner of use should not be discouraged by loading it with part of the production cost of the dearer bagged material. Further it seemed proper to base the cost of cement in any region of the country upon its production cost plus the cost of transporting it to that region. To do otherwise would certainly create more problems than it would solve although with the present arrangement there were inevitably and unfortunately problem areas such as Donegal where the long haul had a significant influence on the delivered cost.

The cost differential between cement in Northern Ireland and the Republic had been mentioned as a factor in the competitiveness of precasting costs. Some figures might be of interest. In giving them, Mr. Duggan said he would confine himself to bulk cement as precasters were unlikely to be buying bagged material. Comparing like with like, namely the cost of bulk cement delivered to the direct buyer in the two regions, normal Portland cement was costing £1.50 per tonne less in Belfast than in Dublin in March 1975, and £1.07 less in Newry than in Dublin. The Dublin-Belfast differential had shifted to £1.42 in June 1975. There were several further figures he might give but he hoped that he had in fact said enough to explain the position as it stood.

MR. T. SHINKWIN agreed with Mr. Pigott about the difficulty of getting reliable national statistics for the precast concrete industry. The picture which had been presented of the fluctuation in annual production over the decade called for comment. He felt that the trough of 1969 might well have been associated with the cement strike of that year, and the peak in 1971, with the very large one-off Ballymun project. The peak in 1968 could well represent not so much the level of production in that year, as a change in the official method of compiling the statistics which had occurred about then.

Mr. Pigott had drawn attention to the significant increase in imports from the North to the South. Several factors had been influencing this.

Firstly, during the last few years, several miles of large prestressed concrete pipes, up to 2.5 m in diameter had been used in civil engineering contracts in the Republic, and all of that material had come from Northern Ireland. Another popular import had been reconstituted stone blocks of very high quality. Possibly the most important single factor however, had been the marked difference between the two regions in the level of State aid to industry. In Northern Ireland, grants of up to 100% were available for capital investment, whereas the industry in the Republic could expect at best a 25% re-equipment grant. The implications of being able to write off one's capital cost in establishing the selling price of articles in a small market were colossal. As regards movement in the opposite direction from South to North, it was a regrettable fact, but true, that he was unable to export to Northern Ireland for the simple reason that his operatives and workers were not prepared to travel to the North. He had, on several occasions, been forced to withdraw successful tenders for that reason alone.

Mr. Pigott had asked whether the industry could hope to survive without heavy investment, and without research. The facts of the matter were that the industry had survived so far, not let it be said through any co-operation from the State, but through the flair and the determination, one might almost say in the present economic circumstances the lunatic determination, of those still engaged in it that it should survive. Regarding research of course the industry would greatly welcome it, and would be only too ready to co-operate in developing building systems based on indigenous materials, provided the necessary funds were made available for the study involved.

MR. L. O'BRIEN said that Mr. Pigott had very properly adverted to the present over-capacity of the precasting industry in Ireland, which had developed as a result of the economic recession. In that context and indeed in the context of the general national economy, designers should always give preference to concrete, which was substantially a native material and one whose cost we could in some measure control, rather than to steel in which perhaps 60% to 70% of the material was imported at costs which we could not control. To a lesser extent, concrete should also be preferred to timber. Although just at the immediate moment, the country was in fact overstocked with timber, that was a passing phase which did not affect the issue in the long term. Mr. Pigott's slides and the discussion had shown clearly that the expertise required to design and build in precast concrete was readily available in the country.

MR. C. BRUCE regretted that he could not wholly agree with Mr. Shinkwin in his reasons for the fluctuation in annual production of precast concrete. Fluctuations would exist even in the absence of the special features mentioned by Mr. Shinkwin, and they would arise in his opinion for two main reasons. Firstly, manufacturers were not doing an effective job of promoting precast concrete for the major in-

dustry it now was and for the greater one which it was destined to become in the future. Secondly Irish designers, architects, engineers and government officials, while genuinely concerned with the well-being of the construction industry, the second largest industry in the country, did not seem fully conscious of their responsibility to co-operate with the producers of precast concrete. Mr. Pigott's figures for imports had been confined to concrete, but there were other figures which were possibly even more important, figures which it did not seem possible to get, but which should be sought out and made available for analysis in the industry. These were for the annual values of imported structural materials which were being used instead of concrete, in particular structural steel and timber. He felt that the analysis of those figures would tell a distressing story.

It was of course very clear that Irish designers could use concrete with great vigour and skill and had contributed brilliantly to the development of the industry up to its present stage. The professions should now however examine their consciences to recognise the responsibility which they had to the country to use the native materials available and thus to contribute to the stability of the industry that had been set up to serve the community in that area. The fluctuating production curve shown by Mr. Pigott represented an injustice to the precast concrete industry.

The establishment of a development council for the whole concrete industry in the Republic should be considered. Such a council had been used very effectively in the U.S.A. and in Canada and could contribute here also to a new dynamism which the industry needed. Mr. Bruce recognised that his close association with manufacture of precast concrete in Ireland for some years might be regarded as colouring his remarks, but he was now an independent consultant and hoped he could be considered to be speaking with a greater objectivity than might otherwise be deemed the case.

He had noticed in some of the slides a feature which he had also observed in the U.S.A. and Canada, namely that some of the exposed aggregates used were too small in size to give a good visual effect. He felt that particle size was very important in exposed aggregate finishes, and designers might find it rewarding to study that aspect of design more fully.

MR. F. P. QUIGLEY in a written contribution considered that some reference should be made to concrete blocks in any paper on precast concrete in Ireland, but surmised that the absence of reference was perhaps in itself a sufficient testimony to the fact that concrete blocks were reliable, trouble-free, and fully accepted. The concrete block was the basic building material in the Republic and its technology had developed considerably in the last ten years. Site-made blocks were now practically unknown and over two hundred million blocks were now made annually in factories throughout the country. The industry

at present represented £22 million per year and employed over two thousand people.

One significant development in the industry had been in the architectural use of blocks as facings. Modern methods now made it possible to produce concrete masonry blocks in a variety of colours and surface textures. While common in America and Britain, the development was new in Ireland. Excellent examples could be seen however at the new Willwood Factory at Tallaght and the Abbott Laboratories Factory at Sligo.

MR. P. AUNGIER in a written contribution recorded that the railway footbridges mentioned by Mr. Pigott had been built by Banagher Tiles Limited, using white cement.

Some reference, but perhaps not enough, had been made to composite precast concrete and steel beam construction for bridges. It was a simple form, easy to design and construct, requiring less supervision in its construction than for instance post-tensioned prestressed concrete, and it could be used for spans of up to 30 m carrying 45 units of HB loading. It had formed the basis for one of the proposals considered by the Commissioners of Public Works as a replacement for an existing main road bridge across the River Boyne at Drogheda.

The discussion on the paper had indicated some quite firmly-expressed opposition to precast concrete and he had formed the impression that to some degree a lack of commitment to maintenance lay at the back of that opposition. Generalising, he thought he detected a considerable lack of interest and expertise in the engineering profession regarding maintenance. Some state and semi-state bodies which were big property owners either no longer had professional engineering staff supervising maintenance or were in the "economical" process of weeding out such staff. This seemed a pity as obviously the design engineer could benefit considerably from feedback supplied on the performance of buildings in service by his colleagues engaged in maintenance; and there could be no such feedback if there was no professional maintenance staff. He had heard in another session that some architects had not known whether they had or had not used high alumina cement in any of their designs, and he suggested that such a situation could not have occurred if a structural engineer had been involved in the specification.

MR. N. M. RYAN in a written contribution commented on a matter which had in fact been raised by Mr. Harrington in Session A, namely that the minimum bearing for precast units should be increased from 75 mm to 100 mm. In his work at An Foras Forbartha Mr. Ryan had been examining the problems of tolerance and fit and he would like to ensure that we did not take account of deviations by an arbitrary increase in nominal bearing dimensions. In his experience, it had not been common to allow for the combination of deviations which could occur in practice. He would propose that, irrespective of the minimum

bearing required, precast units should be sized to take account of both negative deviations in the lengths of the units and positive deviations in the spacing of the supports. Sufficient information had been collected by the Building Research Establishment in Britain and by others to indicate that the dimensions of both spaces and components in building displayed a normal distribution about a mean, and consequently the effects of permissible deviations could be combined statistically rather than algebraically.

Using the statistical statement that the standard deviation of a combination of random unrelated variables was the square root of the sum of the squares of the standard deviations of the individual variables, he would recommend that the length of precast units should be calculated as for instance in the following example:

nominal distance between walls	:	6000
specified bearing (say 2 x 75 mm)	:	150
maximum negative inherent deviation		
due to shrinkage and thermal effects	:	1.5
specified permissible induced deviations		
manufacture of units	-	10
position of walls at bottom	+	10
plumbness	+	15
erection of units	+	5
combined induced deviation		
$= \sqrt{(10)^2 + 2 \times (10)^2 + 2 \times (15)^2 + 5^2}$		
	:	28
		6179.5 mm

In other words, using the above values of permissible deviations, it would be necessary to increase the nominal length of that unit by 29.5 mm to ensure that a specified minimum bearing was achieved. Given that the permissible deviation was three times the standard deviation the technique he had described would yield a 99.73% probability of achieving the minimum bearing.

MR. PIGOTT replied to the discussion.

He apologised for not having referred to the project for the Regional Technical Colleges, and was grateful to Mr. Lydon for mentioning them. That project did in fact highlight one of the points he had been trying to make, namely the value of seeking for a system of broad applicability throughout one sector of the industry, in this instance, in design for education.

Mr. Shinkwin had quite properly aired the problem of obtaining authoritative statistics. The figures in the paper had come, for the earlier years of the decade, largely from the Central Statistics Office, while for the later years the personal co-operation of the statisticians working on the new figures had had to be sought. One problem for statisticians monitoring the concrete industry lay in the difficulty of classifying manufactured items precisely.

The comments made by Mr. O'Brien and later by Mr. Bruce on the use of native materials were very relevant. It seemed to him however that the industry should recognise that, in that matter, it was faced with a hen and egg situation. A rigorous analysis of cost and of performance vis-a-vis the materials used was necessary to establish correctness of concrete in given circumstances, and this could not properly be done without completed buildings to examine. In the absence of such a rigorous analysis, the choice between concrete and steel, or between concrete and timber, could well be based on some quite arbitrary factor, as for instance a short term price differential, or an estimated differential in speed of erection; and that factor might change radically between the design period and the time of starting work on the site. Replying specifically to Mr. Bruce, Mr. Pigott mentioned that An Foras Forbartha was in fact studying the topic of imported building materials and possible Irish alternatives and hoped to publish a report on the matter in due course.

Looking at the industry generally in Ireland, one saw that about £150 x 10⁶ was being spent annually on housing, with about £45 x 10⁶ on industrial buildings, and, regrettably, less on buildings for education. On the general subject of rationalisation of the industry, taking that distribution of expenditure into account, he would argue strongly for using housing as a basis for a rigorous investigation leading towards the development of a building system for widespread use in the country. From such a system developed for housing, there could possibly emerge some systematized approach to building for other purposes.

SESSION D

THE USE OF PRESTRESSED CONCRETE

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Ascon Limited

Introduction

In 1951 a grain silo consisting of eleven 3.6m diameter bins of height 23m was built in Dublin, using 100mm thick concrete walls, prestressed circumferentially by a system of post-tensioning developed by an Irish consulting engineer. These silos are still in use, and although the ingenious and simple method of stressing the wire tendons by transverse displacement of the wires has since been abandoned, the construction of these silos was a useful and economically worthwhile exercise in the application of what was then a comparatively new constructional material, prestressed concrete.

The first use of in-situ post-tensioning was in the construction of prestressed valley beams and top edge beams of 15m span to a shell roof for the Allied Textiles Ltd. factory at Chapelizod.

In 1952 the first prestressed bridge in the Republic was constructed by C.I.E., to carry the Naas to Rathangan road over the main line between Sallins and Newbridge, replacing a cast iron structure which was of inadequate strength for modern traffic. This bridge was of 11m span, and consisted of fifteen 560mm deep precast beam units, each 4.5 t weight, prestressed by means of the Lee McCall system of post-tensioning. The precast beam units were cast and post-tensioned at the C.I.E. concrete works at Inchicore.

Next year, 1976, will therefore be a jubilee year for the introduction of prestressed concrete to Irish civil engineers' practice, and this is an appropriate time to review the progress and developments that have taken place during that period, and the present position of prestressed construction in relation to concrete generally in Ireland.

Freyssinet had described the fundamental properties of prestressed concrete as early as 1927, and by 1939 had developed successfully the Freyssinet 12-wire jack, but it was not until the late forties that the structural engineering profession became generally aware of the potential uses of this new constructional material. In 1946 Freyssinet

completed Luzancy Bridge, a flat arch of 55m span fabricated from 1.8m long precast units assembled and post-tensioned at site; in 1948 he completed the Bridge of Esbly, over the Marne, with a span of 74m, constructed in a similar way, but prestressed in three directions, longitudinally, transversely and vertically. The successful construction of these bridges gave tremendous encouragement to structural engineers everywhere to study the properties of prestressed concrete, and to consider where it could be applied usefully and economically in their own work.

Advantages

During the postgraduate course on Prestressed Concrete for engineers held in University College in 1957 the advantages of prestressed as distinct from reinforced concrete were summarised thus :

1. Freedom from cracking.
2. Economy in steel.
3. Economy in concrete and formwork.
4. Lighter dead loads, hence longer spans and lighter foundations.
5. Reduced construction depths.
6. Principal tensile stresses reduced.
7. Less congestion of steel.
8. Short units may be joined together by prestressing to form a single long unit.

One could add to this list speed of construction in certain cases, but otherwise these are still the main points which should be considered when deciding whether to use reinforced or prestressed concrete construction for any particular job. In the design of the initial concrete cross-section of a beam or slab, and in calculating the prestressing force required, the dead load bending moment is neglected, and the dead load affects only the calculation of the eccentricity required; if there is no limitation on this eccentricity then the dead load is said "to carry itself". This factor is the major source of economy in prestressed concrete, and obviously this factor will be of greater importance with longer spans.

It has been pointed out also that the maxim that "the dead load carries itself" can also be matched by another, that "the dead load should approximate to the live load". This follows from the idealised elastic stress conditions which are being aimed for in economical design in prestressed concrete (Fig. D1). Like all such guides to structural design, or indeed, design of any kind, each of the advantages listed earlier will carry a greater or a lesser degree of importance in any particular case. For example, freedom from cracking will be of particular importance in a marine or corrosive atmosphere, economy in steel may be cancelled out by high cost of anchorages and of the stressing operations, smaller dead loads may be of greater importance for precast work, reduced construction depth may or may not be important, and so forth.

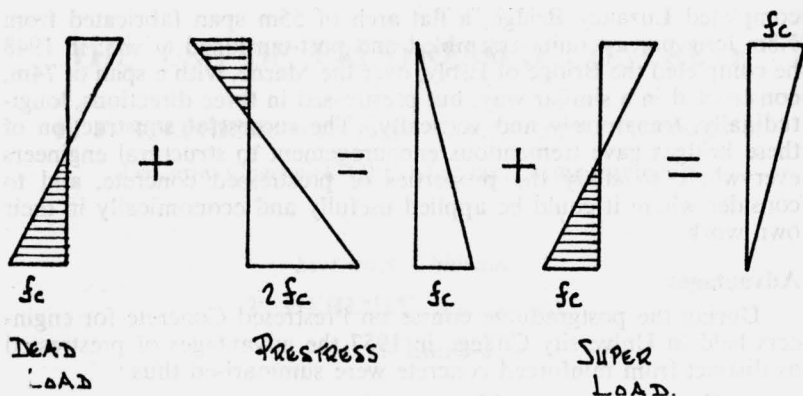


FIG. D1
OPTIMUM PRESTRESSING

Furthermore, higher standards for concrete quality and for the control of concrete quality are required with prestressing, and higher standards of technical supervision of construction, particularly during stressing operations. All such considerations have an effect on the final cost, which may not favour the use of prestressing in many cases.

In the case of a new bridge and approaches crossing the River Dodder at Springfield Road, recently completed, alternative designs were prepared for a single span design in prestressed standard bridge beams of 16m span, of constant depth, and for a continuous three span slab design in reinforced concrete, with varying depth of slab, the spans in this case being 7.5, 15.0, 7.5m. Despite the fact that the overall length of superstructure was greater in the case of the reinforced concrete design, the difference in cost between the two designs was marginal. The three span design in reinforced concrete was adopted, largely because of its generally lighter and better appearance, with less obstruction to the use of the river and its banks for recreational and leisure purposes.

Early History in Ireland

The first medium span bridge to be constructed was Flannery Bridge, at Kilkieran Bay, Co. Galway, built in 1953. With a span of 55m it was at the time the largest prestressed concrete span in Great Britain or Ireland. A foundation of granite rock was available near the surface and thus a single span two-pinned portal design was possible. This design showed a slight saving over an alternative three-span arch design in reinforced concrete, but it was a better design in that a clear waterway was provided, and better vertical alignment of road and approaches was made possible due to prestressing. The system used was the Freyssinet system. Full details of design and construction are given in a paper to the Institution of Civil Engineers of Ireland. Construction time was seven months.

The bridge constructed by C.I.E. in 1952 was followed by the new bridge to carry Kylemore Road over the main line in Dublin, constructed in 1954, with a span of 14m. This also consisted of a number of precast post-tensioned beam units placed side by side. The Lee-McCall system was used, and in this case some prestressing bars were curved in elevation to provide maximum economy. Since that time C.I.E. has reconstructed numerous overbridges and underbridges in prestressed concrete, including the viaduct at Malahide, with four spans of 12m and eight spans of 16m. Various systems of post-tensioning have been used, the maximum span length being about 16m.

An early application of the principle of joining short precast units together to form a long monolithic beam was in the construction in 1955 of a number of pedestrian subways through the railway embankment at Lansdowne Road, Dublin, to give access to the new stand. These subways consist of four twin tunnels, each tunnel being 3m wide by 2.1m high. To construct each tunnel six precast reinforced concrete concrete units 1.7m long and weighing 11 t each, were laid end to end across the railway embankment. These were post-tensioned longitudinally using the Lee-McCall system with ten bars per tunnel section. This scheme allowed each twin tunnel to be constructed with two Sunday possessions of the track, illustrating the property of speed of construction which is sometimes possible by prestressing.

Pretensioning

About this time a factory utilizing the Hoyer long line system was establishing in Feltrim, Co. Dublin, for the manufacture of precast floors and roofs. The first recorded use of pretensioning in the Republic appears to have been in the construction of the Beal Lough Landing at Berehaven, Co. Cork, in 1955, by the Office of Public Works, where pretensioned beams 7.6m in length were used. This was followed in 1955 by a similar pier at Rathmullan, Co. Donegal, where a total of 179 deck beams were used. Pretensioning was also used in a road over rail bridge of 12m span and of composite construction near Longford. The beams in this case were manufactured on the long line system, with 60—5mm dia. wires per beam. The tops of the beams were roughened, and mild steel links protruded from the beams to act as shear connectors, thus giving composite action with the surrounding in-situ concrete poured after erection. Transverse stressing using high tensile bars was adopted in this example.

Speed of construction was again the criterion when reconstructing the rail bridge carrying the northern line over the River Tolka in Dublin, which was swept away by floods in December 1954. Here again post-tensioned I-beam units were used for the deck, which consisted of two 14m spans and one 18m span. Transverse stressing was carried out at site after erection. In the mid-fifties also the Special Works section of the Corporation of Dublin used prestressed construction by the Magnel-Blaton system for a number of bridges at Killester, Jones Road and St. John's Road, South Circular Road.

Irish Prestressed Concrete Association

It could be said therefore that by 1960 the early exploratory days of prestressing in Ireland were over. Post-tensioning systems were available at fairly economic costs, and a pretensioning factory was available for the manufacture of prestressed beams and flooring units in structural concrete. Prestressing was being applied to buildings and other structures, such as the Roche's Stores building in Dublin, an extension to the Medical Missionary Hospital in Drogheda, and the 7 megalitre (1½ million gallon) Beaumont service reservoir in Cork.

There was at that time a great enthusiasm by engineers for prestressed construction, because of its properties of reducing the use of imported materials and the reduction in dead load. The new material was not considered to be a panacea for all the problems of concrete construction, but it was felt by many engineers that prestressing was not being developed as rapidly as it should in Irish practice.

In 1960 the Irish Prestressed Concrete Association was formed, with the objective of promoting the greater use of prestressing, by the holding of technical meetings for engineers, architects and builders, by organising exhibitions, and by providing access for the building industry generally to the publications of organisations like the Prestressed Concrete Development Group in Britain and the Federation Internationale de la Precontrainte (F.I.P.) in Paris. A further aim of the Association was to carry out a survey of prestressed concrete work in Ireland, and this survey showed that the total number of prestressed concrete structures, including bridges, built in the first ten years of its use in Ireland, from 1951 to 1962, was about 103, and this did not include applications in the form of pretensioned flooring systems. The Irish Prestressed Concrete Association must certainly have helped to spread a knowledge of prestressing and confidence in it throughout the industry. The organisation continued its work until a year or so ago, when it was decided that its promotional work was no longer necessary and that the time had come to form an organisation of broader scope. Thus the Irish Concrete Society came into being in 1973.

Some may indeed consider that in the years immediately prior to 1965 prestressing was overused as a medium of construction in Ireland. The author considers that if this were so, it was probably inevitable, as the only way that designers and the construction industry can come to appreciate a new material is by using it in actual construction. The extent of overuse or underuse of prestressing at present should be an important point for discussion in the present symposium.

Reference should also be made to the Symposium on Concrete Practice held in University College Dublin in 1965. Although no special paper dealing with prestressing was included in that Symposium, there are numerous references to it in the papers and discussions of the Symposium. In the remainder of this present paper the author will tend to deal principally with applications of prestressing in the years which have elapsed since that Symposium was held.

Buildings

In the case of concrete buildings, with normal spans and loadings, the use of concrete post-tensioned at site will rarely be economical, unless special conditions arise. The principal applications will be in the form of pretensioned proprietary structural floor and roof systems, and a number of these systems are available. By means of prestressing the weights of the units may be reduced and spans increased, although for spans greater than about 15m these may be difficult to transport or handle.

The use of such floor systems also requires that the design of the building be on a modular basis to suit the dimensions of the units as manufactured. Figs. D2 and D3 show cross-sections of prestressed floor and roof systems available, with span ranges and typical depths. Floors of this type have the advantage that they will take loads immediately after erection.

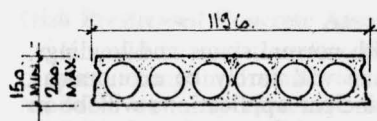
There are also a number of systems in which pretensioned units, spaced apart, are used in conjunction with hollow units of clay or concrete, with a composite structural in-situ slab. The in-situ slab may sometimes be omitted in the case of roofs. Fig. D4 shows cross-sections of the principal systems and span ranges available.

High Alumina Cement

Lyncrete type pretensioned floor units, using high alumina cement in their manufacture to enable de-tensioning to be carried out 24 hours after casting, were manufactured at two precasting works located in Dublin and Cork. Floors and roofs incorporating these units were used in many buildings. In February 1974 two roof beams made with high alumina cement concrete collapsed into a school swimming pool at Stepney, and an investigation was started immediately by the Building Research Establishment in Britain. Local authorities in Britain were recommended by the Department of the Environment to identify buildings with similar type construction incorporating high alumina cement, and to arrange for appraisal of the structural design in all cases. The use of high alumina cement for structural work in buildings was to cease until further notice.

The use of high alumina cement in Ireland also ceased, and public authorities and others initiated systems of appraisal by structural engineers of buildings in which high alumina cement had been used. As high alumina cement had to be imported here, the number of cases of its use is not proportionately as great as in Britain, but nevertheless structural re-appraisal is necessary.

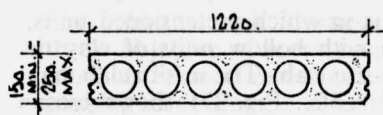
At the time of writing the British Research Establishment report has just been published. The report concludes that most concrete constructed with high alumina cement has reached a high level of conversion in a few years, and that this high level of conversion may in certain conditions give rise to a minimum strength in the concrete which is substantially less than the 24-hour strength. Appraisals of



DEPTH (MM)		MAX. SPAN (M)
150.	-	9.6.
200.	-	11.7.

BRETON LTD.

'SPIRAL' PRESTRESSED CONCRETE UNIT.

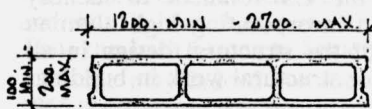


DEPTH (MM)		MAX. SPAN (M)
150	-	5.3.
175	-	6.3.
200	-	7.0
225	-	7.9.
250	-	8.8.

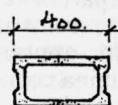
RIVERSDALE LTD.

'RINCON' PRESTRESSED CONCRETE

UNIT.



BISON WIDESLAB.



BISON.

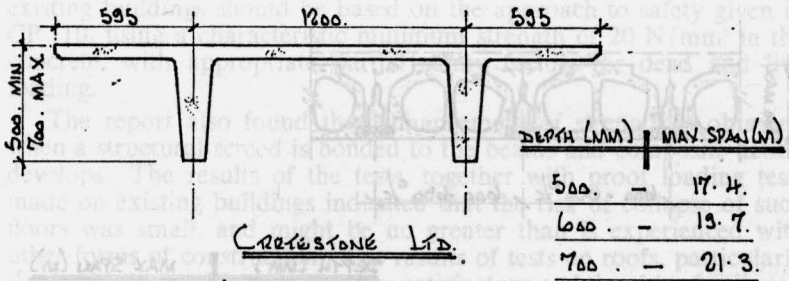
DEPTH (MM)		MAX SPAN (M)
125	-	7.2
150	-	8.0
175	-	8.9
200	-	9.8
225	-	10.3
250	-	11.0

ROCRETE LTD.

BISON PRESTRESSED CONCRETE UNITS.

FIG. D2

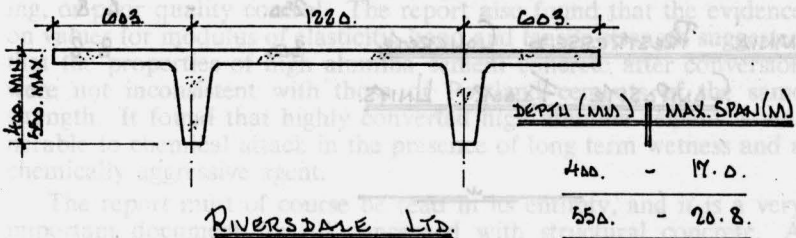
PRECAST UNITS WITH FLAT SOFFITS



CRESTONE LTD.

DOUBLE T. PRESTRESSED CONCRETE

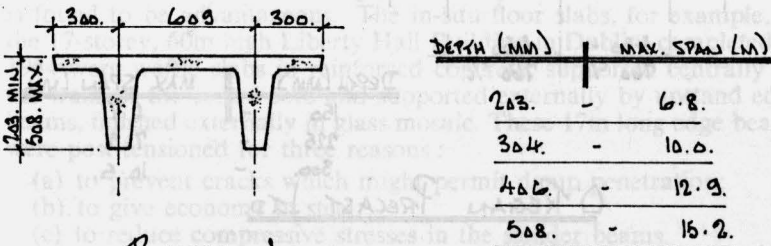
UNIT.



RIVERSDALE LTD.

DOUBLE T. PRESTRESSED CONCRETE

UNIT.



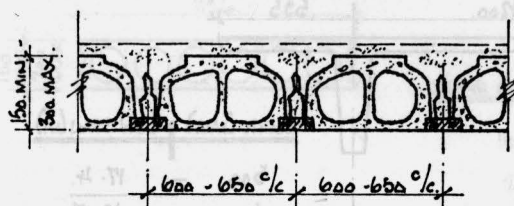
ROOCRETE LTD.

DOUBLE T. PRESTRESSED CONCRETE

UNIT.

FIG. D3

PRECAST DOUBLE-T UNITS

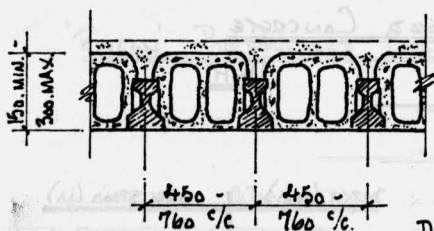


DEPTH (MM)	MAX SPAN (M)
150.	4.1.
200.	5.5.
250.	6.8.
300.	8.2.

CRETESTONE LTD.

OMNIA PRESTRESSED CONCRETE

COMPOSITE FLOOR UNITS.



DEPTH (MM)	MAX SPAN (M)
150	6.7.
225	7.9.
300.	10.5.

O'REGAN PRECAST LTD.

'LYNCRETE' PRESTRESSED CONCRETE

COMPOSITE FLOOR UNITS.

FIG. D4

COMPOSITE SLABING UNITS

existing buildings should be based on the approach to safety given in CP 110, using a characteristic minimum strength of 20 N/mm^2 in the concrete, with appropriate partial safety factors for dead and live loading.

