

CONCRETE PRACTICE IN IRELAND 1965

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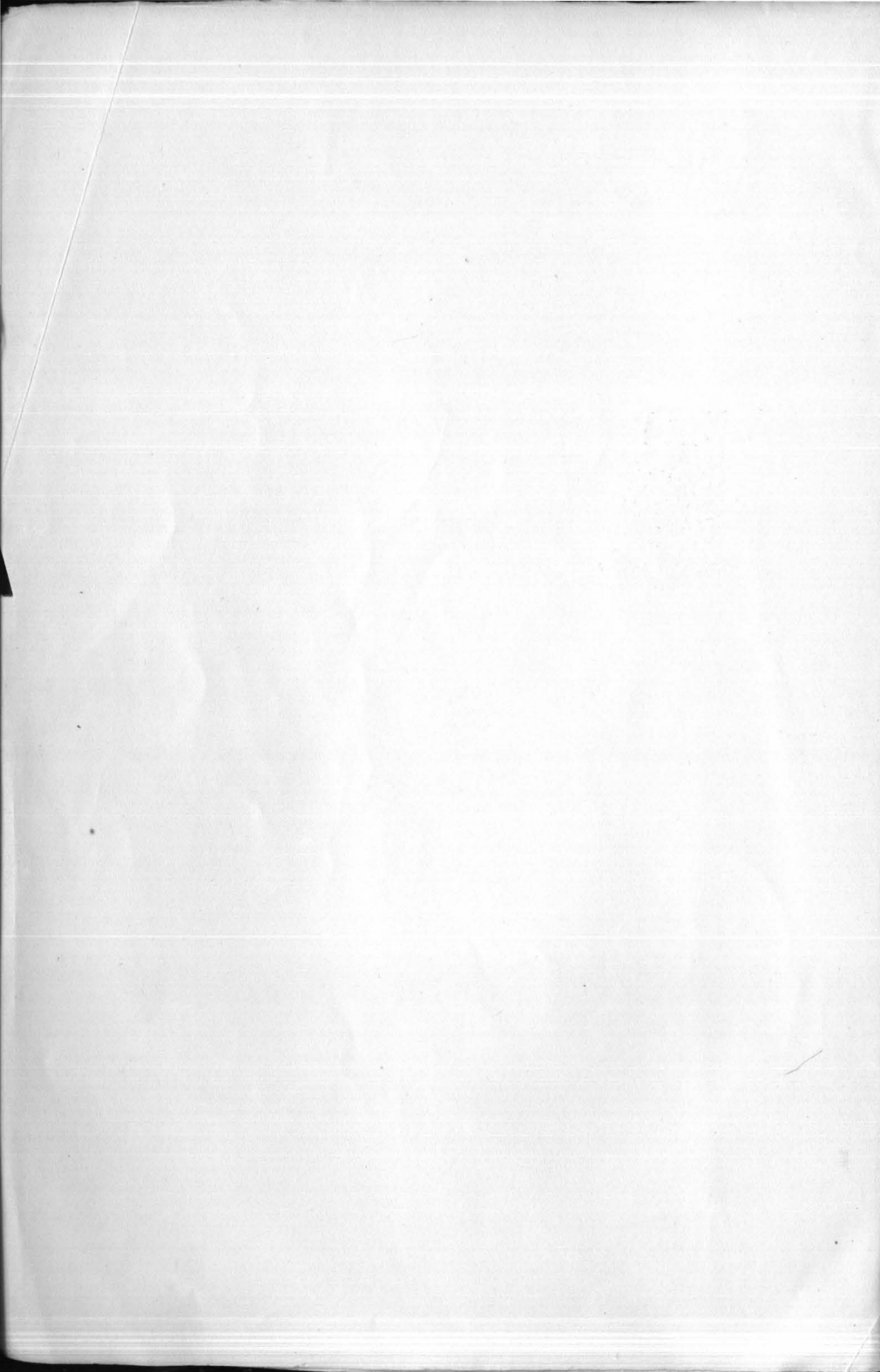
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SYMPOSIUM

SEPTEMBER 1965



UNIVERSITY COLLEGE
DUBLIN



CONCRETE PRACTICE IN IRELAND 1965



**Proceedings of a Symposium
held at University College Dublin
in September 1965**

Published by
the Department of Civil Engineering
University College Dublin

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Irish Practice in Engineering

No. 1 : Concrete Practice in Ireland 1965

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FOREWORD

**PROFESSOR M. A. HOGAN, B.E., D.Sc.(Lond.), D.I.C.,
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Dean of the Faculty of Engineering and Architecture,
University College, Dublin.

The theme of this Symposium, "A Review of Concrete Practice in Ireland," was chosen because concrete is undoubtedly the most important constructional material in Ireland today, and it seemed desirable to bring to light some of the problems still awaiting solution in its applications. By reason of the construction of the new building at Belfield, for Science, more space had recently been made available to the Engineering Departments of the College which now made possible facilities for research by both staff and students. It was hoped that the present Symposium would help in the selection of useful topics for research.

Although owing to shortage of staff, the rapid growth in student numbers, and lack of space, little had been done in recent years, it would be wrong to convey the idea that nothing had been done in the way of concrete research in University College, Dublin. In the years 1917-1920, Professor P. F. Purcell, assisted by Nicholas O'Dwyer, Jerome Carroll, and the writer, took part in an investigation of the properties of concrete mixes made from local aggregates.

A meeting of this sort would not be possible without the support of the various organizations and firms who employ engineers, and from the numbers attending, it was clear that this support was accorded on a generous scale.

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SESSION A

STANDARDS AND SPECIFICATIONS FOR STRUCTURAL CONCRETE

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Partner: T. A. GARLAND, consulting engineer

Sessional Chairman:

W. I. BLOOMER, B.E., B.Sc., A.M.I.C.E., M.I.C.E.I.

Summary

The design standards used in Ireland at present for assessing imposed loads on buildings, including wind, and the corresponding codes, regulations, and standards for general design in structural concrete are mentioned and examined. The principles for specifying concrete and the workmanship related to it are considered and a case is stated for an "agreed specification" to be used throughout the country. It is suggested that an Irish standard loading code might be very useful, but that little advantage would be gained by the introduction of Irish Codes of Practice.

A bibliography includes works referred to in the text and other relevant literature.

Standards for Loading

The loading standards in general use in Ireland are the British Standard Code of Practice No. 3 Cp. V "Loading" (1)* for structural work, and the Ministry of Transport loading B.S. 153 Pt. 3A "Girder Bridges—Loads" (2) for bridge design and for parts of structures subject to heavy commercial traffic. Roads are designed according to traffic density in accordance with Ministry of Transport & Civil Aviation Specification for Road & Bridge Works. (3).

Many engineers consider that the standard wind loadings given in Cp. V (see Cl. 7, Table 3 and Cl. 13, Table 6) are too light for many parts of this country, especially coastal areas, and prefer to calculate wind pressures from the meteorological records available for the nearest similar locality instead of adopting the wind pressures given in Cp. V., when designing structures for which the loading due to wind is an important consideration. Little information is available, however, on the duration of the maximum recorded gusts, so the pressures thus calculated may be too severe for many types of structure since the pressures set

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

out in Cp. V (see Cl. 7b) are based on the average wind velocity over a period of one minute. For certain structures, however, such a period may give insufficient design pressures, since the effect of gusts has been shown by Davenport to depend on the mass and rigidity of the structure (4). It is generally felt that when wind conditions are severe, a conservative design is desirable.

It is considered by some engineers that the loadings in Cp. V (see Cl. 3, Table 1) relating to office and industrial use are too light for modern conditions in view of the increasing use of heavy equipment, and that superloads derived from detailed equipment weights should be used in preference to those given in Cp. V. There is also some doubt whether the loading for hospital wards given in Cp. V is adequate in all cases, in view of the possible use in the future of heavy portable equipment. It is also observed that the minimum superload allowance for partitions in Cp. V (see Cl. 2) of 20 lb./sq. ft. is generally insufficient when blockwork partitions are used, since the weight of these may have the same effect as a superload of 50 lb./sq. ft. or more.

Some engineers consider that strict adherence to the minimum superloads given in Cp. V limits the future use and development of a structure, and consider that unless the planning of the structure is such that variation of use and development are not possible, a minimum superload of 100 lb./sq. ft. should be used in design.

The M.O.T. loading is generally more severe than that used in corresponding Continental and American practice. The case for a lighter loading for bridges on minor roads is being studied in the light of experience elsewhere.

Standards for Design

The standards for design in general use are BSCP 114 "Structural Use of Reinforced Concrete in Buildings" (5), BSCP 115 "Structural Use of Prestressed Concrete in Buildings" (6) and BSCP 2007 "Design and Construction of Reinforced and Prestressed Concrete Structures for the Storage of Water and Other Aqueous Liquids" (7), the last being a revision and re-issue of the code originally published by the Institution of Civil Engineers. Some engineers make use of parts of American and Continental codes instead of the corresponding parts of BSCP 114 and 115, or for matters not fully dealt with in the British codes. BSCP 2007 is rigidly adhered to for water retaining structures.

Only a few engineers in this country use load factor design. When this design approach is used, the method of the design is generally that set out in the British codes, but the methods of Johansen (8) and Jones (9) are also used. The varying load factors recommended by the Institution of Structural Engineers (10) are sometimes used instead of the uniform load factor used in the BSCP 114 method. Engineers using load factor design consider this method gives slightly more economical results than those given by elastic design methods.

Elastic design is preferred by most engineers, mainly because of familiarity with its application, but also because no useful economy is

anticipated in the use of load factor design. Some engineers feel that the possibilities of cracking and of large long term deflexions might be increased in structures designed by load factor methods. It is pointed out by Hajnal-Konyi that if the minimum span/depth ratios permitted in BSCP 114 (see Cl. 309, Table 13) are used, deflexions much larger than anticipated may result (11).

Although the British codes are generally followed, many engineers vary from the exact requirements according to individual judgement especially in regard to matters concerning which they consider the provisions of these codes to be unsatisfactory. The design methods for shear are particularly criticised, especially in view of the research findings reported in an article by Taylor in *Magazine of Concrete Research* No. 36 ("Some shear tests on reinforced concrete beams without shear reinforcement" Taylor) which indicate that the BS code recommendations may not provide an adequate factor of safety in all cases (12). The only revisions in the recommendations relating to design for shear in the 1965 edition of BSCP 114 refer to shear in principal members (see Cl. 316, para. iii) and to reduced stresses in high tensile shear reinforcement (see Cl. 304, Table 11). These revisions appear to indicate that further consideration of this section of the code is desirable.

The provisions in BSCP 114 relating to bond and anchorage are regarded by some engineers as unsatisfactory, and a more conservative design is preferred. Some engineers also consider that the code requirements for nominal reinforcement are excessive when applied to lightly loaded members.

Approval of Design

Building construction in general is required to comply with bye-laws for the appropriate locality, and local authorities are empowered to require the submission of calculations for checking. In practice these requirements are not enforced in full. The structural design requirements of most bye-laws refer mainly to traditional building construction rather than to reinforced and prestressed concrete construction, so that apart from minimum thicknesses for external walls and fireproof casing for steelwork, there are no specific design requirements other than that structural strength and stability shall be adequate. Design in accordance with the relevant British codes is accepted as meeting the requirements of strength and stability.

Work for which a grant from Government sources is sought is subject to further approval by the Department or Board allocating the grant. Such approval is comprehensive, covering design, drawings and specification. The extent of the checking of the design depends on the type of structure, and the importance of the member of the structure. General adherence to design codes BSCP 114, 115 and 2007 is required, and to loading codes BSCP 3 Cp. V and M.O.T. loading as appropriate. Variations from the exact requirements of these codes, except in relation to water retaining structures and bridges, are not objected to, provided that such variations comply with other codes or with specialist opinion. The

requirements of the codes relating to fire resistance, however, are enforced. Except in special circumstances, the minimum superloads of Cp. V are accepted, subject only to the use of heavier wind loadings than those of Cp. V where warranted.

Composite Structures

Composite construction for structural work is rarely used in Ireland, except for proprietary systems of precast decking utilising a structural topping, and for small bridges in which precast units are used with concrete infilling and topping. Composite construction has been used in jetty work, and in conjunction with in-situ reinforced concrete framed buildings. Some steelwork composite construction has been used, mainly for deck construction, but only a few composite steel framed buildings have been completed.

Few engineers are in favour of the more extensive use of composite construction, or consider that any appreciable economy can be obtained by the adoption of this type of construction in preference to normal in-situ construction. It is generally agreed, however, that composite construction could offer a saving in time when compared with orthodox construction. It is possible that the increasing use elsewhere of composite construction, and the publication of a recent report by the Institution of Structural Engineers, "Composite Construction in Steel and Concrete" (13) and BSCP 117 "Composite Construction in Structural Steel and Concrete" (14), may stimulate more interest in this type of construction.

Few contractors have any experience of composite construction, but some are interested in its possibilities, especially if work can be so designed as to reduce the number of trades required to execute the structural work. It is considered important that the weight of the prefabricated elements be suited to the hoisting equipment available for the contract and to the location of the site and that the length of haul of the prefabricated elements to the site be kept to the minimum.

Composite construction using structural steel has little appeal to contractors if the steelwork has to be fully encased in concrete as is at present required by the bye-laws. The development and economy of steelwork composite construction will to some extent depend on the acceptance by local authority and Government departments of systems of fireproofing equivalent to full concrete encasement. It is possible that further experience elsewhere of applied claddings to steelwork as fire protection may allow some easing of the present requirement of full concrete encasement.

Irish Standard Specifications

The Irish Standards applicable to concrete are IS 1 "Portland Cement" (15), and IS 5 "Coarse and Fine Aggregates from Natural Sources" (16). These standards are almost always referred to in specifications for concrete work. All work for or subject to approval by Government Departments must refer to these standards.

Specifications for Concrete Work

The specification for concrete work in any project is prepared by the Consulting Engineer, Architect or Surveyor for the project. The majority of such specifications cover the matters referred to in the workmanship sections of BSCP 114, 115 and 2007 but in greater detail. Some specifications make particular reference to these sections of the British Standards as being parts of the specification.

Concrete mixes are generally described by nominal volumetric proportions, volume of aggregate per cwt. of cement, and cement content per cu. yd. of finished work, and the minimum cube strength for each mix is given. For some types of work, especially waterproof concrete work, the minimum density of concrete is sometimes also given. Weight batching is generally specified. Exact proportions of water for each mix are rarely given, water content being generally related to workability and controlled thereby. Compaction of the concrete by vibrators is almost always specified.

A few consulting engineers have used specifications in which the concrete mixes are defined by the minimum cube strengths required, the cement content of each mix being determined by the contractor. In such specifications, usually referred to as "Strength" Specifications, a minimum cement content is usually stated, and the mix is required to be designed for a cube strength exceeding the minimum specified by a certain proportion or margin termed the control factor, which may depend on the site control and the types of aggregate used. The minimum requirements for adequate site control are sometimes also specified. Apart from the description of concrete mixes by strength, such specifications cover the same general matters as specifications in more common use.

Exact control of workability is rarely specified, but in many specifications slump tests are required and the slump generally allowable is specified.

The qualitative control of fresh concrete by the measurement of the density is sometimes specified.

Cube strength at 28 days is usually specified, but sometimes the equivalent 7-day strength is also given. Tests on cores cut from completed work are sometimes specified for high grade paving.

Tests on completed work other than relatively small precast units are never specified, except for bridges for which the appropriate M.O.T. test load is required. Some use has been made in practice of impact apparatus, which can in certain circumstances indicate the strength of finished concrete. Accounts, as for instance that by Jones (17) on an instrument of this type are of considerable interest, and indicate that further investigation into the possibilities of non-destructive testing of completed work should be carried out.

Waterproof Concrete

Specifications for waterproof concrete usually require the concrete mix to be richer than for normal concrete work, with a cement content

of 625-650 lb./cu. yd., corresponding to the nominal volumetric proportions of $1 : 1\frac{1}{2} : 3$, but some engineers, however, consider that a concrete mix of lower cement content, corresponding to nominal volumetric proportions of $1 : 2 : 4$ is adequate for this type of work, provided that the grading of the aggregates is satisfactory.

Additives of various kinds are quite often specified for waterproof work.

Particular emphasis is usually placed on a high standard of workmanship, especially in regard to joints, placing of concrete and shuttering. Minimum density of the finished concrete is sometimes specified. Water bars are generally specified at joints.

Consulting Engineers engaged in much work of this kind consider that maximum density obtained from a well designed mix carefully placed is the chief requirement for waterproof concrete, and that provided that maximum density for a particular type of aggregate is achieved leakage at joints is the only likely source of trouble. Most Consulting Engineers will allow additives to be used if the contractor wishes, particularly additives of the plasticiser type. It is considered, however, that the use of an additive does not modify in any way the basic requirements of maximum density and careful placing of the concrete, and the only reservation regarding the use of additives in waterproof work is that it may lead to lack of consideration of these important requirements.

Contractors experienced in waterproof concrete work believe that maximum density, resulting from proper grading of the aggregate is the chief requirement for satisfactory work, and that a rich mix is not necessary. They are aware of the additional labour, control and supervision needed for the successful execution of this type of work, and some in consequence consider the desired result difficult to achieve. Many are in favour of the use of additives to increase the workability of the concrete, and thus reduce the labour required to place the concrete, especially in the more difficult parts of the work. Some, however, feel that the use of an additive introduces another element requiring careful control, and that variations in the quantity of additive used could have serious consequences.

Many contractors consider that waterproof concrete work is not always adequately specified and that factors affecting the pricing and the execution of the work, such as concrete profiles, layout of reinforcement, and adverse site conditions are not always given full consideration. It is also pointed out that water bars in horizontal joints may be a hindrance to the proper consolidation of the concrete at the top of the lift and to the proper preparation of the joint surface for the succeeding lift, and that such details require careful consideration.

Self Finished Concrete

Concrete work for which the surface of the concrete is left exposed is termed "Self Finished Concrete," and concrete so termed can be finished in a variety of ways depending on the shuttering and the concrete mix, and on the surface treatment subsequently applied.

Self finished concrete has been used extensively on civil engineering work, and specifications for such work are relatively simple, the shuttering being specified as steel or timber, and the concrete mix determined by the structural requirements. Usually the surface of the concrete is required to be rubbed down with carborundum stone after the shuttering has been removed, air holes being filled or left open according to the type of work.

Self finished concrete is now in common use in architectural work, and a high standard of uniformity and workmanship is expected. Difficulties in executing such work are numerous, the most common arising from leakage at joints in the shuttering, junctions of structural parts, and deterioration of shuttering. The placing and arrangement of reinforcement, and the concrete mix have an important bearing on the satisfactory execution of the work. Colour change is also frequently experienced, arising from variations in the colour of the cement and in the cleanness, colour and grading of the aggregates. In a recent publication by the Cement and Concrete Association (18), Kinnear shows that colour change and surface defects may also be associated with the type of mould oil used and with the quality and usage of the shuttering.

Specifications for self finished concrete for architectural work vary widely, the shuttering being sometimes described in considerable detail. In practice it appears that while a high standard of workmanship is specified, many of the requirements regarding surface defects, joints and uniformity of appearance are left to interpretation. Prior investigation of the technique required and provision of a sample of the finish are rarely practised.

Many contractors find such work difficult to price accurately and to execute satisfactorily, and consider that the concrete profiles and detailing, and the concrete mix should be carefully considered in relation to the type of finish required. Many also feel that specifications for this type of work should be more comprehensive, and that the provision of a representative sample of the work and details of the technique used for its preparation would greatly assist the pricing and execution of the work.

Plasticisers are sometimes specified for self finished work, and have been found by some contractors to be of considerable help in placing the concrete, especially in difficult parts of the work.

Proprietary Additives

The additives most commonly used are waterproofing agents and plasticisers, which have been referred to in the sections dealing with waterproof and self finished concrete. There is a considerable number of other types of additive, which are excellently described in "A Guide to Specifying Concrete," published by the Institution of Civil Engineers (Appendix A) (19). These include accelerators, retarders, air-entraining agents and foaming agents, as well as the types referred to above. The uses and advantages of additives of the various types are also described in this publication.

Consulting Engineers and contractors are mainly conservative regard-

ing the use of proprietary additives, preferring to adjust mix proportions and materials and to use orthodox techniques to meet the various problems encountered in concrete work, rather than use additives for which specific advantages are claimed. Some contractors, however, feel that more interest should be taken in the possibilities of additives of which the particular effects have been established in use elsewhere, particularly accelerators and plasticisers. The beneficial effect of plasticisers in certain types of work has already been referred to, whilst accelerators could allow the early removal of supports and thus facilitate the rapid execution of concrete work as well as permitting the more extensive re-use of shuttering.

Ready Mixed Concrete

Ready mixed concrete has not been available in Dublin until fairly recently, so that experience of its use is limited. It has been used by quite a number of contractors, usually on small works, where space limitations did not allow the convenient placing of concreting plant on the site. It has also been used in conjunction with site concreting plant on large works where large pours have been required.

Ready mixed concrete is usually ordered to the same specification as the site concrete, and the strength is checked by test cubes made on site. The strength of the site test cubes is almost always satisfactory. Consistent standards of workability have generally been maintained.

The use of ready mixed concrete is never mandatory for concrete work, but a few specifications make provision for it, referring to BS 1926 "Ready Mixed Concrete" (20) for requirements for manufacture and delivery. In view of generally satisfactory experience, engineers in consulting practice and in public service readily permit the use of ready mixed concrete in place of concrete produced in accordance with the specification for the work. Some consulting engineers practise occasional works inspection, but generally the site check by cube strength is considered to provide adequate control.

Expense and convenience appear to govern the use of ready mixed concrete by contractors, many considering it to be more expensive than concrete produced by site plant under normal circumstances. To some extent, however, the cost of work in which ready mixed concrete is used depends on the type of work. When the location of the site and the nature of the work are such that a steady rate of delivery can be provided and large volumes of concrete can be discharged directly into the required position, the relative cost of such work compares favourably with that of work executed with site concreting plant. Delays in delivery and in placing the concrete, and re-handling with site plant can add appreciably to the cost of work in which ready mixed concrete is used.

Some contractors consider the control of ready mixed concrete to be better than on site, and that such control would allow the accurate use of additives.

Approval of Specifications

Specifications must be submitted with project drawings for approval by local authority under the Town Planning Acts. Specifications for works for which grants from Government sources are sought are subject to further approval by the Department or Board allocating the grant. Considerable latitude is allowed by local authorities and Government departments in the framing of specifications. General adherence to recommendations contained in the B.S. codes appropriate to the type of work is expected, and specifications of the "Strength" type are accepted for work for which this type of specification is considered suitable. The use of additives other than plasticisers is not generally favoured.

Current Standards of Work

Many engineers and contractors consider that standards of site control have improved greatly in recent years and that a satisfactory standard of work is more generally available, cube strengths for a given mix being greater and workmanship being of a more uniform standard. Much of the improvement in strength and quality is attributed to the wide availability of good aggregates and to the use of mechanical aids such as weight batching apparatus and vibrators. Much importance is also attached to the increased number of qualified engineers engaged in contracting work and to the increased understanding among foremen of the techniques involved in concrete work, from which better standards of supervision have resulted. It is considered that senior foremen can benefit from specialised education in concrete work, and contractors who have sent foremen to educational courses on concrete work have found the results beneficial.

It is not generally considered that there is much improvement in the quality of tradesmen and labour or any marked increase in knowledge of site techniques among operatives engaged on concrete work.

Irish Code of Practice

Despite criticism among engineers of the British Codes in general use, there is little support for an Irish Code of Practice. Some interest has been taken in the recent draft European Code (21) but it is generally felt that the wide use here of British Standards make the choice of British Codes preferable.

The acceptance by local authority and Government Departments of consulting engineers as specialists, and the consequent latitude allowed them in the use of parts of Codes other than British Codes facilitates the working of the present system, and it appears unlikely that any advantage would be obtained by the adoption of an Irish Code of Practice.

It is possible, however, that the introduction of an Irish Loading Code might be considered advantageous, unless BSCP 3 Cp. V is revised in such a manner as would make it more suitable for local conditions. The compilation of a loading code would be within the terms of reference of Foras Forbartha, the national body for Physical Planning, and the enforcement of such a code may be considered to be within the powers

of the Department of Local Government defined in the section of the 1963 Local Government Act dealing with the establishment of building regulations (see Part VIII para. 86), (22).

Agreed Specification

There is a large number of matters concerning the execution of concrete work for which the provisions in many of the specifications in current use are similar, although there is a considerable variety in the identification and proportioning of concrete mixes. Many engineers in consulting and contracting work favour the adoption of an "agreed specification" for concrete work to replace the multiplicity of specifications in use at present.

It is considered that the main advantages which would result from the adoption of an "agreed specification" would be a useful standardisation and clarification of the general specification requirements for and types of, concrete mix, both of which would facilitate job administration and pricing. It is also pointed out that the use of such a specification would enable attention to be drawn to special requirements varying from the standard provisions, since such variations would be set out for the particular work in question. Such matters as the standards of shuttering, accuracy, reinforcement fixing, control of concrete, self finished concrete and curing about which in the present system there is sometimes disagreement as to the interpretation of the requirements, could be clarified in an agreed specification.

The "Guide to Specifying Concrete" (19) may be considered to provide the basis for a similar development in Britain. Some consulting engineers here have suggested the adoption of this or a similar outline specification provided that the specification adopted were suitable in all respects to Irish Conditions. The publication referred to is, however, mainly in the form of recommendations with comments, and so does not appear to be in a form which is directly usable as a specification. It is also chiefly applicable to major contracts (a further publication is being prepared for smaller contracts) so that the application in this country would be restricted. A further consideration is that it is not in a concise form which can be readily understood by persons other than experienced engineers.

The general basis of the "Guide to Specifying Concrete" is of great interest, since this is the specification of results rather than materials and workmanship. Thus concrete mixes are specified by strength with maximum and minimum cement content and shuttering by the type of finish and the tolerances required except where particular surface patterning is provided for.

Many consulting engineers favour the specification of concrete mixes by strength instead of by cement content, and some have used such "Strength" specifications with success. Contractors favour this type of specification, since it permits allowance to be made for variation of aggregate quality according to source, and consider that greater use of "Strength" specifications could exert an indirect control on aggregate

quality, with beneficial effects. Contractors using this type of specification have invariably employed a civil engineering laboratory to design the concrete mixes, as do consulting engineers to determine the proportioning of the aggregates.

Many engineers feel that the application of a "Strength" specification should be limited to works on which main contractors having the staff and equipment necessary to provide control of an adequate standard would be engaged. Contractors are aware that to make the best use of a "Strength" specification a high standard of control is required, but anticipate that this should be economically practicable. The statistical method of control proposed in the "Guide to Specifying Concrete" and the variability factors given in "Road Note No. 4" (23) are of considerable interest in regard to control. It would seem that the use of a "Strength" type specification could be extended to smaller works by suitable adjustment of the minimum cement content and variability factor.

Contractors favour the adoption of a results type specification for shuttering and surface finish which would allow shuttering systems to be used to the best advantage. Special finishes, such as self finish for architectural work are considered best described with the aid of a representative sample of the results desired.

In view of the interest in an agreed specification for structural work, and of the information provided by recent publications it seems that the usefulness and scope of such a specification merits consideration by those directly concerned.

Few engineers or contractors with considerable experience of water retaining structures are in favour of the use of a results type specification for waterproof concrete work. It is generally felt that although maximum density of the concrete and good workmanship are agreed to be the basic essentials for this type of work, there are additional factors such as tensile strength, workability and corrosion resistance which have to be considered, and that the nature of the work is such that more detailed mix design and closer control by the consulting engineer is needed than might be provided with a results specification. It seems that there is a useful field for research in the assessment of mixes for water retaining structures.

Developments for Economy

Engineers generally do not consider that substantial increases in concrete stresses would permit any useful economy in concrete structures other than those of a massive type, since the span/depth ratios in the Codes are as small as practicable. Further, reduced thickness of construction and higher working stresses would require greatly increased site control, which would offset any economy gained. In water retaining structures and in road work, in which there are special considerations other than minimum strength, no economy would be gained by using very high strength concrete.

Engineers consider that precasting should be developed, and that this might lead to economy. Contractors feel that economies could be made in orthodox construction by the standardisation of elements and by the

greater consideration of shuttering systems. Other useful economies could be made by simplifying the work, such as adopting simpler systems of detailing and using a smaller number of bar sizes in reinforced work. Contractors also feel that greater appreciation of the requirements for job planning would be helpful in facilitating economy in construction, and that more consideration should be given to the minimum requirements for the work.

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Discussion

MR. GWYNN introduced his paper.

The criticism of BSCP3, Chapter 5, had been met in part by the introduction in the Amendment of April 1965 of two new classes, namely

class 70 for office floors carrying data processing equipment, and class 100A for office floors used for storage and filing, and by the footnote added in that amendment to Clause 4 calling for special consideration of heavy localised loads. The other criticisms of this loading code would appear to remain valid. In particular, the recommended design load of 300 lb. on the free edge of cantilever steps was inadequately presented insofar as it did not make sufficient allowance for impact and the lack of resilience of the step. This was a problem which arose also in short span duct covers and similar units.

The Recommendation for an International Code of Practice for Reinforced Concrete, drafted by the European Concrete Committee, with an English translation published jointly by the American Concrete Institute and the Cement and Concrete Association, was comprehensive and interesting. The design methods in these recommendations were based on ultimate load theory, and crack formation in structures was given new and warranted emphasis. It was not possible to say whether ultimate load/load factor design was, on the whole, preferable to elastic design, but the danger of long-term deflexion inherent in the choice of sections of minimal proportions must not be overlooked.

Much research was in progress on crack formation in structures as a whole and design codes generally should give attention to this matter.

The provisions for shear in CP 114 were not considered adequate, and research suggested that substantially lower allowable shear stresses should be adopted in beams without shear reinforcement.

Regarding the approval of designs by grant-administering authorities, consulting engineers in Ireland owed a great deal to the liberal attitude of the examining engineers. A more detailed code for fire resistance would, however, be of value and this might be more valid if based on the assessment of fire loading that is to say on the heat liable to be emitted by the combustible contents of a building rather than, arbitrarily, on the nominal type of occupancy for the building.

Composite construction was referred to in the paper. Whilst the extent of the future use of steel beams depended to some degree on the development of cheaper forms of shear connectors, composite construction generally should be developed, not least because of the reduction in site operations which it allowed. The use of prestressed concrete in composite precast/in situ concrete construction, while complex in design, appeared to be particularly efficient.

In the section on specifications for concrete work, the comments related only to specifications prepared by consulting engineers. Less comprehensive specifications sometimes used by architects and surveyors were not reviewed. Professor Walsh in his book "How to make good concrete," 1939, showed that grading was the only sound basis for proportioning aggregates. Nevertheless, most specifications used here contained reference to nominal volumetric mixes, and whilst this practice was encouraged by the retention of such mixes in CP 114, it was suggested that these proportions were largely meaningless for the aggregates

available in Ireland. There would also appear to be an inconsistency in many specifications which, whilst including reference to weigh batching, defined the concrete volumetrically and/or by the weight of cement per cubic yard of finished material.

As regards testing, most codes, including the draft European recommendations retained the 28-day cube test. It would appear, however, that with the increasing pace of construction, earlier testing was required. Further, there was a real need for the development of other manners of testing in situ concrete, and these might properly be aimed at providing a quantitative assessment of the strength of the placed concrete, rather than the qualitative assessment of the concrete generally which the cube provided.

Self-finished concretes were to be treated fully in another paper of this symposium, but it could usefully be noted here that such concrete required separate specification. It was not sufficient to use the general concrete specification with merely an added sentence specifying the finish required.

Regarding additives for concrete, their use in Ireland depended largely on whether or not they were specified, and there was a body of opinion which was against incurring the extra cost, particularly as their composition was sometimes not known, and their behaviour could be uncertain. The only additive the author had ever specified was a fine inert filler which had the same plasticising effect as an excess of cement. If additives were specified, special attention was required to the control of their proportions.

There had undoubtedly been an overall improvement in the quality of concrete work in Ireland in recent years, but it might be significant for future development to realise that opinion credited improved materials and mechanical aids, and better supervision, rather than any increased skill of the operator, for this change. It was suggested that advantage could be taken of this trend, by specifying more rigid supervision by engineers and by properly-trained foremen, and by the increased use of mechanical aids. Further, more emphasis could be placed on pre-planning and on pre-fabrication so that reliance on site operatives might be decreased.

Reverting to standard specifications, there would seem to be merit in introducing an "agreed specification" for concrete in Ireland. It would have the primary advantage of unifying practice to a considerable degree, and would be additionally welcome if at the same time it could allow some small economy to be made in the cost of concrete work.

It was suggested, finally, that economies in construction were more likely to arise from standardisation of orthodox construction than from the use of special methods, and the present interest in modular co-ordination must be beneficial. There was a great need for the increased standardisation of structural components in Irish architectural practice, and it was felt that official grant-allocating authorities might validly use their powers to foster this development.

The author thanked the many consulting engineers and authorities who provided the information summarised in his paper.

MR. J. F. DUNLEAVY said that if there were any dissatisfaction with current concrete practice in Ireland, the continued use of specifications drawn up for an earlier generation must be a major factor. Whilst the habit was not universal, it did exist, and there appeared little serious attempt by us to benefit from our knowledge and experience, and to reflect in our specifications what was required of any particular concrete for a given set of circumstances. The case for an "agreed specification" was strong, but it was important that this document should introduce, as well as strength criteria, proper reference to other essential properties of concrete such as durability, resistance to wear, finish and dimensional stability. It was also advisable that this specification should be based on performance standard rather than on arbitrary mix proportions. The move towards performance requirements as the criteria of acceptability was general. It might be seen in the Building Regulations recently issued in Scotland, and in England and would appear also in the new national building regulations now being drafted for Ireland.

Mr. Gwynn was probably right in his opinion that an Irish Code of Practice was not required for concrete. Adequate recommendations for Irish practice were at present contained in the British Standards and Codes. Research, and development of these documents, was a continuous process in Britain, and the production of an Irish Code would be warranted only if it provided advice on aspects of practice peculiar to Irish conditions. The same comment applied, with one proviso, to the preparation of an Irish Loading Code. The proviso related to wind loading. Irish conditions, at least in parts of the country, were sufficiently different to those in other countries, to warrant a national examination of this aspect of loading, and it was understood that research was at present in progress in the Meteorological Service. The results of this work, in conjunction with shape and pressure distribution studies continuously in progress in Britain should give Irish engineers valuable guidance in this field of design.

The need for earlier determination of the strength and probable performance of placed concrete was considerable, and it was to be hoped that the present 28-day acceptance test would be ultimately eliminated. The Institute for Industrial Research and Standards was studying the general concept of accelerated testing, and had available a Weatherometer which, by comparison techniques, could be used to assess in 3 to 4 weeks the long term durability of a particular surface finish or form of construction. It was the intention that the results obtained from this method would be compared with results from an exposure site also being set up by the Institute.

The demands which industrialised building techniques were likely to make on our designers would have to be accepted if we were to reap the due rewards. Mr. Gwynn had mentioned the need for standardisation of components. Mention should again be made of the need for close-

tolerance manufacture, and for the importance of simple and effective joint design. Against the background of industrialisation, and indeed generally, the absence from the Irish market of light-weight concrete should be noted. Its uses were manifold and it would appear that, in one form at least, namely aerated concrete, there was no serious obstacle to its extensive use in this country. The Institute was at present experimenting with the use of milled peat as a filler. A fairly stable material having a crushing strength from 300 to 600 psi. had been produced, at a density of about 70 lb. per cubic foot. It could be cut and was capable of receiving and holding hammer-driven nails, but it definitely remained highly experimental at present. Mr. Dunleavy felt that the allied aspects of precast techniques and light-weight concretes would play a large part in the future of concrete technology and proficiency in them would be essential to us.

In these matters and in concrete technology in Ireland generally, the contribution of the Cement and Concrete Association through its publications, advice, and research must be fully acknowledged.

DR. L. F. STEPHENS expressed the hope that Mr. Gwynn would accept a partial disagreement with some of his findings as a compliment to his very valuable paper. His views generally had, of course, to be endorsed. These included his recommendation for a conservative approach to problems of wind load in exposed positions, and his opinion that an Irish Standard Code of Practice for concrete construction was not required.

Regarding wind load, a gust velocity of 113 m.p.h. had been recorded at Malin Head during September 1961, with a maximum 10-minute mean speed of 73 m.p.h., this representing a 1-minute mean speed of about 80 m.p.h. This exceeded substantially the design wind velocity of 72 m.p.h. given in Chapter 5 for exposure D. In fact the meteorological records showed four further 1-minute mean speeds in excess of 72 m.p.h. in the period 1955-1961. It had to be realised therefore that the maximum Chapter 5 conditions were at least suspect for exposed structures in the West of Ireland.

In many cases, the most important aspect of wind loading in structural design was not however its effect on the overall stability and strength of the structure, but its effect on the design of connections for cladding, and on the treatment of structural details. As an example, the necessity for protecting the "turn-down" to an asphalt surfacing on the edge of a flat roof slab might be mentioned. If the "turn-down" was not tight against the edge of the slab, wind could penetrate under the asphalt, and this action, combined with high suction on the flat upper surface of the roof, could cause the asphalt to be ripped right off the roof. This danger could be reduced by forming a rebate in the top edge of the concrete slab, the asphalt being turned down into this rebate.

Agreement on the superfluity of an Irish standard code of practice did not remove from us the responsibility for increasing our engineering knowledge by research. Agencies such as the Institute for Industrial Research and Standards, and An Foras Forbartha, should sponsor re-

search in problems of structural concrete. Some of this work should be carried out in the universities where it would be an inspiration to the undergraduate and post-graduate students. The results of all research should be published for the general benefit of engineers in practice.

It was disappointing to learn that few Irish designers used load-factor design, the consensus of opinion being apparently that no useful economy could be expected from its use. Whilst it might be accepted that the behaviour of reinforced concrete frames at ultimate load was not sufficiently understood to rely completely as yet on load-factor methods for their design, a strong case could be advanced for adopting the yield line method for slab design. Elastic analysis of a 12' 0" square slab simply supported on four sides and carrying an imposed load of 100 lb. per sq. ft. indicated that a mid-span bending moment of $0.063 w l^2$ would occur in each direction, the area of reinforcement being 0.39 sq. ins. each way, say $\frac{1}{2}$ " dia. bars at 6" centres, in a $4\frac{1}{2}$ " thick slab. The use of Johansen's yield line method, however, reduced the mid-span bending moments to $0.42 w l^2$, the area of reinforcement being then 0.29 sq. ins. each way, say $\frac{1}{2}$ " dia. bars at 8" centres. Quite apart from the irrationality of elastic design, the yield line method showed a saving of over 25%, and it was strongly suggested that Irish designers could not afford to ignore savings of this magnitude in imported materials. There was a large field of research open in slab design because many problems remained as yet unanswered. There were, for instance, the problems of a slab on four isolated columns, and a slab on one wall and two columns, and other similar combinations met in practice. These were all examples of research which we could be treating here, probably by model testing.

MR. J. DALY remarked that reference had been made by Mr. Gwynn, and was contained also in Professor Dillon's paper, to the use of admixtures in concrete. Shacklock in his paper on the use of admixtures in concrete, published in *Concrete and Constructional Engineering* in September 1962, mentioned the existence at that time of 275 proprietary admixtures. He stressed the dangers attached to the promiscuous use of additives, pointing out, firstly, that an additive could not transform a patently bad concrete into a good material, secondly that an additive causing useful modification to certain qualities of the concrete, might be detrimental to it in other respects, and, thirdly, that thorough control was vital. All of this would suggest that before Irish practice got too involved in the use of additives, research on their use and their effects on concrete made with Irish cement should be initiated. This research might be particularly important for ready mixed concrete which was still quite a new material here, and in this field, examination of the use of additives, particularly pozzolanic materials which were being actively examined in the United States at present could be of great value at this stage.