The report also found that enhancement of strength is obtained when a structural screed is bonded to the beams and composite action develops. The results of the tests, together with proof loading tests made on existing buildings indicated that the risk of collapse of such floors was small, and might be no greater than is experienced with other forms of construction. The results of tests on roofs, particularly those with isolated beams, was less satisfactory and the risk of collapse, although small, might not be acceptable. The few collapses of roofs that had occurred were not all solely due to loss of strength due to conversion, but were in several cases the result of a combination of conversion with defects such as chemical attack, inadequate detailing, or poor quality control. The report also found that the evidence on values for modulus of elasticity, bond and tensile strength suggested that the properties of high alumina cement concrete after conversion were not inconsistent with those of Portland cements of the same strength. It found that highly converted high alumina cement is vulnerable to chemical attack in the presence of long term wetness and a chemically aggressive agent.

The report must of course be read in its entirety, and it is a very important document for all concerned with structural concrete. A further report on the subject from BRE is also expected at time of writing this paper.

In-situ Concrete in Buildings

While post-tensioned in-situ construction is not usually economical for the construction of buildings, there may be certain cases where it is found to be advantageous. The in-situ floor slabs, for example, of the 17-storey, 60m high Liberty Hall Building in Dublin, completed in 1964 were waffle slabs in reinforced concrete, supported centrally on the walls of the centre core and supported externally by upstand edge beams, finished externally in glass mosaic. These 17m long edge beams were post-tensioned for three reasons :

- (a) to prevent cracks which might permit damp penetration;
- (b) to give economy in steel;
- (c) to reduce compressive stresses in the slender beams.

The roof of the low level auditorium beside Liberty Hall tower block is an interesting example of combined reinforced and prestressed concrete construction. This is essentially a concrete lattice truss, the compression chords of the lattice being folded plate R.C. slabs forming the roof deck with pairs of exposed diagonal tie members, crossed over in plan, forming the bottom chords. The diagonal tie members are each 20m long of section 300mm deep and 190mm wide. PSC Monowire prestressing system was used.

In the case of the Arts Faculty Building at U.C.D., completed in 1969, it had been intended initially that the waffle slab floors of 8m two-way span between columns would be in reinforced concrete, 533 mm thick. It was felt, however, that there were difficulties with this scheme, the principal one being the likelihood of cracking due to shrinkage of the high quality concrete necessary for the quality finish required, and the total length of the floors (32m). The waffle floors were in fact constructed in prestressed concrete 400mm thick, cost studies having shown a saving of about £420 per floor. This example is interesting also in that stressing was carried out approximately 7 days after casting in order to satisfy the construction time.

Post-tensioning was also adopted for the main tie member for the hyperbolic paraboloid roof to Athy Church; the tensile design load for the tie was 580 tonnes. The tie is 52m long between anchorages, and if it had been designed in reinforced concrete the calculated extension of the member would have been 38mm. It was felt that an extension of this order would cause large secondary stresses in the shell. Furthermore it was expected that at high flood level in the River Barrow the tie would be under water, and freedom from cracking was obviously essential. The calculated extension of the prestressed tie under full live load was 10mm.

The structure of the restaurant building at U.C.D. Belfield completed in 1970, is mainly reinforced concrete. The concrete roof, which forms an umbrella over the main functional areas, consists of four 22m square bays, each bay being supported on corner columns; the main beams of these bays, 22m span, were precast at site and post-tensioned.

Bridges

In bridgework, prestressing has found many economic applications particularly where long spans are involved, as in the case of Wexford Bridge, with five spans of 64m and two spans of 32m, of in-situ post-tensioned construction. The alternative would have been an open spandrel arch in reinforced concrete, using thirteen spans instead of eight, and higher foundation costs. With small spans, however, of the order of 15m, prestressing will often only prove economical if standard bridge beams can be used. These standard pretensioned beams are usually designed to act compositely with an in-situ concrete deck. Speed of construction will also be a factor, as manufacture of standard bridge units can proceed at the same time as construction of abutments and piers.

In the case of Malahide viaduct which carries the C.I.E. northern line on ballasted track over an estuary of the sea (12m and 16m spans), the choice in design was between welded box girders under each track and precast prestressed concrete units. The greatest obstacle to the use of the prestressed concrete units was the higher weight factor, combined with the fact that transverse stressing was not possible due to lack of time available during Sunday possessions of the track. The

steel box girders were not however an economic section for the spans involved, and the prestressed design, with maximum weights of units of 38t in the 16m spans, was adopted. A total length of 69Km of strand was used in the construction of this bridge, and 2040t of concrete. The 790mm deep prestressed units with 460mm dia. voids were post-tensioned using the CCL system.

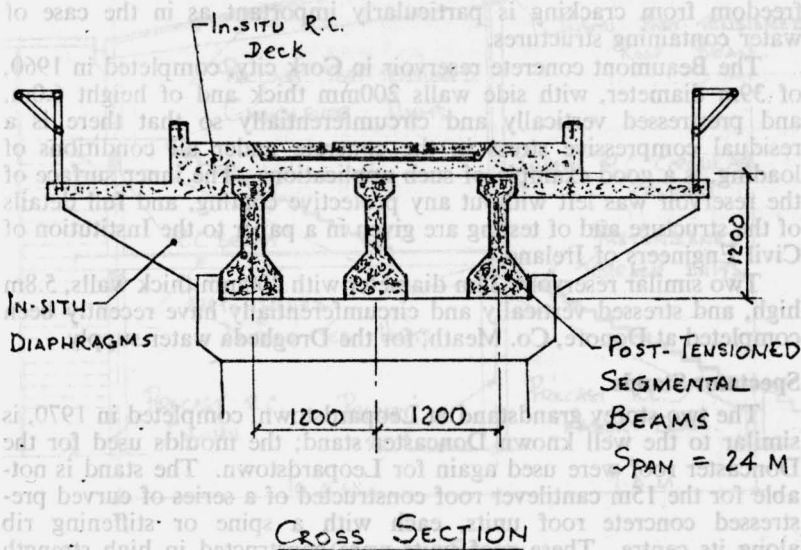


FIG. D5
BRIDGE AT SHANNONBRIDGE

Fig. D5 shows the unconventional cross section of a rail and road bridge across the River Shannon at Shannonbridge, constructed as an alternative to a design in structural steel, and completed in 1968. The bridge superstructure is of length 160m, and comprises six spans of 24m and a navigation span of 14m. The bridge carries the Bord na Mona light railway, and the lowering of the level of the footpaths and parapets below rail level, and the provision of the low level stabilising walls on either side of the track, are to accommodate a special heavy transport wagon used by the Board. The bridge may also be used for road traffic when its use as a railway bridge is no longer required.

In the 24m spans there are three beams per span, supported on Freyssinet rubber bearing pads, interleaved with steel plates. Each beam, of total weight 26t was precast in four equal lengths with joints 75mm long between the segments; they were post-tensioned in position while temporarily supported on sectional steel trusses spanning between the piers. The beams are tied together at the ends and at each

6m point by R. C. diaphragms. The prestressing force per beam is 540t, provided by 10 Freyssinet 12/7mm wire cables. Cube strengths of the order 65N/mm² were obtained during construction.

Other Structures

Prestressing has many applications to other structures, besides conventional buildings and bridges. It should always be considered when freedom from cracking is particularly important as in the case of water containing structures.

The Beaumont concrete reservoir in Cork city, completed in 1960, of 39m diameter, with side walls 200mm thick and of height 6.0m, and prestressed vertically and circumferentially so that there is a residual compressive stress in the concrete under all conditions of loading, is a good example of such applications. The inner surface of the reservoir was left without any protective coating, and full details of the structure and of testing are given in a paper to the Institution of Civil Engineers of Ireland.

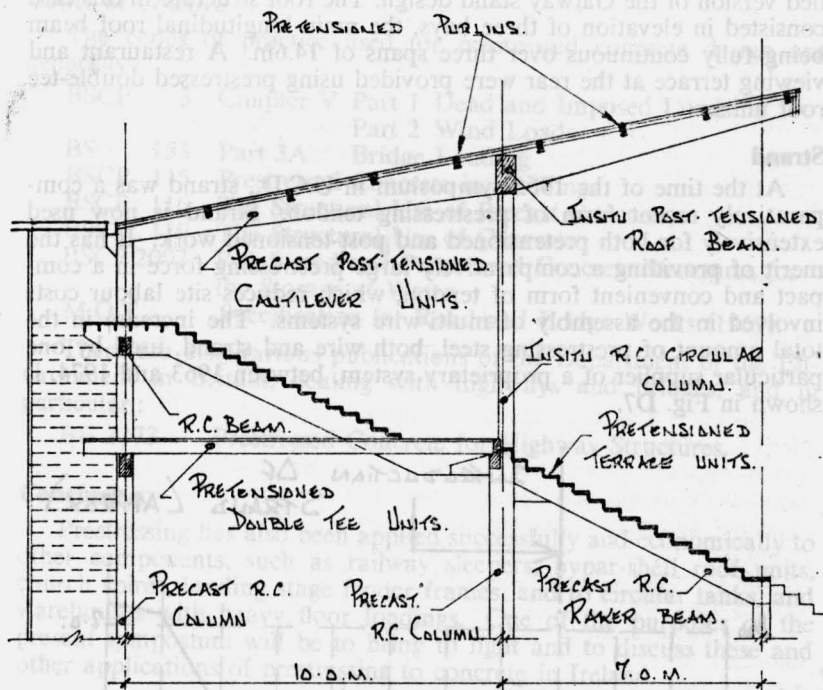
Two similar reservoirs 32m diameter with 200mm thick walls, 5.8m high, and stressed vertically and circumferentially have recently been completed at Donore, Co. Meath, for the Drogheda water supply.

Spectator Stands

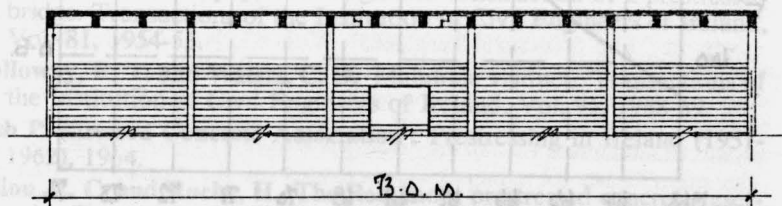
The two-storey grandstand at Leopardstown, completed in 1970, is similar to the well known Doncaster stand; the moulds used for the Doncaster roof were used again for Leopardstown. The stand is notable for the 15m cantilever roof constructed of a series of curved prestressed concrete roof units, each with a spine or stiffening rib along its centre. These roof units were constructed in high strength (55 N/mm²) lightweight concrete of density 1870 Kg/m³. The main supporting structure of the stand consists of a series of precast H frames. The structure is also notable for the high standard of finishes obtained in white concrete made from white Galway marble aggregate. Another interesting technique here was the use of prestressed hanging cladding panels 63mm thick and up to 15m long.

Fig. D6 shows the new stand at Galway Racecourse, which is also constructed using a combination of reinforced, pretensioned and post-tensioned concrete, both cast in-situ and precast being used where considered appropriate in its construction. Prestressed concrete purlins are used to support the steel roof decking. The main 73m long longitudinal beam supporting the precast post-tensioned cantilever roof units is of in-situ construction and consists of five spans of 14.6m. In this beam, both pairs of end spans and cantilevers are continuous, with an 8m central suspended span.

When the timber stand in the general enclosure in Leopardstown was destroyed by fire in August 1972, it was necessary to provide another stand immediately to accommodate about 4000 people and to be ready for use on 26th December 1972. This four month period for design and construction was achieved successfully by adopting a modi-



CROSS SECTION.



ELEVATION.

FIG. D6

GRANDSTANDS AT GALWAY AND LEOPARDSTOWN

fied version of the Galway stand design. The roof structure in this case consisted in elevation of three bays, the main longitudinal roof beam being fully continuous over three spans of 14.6m. A restaurant and viewing terrace at the rear were provided using prestressed double-tee roof units.

Strand

At the time of the 1965 symposium in U.C.D., strand was a comparatively recent form of prestressing tendon. Strand is now used extensively for both pretensioned and post-tensioned work. It has the merit of providing a comparatively large prestressing force in a compact and convenient form of tendon, which reduces site labour costs involved in the assembly of multi-wire systems. The increase in the total amount of prestressing steel, both wire and strand, used by one particular supplier of a proprietary system, between 1963 and 1974, is shown in Fig. D7.

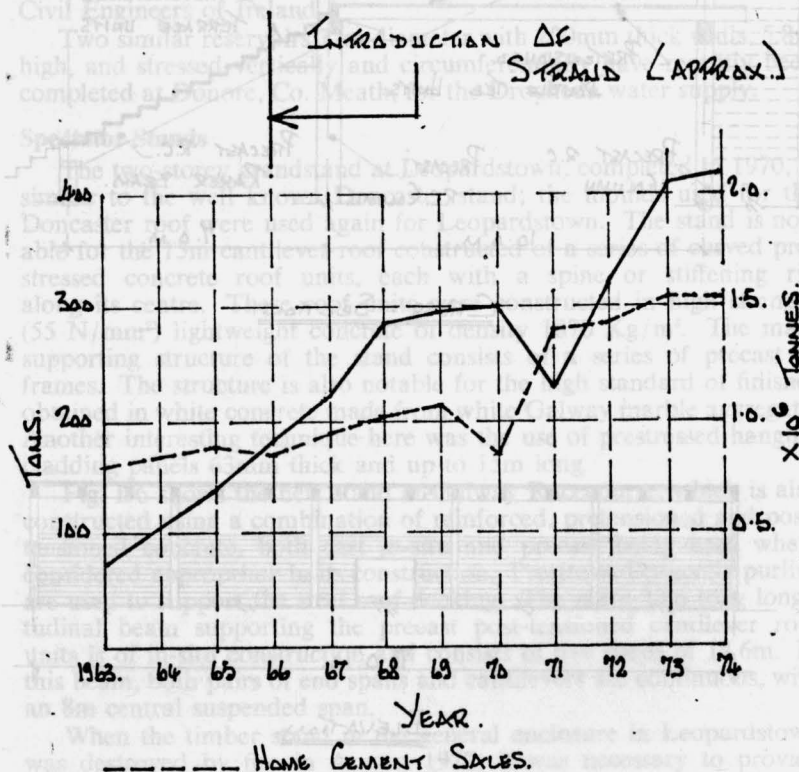


FIG. D7

SALES OF PRESTRESSING STEEL AND CEMENT COMPARED

Codes of Practice

The codes of practice used for prestressed concrete design are generally :

- BSCP 3 Chapter V Part 1 Dead and Imposed Loads
Part 2 Wind Loads
- BS 153 Part 3A Bridge Loading
- BSCP 115 Prestressed Concrete in Buildings
- BSCP 116 The Structural Use of Precast Concrete
- BSCP 110 The Structural Use of Concrete
- BSCP 2007 Reinforced and Prestressed Concrete Structures for the Storage of Water
- M.O.T. Specification for Road and Bridge Works (1969).

There are also various publications of the Department of the Environment in Britain, dealing with highways and bridges, and in particular :

- BE 2/73 Prestressed Concrete for Highway Structures.

Conclusion

Prestressing has also been applied successfully and economically to other components, such as railway sleepers, hyper-shell roof units, church spires, landing stage fender frames, and to circular tanks, and warehouses with heavy floor loadings. One of the purposes of the present symposium will be to bring to light and to discuss these and other applications of prestressing to concrete in Ireland.

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Discussion

DR. STEPHENS introduced his paper.

He drew attention to an alteration in relation to the Bison units shown on Figure D2. The corrected maximum span/depth ratios would appear in the published text. He understood that slightly longer spans were in fact possible with Bison units where advantage could be taken of composite construction. Messrs Roconcrete Limited now also supplied 2.4 m wide prestressed double-T units with a maximum depth of 605 mm and a maximum span of 22.5 m. That was an addition to the information given on Figure D3.

Messrs Riversdale Concrete Products Limited, in addition to the material referred to on Figures D2 and D3, produced Rivcon prestressed beam units, including saddleback units.

Referring to Figure D4, Lyncrete units were now made with Portland cement concrete. The use of high alumina cement had been abandoned. In that context, Dr. Stephens mentioned that, since his paper had been written, a report on the use of high alumina cement concrete had been published by the Department of the Environment in Britain. It had been prepared by a sub-committee of the Building Regulations Advisory Committee of the Department, under the chairmanship of Mr. C. B. Stone, a former president of the Institution of Structural Engineers. (Editor's note: the full text of the report is given in "The Structural Engineer", Vol. 53, No. 10, October 1975, pp 431-438.) The Stone Report had cleared the air considerably in the high alumina cement controversy; and while it was still advisable to have a structural assessment of all buildings containing that cement made in accordance with the recommendations of the Stone Report, the main cause for concern now centred on the use of isolated roof beams where no composite action was occurring.

Dr. Stephens considered that as there had been no paper on prestressed concrete as such in the 1965 Symposium, he should include some of the historical background for the use of prestressing in Ireland. His listeners might like to use his presentation, which would be illustrated with slides, in weighing for themselves the advantages and disadvantages of prestressing and consequently in making their own

assessments as to whether proper use was being made of the medium in this country.

The concept of optimum prestressing as shown on Figure D1 was a significant feature in the prestressing of concrete, and design should tend towards it where possible. Also, it should be accepted that the principal purpose of prestressing was probably the elimination of tensile stress and therefore of cracking, and this would remain so until such time as a concrete having tensile strength was developed. The symposium would be hearing Dr. Glynn's comments on that topic later in the proceedings.

The first prestressed structure in Ireland was the post-tensioned silo built by Terence Mallagh in 1951 for the Dublin North City Milling Company Limited. This consisted of eleven bins, 3.6 m in diameter and 23 m high constructed in precast concrete blockwork and post-tensioned by a method devised by Mr. Mallagh, in which a series of closely-spaced circumferential wires was stressed by transverse displacement. This ingenious and successful method had been used in further structures, but had since been replaced by straightforward jack-operated tensioning. In 1952, the first prestressed concrete bridge, for a span of 11 m, was built by Coras Iompair Eireann, using the Lee-McCall system, and they followed this shortly with a 14 m span over the railway at Kylemore Road, Ballyfermot, using the same system. As Mr. Pigott had pointed out, Coras Iompair Eireann was still using prestressing, mainly for speed of construction, in the renewal of its overbridges and underbridges.

Also in the early 1950's, the Special Works Department of Dublin Corporation, under Dr. M. P. Beausang, had set up a unit for the construction of prestressed concrete, mainly for bridges. The bridge carrying the northern railway line at Killester, prestressed by the Magnel-Blaton system, and the dual bridge over the canal and railway line at Jones's Road in Dublin were examples from that activity.

In 1953 the Flannery Bridge was built near Kilkieran in County Galway. It was a two-pinned portal frame of 55 m span founded in rock, and was at the time the longest prestressed span in Britain or Ireland. Denis O'Leary was the consulting engineer.

In December 1954 the existing railway bridge over the River Tolka at Fairview, Dublin was swept away in a severe flood. It was replaced by a three-span prestressed bridge, the largest span being 18 m, designed by Ove Arup. This bridge made use, for the first time in the Republic, of small precast units stressed together in situ.

In 1959, prestressing was used for the spire of a new church at Spangle Hill in Cork.

In 1964, a seventeen-storey block was built as part of the new Liberty Hall in Dublin. Prestressed concrete perimeter beams, 17 m long and faced with glass mosaic, were used at each floor level. These beams, spanning between circular reinforced concrete columns, formed one set of supports in the floor system, the second being the central

core, containing the services, lifts, and stairways. In the single-storey auditorium in the same project, the roof was an interesting combination of reinforced and prestressed concrete. The roof system was basically a series of trusses in which the compression chords were reinforced concrete folded plates and the main tension chords were post-tensioned concrete ties, prestressed on the PSC Monowire system.

Another example of the use of a prestressed concrete tie occurred at the Dominican Church at Athy, built in 1963. The roof of that church was a shell of hyperbolic paraboloid profile and an underground tie containing an initial prestressing force of 580 tons was used to inhibit spread at the shell roof supports.

In 1959, a road bridge comprising five spans of 64 m and two spans of 32 m, prestressed on the Dywidag system, was constructed over the River Slaney at Wexford, Mr. W. J. L. O'Connell being the consulting engineer.

In 1968, Bord na Mona built a bridge across the River Shannon at Shannonbridge. Designed primarily to accommodate a light railway, but suitable also for later conversion to road traffic use, the unusual cross-section with its depressed walkways and low parapets was to cater for the passage of wide rail-borne loads.

The design consisted of six spans of 24 m and one span, for navigation, of 14 m, all simply-supported. Each span was formed by three precast concrete ribs and an in-situ concrete slab which acted compositely with the ribs. Each rib consisted of four segments, placed end to end with 75 mm of in-situ concrete between each pair, and post-tensioned using the Freyssinet system, with ten cables each containing twelve 7 mm diameter wires in each rib. The operation of post-tensioning had to be carried out with the ribs out of place, as the space between consecutive spans would not have been adequate to fit the stressing equipment. The stressed ribs were then moved laterally on rollers to their permanent positions. The contractors, Messrs P. J. Walls (Dublin) Limited, used a number of Cleveland trusses as supports for the assembly of the rib segments, and the availability of these contributed to the overall economy of the construction.

In 1971, a grandstand, 73 m in length, to accommodate 6,500 spectators was built at Ballybrit racecourse in Galway. The architect was Simon J. Kelly, the general contractors were the Irish Engineering and Harbour Construction Company Limited, and Banagher Tiles Limited were sub-contractors for the precast concrete units. This structure incorporated nearly all forms of structural concrete. Some columns and beams were precast reinforced concrete, other columns were in-situ concrete, the terrace units and roof purlins were pre-tensioned prestressed concrete, and the main roof beam and roof cantilever beam units were post-tensioned prestressed in-situ concrete. The roof was a steel deck. The main roof beam consisted of four 15 m spans and a centre span formed with two cantilever ends and an 8 m long drop-in centre section to accommodate movement. Each set of two 15 m

spans and one cantilevered end comprised a single prestressed continuous beam. The main roof beam supported a series of roof cantilever beam units. These elements were monolithic at their intersections, the cables in the two members crossing each other at right angles. Aspects of design which that project had raised very clearly had included the need for precision in the location of tendons in small-scale units of unsymmetrical cross-section, and the significance of localised windforce of very high intensity in the detailing of cladding fixings.

During the last five years two grandstands had been built at Leopardstown racecourse in Dublin. The first of these, a two-storey stand designed by Jan Bobrowski and Partners followed generally the earlier stand at Doncaster, with some of the same moulds being used on both projects. That project, which would be referred to in Mr. McCullough's paper also, had as a distinctive feature 15 m long curved cantilever roof units cast in lightweight concrete using white cement.

The second grandstand had become necessary following the destruction by fire of an earlier stand in August 1972. Its replacement was required by the end of December 1972. The building team which had designed and erected the Galway stand was invited to undertake the work, and the new stand, for 4,000 spectators, was designed and built in the four-month period allotted. Some of the moulds from the earlier work were fortunately available, but the project did illustrate the speed of construction that could be obtained with structural concrete.

Dr. Stephens discussed road bridges saying that whilst prestressed concrete was frequently used, that medium did not necessarily always provide the best answer. Examples, where normal reinforced concrete had been used, were bridges over the Dodder at Orwell Road in Rathgar and Springfield Road in Rathfarnham. At Orwell Road, the designers, Denis O'Leary and Partners, had decided on an in-situ bridge which suited the location very much better than would a precast deck with prestressed I-beams or similar. At Springfield Road, the alternatives were a three-span structure in normal reinforced concrete or a prestressed concrete single-span structure supported on solid abutments. Very wisely, the three-span bridge had been accepted by Dublin Corporation even though it was marginally more costly, because the two side spans opened up the Dodder vista and helped the development of a linear parkway which was being formed along the river banks.

Returning to his earlier question about the extent to which prestressing was being used in the country Dr. Stephens referred to Figure D7 which showed that the annual sale in the Republic of prestressing wire and strand in connexion with one of the proprietary systems had increased from about 80 tons in 1963 to over 400 tons in 1973. This was an increase of about 400%. During the same period, the sale of cement had increased from 0.8 million tons to 1.6 million tons, an increase of 100%. Those figures would seem to suggest that the use of

prestressing had increased at a rate more than twice as great as that for construction in other forms.

Dr. Stephens showed 81 slides. They included the following buildings complete, or under construction:

Bridges at Ballyfermot, Fairview (Tolka), Jones's Road, Kilkieran (Flannery), Killester, Louisburgh, Rathfarnham (Springfield Road), Rathgar (Orwell Road), Sallins, Shannonbridge and Wexford; Footbridge at Maynooth;

Grandstands at Leopardstown (two stands) and Galway;

Liberty Hall, Dublin;

Church of the Resurrection, Spangle Hill, Cork;

Grain silos at Dublin North City Milling Company;

Guard rails at public park in Howth.

Concluding his presentation, Dr. Stephens thanked all the engineers, architects, contractors and suppliers who had given him information without which he could not have compiled his paper.

MR. R. T. HOLLOWAY opened the discussion.

He recalled that Dr. Stephens had been one of the pioneers of prestressing in the Republic, and, in fact, had designed the first prestressed concrete railway bridge to be built here; and he had undoubtedly been one of the foremost in advancing the use of the medium in this country. Dr. Stephens had referred to the change of attitude to prestressing which the last ten years had brought. Mr. Holloway accepted this. There was now less emphasis on systems of prestressing and more on the end product, and the understanding was that any system which was surviving commercially had to be a good system.

He agreed with Dr. Stephens that prestressing had been over-used in the past, particularly in the form of post-tensioning on building works. This had left contractors somewhat cautious about its use today. Despite its many advantages, it remained obvious that any method of construction that seriously hampered other work, prolonged construction times, and required special supervision and attention to safety, was not always going to be welcomed on site. This situation was not helped by designers sometimes applying prestressing to non-economic reinforced concrete type sections, as for example ribbed floors, that did not permit the efficient application of prestressing. Its use would certainly be justified in buildings of unusual design, as for instance Desmond O'Kelly's low level roof at Liberty Hall, but for normal spans and loading, site stressing was frequently just not economic. He had however to confess to a certain personal dislike of post-tensioning and that possibly shaded his view.

Regarding the use of precast pre-tensioned units, Mr. Holloway questioned whether, with the high cost of in-situ formwork being a dominant feature in building, it might be possible that prestressed elements were adopted rather more because they were precast than because they were prestressed. Undoubtedly the manufacturers were

attracted by standardization and rapid re-use of moulds, the contractor appreciated the reduction in weight, and the designer, pressed for economy in depth of construction, welcomed the shallower cross-section; but such benefits were marginal and he doubted that there were many building projects where any of those points had been the deciding factor that led to a conscious decision to use prestressing.

One quite extensive use of prestressing in Ireland had been in the manufacture of railway sleepers. The suitability of the medium for that purpose was not immediately apparent, but nevertheless they had been successfully designed and manufactured here to suit Irish conditions. Perhaps a representative of Coras Iompair Eireann would discuss that rather esoteric use of prestressed concrete.

Mr. Holloway considered that prestressing came into its own in the design of bridges, because of the longer spans and heavier loads involved and because of the value of prestressing in the resistance of corrosion. He would like to offer some comments on the influence of prestressing on bridge design in the Republic. Irish geographical conditions did not call for long-span bridges, but in the short-to-medium span range that we did need, he noted that at least four distinct categories of design had been employed. These were (i) simply-supported or continuous span bridges on piers and abutments, (ii) portal frame bridges, (iii) cantilever span bridges with piers and abutments, and (iv) trestle bridges.

The great majority of our bridges were of simply-supported beam or slab construction on piers and abutments, and often the most important decision facing the designer was to choose between in-situ and precast work for the deck. While designers generally were familiar with the guide-lines for making such decisions, and while these guide-lines were theoretically sensible, their application was not always clear-cut, and it remained necessary to remember that in any given circumstances, they could be overruled by some more important factor peculiar to that particular project.

Mr. Holloway used two Irish bridges, one under construction and one recently completed, to develop that point. The first of these bridges had been built on fairly level ground of good uniform bearing quality on a site with good access. The design adopted had four simply-supported spans, carried on three piers and two abutments. The site had been excavated extensively to permit a major dual carriageway road to pass under the new bridge. The site for the second bridge had been a tidal estuary with poor ground conditions needing piling for both permanent and temporary works and calling for a situation based on a single main span. The basic guidelines would, in his opinion, have suggested that of the two, the first bridge would be more likely to be in-situ and the second more likely to be precast. Nevertheless, the overall design strategies for the two projects had in fact dictated a reversal of approach. The first bridge, the Belfield overpass on the Stillorgan Road with which he had been associated, had its deck

formed with precast units, and the second, the bridge over the Boyne at Drogheda, had been built in-situ.

Dr. Stephens in his paper had mentioned the railway viaduct at Malahide. Mr. Holloway had been associated with the design and construction of that bridge. The precast units in that project had been formed with large voids circular in cross-section, at the time something of a novelty. The design merit of such a cross-section was clear, and the process was now very well known.

The second category of bridge, that based on portal frame construction, was represented most notably in Ireland by Flannery Bridge. Unfortunately, the relation of that bridge to the road which it carried was such that its form, as one of the most interesting bridges in the country, could not easily be studied.

Cantilever span bridges, Mr. Holloway's third category, were frequently used in Ireland especially in estuary crossings. The soffit lines were usually curved to give the appearance of arches rather than double cantilevers, and Mr. Holloway considered that although this was a deception that might offend the curious, it was a legitimate exercise provided that the final effect was pleasing. The danger of having an unsightly droop develop with time at the end of a cantilever should not be overlooked in designs in that category; and also in that category, he felt that one tended to get from such design a rather heavier elevation than might be expected from prestressed concrete. Mr. Holloway commented on the non-use of segmental cantilevered construction in the Republic.

Regarding the fourth category, the trestle bridge, in which the deck, continuous or simply-supported, was carried on bents which were sometimes pile bents, the only good feature of these was their cheapness. They had little reserve of strength against accidental damage or overload, they could be costly to maintain, and, even with prestressed concrete, tended to look ungainly or top-heavy. They were, in his mind, the complete antithesis to imaginative engineering.

Engineering works in prestressed concrete could add to the grandeur of a river or of an estuary or valley, but it required a conscious effort by engineers to guard the environment against despoliation and in that context to refuse aesthetically bad design offered on the grounds of cheapness.

It was sad to reflect that we had no example to offer of an imaginative prestressed concrete footbridge. He hoped that Dublin Corporation could one day arrive at something other than the steel footbridges mentioned by Mr. Pigott at an earlier session. One could build a footbridge that would enliven the environment and Mr. Pigott's examples had shown something of the effectiveness of precast concrete used carefully in that context. As a general comment on the theme proposed by Dr. Stephens, the place for prestressed concrete was in the conscious struggle for more attractive and aesthetically pleasing, yet economic, engineering structures.

Mr. Holloway illustrated his comments with eight slides showing the Boyne Bridge which was under construction in Drogheda, and the Belfield overpass, recently completed.

MR. N. LOONEY agreed with Mr. Holloway about the problems associated with post-tensioning in building programmes. While unfortunately these problems tended to limit the range of what one could do with prestressed concrete, time and cost were two great pressures on building, and in-situ prestressing perforce found itself relegated to prestige structures or very specialised works where there was no other solution. At the same time, one saw the growth in sales of prestressing wire and strand, and this, he believed, arose from the increase in production in Ireland in the last ten years of prestressed precast concrete.

That trend would continue, and a major expansion in the production of prestressed precast concrete bridge elements was probable. Mr. Looney referred to the original British Cement and Concrete Association inverted tee-beam units, indicating that their use, coupled with a suitable in-situ edge detail, could produce completed bridge decks in a matter of weeks. The need in future would however include a demand for spans longer than the 15m - 16m units at present available. In that context, he felt that there was a great potential in Ireland for the M-beam, a unit one metre wide, which could develop spans of up to 25m - 30m; but, he added, that potential could not be usefully explored until a guaranteed market could be ensured for the product.

Mr. Looney referred to the development of the hydrocarbon resources in the Celtic Sea. He felt regretfully that much of the technology associated with, for instance, the design of large pressure vessels and liquid gas containers would be imported, as oil companies might be reluctant to accept unproven performers. Given time, however, an important field should develop in that area for Irish designers and manufacturers.

MR. T. R. HALL disagreed with the earlier speakers about the economics of post-tensioning. Whilst the point might have been arguable in the past, the introduction of unbonded tendons had cut site labour costs considerably, and had led, he believed, to a type of construction that could compete successfully in cost with any other form of concrete. He referred to the two million gallon reservoir at Glanmire as an example of this technique; and he mentioned an assessment of comparative costs made in the New Civil Engineer earlier in the year which had found in favour of unbonded post-tensioned concrete as against conventional reinforced concrete. Mr. Hall drew attention to a footbridge that had been built at Lough Nahanagan as part of the Turlough Hill electricity project. This bridge, designed by the Electricity Supply Board, had a simply supported span of 60m and was

formed of 2m long concrete box girder segments, jointed with epoxy resin and post-tensioned. That form of construction merited development.

MR. M. SWEENEY referred to the grandstands designed by Dr. Stephens firm at Leopardstown and Galway, with both of which he had been associated, in the contractors organization. He recalled the very exposed nature of the Galway site and emphasized that wind force on the uncompleted structure could be a major hazard and should never be overlooked.

He could not recommend four-month contract periods for major structures as a means for lengthening one's own lifespan, particularly if the contract contained a "no-stand, no-fee" clause !

MR. T. J. DESMOND mentioned that the footbridge at Maynooth consisted of a series of 60 foot spans, each one formed with three 20 foot segments assembled and post-tensioned on site with epoxy resin joints and no infill concrete between the segments. In another similar project with which his firm had been involved, that technique had worked equally well, although there the low temperatures experienced on site had inhibited the hardening of the epoxy resin, until additional fillers had been added to it.

Road bridge construction was an area where, due to the repetition involved, savings could be made by the use of precast prestressed units. Dr. Stephens had showed that through the nineteen-fifties and part of the nineteen-sixties, a major limitation had lain in the length of unit which could be handled, and this had led to the necessity of adopting post-tensioning where longer spans were required. Now, however, the availability of road vehicles of larger capacity, and of more powerful mobile cranes, had made the handling of longer units possible; and the installation in recent years of pre-tensioning beds with capacities up to 500 tonnes had made their construction possible. Dr. Stephens had described the Shannonbridge bridge in which precast segments had been post-tensioned on an elaborate staging which had made use of steel trusses from another project. He wondered what the economics of that bridge would have been, had those elements not been available, and he commented that it would now be possible to make single units up to 23m long in one cast and place them by using direct shore-mounted cranes, or pontoons.

Mr. Desmond believed that the use of pretensioned beam units would increase significantly, as a result of the three features he had mentioned. He added that the savings in cost accruing through the omission of anchorages would be an added advantage.

MR. M. A. LYNN asked Dr. Stephens to comment on the problems associated with the demolition of prestressed concrete structures, and particularly structures containing large heavily-stressed post-tensioned

elements. He was interested to hear the references made to the over-use of prestressing in the early years of its availability. It seemed to him to be, generally speaking, a parallel case to that of high alumina cement, and he felt that they both possibly represented some commentary on the play between the forces of commerce and of human philosophy.

MR. M. O'DRISCOLL said that as Mr. Lynn had mentioned high alumina cement, he should contribute to the discussion, as he had been using high alumina cement since 1967. He felt that Dr. Stephens had commented very fairly on the Stone Report, and there was no doubt but that it had put the whole question into a more sensible perspective. His firm, as it happened, offered no isolated beam construction in the sense of the Stone Report. All of their floor systems would be deemed to be composite. Even though the 6" thick floor which they made had only a cement and sand screed, he understood from the Report that such a slab was considered to act in a composite manner. He had had tests made by the Institute for Industrial Research and Standards. These had shown results in full compliance with standards for loading, and with maximum deflexions considerably less than those allowable, in fact so small as to be virtually unmeasurable.

PROFESSOR J. de COURCY in a written contribution drew attention to the publication "Prestressing in Ireland: a record of the earliest prestressed concrete works carried out in the Republic of Ireland from 1951 to 1962 inclusive" which was mentioned in Dr. Stephens' bibliography. This record, which had been researched and published by the Irish Prestressed Concrete Association (later to become the Irish Concrete Society) in 1964, presented information which supplemented Dr. Stephens' valuable survey in reference to the earlier uses of the medium in the Republic. He would refer particularly to the attributions given in that publication for the Flannery Bridge.

DR. STEPHENS replied to the discussion. In regard to Mr. Holloway's reference to the speed of construction in precast concrete projects, one of the main advantages lay in the fact that precasting could proceed in parallel with the in-situ content of the work, and that was an important element in getting a job finished quickly. He would strongly support Mr. Holloway's remarks about the aesthetic demand in bridge design. He felt in that context that engineers should be prepared to take the advice of their sister profession, architecture, and should pay particular attention to the medium and materials chosen for construction. He felt he would like to deal with other matters individually at a later date, as the time for the session had run out.

CONCRETE RESEARCH

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Introduction

Concrete produced from hydraulic cements and natural aggregates has become so commonplace that its serviceability has tended to be taken for granted. This complacency accounts in no small measure for the recent difficulty encountered with the use of high alumina cement for precast concrete. It must be remembered that our confidence in concrete construction is largely due to world-wide research in quality control undertaken by the cement industry. The setting of siliceous cements is a highly complex phenomenon as can be readily appreciated from an even cursory review of the literature on hydration of cement constituents. The setting process of ordinary portland cement is no less complex than that of the rarer varieties. Portland cement concrete has its limitations. The broad aim of concrete research is to assess the limitations and explore corrective measures to offset the inherent deficiency of the material. Undoubtedly, the most serious defect of ordinary concrete is its comparatively low tensile strength. To counteract the lack of tensile resistance methods of mild steel reinforcing and prestressing were devised. These innovations have resulted in extensive research into such aspects as bond, stress corrosion, fire resistance and durability in aggressive environments. Such investigations have provided a mechanistic perspective of the behaviour of concrete in engineering structures and have influenced our design criteria. More recently researchers have undertaken fundamental studies of cracking and other causes for weakness in direct tension. The work has led to the introduction of crack arresters in the form of fibre reinforcement and polymer additives. From a practical standpoint it is perhaps of small consolation to know the theoretical reasons for the different resistance of concrete to tensile and compressive stresses*. Taking into account present research efforts, it appears not unduly optimistic to

* (The relative strength of van der Waals, hydrogen bonds and valency bonds is of the order of 1:10:100. One theory maintains that in compression the valency bonds are mobilised but in tension the weaker van der Waals forces offer the only significant resistance to fracture of neat cement gel).

predict that the problem of tensile strength of inorganic cements will be solved within a relatively short time on the scale of the overall development of cement and concrete technology. Of course there are other problems associated with construction in concrete as for instance shrinkage, long-term creep and thermal degradation. The various aspects of these properties have ensured a turnover in research projects with prospects for future work.

It is against the background of world-wide research and interest in concrete technology that an attempt is being made herein to document the contributions of research workers in Irish Universities. The research work has been in progress over the past fifty years and has resulted in many publications in international and home journals. The objective of this exercise is to identify fields of endeavour which have been consistently pursued rather than embrace the entire field of isolated studies of specific problems. Albeit there were many worthwhile investigations which will not appear in this review.

Mix Design

Some of the earliest research reported was performed in University College, Cork. The work on aggregate gradings, workability and mix design in general resulted in practical criteria which have been applied extensively on site. The results were reported in several publications between the years 1920 and 1950. Of particular interest are the data reported in References 1, 2, 3, 4.* Research on the properties of concrete made from no-fines aggregate was undertaken in the early fifties in the Queen's University of Belfast (Ref. 5). More recently, research has been proceeding at University College Dublin on Irish aggregate resources and papers from this work are listed in Reference 6 and in the Bibliography. Other research in this area consisted of the valuations of cement-stabilised soils performed as a pilot study in University College, Galway, circa 1950.

Prestressed Concrete

The published works on prestressed concrete derive mainly from research in the Q.U.B. Those listed deal with tests conducted during development of the Speedwell system of permanent building (Refs. 8 and 9). On the other hand a general field study of building behaviour is being undertaken in U.C.D. and this work has included observations of the behaviour of prestressed concrete elements in service (Ref. 7). In the late 1950's, work on the impact resistance of prestressed concrete was undertaken at University College, Galway (see references Nos. 24 and 25).

Stress Concentration and Tensile Strength

In the early sixties, research on stress concentration and tensile strength of microconcrete was undertaken in Trinity College, Dublin.

*The references given in the text are listed at the end of the paper.

The earliest work was reported in a series of papers on the properties of ferrocement (Ref. 10, 11 and 12). It is noteworthy that equipment and testing techniques originating in this work are now widely used abroad. The current research effort in T.C.D. is an extension of the work on ferrocement to which reference will be made later in this paper.

Punching Failure of Reinforced Concrete Slabs

Extensive investigations have been carried out by staff of the Q.U.B. into the problem of punching shear in monolithic column-slab construction. Both experimental and theoretical studies were undertaken during the period 1965 to 1975. This is probably an ongoing research project (Refs. 13, 14, 15 and 16).

Observations of Concrete Structures in Service

Direct observations of the behaviour of existing structures afford the most reliable means of assessing the interactions of a variety of factors in structural response. The observations of structures in service provides the feedback of information necessary for progress in proper utilization of concrete as a construction material. Many facets of structural behaviour are not readily amenable to quantitative treatment at the design stage. For instance the evaluation of the combined effects of shrinkage, creep and foundation settlement on movement of member joints poses a formidable problem. These effects manifest themselves in secondary stresses which may prove detrimental to the function of the structure in service. Soil-structure interaction is a function of the flexibility of the superstructure relative to its foundation, i.e. raft, piles or isolated footings. It seems somewhat unrealistic, but nevertheless it is a common practice, to attempt evaluation of differential settlements on the basis of the results of soil tests and a floor plan showing only the column loading. Evidently differential settlement takes on additional significance in system building. These problems have not been overlooked in academic research. A comprehensive study of the performance of structures in service has been in progress over the past nine years in the graduate school of U.C.D.

Stress-strain Relationships

A study of the stress-strain relationships and the effects of stirrups and inclined bars in concrete beams was undertaken recently in U.C.C. The results of the investigations were reported in the Transactions of the Institution of Engineers of Ireland (Ref. 17).

Over the past few years postgraduate studies have been undertaken in T.C.D. into the stress-strain response of microconcrete. Initially the response of plain concrete sections in static and repeated loading was investigated (Refs. 18 and 19). In the past two years the work has been extended to include the study of the behaviour of reinforced sections. One aspect of the programme is concerned with the influence of steel-mesh reinforcement on the deformation of thin sections. This work

has yielded comparative data on the efficiency of a variety of commercial meshes (Ref. 20).

Fibre Reinforcement

The T.C.D. programme also includes a study of crack arrest using steel fibres. To date the study has been confined to comparisons of the performance of microconcrete reinforced with undeformed wires and the more expensive proprietary fibres (Ref. 20).

A study of glass-fibre reinforcement is under way in Q.U.B. This work centres around the effects of ageing and weathering on tensile strength of the composite material (Refs. 21, 22, 23). Indeed non-ferrous fibres offer exciting possibilities as is evidenced by the development of the West Pile system in Britain.

Simulation

Some researches have been carried out recently on the simulation of the behaviour of concrete structures. They include analysis based on small scale modelling in microconcrete (U.C.D.) expanded polystyrene models of reinforced concrete structures (Q.U.B.) and vibrations damping of simulated mode shapes of high-rise structures (T.C.D.).

Closure

This outline of past and current research conducted in Irish Universities shows that consistent efforts have been made to advance our knowledge of the behaviour of concrete in structural applications. Quite apart from the scientific findings, this research yields an unquantified asset in the training of engineering graduates. Despite the scope of the projects listed there are conspicuous gaps in our research effort, as for instance the blank area of lightweight concretes. The fact that lightweight aggregates suitable for structural concrete have not been developed in Ireland should serve as a pointer for industrial participation in sponsored research.

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Discussion

DR. GLYNN introduced his paper.

He offered it as a review of concrete research undertaken over the past ten years in Irish universities. He had relied on published material, and for that reason it had proved impracticable to include references to the contribution made by industry. Even within the limited scope, there were regrettable omissions in the text. In particular, there was very little reference to the work done in the early sixties in University College, Galway on impact testing of reinforced and prestressed concrete units. The paper reported various topics classified under headings of research consistently pursued in the universities.

Dr. Glynn showed seventeen slides which illustrated the results from some of the investigations mentioned in the paper. He treated his material under the following headings:

- (1) The results of an investigation of the effects of mixing water on concrete strength. Over forty sources of mixing water had been investigated. The influence of water pollution was noticeable in the poor strength of specimens contaminated with sugar and brewery waste.

- (2) Measurements of the movement of buildings as researched in University College, Dublin. The slide shown gave a record of movement between two adjacent slabs taken over a period of time, and included seasonal variation.

- (3) The longitudinal movement of beams in a prestressed concrete viaduct. The opening and closing of the joint between adjacent beams gave an estimate of the coefficient of expansion of the prestressed units. The slide shown had been taken from the dissertation "Prestressed concrete elements in structures in service: behaviour study".

- (4) The behaviour of reinforced concrete buildings under construction on the Belfield campus. The slides shown illustrated the

movement of one bay of a floor slab, the strain in the slab, and the temperature variations. The effect of partially shading the slab by an upper floor was evident.

(5) The use of the BRE scratch gauge for recording displacements in experiments at University College, Dublin. The BRE gauge was a mechanical device well suited to long-term measurements. Movement was reproduced by etching translucent acetate discs with a stylus. The displacement measurements were then retrieved by an optical technique.

(6) The movement of a cantilevered canopy that projected from the gable wall of a heavy duty warehouse. The displacement gauges had been placed at the root of the cantilever, at its mid-span, and at its free end, and gauges recorded the movements between adjacent sections. The slide shown indicated the variation in the width of the joint gap with time and variation of temperature. The restraining effect of the support was evident. The results had been taken from the dissertation "A behaviour study of some buildings in the Dublin port area".

(7) Findings from the dissertation "A comparative study of natural aggregates for concrete from various Irish sources". They demonstrated the weakness of describing concrete merely as a gravel concrete irrespective of the petrological origin of the aggregate. They also illustrated the differences between concretes made from Irish gravels and those based on Thames Valley ballast, which was the favourite medium for research on concrete in Britain.

(8) Research conducted in the Civil Engineering Department of the Queens University of Belfast under the direction of Professor D. Bond. The slides shown gave the results of tests on column-slab interaction with design criteria for punching shear, and also the relationship between the parameters that enter into shearing resistance of flat slabs. The plots on the slides had been reported in the ACI Journal for February, 1975, and represented an extensive investigation of shear failure in reinforced concrete.

(9) Findings from recent research at Trinity College, Dublin into the behaviour of micro-concrete in direct tension and flexure. Steel mesh and fibre reinforcement were being evaluated as part of the investigation. The slides shown indicated (a) the stress-strain relationship for a plain micro-concrete tested in flexure, (b) typical results of flexure tests on one-way slabs reinforced with different types of steel mesh, (c) results of flexure tests on slabs reinforced with steel fibres, with the enhanced flexural resistance imparted by deformed fibres being evident from the results, (d) results of direct tensile tests on specimens reinforced with mesh, confirming that steel area had only a slight influence on pre-cracking behaviour.

Dr. Glynn emphasized the value of the information gained from observation of existing structures. Particular significance attached, in his opinion, to the observation of prestressed concrete structures because of the complex interaction between steel and concrete in such

work. The dissertations from which the material mentioned in the foregoing items, Nos. 1-7, had been abstracted, were held in the library of University College, Dublin.

Dr. Glynn concluded his introduction with some illustrated examples of full scale experimental research work in progress in USA, on curved roof structures, and on the strength of spliced reinforcement. He had used that material to underline the high costs associated with full scale work generally.

MR. P. J. TOBIN congratulated Dr. Glynn on the success of his difficult work of cataloguing the areas of research which were being examined in the Irish universities. He had noted the absence of work from University College, Galway from the paper, and was glad to learn that that void would be filled in the published Transactions of the Symposium.

Mr. Tobin emphasized that significant research had to be conducted by persons of considerable stature and a special attitude of mind, persons able to bear a very lonely load if things did not go right. He had always been impressed by the achievements of Dr. Vincent Barry, whose medical research had attracted international attention, despite the fact that he was not himself a medical doctor. He had also met, during his period of service on the Board of An Foras Forbartha, some excellent researchers in the Institute. Researchers were, taken all in all, a special breed and, like Mr. Sweeney's tonne of cement, an expensive commodity. He felt that it might be unfair to expect universities to fulfil their teaching roles, and at the same time to act voluntarily as wet nurses to the industry, and he appealed for industrial sponsorship of research. Sponsorship could lead to university fellowships, which could be the sources for valuable work in research. Sponsorship had produced significant and widely acclaimed results in An Foras Forbartha, particularly in its Roads Division. The Institute for Industrial Research and Standards surely had an important role to play as well, and perhaps the Irish Concrete Society saw itself as fitting in to the picture. He felt it should be a matter for the Symposium to discuss how sponsored research might be organized and allocated. He did not see any reason why the results of such research, if privately sponsored, should not remain confidential if the sponsors so wished.

Speaking of concrete it was to him quite remarkable that a material reported in the Leeds Mercury in 1824 as having been patented by a local stone mason and given the name of Portland Cement had not yet been perfected, that it still had its original weaknesses, such as lack of tensile strength and intractable shrinkage. Nevertheless he found it hard to share Dr. Glynn's optimism about the likelihood of developing a concrete with good tensile qualities, although he would like to hear him speak further about the use of fibre reinforcement. He had to say however that he was not optimistic about the value of fibres in enhancing flexural performance.

The reference to lightweight aggregate had been interesting, as he felt that there was an important research area involved for Ireland in that topic, especially with the increasing emphasis on building insulation. It seemed to him that the difficulty might be in locating raw materials in quantities adequate to warrant development.

Mr. Tobin considered that Irish research should be geared to the economic situation in Ireland and to its improvement. We clearly had a sound cement industry and a sound position as regards aggregates. What we wanted were native substitutes for steel in building and for bitumen in roads. These needs suggested increased research in prestressed concrete on the one hand, and, on the other, the further study of concrete roads (with perhaps special reference to the proposed highway to the West!).

As a comment on Mr. Donnellan's request to Mr. Mescal at an earlier session, Mr. Tobin referred to the New Civil Engineer of 9th January, 1975, where a quick concrete tester was described. He could not guarantee however that it would be capable of handling Mr. Duggan's "regional" mixes, as superfluity of fine sand might defeat it. Finally, he felt he should just say to Mr. Mescal in relation to his statement that water was a commodity in constant and copious supply throughout Ireland, that, while he allowed Mr. Mescal's opinion, he remembered with some clarity the dry summer just gone, and as, a consequence, reserved his own.

PROFESSOR E. DILLON, noting that one slide had included a reference to both psi units and N per mm², said that it was a tribute to the adaptability of engineers that no one had mentioned so far at the Symposium the fact that one of the big events of the last ten years had been the change from Imperial to SI measurement.

He recognised that Dr. Glynn had had a difficult task in reporting on Irish concrete research of the past decade, as the work of that decade had, in fact, been more in development than in research. During that period, the concrete pump had come back into service to a greater extent and with increased efficiency, improvements had been made in craneage, and concrete mix design had been improved, but these were all works of development. Industry in the concrete field had, in his opinion, been living on the research of a previous generation, as one might say that since the research work on shrinkage and creep, which had been necessitated by the introduction of prestressing, the years had been marked perhaps by refinement, but scarcely, if at all, by the emergence of new ideas.

Arguing with Dr. Glynn that the research which was being done tended to be moving towards analytical studies, Professor Dillon adverted to the high cost in manpower of experimental research. He pointed out what might not always be recognised, namely that technicians were as essential in university work as they were in industry. The same shift in research seemed to have occurred also in Britain,

although the North Sea explorations were one area in which experimental research work might justifiably, and necessarily, develop.

Mr. Holloway, ten years ago at the 1965 Symposium, had discussed gap-grading of aggregates. It was surely surprising that, in a country where so much of our aggregate, otherwise very good, was irregular in grading, no significant work had been done on gap-grading in that interval of time. Perhaps the influence of more extensively used vibration in compaction had masked the need, but Professor Dillon suggested that the increased emphasis on crack control and crack width measurement in recent years might perhaps make a further study of that topic advisable now. He was not sure who should undertake such work. He felt that the universities might not be geared up for it, and questioned whether it might be more appropriate to the Institute for Industrial Research and Standards or An Foras Forbartha. He was taken by Mr. Tobin's reference to researchers as a special breed. He did, of course, agree, particularly as regards engineering research which could, on occasions, be very arid. The situation, he felt, was not quite so drastic in mathematically-oriented research, which he saw, anyway, as a vocation in itself.

Listening to Dr. Stephens' paper at an earlier session, it had occurred to him that not enough feedback came from sites and from completed work, where he was sure troubles must arise from time to time. Analytical research, in some of its new forms, could be of assistance in interpreting some problems of that kind. He had been engaged recently in refining a study on a finite element analysis of shear cracking in beams, which he had presented some years ago to the Institution of Engineers of Ireland ("Some linear and non-linear stress problems by the Finite Element method" Transactions IEI Vol. 96 Sessions 69-71, pp. 66-79). He had found that one could plot the growth and direction of a crack while at the same time plotting the growth of stress in the stirrups crossing that crack; and it was of interest to be able to report that Dr. Swamy, of the University of Sheffield had recorded, in experimental work, results which agreed closely with the model which had been established in the analytical study.

Other applications of mathematical model analysis might lie in the study of shear and other load effects in corbels, and in supporting the experimental work that Dr. Glynn had reported from Professor Bond at Belfast.

On the general matter of "trouble-shooting", he wondered whether possibly the Irish Concrete Society might consider setting up, in its organization, a clearing house for site problems, receiving reports of matters which had not worked out as intended in design, and circulating information on them to its members, without, of course, making specific reference to the projects concerned. He felt that that could be a very valuable service to the industry.

Referring to the operational research projects at University College, Dublin, Professor Dillon asked Dr. Glynn for further particulars of

the experimental equipment which had been found useful in the field studies involved in that work.

Finally, with regard to Mr. Tobin's hopes for a Galway highway, he expressed surprise that no mention had yet been made of continuously reinforced concrete roads for Ireland.

MR. J. GAUGHAN saw the function of research in concrete as leading first to improved performance of components and elements, and from there to reduced costs and to improved performance of whole structures. Dr. Glynn's paper had given him the impression at first that concrete research in the universities was directed towards materials research rather than towards the performance and structures. The author's introduction had somewhat modified that emphasis, however. Mr. Gaughan felt, nevertheless, that a change of direction of university research away from the micro-problem towards the macro-problem would benefit the industry. It would be of value to us to find out as precisely as possible how reinforced concrete components and assemblages of components worked in practice, and to consider the real value of analysis in the total design process. Analytical methods did sometimes take account of the sequence of construction to be adopted, but more often they did not and one had to question the validity of ignoring the influence of the processes of building on the eventual performance of the whole building. Engineers tended to claim on occasions that because they designed a structure in a certain way, the structure would behave in that way. The claim was, generally speaking, imprudent, but if engineers wished to speak in that way in particular instances, it could only be on the basis of a full study of the parameters involved. He suggested, as examples for study in that context, the significance of the detailing of reinforcement and the performance of joints. With those he would couple a more general study into the variations to be expected between details as shown on drawings and as actually constructed, and the extent to which such variations might invalidate the analytical techniques used in the design. Arising from there, he felt that a fruitful area of research might lie in the careful assessment of constructional methods now current in the industry. There was a gap in research in that area at present, in his opinion.

He agreed with the earlier speakers that cost of equipment often played a regrettably large part in the selection of research topics, and directed valuable research efforts away from more significant work towards less important areas, simply because they were cheaper in equipment and in technician man-hour content. One current manifestation of that problem was the substitution so frequently of physical model testing and computer models for full scale component testing. It was Mr. Gaughan's opinion that model testing of whatever form could provide only approximate answers for full-scale component behaviour.

He would like to be able to offer positive suggestions as to how full scale testing might be financed, but there was no easy answer. Finance might come from public funds or from private funds. Discussing only the latter, the sources might notionally be the designer, the builder, or possibly the client. However the fact was that if a contractor were to sponsor research, he would normally want to see a financial gain as a result of his investment, and this meant that his interest had to lie rather in seeking answers to specific problems than in funding general non-oriented research. With the designer, a dilemma arose. If through sponsoring research, the designer produced a building of higher quality, he would probably end up with less reinforcement in his structure, less concrete—and a lesser fee! There was definitely no inducement in the fee structure to sponsor research.

Mr. Gaughan concluded by agreeing with Professor Dillon about the possible merits of an "agony column" organized by such a body as the Irish Concrete Society to circulate information on design and construction difficulties which had been encountered in practice.

MR. E. H. SIDWELL, in a written contribution, reported that the first two parts of the four-part reference in Item 8 of Dr. Glynn's Reference List were as follows:

Part 1: Elementary theory of axially-loaded composites.

Part 2: Stiff concrete columns pretensioned with high strength wires.

Part 2 had been written in collaboration with S. R. Port. The third and fourth parts of the same series were in fact the two items mentioned in Item 9 of the Reference List.

Their titles were:—

Part 3: Design considerations and an economic assessment of reinforced and pseudo-pretensioned stiff concrete columns.

Part 4: Precompression and postflexure of concrete beams sustaining a dead load greater than applied load.

Part 4 had been written in collaboration with F. F. Keatley, and that point might be noted in consulting Dr. Glynn's list.

MR. T. F. BOLAND, in a written contribution, asked Dr. Glynn whether he had given any thought to applying the philosophies of value analysis engineering to concrete as a material or to concrete elements. He felt that such study would not only be worthwhile, but could lead to the development of a new material, as well as to the identification and removal of unnecessary costs in elements.

MR. T. WALSHE, in a written contribution, expressed surprise that Dr. Glynn had not drawn any particular attention to glass fibre reinforced cement in his presentation. Mr. Walshe understood that there was already a company working under licence on that material in the Republic. An article "Glass fibre reinforced cement" which had been published in the magazine "Concrete Construction" for April 1975 gave a useful introduction to the material.