Regarding design, more emphasis should be placed on probabilistic design and more attention, surely, paid to the life expectancy of the building to be designed.

An Foras Forbartha was now, at the request of the Minister for Local

Government, working on a draft of new building regulations for Ireland, and the draft when ready would be submitted to all official and other learned bodies for comment. The matter of a loading code might be resolved by the adoption of CP 3 Chapter 5 which had been used in this country for many years. The new English and Scottish regulations had embodied Chapter 5 as their loading code with only very slight adjustments, and, except for wind load, it should be acceptable here. Our wind statistics here were based on gust and ten minute mean speeds, whereas Chapter 5 was based on one minute mean speeds. It was, of course, not an unreasonable correlation to consider one minute mean speeds as 0.8 times, and ten minute mean speeds as 0.7 times, the maximum gust velocity, but possibly a more precise approach was desirable and would be available in the new regulations. The Meteorological Office was shortly to issue a publication on Irish winds, and this was awaited with interest. It would always be essential to take full account of the new shapes and sizes which would be met in future structures. Wind forces, far greater than normal exposure considerations suggested, might develop as a result of unusual plan and elevation forms and groupings (e.g. the new Toronto Civic Centre) and these would always have to be considered on their own merits, outside any official wind loading code.

MR. T. M. DUGGAN began by stressing the point that the specification of an additive must tie in with the specification of an aggregate or a mix which needed the additive. Irish natural aggregates were amongst the best in the world, and the inclusion of an additive at preliminary specification stage was a premature and often unwarranted admission of defeat, even before work on site began. A possible exception was a good plasticising agent which helped to reduce the bleeding which could be so damaging in fair faced concrete.

In the recent construction of a large basement in Cork, the only additive used was an accelerator which had been required to develop very early working strength, to counter water pressure due to imminent spring tides. Normal concrete had been used and the basement was completely watertight.

It was essential that additives introduced to this country be tested with Irish cements, before being offered for use commercially. At least two instances of serious inconvenience had occurred, both due primarily to the unexpectedly large retarding effect of an additive used with Irish cement when the corresponding effect with English cement had been quite insignificant. It was not quite correct to say that the composition of additives was not known. The Reinforced Concrete Association recognized this shortcoming some time ago and many additive manufacturers were now prepared to supply details of the basic components of their products to anyone interested.

MR. T. J. S. MALLAGH felt that further information would be useful on those additives which affected hardening and setting time, both of which types were confusingly described as accelerators.

Quick setting concrete was rarely desirable except for tidal work where wave action might arise shortly after the concrete was placed.

Calcium chloride used as an accelerator of the hardening process was generally deemed to affect setting time also. Was it not true however that this material when used in a proportion of less than 2% of the cement had no significant effect on setting time? It might be worth emphasising the fact that rapid hardening Portland cement concrete had a setting time almost identical with that of normal Portland cement concrete. Its merit lay in its relatively rapid development of strength, but it was not necessarily the material to use where for instance freshly placed concrete was to be subject to wave action, as, say, in a slipway.

THE CHAIRMAN thanked Mr. Gwynn for his very valuable paper. There was one correction which should be made. The final sentence of the first paragraph under the heading "Standards for Loading" should be amended to read "Road pavements are designed according to traffic densities as set out in Road Note No. 29 issued by the Road Research Laboratory. The specification for works is generally in accordance with that of the Ministry of Transport and Civil Aviation. The geometrical design of roads is based entirely on the Department of Local Government standards."

MR. S. KENNY in a written contribution contended that CP 114 erred in giving specific recommendations for depth to span ratios. Deflexion, and, in particular, that due to long term loading was a cause of concern to all users of reinforced concrete. The method of calculation given in the European code appeared to give more realistic results and the opinions of other engineers on this matter would be of interest.

The writer disagreed most strongly with Mr. Gwynn's statement that he did not see any economy in using higher strength concrete. High strength concrete always had to be the aim of designers, not from the copybook point of view of using higher stresses which were of little importance, but to provide a more durable material with a higher value of E. Concrete practice had reached the point where there was rarely any difficulty in obtaining the specified cube strength, and the design strength was no longer relevant, but such other properties as E, durability, and dimensional stability were of increasing importance. The crushing strength of granite was about 14,000 p.s.i. but we expected 4,000 p.s.i. self-finished concrete exposed to the elements to be durable and to keep its original appearance. He felt that high cube strength should be specified for self-finished concrete.

MR. GWYNN replied.

The development of methods for testing concrete at an early age was urgent, and there was no doubt that whatever testing methods were adopted, engineers would have to bear in mind the significance in concrete of properties other than compressive strength.

The assessment of wind load was extremely important in modern

structures, and, as brought out in the discussion, this problem could not be considered as solved when a nominal wind pressure had been selected.

It was undoubtedly a pity that so few designers used load factor methods, and it was to be hoped that the symposium with the striking example given in the discussion would encourage examination of these methods against possibly the basis of the proposed European code.

The possible lack of compatibility between additives and Irish cement was of extreme importance. It obviously would have to be examined for each product introduced to the country and the proper approach might be through an intensification of research in Ireland on the chemistry of cement.

The correction made by the chairman was important and was welcomed. The author deemed himself fortunate that apart from this matter, he had apparently succeeded in not misquoting any of the engineers who had so kindly assisted him in the preparation of his paper.

MATERIALS FOR STRUCTURAL CONCRETE

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Summary

An estimated $3\frac{1}{2} \times 10^6$ cu. yds. of concrete were produced in Ireland in 1964 of which perhaps 0.75×10^6 cu. yds. was reinforced or prestressed and 0.2×10^6 cu. yds. was ready mixed. Outputs are increasing annually but natural aggregate supplies are plentiful and cheap. No artificial aggregates are produced and few additives are used.

Data are given for Irish cements and reinforcements and the growth rates are examined. The Irish concrete industry is progressive — new plant and techniques are introduced rapidly but few data on the natural aggregate resources of the country are available. It is suggested that this neglect must be remedied if further improvements are to occur.

Introduction

A substantial and general improvement in the production of concrete even on small and medium sites has occurred in recent years, and now it is unusual to receive cubes for test which weigh less than 18.5 lbs. or have strengths less than 3,500 p.s.i. at 28 days. Generally the results are superior.

The more important elements in this desirable improvement undoubtedly have been the general use of internal and external vibrators and the introduction of weigh batching on site, but these advances have been paralleled by improved processing of the ingredients. The uniformly high quality of Irish cements leaves little to be desired and the production of aggregates is more centralised, with an accompanying greater investment of capital in a number of locations to produce washed sand and good clean aggregates which are separated into two or more sizes. It is possible to specify a controlled grading and there is a general realisation of the benefits to be derived from designing the mix to suit the grading and shape of the aggregates, the conditions of placement and the method of compaction. The steady growth in the use of prestressed concrete (1)* has also helped to establish standards of site production and

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

control which are being accepted to a desirable extent as standard practice even on the smaller sites. It is possible to obtain very good results with local aggregates in most parts of Ireland to-day; indeed, a contractor's attitude to concrete quality can be assessed from the strength and weight of cubes forwarded for test, irrespective of the location or size of the site from which they come. Though no specific relation exists between the weight and strength of cubes, the writer suggests that site weighing of cubes when demoulded would give an early indication of concrete quality.

An estimated $3\frac{1}{2} \times 10^6$ cu. yds. of concrete were produced in Ireland in 1964 of which perhaps 0.75×10^6 cu. yds. was reinforced or prestressed and 0.2×10^6 cu. yds. was ready mixed concrete. It appears that regional distribution is reasonably proportional to population density, so that the requirements of Dublin City and County are of the order of 30% of the total production, excepting ready mixed concrete which was confined to that region alone until January 1965. Corresponding data for the U.K. derived from various sources, (2), (3), provide an interesting comparison if it is assumed that distribution per 1,000 of population is a reasonably valid statistic also for the U.K. These and other data are presented tentatively in Table 1 to show the relative position at present and the potential growth of the home market. Production of the two categories of ready mixed concrete in the U.K., central-mixed and transit-mixed, has been increasing by $2\frac{1}{2} \times 10^6$ cu. yds. per annum since 1959 (3) and amounted to 20% of the total concrete produced in 1964. However, a significant future growth is forecast, as just under 50% of the cement used in Sweden is sold to the ready mixed concrete industry which is now the most highly developed in Europe.

TABLE 1: Estimated Quantities per 1,000 of Population for 1964

Material	Ireland	U.K.
	tons	tons
Cement	290	320
Reinforcement and Prestressing wire	8.5	13
	cu. yds.	cu. yds.
Total Concrete Produced	1,250	1,480
Reinforced and Prestressed Concrete	360	520
Ready Mixed Concrete	70	300
	(see text)	
Lightweight Concrete	—	70

Lightweight aggregates are not produced in Ireland and little imported material has been used to date in structural concrete. Neither have aerated concretes been used to any extent, but ready mixed concrete production is already significant in the Dublin region, where it is three

times the national average for 1964 given in Table 1, and is growing rapidly in the Cork, Limerick and Galway areas where plants have operated since January 1965. Since the producers of ready mixed concrete are also the principal aggregate suppliers, it is possible that refinements in mix design and control can be introduced to give a superior product, but it should be noted that diverse opinions on the standards being attained in England were expressed at a Symposium held in September 1964. The writer would refer all concerned to the four papers presented and to the discussion which took place at that Symposium (3). It is reasonable to expect the quality of ready mixed concrete to be higher than site produced concrete and lower than that attained by the precast concrete industry. The latter is already a compact but growing concern in Ireland.

Concrete is a unique material in that the engineer is responsible both for its production and use so that he constantly desires to increase its allowable stresses and applications as the product is improved. Bond and crack control, reduced shrinkage and thermal movements, creep and composite action, improved tensile strength by incorporating uniformly distributed short lengths of wire (4), and improved surface finish are but a few of the interesting and complex problems of the present and the future. For these improvements to be realised, it is necessary to know the characteristics of the materials used and the manner in which they are processed; the purpose of this paper is to review the present position in Ireland and to indicate items on which more detailed information is required.

Cements

Present-day Portland cements are a vast improvement on Aspdin's original product of 1824 but they are still made by mixing substances containing calcium carbonate, such as limestone or chalk, with substances containing silica, alumina and iron oxide, such as clay, shale or marl and heating them together to incipient fusion in a rotary kiln. The clinker is cooled and ground to a fine powder to which a little gypsum may be added to control the rate of setting of the cement. When water is added a chemical reaction occurs immediately, stiffening or setting begins, heat is generated, and as the reaction continues, the compounds that collectively constitute cement (row 2, Table 2) disappear and are replaced by their hydration products. These are the true cementing agents which cause the initial stiffening or setting of the concrete at early stages in the hydration process and the gradual increase in strength or hardening of the concrete as the hydration process continues and the concrete matures. It is a common error of students that drying is the cause of the hardening process whereas the opposite is true; without water for continued hydration, the reaction and hardening cease. Rapid-hardening and ordinary Portland cements are similar in chemical composition but the proportions of the various compounds are slightly different and the rapid-hardening cement is more finely ground.

TABLE 2: Chemical Composition of Irish Normal Cement

Chemical Analysis (%)	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SO ₃	Alkalis
	21.6	3.2	5.4	63.5	2.0	2.3	1.6
Lime Saturation Factor = 0.91							
Compound Composition (%)	C ₃ S	C ₂ S	C ₃ A	C ₄ AF	CaSO ₄	Free CaO	Ignition Loss at 900° C
	42.2	30.3	8.4	9.7	4.0	1.7	1.4
Specific Surface (cm ² /g) = 2900							

Water required for cement paste of standard consistence = 28%

Setting Times: Initial – 4½ hours; Final – 6½ hours

Soundness: Expansion at one day = 1.0 mm.

Cement Quality

Selected properties of Irish Portland cements are given in Table 2 and reliable data on standard tests are given in Table 3. The high standard of the results should be noted; they compare favourably with results from other countries (5), (6), and in particular the low standard deviation and coefficient of variation of the Cembureau or R-C methods of test, proposed by Cembureau and Rilem in 1949 and already adopted by several European countries as an International Standard, should be noted. In these tests a 1 : 3 cement-sand mixture by weight is prepared at a constant w/c ratio of 0.50, the sand being a Belgian standard sand, or a local siliceous sand which is subdivided into fine, medium and coarse fractions on the 0.5 and 1.0 mm. sieves.

TABLE 3: Tensile, Flexural and Compressive Strengths of Irish Cements

Test	Normal Portland			Rapid Hardening Portland		
	Age (days)	Average (lb./sq. in.)	Standard Deviation (lb./sq. in.)	Age (days)	Average (lb./sq. in.)	Standard Deviation (lb./sq. in.)
Tensile Briquettes	1	334	20.3	1	457	35
	3	493	35.2	3	672	55
	7	671	46.3	7	809	84
B.S. 12 : 1958 1 : 2 : 4 concrete cubes (4") with w/c = 0.525	1	1591	248	1	2244	302
	3	3546	338	3	4557	396
	7	4919	420	7	6006	414
Cembureau I.S. 1 : 1964 Flexural	3	654	31.3	3	768	31.3
	7	796	37.0	7	967	28.4
Compressive	3	3769	71.1	3	4836	85.3
	7	4907	71.1	7	6230	92.4

Blending of the mortar is done with a special mixer unit and the 4 x 4 x 16 cm. specimens are compacted mechanically on a specified jolting table. The cured specimens are later tested in bending to determine the flexural strength and then the half-prisms are used for compressive tests. The method is very carefully specified (7). A detailed investigation of the reproducibility of results, published by the Norwegian Department for Testing Materials (5) gives a 2% coefficient of variation for a series of 30 compression tests of a standard cement by a single operator, and coefficients of 3.4% and 4.2% for compression and flexural strengths respectively when a standard cement was tested in four different laboratories. The corresponding coefficients of variation of the results in Table 3 for Irish cements are 1.9% maximum and 4.8% maximum for a single laboratory.

Estimates of Quality Deviation

The increased emphasis on the statistical control of concrete quality has given greater prominence to investigations of the contribution of different factors to the overall variation of works test cubes, but results published to date (see Table 4) show significant differences in the standard deviations associated with the three main sources of variation:—

- (a) Cement quality variations
- (b) Batching errors (in particular variation in the w/c ratio)
- (c) Testing errors.

—which can be assumed to act independently. The data in Table 4 for 4500 to 6000 p.s.i. concretes having an overall standard deviation of 550 to 700 p.s.i. at 28 days, suggest that the variation in cement consignments even from the same source is as great as the batching errors on sites where cement and aggregates are both weighed and the w/c ratio is controlled. The writer considers that this conclusion is not realistic and suggests that the standard deviation of the cement variation must be less than the 70 to 90 p.s.i. values obtained for Irish and Norwegian cements in the Cembureau test where batching and testing errors, though small, still affect the results. Consequently, other factors must be involved and an important variable may be the efficiency of mixing which in turn may affect the bonding affinity of the cement with the aggregate.

TABLE 4: Estimates of Standard Deviation of Component Variables

Source of Variation	Himsworth(8)	Erntroy(9)	Grant(3)
Cement	250 p.s.i.	440 p.s.i.	400 p.s.i.
Batching	460 p.s.i.	370 p.s.i.	450 p.s.i.
Testing	190 p.s.i.	300 p.s.i.	200 p.s.i.
Standard Deviation of the Concrete	557	650	630

That the quality of Irish normal Portland cement has been extremely consistent is shown by the continued validity of the expression

$$S_r \text{ (lb. per sq. in.)} = 2,800 \left(\frac{w}{c} - 0.64 \right)$$

for the compressive strength of 6" cubes made with Cork aggregates when cured in water and tested wet at 7 days. This equation, derived from laboratory tests in 1941 for cement to total water ratios less than 2.1, has been confirmed by the results obtained on the Lee hydro-electric power scheme (10) and on the Cork Airport runway construction (11). The ratio of 7-day to 28-day strengths with Cork sandstone aggregates also remains at 0.66 but a ratio of 0.74 was obtained with Cork limestone chips and natural sand at the Beaumont reservoir (12) construction, which agrees with an 0.75 extrapolated value for the 1 : 3 mortar of the Cement-bureau test of Table 3. Values for other Irish aggregates are not available and it is to be regretted that complete information on the concrete used has not been included in most of the published records of other major schemes constructed in Ireland. Since the rate of strength evolution should be about the same for cement as for concrete, it is possible that an index of surface texture of a particular aggregate could be obtained from its 7-day to 28-day strength relative to that for the specified siliceous aggregate of the standard cement test.

Cement Production

The Chairman of Cement Ltd., Mr. A. G. Larsen, in his 1965 annual report pointed out that imports of normal and rapid-hardening cement were eliminated in 1954 and that Cement Ltd. has more than doubled its cement production since 1958. Last year's output was 1,051,000 tons of which some 820,000 tons was used in Ireland, the remainder being exported. The annual output of the previous two years was a little less than 900,000 tons but the fourth kiln at the Limerick factory went into production in June 1964, increasing the Company's cement capacity by 20%. A fifth kiln at Limerick has been ordered and is planned to come into production in early 1966, increasing the total capacity by a further 16½%, and making the Limerick works considerably larger than the Drogheda works. The growth rate of usage of cement in this country has been relatively uniform at 80,000 tons/year since 1960, corresponding to 10% approximately on the 1964 usage, so that a further increase of production capacity will be needed, as mentioned in the Chairman's report, within a reasonable period of time. Were the rate of growth to remain constant at 80,000 tons/year the annual usage would be 1.5×10^6 tons by 1973, whereas it is more probable that the rate of growth will increase with the expansion of the total industrial output envisaged in the Second Programme of Economic Expansion. It should be noted also that an important feature of the motorway expansion in England has been the increasing use of concrete surfaced roads and it is reasonable to assume that this development will occur also in Ireland. In addition to competitive first cost, concrete pavements provide the added advantage of greatly reduced maintenance, which is likely to be of even greater importance in the future as traffic densities steadily increase.

Other Cements and Additives

Sulphate-resisting, low heat and white Portland cements and aluminous cement are not manufactured in Ireland as the quantities required

for special purposes are quite small. In fact the demand for rapid-hardening Portland cement is as low as 4% of the total output, but an increasing use is being made of bulk delivery which now amounts to 35% of all deliveries.

The effect of admixtures on the strength and workability of concrete varies with the composition of the cement, the richness of the mix, and the mixing and placing conditions. Hence, it is unwise to rely on data published elsewhere and trial mixes, with the actual materials to be used, are essential in order to determine the quantity of admixture required and its effects on the properties of the concrete. Calcium Chloride as an accelerator, pulverised fuel ash as a partial replacement for cement, and the addition of a proprietary air entraining or workability agent, are common practice in many countries but their use in Ireland has been very limited to date.

Aggregates

Glacial sands and gravels are in abundant supply in many regions of Ireland but deficiencies occur (1) along the Western sea-board where the terminal moraine of the Midland general glaciation presumably lies somewhere off-shore, except where it crosses Mayo between Achill and Ballycastle and (2) south and east of the terminal moraine running from the Wicklow mountains south-west to Clonmel, and then along the Cork-Limerick border to enter the Shannon estuary near Ballybunion and traverse the tip of Clare to Kilkee (13). Also co-existing with the Midland general ice sheet was a strong mountain glaciation of the Kerry and West Cork area which left a northern terminal moraine from Glengbeigh to Killarney and a large eastern moraine across the valley of the River Lee near Cork City. The latter glacial sand and gravels therefore are of old red sandstone, whilst the esker and other deposits of the Midlands and West are of limestone or granite.

These natural gravels and sands have a smooth fine-grained texture, are rounded to irregular in shape, and have aggregate crushing values of 5-10% for basalt or dolerite, 10-20% for granites and sandstones, and 20-25% for limestones. The supplies contain few large boulders, are generally clean and reasonably but irregularly graded from 3" maximum down, and the sands are fine corresponding to Zone 4 or more generally of medium grading corresponding to Zone 2. Unsound coarse aggregate does not occur but sand supplies in a few locations contain sufficient mica to make them unsuitable.

Aggregate Processing Plants

Large (300 tons/hour) and medium (75 tons/hour) size processing plants, located where ample supplies of natural aggregates are available near cities and large towns, include washing and screening operations, crushing of oversize material, and bin storage of sands and of two or more sizes of coarse aggregate. One sand grading and two sizes of coarse aggregate, $1\frac{1}{2}" - \frac{3}{4}"$ and $\frac{3}{4}" - 3/16"$, are stored generally at medium size plants, but fine and medium sands and many sizes of coarse

aggregate are stored separately at the Roadstone Ltd. plant near Dublin. The washed and graded materials are also weigh-batched and recombined at that plant to supply a definite demand for the controlled all-in aggregates shown in Table 5 or indeed any other desired grading, and aggregates are supplied also to the company's own concrete production plants. The standard batched gradings correspond to Zone B of Road Note No. 4, and range between the Walsh Type Gradings (14) 5 and 6 for the $\frac{3}{4}$ " aggregate but between Type Gradings 4 and 10 for the $1\frac{1}{2}$ " aggregate. It is advisable to keep the actual grading slightly finer than the type required, especially in the sand part, to reduce the risk of getting occasional batches of too coarse aggregate and subsequent patches of honeycombing.

TABLE 5: Grading of Standard Batched Aggregates

Batched Aggregate	B.S. Sizes and % by weight passing								
	100	52	25	14	7	3/16"	$\frac{3}{8}$ "	$\frac{1}{2}$ "	$1\frac{1}{2}$ "
$\frac{3}{4}$ " Standard	0— 3	3— 10	14— 21	21— 28	28— 35	35— 42	55— 65	95— 100	
$1\frac{1}{2}$ " Standard	0— 3	5— 12	10— 17	15— 25	23— 35	32— 40	40— 55	55— 70	95— 100

It is found generally that the $\frac{3}{8}$ "– $3/16$ " material is in excess of requirements and large stockpiles accumulate though much of it is used by the suppliers in the manufacture of concrete blocks. Regular observations made at one plant (10) also indicate that the gradings obtained are uniform, provided surges of input are avoided, and that 10 gls. of water per minute per ton of material produced per hour is sufficient for washing, whereas an excess of water makes recovery of the fines (25 B.S. sieve) in the sand difficult. This is corrected by the addition of some fine sand. Another requirement is that chutes should be extended when discharging large aggregate into empty bins as a significant amount of breakage can occur when aggregate falls more than 10 feet.

The importance of control on grading is realised by those suppliers who also produce ready mixed concrete and other products. In such locations, the gradings are checked regularly; elsewhere, an irregular but reasonable control is maintained. However, it has been noticed that a $\frac{3}{4}$ " maximum size aggregate reduces almost to a $\frac{3}{8}$ " maximum grading when the annual requirements of the Road Authority for $\frac{3}{4}$ " chip are being supplied. A certain deficiency of the 25 material can also occur, which reduces the period of vibration for complete compaction and eliminates the occurrence of "rotational instability" when precast units are compacted by shutter or table vibrators, but "bleeding" can occur and sand runs may cause surface blemishes if an excess of water is used. The effect of the sedimentation characteristics of the concrete, bleeding

and settlement, on the bond strength of plain and deformed bars has been found to be significant (15).

Specifications and Control of Workability

Little $\frac{3}{4}$ " concrete is produced and the demand for $\frac{3}{4}$ " and $1\frac{1}{2}$ " concretes is equal. Nor is any difficulty experienced in producing suitable gradings provided the client is not unreasonable regarding otherwise acceptable variations in uniformity. However, nominal 1 : n : 2n specifications combined with a requirement for minimum strength are still encountered, and occasionally a specification is so detailed regarding cement content, workability, w/c ratio and minimum strength, that it cannot be fulfilled. Model specifications (16-18) issued recently are simple and logical, and give guidance to the engineer without stereotyping his overall specification. The increased use of ready mixed concrete also requires a different approach to the control of the water content of the concrete. Instead of controlling the w/c ratio directly to maintain a uniform "potential" strength, it seems more logical that the supplier should control the workability to ensure uniform and complete compaction of the concrete on site and the development of a uniform "real" strength. It may be argued that this procedure may lead to strength variations because the w/c ratio is not itself controlled, but the discrepancy is more imaginary than real if proper standards of control of the grading and batching are being used. Power consumption meters on the mixing plant and other apparatus may be used to control workability at the production plant, but the slump cone still is the normal site test for workability. However, it is an insensitive control for very dry concrete and a suitable site alternative in such cases could be the small and easily operated Thaulow drop table (19). A reasonable comparison of consistence measurements by various methods is given in Table 6 (19) but it should be noted that these relations are affected by the richness of the mix and the type of fine aggregate used (6).

TABLE 6 : Consistence Measurements by Various Methods

Consistence (19) Description	Degree of Workability	Compacting Factor	Vebe Time (secs.)	Slump (in.)	Thaulow Drop Table (revs.)
Extremely Dry	Extremely Low	0.65	18-32	—	56-112
Very Stiff	—	0.70	10-18	—	28-56
Stiff	Very Low	0.75	5-10	0-1	14-28
Stiff Plastic	Low	0.85	3-5	1-2	7-14
Plastic	Medium	0.90	0-3	3-4	7
Flowing	High	0.95	—	6-7	—

Total Production

Of the 820,000 tons of cement used in Ireland in 1964, it is estimated that 110,000 tons was used for the manufacture of concrete blocks and for external rendering, so that the total production of concrete is estimated at $3\frac{1}{2} \times 10^6$ cu. yds. It appears also that regional distribution is reasonably proportional to population, and that difficulty in obtaining good natural aggregates occurs only in the regions previously mentioned, for example, it was necessary to crush the excavated rock and to transport natural sands from some distance both for the Erne (10) and Clady (21) hydro-electric schemes, and suitable aggregates for the construction of the Flannery bridge (22) were obtained 50 miles from the site. Elsewhere there is a plentiful supply of good natural aggregates. Consequently, no artificial aggregates are manufactured at present for structural concrete work, nor is aerated concrete used to any extent. No doubt this position will alter as it did after 1946 in the U.K. where the estimated near future annual production of artificial aggregates is $3\frac{1}{2} \times 10^6$ cu. yds. out of an estimated total aggregate usage of $75\frac{1}{2} \times 10^6$ cu. yds. (2). Suitable materials for producing lightweight aggregates would appear to be available in sufficient quantity in Ireland.

Aggregate Research

It is known that the surface texture, shape, strength, elastic modulus and thermal coefficient of the aggregates affect the abrasion resistance, flexural strength, and creep of concrete, yet few published data on these properties of Irish aggregates are available at present. Also it is evident that this knowledge is all the more necessary because of the increased emphasis on the development of high compressive strengths, fire resistance, and crack control. Micro-cracking around the aggregate grains, because of thermal and shrinkage movements in the otherwise unstressed concrete, is important also as micro-cracks are possible zones of weakness which initiate the larger cracks leading to failure of the concrete when stressed. The major factors affecting shrinkage are the shrinkage of the cement paste and the fractional volume and shrinkage of the aggregate.

That research results obtained elsewhere do not necessarily apply to concretes made with some Irish aggregates is known; for example, the E-values of concrete made with a Cork limestone and natural sand are 3.56×10^6 lb. per sq. in. and 4×10^6 lb. per sq. in. for cube strengths of 5,000 lb. per sq. in. and 6,500 lb. per sq. in. respectively, (12) whereas the values recommended in CP115 for these strengths are 4.5×10^6 lb. per sq. in. and 5.0×10^6 lb. per sq. in. The differences are significant. It is suggested therefore that further research on Irish aggregates is necessary, and that it should be undertaken or financed by the Irish concrete industry, which has shown itself to be very progressive in introducing new plant and techniques from abroad in order to increase output and quality. Programmes of field investigation of the stresses and movements in structures are also necessary because there is an undesirable element of risk in extrapolating the results obtained from laboratory-size specimens to actual structures.

TABLE 7: Irish Steel Reinforcement and % Amounts Used

Specification	Ultimate Tensile Strength	Yield Stress	% Elongation (minimum)	% used in home market
Mild Steel	—	—	—	23
28-33	28-33 t.s.i.			28
B.S. 785 (Mild)	28-33 t.s.i.		16-24	47
B.S. 785 (Medium)	33-38 t.s.i.	16½-19½ t.s.i.	14-18	—
B.S. 785 (High Tensile)	37-43 t.s.i.	19-23 t.s.i.	14-22	1
60,000 Yield	—	60,000 p.s.i.	—	1
B.S. 1144	70,000-80,000 p.s.i.	60,000-70,000 p.s.i.	12-16	
ASTM 15 (Structural)	55,000-65,000 p.s.i.	33,000 p.s.i. (Minimum)	20 minimum	
ASTM 15 (Intermediate)	70,000-80,000 p.s.i.	40,000 p.s.i. (Minimum)	16 minimum	
ASTM 15 (Hard)	80,000 p.s.i.	50,000 p.s.i. (Minimum)	13.8 minimum	

Reinforcement

The comprehensive range of reinforcement produced by Irish Steel Holdings Ltd., Haulbowline, and the percentage of each quality used in the home market are shown in Table 7, and it is surprising that the upper two qualities constitute 51% of the 20,000 to 25,000 tons average annual requirement for all types of reinforcement. The mild steel quality at the top of the list is not guaranteed but, having a carbon content of 0.10% to 0.25%, it should attain an ultimate strength of 25 to 34 tons per sq. in. if the sulphur, phosphorus and manganese contents are within the usual limits. It is possible that this steel is being used largely for nominal reinforcement by builders, but it is possible also that in many cases it may be substituted for B.S. 785 mild steel or for the 28-33 quality steel which simply has a guaranteed ultimate tensile strength. All other steels are fully specified and it may be noted that the B.S. 785 three grades of steel correspond to the structural, intermediate and hard steels of ASTM 15.

Deformed bars rolled to the requirement of ASTM A 305-56T, and ribbed and square bars cold-twisted to B.S. 1144 are produced also in the B.S. 785 range of steels, the improved bond permitting partial to full use of the higher yield strengths (60,000-70,000 p.s.i.) thus obtained. The most important factor limiting the allowable tensile stress in the reinforcement at working loads is the maximum width of cracks which, being inversely proportional to the average spacing of cracks, is a function of the ratio of the tensile strength of the concrete and the bond stress between the steel and concrete. Hence the higher the working stress in the steel

the better must be the bond, so that the maximum allowable crack width for different exposures given in the C.E.B. draft recommendations (22) may not be exceeded. These limiting values are :—

- (a) 0.1 mm. for internal or external structural parts exposed to a particularly aggressive medium, or where water-tightness is needed.
- (b) 0.2 mm. for internal structural parts in a humid or aggressive atmosphere, and external structural parts exposed to the weather.
- (c) 0.3 mm. for internal structural parts in a normal atmosphere.

The recent amendments to the Code of Practice on Reinforced Concrete (CP 114) allow a tensile stress of 0.55 the guaranteed yield or proof stress, but not more than 33,000 lb. per sq. in. for deformed bars now termed "high-bond" reinforcement. Also, the bond stresses given for plain bars may now be increased by 40% for high-bond bars provided the bond strength of such bars is at least 40% greater than that of a plain bar. The recommended bond test still is the direct pull-out test but the concrete specimen is reinforced to permit full development of the bond strength of high-bond bars. However, the following significant differences between these proposals and those of the U.S.A. and other countries must be noted :—

- (a) The CP 114 permissible bond stress for plain bars is much higher than that permitted even for bottom bars in the U.S.A. and France.
- (b) In the U.S.A. and France, the bond stress permitted in top bars is 70% approximately of that permitted in bottom bars. "Top bars, in reference to bond, are defined as horizontal bars so placed that more than 12" of concrete is cast in the member below the bar." No such distinction is made in CP 114.
- (c) The permissible bond stress for deformed bars complying with the requirements of ASTM A305-56T is twice that for plain bars. CP 114 limits this allowance to 1.40.

A further and essential requirement when using high-bond bars is to provide adequate transverse reinforcement in the form of stirrups to counteract the bursting effect of the deformed bars. The C.E.B. draft recommendations for limit-state design of bond and anchorage emphasise this requirement—"over the effective anchorage length, the bond stresses are high and the risk of splitting (along the bar) is important. If there is no transverse reinforcement and if splitting occurs, bond may drop to zero."

The use of high-bond reinforcement produces appreciable reductions in quantities. In one American bridge of 24' roadway width having spans of 55-88-88-55 feet (24), the quantity of steel in the super-structure was reduced from 49 tons of ordinary steel to 35 tons of high-bond steel having a minimum yield stress of 60,000 p.s.i. The stem widths of the three longitudinal girders were reduced also from 3' to 2'-4½" because of the reduced number of longitudinal bars. Similar economies are possible for framed buildings, particularly if high strength concrete is also used. Deformed or ribbed high-bond bars may be grouped together in bundles of two or three to facilitate placing and vibrating the concrete, for labor-

atory tests have shown that the space between the ribbed bars is filled with mortar and that the bond strength is not impaired.

However, ordinary round bars still constitute 80% of the annual requirement for reinforcement in Ireland though a limited but increasing use is made of deformed, ribbed, and square bars formed of B.S. 785 mild steel which are subsequently cold-twisted to the requirements of B.S. 1144. The proportions are $3\frac{1}{2}\%$, 3% and $6\frac{1}{2}\%$ respectively at present but it would appear that these amounts will increase as the advantages of increased bond and higher working stresses become widely recognised. Also 50% of the round bars are $\frac{5}{8}$ " diameter and under, and 71.5% are 1" and under.

All prestressing steel is imported and a reliable estimate of the annual requirement is 350 tons, of which some 50 tons is crimped wire used in pretensioned work, and the remainder is 0.2" and 0.276" wire and some strand for post-tensioned constructions. Again it is not possible to predict a rate of growth as a limited tonnage is sufficient for quite large works, for example, 82 tons of 0.276" diameter wire was used in the Youghal bridge, 5 tons of $\frac{1}{2}$ " diameter strand in the Skibbereen bridge, and 13.5 tons of 9 mm. diameter wire in the $1\frac{1}{2} \times 10^6$ gls. prestressed concrete reservoir at Beaumont (12). Strand is a comparatively recent form of tendon which provides a large prestressing force in a restricted area and a reduction in site labour costs compared with the conventional multi-wire tendon.

Most of the standard and well-known post-tensioning systems have been used to date, either by the direction of the Engineer or with his consent, and no difficulties have been experienced with the subsequent grouting provided the cable ducts were well flushed and that injection of the continuously agitated, colloidal cement grout was uninterrupted. The recommendations (25) prepared by a joint FIP-RILEM committee emphasise these and other items of grouting procedure.

Acknowledgement

The writer thanks those who furnished information on the quantities and procedures being used :—

Mr. T. Duggan, B.E.	—	Cement Ltd.
Mr. G. Radley	—	Irish Steel Holdings Ltd.
Mr. T. Golden, B.E.	—	Roadstone Ltd.
Mr. P. Hayes, B.E.	—	Roadstone Ltd.
Mr. L. O'Brien, B.E.	—	Galway Tile Co. Ltd.
Mr. J. G. J. Owens, B.A., B.A.I.	—	T. Pearson & Co. Ltd.

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Discussion

PROFESSOR DILLON introduced his paper.

The general improvement in the quality of concrete which had occurred in recent years was to the credit of all concerned in the production and use of concrete in Ireland. Concrete products manufacturers had sought and accumulated specialised knowledge of their individual products. Improved plant and techniques had been introduced on site, and at this stage it was reasonable to speculate on the manner in which future developments would occur. A study of this kind was difficult as few records were available apart from the total cement usage and its annual growth rate. The method therefore adopted was to estimate the total production as described in the paper and then express it in terms of output per thousand of population. The figures for Ireland in Table 1 therefore could not be considered precise but should be regarded as reasonable estimates on which to base a discussion of the utilization of aggregate resources, and of the importance of the concrete industry in the national economy. The comparative estimates for the U.K. were included to show the relative position at present and also the potential growth of the home market.

It was evident that the potential for ready mixed concrete was very high in Ireland, and the example might be quoted of Sweden where already 50% of the cement produced was going to either the ready mixed concrete suppliers or the precast concrete manufacturers. The future must also hold promise for lightweight concrete. Its use had developed very rapidly in England since 1960. This trend should appear here also and should be of value to the precast concrete industry in the reduction of handling and transport costs.

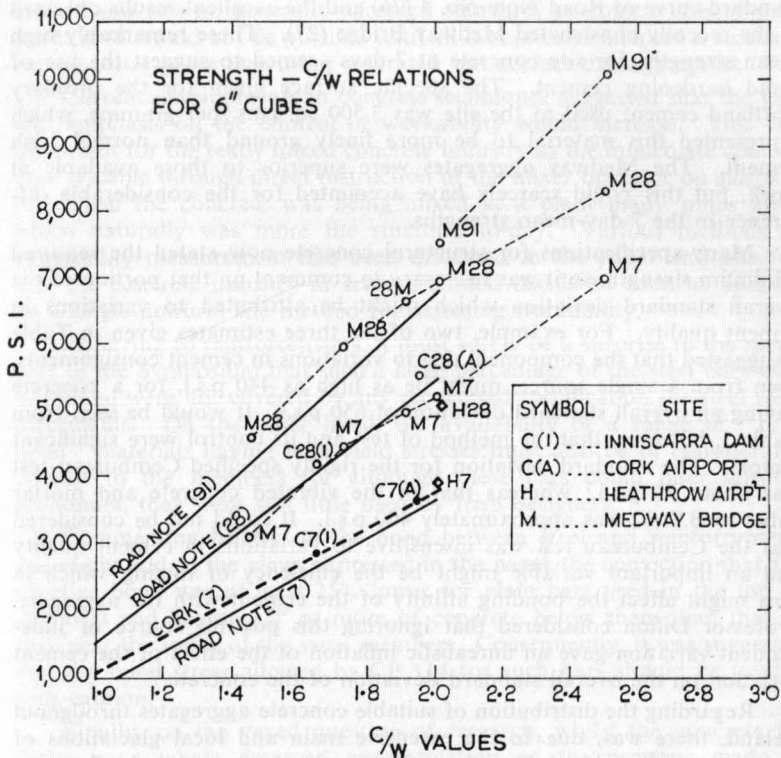


FIG. B1. SOME CUBE STRENGTH
COMPARISONS.

(The Cork 7-day curve is based on tests made in 1941. The C(I) and C(A) results are circa 1960).

The growth rate of usage of cement in this country had been relatively uniform at 80,000 tons per year since 1960 but it was probable that this figure would increase with the expansion of the total industrial output. In view of recent developments in the construction of concrete pavements and their increasing use in other countries, it was reasonable to assume that this development would occur also in Ireland.

The consistent quality of Irish cement over a period of years was shown clearly in Figure B1 which compared the strength of 6-in. cubes made and tested at the U.C.C. laboratories in 1941 with results obtained at the Inniscarra Dam and Cork Airport sites some twenty years later. Also shown, as interesting and useful comparisons, were the corresponding

standard curve of Road Note No. 4 (26) and the excellent results obtained at the recently constructed Medway Bridge (27). These remarkably high mean strengths for site concrete at 7-days seemed to suggest the use of rapid hardening cement. The specific surface given for the ordinary Portland cement used at the site was 3,500 sq. cms. per gramme, which represented this material to be more finely ground than normal Irish cement. The Medway aggregates were superior to those available at Cork, but this could scarcely have accounted for the considerable difference in the 7-day mean strengths.