MR. N. BOURKE, in a written contribution, said that it was worth noting that a glass fibre sufficiently resistant to alkali attack by hydrated cement had recently been developed and that the Concrete Society Innovation Award for 1974 had been presented for work on the project. He considered that a new and versatile material for the construction industry was now emerging, which would combine the high tensile strength of glass fibre and the high compressive strength of the cement matrix. There was an area here in which theoretical research in universities and institutes could be combined with practical experimentation and application in industry. Cladding panels made of that material could possibly answer three of the needs emphasized by Mr. McCullough in his paper, namely high thermal efficiency, light weight and ease of removal or change. Glass fibre reinforced panels had proved to be cost-competitive with precast concrete and with reinforced concrete panels. The material also offered exciting possibilities as a replacement for timber in housing, particularly in floors and roofs.

DR. GLYNN replied to the discussion.

He thanked the contributors to the discussion and dealt briefly with the points raised. He reiterated that the greatest defect in concrete was its comparatively low tensile strength, and suggested that the discovery of a bi-modular concrete would constitute a breakthrough in concrete technology. Certain boron silicate complexes possessed the property of a high modulus in compression and a comparatively low modulus in tension. He expressed some reasons to believe that current lines of research would eventually lead to a ductile inorganic cement with high compressive and tensile strengths.

SESSION F

CONCRETE AND ARCHITECTURE

J. McCULLOUGH, B.E., F.I.E.I., M.CON.S.E.I.

J. McCullough and Partners, consulting engineers

Sessional Chairman

PROFESSOR C. O'NEILL, M.ARCH., M.R.I.A.I., R.I.B.A.

University College, Dublin

Introduction

This paper tries to set out the main factors governing the use of concrete as an architectural medium in Ireland in postwar years. Except in a general sense, it is not concerned with concrete technology or finishing techniques. It is written from the viewpoint of one structural engineer addressing other engineers, but it uses architectural terms and an attempt is made to deal with the subject in the context of architectural history. It is concerned primarily with buildings rather than with bridges, dams, silos and suchlike, the design of which tend to be dominated by engineering considerations, and which have their own logic of architecture. It is concerned more with structure as expressed in elevations than with the structural support of buildings as a whole.

Following a brief sketch of the historical background, the main architectural problems in the design of modern concrete buildings are outlined. An attempt is made to categorise the principal trends in Ireland in recent years, in the context of which examples are discussed. Finally, a brief look is taken at possible developments in the years ahead.

Historical Background

Until quite recent times, probably the only important consideration in the design of most buildings was simply to combat at minimum cost the effects of cold, rain, wind and sun, using whatever materials were most easily available. Architecture, as we know it, was relevant only to important buildings—the churches, mansions, castles—which occasionally merited conscious design rather than simple repetition of the traditional.

Because of its strength, longevity and availability, stone was commonly used in such buildings, and, of course, much of the history of architecture centres around the development of stone arches to cover large spaces and to provide natural lighting to building interiors.

Where suitable clays were available, brick was used. For floors and roofs, if vaulting of some kind was to be avoided, it was common to use timber, which was subject to destruction by fire and decay.

Three aspects of these traditional forms of construction which are of particular interest here are (i) that people were used to buildings looking more or less as they always had; (ii) that of the three materials mentioned, reliable tensile strength was obtainable only with timber, which was otherwise unreliable in its susceptibility to fire and decay; and (iii) that by modern standards the range of possible solutions to structural problems was small.

The advent of metal as a building material must be seen in this relatively static context. Iron, and later steel, gave rise to one of the few real revolutions in building, not less important than the arch. Its use gave rise to buildings looking unlike anything seen before; the material, especially steel, had a high tensile strength and it did not decay or burn (although it could be deformed by heat); and, of course, it became possible to enclose space in new ways.

The early iron-framed buildings like the London Railway Stations, the Paris Markets, the Eiffel Tower, were not thought of at the time as being within the province of Architecture, but more that of pragmatic engineering associated with the then aggressive expansion of the commercial world. Indeed, that association and the mass-production methods inherent in that kind of building gave rise to a reaction towards a specifically non-commercial and craft-oriented architecture which had an important bearing on the development of modern architecture.

It was, perhaps, buildings like St. Pancras Station in 1865, covering 210 x 73 metres without internal supports, and the Crystal Palace in 1851, almost entirely glazed, prefabricated and erected in six months, which best illustrated the potential of the new material; but it was 30 to 40 years later and in Chicago, possibly more open to new ideas, that its real development commenced.

The Modern Movement in Architecture springs from the freedom from traditional masonry styles which steel made possible; it accepted and developed the engineering logic of steel structures. In a space of twenty years steel-framed office buildings up to 16 storeys high were erected. The grid-like elevations, with those large horizontal windows, which became almost the symbol of modernism, and with masonry used clearly as a veneer and not as a load-carrying material, became the norm. This idiom has since been refined and developed to give it an aesthetic of its own, but the basic concept has changed remarkably little. In Germany, a parallel development in industrial buildings took place, which, far from rejecting the Machine Age, accepted and glorified it. It demonstrated satisfactorily (or so it seemed then) that massive masonry construction was not only unnecessary but aesthetically irrelevant as well.

If the advance of engineering technology had, in one sense, destroyed the old Architecture, it had also purified it and forced it to re-examine its own first principles. The Modern Movement might be described as, essentially, a movement away from tradition rather than a movement towards a specific new style. Of course, new theories evolved; form was to follow function; the building framework was to be expressed; the fluid nature of concrete was to be demonstrated, but no one style became dominant.

The Modern Movement can be thought of as having two main branches; one is the classical steel and glass architecture epitomised by the work of Mies Van der Rohe; the other is the concrete architecture in which Le Corbusier was among the principal prophets, although not the only one. Such divisions are valuable only to a limited extent since they merge and overlap, but insofar as the nature of the materials has influenced designs there is a valid distinction between steel and concrete architecture.

Finally, it should be said that to talk at all of the design of most modern buildings in these architectural terms may be misleading. Cost, simple protection from the elements, availability of materials and skills, must surely still be the dominating factors in the design of most of the buildings which surround us. Design solutions based on architectural theories which conflict seriously with these factors are likely to be acceptable only on important buildings; but they do not necessarily conflict, and the historical background is an essential element in understanding that problem.

Architectural Problems

The complexity of finding a satisfactory architectural solution for a project is, unfortunately, very poorly appreciated by most engineers. Attempts to bridge the gaps in professional training do not seem to be successful. It may be a matter more of attitude to learning than adequacy of instruction; and most engineers seem to be at least as ill-adjusted to the architectural problems of the buildings they are concerned with as many architects are to the engineering problems.

In practice, while site constraints and planning regulations such as plot ratio, site density, building line, height limits may seem more important than architectural theory, the process only begins there. The only certain rule after that is that there is no rule; everything is contingent on everything else and neat engineering-like solutions are hard to come by. There are conflicting calls for economy, grandeur, uniqueness, civic-minded neighbourliness; and the architect will have his own inherent wish not only to employ his knowledge and design skill, but to be even a little creative; irrespective of the type of building he will want to try to produce a building of some architectural merit.

Starting with the plan, the user's various requirements must be accommodated within the cost-limits; this leads to the bulk and scale of the building, which must at the same time suit the site and, perhaps,

in urban areas, the neighbouring buildings. The form of the building must be decided in relation to its function, including climate modification, thus leading to the external skin design. The advent of air-conditioning has multiplied the problems considerably.

Except in monumental buildings, economy of construction, which depends on the use of modern technology, calls for the incorporation of mass produced elements as far as possible. The repetitive facades which result have, of course, an aesthetic of their own, the background of which has been outlined above; and even monumental buildings to-day might well be, and usually are, built in that manner. The choice of concrete as an architectural medium in such facades may depend as much on considerations of cost, of speed of erection, of planning and byelaw permissions, of local conditions, of maintenance, and of availability of suitable building workers, as on the preferences of the architect. Concrete is stronger in tension than masonry; it is superior to steel, timber and plastics in its resistance to fire and its low maintenance cost; its self-weight (especially as a roof) and its susceptibility to temperature and moisture movements, are among its serious drawbacks.

The early concrete bridges had demonstrated that concrete could be curved, rigid and strong; the material could be shaped to the designers wishes; it could act as both sheet and structure simultaneously; it was fire-proof; it required little maintenance; and it was relatively cheap.

In choosing between in-situ and precast concrete construction the advantage would seem to lie with the latter where higher speed, better finished, repetitive construction is required. In practice, since precasting is normally carried out by specialist sub-contractors, there may be difficulty in co-ordinating his supply programme with the main contractor's work in casting floors or service blocks. Solutions are either to pre-order and stock the units well in advance, or not to have precast elements on the critical path but to add them afterwards; another is for the main contractor to do his own precasting or for the precaster to become a main contractor. While precasting certainly can result in better finish, the rejection rate of expensive units tends to make non-standard precasting work of any complex shape unprofitable.

Nevertheless, contracts have been satisfactorily completed at remarkable speed using quite difficult but well-finished precast elements. Knowledgeable design, quality control and careful planning are critical aspects. Successful users of concrete recognise that it is, essentially, a rough material. Maximum aggregate size is seldom less than 10mm and it is (loosely speaking) a two-phase material—liquid and solid—which is not easy to cast properly, especially with complicated shapes and finishes. It is subject to moisture and temperature movements. To expect or to specify standards of finish or tolerance beyond the cap-

acity of the material is to risk failure. The cost/finish + tolerance curve is surely asymptotic.

If concrete is adopted as an element of the facade, whether as frame or wall, complex further problems have to be solved. Weathering, especially in urban areas, calls for careful detailing so that the building will continue to look well during most of its life. Colour must be selected in relation to weathering, local colour environment and availability of suitable aggregates. Grey concrete on glaring sunless or rainy days, so common in Ireland, is difficult to use without looking drab; white exposed aggregate, so nice even on rainy days, is probably the easiest to stain. Relationship of glazing line to concrete face will emphasise or simplify the impact of the building, and the profile will also modify glare. Texture has an important visual effect, and the whole subject of surface finishing of concrete, whether in-situ or precast, is fraught with technical difficulties, not the least of which is consistency in colour, texture and weathering effects. Especially in precast work, articulation becomes an important element of the facade design. These are just some of the problems to be solved and many of them are so inter-related as to make their solution all the more difficult.

Finally, the whole design has to be approved by the planning authorities, whose function in civic design control is necessary and valuable in maintaining standards, but whose influence can have a stifling effect on good design, if only because developers are slow to risk planning refusals.

Design Categories

It is difficult to categorise the various directions in which concrete architecture has developed in Ireland, and it is probably more useful to speak of a range than of clear-cut categories. Following the normal engineering method of trying to break down problems into manageable parts, the following quite arbitrary ranging of categories is adopted—starting from what seems simplest and most skeletal on the external elevation, with those of horizontal emphasis first, followed through those with mixed horizontal and vertical emphasis, to those with a vertical emphasis; then moving through elevations which are less skeletal but more solid in elevation; to what can be described as, essentially, wall architecture; and finally dealing with continuous concrete sheet structures. They are itemised below and illustrated in Figs. F1 to F5.

(1) (see Fig. F1)

The simple concrete frame, preferably with flat slab, is at one end of the range. Slab edge or edge beams, like structural steel members, are expressed in the external elevation and the characteristic horizontal windows, so effective in dark glass against white concrete, are emphasised. The slab edge or edge beam may be replaced by spandrel panels much deeper than the beams they cover but the principle remains, and

the spandrels read as deep beams. The hidden concrete frame behind continuous glazing or other veneer is of the same construction but is not relevant here.

(2) (see Fig. F2)

Columns as well as edge beams may be expressed on the elevation, and, for vertical emphasis, the columns may predominate. Columns and edge beams may be in the glazing or out from the glazing line, in which case the structure gets even greater emphasis. Crosswall construction, common in residential dwellings, may have the same type of external elevation.

(3) (see Fig. F3)

A development, common in the last decade, has been the window-wall unit comprising side columns, spandrel and window head in a single unit, usually one module wide and storey-height. These can be loadbearing or otherwise. The characteristic elevation is heavily profiled, although not necessarily so.

(4) (see Fig. F4)

Elevations which are essentially concrete walls, perhaps with window and door opes.

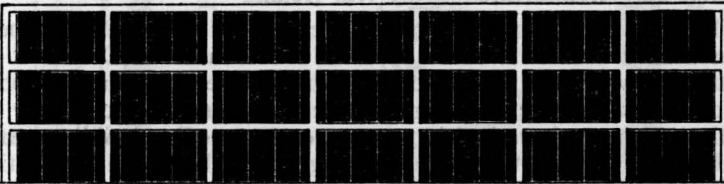


FIG. F1

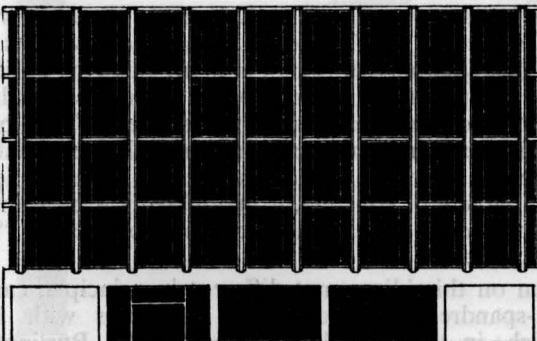


FIG. F2

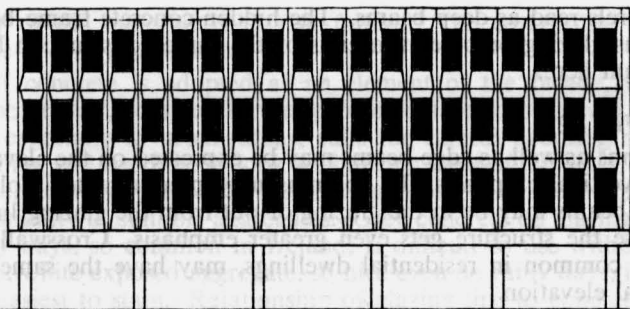


FIG. F3

(5) (see Fig. F5)

Continuous concrete sheet structures making use of the inherent strength of curved shapes—such as barrel-vaults, hyperbolic shapes, domes and suchlike.

To complicate this very roughly-drawn picture, the relative merits of precast and in-situ concrete must be considered, each with its own architectural possibilities and problems; and each stage of the range outlined above has to be seen with this in mind.

Concrete and Architecture — Post-War Ireland

The buildings referred to below are selected primarily for their representative value. If most of them are located in Dublin it is because the writer has easier access to them there. If a large proportion of them are office buildings it is because concrete technology in buildings seems to have had its greatest outlet in office buildings, and possibly also because the office building has replaced the residential building as the standard urban structure.

Concrete frames—horizontal emphasis—1

The newer buildings on the U.C.D. Campus reveal how the concrete frame has become widely and easily accepted, with its emphasis on the horizontal. What appears is not in many cases the basic concrete structure itself, but precast concrete exposed aggregate spandrel panels forming cill-height conduits for peripheral services. The Library, particularly, with its long supporting columns and relatively shallow main library level, seems a product of the concrete age. This whole environment, which is largely of concrete, is undoubtedly a pleasant one and it makes nonsense of so much vulgar criticism of modern "glass and concrete" architecture.

A variation on this idiom, not different in principle, can be seen in the brick-spandrel concrete framed buildings with horizontal emphasis which, in their tree-lined setting, make Burlington Road one of the most successful and pleasant new streetscapes in the city.

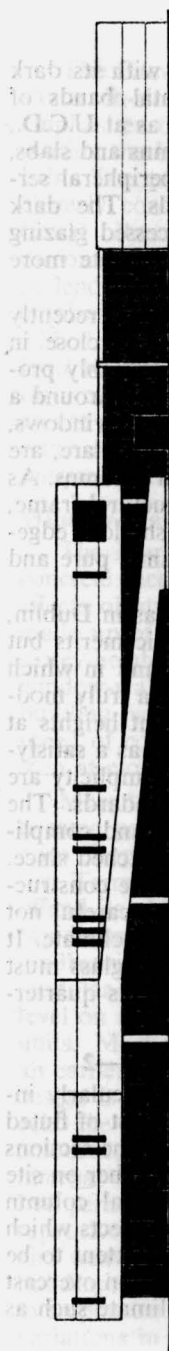


FIG. F4

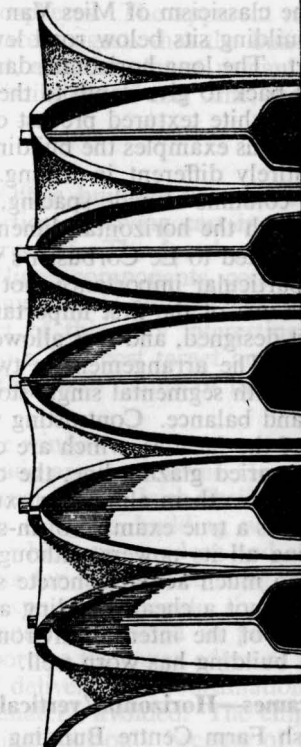


FIG. F5

Office buildings like Apollo House in Tara Street, with its dark exposed aggregate spandrel panels, and long horizontal bands of glazing set well back display the same principle. Here, as at U.C.D., the building is a straightforward concrete frame of columns and slabs, stabilised with terminal service blocks, and the usual peripheral services are housed within the precast concrete spandrels. The dark colour of the spandrel vertical faces and the deeply recessed glazing give the building a massive quality characteristic of concrete more than of any other material.

Contrasting with this is the lightness and simplicity of the recently completed Merrion Hall on Sandymount Strand, which is close in feeling to the classicism of Mies Van der Rohe. This admirably proportioned building sits below road level and is symmetrical around a central court. The long horizontal dark-glazed storey-height windows, located well back to give depth to the facade and to reduce glare, are set-off by the white textured precast concrete beams and columns. As with the previous examples the building is based on a structural frame, but it is entirely different in feeling. Here, only the shallow edge-beams, and columns at wide spacing, appear; it is a frame, pure and simple, but with the horizontal dimension emphasised.

Closely related to Le Corbusier's work is the Bus Aras in Dublin, which has particular importance, not only for its intrinsic merits but because it is one of the first important buildings in Ireland in which the architect designed, and was allowed to proceed with, a truly modern building. The arrangement in two blocks of different heights at right angles, with segmental single-storey piece between, has a satisfying clarity and balance. Contrasting with this apparent simplicity are the details of the facades, which are complex by later standards. The colours, the varied glazing line, the curly low-level roof and complicated skyline give them almost an exuberance, seldom matched since. The building is a true example of in-situ reinforced concrete construction revealing all its powers, although the Architect was careful not to expose too much actual concrete surface to the Dublin climate. It was probably not a cheap building and the proportion of glass must make control of the internal environment difficult, but this quarter-century old building has worn well.

Concrete frames—Horizontal/vertical and vertical emphasis—2

The Irish Farm Centre Building at Bluebell is a particularly interesting example in this category in that the facades consist of fluted fair-faced precast concrete columns, spandrels and lintels. The sections are unusually complex in shape and, fortunately, fitted together on site to produce a remarkably sculptured building with vertical column elements dominating. The strong and interesting shadow effects which these shapes might be expected to produce seem to some extent to be lost by the unavoidable dullness of plain concrete surfaces on overcast days, a feature which is of particular importance in a climate such as ours.

The Fitzwilton Building on the Grand Canal, which is an off-the-shutter in-situ concrete frame structure glazed all around on each floor, emphasises the columns. On the lower sections, the columns stand outside the building and support the in-situ floors on fan-shaped corbels. The two-block arrangement, with car-parking in the angle, is cleverly contrived, especially as seen from Sussex Road across the Canal. Precast concrete "fins" or mock columns are suspended in discontinuous vertical lines on the facades and play a big part, both in lending interest to the elevations and in accentuating the vertical emphasis. The in-situ spandrel beams have been given a vertically ribbed surface and this has helped to even out the black staining which is to be expected in urban atmospheres. The apparent ratio of structural content to usable floor space suggests that the building was not meant to be competitive in cost, and the almost romantic feeling, so much at odds with other Irish buildings of this time, makes it rather unique in character.

Window-Wall—3

The Marlboro Street Post Office building uses fair-faced precast concrete facade panels with vertical grooving cast in to mitigate the effects of streaking from rain run-off. The facade, instead of being made up of columns/spandrel/lintel components, consists of massive storey-height 5.2 metre long inverted U-units—half way to being window-wall units. One aspect of this very interesting and honest building, which was designed to a low cost target and for maximum speed of construction, is the rather drab nature of fair-faced concrete seen at close quarters.

More typical examples of the window-wall unit construction which became popular in the last decade are Lansdowne House, the Phibsboro Shopping Centre, Hill Samuel House, Irish Shell House in Earlsfort Terrace. In attempting to design a building which would not offend its older neighbours but which was modern and susceptible to rapid construction, the architects for this last building elected to use loadbearing precast concrete exposed aggregate (brown in colour) modular-width storey-height panels, supported in part at first floor level on a ring beam, and supporting the outer edges of precast floor units. Most of the problems of delivery and coordination outlined in an earlier paragraph were, fortunately, avoided. The emphasis of the design is very much in the vertical, not only because of the desire to echo the older buildings, but to suit the module as well. The finished, coloured, and textured surface seems to weather well, cost is right, internal environmental control benefits from the reduced glass area; but perhaps the biggest problems are those of handling such large repetitive surfaces and of maintaining consistency of texture, colour and weathering. The question of tolerances is critical on this type of building, not only for ease of erection but because it may be desirable to emphasise joint lines in order to articulate the surface. Consequently, variations in width must be minimised and joints must be made big

enough to absorb the inevitable variations. Perhaps, in deciding to use loadbearing window-wall construction, too much is expected and the idiom has been pushed almost too far.

In Texaco House, opposite the Intercontinental Hotel, loadbearing white precast concrete wall units have been used, rectangular on the outside and slightly 'television-screen' shaped on the inside. These units carry the in-situ floors and the storey-height glazing is set far enough back on this slab to allow working space between the glazing and the insides of the loadbearing units. The building, which is tailored to a very awkward site, is in a class of its own in being of loadbearing wall unit construction but expressing in a modified form a skeletal frame. A development of this scheme is to eliminate the slab between glazing and loadbearing units except for corbels at the column connections.

The U.S. Embassy building is a relatively early example of window-wall unit construction—using extraordinarily complex curved interlocking shapes, produced abroad and transported here at, no doubt, great cost. The curvature is not used for structural but for decorative purposes and, although the Embassy is undoubtedly a modern concrete building, its interest may lie in the excellent quality of the work and in the siting and scale of the building rather than in the concrete as an architectural medium.

Another version of the window-wall idiom is not to use the units for loadbearing, thus freeing completion of the main structure from dependence on their delivery. Since groundfloors or basements are frequently used for purposes such as shops or carparking requiring open spans, loadbearing units are seldom used right down to ground level and the logic of their use suffers thereby. In the "loose fit" concept of future buildings, wherein every part except the basic frame should be capable of alteration to suit the times, the permanent loadbearing wall is out of place, and, of course, for buildings of five or more storeys, loadbearing wall buildings have their problems in the light of Ronan Point type accidental damage.

Non-loadbearing panels have been used on the handsome new development in Sackville Place, in which the two upper deep-plan office floors are enclosed in Armagh Limestone brown precast storey-high units with tall narrow windows, curved top and bottom, on every second module, to give a high thermal efficiency to the building. Originally, two-storey units were proposed but the principle of bigger is better in precast work does not necessarily hold true, and problems of handling, tolerance and distortion become very important. Neoprene gaskets help to seal windows effectively but their very simplicity makes window detailing all the more important. The open drained joint, properly detailed and executed, has been remarkably successful. Mastic-sealed joints, which may be unavoidable with thin concrete elements, have the secondary disadvantage that used in joints between precast

units the mastic tends to show up minor defects and irregularities in the precast edge.

Perhaps the most recent example of window-wall unit construction is the new building at 46 Upper O'Connell Street, opposite the Gresham Hotel, on which "convex", or thrust-out, units of what appears to be a very complex profile have been used, without any apparent serious penalty in finish. The light-coloured fair-faced units, with green-tinted glass, provide a striking elevation.

Concrete-wall—4

The concept of a concrete wall used as a major medium of architectural expression is difficult to define. There are numerous fair-faced in-situ concrete walls to be seen—some in white concrete perhaps with board-marked finish and with grooves cast-in to relieve or proportion the surfaces. Most of the concrete building types described above will have areas, perhaps core blocks, which are faced with plain precast-concrete panels to match the finish on the main elevations. All of these are concrete walls, but what is really intended here might best be illustrated by the following examples.

The new T.C.D. Library is a monumental building, constructed primarily of in-situ concrete. Although there are, of course, window and door openings, the main impression is of solid planes of concrete, or stone-covered concrete, into which the openings are introduced as significant features. To design a large modern library for this particular site was clearly a very difficult task. The architect, while respecting his neighbours in mass and height, seems to have aimed at a contrast with their heavily fenestrated, or quite ornate grey stone facades. His solution is relatively windowless, unornamented and white, and, perhaps his penalty is an unavoidable heaviness. Great care has been taken with modelling the surfaces in order to produce a satisfying whole. The quality of surface finish becomes, of course, a major problem in this kind of construction. It seems true that large areas of concrete seen at a distance can accommodate substantial defects; but they can look very drab at close quarters, and can be unpleasant when rain-streaked. The problems of in-situ concrete wall design, especially in important settings, are very great indeed, and require exceptional skill and experience to be successful.

The Tayto Factory at Coolock is another exceptional example of in-situ concrete wall construction as such, in which various ventilator and plant openings are used like sculptural work to produce a very interesting building. Partly because of its nature and its setting, it is not as "heavy" a building as the library, but the same problems of surface finish have to be met and, no doubt, within the cost-limits of factory building it is more difficult to deal with them than in a University building.

Concrete wall architecture has a special relevance in the design of smaller churches. Perhaps the best known example is the Corbusier

church at Ronchamp, with its massive walls, small windows, and curving roof construction. The new church at Sutton, in Dublin, is a fine composition of curving concrete walls and inter-related spaces, which demonstrates the potential of this kind of design. Although built of concrete block, with an external white rendering, the church recently completed at Maghera, also, is closely related to this category, in that the curving nature and massive quality of the walls, set off with small windows and gargoyles, is in the nature of concrete wall architecture.

Not in the same league, but relevant as concrete wall construction are the two-storey County Council houses at Ballinteer and Finglas using precast concrete exposed aggregate wall panels, with insulation cast within the concrete elements, developed from the design used for the Ballymun Flats. Windows and doors occur where they must and relief of the flat surfaces depends very much on paintwork on these doors and windows, but it is a use of concrete in architecture which might usefully be developed further.

The Revenue Commissioners building on Earlsfort Terrace, finished in dark brick and vertical strips of tinted glazing, is, in fact, an all reinforced concrete building, with perimeter columns replaced by sections of concrete wall, now finished in brickwork. Since a building of this height must have something behind the facade to take the floor loads, which a brick veneer clearly could not, it could be described as a brick-finished concrete-building; perhaps leading to the conclusion that the value of categorisation in architecture has its own limitations.

Concrete sheet structures—5

While development of the concrete building frame has been at the centre of modern architecture, the real potential of concrete as a material, which makes use of its inherent strength in curvature, surely must be in the kind of buildings designed by Nervi and Candela and others. These are, perhaps, best epitomised in recent years by the Sydney Opera House and the TWA Terminal at Kennedy Airport.

Concrete in this form is frequently used in engineering structures like bridges, chimneys, silos, water towers, dams and, especially, hyperbolic cooling towers. The UCD water tower is an example, which has a splendid and dominant place in the architecture of the Campus. Three other examples of its use in building in Ireland come to mind. The roof of the single-storey part of the Bus Aras has an interesting corrugated concrete fan-like structure, and the spiral ramp to Dublin Airport's roof car-park would qualify. Probably the most dramatic example is the precast prestressed 15 metre long balanced cantilever roof over the Leopardstown Racecourse Grandstand, although these are really 2 metre wide concrete elements, curved in section and supported by a ridge beam.

The real drawbacks of using curved concrete shapes in buildings are, of course, that they are very expensive, difficult to waterproof, and suitable really only for large single spaces in monumental or prestigious buildings.

Future Trends

In the decade since the last Symposium, the use of concrete in architecture in Ireland has developed a great deal. It is interesting to conjecture on the trends which may govern its development in the decade to 1985.

There seems to be little doubt that in the years ahead much greater attention will be given to the insulation of buildings against heat loss than was given in the era of cheap energy up to 1973. Large-scale glazing, a central feature of 20th century architecture to date, will be difficult to justify in these circumstances. More solid wall and fewer windows seem a likely development.

While brick will, no doubt, always have a place in established urban areas, where intrusion on the existing scene is to be minimised, it is really a pre-Machine Age material and seems inappropriate for general use in what will, no doubt, be a continuation, perhaps modified, of the Machine Age. There is not even a strong tradition of building in brick in this country as there is in Britain or Belgium. The alternatives are remarkably few, and seem to consist effectively of concrete based materials—block, brick or cast concrete—and, perhaps, plastics.