Many specifications for structural concrete now stated the required minimum strength, so it was necessary to comment on that portion of the overall standard deviation which might be attributed to variations in cement quality. For example, two of the three estimates given in Table 4 suggested that the component due to variations in cement consignments, even from a single source, might be as high as 440 p.s.i. for a concrete having an overall standard deviation of 650 p.s.i. It would be seen from Table 3, however, that the method of test and its control were significant factors. The standard deviation for the rigidly specified Cembureau test was about 70 p.s.i.; whereas that of the vibrated concrete and mortar cubes to B.S. 12 was approximately 400 p.s.i. It could not be considered that the Cembureau test was insensitive to variations in cement quality and an important variable might be the efficiency of mixing which in turn might affect the bonding affinity of the cement with the aggregate. Professor Dillon considered that ignoring this possible source of independent variation gave an unrealistic inflation of the effect of the cement variation on the overall standard deviation of the concrete.

Regarding the distribution of suitable concrete aggregates throughout Ireland, there was, due to the extensive main and local glaciations of earlier times, an abundance of good natural gravels and sands in most parts of the country. There was no general list available of the districts, comparatively rare, in which there was no good aggregate. Information on this would be of much value to the Symposium for a gap-graded concrete with one or two sizes of coarse aggregate and a fine dune sand could be a solution in such areas, now that vibrated concrete was in general use.

Professor Dillon felt that some reference must be made to the nature of the water-cement ratio in a paper dealing with materials for concrete. There was no doubt that the calculation of the w/c ratio of a mix should take account of the water added at the mixer and the water in the aggregates if they were damp. The precise meaning of the w/c ratio was uncertain as the water in the aggregates occurred partly on the surface of the particles and partly absorbed in the pores where it was not readily available for affecting the properties of the concrete. Unfortun-

(26) Road Research Note 4: Design of Concrete Mixes: HMSO: London: 1950.

(27) Kier, M., Hansen, F., Dunster, J. A.: Medway Bridge: Construction: Proc. I.C.E.: Paper 6812: Sept. 1964.

ately, there was no generally accepted standard, so comparison of published data would not be possible until all laboratories adopted a standard experimental procedure using saturated but surface-dry aggregates.

Current developments in concrete techniques suggested that the present emphasis on the control of workability would increase. This was important for the ready mixed concrete industry as the immediate control, now possible through direct instruction of the mixer operator on site, was lost when the concrete was being mixed at a plant many miles away which naturally was more the situation to-day. Various methods of workability measurement had been discussed in the paper and one felt that the concrete industry in Ireland should decide as soon as possible on a single uniform site method for assessing workability.

Referring to reinforcements, it must surely be a surprise to the members of the Symposium that such a large percentage of the steel bars used in Ireland were not covered by any recognised specification for steel reinforcements. On the other hand, the availability of a range of "high bond" materials having high yield stresses must also be of considerable interest to the members for although these bars could offer sensible economies, they were still little used by Irish designers.

Commenting briefly on the bond between steel and reinforcement, one might add to the views expressed in the paper the conviction that the effective bond was at least 25% lower for plain bars used in the top of members and having 12" or more of concrete below them than that of bars near the soffits of the same members. Consequently, it was suggested that the bond stress allowed by CP 114 for such bars should be treated with caution.

Finally, on the vexed question of research, whilst the concrete industry as a whole deserved congratulation on the progress made in recent years, the amount of money which it devoted to research and development was small and disproportionate to the size and importance of the industry. Research with Irish materials on such matters as the control of shrinkage, the relation between the E-value of the concrete and of the aggregate used, and workability/strength relationships would have to be pursued if full advantage was to be taken of the excellent materials available. Some useful but isolated work had been done. The concrete industry itself should either undertake the research it required or arrange for the necessary work to be done in whole or in part by the various laboratories already existing in the country. Programmes of field investigation of the stresses and movements in structures were also necessary.

MR. T. P. SHINKWIN stated that the Irish concrete industry had expanded greatly in the last two years, both in reinforced concrete and in such unreinforced units as blocks, bricks, precast kerbs and other similar precast items. The members of the Symposium might be interested in some details about materials used in an Irish works engaged essentially in the production of precast structural components, either prestressed or normally reinforced. Of a total of 350 tons of reinforcement used during

the last year excluding prestressing wire, 40% was in the form of cold worked deformed bars with a yield stress of 60,000 p.s.i. supplied by Irish Steel Holdings from their mills at Haulbowline. The economic advantage of using this material was considerable as its cost was only £4 per ton, or 7% higher than that of mild steel round bars from the same source, whereas its allowable working stress was 50% higher than that of mild steel. It was to the credit of Irish Steel Holdings that cold worked reinforcing steel could be delivered in Dublin at very little more than the corresponding cost of similar steel from the larger British mills, the margin being appreciably less than the present 25% protective tariff on imported reinforcement. 100 tons of prestressing wire to BS 2691 were used annually at present in the speaker's works, this being divided as follows:—

Percentage	Diameter	Ultimate Tensile Strength
50	0.128"	110-120 tons per sq. in.
30	0.200"	110-120 "
20	0.276"	90-100 "

Mr. Shinkwin felt that a recent experience in the use of 0.128" dia. crimped wire might be of interest. Hair cracks had been found to be developing in the anchor blocks of prestressed beams. They had had no detrimental effect on the unit under load tests but had been noticeable and could be considered unsightly. This had been traced to the use of a brand of wire in which the degree of crimping was too high, and the wire bond was developing in too short a distance.

Professor Dillon's advocacy of "uniform real strength" of placed concrete as distinct from the potential strength implied in a selected water/cement ratio was valid, as was his emphasis of the importance of workability. Mix design might usefully be based on a user requirement form of specification which would vary considerably in detail with each mix, taking into account, amongst others, such factors as strength requirements which might vary from 16 hour figures up to 28 day figures, batching accuracy, methods of consolidation and curing to be used, additives if necessary and finish required. The application of proper control to the making of concrete under such a specification should always give reasonable results.

Figure B2 showed cube test results over a period of six months in the precast concrete works above mentioned. All of the concrete tested had had a slump between $\frac{1}{2}$ " and 1", and vibration had been used throughout. The cubes had been cured under conditions similar to the concrete which they represented. The standard deviation of the results indicated a degree of control between 3 and 4 in a scale ranging from 1 for laboratory precision to 8 for uncontrolled mixing. It was of interest that the results from a mixer fitted with a water measuring device were not significantly better than those representing concrete in which the amount of water had been judged by the operator.

End Product	Types of aggregates and grading	Weight of cement per cu. yd. concrete (lb.)	Additives	Method of curing	Average 28-day strength of 4" cubes (p.s.i.)	Standard Deviation (p.s.i.)	Strength of average cube at transfer (p.s.i.)	Standard Deviation (p.s.i.)	Average 3-day strength of 4" cubes (p.s.i.)	Cube testing arrangement
"BISON" normal and prestressed	$\frac{3}{8}$ " max. rounded Type A	750	Calcium chloride circa 1%	Panel heating — Normal	6,400	545	4,200 (psc) — 1,000 (normal for lifting)	675	4,800 (psc) — 3,400 (normal)	3 cubes/day. 1 cube at release. 1 in 5 at 28 days. Remainder at 3 days.
prestressed bridge beams	$\frac{5}{8}$ " max. angular Type B	770	Sealoplaz circa 0.25%	Steam	7,300	515	4,400	370	5,500	2 cubes/day. 1 cube at release. 1 in 5 at 28 days. Remainder at 3 days.
G80 floor plates, columns, etc. Portal frames, Post-tensioned beams	$\frac{5}{8}$ " max. angular Type B	670	Calcium chloride Sealoplaz $\frac{1}{4}$ pint per cwt. cement	Normal	7,100	510	1,000 (for lifting at one day)	—	2,700	1 cube/day. 1 in 5 at 28 days. Remainder at 3 days.
Hyperbolic paraboloid shells	$\frac{3}{8}$ " max. angular Type A	900	None	Steam	8,000	650	5,000	330	5,400	2 cubes/day. 1 cube at release. 1 in 5 at 28 days. Remainder at 3 days.
White concrete facing units	$\frac{5}{8}$ " max. angular Type B	960	None	Normal	7,100	510	1,000 (for lifting at one day)	—	2,900	1 cube/day. 1 in 5 at 28 days. Remainder at 3 days.

FIG. B2. WORKS CONTROL
FOR PRECAST CONCRETE.

In the same works, including design and drawing office staff, 20% of all personnel engaged were supervisory, whilst of the personnel engaged purely in manufacture and erection, 10% were non-manual supervisors.

Regarding research generally, there was a strong case to be made for an Irish Concrete Research Station. This station which might properly be financed by the appropriate industries and in particular by the major suppliers of raw materials might operate either

- (a) in conjunction with the Institute of Industrial Research and Standards; or
- (b) in conjunction with the universities; or
- (c) in a more ambitious way as an independent centre completely financed as mentioned above.

The third proposal would appear to hold most promise. Other views on this subject would be of value.

MR. P. HAYES felt that it was of considerable interest that the use of cement in Ireland was only 10% per 1,000 of population behind that in Great Britain, despite the difference in development level between the two industrial economies, and that we were nevertheless, at present forecasting increases in use of 10% per annum for the years immediately ahead.

A private survey made recently of the future use of ready mixed concrete in the Dublin area suggested that a total of about 1×10^6 cubic yards of concrete had been made in this area in 1964, and forecast that this figure will rise at an annual rate of 6% compound interest. In 1964, ready mixed concrete supplied 18% of the demand in the Dublin area. It had been estimated that the corresponding proportions for 1965 and 1966 might be 25% and 35% respectively, and that, using current American and Swedish figures as a guide, the proportion by about 1975 might well reach 70%. The figures for the country as a whole would in all probability be lower.

The quality of Irish cement was very high, but cement variation might nevertheless affect the standard deviation of the concrete cubes more than the author suggested. The length of mixing time certainly did affect this figure, especially with stiff mixes, and tests at the speaker's works had shown a 10% increase in crushing strength with an increase in mixing time from 2 to 3 minutes.

Other tests at the speaker's works, relating to the ratio between 7-day and 28-day cube strengths suggested that for 6,000 p.s.i. cement this ratio is about 0.75 : 1.0 whereas with weaker concretes, say about 4,000 p.s.i. at 28 days, the ratio was 0.67 : 1.0. It might be that the strength of strong concretes, say 7,000 p.s.i. and over tended to depend on the strength of the aggregate, whereas in weaker concretes, the cement-sand matrix might control the ultimate strength. He felt that this fact could explain the variations noted in the ratio given above and it was significant that a further comparison between concretes containing hard crushed

rock on the one hand and gravel on the other confirmed this tendency. Other information given on this ratio by Hughes in "Rational Mix Design" (Proc. I.C.E. Vol. 17, Nov. 1960) suggested that the water/cement ratio affects this strength development ratio also, as shown below.

Aggregate	w/c. ratio	7 day/28 day strength ratio
Granite	0.60	0.67
"	0.40	0.74
Gravel	0.60	0.64
"	0.40	0.72

Results using Dublin gravel aggregates compared closely with Hughes' figures for gravel aggregates.

The formula quoted by the author gave higher results, however. The discrepancy might be explained if in fact the water content of the concrete were assumed, for determination of w/c ratio, to include water absorbed by the aggregate. It was surely incorrect so to include the absorbed water. Further comment on this would be welcome, especially if it could lead to a general agreement by Irish engineers, one way or the other.

Regarding sulphate resisting cement, the speaker's firm had used 1,600 tons of this material in the six-month period just completed and it was known that at least a further 1,000 tons had been used by other contractors. Bearing in mind the high cost of importing this material in bags from Britain, a strong case might be made for its manufacture and supply in bulk by Cement Limited in Ireland.

The control of workability by measurement of the work done in mixing, as mentioned by the author, had been attempted at the speaker's works. Workability and ammeter readings had been plotted, but, whilst reasonable curves could be drawn for broad averages, the scatter in the readings made precise control by this means impracticable.

It was probable that research would be supported if a useful end result not damaging to an established practice of the sponsors or the users could be anticipated. Thus, for instance, it would ultimately be to the financial detriment of all parties if a research project were to advocate extensive gap grading, without thought to the larger quantities of unsaleable middle sized pebbles which the process would produce, since this would cause an increase in the price of aggregates.

MR. J. OWENS observed that the figures on Table I implied that Irish designers used 25% less reinforcement per ton of cement than their counterparts in Britain, and this suggested a greater degree of thoroughness in Irish design. This might, in fact, be true, although other factors might also account for the disparity.

The quantity of 28% of consumption given in Table 7 for 28-33 tons per square inch steel included, although this was not indicated in the table, about 1,000 tons of steel which had been turned into twin-twisted

cold worked reinforcements conforming with BS 1144. It might be of interest to record that this type of material had been shown by tests, carried out by the speaker, to have a very high resistance in bond, whereas plain round mild steel in the same tests had failed in bond at stresses far lower than those allowed by CP 114. In this series of tests, carried out on 34 beams ranging from 18 to 30 feet long, a further finding had been a markedly better performance by deformed bars used as tensile reinforcement in beams in improving the shear resistance of the concrete.

Regarding prestressed concrete, the quantity of steel used in bridge construction was far lower than was generally considered. In 1964, about 12% of the total Irish annual consumption of prestressing wire and strand had been used in bridges, and in other recent years, this figure had been as low as 8%.

In the matter of additives, it was definite that additives manufactured in other countries for use in expanding grout for prestressing ducts, did not react with Irish cements in the same manner as they apparently did with the cements of the manufacturers' own countries.

PROFESSOR M. A. HOGAN referred to the author's remarks on cement quality and to his Table 3 and said it would be of interest to know whether his data on standard tests referred to a series of repeat tests carried out on one particular sample of cement with a view to establishing the reliability of the method of test. His reference to the Norwegian tests suggested this, but his following sentences seemed to imply that the tests might have been carried out on a number of different samples.

This matter was of significance in relation to the uniformity of the cement quality. For example, in a recent period, a continuous series of 104 samples, each the average of three days production at one of the Irish Cement factories, had been tested at University College, Dublin in accordance with I.S. No. 1. Taking 7-day mortar briquettes, the average tensile strength had been 593 p.s.i. with an average standard deviation for the group of four briquettes of 9.1 p.s.i. (C.V. = 1.55%), and a coefficient of variation of 3.6% for the 104 samples. Allowing for the variation in testing, these figures represented a coefficient of variation of 3.2% for the cement itself.

He asked the author to indicate the number of samples and the number of test specimens on which the results which he quoted were based.

The author's figures for the growth of strength with Cork limestone chips suggested the occurrence of aggregate reaction. Was it possible that this also occurred in the cubes made to BS12-1958? The strength of these seemed to be very high.

The fact that the quality of cement mortar briquettes depended so much on the skill of the individual operator, as evidenced by the difference in standard deviation, had led the Standards Advisory Committee of the Institute for Industrial Research and Standards to recommend the adoption of the Rilem-Cembureau method in Irish Standard No. 1: 1964.

In this method the production of the mortar prisms was mechanised. The only difficulty lay in the discovery of a suitable local sand. In Dublin, such a sand had not been found, and Belgian sand was used. It would be of interest to hear whether a suitable sand had been found in Cork.

I.S. No. 1 provided that for a period of three years, until the 27th of May, 1967, the strength requirement would be the tensile strength, unless the purchaser were to opt for the flexural and compressive strengths. After that date the flexural and compressive strength requirements would be the specification requirements for the cement. It should be noted that the flexural and compressive strengths were specified in metric, not inch-pound units.

Typical results based on 48 samples each representative of one week's production for normal cement and on 23 samples for rapid hardening cement were as given below.

Cement	Test	Age (days)	Strength specified (kg/cm ²)	Strength obtained (kg/cm ²)	Coefficient of Variation (%)
Normal	Flexural	3	30	48.6	5.2
"	"	7	40	60.4	3.5
"	Compressive	3	150	250.6	6.9
"	"	7	225	389.4	5.7
Rapid- hardening	Flexural	1	20	35.2	5.1
"	"	3	40	56.5	1.9
"	"	7	—	68.0	2.1
"	Compressive	1	100	153.3	6.2
"	"	3	220	309.8	3.3
"	"	7	—	436.7	1.4

BS 12 cube results on the same cements were as follows :

Cement	Age (days)	Strength specified (p.s.i.)	Strength obtained (p.s.i.)	Coefficient of Variation %
Normal	3		2512	6.9
"	7		3158	5.7
Rapid- hardening	3		2904	3.9
"	7		3983	2.9

MR. W. J. L. O'CONNELL recalled that it had been the opinion of Ralph Freeman given 45 years ago when he was one of the two or three best steel designers in the world, that the preparation of the drawings in a structural steel project represented about 80% of the whole task of the designer. This arose from the uniformity of the materials and the relative ease of forming rivetted joints. On the other hand, the corresponding figure for reinforced concrete work was 40%, the remaining 60% being required for supervision of construction.

Whilst the development of site welding might now modify the steel-work figure slightly, the division of effort for reinforced concrete given so long ago was still substantially the same as it then had been.

The consumption figures given by the author, whilst necessarily very approximate, were startling in that they indicated that, concrete blocks and renderings being excluded, 70% of the concrete made in Ireland was neither reinforced nor prestressed. Experience had suggested to the speaker that whether or not reinforcement was required to resist stress caused by loading, it was always desirable to control such factors as temperature movement.

Regarding the author's interesting comments on bond stresses, it seemed difficult to reconcile the use of 18000 p.s.i. as the working stress for reinforcement in direct compression in such elements as columns, with the conditions actually occurring in such a member. It would surely be expected that the stresses in two bonded materials in a compression member would be a function of their E-values, and this suggested that the steel stress should be substantially lower than 18,000 p.s.i. On the other hand, very high working stresses could now safely be used in prestressed concrete, and there seemed no reason why this should not be applied also, under proper control to reinforced concrete. In fact, the speaker's firm made quite regular use of these higher stresses in reinforced concrete.

One comment on Mr. Owen's observation about our using less steel per cubic yard of concrete in Ireland than in England, was that there existed amongst British architects a tremendous vogue for unduly small sections. This did, of course, alter the steel-to-concrete ratio considerably.

MR. T. M. DUGGAN referred to the author's comments on the Medway Bridge cement and observed that the quoted fineness of 3500 square cm. per gramme put that material rather nearer to normal Irish cement than to rapid-hardening cement as made here. The fineness test should not be considered without knowledge of other test results on a particular cement, and in fact, the current Irish standard had eliminated firm fineness requirements. This was possibly because of the difficulty of reconciling results for this test from different laboratories, and because of the limited information it gave by itself of the comparative performances of different cements.

Regarding the variations in compression test results quoted, it would appear that there was little merit in comparing the mortar test with the concrete test when a variation in the latter five times as big as that in the mortar test might be expected. One inference was that in considering concrete, one had to consider more than the actual matrix of cement and fine aggregate and water. The characteristics of the face on which failure occurred might be of high significance. The orientation of coarse aggregate particles in relation to the face of fracture might promote a larger range of variation than that arising in the testing of a mortar specimen containing fine aggregate only.

Regarding the possible manufacture of sulphate-resisting cement in Ireland, mentioned by Mr. Hayes, he felt he should point out that the total annual consumption of 2000 tons represented less than one day's production by the Irish cement works, and that production on this limited scale would be hard to justify.

MR. J. F. DUNLEAVY considered that the building industry would have to face up to its responsibilities in fostering research. Whilst facilities for research had been set up by the universities, and such bodies as An Foras Forbartha and the Institute for Industrial Research and Standards, the total national investment in building research was at present a mere 0.1% of the total annual product of the building industry. Corresponding figures for Britain and continental Europe ranged from 0.5 to 2.0%, while the figure for Israel ran as high as 10%. To one, who was trying with some success to persuade the Board of the Institute for Industrial Research and Standards to set up workshops and laboratories for research, development, and performance testing, and a field advisory service for the building (including the concrete) industry, the exhortation given by the Symposium to the industry to sponsor research was most gratifying.

The quality of applied research for the building industry would be as good as the industry, by its interest and support, allowed it to be. Furthermore, if the industry were to pay for research, it would be much more likely to make use of any results which the research produced.

MR. B. ROCHE in a written contribution stated that Professor Dillon had brought to light the alarming fact that 51% of all reinforcement used in Ireland was not specified to any Standard. What then was the point of going to great trouble in producing high quality concretes, if the steel, the very basic constituent of reinforced concrete, remained suspect?

Surely it was not beyond the steel industry to identify the quality of a given steel by some simple indentation or code mark stamped on the bars every few feet.

Engineers and architects should, he felt, be as vigilant about demanding tests on steel as they were about concrete, and perhaps, in drafting a standard specification, a demand for the production of the steel manufacturer's certificate should be included.

PROFESSOR DILLON replied.

The extra information given by Mr. Shinkwin would be of great value to the Symposium, showing as it did the treatment of control in one unit of the precast concrete industry.

Regarding research at the Universities, it might be observed that, nowadays, many young graduates would not undertake post-graduate studies leading to a higher degree unless research grants were available. While this might be regrettable, it was a fact, and scholarships would have to be found to subsidise this form of research.

Mr. Hayes' authoritative statement on the ready-mixed concrete supply position in Ireland today was a valuable contribution to the Symposium. Regarding the water-cement ratio, common ground would

have to be found for laboratory and field workers. If one were to take an absorbent aggregate, and most of the Southern glacial deposits were such, and make two batches of concrete to equal workability, one with saturated aggregate and the other with surface dry aggregate, the strength of the second concrete could be as much as 10% less than that of the first. This had not been proven fully, but had been noticed a number of times. Obviously in high strength concrete the water/cement ratio was not the only parameter and one might wonder generally whether Feret's expression, which related strength to the ratio of the absolute volume of cement to that of cement, water and air, was not more valid than the now widely accepted water/cement ratio by weight.

In reply to Mr. Owens, the figures given on Table 1 were estimates only, and any inference from them would have to be seen in this light. It would be of great interest to see Mr. Owens' results for his 1956-57 tests formally written up and presented, as his work had been in a field of much concern to Irish consultants.

The Cembureau test had not yet been introduced in Cork, so the data on Table 3 were not in fact based on Cork results, but were drawn from information supplied from the laboratories of Cement Limited. An answer to Professor Hogan's query about the standard deviation figures in Table 3 could not therefore be given on the spot, but this matter would be dealt with later. He felt that the introduction of the Cembureau test in I.S. No. 1 was timely, and the prospective elimination of the tensile mortar briquette test was welcome.

Mr. W. J. L. O'Connell was quite right in saying that the apparent annual volume of unreinforced concrete in Ireland was remarkably high, and one could not say where it was used. It was of interest that the annual production of concrete blocks in Ireland represented about $\frac{1}{3}$ of the total cement production, whereas the corresponding figure in Britain was about $\frac{1}{16}$.

Professor Dillon agreed with Mr. Duggan that specific surface could not be used as a single measure of the characteristics of a cement. This, however, had been the only cement characteristic quoted in the Medway bridge paper and seemed to offer a reason for the considerable difference in the 7-day mean strengths of the Medway and Cork concretes. Whilst it was readily agreed that concrete and mortars might have different fracture mechanisms (in fact the micro cracking revealed by recent research on unstressed material must be more significant in concrete than in mortar), nevertheless it should be noted that the standard deviation of the vibrated mortar cubes (those called Burke cubes by Professor Hogan) was comparable to that of 1:2:4 concrete. It would have to be held that no definite answer was available as to the part played by the variation of cement quality in the overall variation of the concrete.

He would assure Mr. Dunleavy that it had not been intended to imply that industry was not doing any research. Research was in progress, e.g. in the block making industry, but the overall picture was one of isolated piecemeal study, rather than coordinated effort. The time had

come for macroscopic research in the field, and industry would have to provide the necessary finance to send either their own staff engineers or young post-graduate student engineers into the field to do it.

In reply to Mr. Roche, he would suggest that the responsibility lay with the engineers and architects. It was not necessary that the steel producer should stamp each reinforcing bar at regular intervals, but engineers and architects should demand certificates of origin to ensure that the specified quality of reinforcement was used in structural concrete.

ASSESSMENT AND CONTROL OF STRENGTH OF CONCRETE

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Summary

This paper is divided into two parts. In the first part the results of a survey are presented which was carried out to determine current practice in this country in the assessment and control of concrete strength. In the second part some of the more significant results of this survey are discussed and observations made on possible future developments.

Introduction

In April, 1965, Questionnaire forms were submitted to 60 Irish organisations comprising Contractors, Consultants, Architects, Public bodies, Suppliers and Quantity Surveyors. The queries covered methods of specification, mix design and concrete strength control. No reply was received from any of the ten Quantity Surveyors who were approached, but 50% of the remainder replied, consisting of 9 Consultants, 7 Contractors, 6 Architects, 2 Public bodies and 1 Supplier. Those who replied included the biggest concerns in the country in their particular field, so that the answers cover a considerable quantity of work. The replies can also be taken to represent the more advanced methods in use here. Some account has been taken of the one or two smaller firms who replied, because of their special problems in relation to concrete quality.

The author is extremely grateful to those firms who were kind enough to devote time to answering questions. The survey, of course, is not comprehensive and was not intended to be. But the information is sufficient, it is believed, to present a picture of present-day practice in this country. With this knowledge it is possible that some features may come to light in the Symposium discussion, to suggest improvements for the future.

Replies from Group I (Manufacturers)

Replies from the Manufacturing Group will be considered firstly, i.e., contractors, public bodies and ready mix suppliers. Of the twelve

in this category, ten engaged in some form of mix design. The public bodies, ready mix supplier and one contractor had their own laboratories, including cube-crushing machines, for testing materials. Other contractors used the facilities at the Universities for this purpose. In regard to mix design procedures, references were made to Prof. H. Walsh's curves (1)* and to the British Road Note No. 4 (2). In most cases the theoretical mix was checked by making preliminary trial mixes to verify appearance and workability, but only occasionally were preliminary cubes taken. In only one case was gap-graded concrete mentioned and this was for a specialised production process described later. This concern also carried out flexural tests on beam specimens; otherwise all strength tests were done on 6" cubes.

Concrete consistence was measured normally by slump test, but three concerns also made use of compaction factor apparatus. One or two firms indicated that neither apparatus was used, the workability being gauged presumably by visual behaviour when vibrated. In the experience of this group, concrete mixes in a contract were specified variously in the Architects' or Consultants' specification or in the Bill of Quantities. Generally so many properties of the mix were specified that the Contractor was left little scope to avail of his experience or to introduce more intensified control procedure.

This group classified 'normal strength' concrete as that averaging 3,500 lb. per sq. in. at 28 days and 'high strength' as averaging 5,000 lb. per sq. in. All made use of 7-day cube tests in addition to 28-day tests. The 7-day strength was assessed at $\frac{2}{3}$ the 28-day strength, except for one contractor who used a factor varying from 0.61 to 0.74, depending on climatic conditions. Cubes were taken generally in pairs or threes and stored in damp sand on site. Only half those replying vibrated cubes when the main concrete was vibrated. In addition to test cubes, three contractors had experience of cut-core samples and four mentioned the use of an Impact Hammer in measuring strength. Reports on the success or otherwise of this tool varied and further information on this would be of interest.

In answer to a question about control of water/cement ratio most firms stated that this was done by using a water measure. Only one contractor mentioned taking account of contained water in the aggregates and one public body occasionally used a siphon can apparatus for the same purpose. In two instances the appearance of the mix rather than measurement of the added water was used as a check on the water/cement ratio. A certain amount of statistical analysis had been carried out on cube results by three concerns, but obviously this was not by any means normal procedure. Performance had been assessed by calculating the Standard Deviation or Coefficient of Variation. Analysis of fresh concrete was done by the ready mix supplier solely.

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

What happens when cube strengths are 'low'? Many repliers passed over this question discreetly or declined to define what they understood by 'low.' A single contractor maintained that this situation had never arisen. Among the other replies the definition of 'low' varied from any cube below the specified minimum strength (the majority view) to 1 in 20 below the minimum. Remedial measures reported where cube strengths were low were load tests (using applied weights or jacking), sample core tests, impact hammer tests, strengthening of the structure and removal of suspect concrete. Three contractors reported experience of the last sad expedient.

Opinions were divided about the possible economies in using higher strength concretes. While most of the group thought that this could lead to economies, others considered that this could better be achieved by improving quality control rather than concrete strength.

Replies from Group 2 (Specifiers)

We now consider replies from the 'Specifiers,' consisting of 9 Consulting Engineers and 6 Architects. As only two Architects submitted detailed replies some of the remarks in this section will refer to Consultants only. Not surprisingly, the answers on the whole followed the same pattern as those from the 'Manufacturing' group, with one or two notable differences.

Eight Consultants and Four Architects stated that they practised concrete mix design. Some consultants employed special charts for the purpose, others mentioned one or other of the previous references and 'Concrete Materials and Practice' by Murdock (3). Two Architects and all Engineers specified trial mixes and preliminary cube tests. In most cases these were asked for on major or special works only. Gap grading was virtually unknown. Consistence was specified in most cases by slump test. However, one engineer also included compaction factors and one architect specified the use of a vibratory 'Consistometer' to control workability. At the opposite extreme, one engineer declared his reliance on visual tests only as a measure of consistence.

General practice seemed to allow for either the Consultant or the Architect to prepare the concrete specifications, which were also summarized in the Bill of Quantities. The amount of detail given to the Contractor varied considerably. Many engineers specified nominal proportions, aggregate/cement ratio, minimum cement content, maximum water content and minimum cube strength. Notable exceptions were three consultants who merely specified the minimum required cube strength on large scale or prestressed concrete projects, leaving it to the Contractor to choose his own mix to achieve this. One Architect adopted a similar practice.

Generally the cost of testing materials, etc., was covered by a provisional sum in the Bill, but two consultants operated the Contractor with payment in the event of the results not being satisfactory. This group displayed more diffuse ideas of concrete strength than the 'manufacturing' concerns. 'Normal strength' concrete was classified

as averaging around 3,500 lb. per sq. in. at 28 days, as before, but 'high strength concrete' was defined as averaging anything between 3,750 lb. per sq. in. and 7,000 lb. per sq. in. at 28 days. All those replying accepted 7-day cube tests, but this was usually subject to the results at 28 days being also satisfactory. One consultant regarded 7-day cubes as essential for estimating strength gain rate and one architect used them to decide on striking times for the shuttering—this, presumably, being the objective in the former case also. The great majority regarded 7-day strengths as equivalent to $\frac{2}{3}$ of the cube strength at 28 days, although one consultant observed that this could vary from about $\frac{1}{3}$ in cold weather to $\frac{2}{3}$ in normal temperatures.

All concrete quality tests were done on 6" cubes, made in cast iron or steel moulds and stored on site in damp sand or water. Cubes were specified to be taken singly, in pairs or in threes depending on the size of the job. Engineers' opinions were evenly divided about vibration of cubes, half specifying rodding only and the remainder specifying vibration by poker or Kango hammer when the main concrete was vibrated. The consultants were asked about methods other than cube tests, which they had used to assess concrete strength. Four had used an impact hammer and cut core samples, two had employed beam tests and three had used non-destructive methods. Only in one case were weighing tests specified on fresh concrete.

The majority in the 'specifying' group called for the use of a water measure to control the water/cement ratio of the mix, but only one architect and one engineer specified use of a siphon can apparatus for determining moisture content of the aggregates. Statistical methods of analysis had been used on major works by three concerns, in which the Standard Deviations were derived and used as a measure of concrete quality control on the site. All those who replied agreed that any cube below the minimum specified strength should be considered as "low strength."

In cases where the concrete had failed to come up to strength requirements, various expedients had been used. (Only two architects maintained that this had never happened in their experience). The first procedure, apparently, was a check on design stresses and a field inspection. Other measures reported were load test (from 8 sources), removal of concrete (6), and strengthening the structure (1). Finally, six of the engineers and half the architects could see no economy in improving concrete strengths; the consensus of opinion seemed to be that costs would merely go up.

Discussion of Survey Results

Because of the fairly limited scope of the survey no attempt has been made to analyse the replies statistically. While the results were not in any way startling, there are some points worth a little deliberation. An interesting negative result, for instance, was the lack of response from the Quantity Surveyors. Ten of the larger firms had

been circularised, since specification of the concrete to be used in a job is held sometimes to come within the province of the quantity surveyor. It appears, in fact that while the concrete mix may be described in outline in the Bill, the specification for this is invariably prepared here by the architect or consulting engineer.

The rather high proportion of firms who stated that they indulged in concrete mix design may require qualification. Unfortunately no attempt was made in the questionnaire to define what was to be understood by 'mix design.' It may well have happened that some architects or engineers who habitually specified mix proportions, aggregate sizes, aggregate/cement and water/cement ratios, minimum cube strengths, minimum cement contents, etc., were of the opinion that this constituted mix design. Even where sieve tests were called for and the results proportioned according to some standard curve, this description would still hardly be applicable. Strictly speaking this is not 'mix design' but 'mix standardization'—a perfectly acceptable process, of course, in its way.

Concrete Mix Design

Design of a concrete mix to suit specific strength requirements demands a knowledge not only of the materials but also of manufacturing performance standards. These standards must be established either from previous results under similar conditions or from an analysis of a sizeable number of preliminary test cubes. In this connection B.S. Code of Practice CP. 114 (1957) mentions three concrete mix categories :

1. **Nominal concrete mixes**, with volume batching of the aggregates to specified proportions, permissible on small jobs.
2. **Standard concrete mixes**, with weight batching of the aggregates, to be used where quality control requirements for designed mixes are impracticable. The standard mixes are tabulated in relation to aggregate size, workability and 28-day cube strength. These are mixes which have been shown to be satisfactory for producing concrete of the specified strength, assuming a standard deviation of 1,000 lb. per sq. in.
3. **Designed concrete mixes**, designed to satisfy a specified works cube strength requirement, provided that the cement content is not less than 400 lb. nor more than 900 lb. per cubic yard of concrete.

The procedure for designed concrete mixes, as set out in Clause 209 of the Code (4), calls for a design mean strength exceeding the specified works cube strength by twice the expected standard deviation. The standard deviation is to be calculated "from at least 40 individual cube results, each representing separate batches of similar concrete produced by the same plant and under the same supervision, except that no standard deviation less than 500 p.s.i. should be used as a basis for designing the mix." Apart from these preliminary cube tests, full-scale trial mixes are needed where adequate data are not available on the

workability of the proposed mix. Other requirements, where a designed mix is used, are works cubes taken in pairs 8 times a day on the first 5 days of construction and at least each day subsequently, constant site supervision, separate storage of aggregates, accurate measurement of added water and progressive calculations to determine the average strengths and standard deviations achieved. Needless to say all this elaborate and rather costly quality control procedure could only be justified on large-scale works. It seems likely, therefore, that in this country most concrete work will continue to be based on nominal or standard mixes

The extensive investigations carried out by the late Professor H. Walsh and summarized in his book 'How to Make Good Concrete' (1) laid the foundations of present day concrete practice in this country and elsewhere. Mixes based on his recommendations have proved their worth over the years. Such 'standard' mixes, employing approved materials, with adjustments to suit sand grading, etc., should allow quite sufficient strength margin for the average contractor and more than enough for the progressive one who uses modern plant and control procedures. However, the latter will be in a position to get some return for higher capital outlay if mixes on a 'strength only' basis are stipulated on major works in future.

As many investigators have proved, most of the qualities desired of concrete are intimately related to its compressive strength, e.g., strength in tension and shear; resistance to abrasion and wear, durability to weathering, density and watertightness. Exceptions to this are lightness, thermal insulation and shrinkage reduction. Where these properties are vital the use of special aggregates or 'no fines' concrete is usually required. In such cases strength becomes a secondary requirement.

Gap Graded Concrete

Gap graded concretes, on the other hand, aim to achieve strength from sufficient packing of the aggregates, to reduce the voids between them to a minimum. These minor voids are filled by the cement paste. Such a mix can be designed mathematically by taking 'major spheres' to represent the coarse aggregate and 'admittance spheres' to represent the sand particles. In practice, some modification of the theoretically ideal mix is usually necessary, to increase the workability and avoid segregation. Mixes commonly employ a single size coarse aggregate, such as $\frac{3}{4}$ ", and a sand which can pass through the voids in the compacted coarse aggregate. An example of a simple design method will be found in the Institution of Civil Engineers' booklet entitled 'The Vibration of Concrete' (5).

A gap graded concrete will contain less cement than a conventional mix of equal strength and so have a lower materials cost. As only single-size coarse aggregates and sand are required control and stock-piling of aggregates is simplified. By using a coarse aggregate of the maximum practicable size, very high strength concrete can be

produced. With the lean mixes normally utilized, however, strong vibration is essential to ensure consolidation. The lower cement content results in less shrinkage than that obtained with conventional concretes. Furthermore, the creep associated with gap graded concrete is low since, it is claimed, compressive forces are transmitted from particle to particle of the coarse aggregate and not through the cement paste as in normal concrete. It would seem from this that gap grading would be particularly suited to prestressed work. To the author's knowledge, however, the only place where it has been applied in this country is in the C.I.E. concrete sleeper plant at Inchicore.

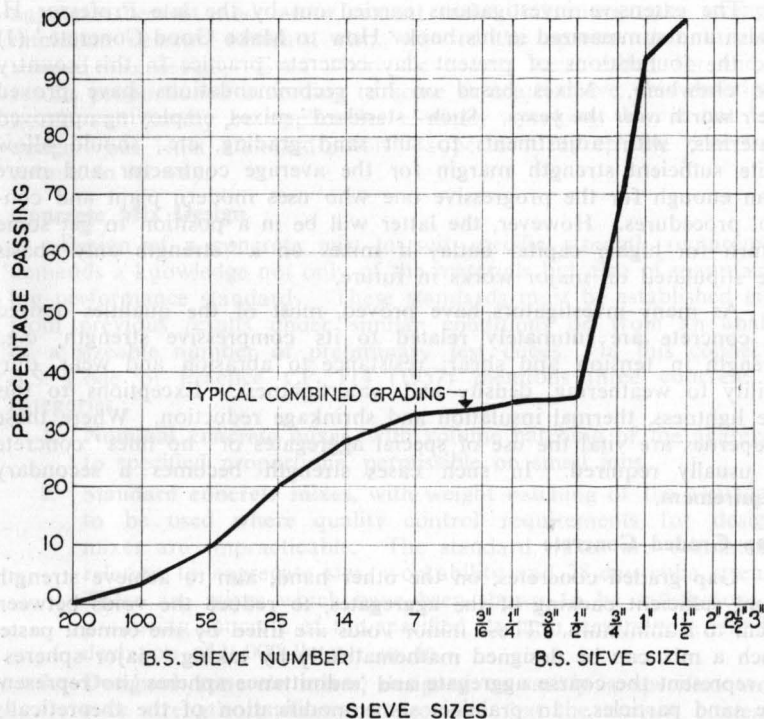


FIG. C1. GAP GRADED AGGREGATE.

The basic problem there was to select a mix which would be fully compacted with the plant available inside the period allowed by the production cycle. In addition the mix had to be cohesive enough for instant demoulding and give a good surface finish. Compressive strength objectives to suit prestressing and loading requirements were 6,400 lb. per sq. in. minimum at 24 hours (using steam curing) and 8,500 lb. per sq. in. at 28 days; target flexural strength was 920 lb. per sq. in. at 7 days. The mix adopted is 1 : 1.5 : 3.3 by weight with a cement content of 680 lb. per cu. yard. Water/cement ratio is 0.35.

Vibration under pressure is used during manufacture because of the low workability. Crushed whinstone aggregate in two single sizes are used, $\frac{3}{4}$ " ($\frac{1}{8}$ " to $\frac{3}{4}$ ") and $1\frac{1}{2}$ " ($\frac{3}{4}$ " to $1\frac{1}{2}$ "). The broken stone is used to get a high compressive strength and also gives good bending and abrasion resistance in the sleeper. It will be noted that there is no material in the mix between $\frac{3}{8}$ " and $3/16$ ". (See Fig. C1). The mix is somewhat sensitive to variations in sand grading and regular sieve tests are made on deliveries. Variations in the stone are not so important. Although concrete cover is only $\frac{3}{4}$ " no honeycombing due to the large aggregate size is experienced. Apart from cold weather difficulties, strength objectives are being obtained. The coefficient of variation, used as a measure of concrete quality control, has been averaging about 8.5% calculated on the cube results.