Concrete is a particularly suitable material in Ireland in that aggregates and water are readily available, and a high level of know-how and skill has been developed in its design and manufacture. Cement, also, is a home-produced material, although its manufacture requires a high energy input, the source material for which is imported for the main part. The resistance of concrete to fire and to noise transmission are bonus points, and it remains a relatively cheap material.

If the LLLFLE concepts (long life; loose fit; low energy) are to be followed, and they seem very reasonable, at least the larger buildings may consist of structural frameworks designed for long life, to take walls of high thermal efficiency which can be removed or changed around to suit the times. The recent reconstruction of the EBS Building in Westmoreland Street is an example of an existing framework re-used. For removable external walls, the use of reinforced or pre-stressed concrete seems a likely solution, perhaps with the necessary connections bolted on rather than cast in. This form of construction would satisfy also the requirements for resistance to accidental damage better than loadbearing construction would.

Although in-situ concrete construction can produce some excellent results, and is really a form of architecture of its own, the practical problems with it of attaining a consistent surface finish are so great that precast concrete, the quality of which is easier to control, seems the more likely choice for most concrete buildings. Contradicting this are the recent decisions of a number of precasting sub-contractors to discontinue tendering for special or "architectural" precast concrete elements. Whether this is caused by price competition or dissatisfaction with the risk element is hard to judge, but what seems probable

is that future "architectural" precast concrete elements will need to be simpler, and designed with a more thorough knowledge of the nature and limitations of the material; or the cost per unit will be higher.

An important area in which development in Irish concrete practice has been slow has been in the use of lightweight concrete. At present, lightweight aggregates have to be imported, and it would be for the aggregate suppliers to introduce the materials here. The facility with which larger precast units could be manufactured and handled, with the same crane capacity, would be enhanced, and for demountable external walls it should be especially apt.

An architecture based on relatively large areas of precast concrete wall surface would, in many ways, be a new architecture, in which the design and integration of windows into the overall surface would be of primary importance. Each wall might be of different design to suit climatic conditions and, no doubt, insulation would be an integral part of the elements. Loadbearing window-wall units seem unlikely to continue as a general idiom, but less sculptured or even standard non loadbearing elements might well have a useful function.

Exposed aggregate precast concrete elements are sometimes considered not to be "concrete" at all, and to be unacceptable for that reason. However, some treatment of concrete seems necessary for surfaces which can be seen at close quarters, and this may include board-marking, grooving as at Fitzwilton House, rope finishing, etc., and coloured concretes may be used. For urban sites, the quartzite type of white exposed aggregate finish seems to be asking for trouble, and seems suitable only in rural areas or non-industrial suburbs. A drawback in this country is the surprisingly small number of reliable sources of good coloured aggregate to be found, but it is, in some ways, a blessing as well.

A recent multi-storey steel building in Chicago has been painted ruby red, using a paint with a 20 year guarantee. To apply paint successfully to concrete is much more difficult than applying it to steel but suitable paints may emerge which would make this solution practicable. The Guinness grain silo, which can be seen from the main road of the Phoenix Park, was painted many years ago and seems to be wearing well. This might well be a realistic solution to the concrete finishing problem. Is it essential to avoid maintenance? Most buildings in central Leningrad are painted, and it is a very common practice throughout Ireland as well.

The subject of concrete and architecture is central to both architecture and structural engineering. Both the architect's intuitive approach and the engineer's analytical one are necessary components in the successful use of concrete in architecture. Without an appreciation of that intuitive side and of the architectural as well as the engineering problems, the structural engineer will find it difficult to perform his part really satisfactorily. To this end, perhaps, the education of that

relatively small proportion of the engineering profession engaged in the design of buildings should have a more special orientation towards architecture than it has at present.

Appendix

The buildings which have been described in the section on Concrete and Architecture in post-war Ireland were designed by the architects whose names are given in the following list :

Ahrends Burton and Koralek
 Leo Carroll, Chief Architect, Aer Rianta
 Costello Murray and Beaumont
 David Cronin
 Brendan Jeffers and Partners
 John Johansen
 David Keane and Partners
 Kidney Burke-Kennedy and Doyle
 Arthur Lardner and Partners
 Howard Lobb and Partners
 Liam McCormick and Partners
 Morris and McCullough
 Robinson Keefe and Devane
 Scott Tallon Walker
 Schoolheifer and Burley
 Spence Glover and Ferguson
 Stephenson Gibney and Associates
 Arthur Swift and Partners
 Tyndall Hogan Hurley
 Andrzej Wejchert

Discussion

MR. McCULLOUGH introduced his paper.

He was to speak about concrete and architecture and he had decided to offer comment on the main factors governing the use of concrete in post-war Ireland and on its use in the future. It seemed to him that the period to observe closely was from 1965 to 1975. Looking back at the records of the 1965 Symposium, it was remarkable how few of the buildings which were more interesting architecturally had been built before that time. The majority had been built in the last ten years.

He would emphasise that he was not an architect and that in an area where opinions abounded, he had no educational background to say that his opinion on the matters he would discuss was the right one. He would try to speak on architecture as he saw it, as a practising structural engineer engaged along with architects in building, and he would assume that the majority of those he was addressing were in fact engineers. His opinions were subjective. The categorisation he had

adopted in the paper was completely arbitrary and would probably meet with disagreement from many. He felt anyway that classification was of doubtful value in architecture. Buildings as built could contain one or two similarities around which a notion of classification could later be developed, but people did not design to classification. The slides he would show would illustrate the developments he had mentioned in the paper. Before showing them however, there were a few points he would like to make about future trends, as he saw them.

It seemed clear that expensive energy would tend to lead towards more wall and less window in building. Architecture to his mind that went against the inexorable laws of economics would not work out today. He thought, not alone from the point of view of heat loss or from the point of view of noise insulation, but from a particularly Irish context, that there was a lot to be said in favour of the idea of going towards more wall and less window. That context was the incomparably dull skies we had during the winter time in Ireland, heavy grey dull skies. When one saw the pictures of houses in America, when one saw the captions on the pictures saying that the outside flowed into the inside, it was all very nice because there was sunshine over there. There were blue skies and it was warm. But looking back into one's own childhood, one remembered the warmth one felt in a small house with relatively small windows, where the outside was outside, and was wet and cold and grey, but the inside was where you wanted to be; so he always retained the feeling that more wall less window was a trend to be recommended. He knew that the souls of some of his architectural friends in the audience were probably turning over in agony at the thought, but he would remind them that he had said he would give his opinions.

Pursuing the idea of more wall and less window, pursuing the ideas of heat conservation, noise exclusion and the delimitation of grey skies, it seemed to him that the traditional house met a lot of those requirements. He was not for one moment suggesting that we go back, but it was interesting to note that, perhaps almost unknown to themselves, our forefathers did build in a manner to which we should now be giving careful consideration, using, of course, our better technology.

One of the odd things about building, it had always seemed to him, was that there were so few building materials available to build the outside of a building. One had bricks, concrete, in the form of blocks or mass concrete, asbestos cement, steel or other metals, and timber; but effectively, in the Irish climate, the material tended to be either concrete or brick.

Bricks belonged in his mind to the pre-machine age. They were suitable and desirable for use in certain locations where they matched their neighbours and in areas of architectural excellence, but they were essentially a pre-machine age thing. One could not describe otherwise little bits of clay 9" x 4½" x 3" laid down one on top of the other. Even though we might dislike some of the stages we had known

in the development of the machine age, no one really felt that technological development would halt, and we had to work on in that knowledge. In certain places, of course, and his experience with An Taisce had shown him this, it was necessary that pre-machine age building should be conserved, but only in certain places. In that context he felt that the influence of Local Authority planning control on architects was unduly restrictive in that it was felt, he thought, that pastiche Georgian could rather too easily get planning permission. Clients tended to know that and buildings tended consequently to get built in that idiom. He felt that there was a defect in the control system in that respect, that needed to be eradicated.

Concrete, on the other hand was a home-produced machine-age material about which we had a lot of know-how as had been shown by the lectures and discussions in the Symposium. It was Mr. McCullough's opinion that concrete would probably be the most likely material of the future for the outsides of building in Ireland. It would not however be simply a matter of concrete walls being built in the same way as brick walls had been built. It was likely to become an art in itself with its own aesthetic. He felt that this would be demonstrated by his slides, and suggested, as examples, the Library at Trinity College Dublin, and the Tayto Factory at Coolock.

He felt and again he hoped to show this on the slides whilst recognising that it was a subject about which many architects might curl up at the thought, that, in keeping with the modern age, more decoration of surfaces should be provided within the external boundaries of the primary shape, more decoration of surfaces on a minor scale. This was an area in which engineers had direct participation, since they prepared the drawings, produced the concrete, and monitored the construction, and he considered that engineers should give the problems of decoration some further thought.

On the issue of precast concrete versus insitu concrete, he found the topic of the long-life loose-fit low-energy concept of building (LLLFLE) particularly interesting to consider. A framework that would last for one hundred and fifty years, coupled with low-energy loose-fit panels that could be changed without undue cost, offered a good solution to building, and precast concrete panels seemed to fit sensibly into such a pattern. The Educational Building Society building in Westmoreland Street in Dublin, whatever one might think of it architecturally, demonstrated the concept well. The building had a steel frame, and it had been possible to remove the stone cladding without damaging that frame, and to replace it with a completely new glass facade. Similar work was, of course, possible with precast concrete.

While on the subject of precast concrete, he personally could not say that it was necessarily cheaper or dearer than in situ concrete, or that the one was necessarily faster or slower than the other. Precast concrete did however have the advantage that one could see what one was going to get, while there was still time to remedy bad workman-

ship. In all, it was his opinion, taking a broad view, that precast concrete was a very important material for future architectural work in Ireland. He would subscribe to the view expressed earlier in the Symposium that prestressing for concrete in buildings seemed more appropriately used with precast concrete than with in situ concrete. As regards lightweight concrete, he recognised the disadvantages of having to use imported materials in its manufacture, but felt nevertheless that it could be a very valuable material, especially in the loose-fit context.

Dealing with surface finishes, Mr. McCullough said that concrete should be treated as what it was, a rather rough material, liquid at on stage and, later on, solid, never wholly inert but responsive to thermal movements, both linear and warping. He would repeat what he had said in his paper, namely that there was a limit to what one should attempt in seeking an improvement in finish. In his opinion, current practice had already gone too far. He did not intend to deal further with the subject of concrete staining or jointing, or indeed any other aspect of surface finish; but he would ask one question which perhaps might be taken up in the discussion, and that was why more concrete buildings were not painted. He knew that there were technical problems due to lime and moisture, but there was a very widespread tradition in Ireland for painting buildings in all the provincial towns. To take an example from another country, in Leningrad, buildings were painted from top to bottom every year because of the harsh winter. It made the city so gay; he was never quite sure why more of it was not done here. One building, with which he had been involved, the Guinness silos at the St. James's Gate Brewery in Dublin had had to be painted in 1954 and repainted in 1963. The paintwork had a life of only about five years because of the industrial atmosphere, but he felt it made the building look very good whereas it had looked pretty terrible before it was painted.

Mr. McCullough referred to an article he had read, written by Colin Rowe in the *Architect's Review* for October 1975, in which he had identified two main types of people whom he categorised as hedgehogs and foxes. The fox, he had said, knew many things, but the hedgehog knew only one thing. Taking examples from the field of literature, he had mentioned Joyce who knew many things and wrote in a very complicated way and had many interwoven ideas, and Tolstoy who dealt in all his works with one big idea. Rowe had then transferred his ideas mainly to the area of city planning and had suggested that the people who had one big idea had had too much influence for too long, one big idea that the scientific Utopia, with all its typical laid out street patterns, with green space between the buildings, and architects' trees all around, was actually going to happen. The analogy, Mr. McCullough considered, could apply also to buildings, to a degree. Somewhat unintentionally perhaps, a feeling had been allowed to develop that buildings could be designed from an entirely scientific point of view, that such a Tolstoyan version of archi-

ture was possible; and this had resulted unfortunately in bad impersonal dehumanised surroundings, even to the extent of blocks of flats having to be demolished in St. Louis because the environment had been just impossible. He did not think architects were entirely at fault for that condition, because architecture itself was at a peculiar cross-roads at this time; and he would say that the structural engineering profession had possibly helped to aggravate the issue by giving architects, if anything, too many options for solving problems.

Architects everywhere were discussing their dilemma and it seemed to him that three possibilities existed. One was to soldier on and become even more modern still. If one looked at the motor car which was designed completely for a particular function and which changed year by year, it was hard to see why we would not accept buildings in the same way. That was a point of view that might be acceptable to the intellectual mind. Another possibility was entirely to reject the scientific statement and go right back to the most romantic kind of old buildings again, as had happened in the middle of the nineteenth century, as indeed was happening in a kind of subconscious way in many buildings in Dublin today. The utilisation of a new scientific idea in something from a past age seemed to him a course that was always likely to lead to a horrible pastiche type of architecture unless some very good reason existed for taking it. Between these two, there lay a via media. People complained about architecture not because it was made of glass and concrete, but because it was badly designed. But people also needed time to adjust, and to his mind the big factor that was missing in modern architecture was that the architects had not given people enough time to catch up. There was a phrase that Rowe used in his article "without a future there is no hope (with modern architecture there is no hope), without a past there is no communication". Mr. McCullough favoured the via media. He added that he felt quite sure that he had tread on many corns in that short speech and would never be forgiven, but he had said it all and was not going to take any of it back.

There was only one exception he would make to that particular theory which he had been evolving some months ago. After forming his view, he visited Chicago, and while there nothing had struck him so much as how wrong he had been about the whole thing. Chicago of course was a city where the vernacular was steel and glass, and as a result, all his thoughts had become confused again and he had asked himself what had he been thinking about. But of course there was an explanation. Chicago was special. It was a city in which the vernacular was the very thing that other cities did not want. What was right for Chicago was not necessarily right anywhere else.

Mr. McCullough acknowledged the assistance he had in conversation, especially with Kevin Fox, Brian Hogan, Neil Downes, Arthur Gibney, Hugh O'Neill, Pat Kilbride, John O'Reilly, David Keane, and Bill Doran who had taken many of the photographs which

would be shown. With regard to the slides, he would repeat that he had used a completely arbitrary classification. The buildings were all in Dublin, unless otherwise stated, for the simple reason that he lived there. He would be using architectural terms in a very loose sense and hoped his architect friends would forgive him. Many of the buildings shown had been built within the last five years, and in showing them he was breaking an old rule he had always held that one should never come to any kind of conclusion about a building for at least five years after its completion.

Mr. McCullough then showed thirty three slides that included the following buildings:—

Office for Irish Shipping Limited Sandymount
 Science building and library, University College, Galway
 Offices for Fitzwilton Limited, Dublin
 Woolfson College, University of Oxford
 Irish Farm Centre, Inchicore
 Grandstand, Leopardstown Racecourse
 Church, Sutton, Co. Dublin
 Ampleforth College, Yorkshire
 Texaco House, Ballsbridge
 Shell-BP House, Dublin
 Aras Mhic Dhiarmada, Dublin
 Office Development, Sackville Place, Dublin
 Lansdowne House, Ballsbridge
 Shopping Centre, Phibsboro
 National Theatre, London
 National Film Theatre, London
 Arts and Administration Buildings, University College, Dublin
 Library, University College, Dublin
 Kiosk, St. James's Park, London
 Norwich Union Building, Liverpool
 Tayto Factory, Coolock Co. Dublin
 Teach Earlsfort, Dublin
 Library, Trinity College, Dublin
 Liverpool Post Building, Liverpool

MR. T. M. DUGGAN opening the discussion acknowledged the depth of Mr. McCullough's understanding of the engineer - architect relationship in building. The close attention with which his introduction and slides had been received showed clearly the great interest of engineers in the subject. He hoped that the reality of the interest would not pass unnoticed by our architect colleagues, especially as it had been so well voiced by the speaker. Mr. Duggan recalled that in presenting a paper to the 1965 Symposium on the same general area of practice, the accent had been more on the cosmetic treatment of concrete. He would say that his views had now changed and he would no longer emphasise that aspect. Views generally would continue to change, and

he felt that he would probably have to wait for a third paper in 1985 for a complete picture as to how architecture was faring and likely to fare in relation to concrete.

The non-architect, faced with the array of buildings in his community, was liable to wonder what architecture was all about. He had three choices, rather like the first-time spectator at a strange game, either to find some friendly soul to explain the rules, or to try to deduce them for himself from what he saw happening, or to give up and sit back and enjoy the display without understanding it. He would set himself in the second group, and that led him to certain personal attitudes and questions. Firstly, he would question the title of Mr. McCullough's paper, and would propose "Concrete in Architecture" rather than "Concrete and Architecture". The latter suggested that the two were separate entities, like fish and chips, often seen together but not integrated. That was far from correct. He would ask Mr. McCullough whether his presentation had shown whether concrete was influencing the architecture of today, or whether the architecture was influencing concrete. Was architecture, he wondered, forcing concrete to do things it should not do?, or was concrete, posing as a versatile medium, trying to persuade architects to do things which they should not be trying to do with that medium?

Concrete was the most widely used building material in Ireland, and despite its disadvantages, would continue to be, for decades or perhaps centuries. The architecture of concrete was in an early stage of its development, and, quite clearly, the potential of the material had not yet been fully realised. Perhaps its users had been over-inclined to stick to rules and forms devised for other materials and other ages. It was a sobering fact that by the time of the next Symposium in 1985, many further millions of cubic metres of concrete would have been cast in Ireland, and the present audience would share in responsibility for its form. A question then would be whether, during that time, it had been thought more important to have results which were architecturally pleasing, or to have results that pleased the people who had to live in the buildings. He felt the answer was obvious. The users, the people who had to live in the buildings, had to be more important than the architects who designed them, or the structural engineers who made them stay up. Nevertheless if a member of the user-group ventured an opinion, he was quickly told that others knew what was good for him, that other knew what harmonized, knew how a building should look, what size of windows he should have, and so on. The expression of an opinion was also likely to be deemed a taking of sides in some controversy on a particular building. Such reactions inhibited the development of a public taste and encouraged a rather negative attachment to older well-worn modes. Mr. Duggan did not feel that that represented a new phenomenon. He wondered how Dubliners in the eighteenth century would have reacted to the then new mode, later to be called Georgian, or, indeed, how the "locals" had reacted when planning permission was sought for the Colosseum.

Mr. McCullough had said in his paper that until quite recent times, probably the only important consideration in the design of most buildings had been simply to combat at minimum cost the effects of cold, rain, wind, and sun, using whatever materials were most easily available. Mr. Duggan wondered whether that attitude had gone. He was by no means certain that it had. It was possible that rather similar restrictions were being forced on architects today, and that Planning Authorities and minimum cost demands by clients were inhibiting progress. A client's wish merely to repeat what previously had been successful did not necessarily lead to good architecture. Thinking about many buildings that he had seen in many countries, it was hard to believe that architects always had the last word. As just one example, he could not understand why, in the design of single family homes in large developments, an identical plan had to be maintained for all units, irrespective of the way the unit faced, unless some over-riding minimum cost factor, imposed by the developer rather than the future user existed.

From his limited experience of building in the United States of America he wondered perhaps whether a rather different client-architect relationship had not developed in that country. There seemed to him a feeling that in the particular field of concrete, American practice had quite firmly distinguished between structural concrete and architectural concrete. Structural concrete was a cheap material designed to fulfil a given structural function for a given period of time under certain conditions of load and other external factors, while architectural concrete was a material to serve a similar function, but having in addition a certain interest of shape or surface, and costing more in consequence. A project could run into considerable architectural and constructional confusion unless the designer deliberately selected early in his work where he was going to use one or the other category of concrete, accepting at the same time that extra cost would be involved where the medium was to be architectural concrete.

Inherent in the concept of architectural concrete were the qualities of form or shape and surface or texture. As he had said, he had ten years ago been devoting a lot of attention to surface finish and texture. He now felt that Irish expertise in finishing concrete surfaces was as high as in any other country, and that it was time to concentrate more on the second quality, the form or shape of the building. There were, in his opinion, buildings in Dublin where the quality of finish was superb, so good in fact that one wondered how many units had had to be rejected to reach such a level, but which left one wondering whether in the overall context of the completed building, all the effort had been worthwhile or had been merely effort wasted.

In acknowledging the flexibility of concrete, one necessarily recognised the many problems attending that flexibility. One had to accept that there were bad architects and good architects, just as there were bad engineers and good engineers; and if in the long run the supreme

flexibility and adaptability of concrete were going to be understood, we had to face up to the fact that we were probably going to have, during the learning process, even more dramatic disasters in the future than we had had in the past. We should nevertheless persevere in our study of shape and form in concrete buildings. One field in which that study had advanced quite far was, in his opinion, in long-span bridges. Whether they were solely engineers' designs, or whether joint designs by engineers and architects, one felt that the essentially structural nature of the long-span bridge had brought about its own art form in concrete, a form that reflected not only the function of the bridge but the beauty of the material as well.

Mr. Duggan ended by addressing two questions to the Chairman. The first asked whether he was satisfied with the way concrete was being used visually in architecture today. The second asked whether he thought that, in say forty years time, people would look back on the Seventies as the golden age for architecture, or for design, or for concrete, or for anything.

MR. T. P. SHINKWIN congratulated Mr. McCullough on the breadth of treatment he had achieved in a relatively short paper, and on his leaving questions unanswered in it to tempt his audience. He had referred for instance to seeking a solution for the difficulties of co-ordination between the main contractor and the precaster, and had suggested for discussion that the solution might be for the main contractor to do his own precasting or for the precaster to become the main contractor. Mr. Shinkwin had in fact acted in both capacities, at one period as a subsidiary company to a major contractor and later in his own right as a precaster who had undertaken main contracting. He would assure Mr. McCullough that there were considerable problems in both courses.

Firstly, main contractors and specialist sub-contractors had completely different philosophies as regards management and work-force. Main contractors who decided to do their own precasting tended to be reluctant to invest capital in production buildings and in specialised plant, such as costly moulds, vibration equipment, and steam curing facilities, and were reluctant to reinvest profits or to provide replacement capital. His comments of course did not refer to the type of operation mounted on a major once-off contract as for instance the Ballymun project had been, but to the general principle of main contractors acting as their own precasters. In such circumstances he had observed also that in times of recession, it was generally the subsidiary precasting activity that was axed. Several examples might be cited from recent experience among the major contracting organizations in Britain. Further, where the precaster was subsidiary to the main contractor, the workers tended to be of good general site calibre and trained in in situ conditions and techniques. For high quality precasting however, the employers had to seek out workers with a flair for precasting, and to develop that flair on the shop floor. Quality control

played a high part. In an organised precasting industry, the ratio of supervisors to operatives could fall as low as 1:2 particularly where the architectural concrete we were discussing was involved. The corresponding ratio for heavy prestressed units would be higher, perhaps up to 1:5. Where, Mr. Shinkwin asked, would one find ratios like that in the philosophy of a main contractor?

The other approach, that in which the precaster acted as his own main contractor, also presented contradictions. A precast concrete manufacturing firm might have a throughput of 100 to 150 contracts annually, varying in size from £2,000 to £250,000. That diversity of work demanded its own form of organization. Again, the precast concrete content of a building tended to be perhaps 10 - 15% of the total cost. Thus the turnover in main contracting terms would be about £10 million to £7 million for each million pounds worth of precast concrete. It would be folly for a precaster concerned with his own operation to burden his organization with the handling of such an annual turnover, if only because the management problems in the two sectors were so completely different. The proposal had been suggested earlier that in isolated contracts all of the work, main and specialist, might be handled by a single source, from one sector or the other. This was not really practical, in his opinion, largely for the reason he had already given.

The second topic he would like to discuss was the question of choice of building medium. There were many facets of that topic. Mr. McCullough had pointed out that while precast concrete seemed the most likely choice in concrete buildings, many precasting sub-contractors had recently decided to discontinue tendering for special architectural precast concrete. Mr. Shinkwin believed however that that decision was confined to companies which were subsidiaries to large main contracting firms, and so did not reflect the attitude of independent specialist precasting firms. On that score, however, he agreed that, in future, precast concrete should be designed with a more thorough knowledge of the nature and limitations of the material than shown at present, if costs were to be kept under control. He would underline that opinion by commenting that Mr. McCullough in showing his slides had possibly not made sufficient reference to the quality of the precast elements shown or to the difficulties in achieving such results. About cost, Mr. Shinkwin considered that precast concrete was unlikely to be cheaper than in situ concrete, but, in his opinion, it was a quicker form of construction.

Insulation had been discussed, and he would like to mention experimental work that had been in progress during the previous year, and that was about to be translated into practice in a major high-rise building. Insulated panels would be used, having dimensions 12 m x 2.4 m x 150 mm thick. Each unit would weigh 9 tonnes and the principle of cladding would be loose fit, with the panels placed one on top of the other, and tied back into the structure.

Reference had been made to the conflict between the mental attitudes of architects and structural engineers in the subject of precast concrete. One was told that most engineers were as ill-adjusted for the consideration of architectural problems as architects were for those of engineers. Surely it was the combination of the analytical approach of the engineer and the intuitive approach of the architect that led to the successful use of concrete in architecture, just as collaboration between pianist and violinist, each world-renowned in his own field, but perhaps not so conscious of the subtleties of the other, led to the memorable concert. He wondered whether, in considering that dilemma of the architects and engineers, the solution in a given instance might not perhaps lie in converting the duet into a trio, with the precaster as a catalytic third instrument. As he had said earlier, quite possibly neither the architect nor the engineer knew enough about the practical process of precasting.

In conclusion, he had intended to ask, before he saw the slides, and would still ask, Mr. McCullough for his opinion on sculptured concrete. He personally considered such work, particularly in the form of mural panels, to be an art form of high potential, and one which should be as rewarding in tax concessions as other forms which now enjoyed the benevolence of Government.

PROFESSOR E. DILLON agreed with Mr. McCullough that an architecture based on relatively large areas of precast wall surface was clearly possible and would be very sensible. The slides had been very informative. He was interested in the relationship between money spent and result achieved. He had seen two university libraries in America, the general library at Toronto and the medical library at Harvard. In both instances there had been ample funds and both architects had chosen concrete as a medium. In his opinion, however, one building resembled a museum rather than a library, whereas the other was an admirable library. He wondered whether the availability of ample funds was ever in fact a deterrent to good architecture, and whether in a condition of austerity imposed by a shortage of funds, the good architect might not sometimes produce a better building.

MR. H. DELAP referred to Mr. McCullough's former chairmanship of An Taisce and his current responsibility as representative of the Irish engineering profession in the organization for European Heritage Year. He felt that the paper that had been presented could make a valuable contribution to public understanding of the engineer's role in architecture.

He wondered whether some of the dissatisfaction with completed buildings sometimes felt by the public generally and by clients in particular did not stem from the fact that, before being built, they were displayed as two-dimensional drawings, whereas the later reality was a three-dimensional building. He would offer some examples.

He believed that some people felt that the rather controversial E.S.B. building in Fitzwilliam Street in Dublin was not a happy building in a long street of Georgian buildings. The design had been highly praised as the one that would fit into its surroundings. But there had been dissatisfaction, and he wondered whether it was possible that what might have gone wrong was that the building was shown as an elevation, whereas it was in reality viewed by most people nearly end-on. He imagined that one of the essential beauties of Georgian architecture lay in the arrangement of windows and doors, and perhaps in the use of colour variation, all elements of elevation. However, his reaction to the E.S.B. building was that the main feature one saw was the series of very deep mullions sticking out between the window frames, which when viewed end-on completely concealed the windows.

Another excellent building we had been shown was the Slaney bridge at Wexford. This was very fine in elevation, but it was viewed by many people, close up, from the Quay on to which it came at right angles. It was possible to get an almost end-on view of that bridge which was really rather horrifying because instead of a long succession of greyhound leaps, one got the impression of a squashed-up series of almost right-angled gables; and this was the view which in fact many people saw.

Other examples he might quote were the water tower on Belfield campus, which made him personally unhappy because unless one looked at it from certain positions, it appeared as somewhat lopsided; and a monument, formerly on the sea-front at Dun Laoghaire, consisting of a triangular column with a ball on top, which, unless viewed from the right direction, gave one the impression that the ball was about to fall off.

Consideration of these examples suggested to him that perhaps more use should be made of three-dimensional models in presenting proposals to clients and to the public generally.

THE CHAIRMAN mentioned that people had spoken about the difficulties associated with concrete in architecture. He personally felt that, paradoxically, concrete was too easy a material to work with. It was too flexible, too tolerant, too versatile, and it was in those very qualities that many of the difficulties lay. Architects also found difficulty in the fact that concrete was a composite material, lacking the homogeneity of other materials such as glass, brick and steel. An aspect of this was the invisibility of the reinforcement in the finished work, because to him it seemed that the beauty of the purposeful arrangement of the reinforcement, essential in the structural element, should remain always apparent to the viewer. He agreed with earlier speakers that one should not be as much concerned about surface texture as about the real nature of concrete as a material. With better understanding we would get better expression.

He would like to comment on the education of engineers, a point raised by Mr. McCullough. Engineering graduates received no archi-

tectural education, whereas there was a very considerable input from engineers to the undergraduate course in architecture. He regretted that the new Engineering School to be built at Belfield for University College would not accommodate the School of Architecture also. He would however appeal for a larger content of architecture in engineering education, and would invite engineers to become more involved in the whole field of architecture.