Beam tests as a measure of concrete strength are rarely employed in this country, apparently. These have been used to supplement cube tests at Inchicore because the modulus of rupture is taken into account in assessing the theoretical bending resistance of the sleeper. The beam specimens are kept moist until tested, as shrinkage stresses can reduce the test values appreciably. The loading system can also influence the results; it has been found that flexural strengths under third-point loading (to B.S. 1881) were only about two-thirds of those recorded under single point central loading (specified in German DIN 1048). Greater variations in beam results than in concrete cubes over the same period were also experienced. Despite the simpler apparatus which can be used in testing beam specimens it is most unlikely that these will supplant crushing tests, which are now well-established as a means of specifying and determining concrete quality.

Workability

The term 'workability' covers the ease of placing, compacting and finishing concrete. Various devices have been evolved for measuring this property such as the slump cone, compaction factor apparatus and Vebe consistometer. While they do give some measure of workability, none of them is completely satisfactory in this respect. This has given rise to two different attitudes evident in the replies to the Questionnaire.

One section specified some form of apparatus, the other relied on visual inspection only. A similar difference of opinion was evident regarding control of the water/cement ratio. In some cases this was done by water measure and allowance for moisture in the aggregates, in others again by the appearance of the mix. Past experience at Inchicore may be of interest here. In the early production stages it was endeavoured to get strict control by making regular siphon can tests on the aggregate stockpiles, which were in an uncovered area, to check their moisture content. Fig. C2 shows the results obtained over a period of several months. Immediately after each test instructions were relayed to the mixer man as to the exact amount of water to be added to the batch and the batch weights were adjusted in proportion. In time it was found that, because the mix was so 'dry,' the

MOISTURE CONTENT %	SAND	$\frac{3}{4}$ " SIZE	$1\frac{1}{4}$ " SIZE	COMBINED AGGREGATE
AVERAGE	7.4	0.4	0.2	3.7
MAXIMUM	10.8	1.4	0.6	4.0
MINIMUM	4.2	0	0	3.0
RANGE	6.6	1.4	0.6	1.0

FIG. C2. MOISTURE CONTENT OF AGGREGATE.

(Summary of approximately 100 siphon can tests at Inchicore).

mixer man could judge accurately for himself the amount of water which was required from the appearance of the mix alone. This is the present procedure, with sporadic checks after showers or heavy rain to confirm the accuracy of his judgement. Average batch weights are used. An upper limit is set to the amount of water which may be added, of course.

Test Cubes

As can be seen from the results of the survey, opinions differed as to whether site cubes should be vibrated or not. Possibly some regarded the rodding method as standard procedure, irrespective of how the concrete was consolidated in the job. At first sight this would seem to correspond to the viewpoint that cubes should be stored under standard conditions irrespective of what temperature changes are experienced on the site. There is this difference, if one accepts that cubes are intended to indicate the potential strength of the concrete under standardized conditions. With 'dry' mixes rodding may not be sufficient to consolidate the mix adequately, so that cube results will be abnormally low. The real root of the differences of opinion here may lie in the physical difficulty of vibrating cubes in 6" moulds with a poker vibrator. Suggested methods for doing this satisfactorily might be put forward in the Symposium discussion.

The observations made by some of those who replied about 7-day strength variations show the importance of curing cubes under controlled temperature conditions, especially for early testing. They should be stored in a thermostatically controlled water tank and tested as soon as possible after removal from the tank. Given these conditions there seems no reason why 7-day cube strengths should not become more

generally accepted as a measure of concrete strength. While the British codes base their requirements on 28-day tests there is a definite demand, with modern speed of construction, for much earlier assessment of concrete strength if remedial measures are to be taken in time. (Where 7-day cubes are used for determining stripping times and not concrete quality, they should be cured in the same way as the main concrete, of course, and subjected to the same temperature variations).

Use of Impact Hammer

Non-destructive methods of measuring concrete strengths have been sought over many years without any outstanding success. One of the most widely used in this country, it would seem, is the Schmidt impact hammer. The author has used the tool in a series of tests on 6" cubes in two ways :

- (1) Vertically downwards, with the cubes supported on a concrete floor.
- (2) Horizontally, with the cubes gripped in a compression testing machine.

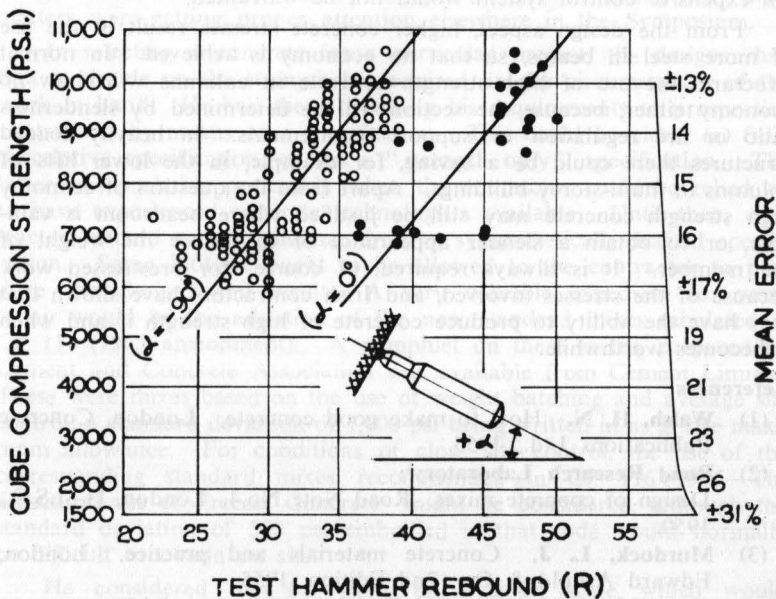


FIG. C3. CONCRETE TEST
HAMMER RESULTS.

The results showed considerable scatter. (See Fig. C3). The best assumed straight line relationships, when plotted against cube strengths, were

quite different from those suggested by the manufacturers for general concrete work. Although the hammer blows were confined to a circular area about 2" in diameter drawn centrally on the cube face, considerable variations were found also in the reading on individual cubes. Tests made on concrete members gave readings generally higher than those on cubes of the same age, presumably due to the effect of the greater mass on the rebound of the hammer. It is only fair to add that the author has heard from other sources of satisfactory results being obtained.

Improvements in Concrete Strength & Quality Control

Too often higher concrete strengths and better quality control are advocated without thought to the incentives necessary to make them worthwhile. Better quality control is advantageous if the contractor can save cement by using a leaner mix. This is achievable with a 'strength only' type of specification. With 'fully specified' mixes the only incentive is in avoiding the expense of remedial measures, which could become necessary if the cube strengths were low. This standard should be attainable with ordinary control and normal precautions, such as those recommended under cold weather conditions. An expensive control system would not be warranted.

From the design aspect, higher concrete stresses result in the use of more steel in beams, so that no economy is achieved. In normal structures the use of high strength concrete in columns will show no economy either, because the section will be determined by slenderness ratio or fire regulation or support requirements. In heavily loaded structures there could be a saving, for example, in the lower lifts of columns in multi-storey buildings. Apart from the question of economy high strength concrete may still be justified where headroom is valuable, or to obtain a slender appearance or to reduce the weight of the member. It is always required, of course, for prestressed work because of the stresses involved, and Irish contractors have shown that they have the ability to produce concrete of high strength if and when it becomes worthwhile.

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Discussion

MR. HOLLOWAY introduced his paper.

The theme of Session C was concrete strength and the objective was to define the present practice and views held in Ireland on this subject. For this reason, the most useful section of the paper was possibly the summary of current practice based on the replies received to the questionnaire mentioned in the introduction to the paper. The facts which emerged spoke for themselves, and were offered for discussion without further comment.

He felt, however, that some contentious aspects of strength control and mix design mentioned in the paper might with advantage be underlined.

The compressive strength of concrete generally reflected many other desirable qualities of concrete such as strength in tension and in shear, resistance to abrasion, durability, density and watertightness. Strength, however, had to be seen in proper perspective in relation to other desiderata of the finished product; for instance, good quality finish and dimensional accuracy in casting. It was fitting that these matters were getting proper attention elsewhere in the Symposium.

In selecting a concrete for a particular project, the designer had first to decide on the strength he required, in the circumstances of the work in hand. He had then to convey his requirements to prospective contractors by means of a specification. This could be either (a) fully descriptive specification, or (b) a "strength only" specification. The latter was probably preferable when the contractor could be relied on to have experienced concrete technologists available. Until then, contractors should accept guidance from a sympathetically-drafted specification. Some latitude ought to be allowed to the contractor to produce the desired end result. A very valuable expedient for work today would be the adoption of the new standard mixes tabulated in CP 114 (1965 amendment). A pamphlet on these mixes, prepared by Cement and Concrete Association was available from Cement Limited. These were mixes based on the use of weight batching and average site control, a standard deviation of 1,000 psi being written in as a safe maximum allowance. For conditions of close site control, the use of the corresponding standard mixes recommended in CP 116:1965—The Structural use of Precast Concrete—might be considered, although the standard deviation of 500 psi embodied in that code would normally be difficult to obtain on site.

He considered that for work on a larger scale, which would justify the initial expense and close site control, the designed mixes described in CP 114 could be recommended. It was essential, however, that a contractor proposing a designed mix should demonstrate the quality of the concrete as made, before the work had progressed too far; and further that he should show his ability to maintain the necessary site control. Statistical analysis of the cube results would

be required, and reference might be made to a useful synopsis of this subject in the appendix to the "Guide to Specifying Concrete : Part 1 : Type 1 Specification " published by the Institution of Civil Engineers.

Volume batching by nominal 1 : n : 2n proportions was gradually disappearing except on small works where it was likely to continue indefinitely.

Concrete cube testing as the primary measure of quality was unlikely to be superseded by beam testing. In this connexion, it should be observed that there were in Ireland at least a dozen concrete laboratories, distributed between the universities, public bodies, manufacturers and research institutes, and that none of these was working to full capacity. It should be recognised that modern concrete control required more tests than it had been our practice to do heretofore. Arising from this was the importance of sponsoring in Ireland research into accelerated testing, towards the time when the 7 day test could safely replace the 28 day test.

Regarding the control of the w/c ratio, Irish climatic conditions did foster large variations in the moisture control of, particularly, fine aggregates. Figure C2 in the paper indicated a range of $\pm 3.3\%$ approximately. To ignore this would allow a significant variation to occur in the w/c ratio, e.g., from 0.35 to 0.45. It was impracticable to follow precisely every moisture fluctuation, and a good practice might be to legislate for average conditions, leaving it then to the mixer man to keep the workability constant, subject to some over-riding maximum allowance for added water.

Some reference might be made to gap graded concrete, a material which with the shortage of middle sizes in certain Irish gravel aggregates, might be particularly suitable in this country. The mix described in the paper with a cement content of 680 lb. per cu. yd. of concrete was slightly richer than a nominal 1 : $1\frac{1}{2}$: 3 mix. Whereas, however, the strength often specified for 1 : $1\frac{1}{2}$: 3 concrete was 4,500 psi, at 28 days, the gap graded concrete had a minimum strength of 8,500 psi and individual results in excess of 10,000 psi had not been uncommon. The workability was low, of course. More interest could usefully be taken in gap grading in Ireland.

Regarding the use of non-destructive testing, the impact hammer system would appear to be the only method which had so far got beyond the laboratory. Its value as a direct measure of strength appeared uncertain, and information on any other system known to members of the Symposium would be of great interest.

Finally regarding the acceptance level of cube test results, it was often difficult to decide what percentage of cubes might safely be allowed to fall below the specified minimum. It was notable that low strengths occurred more frequently in cold weather conditions and the relatively simple precautions which were all we needed in Ireland against frost should be rigorously enforced on our sites. It was useful to remember that strength in concrete was not a function of age, but rather of maturity, i.e., age multiplied by temperature.

MR. A. D. H. MARTIN opening the discussion said that Mr. Holloway and also the writers of the other papers for the Symposium were to be congratulated on their clarity and conciseness.

The attitude revealed by many of the replies to the questionnaire that there was no economy in improving concrete strength was surprising. It might be true in a hard businesslike way, but was surely contrary to the whole concept of engineering; and in fact, if handled intelligently, improved strengths had to be to everyone's advantage.

There was definitely a place in concrete technology for visual judgement of good quality material, and it was justifiable to allow the mixer driver some latitude in the control of his concrete, if he was experienced and was on a project where large quantities of concrete were being produced.

Further comment would be welcome on some points in Mr. Holloway's paper and introduction. He would ask, in particular,

- (1) Was gap graded concrete more porous than dense normally graded concrete ?
- (2) How many people in Ireland had used the impact hammer test ?
The scatter of the results which Figure C3 shows had cast some doubts on its general usefulness.

The members of the Symposium might be interested in some facts about the new Kish Bank lighthouse. These comments might be divided up among several of the papers, but it was probably more sensible, with the permission of the members, to make them all together. The contractors for this project had not worked in Ireland before. In selecting their aggregate they visited every source of supply within 40 miles of Dublin. The Kill pit in Co. Kildare was chosen. Material up to $\frac{3}{4}$ " was required and it was stipulated that this be delivered straight from the bins, rather than from stockpiles. Gradings from Road Note No. 4 were used as a basis for mix design, and about 24 gradings were tried by the contractors, before a mix was finally selected. Further tests with additives followed, and air-entraining agents and plasticisers were used in all the placed concrete.

Two mixes were used, as follows :

- (a) For all concrete exposed to wind, rain and/or sea water.
aggregate/cement ratio 4.43.
w/c ratio 0.425.
Quantities per cu. yd.: 660 lb. cement, 910 lb. fine aggregate,
2,010 lb. coarse aggregate ($\frac{3}{4}$ " - 3/16"), 280lb. water.
air entrainment 4.5%
Plasticiser 0.25 pints per cwt. of cement.
- (b) For all other concrete
aggregate/cement ratio 4.46
w/c ratio 0.475
Quantities per cu. yd. : 675 lb. cement, 990 lb. fine aggregate,
2020 lb. coarse aggregate ($\frac{3}{4}$ " - 3/16"), 320 lb. water.

The results from crushing tests of 241 cubes of concrete (a) were as follows:

No. of Cubes	Age days	Maximum psi	Minimum psi	average psi	standard deviation psi
117	7	6,600	4,500	5,820	—
124	28	8,400	5,500	6,780	446

Irish Portland cement was used throughout, except in the outer wall of the caisson from below low water level to above high water level. In this region, imported sulphate resisting cement was used.

Air bubbles $\frac{1}{4}$ " to $\frac{3}{8}$ " deep and up to $\frac{1}{4}$ " in diameter appearing on the surface were attributed authoritatively to the use of an emulsion type mould oil and/or to an unduly fast initial set (15-20 minutes) with resulting loss of workability, due to a reaction between the air-entraining agent being used and the finely ground sulphate resisting cement. It was recommended that neat oil be substituted for the emulsion type oil and that the air entraining agent be changed. It was generally felt that the second reason was the significant one and the introduction of a new air-entraining agent, which possibly contained a retarder, removed the trouble.

Compaction factor apparatus was on the site and in constant use throughout the work, a whole time concrete inspector being on the staff. Compaction factors of 0.90 were normal, the maximum being 0.92. The slumps were normally $1\frac{1}{2}$ " with a maximum of 2".

Wall concrete was generally stripped under 24 hours, and frequently at very little over 12 hours.

The lighthouse was now in position about 9 miles out to sea, and for the record, was both in its right position and vertical. This was correct despite the assertion of one "side walk superintendent" in Dun Laoghaire who was satisfied it was not vertical because it did not line up with the promenade lamp posts.

PROFESSOR E. C. DILLON.

The very interesting description of the Kish Bank lighthouse recalled to the speaker the wartime Phoenix "ships" on whose construction he had been engaged as a young engineer. The base and lower part of the walls of these units, which were 200 feet long and 60 feet high with a beam of about 50 feet, were of heavily reinforced concrete 1' 3" thick placed by pump. Despite the occasionally casual control of construction and the emphasis on output rather than quality, it was a surprising fact that there had been no leaks in the group of which he had experience.

Regarding gap grading he would prefer to describe the mixes indicated by Mr. Holloway as "grading with a gap" or "with two gaps." He felt the term "gap graded" should be reserved for concrete with a single sized coarse aggregate and a rather fine sand, a mixture in which there could be no question of particle interference. It would

be of interest to hear from Mr. Holloway why he had chosen that particular mix for railway sleepers, and also what results he had obtained for the E value and for the creep and shrinkage characteristics of the concrete described.

The matter of making cubes as discussed by Mr. Holloway was of particular importance. Concrete of low workability could not be compacted in cube moulds with the British standard 1" square tamping rods. In University College, Cork, a tamper consisting of a $4\frac{1}{2}$ " square plate $\frac{3}{4}$ " thick welded to a 1" diameter rod 18" long had been devised, and was used in the following manner. Each layer of concrete in the cube was tamped to refusal three times; first with the tamper tilted to ram towards one vertical face of the mould, then with the tamper tilted to ram towards the opposite vertical face and finally with the tamper plate horizontal. The slightly proud surface of the cube was then finished by cross-striking with the trowel on edge prior to the usual skimming and trowelling operations. With this procedure the operator could obtain consistent and representative results with dry concretes, and sites using the same technique could readily produce comparable cube results. The strengths obtained compared consistently with those of cubes made on a Westool vibrating table, to within 50 p.s.i. or so.

It was difficult to see how normal cubes could be made by direct insertion of a poker vibrator in the cube mould. A weakness had to exist around the space occupied by the vibrator, due to the nature of the material which flowed in to fill the void left by the withdrawal of the tool. This effect whilst negligible in the actual structure was highly significant in the cube.

Another method, the pneumatic hammer with a tamper head, had been tried at University College, Cork, and had not been found suitable.

It seemed to him extraordinary, when so much dry concrete was being cast, that standardised testing methods had not been developed, and this matter was well worth discussion at the Symposium.

He considered that the use of the Schmidt impact hammer as a means of non-destructive testing deserved serious consideration. Whilst there was a wide scatter in results obtained, there would be formed, in any series of tests, a minimum envelope which in itself was a useful check on quality. It was better to grip a cube, which was to be tested by this method, in a testing machine with a little load on, and to strike it horizontally, than to lay it on the floor and strike it vertically. It was also important to rub off the mortar surface before testing. Ordinary experience with any form of impact on concrete shows that the "mortar" surface of many concretes could be readily "dented"; the true strength of the concrete should be measured on the material behind the mortar face. It was suggested also that the Schmidt rebound number could be a useful index of the durability of a concrete.

M. A. B. HARMAN found Professor Dillion's remarks on making cubes of extreme interest. A technique using a flat plate welded

to the head of a pneumatic hammer had been used successfully in Britain for a wide range of concretes, many with low workability. The speaker would like to know the lowest workability with which Professor Dillon's method could be used.

Regarding the bibliography to Mr. Holloway's paper, it might perhaps be mentioned that there was now a third edition of Dr. Murdock's "Concrete Materials and Practice" which had superseded the edition mentioned in the references.

British opinion found it hard to be enthusiastic about the value of the impact hammer. Many people would consider that its merit had not been proved, so it was of interest to hear an opinion here which suggested that it deserved more intensive examination.

MR. C. CLIFTON remarked that in his practice, preliminary cubes were not usually made, the quality of the concrete being determined from the work on the foundations where the strengths required generally were not high. Any necessary adjustments to the mix could be made at that stage. The writing of specifications could be shortened by putting the onus on the contractor to provide a concrete of minimum strength and minimum density with materials complying with relevant standard specifications; and in most instances only one mix should be necessary for the whole of a given project. Tolerances should be specified for precast work, and as regards finish, the contractor should be required to prepare prototype members or samples for approval, the understanding being that members used in the project would have to have at least the quality of the approved sample.

This approach to specification was not so satisfactory when one could not be certain that the contractor to be appointed would be knowledgeable. Then, it might be necessary to adopt, say, Road Note 4 and nominate a concrete with a substantial safety margin. This, in turn, could be very wasteful if the appointed contractor turned out to be one who could in fact make good concrete with only a small coefficient of variation. So much depended, eventually, on the skill of the site workers.

Referring to the use of cubes in testing concrete, the 7-day test had a lot in its favour. The procedure for 7-day testing required careful thought, particularly if correlation between 7- and 28-day strengths continued to be required. At present two distinct approaches existed. If the cubes were cured under standard conditions, the 7-day strength foreshadowed the 28-day strength quite accurately, but gave little idea of the strength of the site concrete at 7 days. If the cubes were cured under site conditions, they gave at 7 days a useful indication of the strength of the site concrete at 7 days, and this information might be very important for stripping formwork. On the other hand, they did not indicate, with any degree of certainty, the approximate 28-day strength of the site concrete.

On one project it had been found that 7-day cubes cured under site conditions had ranged, due to site temperature variations, from $\frac{2}{3}$

down to a $\frac{1}{3}$ of the subsequent 28-day strengths, the 28-day figures being well up to specification.

The development of the Schmidt hammer, not so far used by the speaker, would appear to be useful. It had been used on the Medway bridge project to assist in gauging the readiness of concrete to receive prestress.

MR. H. B. ROCHE reported that he had used the Schmidt hammer at the Beaumont reservoir in Cork, and in work on precast piles and other precast units. Where the hammer was used on the concrete surface as stripped from the formwork, a series of blows on the same point of impact would give progressively larger readings. To avoid this it was therefore necessary, as Profesor Dillon stated, to remove, with the carborundum stone provided, the "mortar" face of the surface to be tested. Consistent results could then be obtained. An interesting point in justification of the hammer was that, where two mixes of concrete were used in one unit, e.g., the bead and toe of a pile being required to be stronger than the bulk of the shaft, the hammer could indicate where the richer concrete took over from the leaner mix.

The method of making cubes from stiff concrete, described by Professor Dillon had been used by the speaker with good consistent results. An interesting problem in the curing of cubes had been observed. Two sets of cubes of similar concrete had been stored, one totally submerged in water, the other standing in water 2" - 3" deep in an atmosphere of about 90% relative humidity. The second set had given higher results than the first. He would suggest that, possibly, partial submergence with the attendant constant evaporation off the exposed areas gave satisfactory hydration conditions in the heart of the cube; whereas total submergence might have imprisoned within the cube a quantity of concrete unable to receive as much hydration as it required.

THE CHAIRMAN felt that Mr. Martin's praise of the clarity of the papers must be supported. Engineers must avoid jargon. About 50 years ago, a report to Cork Corporation had described the surface of the water in a reservoir as having an evanescent iridescence. Certain of the councillors had felt that this would have been more clearly described as a kind of greasy look; and he felt that perhaps they were right. More recently, the words "circumscribed sphere" had been used in a circular from engineers to engineers in a manner to be deprecated. These two terms, both essentially geometric, at least insofar as engineers with their mathematical training were concerned, were used without any mathematical connotation whatsoever, the one implying "restricted" and the other "department."

Turning to the specification of concrete, the speaker was associated with the late Professor H. N. Walsh in drawing up, about 40 years ago, type specifications for concrete. Basically, the approach used was to state that a certain strength of concrete was required and that a mix consisting of stated quantities of coarse aggregate, fine aggregate and

cement was likely to provide it. This form of specification had been used successfully since then by both engineers and architects. In the speaker's more recent practice, he had introduced a modification. It was now stated in his specification that if it was necessary to use more cement than required to produce the desired strength, this would be treated as a measured extra; whereas, if less cement was required, this would be dealt with as a measured deduction.

DR. E. T. HANRAHAN in a written contribution, observed that it was somewhat surprising that the compacting factor apparatus had not passed into general usage, especially on the larger contract. It would have appeared, however, that the apparatus could have been substantially improved by inverting the two top truncated cone containers thus reducing the effect of friction.

MR. H. T. GOLDEN in a written contribution maintained that on large contracts where uniformity of quality was important, the site staff frequently used the 7-day cube test results, accepting the 28-day figures as 50% larger. It was important to be clear about the significance of cube test figures. 6" cubes cured under site temperature conditions gave no information about the behaviour of a large mass of concrete on that site. Cubes were of value in controlling consistency, and for use in this way had to be made, and cured, in a standard manner. He had found a small site-made vibrating table satisfactory for stiff mixes. Regarding strength variations the use of an immersion heater and thermostat in the curing tank obviated much trouble on site. It was to be noted that BS 1881 recognised this in that they quoted factors for variations in strength with the departure of the curing water temperature from 64°F., thus:

50°F.	84%
64°F.	100%
70°F.	105%

Where an accurate assessment of the strength of the placed concrete was required, the correct approach was to cut and test cores of the actual concrete.

The writer had found the Schmidt hammer valuable as a guide to uniformity, but not as a substitute for cube tests. Tests at 3 days revealed a variation in the concrete which later 7-day tests on cubes confirmed. On another occasion the hammer detected a faultily-completed area, not visible on the surface.

MR. HOLLOWAY replied.

Mr. Martin was to be congratulated on the remarkably low standard deviation achieved on the Kish project. It showed what could be done with close site control. Gap graded concrete had a high density and whilst he had not used it in water-retaining structures he was confident that it would not be porous.

His remarks on the impact hammer did not constitute a condemnation of that tool. Concrete was not a precise material and the hammer

was quite suitable in deciding whether a given concrete belonged, for example, to the 3,000 p.s.i. or 6,000 p.s.i. category.

The decision to use gap graded concrete, queried by Professor Dillon arose from the need to have a concrete with :

- (a) very high strength requirements, viz., 8,500 p.s.i. minimum at 28 days and 6,500 p.s.i. at 20 hours, with steam curing.
- (b) the highest concomitant workability.
- (c) low creep characteristics.

Gap grading met these conditions more adequately than normal grading, and in fact it was a feature of a gap graded mix that its workability at high strength level is better than that of a mix with continuous grading. E had not been measured for this particular concrete.

Regarding the preparation of cubes with concrete of low workability, this was long a matter of debate between engineers. It was his practice to use a vibrating table where available.

Dr. Hanrahan's suggestion in regard to a modified compaction factor apparatus was of interest. Such devices, however, gave a measure more of consistence of the mix than workability and it was the latter (the ease with which concrete could be placed, compacted and finished in particular circumstances) which was of importance. With poker-vibrated mixes, this property was probably best judged by observing the behaviour of the concrete as it was vibrated, particularly as the poker was being withdrawn from the mix.

Mr. Golden's contribution enhanced his belief that where cubes were stored in thermostatically-controlled tanks and tested immediately after removal, 7-day strengths could be accepted. Research on the conditions under which even earlier cube strengths might be acceptable (perhaps with high-temperature curing) might prove extremely valuable.

SESSION D

THE DURABILITY OF STRUCTURAL CONCRETE INCLUDING ROADS

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Summary

Durability is defined. A history of structural concrete in Ireland for the last 120 years is given in outline. The long term behaviour of Irish structures of various periods is considered under eleven headings. The inauguration of a continuing durability survey based on records of selected structures including roads and observation of their performance from completion onwards is suggested.

The Meaning of Durability

The satisfactory life of a structure, e.g. a building, tank, bridge, or road slab is the period during which the structure fulfils the function for which it was designed without excessive expenditure on maintenance or repair or on unanticipated redecoration. The designer will usually, whether implicitly or by direct brief, plan his structure for a minimum satisfactory life which may vary from 100 years to as little as 10 years.

The durability of the structure is that quality which measures its ability to achieve the satisfactory life required. It is a function of the total structure as designed, detailed, and constructed, and also to varying degrees a function of the different materials and components of which the structure is formed. The application of this general definition to a specific problem, however, requires the designer to assess the effect on his chosen materials and on their assembly of the particular environment in which the structure is to function and the uses to which it will be put.

The present paper considers structural concrete in Ireland in the light of this definition. It reviews broadly the actual performance of structures built wholly or in part of concrete in this country during the last 120 years. It suggests from this review some points which appear to warrant special consideration by designers for Irish conditions.

The History of Concrete in Ireland

The use of Portland cement appears to have developed quite slowly after its discovery by William Aspdin in 1824. Many of the eminent

engineers of the quarter-century which followed expressed doubts about its value. An engineering publication in England (1)* dated 1837 contains two references to experiments with pre-Aspdin cements and no reference whatsoever to Portland cement. Presumably supplies began to come to Ireland at an early stage, but in the circumstances it is not surprising to find no definite reference to its use in this country until about 1846 when it was used to build a tank below high water level on the south side of Howth Head (2); and again in 1850 when Manning (3) used it in the foundations of a bridge over the river Glyde.

At about the same time the French engineers, Coignet, Monier and Lambot started using metal frameworks to hold cast concrete together in relatively thin sections and in 1855 Coignet took out patents for what were in effect the first reinforced concrete slabs, although it would appear he did not fully recognise the significance of embedding "beams, iron planks, or a square mesh of rods" in the concrete. Development spread quickly from France to England, and in the 1860-70 period when the theoretical background of the function of reinforcement was beginning to be appreciated the use of structural concrete in many forms expanded rapidly and spread over to this country. In 1866, Mallet in his presidential address to the Institution of Civil Engineers of Ireland (4) recommended to his colleagues a new cement developed by the French chemist Delville, saying that it was available "at a price that ought to compete with Portland cement. The process is hampered with no patent . . ."

During the period 1860-1880, Stoney (5) carried out extensive structural concrete works particularly in the port of Dublin and in fact by about 1869 had already devised and used in his practice a concrete mixer with a capacity of up to 10 cubic yards per hour.

From 1870-1880, plain concrete was used widely throughout Ireland, a major structure being Grattan Bridge in Dublin. In a paper to the I.C.E.I. in 1877, Cotton (6) described experiments on concrete arches which he proposed to use as tank roofs, and reached the surprisingly high failure load of 754 lb. per sq. ft. on plain concrete arches with a span of 12' 0", a rise of 1' 0" and arch thicknesses of 6" and 2" at springings and crown respectively. In the discussion on Cotton's paper reference was made to the satisfactory behaviour of 18' 0" span roadway arches and several farm buildings, all dating from about 1873 on an estate in Kerry, and the use of plain concrete road bridge arches "particularly economical for skew bridges" was reported from Cork.

There was as yet little reference to reinforcement and in fact the discussion of the previous paragraph also reported the completion in Kerry of a 14' 0" square suspended two-way plain concrete floor slab 6" thick and its satisfactory behaviour under the test load of a 56 lb. weight dropped centrally on to it from a height of 7' 0".

In 1881, the manufacture of Portland cement was commenced in Ireland by the Drinagh Portland Cement Works at Wexford, and by

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

1887 it had been joined by the Dublin Portland Cement Company with quarries in Inchicore and works at Ringsend.

Reinforced concrete was well established on the Continent by this time and the French contractors, particularly, were beginning to work in England, and, from their bases there, in Ireland also. Whilst details in a form which would be recognisable to us to-day were already being used in bridges, columns and beams, plain concrete and arch traditions were still strong. Much of the floor and roof construction in structural concrete took the form of plain concrete jack arches of up to 6' 0" span supported on the lower flanges of steel joists which in turn spanned between supporting walls.

An interesting structure of this period is the C.I.E. coal store at Knocklong, Co. Limerick. Dating from before 1890, the roof is a flat arch of plain concrete of 23' 0" clear span and 103' 0" long. It is supported on masonry walls with flat arched mass concrete lintels over the openings. The arch rise is 2' 0", and the thicknesses at springings and crown are respectively 9" and 4". The horizontal thrust of the arch is taken up by $\frac{3}{4}$ " dia. steel tie bars at 5' 0" centres, anchored in the arch concrete at the springings.

By this time, plain concrete was being used extensively in the walls of houses, to replace masonry and brickwork. Ornamental scroll-work in concrete was a feature of this period.

The 1900-1914 period brought a new measure of diversification to concrete practice in Ireland and many ambitious and successful projects were carried through. The French engineer-contractors came here in greater force and they, and a number of Irish designers, built bridges, jetties, granaries, warehouses, factory buildings, reservoirs and water towers throughout the country. The first reinforced concrete highway bridge was built at Knockmahon, Co. Waterford (7) and in Kilkenny, an arched bridge in reinforced concrete with a clear span of 140' 0" which was at that time the longest such span in Great Britain and Ireland (8). Earlier in about 1898 a reinforced concrete footbridge was built crossing a sea inlet at Kincasslagh, Co. Donegal, and in 1909 one of the most interesting reinforced concrete structures ever constructed in Ireland up to this day was completed, namely, the Mizen Head footbridge, a partially precast 172' 0" span arch crossing a sea inlet at a height of 150' 0" above water level.

A contemporary account of a new five-storey mill building in Sligo (9) indicates the air of mystery which still attached to reinforced concrete at that time:—"After exhaustive enquiry, Messrs. Harper Campbell Ltd., decided upon having their new premises erected in Hennebique's Ferro-concrete, a system whereby Portland cement concrete is strengthened by use of a steel skeleton, or network of steel bars, which combines great strength with lightness of design . . . we hope in another article to give some fuller details regarding Ferro-concrete and its rapidly expanding use."

The next period from 1914 to 1930 saw the arrival of plain and

reinforced concrete roadways. The First and Second Irish Roads Congresses, in 1910 and 1911, had passed with no reference to the use of normal in situ concrete as a finished road surface. Concrete paving slabs for roadways had been used at least ten years earlier in England, rolled concrete macadam, which resembled the so called "sandwich" roads used later in Ireland (1925-1940) had been used in Edinburgh prior to 1880 and concrete up to 12" thick was being used in Belfast as a base for stone setts. The first ordinary in situ concrete roadway in England was, however, not laid until 1912, at Chester, and concrete does not appear to have been used in Ireland for this purpose until about 1925.

Towards the end of this period the last of the early Irish Portland cement works (the first two plants had been joined in the interim by others) ceased production leaving this part of Ireland totally dependent on cement supplies imported from Britain and the Continent, where the main source was Belgium. The plant at Magheramorne in Co. Antrim, which had started production in 1913 carried on through this period and still functions to-day in a greatly expanded form.

The major concrete project of this period was undoubtedly the Shannon hydro-electric scheme in which the intake works, generating station ship lift and headrace and particularly the bridges, all based on structural concrete, reflected a high level of technique and appreciation of the material. This period also saw the construction of the first large grandstand projects, at Lansdowne Road, Dublin, for the Irish Rugby Football Union and at Ballsbridge for the Royal Dublin Society.

The pattern of design and construction which developed during the 1920-1930 period continued without much change into the 1930-1950 period. The most significant date in this time was 1938 when the manufacture of Portland cement was resumed in the Republic by a new Irish company, Cement Limited, with works at Limerick and Drogheda. The use of mass concrete walling for rural housing was very popular during this period, but after the war years, the growing use of the 18" x 9" x 4½" concrete block which had been introduced to Ireland, certainly prior to 1925, coupled with the raising of housing standards and the fairly widespread adoption of cavity wall and hollow block wall construction largely superseded it.

In the final period from 1950 to the present time structural concrete has, on the whole, been greatly refined in design and construction, and in architectural treatment. The scale of the work done has tended to increase during this period and there are now many structures or groups of structures such as office blocks, hospital complexes, industrial buildings, cooling towers, grandstands and bridges all of which are larger than anything of their kind built in concrete in this country before 1950.

During this period in 1951, prestressed concrete was first used in the Republic. Its growth was slow at first, as in fact it was in many countries, but familiarity with its techniques is growing and since 1960 a very sizeable quantity of new work has been built in this material. In particular, bridge design, especially for the larger spans, has become almost exclus-

ively a subject for prestressed concrete, and this trend, which is worldwide, appears unlikely to be altered in the foreseeable future.

Summing up this section, there is, or has been, concrete work in Ireland representing all stages of the evolution of the material during the last 120 years, and there would not appear to be any general technique so far developed, with the exception of "heavy" concrete for nuclear power shielding structures, which has not been used here.

The Condition of Irish Structures

As the purpose of this paper is consideration of the durability of structural concrete of the types used here up to the present, a questionnaire was issued throughout the country to elicit factual information on the condition of the older concrete structures and to seek opinions on the reasons for their behaviour whether good or bad. The form of the questionnaire was as follows:—

- (1) What are the oldest buildings/structures which you know in which reinforced concrete has been used to a substantial extent?
- (2) Are they still being used?
- (3) What condition are they in?
- (4) Has the reinforced concrete portion required extensive repair at any time, and if so what type of repair was used?
- (5) Why was the repair necessary?
General appearance, spalling of concrete, defective cement, defective aggregates, inadequate cover, inadequate compaction, corrosion of reinforcement, other cracking, failure under load, faulty construction joints, malfunction of bearings or of other permanent joints, leakage at joints in water towers, etc., seepage through walls of water tanks, ground water attack, creep due to sustained load, settlement of foundations, inadequate design or detail of concrete section or reinforcement by modern standards, corrosive atmosphere, frost, seepage through basement walls, other causes.
- (6) Have any reinforced concrete buildings/structures which you know deteriorated to the stage of having to be taken out of service?
- (7) Why was this necessary?
- (8) What are the oldest reinforced concrete/plain concrete road slabs which you know?
- (9) Are they still being used?
- (10) What condition are they in?
- (11) If they have deteriorated seriously what has caused this?
Wear, potholes, oversmooth surfaces, overloading through increased traffic loads, defective cement, defective aggregates, excessive jointing, insufficient jointing, defective joint design, omission of joints, inadequate reinforcement, omission of reinforcement, defective foundations, other causes.

- (12) Do you know of any reinforced concrete structures which are less than 25 years old and have deteriorated abnormally in appearance or performance?
- (13) What caused the deterioration?
- (14) What do you consider to be the three or four principal causes of deterioration in reinforced concrete buildings or structures in Ireland?
- (15) do. for roads?
- (16) General comments.

Seventy forms were issued and forty-eight replies were received from most of the branches of civil engineering and architecture in the country.

It is now proposed to state briefly the matters which can adversely affect the durability of structural concrete and to examine in the light of these matters the behaviour of the structures mentioned in the questionnaire replies, and, with due circumspection, the behaviour of Irish structures generally.

The British Standard on durability (10) lists among the causes of deterioration of materials used in buildings the following which can apply to structural concrete:

Atmospheric and climatic action.

Soil and ground water action

Fungal and plant action.

Specific chemical action or chemical changes in materials.

Wear.

Impact and Vibration.

Action of domestic or industrial wastes.

Accidental causes, including fire.

Intermeshed with these, but having additional aspects which would seem to entitle them to further individual treatment are the following:

Quality of materials.

Quality of design.

Quality of construction.

Atmospheric and climatic action

The mean monthly temperatures in winter in Ireland are from 44°-45° F. in the west of the country and from 41°-43° F. in the east. The mean summer temperatures range from 61° F. in the south to 57° in the north. Rainfall varies from over 100 inches annually in some of the western upland regions to less than 30 inches in an area of less than 500 square miles along the east coast north of Dublin. About 80% of the country has an annual rainfall of between 30 and 50 inches. The number of raindays, i.e. days in the year on which at least 0.2 m.m. of rain falls varies from 250 along the west coast to 175 in the extreme south east corner around Wexford, with the greater part of the country in the 200 to 225 range. Winds in Ireland are predominantly westerly, records from both the west and east coasts showing that nearly two-thirds of all winds are from some point between southwest and northwest. Gusts of

upwards of 110 m.p.h. have been recorded along the west coast, and wind velocities of 90 m.p.h. are not uncommon.

The overall picture is of a climate without extremes of temperature, but with high rainfall, humidity, and wind conditions. It is reasonable that the individual will recall vividly periods of intense frost and snow, and more rarely, days of extremely high temperature, but in fact, frost is not a serious primary problem in completed structures in Ireland. (Our usual lack of preparedness for it during construction periods is really indirect evidence of its relative unimportance in the overall picture). This is borne out by the questionnaire replies in which only three mentioned frost in any way, two of them being specific references to single buildings.

There is no reference to deterioration of road slabs as a result of chemical de-icing methods and no direct reference to frost action as a primary cause of damage.

On the other hand the inadequate cover—moisture penetration—reinforcement corrosion—spalling sequence which the wind-driven rain of our climate particularly fosters has been widely reported, and will be discussed later. The action of frost in cracks already developed by other means cannot of course be overlooked as a secondary cause of damage.

Condensation, whether purely climatic, or partly influenced by the nature of stored substances or by the function of the structure is a major source of deterioration. The soffits of bridge slabs and beams, of reservoir roofs, and of suspended slabs and beams in buildings where the relative humidity inside the building is high (all being places on which rain does not fall) are highly susceptible to defects arising from moisture penetration. This, in particular, is to be seen in early jack arch construction where the concrete slabs are supported on iron or steel joists with the bottom flange either exposed or covered with a thin layer of concrete. There are many instances of advanced corrosion of the metal and of widespread spalling of the cover concrete, but damage has been wholly prevented in other instances by reasonable maintenance.

Soil and ground water action

Soils and ground waters containing significant quantities of soluble sulphates, acid soils, and "made ground" or fills which are not chemically inert will cause deterioration of concrete in contact with them unless provision by way of special cements or surface protection is made to prevent attack. This condition is aggravated in the instance of ground water if there is a flow of sulphate-bearing water through the concrete. Whilst this source of damage has existed at all stages of concrete development, it would appear that general recognition of its structural significance is relatively new. There is as yet no British Standard for sulphate resisting cement as such.

No report has been received of any Irish structure which has failed as a result of attack in this form, but it is without doubt an aspect of site examination and design which warrants closer consideration than we have generally given it heretofore.

Fungal and plant action

This is substantially confined to the disfigurement of concrete surfaces by an organic growth, generally red or black in colour. It occurs principally on vertical surfaces in rural and coastal areas and postulates an open-textured surface finish, either concrete or plaster, which gives the initial windblown spores a first purchase on the surface. The formation of an impervious skin on the concrete will inhibit this growth, but it has been strongly suggested in one reply that periodic chemical removal of the growth is generally a more economical and satisfactory solution for this problem than initial surface protection.

Specific chemical action or chemical changes in materials

The principal source of damage to structural concrete under this heading is the corrosive attack of reinforcement by fumes arising from chemical processes and by spray laden with sea salt. The approximate rates of corrosion of exposed mild steel under varying degrees of atmospheric pollution have been estimated as follows (10):

Industrial areas: the central areas of manufacturing towns engaged in heavy industries or in certain chemical industries

5×10^{-3} ins. per year

Urban areas: extensive built-up residential areas or areas associated with light industries

3×10^{-3} ins. per year

Coastal areas: non-industrial areas within a few miles of the sea where the air may carry salt spray

2×10^{-3} ins. per year

Rural areas: any area not included above

1.5×10^{-3} ins. per year

The type of industrial area described above exists to only a quite limited degree in Ireland, and it is possibly not surprising that only one example of a building which has deteriorated significantly as a result of corrosive fumes, as distinct from sea spray, has been reported.

What is of considerable interest is the differential said to exist between the corrosion of exposed mild steel in coastal areas and inland rural areas. Given an equal degree of cracking and exposure of steel in two similar structures, one in each area, the satisfactory life of the structure in the rural area should, very roughly speaking, be one and one third to possibly one and a half times that of the structure in the coastal area. The increase to one and a half makes a speculative allowance for an acceleration of the rusting-spalling process in the later part of each structure's life.

The provision of adequate cover of dense concrete and the use of a design and details directed towards minimal crack widths will largely resolve this problem and it may be noted that British standard practice (11) does not call for any distinction in cover thickness between structures in external conditions of different exposures.

Attack by corrosive fumes may be intensified if the fumes have a high temperature. This condition is demonstrated in an engine shed structure, built in 1910 and in general extremely satisfactory in its performance since that time. In a series of roof beams spanning across one

of the tracks, the beams near the entrance doors show spalling of the soffit concrete and exposure of the reinforcement whilst those near the back wall of the shed which differ in form and history from the others only in that fumes from engine stacks have rarely if ever played on them for any length of time are still in their original condition.

Wear

This section refers mainly to wear by abrasion. Of the 20 questionnaire replies which made references to road slabs, eight referred to the formation by traffic of oversmooth surfaces on the slab. This matter is of course a subject receiving universal attention from road designers at present. Frequently, polishing indicates that the coarse aggregate may be somewhat "soft" but that the concrete as a mix has been properly designed, placed, and cured. Inferior concrete will break up and allow local depressions to form to the point of general failure, long before the abrasive action of the traffic on it forms the terrazzo-like smoothness here envisaged.

The same problem applies extensively in old concrete stairways, where the familiar dishing of the treads and nosings reflects the distribution of traffic. It would appear that wear, in this pattern, is inevitable and may develop quickly, no matter what structural material is used, if the traffic is heavy. Fortunately the advent of the epoxy resins and other binders has made feather-edged patching feasible in concrete and provides a good answer for wear of this kind.

The third form of slab wear is in factory and warehouse floors where the loads associated with palletisation can produce traffic of a very high load intensity on the passageways. In such a floor as this, over-smoothness is of little consequence and the defects, if there are any, are far more likely to be gross local wear with friable surfaces generally and defective construction joint or permanent joint treatment between the slab panels. This would appear to be solely a matter of the competence of the builder, as floor slabs of this type with a satisfactory life of not less than 50 years should be easily within reach with properly selected materials and good workmanship. The same comments apply to concrete floors in dwelling houses, subject always to freedom from abuse of the surface by the occupier.

A form of abrasive wear, which has received no notice in the replies, is marine erosion of coastal protection works. There have been several collapses of parts of sea walls, through direct wave impact preceded sometimes by deterioration of the foundations, but it would be of interest to hear the comments of designers of coastal protection works on their choice of aggregates and concrete mixes and on the results obtained. It has been suggested that rich gap graded concretes using very large coarse aggregate should be used and that the coarse aggregate should as far as possible consist of beach pebbles and small boulders or similar marine-eroded material. There is no shortage of aggregate of this kind in many of our coastal areas, if it is thought suitable for this purpose.

Impact and Vibration

The reaction of structural concrete to impact, whether in the emptying of storage silos, or by wave action on sea walls, or during rough-weather berthing at jetties and wharves is primarily a function of design. No information has been received of the long-term behaviour of the first two types of structure. Regarding the third type, however, it is reported that a piled jetty built in 1910 and still in use has shown some spalling of the cover concrete in the reinforced concrete piles and corrosion of the reinforcement. This appears principally between high and low water levels, and it is suggested that the alternation of wetting and drying aggravated by impact due to rough-weather berthing has produced this localised condition.

No report has been given of failure of structural concrete through vibration. Other countries have experienced damage to heavy machine foundations from this cause, in the form of vertical or horizontal cracking of the foundation blocks, and recourse has been made to horizontal and vertical prestressing to combat these effects. Information on Irish experience in this matter would be of interest.

Domestic and industrial wastes

This section applies in the present context to the effect of industrial spillage on concrete surfaces. The principal liquors are vegetable and mineral oils, brewery spillage, condensation deposits in laundries and dyehouses, and, of particular importance in Ireland, creamery and dairy spillage and washwater. The only report received under this heading related to brewery spillage due to which the surface of a dense concrete floor slab has been deeply etched after only 12 years of service. Further information would be valuable, especially referring to milk processing, listing the aggregates, mixes, additives and surface treatments used and the results obtained.

Accidental causes, including fire

There would appear to be very little Irish information available about the behaviour of structural concrete in a building on fire, and no report on this matter was received in the present instance. Some detailed consideration of this aspect of structure could, with advantage, be made, particularly should the time come to incorporate regulations on this matter in a national building code. It is often felt that existing regulations in other countries are unduly restrictive, particularly as regards the minimum sizes of members, and that refined architectural design may be hampered as a result. The validity, or otherwise, of this opinion could, with advantage, be probed.

Quality of materials

Since 1938 cement supplies in Ireland have come almost wholly from the Drogheda and Limerick works of Cement Limited. The principal structural advantage of this, and one which larger countries cannot hope to have is uniformity of product, and this uniformity at a high level of quality has played a major, possibly disproportionate, part in keeping the

performance of structural concrete at a high level in this country in the last 27 years. Before then, the difficulty with cement was not at all that it was necessarily of low strength (in fact tests on shipments arriving here by sea during the 1920-1930 period occasionally revealed strengths substantially higher than we now specify as satisfactory) but that it was not possible at the design stage to be certain of the behaviour of the material likely to be delivered for any particular work. This applied both to 28 day strengths and to the rate of hardening, and one report has been received of concrete made with a Belgian cement which, whilst it was ultimately satisfactory, took approximately three weeks to reach the hardness normally associated with an age of about two days.

Looking at Irish concrete aggregates in their relation to durability, it may not always be realised that whereas the country generally has an ample supply of sound aggregates, there are some quite large areas, up to 600-700 square miles in extent or even more, which have no good local aggregates, and in particular no good fine aggregate. Major contractors will usually be aware of this lack, but small works in these areas sometimes embody soft flaky shales, dirty poor quality river sands and shaley gravels. Concrete walls made with these materials can be so unstable as to be little better than the mud walls of earlier times, and it is not unknown for a strong cement rendering coat falling away from such a wall to take part of the concrete with it.

Less reprehensible than the use of such materials, but still far from good practice, is the use of pit-run or "as-dug" gravel, by its nature non-uniform, as an all-in aggregate. This usage is widespread through the country, and continues to be allowed, largely because (a) concrete strengths, when checked, continue to be passable, although this could be largely on account of the quality of the cement, and (b) the very roughness of much of the concrete produced calls for the coat of plaster which is a very common finish in Ireland, and which, it must be suspected, is still often specified as a line of least resistance.

There is no report in Ireland of damage arising from the use of shrinkable aggregates, at present under investigation in Scotland and South Africa. Any evidence of unanticipated deflexions of slabs or beams, or apparently inexplicable cracking of concrete would be of interest in this connection.

Turning to the artificial aggregates, there are no native lightweight aggregates, with the exception of breeze and clinker, both of which are available in small supplies, and are little used to-day in Irish concrete. These materials have, on the whole, been used successfully in the past, but there are reports of damage due to the difference in thermal properties between breeze concrete walls and contiguous concrete made with natural aggregate in beams, slabs, and block walling. There is also one report of large scale corrosion of reinforcement through the action of "unsound" breeze in floor slab concrete.

Quality of design

Structural concrete design in Ireland has kept closely in step with

good international practice. Many matters in this practice have had to be modified from time to time to eliminate earlier weaknesses. Our structures of the appropriate periods exhibit these weaknesses.

The most widespread fault is a combination of inadequate allowance for cover to reinforcement and poor quality concrete in the cover. Seventeen questionnaire replies listed this as one of the main causes of deterioration, as a function of either design or construction. One report was received of the long-term behaviour of jetty beam concrete about 40 years old in which a practice, at one time considered "good," almost to the point of being a counsel of perfection, by many designers, was used. This was the formation of the soffit cover in 3 : 1 sand : cement mortar. This material fell away completely in the jetty referred to, and about 25% of the reinforcement value was lost through corrosion, before remedial action was taken about 30 years later.

Detailers of reinforcement have often lost sight of the importance of providing adequate cover to all reinforcement, not only the main bars. Corrosion can equally well start in the binders and hoops, and even when cover to main bars is ample, a concurrence of bad detailing, bad bending, and bad placing, can reduce the binder cover to $\frac{1}{4}$ " or even to nothing. A related detail is the tendency to fit too much reinforcement into a section. Even if possible on the drawing board, over-full sections can mean poor compaction and therefore inadequate protection to the reinforcement.

Due to the increases in allowable working stresses over the years, creep is now having to be considered more closely in design. This phenomenon has always existed and will manifest itself in old structures, particularly those designed for light loads and having a high span/depth ratio. One report has been received of a tank roof 55 years old, sagging but still structurally sound. This may be a case in point, and it is felt that there may be many such structures in the country.

In road design Irish practice has always been good, the Monaster-evan-Kildare road, laid in 1926 on a peat sub-grade being considered a model example of the durability of concrete roads. This road performed satisfactorily for 30 years without major repair. Many road failures are attributable in the main to the imposition of much heavier traffic on the roads than they were designed to receive, and ten questionnaire replies gave this opinion. Contributory causes of deterioration are the arrangement of slab joints, and the disposition of reinforcement, particularly that relating to warping. Eleven replies refer to defective joint design and it is of interest to note that the spacing of main transverse expansion and contraction joints is only mentioned once, the emphasis being on the behaviour of the longitudinal joints, and on corner warping and fracture.

Quality of construction

This section refers to site processes. It is accepted that sound design details are often mishandled on the site with unfortunate results, but the skill of good builders in interpreting inadequate design instructions, with results often more fortunate than the designs and their presentation warrant, is also recognised.

Carelessness in the proportioning, mixing, water content, placing, compacting and curing of concrete is the greatest factor in the deterioration of concrete structures. The significance of the water/cement ratio is often not realised, the purpose of the water being taken to be the facile placing of the concrete without undue exertion. The short-term strength of such over-wet material may not cause concern, unless cubes are tested, but its efficiency as cover to reinforcement and as an impermeable wall or floor in reservoir construction is low. A case might have been made in earlier years for a concrete having a water/cement ratio up to 0.75 or 0.80 in water-retaining structures to ensure maximum compaction, but the advent about 1930 of vibration, now used widely throughout the country, makes this no longer tenable.

Construction joint practice, commented on extensively in the replies, has always been somewhat haphazard particularly in smaller works where site supervision is necessarily intermittent, and joints following the angle of repose of the first-placed wet concrete are far too numerous in our structures. Poorly made construction joints constitute planes of high permeability and the characteristic staining on many of our reservoir and water tower structures reveals this all too clearly. It has long been the practice of many designers to incorporate water bars in all construction joints, and this is prudent, provided the designer gives prior thought to any difficulties the builder may have in carrying out his instructions.

It is probable that the satisfactory life of a structural concrete water container can be increased from 25 years to 100 years at least, using the same basic materials in both instances and without extra cost, by paying attention to the points above mentioned, and to the accurate placing of the reinforcement.

An unusual instance of damage caused by porous concrete at construction joints was reported in the questionnaire replies. Moisture penetrated to the main reinforcement in long exposed columns, and travelled about 6 feet along the steel in each direction from the joints, causing corrosion and spalling for that distance and making extensive repair necessary about 20 years after the building was constructed.

The provision by the designer of adequate permanent joints in concrete structures and the painstaking construction of these joints with good materials and in a complete manner by the builder, is important. Malfunction of joints or their total omission can cause damage ranging from superficial cracking, through penetration of dampness, to incipient failure of the complete structure. Examples of these conditions have been reported in the questionnaire replies.

In road construction, the replies have emphasised the primary importance of sub-grade preparation, and performance. Inadequate consolidation, lack of uniformity and poor drainage are mentioned. Mud-pumping at joints, with the transverse slab cracking consequent on it, is quoted both as a product of poorly-made joints and poorly-maintained joints. The cutting through of slabs for services, aggravated as this process generally is by the difficulty of restoring the sub-grade and slab

properly, is quoted in many replies as a major source of deterioration of road slabs.

Durability Survey

The most positive way of investigating the durability of structures is to begin observing them on their completion and to keep a record of their behaviour during their working lives. Such a process cannot produce an immediate return but twenty years or so after it is started, information will begin to be available and thenceforward, new structures having been brought into the survey all the time, the flow will be continuous. A scheme of this nature is to be initiated in Great Britain and adoption of a scheme here through an appropriate central authority is to be recommended. One questionnaire reply suggested this also for roads, and they should certainly be included in such a project.

Conclusion

This has been of necessity merely an outline survey of an important aspect of Irish concrete practice. Its compilation would not have been possible without the co-operation of the recipients of the questionnaire to whom grateful thanks are offered. Its further usefulness will depend upon augmentation of the information already received; the author looks forward to the discussion at the Symposium, and will also greatly appreciate any further communications he may receive either before or after the Symposium dates.

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Discussion

MR. DE COURCY introduced his paper.

He considered that durability as a factor in design was a qualitative problem. The designer began by assessing the environment of the proposed structure, and deciding on the length of satisfactory life required for it. Next, he chose the materials, and methods of assembly appropriate to his conditions. The contractor, working under the designer's supervision, then built the structure, using the skills and experience available in his team. The durability of the completed structure was the measure in which it achieved the satisfactory life required, and was on that basis a reflection of the combined skills of the designer and builder.

The concept of "satisfactory life" was new. In so-called traditional building, it was not usual to state the length of time for which the structure was to last, nor at the time of construction, was the future demolition of the structure, to make way for newer work, being already envisaged.

The position now was that in city areas the demolition of buildings still structurally in their prime, but considered senile in their function, was becoming very frequent. One could not help wondering whether the structures to replace these were not likely to meet a similar fate in about 25 years time. If this were true, then to design such structures for a satisfactory life of say 100 years would be futile and wasteful, and some attempt would have to be made to relate their design to a realistic satisfactory life.

He felt that this posed a question, namely whether it was in fact possible to differentiate in design between satisfactory life periods of 25 and 100 years, or whether a durability appropriate to the longer period was not intuitively built into all permanent structures. He suggested that durability was intuitively built into traditional structures using traditional materials and skills, but that with new materials, and construction technique, the durability of the completed structure was far more of a mystery.

Within this field of new building, it would be of value to this generation, and to the ones which follow, to start examining concrete now as a structural material with a view where possible to relating the design

and construction techniques involved to the satisfactory life of the structure as a whole.

A strong case might be made for the inauguration, on an official basis, of a durability survey to record the performance, over a period of 20 years or so, of selected buildings in all their structural aspects. The work of that survey, once started, would continue indefinitely, selected new structures being brought into the scheme from time to time, to maintain a steady flow of material for study. The reports of the survey, fed back to the building professions and industry, could assist greatly in assessing the long term merit of materials and techniques which at the time of their use would quite probably have been experimental to some degree.

Were such a survey started, it should welcome also information relating to buildings which were at the time of its inauguration already say 20 years or more old. The value of such information was obvious. Referring to concrete, a record of old structures and their long term behaviour would be of interest. Durability was often assessable through the very inconspicuousness of the structure or structural element being considered. He referred to two large areas of reinforced concrete suspended slab, both about 75 years old, one in a church and one in a school, which had been in continuous use without repair over that period and which still appeared to have unlimited useful life ahead of them. There must be many such examples in the country and a body of information about these would have obvious value for a durability survey.

The answers to the questionnaire which was mentioned in the paper showed that for structures, other than roads, the following four items were considered to be those most seriously affecting durability :

- (a) faulty construction joints, particularly in liquid retaining structures;
- (b) inadequate cover to reinforcement either through design or construction but mainly through construction;
- (c) permeable concrete in cover;
- (d) over-wet or otherwise defective concrete mixes.

The four predominant defects in concrete roads were considered to be :

- (a) failure through overloading;
- (b) poor joint design and maintenance;
- (c) openings for the installation or repair of services;
- (d) inadequate preparation of the subgrade.

Reference to failure of road slabs through overloading prompted not criticism but in fact praise of the designers and builders of many of the Irish concrete roads of the 1920's and 1930's. It would have been difficult to forecast at that time the speeds and loads of road traffic today, and it was at least arguable that without the increased loadings, many of these roads would still have a long useful life ahead of them. The development of road traffic requirements made a study of the behaviour of existing concrete roads important. The extension of any

formal durability survey to include roads and pavements generally would appear to be appropriate.

MR. D. P. O'LEARY opened the discussion. He coupled, with the inconsistency of pre-1938 cement, the variability of aggregates of that period. Except for major projects for which temporary washing and grading plants were set up on site, most concrete was made with poorly-graded pit-run gravels. In considering durability, he would divide structural concrete into (a) mass concrete, with which he would class all heavy foundations, whether reinforced or not, (b) reinforced concrete, and (c) prestressed concrete.

Heavy foundations were usually embedded in the ground and were the structural elements most prone to ground water attack. Reinforcement in foundations should be given 3" - 4" cover if possible, particularly near the bottom surface, as that zone invariably contained some bad concrete. In a pump house, which he had investigated, the sump floor was cast on top of a layer of lean concrete which had been placed there to make up the space left by the removal of a layer of soft clay. Particles of stone and sand were being drawn into the pump casing, and it was discovered that these were coming from the lean concrete which was disintegrating in places through the action of peaty water. A repair was made by cutting out 6" of the lean concrete and replacing it with a dense 5 : 1 concrete, and this repair, now 20 years old has been successful to date.

Mr. O'Leary felt that he could not over-emphasise the dangers arising from corrosion of the reinforcement.

Fortunately, deterioration often commenced with the stirrups and distribution steel, and damage detected at that stage could be repaired at reasonable cost. It could not be overlooked, however, that even when only the stirrups had been exposed by corrosion, there might already be incipient corrosion in the main bars.

Mr. O'Leary had had experience in the repair of three large main road bridges, which, when 25 years old, had shown signs of deterioration through corrosion. The bridges were in rural surroundings, and were subject only to rain and atmospheric moisture. During the repair work some interesting points had been noted. Where the bridges had two outer and two inner longitudinal beams, the outer beams were more damaged than the inner beams. Also, even where the outer surface of a beam appeared to be sound, areas of badly compacted segregated concrete were found behind the surfaces, and the bars at these points were heavily corroded. Again, where bars had been placed too close together, arching of the aggregate had occurred and in the unfilled voids, heavy corrosion had set in, with the outer oxidised layers of the steel swelling out to fill the voids. All affected bars were cleaned and sandblasted, concrete surfaces where necessary were scabbled, and the beams were "gunited," the outer beams with a 1½" thickness of reinforced "gunite" and the inner beams with a ½" thickness of unreinforced "gunite." The repairs which were now 15 years old, had been successful.

In the investigation of a reinforced concrete brick-lined chimney with an air space outside the lining, it was found that corrosive fumes passing through defects in the lining were causing no trouble beyond surface discoloration to the concrete skin. This attack had been in progress for about ten years and Mr. O'Leary was satisfied that the good quality of the concrete had enabled it to protect the reinforcement embedded in it from deterioration.

He had had little experience of prestressed concrete, but in view of the small wire diameters normally used, would demand stringent precautions against corrosion.

He considered it deplorable that even to-day so much of the production and placing of concrete was entrusted to an unskilled labour gang, and recommended the training of concrete technicians, versed in all aspects of site concrete.

The regular inspection of concrete structures was in his opinion a very valuable aid in preventing gross deterioration. In his organization, their structures were examined every five years.

Subject to such periodic checking, and provided that a structure was not put to uses more severe than those for which it had been designed, the life of mass and reinforced concrete in Ireland was in his opinion unlimited. He recommended the use of the covermeter in reinforced concrete structures.

Mr. O'Leary finished his remarks with comments on a series of slides, which showed

- (a) the disintegration of weak surface layers of concrete on the tops of walls;
- (b) the first stage of deterioration, viz. cover concrete being forced off by corroding bars, and surface rust marks;
- (c) successful 30 year old mortar patching over reinforcement exposed at time of stripping formwork;
- (d) porous cover concrete;
- (e) leaching effects at construction joints;
- (f) good concrete surface with segregated concrete behind, possibly due, in days before vibration, to tapping shutters with hammer to achieve good finish.

DR. L. F. STEPHENS referred to the work of George Semple, the builder of Essex bridge across the Liffey in Dublin in 1750. Lime cement had been used in that bridge. It was clear that a very fine tradition of good workmanship in building existed in Ireland.

Dr. Stephens showed some slides of the Mizen Head footbridge, a reinforced concrete arch built in 1909, leading to the fog station operated by Irish Lights at Mizen Head. This bridge, which he felt was one of the few really good looking bridges in Ireland, had a span of 170 feet, the deck being 150 feet above sea level. Designed by Mr. Noel Ridley, A.M.I.C.E., the supporting elements were two arch ribs, each precast in two sections, and connected at the crowns with insitu concrete. Each

rib was about 15" wide and tapered from 3' 0" deep at the springings to 1' 6" at the crown. 3" x $\frac{1}{2}$ " flat bars were used as reinforcement, four top and bottom, and a light gauge steel corrugated sheet was used to hold the bars in position.

The deck was reinforced with 1 $\frac{3}{8}$ " diameter bars, which were spliced at the joints by being flattened and connected with cover plates. Wind resistance was provided by splaying the arch ribs outwards in plan, the distance between the ribs being greater at the springings than at the crown.

Whilst this bridge was still in normal use, and was a great credit to its designers and builders, there had been, as might be expected in this exposed situation, some deterioration in the form of corrosion and spalling. This was visible in the slides. It was interesting to speculate how such a structure might be repaired. "Gunite" might increase the weight of the bridge unduly. Epoxy-resin bonded patching might be an answer, although he wondered whether we had enough experience of this material to warrant recommending its use. He felt that, possibly, the proper approach was through hacking off the defective concrete, cleaning off the rust on the bars, and making good with dry packed mortar, perhaps using a polymer bonding agent to secure the mortar. The suitability of the bonding agent for use in marine conditions would, of course, have to be proved. The opinions of other speakers would be of interest.

MR. J. McCULLOUGH described a large building erected in 1940, which had deteriorated badly. Examination had shown that the concrete had been of poor quality, the techniques of placing, steel fixing and construction joint detail had been bad, and some of the concrete sections were appreciably thinner than the drawings indicated. The contractor had long gone out of business, and he felt that that was good.

The building was not being taken out of service, however, but was being reconstructed where necessary. A feature of this building was the sagging of suspended floor slabs. These slabs, spanning continuously in two directions in square bays of 16' 0", were 5" thick. They had been subject to some vibration, but to no loading other than self weight and foot traffic. Over the years they had dipped up to 2 $\frac{1}{2}$ " so that the entire floor had assumed an architecturally interesting but structurally disturbing pattern of regular hollows. The sagging had been gradual, and the possibility of formwork deflexion as the cause of the trouble had been ruled out. Over each support a very fine hair crack was usually visible, but the gentle curvature of the slab over the supports appeared to conform to the general presence of top reinforcement at these places. The reason for the dishing was obscure and comments would be welcomed.

A second interesting feature of this building was the development under direct tension of a crack $\frac{1}{4}$ " wide between two reinforced concrete elements. This was cut out and refilled with "gunite" about nine years ago and had not re-appeared, although the loading which presumably caused the cracking in the first place had been imposed frequently since that time. It had not been decided why the crack had not re-appeared.

One suggestion was that the reinforcement resisting the tension had been work-hardened by elongation, another that the reinforcement had at some time early in the life of the structure been stressed beyond its yield point, and had a residual strain, which no later loading had been sufficient to increase. Neither solution was wholly convincing.

Regarding the performance of jetties, he knew of two adjacent jetties identical in design and site conditions, one built in the period 1905-1910, and the other in 1925. The earlier jetty was, in 1955, in relatively good condition, but the later one was in very bad condition, so bad, in fact, that one could have pulled out literally handfuls of rust-eaten steel from the bottom layer of the beam reinforcement. The fault was found to be in the quality of the concrete used, particularly in the use of what seemed to be a cement mortar to cover the reinforcement.

Finally, Mr. McCullough, referring to "satisfactory life," asked whether anyone could foretell the use to which the natural draught cooling towers at the peat-burning electricity generating stations would be put when the bogs were worked out. On the other hand, he also wondered how else they could have been designed except as the quite permanent concrete structures that they are.

PROFESSOR M. A. HOGAN commented that, in considering the durability of concrete structures, one had to take into account the properties of the materials used in their construction. There was no doubt that there had been a gradual development in the quality of cement, in the care devoted to the proportioning of the aggregates, and in the control of water quantities. Thus much of the concrete made half a century ago was definitely inferior to that of the present day.

Taking cement for an example, cement testing had begun in the Civil Engineering laboratory of University College, Dublin, in 1912. At that time BS 12 called for both neat cement and 1 : 3 mortar briquettes, the strengths for the latter being 150 p.s.i. at 7 days and 250 p.s.i. at 28 days. The permitted maximum residue on a 180 mesh sieve was 18%. In 1915, the 7-day strength was raised to 200 p.s.i. and the 180 mesh residue reduced to 14%.

Serious problems arose when construction of the Earlsfort Terrace building for University College began in the summer of 1914. Various consignments of cement failed to reach the specified tensile strength, showed excessive residue on the 180 mesh sieve and failed in the Le Chatelier soundness test. At that time an expansion of 10 mm. was permitted in the 24 hour test, but some specimens gave three times this expansion.

Thirty years ago, before the Irish cement factories went into production, imported cement came from various works in many countries. A series of 59 separate samples of normal cement in the records of University College for the year 1937 showed that 27 of these came from 14 different sources. The origins of the remainder could not be identified. The average 7-day strength for mortar briquettes from these samples was 561 p.s.i. with a coefficient of variation of 11.6%, and a

range from 367 to 690 p.s.i. or 58% of the mean. These cements varied in grinding, the residues on the 170 mesh sieve ranging from 1.8% to 9.2% with an average of 4.3% and a standard deviation of 1.7%.

Modern cement was much more uniform. The residue on the 170 sieve remained practically the same for all samples at about 10%. The tensile strength was slightly higher but with a standard deviation for a year's samples of 3.6% and a range of 21% of the mean.

MR. A. B. HARMAN referred first to durability vis-a-vis sulphate attack. Whilst there were occasions on which sulphate resisting cements were warranted, serious failures in practice through ground water attack were rare. They usually occurred only where the ground water was moving and where consequently the action could be replenished continually. He saw little objection to small increases of foundation sizes, and the provision of an additional inch of good concrete was quite often all the precaution necessary to counter a suspected danger of ground water attack. If erosion to a depth of $\frac{1}{2}$ " then took place over a period of years, it was a matter of little concern.

On a more general aspect of durability, he questioned whether there was not, with everyone, a tendency to accept without sufficient question, firstly, matters which had been "normal practice for years," and, secondly innovations which appeared from superficial examination handy or cheap. As an example of the second type, he would quote the development of plastic spacers for reinforcement. There was scope for something to supersede the traditional methods of maintaining cover, e.g. the use of mortar blocks with galvanized wire ties cast into them. The plastic spacers seemed to be suitable, and their use had spread rapidly. Then, it was observed that, whilst they were being successfully used in many projects, some surface defects were being caused particularly with the chair type of spacer. He knew of one such job in Ireland. He was glad to say that at a meeting of manufacturers and others, sponsored by the Reinforced Concrete Association, it was reported that tests on different types of spacer were now in progress. These were being made at the Building Research Station and, under the sponsorship of the British Pre-cast Concrete Federation, at the laboratories of the Cement and Concrete Association.

MR. W. J. L. O'CONNELL referred to the difficulty of obtaining site results with resins, to match those achieved under laboratory conditions. Both temperature and atmospheric conditions had to be controlled. He had gone so far as to provide surface heat with an implement resembling a glorified hair dryer, and completely waterproof covers, but had found, nevertheless, that the setting time for the repair work on a not very big job was about three times what it should have been and the strength was much lower than that obtained in the laboratory.

He shared Professor Hogan's experience of the improvement in the cements used in Ireland. About twenty years ago, at a time when the Irish cement works could not meet the full demands of the home market,

some British cement was imported. It was used on three jobs in Cork, and gave satisfaction in none. He had been engaged on one of these jobs, and as the project was a large one, had had the cement tested. He had found in that material something unique in his experience, 7-day briquette results which were in fact lower than the 1-day figures! Very formal discussions with the manufacturers had followed and had led to two parallel sets of tests on the imported cement, one by the manufacturers, and one in University College, Cork. The purpose of the tests had been (a) to determine the strength/age characteristics of concrete made with the imported cement and (b) to compare the imported cement with Irish cement.

Whilst he had satisfied himself completely about the superiority of the Irish cement, he felt that the kindest comment he could make about the parallel tests was that they were inconclusive.

Arising from a consideration of road joint design, Mr. O'Connell felt that local authorities had responsibilities towards the public which they could not shed by pleading the ignorance of their engineering staffs. Accidents arising from defective joint design and/or construction and from defective maintenance generally had, in his opinion, their origin in malfeasance rather than in non-feasance, and those responsible should be dealt with accordingly.

Another aspect of slab design was the deterioration of surfaces through wear. He did not agree with the use of thin cement and sand screed on a concrete slab. The late Professor Walsh had pointed out many years ago that the right way to make a concrete slab was to come up in one body to the top surface, gradually decreasing the aggregate size, so that the whole slab was concrete with no separate surface screed; and this was undoubtedly the correct procedure.

He had noted Dr. Stephens' description of the Mizen Head bridge. He accepted Dr. Stephens' opinion, *de gustibus non est disputandum*, but did himself consider that the abrupt kicking out of the arch ribs, which had been found desirable for stability, was rather unfortunate, in that it gave the bridge a slightly broken-backed appearance. The tilting of the arch ribs into an oblique plane might have been better, in that the same stability would have been achieved with ribs with a single smooth curvature.

MR. A. D. H. MARTIN said that he had examined the Mizen Head bridge and was pleased to be able to say that there had been really very little increase in deterioration over, say, the last fifteen years. Repairs had been carried out before the second world war, and from the appearance of relatively new board marks, these repairs would seem to have consisted of cutting away defective concrete and replacing with new concrete.

Further maintenance work was now envisaged. He was grateful for the suggestions being made about repairs, and in particular about the use of epoxy resin, although he was not sure that this was the answer.

He felt that the Symposium might be interested in some facts relating to the design and construction of the bridge. The contract was let in 1908 to Alfred Thorne and Sons of Westminster. Their contract sum

was £1,272, which included an extra amount of £75 for scaffolding and for the overhead cablework required to place the precast arch ribs. The concrete was 1 part best Portland cement to $1\frac{1}{2}$ parts of clean sand, no size being mentioned, to 3 parts of broken stone passing a $\frac{3}{4}$ " mesh. The maximum compressive stress in the concrete in the structure was calculated as 452 p.s.i. The wind pressure allowed for was 56 lb. per square foot, the total force on the bridge being estimated as 27 tons.

Finally in the matter of satisfactory life for concrete structures, the new Kish Bank lighthouse was assumed to have a satisfactory life of 75 years. He made no claim for a technological basis for this decision. It had developed somewhat fortuitously from a consideration of first costs and the estimated satisfactory lives of other forms of construction.

MR. S. MASTERSON would like to see a convention develop whereby the loading for which a floor slab had been designed would be embossed somewhere on the slab surface. This was particularly important, in his opinion, for small structures where records and drawings might not be available to assist investigation, some years after construction, of possible change of usage.

MR. J. O'CONNOR (J. C. Thompson and Associates), in a written contribution, commented on the absence of reference in the Symposium discussion to the effects of expansion and contraction due to variation in temperature. He felt that this important subject had been insufficiently studied, and that more attention to the judicious use of expansion joints would lead to a greater durability for many of our structures.

He also considered that the Irish attitude towards the selection of foundation bearing pressures was too casual, and that facilities for testing soils should be improved, and when available, should be used.

MR. DE COURCY replied.

There was no doubt that "gunite" could make a very effective repair, but the effect of its weight and, possibly, the change which its addition could make to the appearance of a slender structure did always need consideration. There was a fruitful field for research in the use of epoxy resins. He had seen it used successfully for the repair of concrete which had been extensively damaged in a factory by impact. It scarcely required to be emphasized that no repair had any value if badly corroded bars were to be left untreated under any form of surface renewal.

On the matter of site control, he had been very interested to hear, at the Concrete Symposium in London in November 1964, criticism expressed about the disparity which too often existed between the technical skills of the site staffs employed by the contractors and the designers. The significant aspect of the criticism had been that it was the contractors who were aggrieved.

Regarding the floor mentioned by Mr. McCullough one might wonder whether this was an example of long-term creep. Far greater creep deflexions than the figure he mentioned had been obtained in experimental slabs, although admittedly the span-depth ratios would have been larger, and there were other examples in Ireland of slabs grossly sagging but still

structurally sound. The jetties mentioned by Mr. McCullough were not those referred to in the paper. The jetty damaged by berthing impact was in Cork harbour.

Professor Hogan's comments on the evolution of cement in Ireland seemed to underline the good fortune of Irish designers in having such a uniform cement at their disposal to-day. It had been stated recently in Britain as an opinion that the situation still remained there in which the use of cement from one source could justify a general increase in the safe working stresses used on a project, whereas it was not safe to use cement from other sources under any conditions whatsoever.

Referring to Mr. Harman's observations on sulphate attack, he would not like to be considered as opposing completely the use of sulphate-resisting cement. There were undoubtedly places where its use would be necessary, where in fact its non-use could be construed as negligence, but the danger, speaking generally, could be magnified far beyond its real limits.

He knew the Irish project to which Mr. Harman's comment on plastic spacers had referred, and in fact it was possible that this was one of the jobs which had prompted the current investigation. The particular type of spacer used in that project had a cruciform base of overall size about 1" across which sat on the formwork. These spacers were used in large precast concrete wall panels and some months after erection it was observed that, in a few places, discs of the fine cementitious surface of the panels, about $1\frac{1}{2}$ " diameter or so had spalled off, exposing the surface of the plastic spacer. The body of the concrete was excellent, and the thickness of the spalled discs was, at most, about $\frac{1}{8}$ ". The defect was one of unsightliness.

He felt that the plastic spacer had enormous potential value, and was glad to know that its possible improvement was being formally studied.

He agreed wholeheartedly with Mr. O'Connor's remarks on the use of permanent joints. There was an increasing awareness of the significance of movements in buildings. Whilst possibly the tendency should be to avoid joints where not absolutely necessary, no major structural design was complete which had not considered and decided on the necessity or otherwise of movement joints.

Regarding refinement of the examination of foundation soils, he felt that the initiative here should properly come from the designers, both engineers and architects; the testing facilities would expand to meet the demands made on them.

There had been surprisingly little comment during the discussion on the damage done to road slabs by excavating for new services and service maintenance. Remarks made to him outside the Symposium had indicated the high degree of irritation caused at many technical levels by the haphazard cutting of road slabs for this purpose. It had been suggested that the time had surely come when the containment of services in public thoroughfares could be preplanned, more use being made of the footpaths; and the general introduction of large precast paving slabs for footpaths had been strongly advocated.

SESSION E

MIXING, PLACING AND CURING METHODS

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Introduction

Over the past five years considerable changes have been and are taking place in concrete practice in Ireland and particularly in manufacturing and placing methods, and it seems to be an appropriate time whilst in the midst of these changes, to review the old and assess the new techniques.

The manufacture of concrete is carried out mainly by private industry. To collect reliable data one must rely on private firms to supply the necessary information which can be supplemented by personal experience and investigations.

With the above ends in view a questionnaire was circulated to all building and civil engineering contractors who are members of the Federation of Builders, Contractors and Allied Employers of Ireland.

The total number of forms distributed was 340 and the number of replies received was 32 representing nine per cent., which is a low percentage return, but not unexpected when one considers the number of forms which are being circulated in these times.

It must also be remembered that it is not the number of replies alone which is important, but rather the number of replies which are received from the major users of concrete. In this respect even though the identity of the individual firms who replied to the questionnaire was deliberately excluded from the form, it can be stated that the information received confirmed the pattern and trends of concrete practice in Ireland, which are familiar to all who are actively engaged in the Industry.

The three principal aspects of concrete practice dealt with in this particular Paper are :

- A. Mixing of concrete.
- B. Methods of placing concrete.
- C. Curing of concrete.