He invited Mr. McCullough to reply, apologising however to him for the fact that because of the considerable interest in the discussion, his time for reply was regrettably short.

MR. McCULLOUGH replied. He appreciated Mr. Duggan's dilemma, whether concrete was influencing modern architecture or whether it was the other way round. He did not feel there was any clear answer to that primary question but felt that Professor O'Neill had thrown light on it in his reference to the paradox of the versatility of the concrete making it difficult to use. Mr. Duggan had also suggested that office block designers kept perhaps too close an ear to the promptings of estate agents. Maybe that was so, but one would always hope that those who bought or leased the finished buildings had some part ultimately in calling the tune as well.

He had every sympathy with Mr. Shinkwin when he spoke of the difficulties involved in having precasting specialists act as their own main contractors, or vice versa. What he, Mr. McCullough, had wished to convey, and he felt Mr. Shinkwin would agree, was that there was so frequently difficulty on site in co-ordinating the work of the main contractor and the precast concrete sub-contractor. How that could be resolved he did not have the experience to say but it remained a fact in his knowledge that whereas on many jobs one could have very satisfactory co-ordination, on far too many others there was real dissatisfaction and constant friction between the two parties. He regretted he had not referred to the difficulties attending the manufacture of architectural precast concrete. He was well aware of them. He recognised the load that manufacturers carried, and appreciated that the architects' attitude towards the quality of the work could well represent the make-or-break margin on a job. He was interested to hear of the large insulated panels, and looked forward to more details in due course.

Referring to Professor Dillon's interesting comments, it was hard to be certain about any positive influence that cost restrictions, and, as he had said, austerity, might have on quality. He could say quite certainly however that ample funds and good architecture did not necessarily go together. There were many expensive buildings that were very bad architecture.

What Mr. Delap had said about presentation was very true, although even with models one did not always succeed in communicating, as one would wish. Recently in connexion with European

Heritage Year, a model had been prepared to illustrate the conservation work at St. John's Square in Limerick. The model had been beautifully made and set up on a table, but what had struck him was that he had not seen any viewer stooping down to look at the model as the man-in-the-street must inevitably see the finished buildings. He felt that one relied both on the architect who prepared the drawings and on the officers in the Planning Authority to whom the project was submitted as people qualified to interpret the two-dimensional drawings, and to understand, from them, the ultimate appearance of the building.

MRS. McCULLOUGH replied. He appreciated Mr. Duggan's dilemma, whether concrete was influencing modern architecture or whether it was the other way round. He did not feel there was any clear answer to that primary question but felt that Professor O'Neill had thrown light on it in his reference to the paradox of the versatility of the concrete making it difficult to use. Mr. Duggan had also suggested that office block designers kept perhaps too close an ear to the promptings of estate agents. Maybe that was so, but one would always hope that those who bought or leased the finished buildings had some part to play in calling the tune as well.

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Referring to Professor Dillon's interesting comments it was hard to be certain about any positive influence that test restrictions and, as he had said, austerity might have on quality. He could say quite certainly, however, that simple funds and good architecture did not necessarily go together. There were many expensive buildings that were very bad architecturally and he pointed them out to his students. What Mr. Dolan had said about precast concrete was very true, although even with models one did not always succeed in communicating as one would wish. Recently in connection with European

CONCRETE FOUNDATION PRACTICE

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Introduction

Concrete is a material which is so obviously right for foundations that its use has been accepted universally. If a symposium were set up to consider the ideal material for foundation work and to produce a specification for it, the result would probably be concrete as we know it to-day.

The foundation of a structure must be designed as part of that structure and in conjunction with the ground which must support it, but it is the foundations alone and their support by the ground that are considered in this paper. The paper is further limited to dealing with foundations for buildings and for some of the plant and equipment within the buildings. The aim is to ascertain the methods used by various designers, to see if similar methods are used by everyone, and where a designer is using a new or novel method of design, to draw attention to these different methods.

To ascertain the various methods used by different designers a questionnaire was prepared and circulated to architects and engineers. The distribution of the questionnaire and the replies upon which this paper is based were as follows :

	Number issued	Number of replies
Architects	53	8
Consulting engineers	43	26
Local Authorities and other specifying bodies	7	3
Firms specifying and designing their own work	8	6
Contractors or suppliers who design some of their own work	13	3
TOTALS :	124	46

One of the replies from a Local Authority and one from a firm designing their own work were from architects and these have been grouped with the other replies from architects in the analysis of the replies. Geographically the replies have come from Athlone, Clare, Cork, Donegal, Galway, Limerick, Wicklow as well as Dublin.

A copy of the questionnaire is shown as Appendix A. This copy has been marked to show as many of the results as possible. In questions with a simple alternative, the number of answers choosing each alternative is shown. In questions where the answer indicates a frequency of use, the replies have all been noted and are indicated as follows:

In each question xxxx indicates the box which received most replies. x's are shown elsewhere in the proportion of the number of replies in that box to the number in the box receiving most replies. A stroke indicates a half x. An additional figure is now shown as a percentage in these questions, this figure has been arrived at by taking the results for each case, weighing them according to the frequency shown and the figure is given as a percentage of all replies to that question.

A report on the answers to the various sections of the questionnaire follows.

SECTION A : Foundations for brick or blockwork building

A.1 Methods used to assess the allowable ground bearing pressure

The answers here show the overall preference for trial pits, surprisingly used more frequently than site investigation. Also the use by many people of site investigation regularly but only on a small number of jobs. Replies from architects and engineers showed a similar pattern except that architects note the use of site inspection approximately twice as frequently as engineers. (Note that many people by their reply indicated the use of more than one method so the percentages add up to considerably more than 100%).

A.2 Usual allowable bearing pressure for ordinary ground

The replies to this question show a surprising range of bearing pressures used by engineers, 20 of whom gave a figure and 4 gave a range of figures. The figures ranged from 50 kN/sq.m. up to 300 kN/sq.m. with no predominant value; the following were the most frequently given:

150 kN/sq.m.	—	7 times
100 kN/sq.m.	—	5 times
200 kN/sq.m.	—	4 times.

Architects with one exception gave 200 kN/sq.m. No reply referred to CP. 101 (1)*. If compared to the bearing pressures recommended for various types of ground in this code, the range of answers cover every-

*These numbers refer to the bibliography at the end of the paper.

thing from soft clays and silts up to medium dense gravel. The figure of 200 kN/sq.m. given by most architects is the figure shown in the code for medium dense gravel or stiff clays.

A.3 Criterion for width of foundation

The answers here show a clear overall majority for fixing the width of foundation by reference to the width of wall over footing. Ground bearing pressure is frequently the criterion. As well as the methods noted two people note the use of the Standard Method of Measurement as the criterion for width of foundation.

A.4 Level of underside of foundation

The answers here indicate a small overall preference for fixing depth by inspection on site. Engineers show a preference for site investigation but architects are overwhelmingly in favour of site inspection as might be expected from the answers to question A.1. One reply noted the significance of the level of ground water and that this level can vary considerably from one time of year to another.

A.5 If ground conditions are not good enough to carry bearing pressure indicated in A.2 above

The use of wider strip footings is obviously the most used solution. One reply pointed out the importance of varying the area of each footing to give equal ground bearing pressure and to avoid differential settlement. One other reply from a firm engaged in development of an area reclaimed by tipping of corporation refuse is at variance with the general trend by showing a total reliance on piles.

A.6 Specification for concrete

This will be reported under Section D.

A.7 The range of buildings covered by the replies to this section

Housing; schools; office blocks; stores; workshops; hotels; hospitals; churches.

It was hoped that this section of the questionnaire might show up some significant variations in the approach to foundation design by architects and engineers. The very small response from architects, however, means that it would be hard to consider the results as properly representative and this must be remembered in considering the variation noted.

SECTION B : Foundations for reinforced concrete or steel framed buildings

B.1 Methods used to assess the allowable ground bearing pressure

Trial pits and site investigation are shown to be the two most used methods, in fact only 2 replies did not show trial pits at all and both

of these use detailed site investigation in more than 90% of cases. As before, site inspection is used much more by architects than engineers.

One consulting engineer from Cork pointed out the dangers of comparing foundations for old buildings with what is necessary today. He pointed out the fact that in many old buildings built of brickwork the load was applied slowly as the brickwork progressed and in many cases corrections to levels were made as settlement occurred. He says he has had difficulty in convincing clients that more elaborate and expensive foundations are not a waste of money after the client has done his own comparison of foundations for an extension with foundations for some very old part of his works. This, of course, shows the importance of the right person doing the comparison.

B.2 Allowable bearing pressure in ordinary ground

As in A.2, the range of allowable bearing pressure for dead load conditions was surprising ranging from 50 kN/sq.m. up to 500 kN/sq.m. As in A.2 no figure was predominant though 150 kN/sq.m. was quoted by 10 out of the 31 people who replied to this question. Sixteen of the 31 replies gave the same allowable bearing pressure for wind and live load conditions as for dead loading, 2 people gave an increase of 25%, other increases given were up to 100%. Again no replies referred to either CP.101 or CP.2004 (2).

It was hoped when issuing the questionnaire that the use of the words "ordinary ground" in this question and in A.2. might indicate a uniformity of thought on what would be considered ordinary ground or a level of acceptance which would be sought when investigating the site. This does appear to be the case with architects but not engineers.

B.3 Foundation types in ordinary ground conditions

There is a clear preference for independent bases, with bases and connecting beams used in most other cases. Rafts are hardly ever used. The other type mentioned by 3 people was piles.

B.4 Foundation type in poor ground conditions

Here the clear preference is for piles, otherwise rafts or bases with connecting beams are used about equally.

B.5 Specification for concrete

This will be reported under Section D.

B.6 Difference in foundation problems presented by steel frame and concrete buildings

Of the 18 people who considered there is a difference almost all said that steel is more flexible and will tolerate greater differential settlement, only one person qualified this by excluding portal frames.

The writer would like to sound a word of warning about the ability of steel frame buildings to tolerate differential settlement. Many steel buildings being designed now have a significant rigidity at joints; as

the use of high strength friction grip bolts increases, the tendency will be for the joint rigidity to increase and these buildings have very little tolerance to differential settlement.

One person noted that large single span portal frames, particularly with low eaves, have considerable horizontal thrust at the base which must be resisted by the foundations. With the recent popularity in Ireland of steel framed buildings of this sort, this is an important consideration.

Lightness of steel giving lighter foundations but uplift problems was also mentioned in a number of replies. This can be very significant in high buildings and the writer has sometimes found large concrete foundations are required purely as dead weight to hold down a building. This is particularly the case where the foundations are in rock and a small concrete base would have transmitted all the downward forces. Rock anchors or grouting of bars into rock might be a solution.

B.7 The range of buildings covered by the replies in this section

Offices; factories; schools; large stores; hospitals; warehouses; shopping centres; churches.

One very interesting foundation method has been used by a consultant for buildings in the Cork area. The site where this method was first used was adjacent to but partly on an old railway station, the ground was marshy and very poorly drained. Filling was required in the area for a depth of approximately 3 m, and the initial proposal was to use piles after this fill was placed. It was realised that the small area filled for the station platform seemed to give a good bearing surface. The old fill for the platform was removed to give a uniform surface and the site area filled for the 3 m depth using quarried limestone generally in big pieces about 0.5 m to 0.75 m cubes. These stones were spread in layers about 700 mm thick and consolidated by the bulldozer used for spreading and where possible by a roller. After filling in this manner to the required level an industrial building was constructed on the fill with a strip footing foundations, and a bearing pressure of 150 kN/sq.m., the strip footing being reinforced top and bottom. The building has been in use for some years with no sign of settlement. The same consultant has used a similar fill to a depth of 1.5 m more recently for a cold store. As in the previous case the ground was soft and marshy, the fill was placed and consolidated in layers and the building with floor loading of about 250 kN/sq.m. was constructed. Using this method the fill must extend well beyond the area of the buildings, a minimum figure of approximately twice the depth of fill is suggested. The consultant first saw this method described in reports of work carried out by the American Army. The method would obviously not be suitable for filling over an area containing silty material, but in marshy ground where fill is required anyway, it appears to have many advantages.

Another example of an unusual foundation problem was encountered by the E.S.B. on the site for a 220 Kv Station near Limerick.

About half the site was dry and well drained, the other half was slightly lower and marshy with rushes growing in clumps. Trial pits showed a layer of water-bearing silty sand varying in thickness from nil up to 1.25 m with top surface at a depth of 1.3 to 2 m below ground level in the marshy area. This layer of silty sand appeared to be under pressure. Anywhere it was encountered in a trial pit the sides of the pit collapsed and the pit enlarged to a circular pool in about 15 minutes. Buildings were re-located to be clear of this marshy area. Filling was placed to bring it up to the level of the remainder of the site; depth of fill was nil up to 400 mm. Masts and other switch equipment were located over this bad area by re-designing the foundations to reduce the ground bearing pressure to 50 kN/sq.m., the depth of foundations was limited to about 600 mm below original ground level. One mast built in this area was subsequently load tested and proved the stability of the foundation.

SECTION C: Piles

C.1 Choice of piles

The replies show clearly that cast-in-situ bored piles are used much more frequently than any other sort. Engineers very seldom use pre-cast concrete piles; the use of these is shown almost entirely by architects.

C.2 Available range of piles

Everyone is satisfied with range of carrying capacity of piles available. A large majority of people are satisfied with range of types of piles available. The 9 people who wish to see a bigger range of types of piles noted the following as what they would like to see:

Lightweight driving equipment;

Auger type pile for use where vibration must be avoided;

Small diameter under-pinning piles;

Screw piles;

Further shell piles.

As well as the above a number of people mentioned the difficulty of getting 3 quotations for a particular type or range of piles.

There is no doubt that piles are not used very extensively in this country and hence there is a restriction on the range available. As development of new industrial areas proceeds it may be that the use of piles will increase.

SECTION D: Concrete

D.1 Specification of concrete for foundations

All people completing this part of the questionnaire use strength of finished concrete in their specification. In ten out of the overall total of 43 the strength is the only item specified, and in eight cases

strength and cement content are the only items specified. Two engineers specify the minimum density.

Many people indicated that they are now working to CP.110 (12) and this is very frequently quoted in the answers to concrete specification in A.6 and B.5.

D.2 Reinforcement in foundations

The replies to this question indicate a rather surprising number of cases where reinforcement is not used. Five people say they never use reinforcement in foundations for a single storey brick or block building and nine others seldom use reinforcement in these foundations. At the other end of the scale twenty people always use reinforcement in all foundations. The reply on one questionnaire which said "All foundations should be reinforced even those for single storey buildings and houses", is in accordance with the writer's thinking and with CP.101 (1).

D.3 The specifying of ready-mixed concrete

The replies show an almost equal division between 'yes' and 'no', but many of the 'yes' replies point out it is specified as an alternative and quite a few 'no' said they would not object to its use if requested by the contractor.

The most frequent reasons given for the use of ready-mixed concrete are :

quality control or guaranteed quality (2 times);
inexperience of contractor or doubts about contractor's ability

(5 times);

convenience on restricted sites (3 times);

regularity of supply for large pours;

to save time on programme;

better for pumping.

The E.S.B. has recently had experience of ready-mixed concrete in three significantly different conditions. For the foundations to the extension of Shannonbridge power station the contractor elected to use ready-mixed concrete for all work though the site is 30 kilometres from the nearest ready-mixed concrete plant. The total quantity of concrete was 2,800 cu.m. with the largest single pour 340 cu.m. Discussions with the ready-mixed concrete supplier showed that the concrete was being made with a well shaped nicely graded coarse aggregate and fine aggregate of cohesive sand falling within the zone 2 grading of Table 2 in B.S.882; this combined to produce a very good workable and dense concrete. The work was completed using this ready-mixed concrete and has been a complete success; workability and quality have been consistently good despite the 45 minute trip to site.

For the foundations for the extension to Poolbeg power station in Dublin, the contractor also elected to use ready-mixed concrete. The site is within 1 kilometre of the ready-mixed concrete plant and the

total amount of concrete required was 11,500 cu.m. with a number of pours of about 900 cu.m. Preliminary testing and discussions showed that the concrete from the ready-mixed concrete plant was a gap graded concrete producing very high strength and consistently good cube results but very hard to work. It was felt to be unsuitable for such things as water-retaining structures, heavily reinforced areas, thin sections and it would also be difficult to achieve a good finish using this mix. After much discussion and tests of different aggregates, a revised mix of concrete using graded aggregates was agreed. Using this concrete, results are proving very successful. With a job of this size the Engineer and Contractor can insist upon getting concrete of the quality and properties that are required. On smaller jobs, it may be very much harder to get concrete with the required properties and tests should be carried out to ensure the suitability of the concrete for the proposed work before concreting begins.

At Great Island and Tarbert extensions ready-mixed concrete was used only on very big pours to supplement the site batching plant. The distance from the ready-mixed concrete plant was about 65 kilometres in each case. The foundations where ready-mixed concrete was used were big open concrete pours and the concrete proved satisfactory for this type of work.

SECTION E: Water retaining structures

E.1 Where structures must retain or exclude water

Part (a) Under what conditions would the concrete be designed and relied upon to exclude water ?

Twenty-six engineers replied to this section; of these, nineteen would rely entirely on concrete for all normal work, most noted reservations such as : must be designed to CP.2007, (3) experienced contractor, low water table, design mix must be approved. Six of the remainder exclude basements but rely on concrete for all other cases.

Part (b) Under what circumstances would a coating or membrane be used to act as the water barrier ?

Five engineers were adamant "No circumstance". Almost all the remainder would use membranes in the following cases :

small sumps;

machine pits;

where dampness is critical to building usage;

where there is a high water table;

where specified by architect.

The answers by architects to this section were: Part (a) five replies, one said 'never'; two 'only if consultant engineer employed' and two 'if exclusion of dampness is not critical'; Part (b) one, predictably, said 'always'; one 'if architect designed wall' and remainder use it 'to control dampness'.

The completely different emphasis here is summed up in one reply 'membranes are used where dampness is critical to building usage' and reflects the architect's involvement with foundations for private and commercial buildings and engineers' more usual involvement with foundations for structures for plant or machinery.

E.2 What special precautions are taken at the joints of these structures ?

In all the replies there is almost complete uniformity about the value of water bars, and many people quote the recommendations for joints in CP.2007 (3). Among other recommendations were :

- exposing of aggregate at joint by water spray or scabbling;
- sealing of shutter at joint;
- avoiding congestion of reinforcement at joint;
- removal of laitance;
- sealing in of mastic in rebates.

Three people, however, object to the use of water bars on the grounds of difficulty of compaction at joint. This is a very real problem but one that must be overcome by close supervision on site. Two people said they would use water bars on vertical joints but preferred a thoroughly prepared concrete surface on horizontal joints.

There are a few comments the writer would like to add. The quality of the concrete required for waterproof work cannot be over emphasised. In the previous symposium held in 1965 Mr. J. Gwynn in his paper (4) sets out the requirements for a waterproof concrete very completely and concisely. Another publication of note from C.I.R.I.A. (5) gives formulae for determining the critical steel ratio to control cracking and some other facts about crack spacing and crack widths.

The writer worked with a firm of consulting engineers in Glasgow. This firm had original views on some aspects of the use of concrete. One of these was to make use of the expansion of concrete as it absorbs water to seal cracks which had formed as the concrete initially dried. For example culverts were constructed for the full length with concrete to concrete joints, no soft expansion joint material was used between the surfaces. In use, the concrete absorbs some water, expands and goes into compression, thus sealing all the cracks. A concrete mix with a high cement content was always used and though this produced a high level of initial cracking, tests on completed culverts showed that on filling there was a significant rate of loss, this loss reduced rapidly, and by ten days, losses were negligible.

SECTION F : Large concrete pours

There were eighteen replies to this section indicating experience of large concrete pours. Precautions listed most frequently concerned the physical arrangements such as :

- sufficient plant, materials and labour available;

do large pour only when sufficient light available;
check shuttering for maximum rate of pour;
availability of stop ends should problems arise with supply.

Of the actual safeguards to the concrete the principal ones listed were :

ensure each layer vibrated;
care with curing;
spray on curing membrane;
protection from sun;
early inundation with water;
ensure heat loss can take place;
see that finish progresses with pouring.

The increasing availability and use of ready-mixed concrete leads to the use of larger and larger pours as the contractor sees the chance to reduce the number of costly stop ends. Much research has been done recently into large pours and a considerable amount of material has been published by C.I.R.I.A. (6) and others. The C.I.R.I.A. report reviews a number of large pours and reports on the successes or on defects from their use.

The definition of a large pour has been attempted by Mr. M. E. Fitzgibbon in a paper (7). One criterion given by him is "any pour with a least dimension of 2m." In the same paper a formula is given to calculate the temperature rise of concrete due to the heat of hydration of cement. This formula is 12°C per 100 kg per cu.m. of cement content. It is further suggested that the temperature gradient through the concrete should not exceed 20°C . Using this formula one can estimate the maximum temperature and then by considering what cooling occurs naturally it should be possible to decide on the sort of precautions that must be taken. The essential difference between pours of large area and pours of large volume must be realised and the different precautions for each must be considered, as well as the basic fact of whether the pour is a completely self-contained unit or part of a structure where distortion relative to another part can be significant. Having considered these, the problem then becomes a matter of which of two things should be done.

The first, by conducting the heat away from the concrete as efficiently and as quickly as possible to stop temperature build-up and the associated thermal effects, including possible distortion. It is considered that the maximum temperature can occur in about 14 hours and continuous spraying with water is considered the most satisfactory way of dissipating the heat due to the evaporation which occurs. If the concrete is inundated with water this must be done immediately. This is nearly always the case in relatively thin slabs or walls or such like construction.

The second case occurs in massive pours, particularly if the pour is completely self-contained. Here temperature build-up is inevitable and the problem is one of reducing heat loss at surfaces to keep the

temperature gradient as small as possible. It may be worth backfilling behind side shutters; certainly it is worth trying to reduce the air flow around shutters. The top surface should be protected against loss of heat and if it is at all possible ponding with water to a depth of about 100 mm is a very good solution. If this is not feasible a plastic sheet laid on the surface and covered with sand (25 mm is sufficient) is effective provided the edges are properly sealed to protect the concrete from air flow. The worst things that can be done are water spray or to lay damp hessian on surfaces as these will cause big heat losses by evaporation.

The E.S.B. have used thermocouples to record temperatures in large concrete pours on a number of occasions. In part of the turbo alternator block at Great Island it was considered necessary to keep the temperature rise in the concrete to a minimum to avoid distortion, the concrete was 2.3 m deep and 50 mm diameter pipes were used at 600 mm centres to water-cool the concrete. This was done in similar positions on two foundations, the calculated temperature rise using the formula given above is 39° and the actual rises in temperature at a point in the area cooled by the pipes and at another control point clear of the area cooled by the pipes together with the placing temperature of the concrete are :

	Placing temperature	Temperature rise in areas of pipes	Temperature rise at control
No. 1	12.5°	29°	35°
No. 2	19.0°	17°	29°

More water was pumped through the pipes in Block No. 2 on the day after pouring and this held the temperature rise down by a certain amount but does not account for the 12° difference. The higher placing temperature of the concrete in Block No. 2 was because of higher aggregate temperatures and higher ambient temperature.

At Tarbert and Poolbeg thermocouples were used to record the temperature at various locations in the foundations for the turbo alternators. There were two of these foundations at Tarbert and one at Poolbeg, each similar in size 33 m long x 11 m wide x 2.5 m deep, volume approximately 900 cu.m. each. The concrete had a cement content of 375 kg/cu.m. at Tarbert and 310 kg/cu.m. at Poolbeg. At Tarbert the foundations were each cast inside a box lined with cork 30 mm thick on the sides and 60 mm thick underneath. At Poolbeg the side shutters consisted of hollow concrete blocks 150 mm thick. Tarbert foundations were not flooded with water due to the risk of wetting the cork and each was covered with sand which was kept damp. At Poolbeg the foundation was covered with water to a depth

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of 75 mm, though unfortunately this was not applied until the next day. Thermocouples were positioned at a number of points; the following table shows the readings ($^{\circ}\text{C}$) of the three at the centre point in plan of the pours, No. 1 near the bottom, No. 2 at mid depth and No. 3 near the top surface.

	Tarbert 1			Tarbert 2			Poolbeg		
	1	2	3	1	2	3	1	2	3
Day of pour	Not taken			31	29	25	Not taken		
Day of pour + 1	44	50	38	41	45	43	41	45	35
Day of pour + 2	48	58	40	46	53	37	42	50	34
Day of pour + 4	50	56	38	46	52	35	42.5	48	28
Day of pour + 6				46	50	31	41.5	45	26
Day of pour + 15	40	39	27	35	39	27	34	33	21
Day of pour + 30							22.5	22.5	16
Day of pour + 60	Not taken			18	18	20	Not taken		

The readings indicate the reduced heat generated by the concrete at Poolbeg due in part anyway to the reduced cement content. Using the formula shown previously the rise in temperature at Tarbert should have been 45° and at Poolbeg 37° ; in each case the ambient temperature varied between about 10° and 13° so the maximum temperatures that would be expected are approximately 56° at Tarbert and 49° at Poolbeg. This corresponds fairly accurately with the readings.

It will be seen from the readings at Great Island that the casting temperature may be significantly different for different pours. There are a number of practical precautions which can be used to keep down this temperature, such as :

- keep all materials in shade;
- aggregate can be kept wet and if possible in a free air flow—this requires monitoring of aggregate moisture content;
- use of iced water.

SECTION G: Foundations for other structures

G.1 Is it considered that foundations for systems buildings present any special problems ?

Ten of the people replying consider that there are special problems. These were indicated as :

- difficulty of ensuring fixity—degree of fixity of precast columns to base doubtful;
- difficult to ensure proper key between base of columns and foundations;
- difficulty of achieving bond between sides of pockets and columns;

fixings normally more frequent and to greater accuracy;
 r.c. system buildings rely on adequacy of foundations for stability
 therefore generally heavier foundations;
 non conventional shape.

The majority of designers do not consider system buildings present any special problems and many of those noted above are of a minor nature.

G.2 The range of foundations for other structures

The range mentioned by people in their replies was immense. It is regretted that they cannot be dealt with in a short paper. One type that is mentioned very frequently is machine foundations and a number of people have asked for comments about them. A new Code of Practice No. 2012 Part 1 : 1974 (8), is now available and deals very fully and completely with the elaborate calculations for dynamic design. The writer would like to make two general comments about the design of these foundations :

- 1) Is an elaborate dynamic calculation for the foundation necessary or could the machine be mounted on springs ? These spring mountings are now available for plant up to very big sizes, any pipes etc. connected to pumps would of course have to have flexible connections but this in itself may be an added advantage.
- 2) Where dynamic calculations are necessary, there are a number of computer programmes which have been specially written for this work. The use of one of these programmes will allow many changes of foundation size to be tried to achieve a uniform vibration amplitude throughout the base, and to match this with properties of the resilient mat if it is decided that a resilient material is necessary around the foundation.

SECTION H : Foundation failures

H.1 Knowledge of any building where the foundation has failed to carry the load satisfactorily

The answers here indicate very clearly that inadequate investigation of ground before design of foundations is much the most frequent cause of foundation failure, in fact accounting for 40% of cases noted. As well as the causes listed in the questionnaire the following were also mentioned in replies :

pile failure (bored piles);
 ground water movement;
 loss of lateral support;
 leaking of an acid drain due to jointing with a non acid resisting material, the leaking acid caused disintegration of hardcore filling.
 One reply referred to the failure of the foundations for a 50 year old brick building, the cause was thought to be pumping of water from wells several hundred metres away.

Three comments made in replies to this question were :
 "In faulty design of foundations the main factor has been insufficient attention paid to unequal settlement".
 "Extra load not known at design stage—designers may share blame here in not providing suitable records of design loadings for posterity".
 "Faulty design of foundations—due to extrapolation of safe bearing capacity of a single pile to groups of piles (mentioned twice)".

Other foundation methods

Novel and cheap methods of foundation construction are not easy to find. Some other ideas which are not new but may be used more in the future are mentioned below :

Vibro-flotation has been used on a number of jobs over a long period. It has recently been used in the Dublin area on a relatively small job involving 80 pressure points, air lubrication instead of the more usual water lubrication was used and the cost of the job was equal to the lowest quotation for piles despite having to cover cost of transport of all equipment from, and return of it to, Britain, this transport cost being approximately 50% of the total cost.

Dynamic consolidation is a method of consolidation used for a long time by Dublin Port and Docks Board and described in a paper by the late Mr. P. M. O'Sullivan (9). He described the use of 3 tonne weight 900 mm square on plan repeatedly dropped through a height of up to 6 m. More recently Contract Journal (10) described a method where a 10 tonne weight is dropped from heights up to 25 m.

Small-diameter sand drains (11) are another method of achieving accelerated settlement in water bearing soils, usually clay soils and certainly if a depth of fill is necessary these drains could prove a very useful method of draining the existing soil.

Conclusion

This has been of necessity a very brief outline of Irish practice in concrete foundations. It would not have been possible without the co-operation and helpfulness of all the people who devoted their time to completing the questionnaire and those who supplied further information. The writer hopes that they and others find some information of use to them in the paper.

Acknowledgments

The writer is indebted to the Electricity Supply Board, and in particular to the Chief Civil Engineer, for permission to present this paper. The opinions expressed are entirely personal and are not necessarily those of the E.S.B. The writer would like to express his appreciation of the time spent by all people who returned the questionnaire, and thank them for their assistance. He would also like to thank his colleagues in Civil Works Department for their assistance and advice in the preparation of the paper.

APPENDIX A

SECTION A : FOUNDATIONS FOR BRICK OR BLOCKWORK BUILDING :

A.1 How frequently is each of the following methods of assessing the allowable ground bearing pressure used for foundations of this type of building :

	%	< 10%	10% to 50%	50% to 90%	> 90%
Previous experience in area	28	x/	xxx	x	x
Enquiry from people who have done work in area	12	xx	xx/	/	
Inspection of other foundations in area	12	xxx	x		/
Site inspection	40	x	x	x	xx/
Trial pits	60	x	xx	xx/	xxx
Some other methods e.g.					

A.2 Do you have a usual allowable bearing pressure for ordinary ground ?

YES 26

NO 15

If YES, what is this figure ?

Architects 150 - 200 k N/m²Engineers 50 - 300 k N/m²

A.3 Assuming ordinary ground conditions how often are each of the following the actual criterion for the width of foundation :

	%	< 10%	10% to 50%	50% to 90%	> 90%
Ground bearing pressure	31	xx	xxxx	xx/	x
Width of wall over footing	42	x	xxx/	xxx	xx
Min. width for men to excavate	14	xxx	x	x	/
Min. width for machine to excavate	13	xxx	xx	x/	/
Other reasons e.g.					

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A.4 How frequently is each of the following the criterion for fixing the level of underside of foundation :

	%	< 10%	10% to 50%	50% to 90%	> 90%
Depth fixed by usual practice	20	xx	xx	/	xx
Min depth to avoid frost action	20	xx	x/	x/	x/
Depth fixed by lateral ground pressure	8	xxxx	/	/	/
Depth fixed by information from site investigation	23	xx	xxx	x	x/
Depth fixed by inspection on site	29	x	xx	xx/	xx
Other method e.g.					

A.5 If ground conditions are not good enough to carry the bearing pressure indicated in A.2 above, how frequently do you use one of the following types of foundation :

	%	< 10%	10% to 50%	50% to 90%	> 90%
Wider strip footings	52	x	xxx	xxxx	x
Raft	24	xxx	xxxx	x	
Piles	24	xxx/	xx	xx	
Other method		x			

A.6 How do you normally specify the concrete for the foundation of this type of building

A.7 Please give a short description of the type(s) of buildings to which the above answers refer. Some estimate of the numbers (or percentage) of each type should be indicated

.....

SECTION B : FOUNDATIONS FOR REINFORCED CONCRETE OR STEEL FRAMED BUILDINGS :

B.1 How frequently are each of the following methods of assessing the allowable ground bearing pressure used for foundations of this type of building :

	%	<10%	10% to 50%	50% to 90%	>90%
Previous experience in area	20	xx/	xx/	x	/
Enquiry from people who have done work in area	11	xxx/	x	x	
Inspection of other foundations in area	10	xxx	x/		
Site inspection	45	x/	x	x	xxxx
Trial pits	62	x	xx	xxxx	xxx/
Detailed site investigation	46	x/	xxxx	xx	xx/
Some other methods e.g.					

B.2 What allowable bearing pressure would you normally use for design of these buildings in ordinary ground :

a) for dead load conditions	50 k N/m ² - 500 k N/m ²
b) For wind or live load conditions	See text

B.3 Assuming ordinary ground conditions how frequently would you use each of the following types of foundation for this type of building :

	%	<10%	10% to 50%	50% to 90%	>90%
Independent base under each column	57		x/	xxx/	xx
Base under each column with connecting beams	28	xx	xxx	x	x
Raft	10	xxxx	x	/	
Other type e.g.	5	/	/	/	

SESSION G

B.4 Assuming bad ground conditions how frequently would you use each of the following types of foundation for this type of building:

	%	<10%	10% to 50%	50% to 90%	>90%
Independent base under each column	10	xxx/	/		
Base under each column with connecting beams	22	xxx	xxx	x	
Raft	25	xx	xxxx	x	
Piles	42		xxx	xxx/	x/
Other type e.g.	1	x			

B.5 How do you normally specify the concrete for this type of building

--

B.6 Do you consider that steel frame buildings present any different foundation problems YES 18 NO 21 from concrete buildings

If YES, what is the difference

.....

B.7 Please give a short description of the type(s) of buildings to which the above answers refer. Some estimates of the numbers (or percentage) of each type should be indicated

.....

SECTION C : PILES :

C.1 If you use piles in a foundation how frequently do you use each of the following types of pile :

	%	<10%	10% to 50%	50% to 90%	>90%
Pre-cast concrete piles	12	xxx	x	x	
Steel piles	5	xxx	x		
Cast in situ driven piles	22	xxx	xx	x	/
Cast in situ bored piles	60	/	x	xxxx	xx
Other type of pile	1	x	/		

C.2 Do you consider the available range of piles sufficient for normal purposes :

For range of carrying capacities or size	YES 42	NO —
For range of types of pile	YES 33	NO 9

If NO, what further type would you like to see available

SECTION D : CONCRETE

D.1 How do you specify concrete for foundations :

By weight batching	YES 17	NO
By volume batching	YES 8	NO
Amount of cement per cu.m. of finished concrete	YES 27	NO
Strength of finished concrete	YES 43	NO
Other method	YES	NO

D.2 How frequently do you use reinforcement in foundations for the following types of building :

	Never	Seldom under 50%	Frequently over 50%	Always
Single storey brick or block building	/	x	x	x/
Multi storey brick or block building			/	xxx/
Single storey framed building		/	/	xxx
Multi storey framed building				xxxx

SESSION G

D.3 Do you ever specify the use of ready-mixed concrete

YES 22	NO 20
--------	-------

If YES, for what reasons :

.....
.....
.....
.....

SECTION E : WATER RETAINING STRUCTURES :

E.1 Where structures must retain or exclude water :

a) Under what conditions would you design and rely on the concrete to retain or exclude the water :

.....
.....
.....

b) Under what circumstances would you use a membrane or coating to act as the water barrier :

.....
.....
.....

E.2 What special precautions do you take at the joints of these structures :

.....
.....
.....

SECTION F : LARGE CONCRETE POURS :

F.1 Have you experience of concrete pours of 100 cu.m. or greater

YES 18	NO
--------	----

If YES, what if any special precautions do you specify :

.....
.....
.....
.....

SECTION G : FOUNDATIONS FOR OTHER STRUCTURES :

G.1 Do you consider that foundations for system buildings present any special problems

YES 10	NO 30
--------	-------

If YES, what are these special problems :

.....

.....

.....

G.2 Are you involved in foundations for other types of structures

YES	NO
-----	----

If YES, please give a short description

.....

.....

.....

SECTION H : FOUNDATION FAILURES

H.1 Have you knowledge of any buildings where the foundation has failed to carry the load satisfactorily ?

YES 27	NO 19
--------	-------

If YES, to what do you attribute the cause of the failure :

Inadequate investigation of ground before design of foundations

xxxx

Faulty design of foundation

x/

Faulty workmanship in placing foundation

x

Extra loading not known at design stage

x

Other work adjacent to foundations after structure has been completed

x

Other cause

x

Any further comments you may wish to make relating to the above questions or to any other aspect of concrete foundations would be welcome.

.....

.....

.....

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- (11) **F. H. Hughes and A. Chalmers.** Small Diameter Sand Drains. Civil Engineering and Public Works Review March, 1972.
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CP.110 : The structural use of concrete : 1972 (see Session A, ref. 10 for further detail).

Discussion

MR. BROWETT introduced his paper.

While it had been his firm belief that all foundations nowadays were made with concrete, he felt he should report to the symposium that that was not universally true. Recently, in a casual holiday investigation, prompted by the extraordinary neatness of walls in a house under construction, that rose cleanly from a cut in the ground of their own width, he had unearthed a novel alternative. The foundation system there was half an inch of mortar on a nice firm marl. He hastened

to add that he had found no formal support for such a construction in preparing his paper!

A study of foundation practice for the whole range of construction would have been too extensive to offer. He had decided accordingly to limit his study to certain aspects of the subject which he hoped might be of particular interest in the context of the symposium. In considering foundations for buildings he had ranged, however, across the whole of that area, from small foundations in one-off situations to major foundation systems.

He had begun by issuing a questionnaire, drafted to find out, as one of its aims, how many design approaches there might be to some given situation, or whether there were in fact situations for which the approach of Irish designers was largely uniform. The questionnaire and the answers it elicited were reproduced in appendix A. He recognised that questions A2 and B2 were phrased in terms perhaps somewhat unacceptable to foundation engineers. Nevertheless, he felt that the replies were interesting, and he had found the range of "unusual ground" quite surprising.

In the matter of piled foundations, the questionnaire had shown, as might have perhaps been anticipated, the predominance in Irish practice of cast-in-situ piling. Attention had been drawn however by some of his correspondents to dangers associated with that process. Flowing ground water could wash out cement, unstable localized soil lenses could collapse or contain contaminants, the soil generally could contain salts aggressive to concrete. If a site investigation suggested the possibility of any of these, then the use of liners might have to be considered, with a consequent considerable increase in cost. It was interesting to recognise that an adequate investigation, as envisaged above, could also reveal a suitable stratum of, say, gravel at a uniform level, and that had led him to question whether more use might not be made of precast piles. He recalled two projects based on cast-in-situ piling where, on each site, all of the piles turned out to be virtually the same length. He mentioned that because the ability to vary length was one of the advantages generally urged in favour of casting in-situ.

Section E of the questionnaire dealt with water-retaining structures. Many who had sent him comments had referred especially to the difficulty of holding flexible waterbars in position; and one had reported his success with a rigid mild steel waterbar which by its nature could resist the displacing influence of concrete being placed. The use of surface-type proprietary waterbar assemblies with supplementary mastic-type surface sealants had been recommended. It was urged that abrupt changes in concrete cross-sections and in cross-sectional areas of reinforcement should be avoided, and that, where changes of bulk were unavoidable as for instance at the junctions of slabs with heavy beams, the content of reinforcement should be kept high.

Mr. Browett then mentioned large concrete pours, and drew attention to the distinction necessary between pours of large volume and

pours of large surface area. It seemed to him that the distinction was not always sufficiently appreciated. Referring to the Table in Section F of his paper, he had to say that the temperature readings which were to have been taken 60 days after casting at Poolbeg Power Station were not taken. Readings had however been taken 30 days after casting and these would be shown on the Table in the version of his paper contained in the published Proceedings.

The final area of the questionnaire had dealt with foundation failures, and the cause most frequently quoted for failure had been inadequate investigation of ground before the commencement of design. The consequences reported had ranged from collapse right through to the relatively speaking mild one of delay through having to redesign the foundation system because of an incorrect assessment of ground conditions, revealed only when the first contract excavations had been made. The pertinent question was: how do you know when you have done an adequate site investigation? He asked members of the symposium to comment, as he felt that the answer to such a question was largely a matter of personal experience, which the members would have. He saw as a weakness the fact that soils investigation organizations often reported on a site without reference to the use to which the site was to be put. In his opinion, the process of investigation should be based in part on a pre-knowledge of the tentative schemes prepared for the foundation system. He had received one comment in that area that had interested him. The suggestion had been made that the omission of a site investigation might still lead to an overall saving for the client, even if unexpected conditions led to a necessity for repair of faulty work after completion. The suggestion struck him as unusual.

He was interested in the remark made by Professor de Courcy about a lack of reference in the symposium to the change to the SI system. He had intended to comment on that point in the context of his own paper, because he had found that in foundation design, there was sometimes a tendency to equate 1 ton per square foot to 100 kN per square metre, and to calculate areas of footings in SI systems accordingly. There was in fact a difference of about 7% between the two pressures, which, unless corrected, could lead to the metric footing areas being appreciably larger than necessary. He thought that we might perhaps be a little casual in that matter and observed that the ground itself was unlikely to appreciate that it had "changed to metric".

MR. J. GWYNN opened the discussion. He observed that there had had been no paper on foundation practice in the 1965 symposium, and that there would have been little change in that decade. Mr. Browett had written in a very self-effacing manner, reporting concisely what he had learnt and allowing himself very few personal comments. He felt therefore that the proper course for a speaker in the discussion

was to contribute experiences, as Mr. Browett had requested, rather than to ask questions.

Regarding site investigation, Mr. Gwynn wondered whether he was unlucky in that, so often, for him site investigations were so misleading. Perhaps, rather than worrying about doing too little on a site survey, we should beware of doing too much, and as a consequence, getting results beyond comprehension. A report submitted to him on one occasion had identified fifteen feet of soft material overlying sharp sand. A bored pile system had been adopted, but when work started, difficulty had been experienced in penetrating the sharp sand. A sample had been sought, and the sharp sand had turned out to be large stones. Comment would be superfluous. Again, a colleague had told him about borehole investigation for a new bridge, which was shown subsequently to have found most accurately the only three places on the entire site at which rock was present at a suitable level. Yet again, boreholes in silt were, demonstrably, completely deceptive in that the very method by which the borings were made ensured that the results could only be totally false. Perhaps what was needed was the introduction of new geotechnical exploratory techniques, and in that context he hoped that others who knew something about soil mechanics would get involved in the discussion.

One thing he would say however was that one could not substitute hearsay for a good investigation of the area on which one was actually going to build. Other people's opinions and records of nearby sites were interesting but could not be used instead of investigation. Local variations could be very critical. In his own experience, he had had to build on a boggy site 30 metres away from an existing three-storey building, in immaculate condition, built by the same contractor, who had assured him he had had no foundation problems in the earlier work. Investigation revealed that the earlier building sat on a magnificent ridge of gravel which rose like a hill through the bog, but that the new site was in fact boggy material 10 metres deep throughout.

Mr. Gwynn had been interested in the reference made earlier in the symposium to the prestressed tie below ground level at Athy. He, also, had used prestressed ties on a project at Limerick where the ground had been very poor, and also in the Jumbo Jet hangar at Dublin Airport, where any spread of the foundations for the main 82 metre frames would have had serious consequences for the working of the main doors. He questioned the validity of ground ties incorporating mild steel rods.

The engineer's attitude towards bored piling was something of a love-hate relationship. He would like to see more attention given to the development of piling methods that would reduce vibration, a constant problem on building sites; and if Mr. Browett's report of a desire for lightweight piling equipment referred indeed to the equipment, his reaction was that piling operators had already reached such a remarkable economy in their equipment, that the possibility of further lightening was hard to envisage.

The variety of opinions expressed on water-retaining structures was extremely interesting, but two features were missing. The first of these was minimum thickness of slab. Mr. Gwynn felt this was particularly important if one were to be serious about the proper use of reinforcement, and, if thought desirable, of waterbars. The second was in fact reinforcement. He recalled the care he had given to the reinforcement in a tank in which circumstances had dictated that the walls should be 100 millimetres thick. The tank had been successful, but then, and this was the intriguing point, so had a subsequent tank of similar dimensions built by his client with 100 millimetre thick concrete block walls with no reinforcement. In such circumstances one could only comfort oneself that knowing that such structures did sometimes fall down, and that it did remain reasonable to specify some reinforcement.

An aspect of water-retaining structures that merited comment was flotation. He had seen a complete basement rise 300 millimetres, as a result of the injudicious use by the contractor of the excavated space around the basement walls as a holding area for water pumped from other parts of the site. The correct attitude to adopt in sites where there could possibly be flotation had perplexed him over many years. He felt however that whatever approach might be chosen, the contractor should always be warned of a possible danger and not left to find out the hard way.

Mr. Gwynn wondered how much we understood about the working of a waterbar. One generally used them, but there always existed a danger of cavitation as a result of their being there, particularly if they folded over when concrete was being placed, as the flexible types were prone to do. In the water tower at Belfield, where many of the walls were raking, the conditions for cavitation would have been just right. In fact, the decision had been taken to rely on carefully-prepared construction joints without waterbars, but with a waterproof strip, 225 millimetres wide, applied to the scabbled faces of the concrete on the inside of the tank along the line of each joint. That arrangement had worked well, and, in fact, the only joint leakage experienced in the tower had been in the vertical shaft inside the tower, where traditional waterbars had been used.

He was interested in the reference made to thermal effects by Mr. Browett in his discussion on large pours. In that context in the field of water-retaining structures, he recalled an interesting paper by Dr. Nael Bunni on new ideas associated with the performance of concrete at early age (Editor's note: "Critical analysis of the draft British Standard Code of Practice for the design and construction of reinforced and prestressed concrete structures for the storage of water and other aqueous liquids: B.S.CP. 2007" given to the Republic of Ireland Section of the Institution of Water Engineers in January, 1975). On the matter of failure of foundations, one cause might be added to those discussed in the paper, namely the most unusual one of fire, which he, in fact, had experienced. It had occurred on a site where a garage

had been built on a fill of boiler ash. It was the practice of the owners to set fire to rubbish on a bank behind the garage, and this fire, aided by diesel oil which had been thrown out, ignited the ash, which burned steadily in the fill, the combustion leading to a reduction in volume of the fill, and consequent settlement cracking of a secondary structure on top. A dilemma existed in that excavation to isolate the burning area admitted more oxygen and as a result tended to encourage further combustion. Continued effort, including the use of barriers did however stop the fire before it reached the fill supporting the main structure, but the whole episode had been for him a new experience in foundation behaviour.

Generally speaking, one could ask the question as to what actually constituted failure. He would not offer an answer but merely observe that, in different opinions, it ranged from the structure containing some small cracks which were quite harmless up to the building that was falling down. A form of failure which he, and he was sure many others, had seen was in bored piles. He would agree with Mr. Browett about the need for sound prior investigation, but he would repeat that site investigation could be misleading and it was hard to know what was really happening with an individual pile being formed ten metres below the ground. There was no doubt in his mind but that the quality of workmanship was as fundamental in bored piling practice, as in any other part of engineering.

DR. I. G. DORAN said that he considered one of the major developments in Northern Ireland to be the use of large diameter piles. Much of Belfast was built on a material known locally as "sleech". This material, that his professor used to refer to as impalpable mud, had a high organic content and could be ten metres thick or more. Small diameter bored piles had been widely used and, in small buildings, still were used, but the tendency had developed to support large buildings on large piles, possibly up to two metres in diameter, taken right down to the underlying sandstone. The problems that had been mentioned for small bored piles existed also for the large piles; and he could not say that many of them had been resolved. The production and placing of concrete was carried out under the most unfavourable conditions, the pours tended to be large pours in their own right, and the site was usually at an early stage of development, dirty and perhaps very wet. The process of getting a large volume of properly compacted concrete into such a place was formidable and one had to rely greatly on having highly competent people to supervise the work. It might be that it was often the absence of good supervision that led to foundation failures of the kind being considered, although he felt one should make the comment that foundation failures were in fact remarkably rare. He felt that ordinary settlement did not often reach proportions where one would have to describe it as failure.

Foundation failures that related possibly more directly to soil mechanics were those involving the stability of whole sites. He had once been shown an example where a nearly completed petrol filling station, consisting of very light timber buildings erected on a partially filled site on a river bank, had disappeared quietly into the river during one weekend. He supposed that might class as a foundation failure! Case studies of such matters could be very useful.

On the matter of case studies, he recalled a study being made on an old school building where some cracks had developed in walls. Dated tell-tales of sticky paper had been placed across the cracks to monitor any further movement, and shortly afterwards, an interested observer had written with chalk on the wall beside one of the tell-tales "This will never hold it!"

In considering Mr. Browett's questionnaire he had thought about a topic that had been raised during the session, namely the amount of site investigation needed, and the designer's dependence on it. He was concerned, firstly, lest designers should feel that they should have a site investigation because it was the done thing, and, secondly, lest, having had one made, they should feel that their own problems had thereby been solved. Soil mechanics and foundation engineering were very different things. Soil mechanics was a highly theoretical subject that had produced valuable methods, involving liquid limits, plastic limits, moisture content, and so on, to help in soil classification. He agreed that by means of such soil mechanics techniques as for instance triaxial testing, one could reach the stage of applying formulae to suggest safe loading levels, and these the engineering designer was then liable to use uncritically. He could not feel that that was engineering. An engineer had to know for himself the materials he was dealing with. Soil was just as much an engineering material as concrete, and it was not good enough for a designer to get someone to do investigation for him and tell him what to do. The purpose of a site investigation should be to tell the designer clearly what the nature of the soil conditions on the site was and it was then the function of the designer to select his foundation system on his own personal understanding of those conditions.

MR. H. CLIFTON pointed out that however unfortunate foundation failure was, it was really only from that condition that one could learn of ground behaviour, because it was only there that one reached a factor of safety of one or less. He recommended a lecture by Terzaghi, given in 1939 as an important source to study (Editor's note: "Soil mechanics—a new chapter in engineering science" the James Forrest Lecture by Karl Von Terzaghi Dr. Ing. M.I.C.E., published in the Journal of the Institution of Civil Engineers, No. 7, 1938-39, June, 1939, pp. 106-141). In that study, a number of failures had been examined. Each had been of a structure carefully designed in all respects except that in each some essential aspect of ground behaviour had

been neglected, and failure had resulted. One of the structures had been a small mass concrete gravity dam. This had failed, due to piping, and, a few days later, could only be located under the material that covered it, by probing with a long rod. Terzaghi had been personally concerned in that episode, and it had left an indelible impression upon his mind.

In Mr. Clifton's own experience he had come across only two failures in over thirty five years of practice. In the first, in the early 1950's, concrete in a foundation had failed to harden. A Belgian cement had been used in that work. More recently a decision had been taken, he hoped by an administrator rather than by an engineer, to install a new washing machine in a laundry. Shortly after completion, it had been noticed that the machine was tilting. The facts had been quite simple. The floor had not been designed to receive such a load, and the designers had not been consulted about the proposed change.

MR. M. SWEENEY commented on the facts that Mr. Browett had assembled concerning the choice of a piling method. The conclusion reached was that bored piles were generally used in Irish practice. He had experience in that area, both with structures on land and marine structures, and he wondered if in fact Mr. Browett had been given the material to offer a truly representative answer on the matter. In Mr. Sweeney's experience, there was nothing to equal the precast pile, given a virgin site with no problems likely to arise from possible vibration on driving. The pile would have been made under excellent conditions, and the driving programme provided a dynamic check on load capacity. With bored piles, one had to worry constantly about underground water and the possibility of a pile section nominally 300 or 400 millimetres in diameter ending up with a "necked" concrete section 75 millimetres in diameter.

He would assure Dr. Doran that Belfast did not have a monopoly of poor ground. Cork had the very same problem, only they called it silt instead of sleech. In Cork, one might find oneself piling in what was virtually a swamp, and vibration was a real problem.

Mr. Sweeney said that he preferred to place reliance on a test pile approach for proving ground, rather than on a site investigation as he understood the term. The test pile did not have to be full size, a 50 mm scaffold tube driven with a known weight could provide useful results. The reference to large diameter bored piles had been interesting. The Electricity Supply Board had used quite large bored piles in the Poolbeg Power Station foundations. That project had included some of the longest bored piles ever made, and they had been tested successfully up to a load of 600 tons.

Referring again to the "red lights" associated with bored piling, Mr. Sweeney recommended that a liner should always be used, pointing out that, in his experience, some of the outstanding foundation failures had arisen through the action of water on bored piles.

MR. N. LOONEY endorsed the warning given by Mr. Sweeney about bored piles. There had been many failures in Britain that could be attributed to the use of bored piles without adequate prior investigation of the ground conditions. Dealing with water-retaining structures, he mentioned a project in which lengths of corrugated metal decking had been used as waterbars. The material had adequate rigidity and long-term corrosion was inhibited by its being coated with a bituminous skin. He also suggested the merits of butyl rubber linings, which could solve many of the problems of water-retaining structures, with a considerable saving in construction cost. Regarding flotation he felt that one interesting solution lay in the use of relief valves, which by permitting the flooding of a basement by rising ground water, could thereby inhibit the development of differential hydrostatic head.

Regarding site investigation, he mentioned a practice he had seen used in other countries, which involved the lodging of site investigation results with a central authority, for inspection by others interested in the area. A library of such information for a town or city would be very useful. He realised that one could not advocate such a practice as a means for saving money on the investigation of any particular site, as the possibility of local variations, between for instance adjacent sites could not be ignored.

MR. J. McCULLOUGH, in a written contribution, discussed the problems associated with the adequacy of site investigation. He quoted paragraph 800 of BSCP 2001 "the cost of adequate exploration is low when compared with the total value of the work, but varies with the type of structure and the nature of the ground, a usual figure being of the order of one per cent". Subsequent paragraphs in the Code would suggest that that value was intended to apply mainly, if not wholly, to soils investigation.

Mr. McCullough pointed out that a new 2,000 square metre office building in Dublin might be expected to cost one million pounds, including land purchase. On the basis quoted, a site investigation would cost £10,000, but in practice, experience suggested that to persuade a client to spend even £1,000 (0.1% of the total cost) on such work, or to convince his architect that even £1,000 was necessary, was not often possible.

The engineer's position was too often that he could not have a proper investigation carried out. Nevertheless, despite all the consequent reservations and the contingency sums which he had to seek to have included in the contract documents, he risked being considered incompetent if the foundation design assumed for contract purposes had to be re-designed in a more costly form as a result of post-contract information.

The concept of an "adequate" site investigation was, possibly, nonsense. A more realistic approach might be to follow the present procedure of having relatively inadequate site investigation done, and

to take steps as a profession to try to ensure that the risk involved was fully understood by all parties concerned, and that appropriate reservations and contingency sums were entered into the contract documents.

MR. P. KWIK, in a written contribution, mentioned the design and construction of a number of industrial reinforced concrete buildings, supported on 445 mm diameter "West" driven piles with a safe working load of 75 tonnes, to support column loads ranging from 50 to 450 tonnes. The piles supporting loads over 70 tonnes had been driven at a spacing of 1.335 metre centres (3d). The ground consisted of very soft clay overlying a dense gravel layer, into which the piles had been driven to the required set. The length of the piles was generally 10 metres. Since seven or eight piles had been required to support the heavy column loads, reduction factors for the safe carrying capacity of a pile ground had been taken into account. No special provision had been made however for uplift of piles due to driven displacement.

He had read an article in Civil Engineering and Public Works Review, in its issue for March 1972, that dealt with that matter, and he had concluded from the article that very large bending moments might now exist in the ground floor beams and columns of the buildings mentioned. He had recently made observations on similar driven piles that seemed to confirm such an opinion. The buildings however appeared to be still sound, despite the fact that the ground floor beams and columns were most probably resisting bending moments for which they had not been designed. He would like to hear of building failures, shown by the cracking of foundation beams or the lower parts of columns, where uplift of closely driven piles had not been taken into account.

MR. BROWETT replied to the discussion.

He thanked Mr. Gwynn for introducing the topics of prestressed foundation ties, and flotation. They were both important aspects of foundation design, and the matter of flotation had in fact been touched on in the answers on some of the questionnaire forms.

Referring to the discussion on large diameter piles by Dr. Doran and Mr. Sweeney, Mr. Browett commented that at the Poolbeg site, which Mr. Sweeney had mentioned, there had in fact been constructional difficulties. It had been the intention to form the pile excavations with the metal driving tubes, to be withdrawn as concrete was placed. After casting the first piles, trial borings had been made down through them to determine their quality, and it had been found that for quite a significant length, the piles had consisted of nice clean gravel with no sign whatsoever of cement. The first proposal to overcome that problem had been the use of a light liner inside the driving tube, a liner of the type used in the car ferry pier construction at Dun Laoghaire. This would have been satisfactory but for the fact that the

driving tube had a wall thickness of nearly 50 mm. The removal of that tube at each pile would have left a considerable void which would have eventually been filled by general site settlement. It was felt that such a settlement, which might be of the order of three to four inches would not be acceptable, bearing in mind that the lighter elements of the structure were being supported on a second system of lighter shorter piles, in the same general plan area. Ultimately the decision had to be taken to use permanent heavy-walled driven liners, and that form of construction was used both on the first Poolbeg project, and later on its extension. The influence of ground water was clearly significant.

Regarding Mr. Sweeney's preference for using a pile system in which load capacity could be related to driving set, he would mention that some cast-in-situ piles were actually inserted by a driving process and, for these, a set-capacity relationship could be obtained.

Mr. Browett agreed with the use of strips of metal decking as a waterbar, as Mr. Looney had reported, but wondered whether possibly the greater thickness of such a material might not itself constitute a difficulty in construction. Butyl rubber linings clearly had value, particularly in short-term service. It would appear however that they did not respond so well to the high-sunlight conditions of the Middle Eastern countries, and he would have some reservations about their long-term behaviour in this country also. He felt that Mr. Looney's report of the system in some other countries of lodging trial bore results in some central place of general access was extremely interesting and should be investigated further for possible adoption in this country.