A. Mixing of Concrete

The mixing of concrete can be considered under two distinct methods, i.e.,

Concrete mixed on the working site subsequently described as site-made concrete.

Concrete mixed off the site and delivered to the working site by truck mounted mixers and which will subsequently be described as factory-made concrete.

Site-Made Concrete

Concrete mixed on the working site is the traditional method and accounts for the largest volume used, but within recent years it is to a certain degree being replaced by factory-made concrete.

Site-made concrete will be considered under three headings:

Materials.

Feeding materials to the mixer.

Mixing.

Materials

Aggregates : The general practice nowadays is to purchase from specialist firms who can supply aggregates to meet the normal standard specifications and geographically and geologically the country is generally well served in this respect. In fact the growth and expansion in the supply of graded and washed aggregates is one of the outstanding features in recent years and Contractors nowadays do not find it economical or seldom necessary to set up their own aggregate plants as was often the case in former years.

Aggregates are generally sold on a tonnage basis and when this is the case, adjustments for bulking in the sand is not usually done, but however, when delivered on a cubic yard basis, purchasers nowadays are more aware of the bulking problem.

Generally the aggregate suppliers have advanced to meet modern requirements in concrete technique, and can supply in all sizes and combinations together with grading curves and laboratory tests. In this way much of the former site testing work has been lessened and more uniform concrete can be produced.

A comparatively recent development is the use of batched aggregate. In this case the coarse and fine aggregates are batched in the required proportions at the pit and delivered to the site as one combined aggregate. The batched aggregate simplifies considerably the mixing arrangements on the site, especially when using mixers with weighing apparatus, and feeding with scrapers. Even when the aggregate is volume batched the combined aggregate is less laborious to handle. Some authorities are not keen on using batched aggregate fearing that the aggregates as delivered to the mixer will not be in the specified proportions. However, in the author's experience, test cube results carried out on various sites where batched aggregates are used have given excellent results.

The author suggests that more use should be made of batched aggregate as there is a definite labour saving advantage and also there is the simplicity of having one instead of the usual two or three stock-piles.

Cement: The most significant development as far as the supply of cement is concerned is the increasing trend towards using bulk cement rather than the traditional one cwt. bag. Cement is supplied directly from the factory in specially made bulk carriers and pumped into silos located close to the mixer.

Standard steel silos can be supplied in twelve, twenty or thirty ton capacities and the outstanding features of modern silos are: Cement can be fed to the mixer in a required weight for a certain mix. With certain mixers and certain specified mixes using bag cement, it is necessary to split the bags or else run the mixer below its capacity. Using bulk cement this difficulty can be eliminated and it also simplifies the design of the proportions of the aggregates and cement. Modern silos are fitted with an automatic weighing device, built in mix counter for recording number of batches, aeration unit, and cement contents indicator.

The main advantages of using bulk to bag cement are: Cement delivered in bulk is cheaper to purchase than bag cement, the difference in price depending on the distance of a particular site from the factory.

In the Dublin area the difference in price per ton is approximately 12/- and taking the average cost of a silo complete with all equipment as £1,000 it can be seen that the initial cost of the silo will be recovered after using 1,600 tons of cement or approximately 6,400 cubic yards of concrete.

Unloading, storing and re-loading costs are eliminated, and waste is reduced.

Storage conditions are better and possible damage from atmospheric conditions are eliminated.

A particular size mixer can be used more readily to its full capacity.

On the other hand, the main disadvantages of using bulk cement are:

On some jobs it is more economical to move the mixing plant to various locations on the site and very often this is not practical when using silos.

Bulk cement is delivered in either one 15-ton container or twin 8-ton containers. Unless there are two silos on the site it is often difficult to arrange pours and maintain an adequate supply of bulk cement. It would be a considerable help in this respect if the transport authority delivered also in single 8-ton lots.

A hold up in the transport from the factory during a large pour can cause serious difficulties on the site, and it is usual practice to keep a reserve of bag cement.

It is not economic to use silos where the normal consumption of

cement. on a particular work is less than five hundred tons or when a silo has to be shifted frequently to a number of sites.

However, considering both the advantages and disadvantages, the trend is to use bulk cement as far as practical for a particular site.

Water : This, even though being the cheapest of all the materials used in making concrete, is also the most troublesome to control. The old fashioned method of the mixer-operator having barrels of water and buckets adjacent to him to feed directly into the mixer is almost gone. In the modern mixers, a pre-determined volume of water is fed by push-button control generally electrically operated. On sites where water pressures are low, it is usual to have an elevated water tank to give the required volume of water.

Additives : The number of additives on the market today is quite large, and it would be almost true to say that if there is a particular problem or requirement associated with concrete, there will be a manufacturer who will claim to have the right additive to solve the problem. Additives in liquid or powder form are placed directly in the mixer and the trend seems to be to use additives more in the liquid than in the powder form.

Feeding Materials to the Mixer.

The methods in use in feeding aggregates to the mixer can be considered under two main headings, i.e.:

Volume batching and weigh batching.

Volume Batching

Barrow Hand Loaded : This is a common method in use but the labour content is high and is liable to give incorrect batching proportions especially if no adjustments are made for the bulking of the damp sand.

Gauge Boxes : This method gives better control on the batching proportions but if anything, adds to the labour costs.

Weigh Batching

Manually Loaded : Shovelling: In this method the skip can be directly loaded by shovelling in succession from the coarse and fine aggregate stock-piles until pre-determined weights are reached on the dial gauge attached to the mixer. Another variation of this method is to use an independent swing type weigh batcher consisting of two buckets usually 14 cubic feet capacity. Each bucket has an independent weighing apparatus thus allowing feeding of the two buckets simultaneously; loading can be carried out when the mixer skip is in operation.

Hand Scrapers or Scoops

This equipment consists of a steel scoop with two handles which is drawn to the skip by a steel wire rope, power operated from the mixer. A winch with magnetic clutch driven from the main engine is push-button controlled by the scoop operator. A feature of the scoop equipment is the flat angle of the hauling cable which ensures maximum horizontal pull. The electric cable to the scoop is suspended

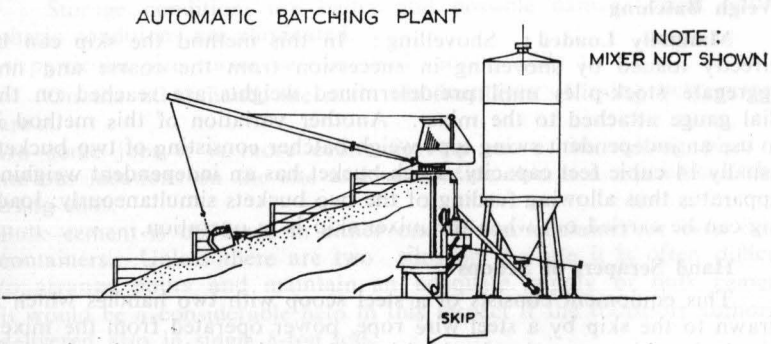
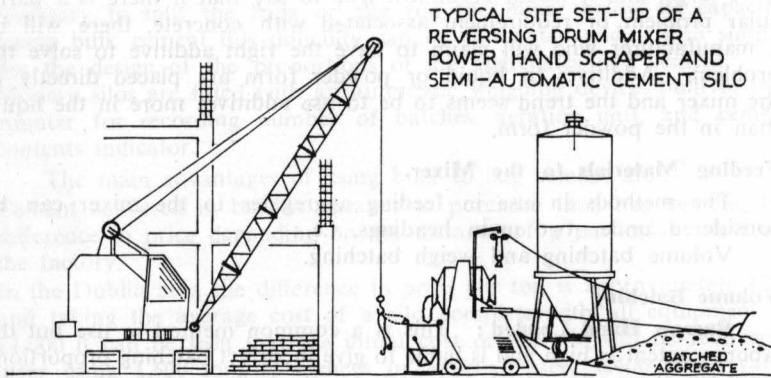
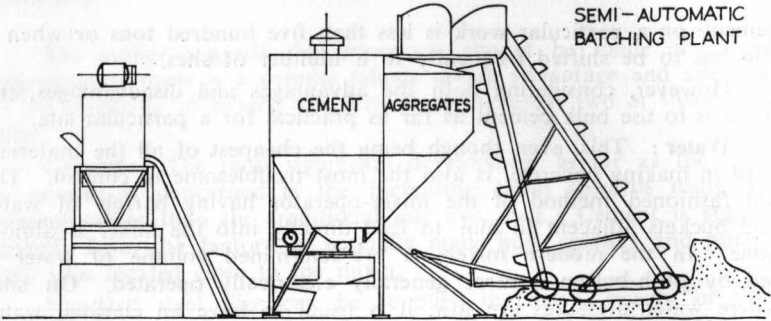


FIG. E1. PLANT FOR
SITE-MADE CONCRETE.

from a light tubular mast which is held to the frame on a pivot and maintained in position by a clip at the bottom of the jib.

This method is becoming quite popular especially when used with combined aggregates, but is limited, from the labour point of view, to mixers with a half cubic yard or under output capacity.

Power Weigh Batching

There are many types of power weigh batching plants in use. These are usually used with mixers of three quarter cubic yard capacity or more, or with two half cubic yard mixers working in tandem.

A typical plant of this type would consist of an elevated circular aggregate bin with three compartments and a bulk cement bin. The flow of materials to the weigh hopper is controlled through guillotine type gates and the discharge of the cement from the bin to the weigh hopper is accurately controlled by a special roller type valve. The aggregates are loaded by a multi-bucket loader which is manually slewed through 230° on a vertical axis concentric with the aggregate bin. Where the concrete quantities and outputs required are high, power weigh batching is the practical answer and the modern plants available on the market are push-button controlled by the mixer operator, and in some cases, as for factory-made concrete, almost entirely automatic.

Figure E1 illustrates some types of power weigh batching plants in use.

Mixing

There is a wide variety both in size and type of mixers in use in Ireland. Mixers in the 10/7, 7/5 and $5/3\frac{1}{2}$ range are manufactured in Ireland, but the larger number is of British manufacture, and in recent years some Continental mixers have also come on the market.

Generally the mixers in use on sites can be divided into four main types as follows:

- Tilting drum type.

- Non-tilting drum type.

- Continuous or pan type.

- Reversing drum type.

The most popular size mixer in use is the one-third cubic yard output capacity (14/10), but there is a definite trend among contractors to purchase the half cubic yard mixer (21/14). In this respect experience shows that it is not advisable to work a mixer continuously to its full capacity, but rather when one has the choice to purchase the higher output mixer.

The tilting drum type is mostly used in the small sizes, i.e., $5/3\frac{1}{2}$ and 7/5, while the non-tilting drum is a popular type in the one-third and half cubic yard sizes.

There are two distinct types of pan mixers. In one type the pan revolves clockwise and a multi-blade mixing star rotates in the opposite

direction. In the other type the pan is stationary and mixing is carried out by fast rotating blades.

Claims put forward for the pan type mixer are that it gives a faster mixing cycle, better homogeneous mixing, higher compressive strengths, and also a saving in cement as compared with concrete produced from the drum type. These claims are substantiated by tests carried out by The Government Testing Institute of Sweden.

So far the pan type mixer is not used much on sites in this country but it is the type that is used in large mixing plants for factory-made concrete.

The reversing drum type mixer in one-third and half cubic yard sizes is the most recent addition to the market. In one type the mixing drum and skip are each hydraulically operated, while in another type the drum is mechanically driven and the skip hydraulically operated. A hand lever controls starting and stopping and forward and reverse rotation of the drum, and the concrete can be discharged rapidly at a height of 5' 6" when the drum rotation is reversed. These machines are fitted with built-in weighing equipment and a push-button controlled aggregate loading scoop, described elsewhere in this paper. This type of mixer in combination with a bulk cement silo and using the half cubic yard size, can be fed and mixed by three men, and can give a continuous output of six to eight cubic yards of concrete per hour over a normal working day. Compared with the older types of mixers, there is a definite saving in labour costs using this type of mixer: the work of the operator is also less laborious.

Factory-Made Concrete

Factory-made concrete was first produced in Ireland on a commercial basis in 1949, and since then the demand has risen steadily. Within the past few years with the expansion of work in the building and civil engineering industry, the output of factory-made concrete has increased considerably and plans are being made for further expansion.

In Dublin city and suburban areas there is a potential plant output of 4,500 to 5,000 cubic yards of concrete per day.

For the rest of the country plants are in operation in Cork, Limerick, Galway, Dundalk, Drogheda, New Ross and further plants are being planned for other areas.

Type of Plants

There are three main methods of supplying factory-made concrete viz :

Dry Batching

In dry batching the dry aggregates and cement are added to a truck mixer and transported to the site, where water is then added and the concrete is mixed by means of the truck mixer.

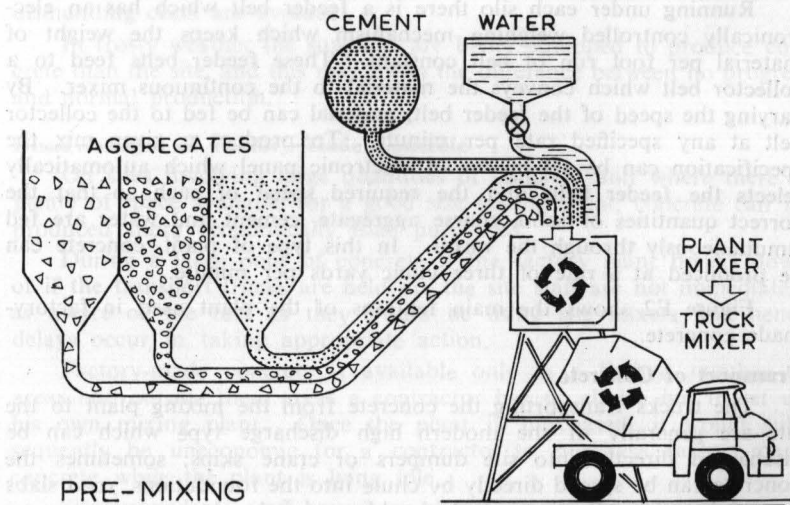
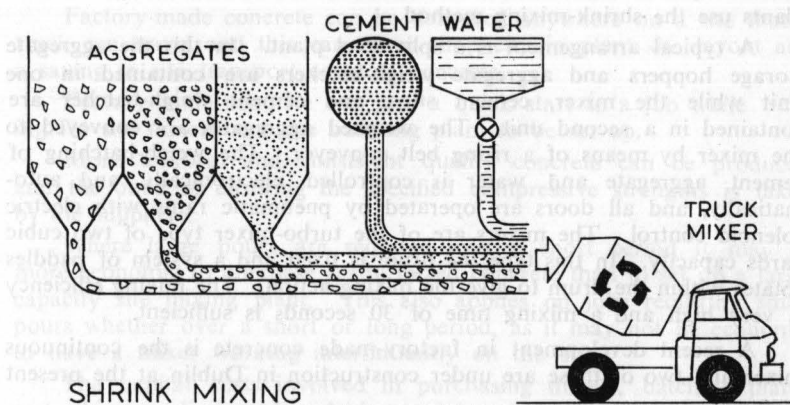
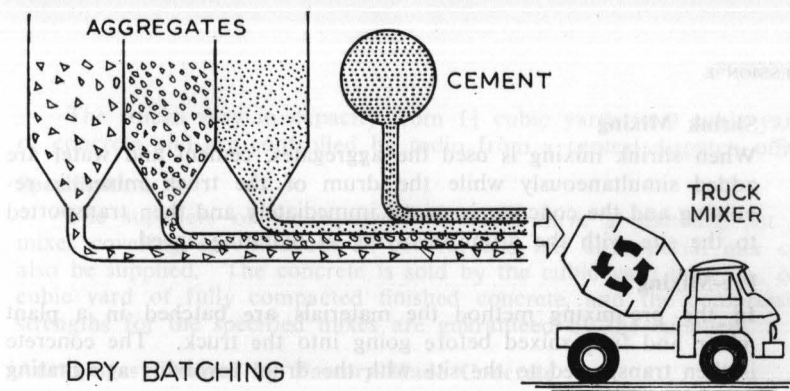


FIG. E2. PLANT FOR
FACTORY-MADE CONCRETE

Shrink Mixing

When shrink mixing is used the aggregates, cement and water are added simultaneously while the drum of the truck mixer is revolving and the concrete is mixed immediately and then transported to the site with the drum revolving at agitating speed.

Pre-Mixing

In the pre-mixing method the materials are batched in a plant mixer and fully mixed before going into the truck. The concrete is then transported to the site with the drum revolving at agitating speed.

The pre-mixing method is the one in general use while some plants use the shrink-mixing method.

A typical arrangement is a split level plant. In this the aggregate storage hoppers and aggregate weigh-batchers are contained in one unit while the mixer, cement silos, and cement weigh-batcher are contained in a second unit. The weighed aggregates are conveyed to the mixer by means of a rising belt conveyor. The weigh-batching of cement, aggregate and water is controlled electronically and automatically, and all doors are operated by pneumatic rams with electric solenoid control. The mixers are of the turbo-mixer type of two cubic yards capacity. In this type the drum is fixed and a system of paddles rotates within the drum to give the mixing action. The mixing efficiency is very high and a mixing time of 30 seconds is sufficient.

A recent development in factory-made concrete is the continuous mixer and two of these are under construction in Dublin at the present time.

Running under each silo there is a feeder belt which has an electronically controlled weighing mechanism which keeps the weight of material per foot run of belt constant. These feeder belts feed to a collector belt which conveys the material to the continuous mixer. By varying the speed of the feeder belt, material can be fed to the collector belt at any specified rate per minute. To produce a given mix the specification can be set up on an electronic panel which automatically selects the feeder belts and the required speed of each so that the correct quantities of sand, coarse aggregate, cement and water are fed simultaneously through the mixer. In this type of plant, concrete can be produced at a rate of three cubic yards per minute.

Figure E2 shows the main features of the plant used in factory-made concrete.

Transport of Concrete

The trucks transporting the concrete from the mixing plant to the site are generally of the modern high discharge type which can be discharged directly into site dumpers or crane skips; sometimes the concrete can be spread directly by chute into the foundations, road slabs or trenches thus effecting a considerable saving in placing costs.

The trucks vary in capacity from $1\frac{1}{4}$ cubic yards to 9 cubic yards of concrete and are controlled by radio from a central dispatch office.

Specification

The suppliers of factory-made concrete have a standard list of mixes covering specifications in general use but any special mix can also be supplied. The concrete is sold by the cubic yard unit, i.e., one cubic yard of fully compacted finished concrete, and the compressive strengths for the specified mixes are guaranteed by the suppliers.

Advantages Claimed by Factory-Made Concrete

On some sites, especially in built-up areas, space is very restricted and factory-made concrete is the practical answer.

Factory-made concrete can be delivered anywhere on a site that a truck can travel and this can mean simplicity in plant site layout and a saving in site transport costs of concrete.

Factory-made concrete can give a quick start to a job while waiting for site mixers and site batching plant to be set up.

More uniform and consistent quality concrete can be produced and the onus of ensuring the specified compressive strengths is taken by the suppliers.

Where large pours are required over a short period it may be more economic to purchase ready mixed concrete than to set up a large capacity site mixing plant. This also applies on jobs requiring small pours whether over a short or long period, as it may not be economic to have a mixer working intermittently on the site.

The capital costs involved in purchasing mixers, batching plants and silos are eliminated and also maintenance, transport, erection and dismantling costs are avoided.

In frosty weather the suppliers are better equipped to produce concrete than the site, and this may mean the difference between no progress and normal production.

Disadvantages of Factory-Made Concrete

On sites involving large quantities of concrete and where there is plenty of space available for a good size mixing plant, concrete can be produced more economically than purchased.

During a large pour of concrete if the factory plant breaks down or if the transport trucks are held up, the site staff are not immediately as aware of the fact as they would be using site mixers and hence delays occur in taking appropriate action.

Factory-made concrete is available only in a limited number of areas and outside these areas a contractor has no choice but to set up his own mixing plant. Once the plant is purchased, it would subsequently be uneconomic for a contractor to purchase factory-made concrete while the plant is lying idle.

Site supervisory staff have been accustomed to ensuring that there

is always an ample supply of aggregates and cement on the site and the site mixer can be started readily as required. Using factory-made concrete the planning and timing of pours have to be much more exact or otherwise there could be serious delays in completion of a pour or in having the delivery rate too high for the placing equipment.

To sum up, it would seem that the tendency is to use more factory-made concrete, especially on jobs involving small quantities, and also in certain cases on jobs involving medium sized quantities. On jobs involving large quantities and where the contractor has available the required plant, it would be more economical to produce site-made concrete.

B. Methods of Placing Concrete

The methods of placing concrete are many and varied and apart from site features which necessitate a particular method there are many sites where it is difficult to say that one particular method is better than another.

Figure E3 shows the most common methods in use and hereunder are given views as expressed by some contractors on the various methods.

Cranes

The most common types in use are the tower crane with a fixed horizontal jib, and the derrick type with luffing jib.

For multi-storey buildings and factories, the crane has many advantages and can be added to in height as the building progresses.

In the construction of power stations, dams and heavy foundations the tower crane is used quite frequently, as it can place the concrete accurately as required within its reach, where other forms of transport, such as dumpers, would be unable to travel.

Provided that the crane with a concrete bucket can pick up directly from the mixer or truck, and that no crane travelling is involved, the rate of placing can be quite satisfactory and labour-wise is one of the most economic methods of placing concrete.

Apart from placing concrete the crane also lifts the shuttering and steel into position, and with so many other pieces of equipment to be lifted on and off daily, very often the anticipated period for placing concrete is not realised. To overcome this difficulty one solution is to use a platform hoist for the minor lifts and leave the crane free to concentrate on placing concrete, steel and shuttering.

Apart from tower and derrick cranes the general purpose excavating machine with a crane attachment is also used: on sites where a dragline is required, very often the machine can do the excavation work and also place the concrete.

Dumpers

Dumpers and tipper trucks are used quite extensively, especially for road work, and for concrete below ground level. With high dis-

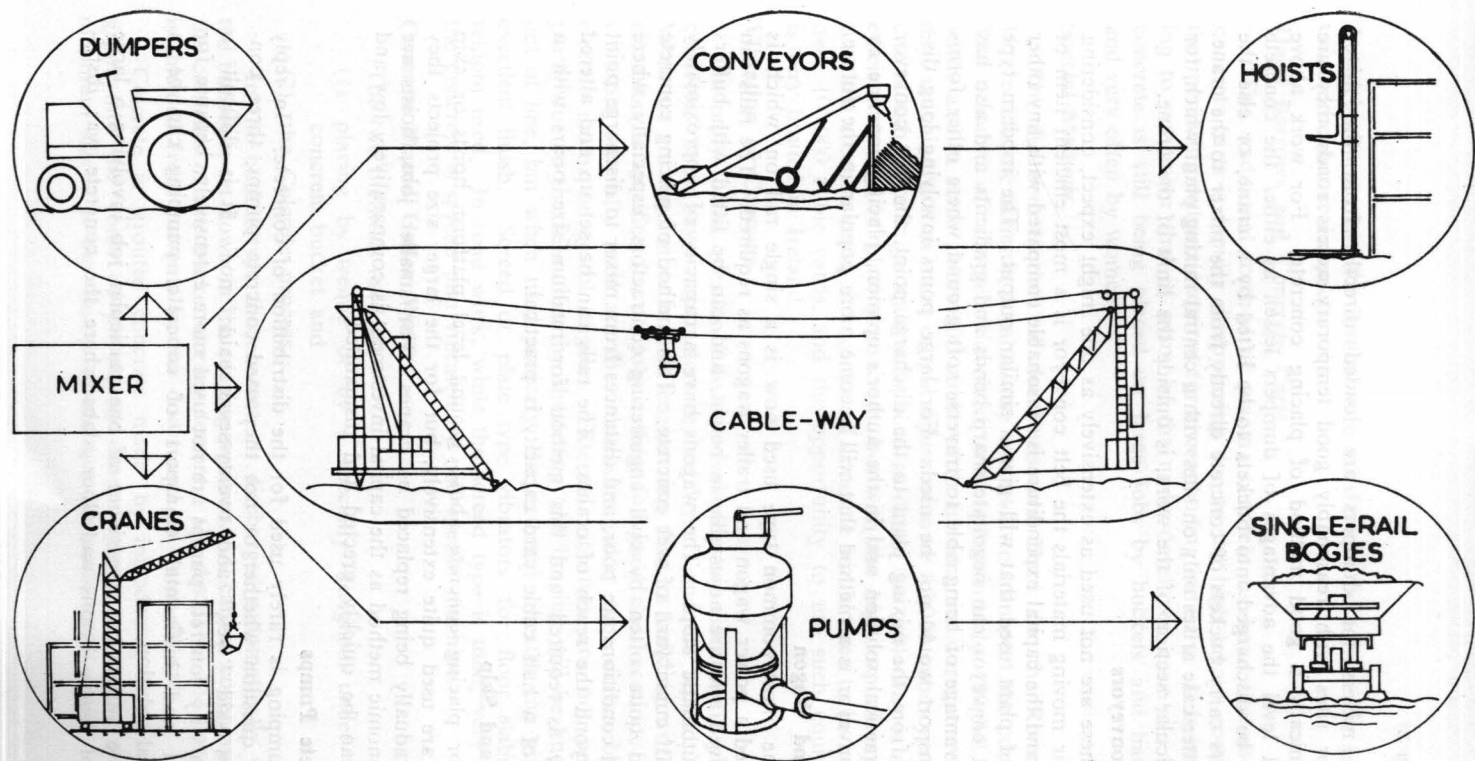


FIG. E3. SOME METHODS OF TRANSPORTING AND PLACING CONCRETE.

charge mixers the dumpers are loaded directly from the mixer and for sites with reasonably good temporary access roads they are economically a good method of placing concrete. For work above ground level the advantages of dumpers lessen as either the concrete has to be discharged into buckets to be lifted by a crane, or else the dumpers carry buckets of concrete directly from the mixer to the crane. The latter case arises only on sites with a central mixing plant which, for a particular section of the work, is outside the limit of the crane.

Belt Conveyors

These are not used as extensively as one might expect, considering that for moving materials the belt conveyor is a most efficient item of plant, and the capital expenditure is reasonable compared with any other form of plant used that will give a similar output. The modern type of belt conveyor can negotiate sharp bends and gradients and also has the advantage of being able to traverse soft ground where other forms of transport would not be used. For large pours involving long distances from the mixing plant to the discharge point, the belt conveyor is a practical solution and in the author's opinion, placing concrete by belt conveyor is a method that will become more popular in the future.

Rail and Wagon

The most common type used now is a single rail on which is mounted a power wagon and trailer wagons as required. The rails can be curved and are adjustable in height, and can be fitted with buffers and automatic stops. The wagons have a capacity of approximately one half cubic yard of wet concrete. This method of placing concrete is used quite often by civil engineering contractors, especially where ground conditions are poor, and distances from mixer to discharge point are beyond the reach of cranes. The rails can be set up and altered quickly as required and this method for medium size pours with a mixer of a half cubic yard capacity is practical.

Hoist and Skip

For placing concrete above ground level platform hoists or skip hoists are used quite extensively, but for the larger size projects they are gradually being replaced by cranes. For smaller jobs, hoists are an economic method as the capital investment is comparatively low and they can be quickly erected and dismantled.

Concrete Pumps

Pumping is rarely used for the distribution of concrete. In reply to the question whether or not they used concrete pumps, three contractors said "yes," and twenty-seven said "no." It is difficult to explain why concrete pumps are not used more extensively, because for vertical and horizontal transport of concrete, pumping can be a practical solution.

The author has experience of one particular job involving a large area of heavy beams and floor slabs where the concrete was distri-

buted by pumps and the results were satisfactory both from the technical and economical aspects.

Hand Barrows and Concrete Carts

The traditional method of placing concrete by hand barrows and concrete carts is rapidly disappearing due to the high labour costs, and the increasing outputs required for an expanding industry. It is interesting to remember that in many of the under-developed countries today, concrete is still being placed on large jobs by buckets and barrows, and very often by women.

Special Methods

On the construction of the Inniscarra Dam on the River Lee Hydro Electric Scheme, a cable-way was used to transport the concrete. The amount of concrete involved was approximately 120,000 cubic yards and in some pours 600 cubic yards of concrete were poured per day, reaching a maximum output figure of over 10,000 cubic yards in one month. For large scale jobs, such as dams, the cable-way is a very efficient method of placing concrete, but with the high capital expenditure and erection costs, the volume of concrete would need to be at least over 100,000 cubic yards, and the opportunity to use such equipment is very limited in Ireland.

Vibration of Concrete

In reply to the question "do you normally use vibrators in placing concrete," twenty-two contractors replied "yes" and ten replied "no." Vibrators are used more in civil engineering than in building work and vibration is specified for all jobs calling for good class concrete. The vibrators generally used are the immersion poker type driven by air, electric motor or petrol engine. External vibrators are not popular partly due to the fear that the shuttering and bracing will be knocked out of line, but when used properly, the external vibrator can give an excellent finish. Screed or plate type vibrators for floor slabs are seldom used. In road work, while the screed type is used, very often the concrete is spread and vibrated by one special machine.

Concrete Placed Under Water

The two methods used are :

- (1) placing by tremie or by a specially designed under water concrete bucket and
- (2) the Colcrete process.

In the bucket type the concrete is discharged automatically when the bucket is set down in the placing position. A canvas cover protects the contents of the bucket during descent. On discharge the concrete is shielded from currents by the doors and an outer shroud.

Colcrete is grouted concrete made by introducing sand/cement grout into the voids of pre-placed coarse aggregate, usually of $1\frac{1}{2}$ " minimum size. It has many advantages for underwater work. The

grout is produced by high speed mixing in a special type mixer and is almost immiscible in water.

Specifications for underwater concrete usually give the choice of placing concrete by bucket or by Colcreting. Generally the Colcrete method is more popular.

Concreting in Cold Weather

Despite complaints about our weather we have in this country the advantage that concrete work is seldom impeded by prolonged cold. Aggregates and water rarely need to be heated to overcome the effects of heavy frost, and when such climatic conditions do occur the usual procedure is to postpone concrete work until weather conditions improve. As mentioned previously, factory-made concrete has the advantage in cold weather, because equipment to heat the aggregate and water is available.

C. Curing of Concrete

After concrete is placed in position the natural tendency for the foreman in charge is to forget about it until he is reminded that the concrete has to be cured. Admittedly our climate is a considerable help in curing concrete and very often it is more a matter of protecting the concrete against heavy rain rather than curing it with water. However, for the benefit of all who are concerned with the practical side of concrete, the following points will help to explain why proper curing is so important.

Authorities agree that one of the factors governing the strength of concrete is adequate curing after placing. Neglect of curing is frequently not appreciated and the result is surface cracking of the concrete, loss of strength, low density and the formation of a surface skin of weak concrete.

Concrete attains its strength through chemical action between the cement and mixing water. During setting and hardening the concrete shrinks, partly as a result of this chemical action, and partly from the drying out of excess water. If moisture is allowed to escape too rapidly, there may not be sufficient to permit complete chemical action. In addition shrinkage due to the drying will take place before the concrete attains reasonable strength, thus increasing the extent of cracking.

When concrete is wet at the time of placing, the cement particles are never hydrated thoroughly and the chemical reaction is at first limited to the surface of the particles. Water in the mix will have portion reacting slowly in the partially hydrated cement, thus gradually increasing the strength and density of the concrete. If the concrete is deprived of water too early the outer surface of the particles becomes too dense and further chemical action is prevented. In addition the surface of the concrete will lose moisture more rapidly than the in-

terior, causing cracking. It is therefore necessary to adopt some means of preventing the placed concrete losing essential water.

The methods usually adopted are :

Spraying or floating with water.

Spraying with proprietary liquids forming a plastic-like film.

Covering with materials such as hessian, straw, plastic sheets, sand, sawdust, and spraying with water.

Flooding with water is the most efficient method but it is not often practical. Spraying with proprietary liquids is also an efficient method but it is not so popular due mainly to the higher costs. For road slabs and runways, covering with sand that is kept damp is quite a good method. Plastic sheets are becoming popular and can be purchased in rolls of 12 and 24 feet widths, usually 250 or 500 gauge. The material is impermeable and can be spread over slabs to hold water ; being light it will not mark the fresh concrete.

The period of curing is usually specified to be not less than seven days and in summer conditions, fourteen days. It should be remembered that it is during the period of dry east winds often prevailing in this country in early spring, that the curing should be watched carefully, especially on elevated structures.

Stripping Formwork

There are no hard and fast rules about the time for stripping formwork as the conditions and factors vary from job to job, and it is often left to the contractor and resident engineer to agree on the exact stripping time. The contractor is responsible for any damage that might arise from the early removal of shuttering or supports whether within the specified time or not, and under these circumstances, the contractor will not take undue risks. As far as suspended slabs and beams are concerned, cube crushing tests will give a reliable indication and very often the usual specified time of 21 days can be reduced to 14 days and sometimes even less.

Wall and beam side shutters are usually removed within 24 hours to three days depending on weather conditions and design factors and it is important to remember that once the shuttering is removed, the concrete will dry out quickly unless curing methods are put into operation at once.

Construction Joints

Quite often specifications call for hacking the top of the set concrete to remove laitance and form a good bond with the succeeding lift. This, in the opinion of the author, is a wasteful and inefficient method as the net result is to lose concrete and not gain the desired result of exposing the coarse aggregate. A much more efficient and practical method is to use a jet of water and air on the concrete before

the initial set has taken place. In this way the thin layer of laitance is removed and the coarse aggregates are exposed and clean.

Before the next lift is poured a good washing down will remove any dust or debris that may have fallen on the surface.

Conclusion

Again it may be repeated that one of the outstanding features in the concrete industry today is the variety of mixing and placing plant on the market, and it is not an easy matter to make a choice, especially after listening patiently to rival salesmen. Sometimes the output figures given in the trade literature can be misleading and generally tend to be on the optimistic side.

It would also be less confusing if mixers were classified on the basis of a given output of concrete, say in sizes of $4\frac{1}{2}$; 9; $13\frac{1}{2}$; 18 and 27 cubic feet, instead of the present classification of $5/3\frac{1}{2}$; $7/5$; $10/7$; $14/10$; $18/12$; $21/14$ etc.

It is the opinion of the author that the concrete industry in Ireland is generally operating efficiently with room for further improvement. We have the great advantage that the raw materials required are readily available and produced here, and the industry can look forward with confidence to participating in the second programme of expansion.

Discussion

MR. SWEENEY introduced his paper.

He saw it as concerned largely with the various factors which influenced the economics of the concrete industry. One of the main problems facing contractors today was the use or otherwise of factory-made concrete. This was essentially a matter of comparative costs, and many factors had to be taken into account. An example of comparative figures might be of interest.

The cost of a half yard mixer, with weighing apparatus, hand scraper and 30 ton cement silo was approximately £3,000. This represented an annual cost of £750 per year on a straight line depreciation period of four years, or, at an annual output of 5,000 cubic yards, a depreciation cost of 3/- per cubic yard. Repairs and renewals to plant at an estimated cost of 33 $\frac{1}{3}$ % of depreciation would represent 1/- per cubic yard. Fuel oil, lubricants, water supply and erection and removal of the mixer would cost a further sixpence per cubic yard. Labour costs in the mixing operation, at the rate of 0.5 man-hours per cubic yard would represent a further 3/9. Materials, based on Dublin prices and using bulk cement at the rate of 525 lb. per cubic yard, would cost approximately 53/-. The total net cost of one cubic yard of concrete would therefore be 61/3d. This might then be compared with the quoted price of 79/- per cubic yard for factory-made concrete delivered to the site. A reduction in annual output of the site plant to say 1,000 cubic yards would, of course, influence the

figures considerably, and, in further favour of factory-made concrete the ability of a truck mixer to deliver to any given part of site was significant.

In the questionnaire which Mr. Sweeney issued to the Irish contractors, he asked whether concrete should not be specified on the basis of minimum crushing strength, the design of the mix required being left to the contractor. 80% of the replies favoured that procedure. One contractor in his reply writing with particular reference to reservoir construction, strongly criticized the attitude of consultants who specified a concrete in detail (and possibly the wrong concrete) and then held the contractor responsible for any leakage in the finished work.

Mr. Sweeney was glad to see representatives of the plant manufacturers at the Symposium. The contractor was, in one sense, the connecting link between the consulting engineer and the plant manufacturer, as the onus for relating the right plant for any given project rested on the contractor. This was not always an easy task, but he had to say that he found the manufacturers' representatives very helpful at all times, and, he might add, sale or no sale.

MR. D. V. HICKEY opened the discussion. His organisation considered the upsurge of factory-made concrete to be the most significant single development in Irish concrete practice in recent years. He described their change over to factory-made concrete by reference to their building programme over the last decade. In the period 1956 to 1959, a two storey tobacco warehouse was built by contract, with a total floor area of just over three acres. The foundations, columns and spine beams were reinforced concrete. The roof trusses were precast concrete. The main beams spanning 54 feet were precast concrete, post-tensioned by the Freyssinet method. A minimum 28-day strength of 6,000 p.s.i. with a minimum cement content of 672 lb. per cubic yard, was specified for the prestressed concrete, and the highest level of control (see Road Note No. 4) was stipulated. The contractor had used a high level mixer with weigh batching, power plough feed to the skip and bulk cement, delivering the concrete to the formwork with dumpers or with a tower crane and bucket, depending on the location of the pour. 725 cubes had been tested, and had had an average 28 day strength of 6,900 p.s.i. 9.1% of the cubes had failed below the required strength of 6,000 p.s.i.; less than 1% had failed to reach 90% of that figure. In the reinforced concrete sections of the work, 253 cubes had been tested, 4% failing to reach the specified strength. Mr. Hickey commented that these results had been considered as very satisfactory, although they might now, 7 or 8 years later, be quite commonplace. Good finishes had been obtained consistently also, and it was his opinion that this combination of good strength and finish had been due primarily to the use throughout the contract of a Vebe consistometer. He considered that this instrument was very suitable as field

equipment, and on the warehouse project, it had been sited beside the mixer for nearly three years and had been trouble-free for the whole of that period. It should be stated that the whole of the concrete and aggregate testing had been in the hands of qualified engineer.

After the project above described, a second building contract had been started, using both site-made and factory-made concrete, the site control being lowered to the second level set out in the Road Note No. 4. The same contractor had been employed, and the same plant used for the site made concrete. There had been no resident engineer, and no consistometer on the site. Site cube failures had risen to 10% and factory-made concrete cube failures had been as high initially as 17%. The rise from 4% to 10% highlighted the importance of skilled professional supervision, and control equipment.

In a third contract, with a different civil engineering contractor, failures in the site made cubes had risen to 12%, whereas for factory-made concrete, the cube failures had fallen to 11%.

In a fourth and fifth contract, site made cube failures remained steady at 10%, whereas factory-made cube failures dropped to below 4%; and it was significant that this figure of 4% had been the acceptable standard for the first warehouse contract, where a very high degree of concrete control had been specified.

It had to be pointed out, of course, that the factory-made concrete suppliers usually undertook to provide a mix of 10% stronger than specified, for example, a mix with a 28 day crushing strength of 3,300 p.s.i. where the designer's specification called for 3,000 p.s.i.

The five projects mentioned had a total cost of over £300,000. In all, over 600 cubes were tested, and Mr. Hickey's organisation had become satisfied with the dependability of factory-made concrete. In fact, with the completion of the Board's post-war capital works programme, and the consequent drop in concrete consumption to about 1,000 cubic yards per annum, their batching plant had been sold, and reliance would be placed entirely on factory-made concrete for their normal annual needs. Two major reasons for this decision had been, however, the existence of two ready-mix plants within the general port area and the availability of the Board's own transport for collecting concrete from these plants.

Mr. Hickey told the Symposium that the Board had not yet used precast factory-made concrete so far on any major contract work. They were, however, using it on a growing scale, in small works, and had found it of value, primarily, for rapid erection.

One addition might be made to Mr. Sweeney's comprehensive list of methods of placing concrete, namely a method of placing in isolated marine structures.

The Board had at one time a floating plant, consisting of a pontoon type dump float with a crane at either end and a concrete mixer, topped with a large platform amidships. One crane equipped with a short jib and clamshell grab fed materials from 120 ton capa-

city dump floats to the platform whence they were delivered to the mixer. The second crane which had a long jib and a concrete bucket, delivered from the mixer to the formwork. Four materials floats were required for continuous operation in one 8-hour shift, with small tugs to provide motive power. This plant had many disadvantages and had been dismantled. There was certainly room for new suggestions in this very difficult matter of placing concrete away from the shore.

Mr. Hickey then turned to the subject of light weight concrete, an unusual topic in Ireland, and one which presented unusual mix proportions. It had become necessary to renew the decks of two rolling lift top counterweighted bridges which gave shipping access from the river to the Custom House docks. Built 30 years ago by Messrs Arrols, the deck had consisted of $1\frac{1}{2}$ " asphalt on 5" to 7" breeze concrete on shallow steel troughs. The breeze concrete, with a density of 90 lb. per cubic foot, had been adequate at the time but had proved too weak for the stresses of modern traffic.

It would be appreciated that the new deck should have the same weight as the old, to avoid alteration to the counterweighting system. It was decided that a concrete with a minimum ultimate strength of about 2,000 p.s.i. would be suitable and it was recognised that the bridges could remain out of action for only five or six days, if normal traffic were not to be disrupted. These exacting conditions led to the adoption of Leca light weight expanded clay aggregates and high alumina cement. Preliminary tests indicated 3-day strengths of 2,500 p.s.i. for a density of 90 lb. per cubic foot, and 3,000 - 3,200 p.s.i. for a density of 92 lb. per cubic foot,; and these would, of course, also be virtually the ultimate strengths. It was decided to keep to the lower density, and the mix was thereupon specified as 1 part cement : 2 parts fine Leca aggregate : 4 parts coarse Leca aggregate, all by volume. The equivalent weight proportions were 1 : 0.26 : 0.81. Expanded clay aggregate absorbed a lot of water, and as the material was delivered dry, all the water had to be added at the mixer. This led to the use of a w/c ratio of 0.72 (0.70 was usually considered a minimum by the makers), this figure having been based largely on visual judgement. It was found desirable to reduce vibration and tamping to the lowest amount possible, and it had to be realised that due to the weights of the ingredients, screeding to a flat smooth finish was not practicable. The use of high alumina cement made curing very critical, and heavy watering had been necessary between the fifth and seventeenth hour after placing. Cube strengths from the concrete as placed ranged from 2,200 p.s.i. to 2,700 p.s.i. at 3 days with a mean, as forecast, of 2,500 p.s.i. The bridges were available for traffic within a week of being taken out of commission, and five months later there had been no evidence of distress.

Mr. Hickey felt that the costings for this concrete might be of interest. They were, of course, abnormally high due to the materials and the size of the job although he was satisfied that had the job been

larger, the contractor and supervisory staff would with increased experience, have been able to reduce the labour costs at the later stages. 50 cubic yards of concrete were made. The aggregate cost £117 ex works, and £337 delivered free on quay at Dublin. The all in cost of the concrete was £18 per cubic yard, and this, in the speaker's opinion, was a reasonable minimum figure on which to base future estimates. Corresponding concrete with normal Portland cement would have cost about £13 10s. 0d, per cubic yard.

Finally, it was of interest to note that other lightweight aggregate manufacturers had shown that with densities of about 110 lb. per cubic foot, ultimate strengths of about 6,000 p.s.i. could be anticipated.

MR. M. A. LYNN complimented University College on the success of the Symposium. A reservoir of very useful knowledge would be made available as a result of it, and this should be accessible to engineers throughout the country through publication of the proceedings. Mr. Sweeney's paper was particularly valuable in this respect. It would have been of considerable interest if Mr. Sweeney had discussed the selection of plant in relation to the volume of output required, as so many contractors lived in the perpetual conflict between inadequate plant and underutilization of larger installations.

A comment by Mr. Sweeney on the extent to which crushed aggregates are used in Ireland would also be welcome.

MR. W. S. MEAGHER commented, with the Chairman's permission, on some points arising from other earlier sessions as well as from Mr. Sweeney's paper. He felt it was necessary to have research conducted on (a) the relationship between cube strength and cube density, with a view to reaching a standard method of making cubes and (b) the relationship between site cube strength and placed concrete strength. This research could be promoted by having a centre at the Institution of Civil Engineers of Ireland or at the Institute for Industrial Research and Standards, to receive and collate information submitted to it from sites throughout the country. Firms and authorities engaged in concrete work should co-operate in this research and a standard method of reporting to the centre should be developed.

Regarding concrete consistence control, he had found the compaction factor apparatus to be a most valuable tool.

Regarding additives, he had been interested in the paper given by Ashworth to the Institution of Civil Engineers in June, 1965 dealing with sugar as a concrete additive. The conclusions drawn were that sugar used in very small quantities (up to 0.05% of the cement content) would have the following effects:

- (a) The setting time would be retarded by about 4 hours (a very useful property in certain circumstances).
- (b) The 7- and 28-day compressive and flexural strengths would be increased by about 8%.
- (c) The mix would become more workable.

- (d) A reduction in cement content of about 15% could be made with resultant saving in material costs.
- (e) The density, and shrinkage and absorption properties would be affected, and the durability of the concrete would not be disimproved.

In the matter of repairing defects, he was prepared to accept such materials as epoxy resins for repairs where wear and impact were not important factors in the use of the structure. Possibly there was information now available which would convince him that these materials could in fact be safely used for all repairs.

Finally, in reference to the design of road joints, his experience had shown that some B.S. low-extension joint sealers, nominally capable of sealing joints spaced up to 40 feet apart, were not effective even at spacings much less than 40 feet.

MR. L. NAUGHTON said he was sorry not to see any reference to air entrainment in Mr. Sweeney's paper. Some work had been done with air entraining agents and the results were available in some consultants files. The collection, assessment, and publication of this information would be useful. It appeared a general opinion that cold weather was not a serious problem in Ireland, but one wondered how contractors would react to that attitude, who had experienced the 1947 and 1963 winters.

Mr. Naughton supported the trend towards the more extensive use of 7-day tests, and referring to cube testing generally, felt most strongly that all contractors nowadays should have steel cube moulds on site or at least available in their stores. He regretted that this was by no means the present position.

MR. P. BRODY felt that Consulting Engineers should ensure that their specifications contained powers to withhold approval of unsuitable plant for batching and mixing of concrete. The procedure for site sampling and for making of cubes should be described in detail, and the equipment for tests required to be supplied by the Contractor should be fully listed. Suitable items for the cost of equipment and for payment of laboratory fees should be provided in the Bill of Quantities. The Contractor was entitled to know, at the tender stage, the degree of quality control required on site. The specification should make it clear that the cost of labour and materials for testing would be deemed to be included in the unit rates for concrete.

He had noticed that it was common practice, with mixers of up to $\frac{1}{2}$ cu. yd. capacity, to load the mixer skip by means of a power-hauled shovel from coarse and fine aggregate heaps on the ground, and to feed the cement from a silo having an accurate lever-type weighing device. While the quantity of cement per batch was usually correct, both the absolute and relative quantities of the fine and coarse aggregates were often wrong. The weighing of aggregates was supposed to be achieved by the unskilled operator, by reading a dial mounted on

the mixer frame. It was often difficult, if not impossible, to read the gauge owing to vibration. Even when this problem did not arise, unless the operator was very conscientious, or very close supervision was maintained, careless batching often occurred, especially when the operator became fatigued. Mr. Broy mentioned an actual case where it was necessary to maintain the sand content within close limits, owing to grading peculiarities. This was not achieved owing to careless batching and the concrete produced was unplaceable without additional water, which the placing gang demanded and got. The permissible maximum w/c ratio was exceeded to such an extent that the concrete strength was reduced to an unacceptable level. All sorts of excuses were then made, while the basic cause, careless batching, was ignored. One merit of batched all-in aggregates was that the loading man had only to watch the dial for a single reading—the total batch.

Another source of inaccuracy in batching was that even the best weighing devices needed regular calibration against actual standard weights. Nominal one cwt. bags of cement could be used for an approximate check, but in his experience the only really satisfactory method involved having enough 56 lb. weights on site to check up to half the scale reading, the full scale being checked by removing the weights and reloading with aggregate to a known calibrated reading, and then continuing with the weights.

As regards the w/c ratio, it was necessary to base both mix design calculations and control measures on a clear definition of the free water in the aggregates. Mr. Broy suggested that the datum for measurement should be the "saturated surface-dry" condition. It was a simple operation in site testing to dry out the aggregates completely (i.e. to constant weight), and then to subtract a correction for "absorption." Major aggregate suppliers were able to quote the absorption percentage for their materials, as it was one of the properties regularly measured in their laboratories. He was happy to acknowledge that this and allied information was always made available on request by the suppliers, who were pleased to find that site organisations were sufficiently interested to seek their assistance in controlling the quality of materials.

It was a commendable practice to take samples from the actual aggregates as loaded for each batch from which test cubes were made. By noting also the quantity of mixer water used and adding the moisture content determined from the samples, it was possible to estimate the actual w/c ratio quite closely, and to establish a correlation with cube strength for the actual mixer and materials employed. With this knowledge it was easy to see to what extent additional water could be permitted to ease the workability problem in congested sections.

Finally, Mr. Broy stressed the importance of having adequate technical staff, knowledgeable about concrete and its ways, on both site teams on any major project. Much of the trouble that arose on site was caused by inadequate supervision due to understaffing.

MR. J. P. O'F. LYNAM described the use of Colcrete for underwater construction. Colcrete and tremie concrete were at present the only general methods of placing concrete under water, and tremie concrete had always been a material of doubtful value. A reasonable prejudice against Colcrete was the difficulty of testing its quality. Aggregate may be 3" or 4" material or even up to 12" for mass work, and the 6" cube used in normal concrete would obviously be of little use. He, however, in work in India, had had available a testing station a mere 300 miles away which could test 30" cubes. Approximate minimum results for such cubes made in a tank of water under an induced pressure equivalent to a head of 40 feet were as follows:

Mix	Age	Crushing strength
1 part cement : 2 parts sand	28 day	4,000 p.s.i.
1 " " 1½ parts sand	28 day	4,500 p.s.i.

A further objection to Colcrete was an uncertainty as to whether the sand : cement "grout" did fully penetrate the voids in the pre-placed coarse aggregate. This objection could only be met by examining cores from finished work. He had done this both here and in India and the results had been satisfactory. (At this stage, Mr. Lynam showed slides of the cores to the audience).

He would consider the advantages of Colcrete to be:

- (a) A 1 : 1½ cement : sand mix Colcrete used about 560 lb. of cement per cubic yard, whereas in a 1 : 1½ : 3 concrete, the corresponding quantity would be about 670 lb.
- (b) Colcrete required very much less mixing plant, in that the mixer had to handle only 50%, or in the case of work above water, about 40% of the total finished mass. Power consumption tended therefore to be much lower than for concrete. Single pours of 2,000 cubic yards of finished Colcrete required a total plant capacity for mixing and placing of 40 horsepower. Concrete in that quantity might require ten times as much.
- (c) Distribution of "grout" was easier than distribution of concrete. Pumping over distances of 200-300 feet presented no problem.

There were many difficulties in using Colcrete and bad Colcrete was, if anything, worse than bad concrete. Some matters which had to be watched were:

- (a) Underwater Colcreting could not be allowed to stop until the top of the lift was in a position where it could be cleaned off before resumption.
- (b) The preplaced "coarse aggregate" should never be less than 1½" material, as otherwise there might be difficulty in getting "grout" into the interstices.
- (c) Angular coarse aggregate was preferable to smooth rounded aggregate, as the broken surfaces of the crushed material provided better bonding characteristics for the grout.

- (d) It was even more important in Colcrete to have thoroughly clean coarse aggregate than in concrete, as the "grout" to aggregate bond was easily inhibited by dirt.
- (e) A coarse sand provided a stronger "grout" than a finer material, and should be used, although the mixer man usually found out quickly that a finer sand "grout" was easier to pump.
- (f) The shuttering for Colcrete had to allow for the fact that the "grout" was a liquid and would escape through a faulty joint more readily than concrete would.

MR. J. E. WALLACE noted the infrequent use of pumped concrete in Ireland despite the fact that this method, first originated in about 1920, had developed extensively all over Europe since about 1950. His firm had recently placed about 5,000 cubic yards of pumped concrete at the new Fertiliser Factory near Arklow in ten months. They had used a pneumatic concrete placer with a second on site as a standby, and an electrically driven stationary compressor. Using a concrete, with river gravel aggregate predominating, but with some crushed stone included, they had pumped through a 6" bore pipe at rates of up to 12 cubic yards per hour against vertical heads of up to 25 feet and horizontal distances of up to 850 feet. The same crew using the same plant had previously pumped at a rate of 20 cubic yards per hour at the Verolme dockyard in Cobh.

In the Arklow project, the floor of the stores was 100 metres x 60 metres with beams 60 centimetres deep at 3 metre centres, and pours of 100 cubic yards per 10 hour day had been considered very satisfactory under the circumstances.

There was one point which any prospective users of pumped concrete should note, namely, that the mix had to be correct and the consistence uniform if pumping was to be successful.

In Arklow, it was found necessary to use a mix containing 550 to 560 lb. cement per cubic yard to obtain the necessary lubrication of the pipe line. If too much water was used, the effect was segregation in the pipe and consequent blockage. The satisfactory operation of the plant was found to be, to a large degree, in the hands of the mixer and pump operator, who when practised could control fully the passage of the concrete along the line and the mode of its discharge at the formwork. With correct operation, the concrete moved along the pipe line in isolated "slugs" separated by cushions of air.

MR. D. P. O'LEARY commented first on the fact that much of the concrete being placed at present in Ireland was not vibrated. He saw vibration as essential in modern concrete practice, although it could not be used, as many operatives appeared to think, to cure segregation inherent in a badly-designed mix.

Mr. O'Leary raised the question of the stripping time for formwork as a function of the temperature gradient through the fresh

concrete and the ambient air temperatures. Whereas he felt that a thin section could on being stripped accommodate itself rapidly and without distress to ambient conditions, a thick section could have the external 3" or 4" of its bulk weakened by shrinkage stresses, particularly if it was cured, on stripping, by being doused with water having a temperature of perhaps, 45°F.

Regarding construction joints, he considered that a very thin layer of sand and cement should be used on top of the placed concrete, when starting the next lift. Regarding the testing of concrete, he would recommend the use of small, say 1½" diameter, cores as a means of checking the quality of placed concrete.

Finally, he wondered whether Mr. Sweeney had any information on a coefficient of variation to be applied to foremen as a function of their off-site activities. He felt that this was a matter of considerable significance in quality control.

MR. P. HAYES was greatly interested in Mr. Sweeney's analysis of the cost of concrete.

Mr. Hayes felt that the labour cost should be about 5/- per cubic yard, and that transport of site-made concrete across a site should be reckoned at 2/- per cubic yard. Further, he would add an amount for wastage of materials in site-made concrete, of, say, 5% or 2/6d. per cubic yard. He conceded that there would still remain a difference of 5/- to 10/- between site and factory-made concrete, in favour of the former, but he submitted that the factory-made concrete was worth the extra amount, and made the following points.

- (a) Very often a contractor erred in comparing what he hoped the cost of his site-made concrete would be with what he knew the cost of factory-made concrete would be.
- (b) If factory-made concrete permitted a job to start more quickly and be completed earlier, the saving in overhead costs would be significant.
- (c) Any size of pour that might be deemed necessary could be handled with factory-made concrete; whereas the necessity of having 2 or 3 large pours on a project in which the bulk of the pours were small, might mean the uneconomical retention of a site plant on the job for long periods of idleness.
- (d) Site plant bought for one large project might have to remain idle until the next large contract was secured.
- (e) It was probable that less site supervision was required where factory-made concrete was used.
- (f) The advantages in placing direct into formwork below ground level from the truck mixer were obviously considerable.

Regarding that final point, a recent report prepared by the National Building Agency in Britain had stated that the labour involved in placing below ground level direct from a truck mixer was about 0.33 man hours per cubic yards, whereas the equivalent figure for site-

made concrete on housing sites was about 4.9 man hours per cubic yard for mixing and placing.

Mr. Hayes agreed with Mr. O'Leary that all concrete should be vibrated. It was a guarantee of good work, and it did not cost any more than other methods of compaction.

Regarding additives, the suppliers of factory-made concrete did not add additives unless the customer asked for them. They always represented an extra cost which the customer, of course, had to pay.

Finally, it appeared to Mr. Hayes, that the matter of relating the actual strength of concrete as placed to the cube strength hinged wholly around knowing that the concrete as made had the appropriate consistence for the method of compaction to be used. The cube tests were then an adequate guide to the strength of the concrete as placed.

DR. E. T. HANRAHAN in a written contribution, expressed himself puzzled by the concrete technologists' continuing neglect to obtain measurements of the interstitial water pressure which was almost certainly the most important single parameter especially during the early life of the concrete. He said that

- (a) immediately after placing, the concrete behaved essentially as a saturated sandy gravel with a slight colloidal content. In that condition the total pressure exerted by the wet mix was governed mainly by the porewater pressure, and the rate at which the total pressure fell off was influenced perhaps more by the reduction in porewater pressure than by the rate of gain of strength of the skeletal solids. Some recent tests suggested by him had confirmed the validity of the hypothesis,
- (b) before final hydration took place, the porewater was certain to pass into a condition of high suction or tension. This tension fundamentally influenced both total tensile strength as well as (true) compressive strength. It exerted no influence on shear, since water did not have shear resistance. The effects of that suction were clearly demonstrated by, for example, the phenomena associated with curing, volume reduction on drying, and the lack of consistency between cube failure which is a shear process, and flexural and tensile tests. He was unaware of any measurements made of that suction, even though no great difficulty was involved,
- (c) the resistance to flow of pumped concrete in a pipe was almost certainly governed by the fundamental Coulomb equation.

$$s = c + (n - u) \tan x$$

The first term on the right hand side was negligible, so that if u (the porewater pressure) was increased, the resistance to flow was diminished. The validity of that hypothesis had been confirmed by the experience of Mr. Wallace, who had pointed out the effectiveness of pressurizing both ends of a plug of pumped concrete,

- (d) the effectiveness of water in compacting concrete was well-known. The reason was almost certainly the elimination of porewater tension which thus reduced the effective stresses and friction between the particles and allowed the particles to interlock more easily.
- (e) the workability of a mix was almost certainly influenced to a large extent by the induced porewater pressure. If this was high, the applied compactive effort was wasted by elastic pressurization of the porewater.

Many other examples were available of the probable influence of the porewater pressure and it was clear that measurements for this parameter were urgently needed.

Dr. Hanrahan also questioned the absence of vacuum concrete from Irish practice. With its advantages of wet placing for good consolidation and subsequent low w/c ratio for high strength, it would be of interest to learn why the method had not been favoured to a greater extent, at least for precast work.

Mr. T. M. DUGGAN in a written contribution questioned Mr. Sweeney's statement that considerable advantages might be obtained by deliveries of bulk cement in 8-ton consignments. It was difficult to see that this would significantly change the pattern of deliveries to silos of 30 tons capacity and upwards. Perhaps the implication was that the smaller deliveries would allow the use of smaller silos, of, say, 12 tons capacity. If this were so, he felt it should be noted that a 12-ton silo with 8-ton deliveries would cause service difficulties in the long term, as the user would have not more than $3\frac{1}{2}$ tons reserve (say 2 hours working with a 14/10 mixer) which was scarcely sufficient for smooth planning. It would also have to be borne in mind that transport costs would increase with a reduction in delivery tonnages.

He knew, however, that should special conditions arise on any site or for any particular stage of a project, the cement industry would welcome discussions with those involved, to assist in solving their difficulties. Deliveries in 8-ton loads were in fact now possible, but no requests for them had been received so far, and it remained questionable whether the general considerations quoted above would make the smaller deliveries generally appropriate.

Mr. S. KENNY in a written contribution commented that there appeared to be very little published information on the vibration of concrete. Contractors buying their first vibrators rarely had a satisfactory specification to work on. They should be given guidance on (a) size (b) frequency of vibration (c) horsepower input. Incidentally, there did not appear to be any established relationship between these factors.

He had recently seen in use a vibrator having a frequency of 12,000 cycles per minute, and felt that there was a marked improvement in the quality of the concrete it produced over that produced with

vibrators generally in use throughout Ireland with a frequency of 3,000 to 4,000 cycles per minute.

The poker size was important. He found a 2" poker suitable for foundations and heavy beams, but too powerful for columns less than 12" square.

Mr. Kenny considered that "A survey of post-war British research on the vibration of concrete" by W. E. Murphy and published as TRA382 by the Cement and Concrete Association was a useful reference in this matter.

MR. SWEENEY replied.

He thanked Mr. Hickey for his valuable information on actual job performance and on lightweight concrete.

He would like to have amplified his remarks on plant, as Mr. Lynn suggested, but felt that would have made his paper too long. In his own experience, crushed stone aggregate was not used much in Ireland, due, no doubt, to the general availability of gravels.

He sympathised with Mr. Meagher's difficulty about strength of placed concrete. He personally had little faith in the value of the impact hammer, and regarded the testing of cores as the best method available.

To Mr. Naughton's point about cold weather work, he could only answer that contractors should probably take more precautions, but on the whole tended as a class to be confirmed optimists in these matters.

He agreed with Mr. Broy about the great merit of batched aggregate; his firm was using this material and finding it very satisfactory.

He was very interested in Mr. Lynam's description of Colcrete, but he himself had had the experience of having to remove concrete placed underwater by special bucket in temporary works at the Lee hydro-electric scheme, and from that and other experience would have no fault to find with underwater concrete placed in that manner. He would, he felt, prefer it to Colcrete.

He considered that pumping, as mentioned by Mr. Wallace, was an excellent method of placing concrete provided the proper precautions were taken to keep the mix right.

Regarding Mr. O'Leary's comments, the figures given in the paper for the use of vibrators could be misleading. It was probable that 90% of civil engineering contractors used vibrators, but it would not be possible for him to assess accurately the corresponding figure for building contractors. He agreed that the state of the concrete ganger's well-being was an important consideration in quality control. He had found Fridays to be good days for big pours, and Mondays definitely bad. He also agreed with Mr. O'Leary about the merit of sand and cement at construction joints, and the value of 1" - 2" cores in assessing the quality of placed concrete.

He was glad he had drawn Mr. Hayes out regarding the costs of factory and site-made concretes. He thought the point about comparing the known cost of one against the unknown cost of the other was particularly important.

THE CHAIRMAN in winding up the meeting expressed the trust that the Irish Sugar Company would not be used as the source of a new cheap additive. The work mentioned by Mr. Meagher had aroused considerable interest, but it remained all too true that sugar in the appropriate quantities might prevent the concrete from setting at all.

SESSION F

PRECAST CONCRETE

T. F. LYDON, B.E.

OVE ARUP and PARTNERS, consulting engineers

Sessional Chairman :

D. McILVENNA, F.I.O.B.

Summary

Not so long ago the term "Precast Concrete" would have meant to most people in Ireland a block, a paving slab or perhaps a window cill. To-day the term is being more generally applied to large building components and indeed to whole buildings. The development in the use of precast concrete in building construction has recently become more rapid and its influence in our contemporary architecture is becoming more and more noticeable.

Precast concrete means different things to different people. Architects are interested mainly in the aesthetic possibilities of the material and possibly the relief it offers from the tyranny of the glass and metal curtain wall. Builders probably think of it in terms of rapid construction and superior quality. The precast concrete specialist firms see it as the logical material for this country in the application of industrial processes to the building industry. What needs to be appreciated is that it is an essentially new and different building material, and it is worth emphasising that its use does require a new and different approach to design and construction methods. The examples of precasting referred to in this paper are intended to illustrate the standards of precasting reached in Ireland. They are not necessarily the best examples and they certainly are not the worst but they do show a slow but steady progress in the exploitation of the material in this country.

History

The earliest example of the use of precast concrete on a large scale here was the work carried out by Bindon B. Stoney at the Port of Dublin about 1880. At that time very large precast concrete blocks of irregular shape weighing from 140 to 360 tons were cast on a wharf near the present North Wall. They were then lifted and conveyed to their destination in the new quay walls then being constructed by means of floating shears. Mr. Stoney not only designed all the harbour works but also all the mechanical equipment required to handle the blocks. There are references to earlier work at Rosslare harbour where large concrete blocks were used about the year 1876.

Another example of the early use of precast concrete comes from Mizen Head in the extreme south west of Ireland. In 1909 a footbridge, spanning 172 feet at a level of 150 feet above the sea, was constructed at this spot. The arch ribs were precast in four sections on shore and erected by means of a wire ropeway. The deck and hangers were cast in situ. This suspension method of erection is used to-day for many modern bridges.

The distinction of having built in 1951 the first prestressed concrete bridge in Ireland belongs no doubt to C.I.E. but a Mr. James Price describes in the course of a paper to the Institution how, in 1861, he built a bridge at Poyntzpass using "a peculiar and novel method of construction." The bridge was a series of parallel flat Portland brick beams combined with a deck of in situ concrete. Along the bottom of each of the beams he positioned a flat wrought iron bar. The ends of the beams had special cast iron anchor blocks and he was able to tension the bars off these by means of pairs of folding steel wedges. Mr. Price further remarked "that had the bars been formed into screws at the ends and drawn up to a tension of say five tons per sq. inch, the load could afterwards cause no deflection." He was quite enthusiastic about this system of construction and used it again for a roof beam at Dundalk railway station, but the idea seems to have been subsequently ignored or forgotten.

From the historical point of view the new Kish Bank Lighthouse holds the record as the largest piece of precast concrete ever in Ireland. The structure weighs over 6,000 tons and measures 158 feet from the sea bed to helicopter platform.

Advantages of Precasting

In most books on the subject of precast concrete discussion of its advantages and disadvantages is usually confined to comparison with in situ concrete and is not extended to discuss the merits or demerits of other building materials. In practice designers must consider the possibility of using other suitable forms of construction besides the two mentioned before arriving at a final decision. In domestic type buildings, low rise office blocks, flats, classrooms, bedroom blocks and similar structures, a comparison would have to be made with the more traditional methods of building, such as block wall combined with in situ concrete floors. In single storey factories, assembly halls, farm buildings and the like, structural steel would certainly be considered. For multi-storey buildings, heavy industrial buildings, car parks and buildings of irregular shape, in situ concrete might prove the best solution.

The three questions usually asked when precast concrete is proposed for a building project are:—

- (1) How much will it cost?
- (2) What will be the delivery time and how long will it take to erect?
- (3) What will it look like?

These three questions are not really separate questions but dependent ones. For example, a self-finished wall unit which can be painted or papered on directly would be more expensive in first cost but could save time and money in the overall picture. If precasting can reduce the overall time for a project, the time saved could be more valuable to a client than the initial extra cost of the building.

Delivery time is a big factor in the economics of precast concrete. There is a limit to the rate at which a mould can be reused, as distinct from the number of times it can be used. If the delivery date is tight this may necessitate increasing the number of moulds above that which would normally be used, and the cost of the units will go up accordingly.

The often quoted advantage of speed of erection for precasting needs closer examination. Is there much point in paying more for putting up a structure at great speed if all the other building trades are going to lag far behind? The critical path may in fact run through the plasterers rather than the precaster. This, of course, raises the point that if you want to get the greatest benefit from an industrialised structure you need to industrialise the rest of the building process as well. It is as well to remember that in situ concrete can be speeded up by using better concreting techniques and rationalising the design in such a way as to give a standardised reinforcement and shuttering arrangement. In Dublin recently the structure of a multi-storey office block was completed at the rate of one floor per fortnight. Each floor measured 15,500 sq. feet and the time mentioned includes for all the columns and walls to each floor.

On a confined site where there is little room to store materials a precast or partially precast building might be the answer. On the other hand awkward sites often lead to awkward buildings especially on urban sites and this might not in the long run favour precasting. The availability of a supply of ready mix concrete to the site is another factor that needs to be considered before making a decision in favour of a precast solution.

On remote sites precast units are popular because they solve the difficult problem of quality control and simplify the transport of material but the units have to be kept small enough to be man-handled or erected with very light equipment.

Cranes

It is interesting to speculate whether the demand for larger and heavier precast concrete units has led to the development of better and more economical handling and lifting gear or vice versa. In any event there is now available in Ireland a fairly wide range of mobile and tower cranes suitable for handling large precast units.

In the Dublin area fourteen medium to large contracting firms are using, at the moment, a total of 34 tower cranes (Fig. FI). Of these 34 cranes about $\frac{1}{3}$ are capable of handling loads of about two tons at a radius of 60' or more. Another $\frac{1}{3}$ are capable of handling $1\frac{1}{2}$ ton loads at a radius of from 40' to 60' and about $\frac{1}{3}$ can handle only light loads. The loadings quoted take no account of the weight of the tackle. When cal-

CRANE CAPACITY

2 TON
TO
1 1/2 TON

RADIUS OF
OPERATION

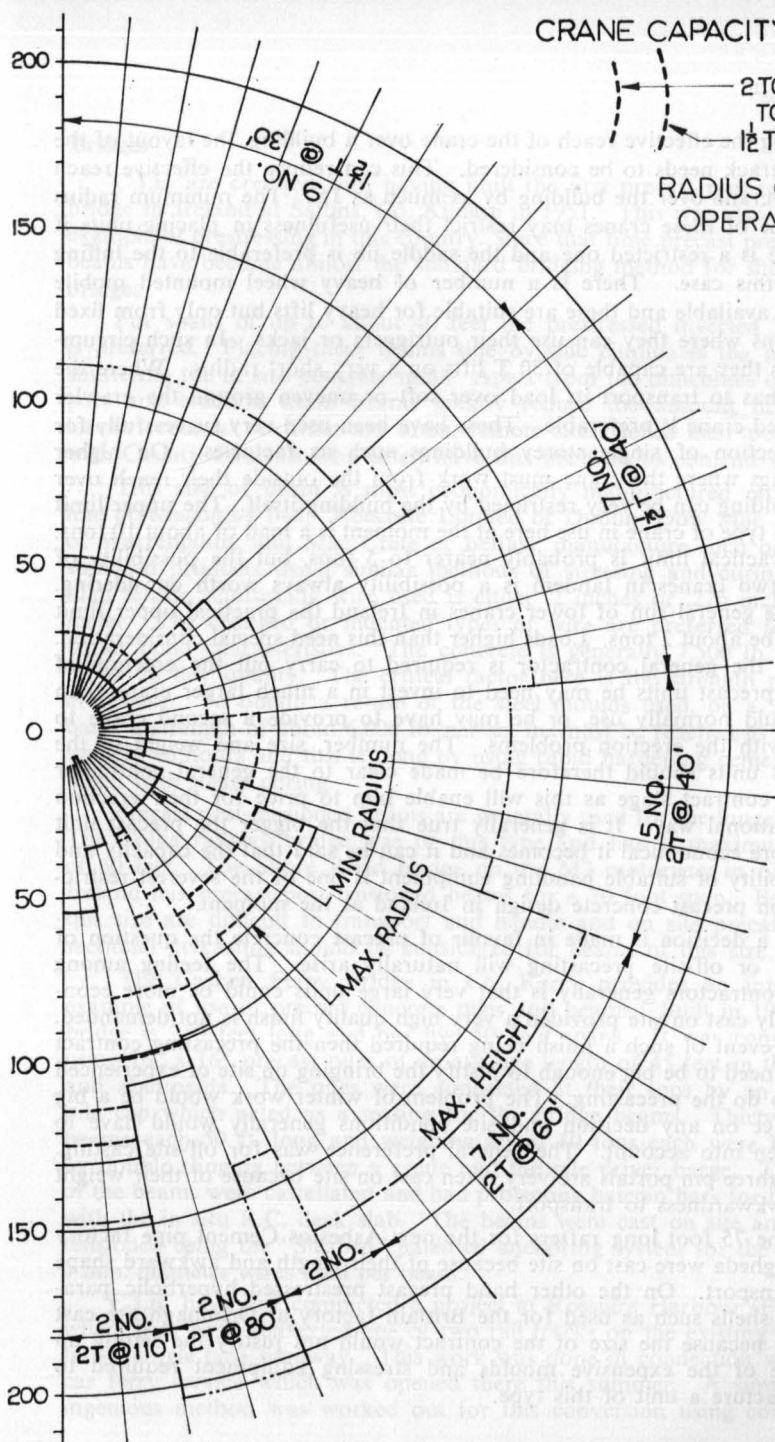


FIG. F1. DETAILS OF THIRTY-FOUR TOWER
CRANES IN USE IN DUBLIN—JUNE 1965.

culating the effective reach of the crane over a building, the layout of the crane track needs to be considered. This can reduce the effective reach of the crane over the building by as much as 15'. The minimum radius of some of these cranes may restrict their usefulness in placing units if the site is a restricted one and the saddle jib is preferable to the luffing jib in this case. There is a number of heavy wheel mounted mobile cranes available and these are suitable for heavy lifts but only from fixed positions where they can use their outriggers or jacks. In such circumstances they are capable of 30 T lifts on a very short radius. Where the crane has to transport its load over soft or uneven ground the crawler mounted crane is preferable. These have been used very successfully for the erection of single storey buildings such as factories. On higher buildings where the crane must work from the outside their reach over the building can be very restricted by the building itself. The upper limit for the type of crane in use here at the moment is a load of about 10 tons. The practical limit is probably nearer to 5 tons, but the possibility of using two cranes in tandem is a possibility always worth considering. For the general run of tower cranes in Ireland the practical upper limit would be about 2 tons. Loads higher than this need special consideration. Where the general contractor is required to carry out the erection of heavy precast units he may need to invest in a much larger crane than he would normally use, or he may have to provide a second crane to cope with the erection problems. The number, size and weight of the precast units should therefore be made clear to the general contractor at the contract stage as this will enable him to price for their erection in a rational way. It is generally true that the bigger the precast unit the more economical it becomes and it can be said that the capacity and availability of suitable handling equipment is one of the severest restrictions on precast concrete design in Ireland at the moment.

If a decision is made in favour of precast concrete the question of on-site or off-site precasting will naturally arise. The feeling among Irish contractors generally is that very large units could be more economically cast on site provided a very high quality finish is not demanded. In the event of such a finish being required then the precasting contract would need to be big enough to justify the bringing on site of experienced staff to do the precasting. The problem of winter work would be a big influence on any decision and site conditions generally would have to be taken into account. The general preference was for off-site casting. Large three pin portals are very often cast on site because of their weight and awkwardness to transport.

The 75 foot long rafters for the new Asbestos Cement pipe factory at Drogheda were cast on site because of their length and awkward shape for transport. On the other hand precast prestressed hyperbolic paraboloid shells such as used for the Brittain factory at Drimnagh are cast off-site because the size of the contract would not justify the setting up on site of the expensive moulds and stressing equipment required to manufacture a unit of this type.

Bridges

C.I.E. are credited with having built the first precast post-tensioned bridge in Ireland at Sallins, Co. Kildare in 1951. This was also the first example of prestressing in this country. Since that time precast prestressed beams have become almost the standard bridging method for short span bridges.

For spans of up to about 40 feet the prestressed inverted T beam is preferred. Placing these beams side by side eliminates the need for shuttering the in situ concrete infill. Apart from the difficulties of transport and erection these beams greatly reduce the amount of skilled labour required on, what are often, remote sites, hence their popularity with County Councils who often have this problem to contend with.

This size of beam is most economically manufactured on a long line pretensioning bed. Rocrete Limited of Dublin, Dow Mac Limited of Warrenpoint, and Mac Crete of Belfast, manufacture such beams as standard products using similar methods of stressing and curing. The high tensile reinforcing wire used is either .2 inches or .276 inches diameter. The crimped or indented types of wire are preferred for their better bond characteristics. The concrete is generally 7,500 lb. per sq. in. at 28 day quality. The critical factor here is the strength required at release. To obtain a re-use of the steel moulds used, on a 24 hour basis, a strength of about 6,000 lb. per sq. in. must be reached in approximately 16 hours and this is done by using rapid hardening cement combined with steam curing.

Precast post-tensioned beams are generally used for the longer spans. The Tolka railway bridge was of this type and had a maximum span of 60 feet. The Shore Road bridge on the M2 motorway in Northern Ireland has precast post-tensioned beams for a 70 foot span. Beams of this size are difficult to transport and handle and on site precasting or sectional precasting should be considered for beams of this size.

The Cashen Ferry Bridge in Co. Kerry provides an interesting example of use of precast concrete piles and beams. Built in 1961, this bridge is 250 feet long and has five 50 foot spans. It was constructed using 16" x 16" precast piles of an average length of 45 feet in the piers and abutments. The piles were connected at their tops by an in situ pile cap which acted as a seating for the bridge beams. Thirty bridge beams each 50 ft. long and weighing about 10 tons each were handled by double slinging between a crane and the pile driver barge. The tops of the beams were castellated and had projecting hairpin bars for bonding with the in situ R.C. deck slab. The beams were cast on site and post-tensioned using the "Strabed" patented anchoring system for the 28 No. 9 mm. diameter wires used per beam.

C.I.E. have just completed a project at Rosslare Harbour (Fig. F2), where they have converted one of two rail tracks on the existing viaduct into a single lane roadway. This work was done in connection with the car ferry service which was opened there this summer. A simple and ingenious method was worked out for this conversion using composite

structural steel-concrete units. The largest units measure $10\frac{1}{2}$ feet by 20 feet and weigh about $8\frac{1}{2}$ tons. They consist of four 8" x 4" R.S.J. sections with a 7" thick deck slab cast on the top flanges and connected to them by means of welded studs. The total weight of the units is about 200 tons. They were cast in Dublin by C.I.E., transported by rail to Rosslare and brought directly on to the remaining track of the viaduct. A Smith 30 ton road crane lifted each unit off the train and placed it ahead of itself on the existing cross girders. Temporary connexions were made as the erection proceeded. The final connexion was made by using high strength friction grip bolts between the existing cross girders and the 8" x 4" sections of the composite unit. Joints between units were filled with in situ concrete and the kerbs were cast in situ to bars left projecting from the sides of the precast units.

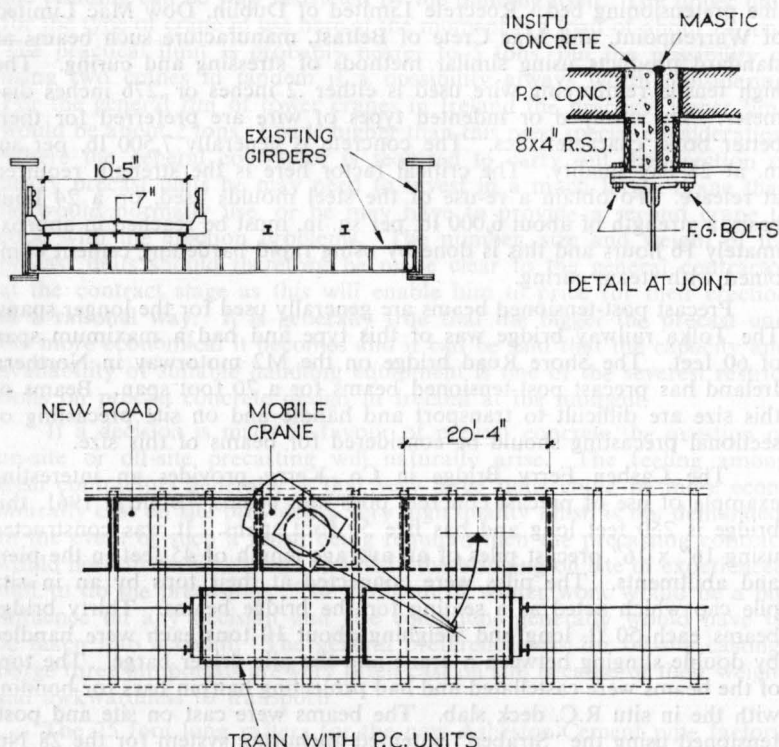


FIG F2. COMPOSITE CONSTRUCTION
—CARWAY AT ROSSLARE VIADUCT.