MR. BROWETT replied to the discussion. He thanked Mr. Gwynn for introducing the topic of prestressed foundation piles, and Mr. Looney for introducing the topic of prestressed foundation piles, and the matter of foundation had in fact been touched on in the answer to some of the questions. He referred to the discussion on large diameter piles by Dr. Dorman and Mr. Sweeney. Mr. Browett commented that at the Poolbeg site which Mr. Sweeney had mentioned, there had in fact been construction difficulties. It had been the intention to form the pile extensions with the metal driving tubes to be withdrawn as concrete was placed. After casting the first pile, trial borings had been made down through them to determine their quality, and it had been found that the piles had consisted of the clean gravel with no sign whatsoever of cement. The first proposal to overcome this problem had been the use of a light liner inside the driving tube. This would have been satisfactory but for the fact that the

SESSION H

GENERAL REPORTS AND DISCUSSION

Sessional Chairman :

PROFESSOR J. W. de COURCY, M.E., F.I.E.I., F.I.STRUCT.E.

University College, Dublin.

Short personal viewpoints of each of the seven sessions were invited from members of the Symposium as follows:

Session A: — N. G. Bunni, PH.D., M.SC., M.I.E.I., M.I.C.E., M.CONSE.I., A.I.ARB.

Session B: — J. J. Higgins, B.E., M.I.E.I., M.I.C.E., M.I.MUN.E.

Session C: — B. Le C. Byrne, B.E., M.I.E.I., F.I.STRUCT.E., M.I.C.E.

Session D: — O. Leach, B.ARCH., F.R.I.A.I., R.I.B.A.

Session E: — J. G. Douglas, B.A., B.A.I., M.I.E.I., M.I.C.E.

Session F: — N. Montgomery, B.ARCH., F.R.I.A.I., R.I.B.A.

Session G: — S. MacCraith, B.E., M.I.E.I.

DR. N. G. BUNNI referred to the huge volume of work dealt with by Mr. Harrington. Revisions to standard documents had been widespread in the previous decade with CP3 and CP110 representing particularly extensive development. Mr. Harrington had just missed having to deal also with CP2007 (Design and construction of reinforced and prestressed concrete structures for the storage of water and other aqueous liquids) which was now under revision and for which a draft was in circulation for comment. Reference to that draft might have had particular interest in view of its stringent references to the spacing of joints and in the light of Mr. Gwynn's earlier comments on the omission of waterbars.

Mr. Harrington's finding, that 70% of Irish concrete design was now being based on CP110, was extremely interesting, but he wondered whether it could really be true. He noted that only 57% of the consulting engineers asked by the author to supply information had done so, and considered that response to be really poor.

The paper had shown the necessity for an Irish Standard on ready-mixed concrete and in fact a final draft for that document had already been circulated for comment. On the subject of special Irish Standards generally, he felt that unless there was something definitely wrong or incomplete in an already established Code or Standard, the development of an Irish Standard would be unnecessary. As an example of one such topic, he considered that the function of lateral ties in reinforced concrete columns was not given sufficient weight in current Codes, and drew attention to a recent paper written for a symposium

of the American Concrete Institute in which what he felt was a more reasonable load-capacity equation was stated.

Concerning accelerated testing, his opinion was that adequate techniques did now exist. All laboratories, not only those directly associated with the supply of ready-mixed concrete, should now interest themselves in accelerated tests. That interest would enhance their acceptability with general specifiers.

Dr. Bunni felt he should comment in some detail on Mr. McCullough's observations on the certification and checking of calculations. Many countries required that that be done, not because of doubts regarding the ability or the qualification of the designer, but mainly to eliminate human error. Checking had to be whole-hearted. In Germany it was done by consulting engineers who were recognised as experts in their field and who charged the client a percentage of the original design fee. In Britain, it was mainly done by the various Local Authorities who employed special staff for the purpose. If the practice were now to be adopted in Ireland, those involved in checking would have to be qualified, competent, and experienced in their several fields and would have to be remunerated accordingly. A half-hearted approach could only be futile.

MR. J. J. HIGGINS complimented Mr. Mescal for having given the Symposium in addition to a valuable commentary, an important catalogue of the facts of concrete production and handling as they were in Ireland at present. The arguments made in the paper and in the subsequent discussions on the costs of bulk and bagged cements and of site-mixed and ready-mixed concrete had been very informative. It did however remain to him an unanswered question as to why bulk cement was not being used more widely in the country. He could of course see the attractions of ready-mixed concrete, but in areas remote from suppliers of that product he would have expected bulk cement to become more widely used. He heard with relief that other concrete users had been having the same problems as he had of an unsatisfactory delivery service from suppliers of ready-mixed concrete; and Mr. Mescal had made the point that that might be particularly so in the co-ordination of large orders. He felt sure that suppliers would take heed of the criticism of the Symposium in that matter.

Mr. Duggan had said that a lack of raw materials prevented the manufacture of white cement in Ireland. Perhaps in a country with our climate, imposing as it does frequent cycles of precipitation and drying, with consequent staining, we should regard white concrete surfaces, and indeed ultra-white painted surfaces as something of a frivolous extravagance. He did feel however that investigation of Irish coloured aggregates should be pursued and recommended this to University College as a useful study. Mr. Higgins welcomed the counsels offered on additives. He could testify from his own experience that wrong dosage could lead to complete failure. Stringent control was always essential in their use.

MR. B. Le C. BYRNE thanked Mr. Pigott for having given the Symposium a valuable survey of the range and volume of current precast concrete production in Ireland, and for his useful analysis of costs and of dimensional tolerances. For Mr. Byrne however the most striking feature of the session under review had been its preoccupation with an industry which had an annual value of about one million pounds, while at the same time ignoring the potential of the energy industry developing in our coastal waters.

The Marathon Petroleum company had recently stated that it was considering two platforms in the Celtic Sea. The combined cost of these would be of the order of eighty million pounds, and every member of the Symposium and all engineers in Ireland with an interest in concrete should be concerned that they be concrete structures made in Ireland. The gravity form of structure, typified by the Condeep design, might be suitable. These were made near the shore and towed out to their working sites when largely complete, and came therefore into the category of precast concrete. What was important to us was that platforms for use in the Celtic Sea be made near the shore of Ireland, rather than, as at present, near the shore of Norway; and that would not happen unless Irish engineers took some initiative.

MR. O. LEACH considered that as an architect there were many areas of civil engineering on which he could not speak. He believed that architects had not yet learned to live with prestressed concrete in a civilised manner as while they could design simple reinforced concrete, they regarded prestressing as a mystery. So far as precast units were concerned they tended to leave the matter of their strength in the hands of the suppliers, not always even knowing in fact whether units being used were prestressed or not. He found it quite frightful that architects would not know what materials they were using, but it seemed to him that this could actually happen, as he himself had found in an investigation into another matter, namely the use of high alumina cement, that some architects who had used it were not in fact aware that they had done so. So far as post-tensioned in-situ work was concerned, he had found that maintenance staff were so scared of the stresses locked into the structures that they balked even at a rawl-plug for a lighting pendant.

Mr. Leach was critical of much precast work and not merely that which was prestressed. As the slides had shown, during the Symposium, precast units could impose a cruel deafening rhythm in which any delicate counterpoint was completely lost. System buildings had to be looked at closely also. Few of them kept the rain out for long, and all incurred maintenance costs about double those for traditional building. Frequently, too, most brutal inaccuracies occurred and these led, in erection, to inadequate bearings on the one hand, or, on the other, the necessity for a "ten-kilogram persuader" to get them into position at all.

MR. J. G. DOUGLAS reminded the Symposium that while the immediate relevance of a research project might not be obvious, it was the research of five to ten years ago that made the Standards and Codes of today. Dr. Glynn's survey would be a useful source for reference in future years. Mr. Douglas spoke of the role of the Institute for Industrial Research and Standards. It had sometimes been criticized for its apparent lack of contribution to concrete research. He would say firstly that the main objective of the Institute was to assist with the effective transfer of new and approved technology into the industry. This was done by providing technical support to all sections of the industry, be they contractors, manufacturers, designers, or clients, in their pursuit of objectives valuable to society. In that context he would urge that research and development always bear in mind and be relevant to the legitimate prospects of the various entrepreneurs. Secondly, it would be realized that many such projects, representing co-operation between the Institute and individual clients, involved complex technical and production processes and as such were always confidential to the client and had perforce to remain unpublished. Mr. Piggott, in his paper on precast concrete had given a very good account of the type of work which had been carried out by the Building Division of the Institute during recent years in relation to precast concrete. A very similar statement might have been prepared for in-situ concrete. These would indicate the interest of the Institute in research.

He did not feel that it was an appropriate time to discuss high alumina cement in depth. He should report however that the Institute, working in conjunction with consulting engineers, had done a considerable amount of work in that field, in Ireland, and it was hoped to make that work the subject of a paper in the not-too-distant future. He should also report regarding the rapid analysis of fresh concrete that the machine developed by the Cement and Concrete Association was at present being evaluated by the Institute, for possible recommendation to the Irish industry. He felt however that the inability of the machine to distinguish automatically between cement and silt in the aggregate militated to some degree against it.

Regarding lightweight aggregates it was the smallness of the Irish market, in his opinion, rather than the absence of suitable raw materials, that had heretofore discouraged investment in Ireland in that area. He suggested that the new world energy conservation situation might encourage further exploration.

MR. N. MONTGOMERY considered Mr. McCullough's paper to be excellent, but that was no more than he would have expected from an engineer who had distinguished himself not only in engineering, but also as a citizen in his work for conservation. The presentation of his paper had been masterly. Mr. McCullough had set the present scene, observing quite rightly that modern architecture in the post-war period

had not reached Ireland until 1965. He had also looked at the future, talked about the energy crisis, said we would have to think of buildings with less window and more wall, and discussed the advantage of different forms of insulation. He had spoken about the dull grey skies over Ireland and the feeling of comfort given by the old-fashioned house; but he had been quick to add that we should not on that account build nostalgically, or indulge in pastiche, but should bear in mind, for instance, the automobile industry which turned out new car models every year.

Mr. McCullough had revealed, in his presentation of slides, modesty and sensibility, and generosity in the sense that he had praised so much the work of other designers. Mr. Montgomery had been staggered to hear, during the symposium, so many engineers praise the work of others, a phenomenon, he felt compelled to add, not necessarily common to all professions. A remarkable feature of the period under review had, in his opinion, been the outstanding excellence of the work of Scott Tallon Walker with its beauty of proportion, its detailing, and its general architectural splendour. Mr. Montgomery also expressed a certain interest in the church slides which had been shown.

Reverting to details of the paper, and its presentation, Mr. Montgomery felt that he could not agree with the idea of painting concrete. One of the great things about this part of the century was that women had stopped painting their faces. He preferred wrinkles to rouge, and concrete should be expressed for the material it was.

He was very much in sympathy with Mr. Duggan's call for more human architecture, for architecture which did consider the requirements of humanity and of amenity as parameters. Most of the buildings that Mr. McCullough had shown were, at once, of wonderful quality, and, at the same time, most insistent in their design that they should not look like buildings. Perhaps architecture had become what the young were calling it, a bourgeois pursuit unconcerned with the common weal, perhaps it had indeed become the enemy of the people. On reflection, it seemed to Mr. Montgomery that there might be a parallel between our predicament at this end of the twentieth century and that of civilized people in the fifteenth and sixteenth centuries. Gothic architecture, too, had been, like ours, strange, exhibitionist, inhuman. There was a sense in which a Gothic cathedral did not look familiar, did not look like a building. The world of the Renaissance had been inspired by the Greek ideal, by the notion that man was the measure of all things. The devotion to that ideal was seen in the splendour of humanism, more apparent perhaps in architecture than in the other arts. It was human also to be bored and to seek change and he wondered whether perhaps the Modern Movement, so impressive to people of his generation, was simply twentieth-century Gothic. The time might well be ripe not for a nostalgic eclectic architecture but for a return to those human values for which Mr. Duggan had made his plea.

MR. S. McCRAITH reported on Mr. Browett's paper on concrete foundation practice. The survey made by the author had been broadly based and painstaking, the results were quite revealing, and many important topics had been raised in the author's commentary and in the discussion from the floor.

It was clear that many opinions existed as to what constituted "ordinary ground". Belfast, Dublin, and Cork had their own understanding of the term. Again, as regards loading, while ordinary ground represented a safe capacity of 1 to 2 tons per square foot for the architect, the engineer saw that capacity ranging from $\frac{1}{2}$ to 5 tons per square foot.

Site investigation attracted mixed stances and views. The general consensus accepted their importance, as one could not gamble on foundations. Individual attitudes were however expressed against that background. Mr. Gwynn wondered whether perhaps investigations had sometimes been overdone and questioned whether results had sometimes been misleading rather than helpful. Mr. Sweeney considered that the driving of test piles often constituted an important part of a site investigation. Dr. Doran took a general materials viewpoint, say that soil was a material just as steel and concrete, and deserved as much study and understanding by engineers as they did.

Many other areas of the subject were discussed. Several speakers mentioned piling. The potential hidden weaknesses of in-situ piles, of both small and large diameter, arising from faulty construction were stressed, and there emerged considerable support for precast piling. Various failures were discussed in an interesting and helpful manner. Flotation was clearly a problem, to judge by the references made to it, and Mr. Looney's point of using relief valves in the walls of large basements had been noted.

Mr. McCraith found one of the implications surrounding the introduction of the SI system of particular interest. Mr. Browett had said that translation and "rounding up" of quantities from imperial to SI measure appeared to him to represent increases of up to 7% in plan size, especially of large foundations; and such increases tended to attract consequential increases in slab thicknesses, or in reinforcement, or in both. Such cumulative increases could easily become extravagant and should be kept closely under review.

Mr. McCraith concurred with the view expressed by Messrs. Browett and Looney that records of site investigation should be lodged with Local Authorities as a matter of course. The building-up of information on local ground conditions was to the advantage of everyone.

General discussion followed.

MR. P. J. McMULLAN was disappointed at the shortage of reference to work in Northern Ireland. It had been limited to comments by Mr. Pigott, Mr. Duggan, Mr. Shinwkin, Dr. Glynn and Dr. Doran. He

questioned whether adequate notification of the symposium had been given to Northern engineers. After all conditions were largely the same throughout the whole island, and experience could usefully be shared.

He found it hard to accept Mr. Shinkwin's contention that subsidy, in some form, of Northern industry was a significant factor in enabling precast concrete to be exported from Northern Ireland to the Republic. He wondered whether some of the engineers who had come from Belfast to the symposium might comment on that point.

Regarding prestressed concrete, Mr. McMullan felt that the bridges on the M1 and M2 motorways deserved mention, while as regards foundation problems, the same bridges, in the stretch of motorway between Craigavon and Dungannon, had been founded on rock in some instances, and in areas covered with peat 20 m deep in others. Many difficulties had been successfully surmounted in the design and construction of the foundations and notes on the methods used could be useful to many designers. The range of concrete buildings shown by Mr. McCullough had been impressive, but there again there were many fine examples in Northern Ireland which might have been included. He would single out, perhaps, the extension to the Ulster Museum, where a fine harmony had been established with the adjacent older buildings.

It was depressing to find Dr. Glynn having to repeat what had been said in 1965, namely that Irish industry should accept its responsibility in the fostering of research, and to have to contemplate the possibility of hearing the same criticism in 1985. Mr. McMullan, as a student at Queen's University, Belfast in 1969, had made a special study of full scale component testing, and his project had taken him to Dundee, Glasgow and Strathclyde. He had found, in Scotland, a quite close liaison between the construction industry, sometimes represented by a Local Authority, and the universities. He felt it might be heartening to report that much of the testing involved had quite clearly paid for itself in the consequent increased economy in use of the components tested.

In answer to Professor Dillon's query to Dr. Glynn concerning systems of measurement for field studies, and including the BRE scratch gauge, detailed information on this matter in general would be found in the dissertation mentioned by Dr. Glynn "A study of methods for the measurement of movement in structures and an assessment of their accuracy" (Session E, reference 11). Finally he had noticed that no reference was made to the Schmidt hammer in the discussion on the testing of in-situ concrete. He understood that there were situations in which it could validly be used to assess concrete strength and that studies had been made by Duggan and Hallinan in that matter at University College, Dublin.

MR. T. M. DUGGAN expressed a fear that his remarks at Session B might have led to a misunderstanding. He has expressed surprise, in

connexion with a comment made by Mr. Sweeney about the cost of cement, that a differential considerably in excess of £5 per tonne pertained between bagged and bulk cement prices in the Dublin area. He hastened to say that in no way had he been querying the accuracy of Mr. Sweeney's facts. His surprise had been based, and still remained so, on the fact that any contractor should, unfortunately, have been required to pay such a large differential, when the correct differential for delivery in Dublin, in Mr. Duggan's belief, was of the order of £1.67 per tonne (to which would be added the small delivery charge necessary from the rail head to the city site).

He would like to correct one error which he had made in the figures given to the earlier session. The price of bags per tonne of cement should have been £1.50 and not £1.75 as mentioned earlier. He had to add that it still continued to puzzle him why such a high use of bagged cement persisted, especially in view of the costs which bagging as such attracted, namely such things as the actual cost of bags and their filling and emptying and subsequent disposal.

MR. P. AUNGIER in a written contribution* said that while the principle of having authors from the 1965 symposium as lead speakers for the 1975 papers was good, it might have tended to make the 1975 symposium the prisoner of the 1965 event, and might have restricted the choice of papers. He would have liked a paper in 1975 on in-situ construction, making reference for instance to the road bridges built by Dublin Corporation and the slip-formed silos at Platin. New methods of reinforcement might have been noticed as for instance galvanized bars, very high strength bars, and unbonded prestressing tendons, and the use of Cor-Ten steel beams in composite construction. The remedial use of prestressing, as instanced for example by the strengthening of the Terminus Street Bridge at Wateford about three years ago, would have been worth discussing.

The paper on foundation practice might with advantage have extended its scope to discuss practice for quay walls and pier and abutment foundations in potential scour situations. Mr. Aungier would have liked Dr. Glynn to have included in his paper short synopses of the findings of the research which he had described. He agreed with Dr. Glynn on the value of observing existing structures in service, and in that connexion would stress the importance of having properly qualified persons in charge of maintenance.

Finally he would have welcomed a paper on concrete design and construction in the world at large. He had been glad to hear Mr. Byrne's exhortation on off-shore structures, and many other topics might be raised. He referred in particular to the suggestion of a barrage

*(The organisers of the Symposium thank Mr. Aungier for his remarks, and will bear them in mind for possible future occasions. They regret that a need to establish length and scope restrictions for the published papers prevented the extended treatment which Mr. Aungier suggested and which all, including the authors, would have welcomed.)

on the River Liffey instead of the bridge proposed east of Butt Bridge, the concept of concrete ships, the floating tunnel proposed for the Straits of Messina, aid a general approach to off-shore nuclear power plants. He considered topics like these should receive some attention from Irish engineers.

THE CHAIRMAN read a letter he had received from Mr. J. O'Sullivan, a member of the symposium. It stated:—

"I would like to comment on a point mentioned in passing by Dr. Orr, the principal speaker to the first paper, namely continuing education. I think that at a conference on concrete practice in Ireland it is essential that a call be made for the provision of continuing education courses for engineers, on concrete practice, concrete developments, and changes and revisions in the Codes. The course organized at University College, Cork on CP110 is an example of what should be available at all times.

I am not sure where the responsibility for such courses lies, maybe I.E.I., maybe the Concrete Society, or maybe it is an obligation on the universities to provide these continuing education courses as well as the basic educational courses.

To summarise, I feel that the opportunities for engineers to keep informed of changes and developments in concrete practice and design in Ireland are very limited and urgently need to be improved".

Professor de Courcy felt that that was an important contribution to the discussion and he hoped that members would advert to it in answering the questionnaires which had been circulated to them.

In reply to Mr. McMullan, the main medium of publicity for the symposium had been the journal "Irish Engineers" and this was circulated to some hundreds of engineers in Northern Ireland. The organizers would of course welcome the fullest participation in their conferences, but possibly the publicity for the present event had not been very forceful.

Dr. Glynn and Mr. Lydon deserved support for their remarks regarding the importance of observing the behaviour of buildings in service. As a counsel of perfection, he felt that every structural designer should at any time have at least one building under his own personal observation, as an on-going exercise in relating design to performance. Regarding research generally, it could be argued that the major part of our limited national research funds should be devoted to the study of Irish problems. Basic research in concrete was in progress all over the world and the results could be applied here, with little adaptation. Our geographical location however gave us some unusual problems, associated for instance with high wind and high rainfall and, in another sphere, a small market, and we should examine these for ourselves. In the area of the effect of wind and rain on buildings, a useful source of reference was the symposium "The weathering

of concrete" organized by the Concrete Society in London in January, 1971.

Another area of research lay in the study of our extensive deposits of glacial gravel aggregates. The Civil Engineering Department of University College, Dublin had maps for each county, showing many of the worked sources of aggregate, both gravels and crushed rock. It would welcome assistance in developing the information on those sheets. Continuing in the subject of concrete aggregate supplies, Professor de Courcy referred to an anomaly which he believed to exist in Irish practice at present. On the one hand there were vast unworked deposits of glacial gravel in the Midlands and in East Connaught, and on the other, enormous quarry complexes were being developed near some of our major cities. There seemed to be a case for a national socio-economic study of that matter, with particular reference to the future development of the precast concrete industry. The movement of factories towards the general aggregate sources, which were in areas relatively underdeveloped industrially, offered long-term benefits to both producers and consumers. There would of course be obvious short-term problems of housing and transport, but these had been faced in quite similar circumstances by Bord na Mona; and one might also quote Cement Limited as exemplifying the sense of erecting processing works nears the sources of the raw materials being processed. Finally, still on the subject of concrete aggregates, the time was rapidly coming when studies of our off-shore gravel deposits would become imperative.

On research generally, Professor de Courcy knew how much Dr. Glynn had regretted having to confine his paper in the symposium to a review of concrete research in the universities. Research was, of course, in vigorous progress in many other establishments in the country and it would be greatly to the general benefit if as much as possible of it could be assembled and reviewed. Methods of transmitting research findings to the industry should also be examined, as that always appeared to constitute a bottleneck. Some consideration should be given to the setting up of a small representative body with the function of collating building research findings reported to it and making their availability known to the industry.

Mr. Browett's identification of "shuffle" in imperial-to-SI translations was revealing. There was much to be done in agreeing between ourselves what precise SI dimensions we wanted to use, what increments in slab thicknesses and beam dimensions, what standardized reinforcement spacings, and the like. It was not of course purely an Irish problem, but existed in all countries where the change-over had occurred, and was in fact being studied internationally.

Professor de Courcy said that as one of the organizers of the symposium, he wished on behalf of everyone to thank the authors for their essential contributions to the success of the event, and to thank the lead speakers and chairman for the parts which they had played so

well. The viewpoint speakers who had just reported on the seven sessions had provided significant subjective commentaries on the proceedings and deserved the members' thanks for having undertaken their tasks at such short notice. Mr. Montgomery's sartorial reference had contained an added piquancy in that the first Professor of Civil Engineering at University College, Pierce F. Purcell, who had held the chair from 1909 to 1953, had himself been a graduate of Trinity College.

He was delighted to thank all those who had worked behind the scenes for the efficient running of the symposium. If digression for a moment were permitted, he would like to mention to the members of the Symposium the name of Paddy May who had been the head technician in the Civil Engineering Department of the College from 1918 to 1965, with, as would be recalled by those who had known him, a particular expertise and interest in concrete and cement. He was glad to say that Mr. May was hale and hearty, living in Bray, and he would like to extend good wishes to him from the Symposium.

Finally, he was honoured to thank, on behalf of the organizers, all who had attended the Symposium and who, by their attendance, had made the event successful.

MR. A. B. HARMAN speaking on behalf of the members of the Symposium thanked the Civil Engineering Department for its organization of the event.

DUGGAN, P. J.

DUGGAN, R. A.

DUGGAN, T. M.

GLYNN, T. E.

GWYNN, J.

HALL, T. R.

HALLORAN, K. M.

HARMAN, A. B.

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APPENDIX

A list of subjects suggested by the members of the Symposium for further study.

One of the questions in a questionnaire circulated during the Symposium asked whether there were any topics in the field of concrete practice on which the members would find short symposia, or other short events, useful. The following proposals were made :

(a) Materials, processes, and equipment

Admixtures, concrete blocks and blockwork, grouting and guniting, soil stabilization, fibre reinforcement, the use of indigenous materials to replace imports, epoxy resins including their long term behaviour, aggregate types and sources, concrete production equipment, lightweight aggregates and possible local sources, concrete mix design.

(b) Design and detail

Finite element analysis, limit state design and CP.110, specific design examples, design and construction errors and their influence on the safety of the finished structure, optimisation related to locality, crack control, temporary and permanent joints, fire protection, the elimination of staining, high alumina cement in existing structures, water-retaining structures, piling, offshore concrete, concrete pavings, concrete finishes, the fixings for precast concrete.

(c) Organization and control of works

Accelerated testing, testing finished structures, training for site personnel, the drafting and enforcement of specifications, building regulations, the role of the technician, general trends in international practice, co-ordination of research and development.

Mr. Browett's identification of "shuffle" in imperial-to-SI translations was revealing. There was much to be done in agreeing between ourselves what precise SI dimensions we wanted to use, what increments in slab thicknesses and beam dimensions, what standardized reinforcement spacings, and the like. It was not of course purely an Irish problem, but existed in all countries where the change-over had occurred, and was in fact being studied internationally.

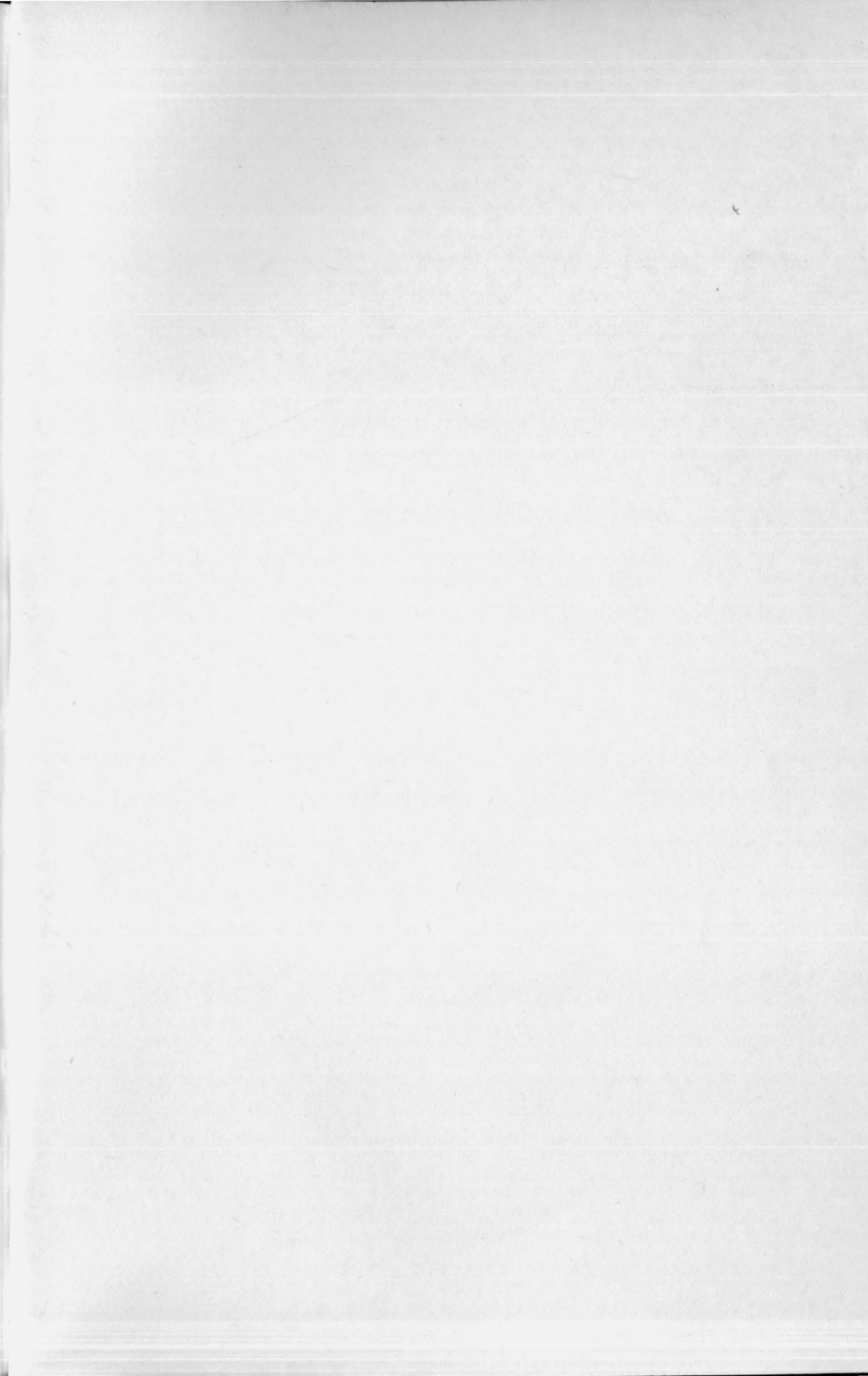
Professor de Courcy said that as one of the organizers of the symposium, he wished on behalf of everyone to thank the authors for their essential contributions to the success of the event, and to thank the lead speakers and chairman for the parts which they had played so

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