Piles

Precast concrete piles and sheet piling have been used since the late 1890's. They are generally used for bridge and jetty work where they

must compete with steel. For foundations to buildings it is difficult for them to compete in cost with the excavated cast-in-situ type of pile. Precast piles also suffer from the disadvantages of being heavy and difficult to handle. Transport is a problem and road routes have to be carefully surveyed when the piles being transported are very long. Nevertheless, in certain circumstances they prove to be the best type of pile and have been extensively used around the Belfast area. A contract for the foundations of the new Belfast abattoir has just been completed by Mac Crete Limited. This contract consisted of over one thousand piles, 14" x 14" and 16" x 16" in section and ranging from 80 to 90 feet in length. The largest piles weigh over 10 tons each. Dow Mac of Warrenpoint have supplied hundreds of similar sized piles 70' in length for the new Stormont Wharf at Belfast Harbour. This type of pile is also being used extensively for the foundations to the new Motorway bridges in the Belfast area. Interlocking concrete sheet piles have been used recently at the new Wexford bridge site. 500 piles ranging in length from 16 feet to 35 feet have been driven on this site. These sheet piles were manufactured by Rocrete at their works in Dublin and are prestressed and fitted with steel shoes.

Sleepers

30,000 prestressed concrete sleepers have been manufactured at C.I.E.'s Inchicore precasting yard. The German Dywidag system of prestressing is used for this type of sleeper. Two hairpin shaped $\frac{3}{4}$ " diameter high tensile bars are tensioned and anchored with nuts threaded on their ends. The concrete is gap graded and designed to achieve a strength of 8,500 lb. per sq. in. at 28 days. The sleepers are cast in individual moulds on a vibrating table, demoulded on to pallets and steam cured to a strength of 6,400 lb. per sq. in. in 24 hours. The pilot plant for making these sleepers was set up in 1956 to produce an experimental 500 sleepers per week.

Buildings

Precast concrete three-pin arches make convenient and economical structures and have been adapted successfully for churches, halls, gymnasias and factories. They have been used fairly extensively in Ireland since the early 1950's. The Jeyes factory at Finglas could serve as a typical example. This factory has 80 foot span arches at 20 feet centres and uses precast concrete purlins to span between each arch. The half arch at this span weighs about 9 tons. These arches are very convenient from the casting point of view as they can be cast flat, one on top of the other. This battery type casting effects a great saving in the cost of shuttering as only the narrow side of the units need to be shuttered and the unit previously cast acts as a bottom shutter. Lifting is the only big problem, as the units are weakest lying on their sides. Careful attention is therefore given to the slinging positions and the units are always reinforced to cater for the erection stresses.

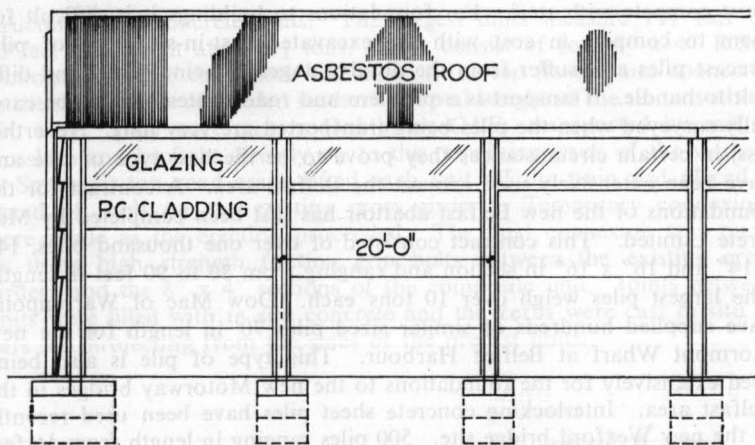


FIG. F3 (a). PART ELEVATION,
ASBESTOS CEMENT PIPE FACTORY,
DROGHEDA.

The new Asbestos Cement Pipes Limited factory at Drogheda has some very interesting precast concrete features (Figs. F3a and F3b). The main production area is 450 feet long x 81 feet wide and 34 feet to the eaves. The basic structure is a series of pitched portal frames at 25 feet centres. The vertical legs of the portals are cast in situ and designed as fixed ended. The rafter unit is a cranked beam 2' 6" deep x 1' 0" wide x 75 feet long and was precast in one piece.

Two Smith 21 cranes were used to lift the rafter which weighs about 12 tons. To prevent it spreading on its bearings at the tops of the columns a temporary prestressed tie was designed and stressed to a pull of 18,000 lb. The permanent connexion between the columns and the rafter was achieved by means of an in situ concrete joint using a high alumina cement. This joint was allowed to mature for two days before removing the temporary tie. The design called for full continuity between the rafter and the column. Another feature of this building was the large precast cladding panels used. The panels measure 25 feet long x 6 feet high. Each panel weighs about $4\frac{1}{2}$ tons and covers an area of 150 sq. feet. They rest one on top of the other with a weather boarding effect and are connected to the columns by bolts. Some idea of the scale of the units used can be gained by considering that the 14" x 10" precast purlins of which there are 22 per bay, each weigh about $\frac{1}{2}$ ton. The gutter beam which is cast in 25 feet lengths weighs nearly 3 tons while the gable bracing columns weigh up to 13 tons each. The large precast rafters were cast on site and the other units were cast at Dublin. The cost of a typical bay of this structure works out at just over 31/- per sq. foot. This includes a floor slab at 5/-, side cladding at 6/- and the roof clad-

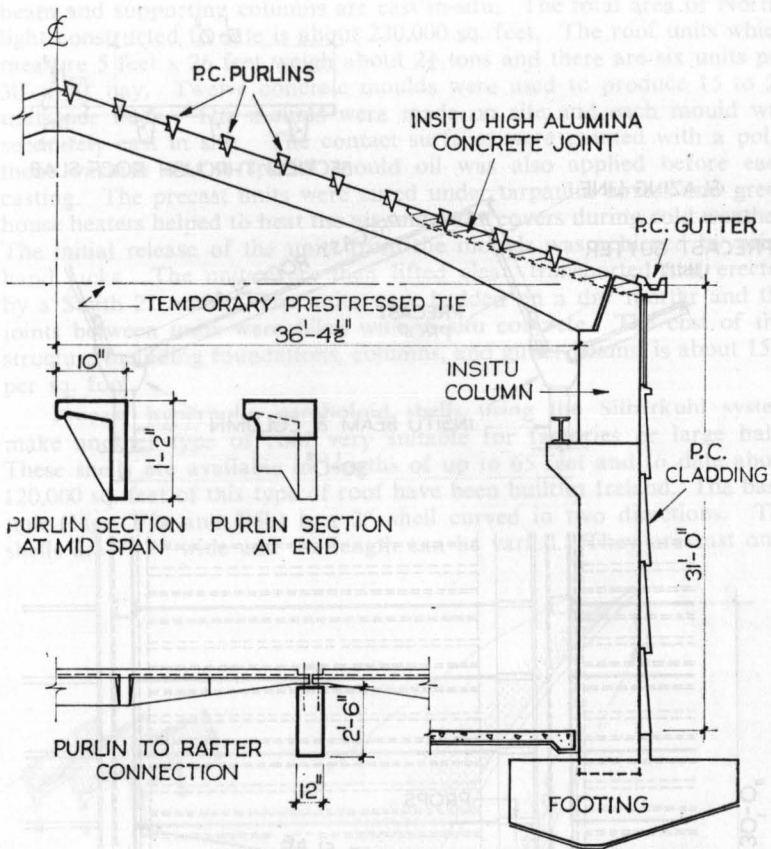


FIG. F3 (b). CROSS-SECTION,
ASBESTOS CEMENT PIPE FACTORY,
DROGHEDA.

ding at 5/-. The bases, frames, crane beams and purlins come to about 15/- per sq. foot. The cost of the side cladding would work out at about 12/6 per foot super. The costs are very reasonable when compared with structures of similar dimensions and the fabric of the building is of course maintenance free.

Fry Cadbury's factory at Coolock, Co. Dublin (Fig. F4) is a good example of on-site precasting on a large scale. This factory has been constructed in stages starting in 1954; stage 3 is being completed at the moment.

The factory area uses a form of precast Northlight consisting of a series of sloping precast slabs supported on precast props; the gutter

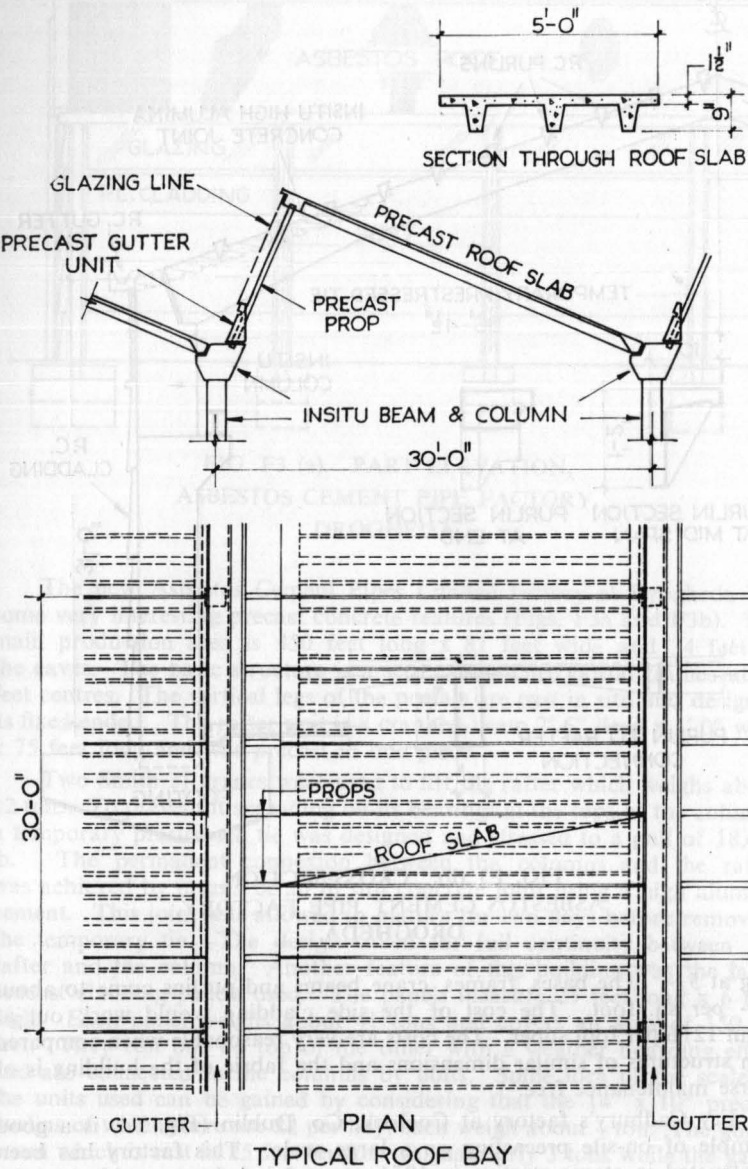


FIG. F4. FRY-CADBURY FACTORY,
COOLOCK.

beam and supporting columns are cast in-situ. The total area of North-light constructed to date is about 230,000 sq. feet. The roof units which measure 5 feet x 26 feet weigh about $2\frac{1}{4}$ tons and there are six units per 30' x 30' bay. Twelve concrete moulds were used to produce 15 to 20 units per week. The moulds were made on site and each mould was separately cast in situ. The contact surfaces were painted with a polythene varnish and a special mould oil was also applied before each casting. The precast units were cured under tarpaulin covers and green house heaters helped to heat the air under the covers during cold weather. The initial release of the units from the moulds was achieved by using hand jacks. The units were then lifted clear, transported and erected by a Smith 21 crane. The units were bedded on a dry mortar and the joints between units were filled with in situ concrete. The cost of this structure including foundations, columns, and gutter beams, is about 15/- per sq. foot.

Precast hyperbolic paraboloid shells using the Silberkuhl system make another type of roof very suitable for factories or large halls. These shells are available in lengths of up to 65 feet and to date about 120,000 sq. feet of this type of roof have been built in Ireland. The basic unit (Figs. F5a and F5b) is a 2" shell curved in two directions. The shells are 7' 7" wide and the length can be varied. They are cast on a

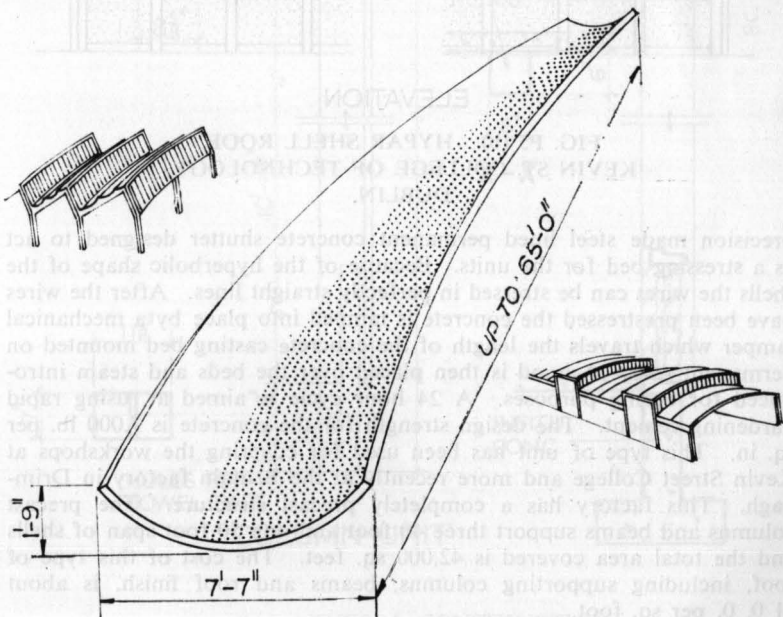


FIG. F 5 (a). TYPICAL HYPAR SHELL ROOF.

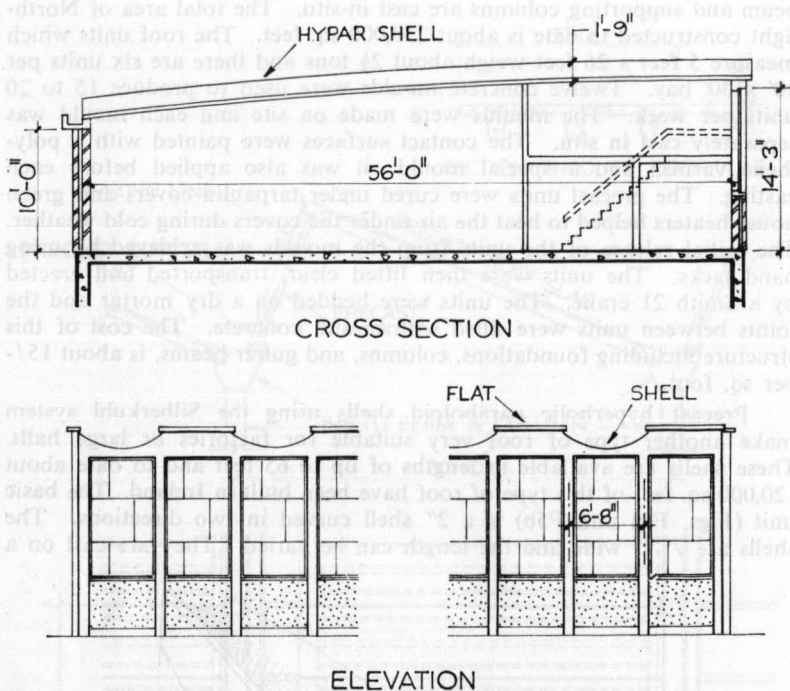


FIG. F5 (b). HYPAR SHELL ROOF,
KEVIN ST. COLLEGE OF TECHNOLOGY,
DUBLIN.

precision made steel lined permanent concrete shutter designed to act as a stressing bed for the units. Because of the hyperbolic shape of the shells the wires can be stressed in perfectly straight lines. After the wires have been prestressed the concrete is tamped into place by a mechanical tamper which travels the length of the concrete casting bed mounted on permanent rails. A hood is then placed over the beds and steam introduced for curing purposes. A 24 hour cycle is aimed at, using rapid hardening cement. The design strength for the concrete is 7,000 lb. per sq. in. This type of unit has been used for covering the workshops at Kevin Street College and more recently at the Brittain factory in Drimnagh. This factory has a completely precast structure. The precast columns and beams support three 40 foot and one 50 foot span of shells and the total area covered is 42,000 sq. feet. The cost of this type of roof, including supporting columns, beams and roof finish, is about £1 0. 0. per sq. foot.

A good example of composite precast/in situ construction is the new offices built for the Esso Company at Stillorgan Road (Fig. F6). The structure incorporates precast columns, precast rib stems and precast

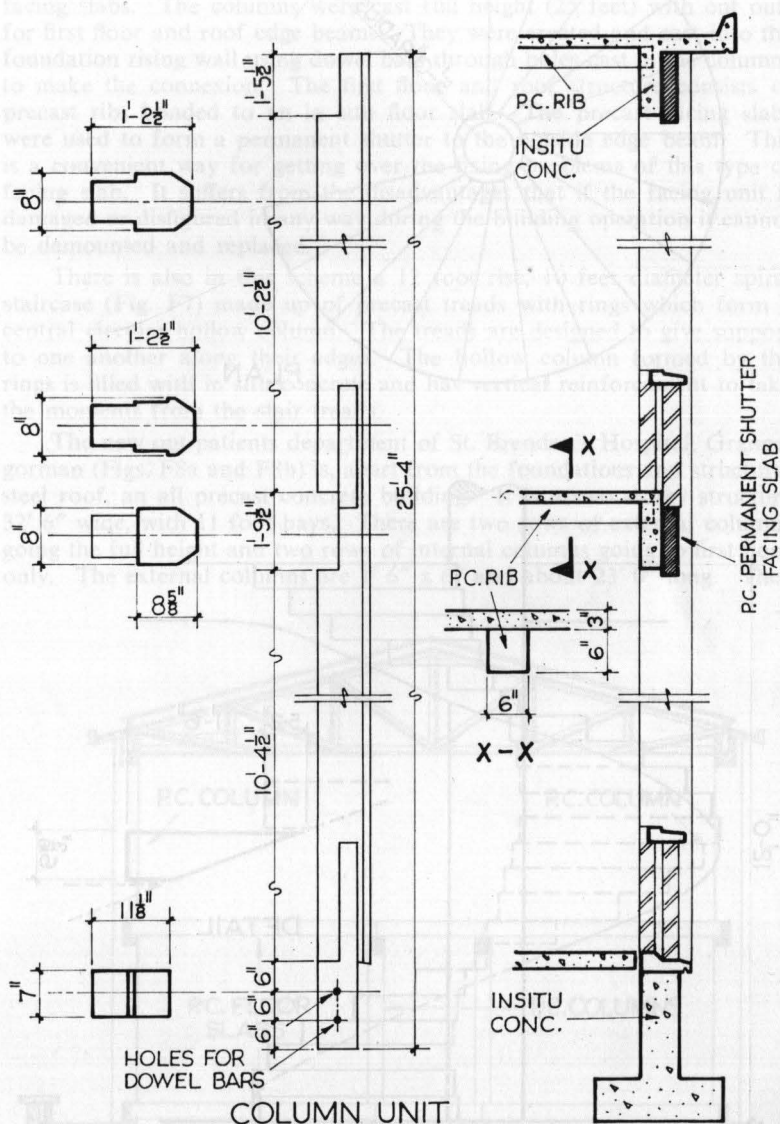
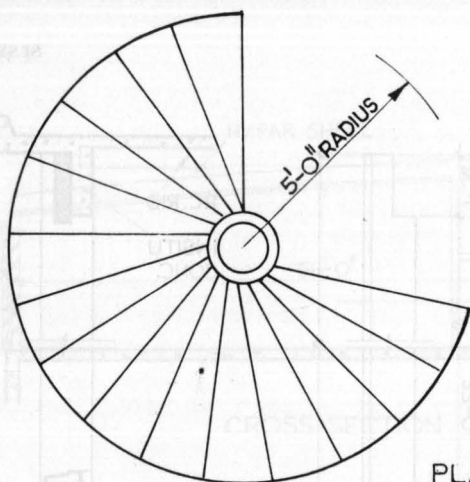
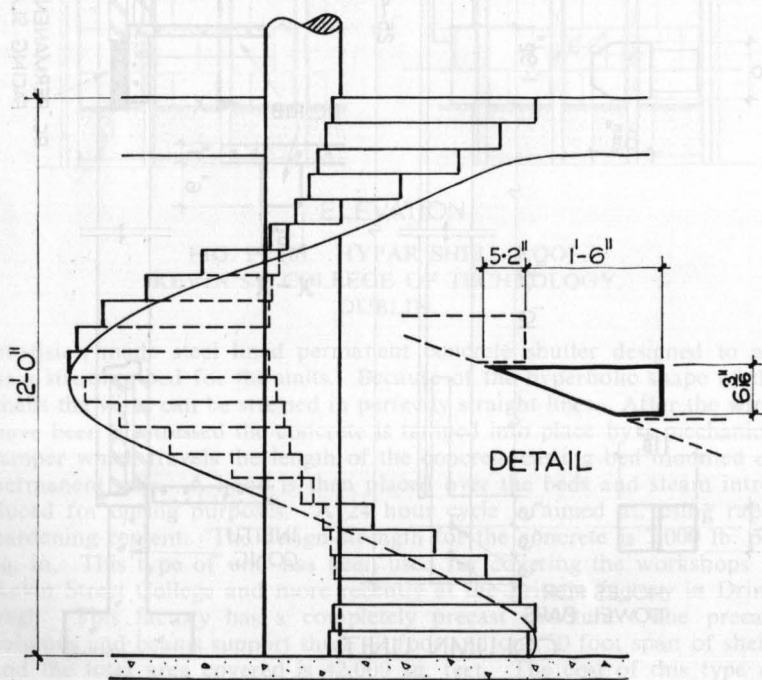


FIG. F6. GENERAL CONSTRUCTION,
ESSO OFFICE BLOCK,
STILLORGAN



PLAN



ELEVATION

FIG. F7. PRECAST STAIRWAY,
ESSO OFFICE BLOCK,
STILLORGAN.

facing slabs. The columns were cast full height (25 feet) with cut outs for first floor and roof edge beams. They were erected and cast into the foundation rising wall using dowel bars through holes cast in the columns to make the connexion. The first floor and roof structure consists of precast ribs bonded to an in situ floor slab. The precast facing slabs were used to form a permanent shutter to the outside edge beam. This is a convenient way for getting over the fixing problems of this type of facing slab. It suffers from the disadvantages that if the facing unit is damaged or disfigured in any way during the building operation it cannot be demounted and replaced.

There is also in this scheme a 12 foot rise, 10 feet diameter spiral staircase (Fig. F7) made up of precast treads with rings which form a central circular hollow column. The treads are designed to give support to one another along their edges. The hollow column formed by the rings is filled with in situ concrete and has vertical reinforcement to take the moments from the stair treads.

The new out-patients department of St. Brendan's Hospital, Grangegorman (Figs. F8a and F8b) is, apart from the foundations and structural steel roof, an all precast concrete building. It is a two storey structure 32' 6" wide, with 11 foot bays. There are two rows of external columns going the full height and two rows of internal columns going to first floor only. The external columns are 1' 6" x 6" and about 23' 0" long. They

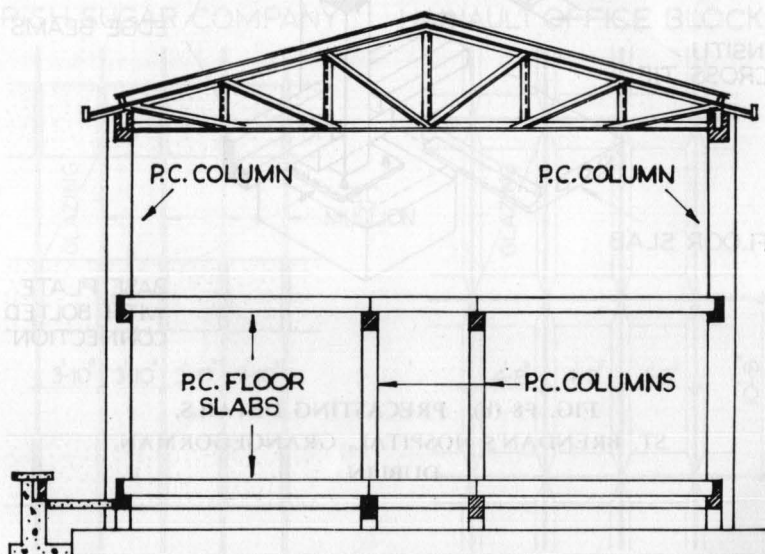


FIG. F8 (a). CROSS-SECTION,
ST. BRENDAN'S HOSPITAL, GRANGEGORMAN,
DUBLIN.

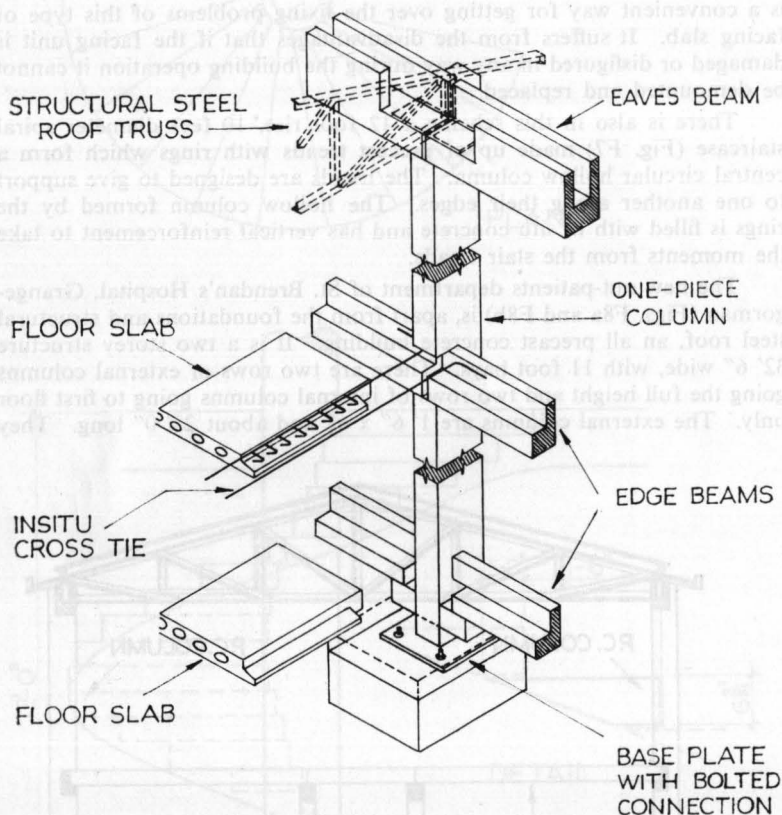
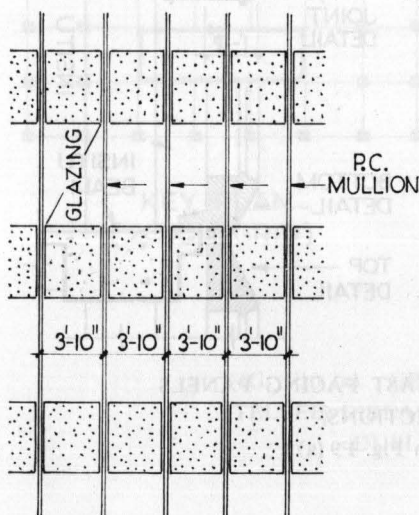


FIG. F8 (b). PRECASTING DETAILS,
ST. BRENDAN'S HOSPITAL, GRANGEGORMAN,
DUBLIN.

are fixed to the base by foundation bolts which connect to a steel base plate cast with the precast column. The precast longitudinal edge beams are seated on a notch cast into the column at first floor level and the internal longitudinal beams rest on the corridor columns. Precast floor plates 6' 6" x 13' span between these beams. The edges of the floor plates are formed to accommodate reinforcement for an in situ tie between the external columns. A precast U shaped eaves beam spans between the tops of the external columns and supports the intermediate roof trusses. This design has been very successful and a second stage is now being built.

The striking appearance of the Sugar Co. office block (Figs. F9a and F9b) owes much to precast concrete. Precast white concrete structural mullions 6" x 1' 6" at 3' 10" centres support the edges of the in situ concrete floors. The height of the columns is 10' 9" and they have a dowel connexion to the floor edge beam at the top and a simple mortar joint at the bottom so that they are in fact discontinuous. In between the mullions exposed aggregate spandrel panels about 3' 6" x 4' 6" deep are side fixed to the mullions. There are 564 precast mullions of 6 types and about the same number of spandrel panels. All the units are small and easily handled.

IRISH SUGAR COMPANY



HAINAULT OFFICE BLOCK

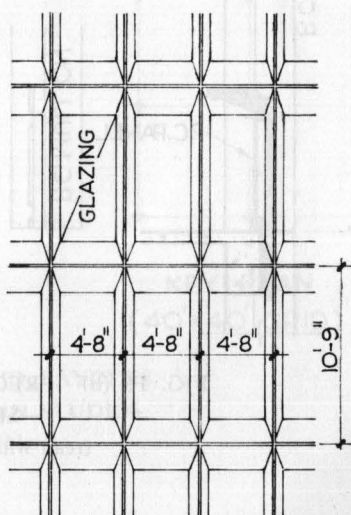


FIG. F9 (a). PRECAST FACING PANELS
—ELEVATIONS.

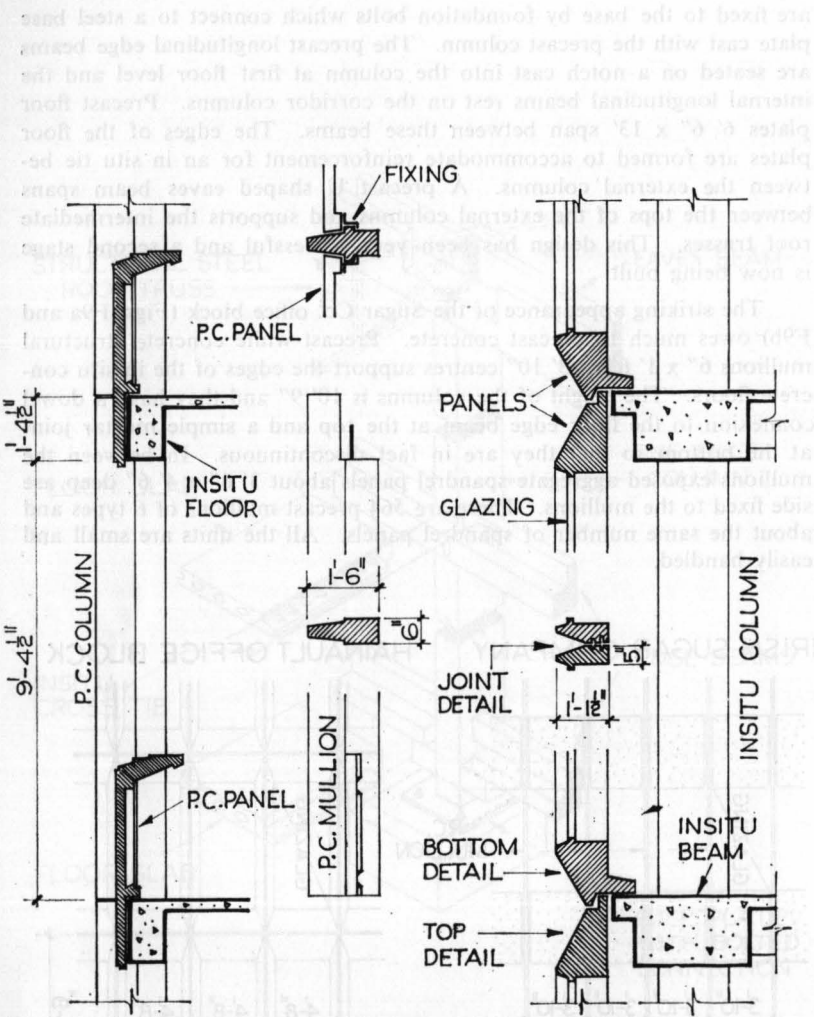
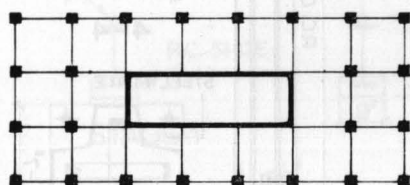
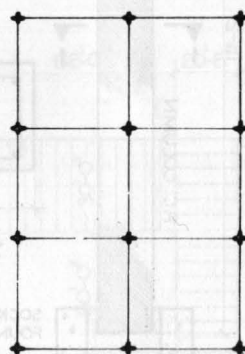


FIG. F9 (b) PRECAST FACING PANELS
—SECTIONS.
(read with Fig. F9 (a)).

Another example of composite construction is the new television building at Donnybrook (Figs. F10a and F10b). The second stage of construction is now proceeding and the design features precast columns used in conjunction with a flat slab in situ floor. The columns are 16" sq. in section and about 15' long. They weigh close on 2 tons each and are self-finished with an exposed aggregate surface. The columns are dropped into sockets in the foundations and grouted in using an expanding grout. The top projecting bars are designed to give a fully monolithic connexion to the in situ slab. The main problem with columns of this size and weight is handling. They have to be accurately plumbed, positioned and levelled before the floor slabs are cast and because they are self-finished slight errors cannot afterwards be rectified as with plastered columns.

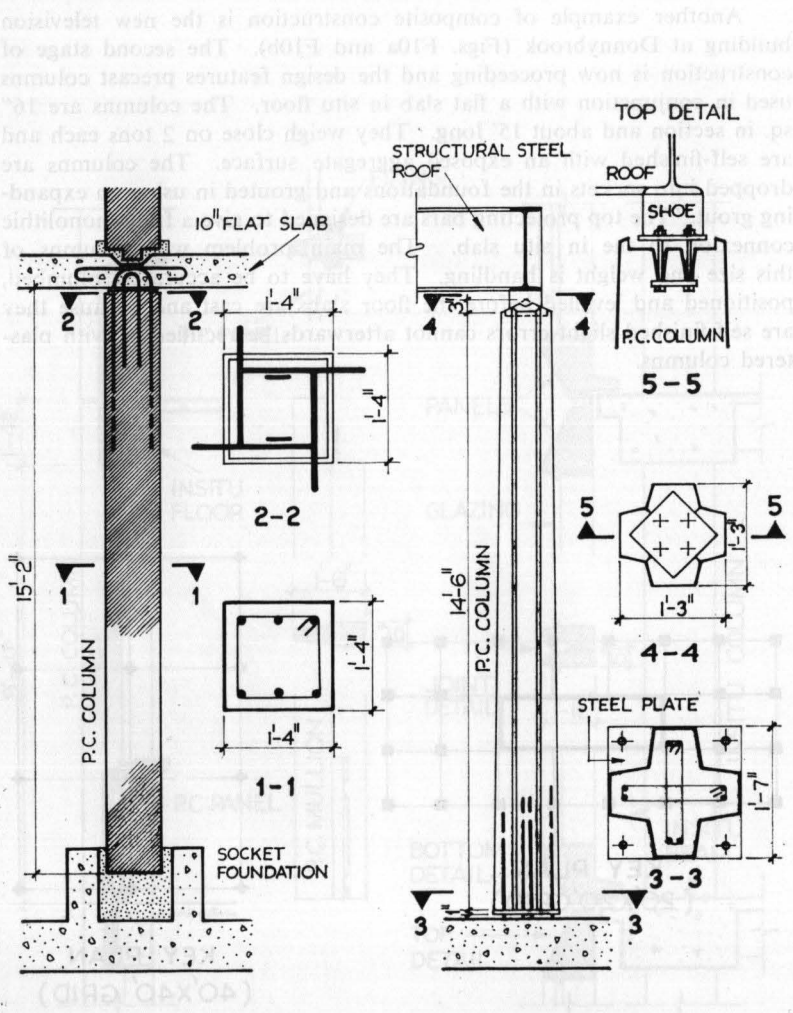


KEY PLAN
(20'X20' GRID)



KEY PLAN
(40'X40' GRID)

FIG. F10 (a). GRID LAYOUTS,
TELEFIS EIREANN STUDIOS,
DUBLIN.



OFFICE BLOCK CANTEEN

FIG. F10 (b). DETAILS,
TELEFIS EIREANN STUDIOS,
DUBLIN.

Mention has been made already about the use of precast permanent shuttering at the Esso Offices. This technique has also been used with success on the laboratory extensions at University College, Galway, and at Knockbeg College in Co. Carlow, mainly for architectural reasons. At the new Abbey Theatre, however, precast shutters were used for very different reasons (Fig. F11). The fourth floor in this building is 70 feet above the next floor below it, and to shutter this floor for in situ concrete would have involved a large volume of expensive scaffolding. The second factor involved was the crane capacity. This would have been inadequate to handle any suitable 30 foot long precast concrete beam. An R.S.J. could be handled at the radius required but would, of course, have to be encased for fire protection. To overcome these difficulties a small shoe was precast onto the bottom flange of a suitable R.S.J. which was then erected. Precast concrete shutters were then placed between each R.S.J. supported on each side by the precast shoe of the R.S.J. In situ concrete was then poured on to this shutter to complete the composite structural steel/precast/in situ concrete floor. This is an example of a situation where the crane capacity was the governing factor in the design of the various elements of the structure.

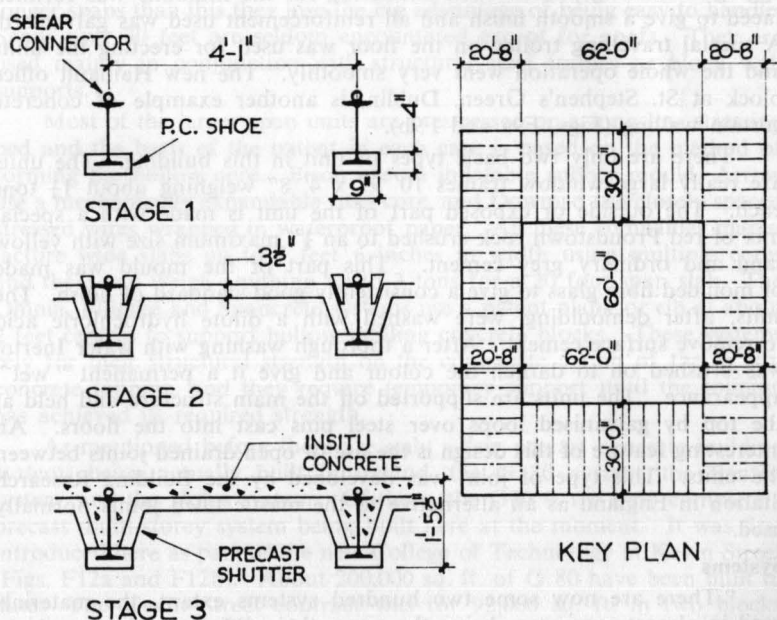


FIG. F11. PRECAST CONCRETE
PERMANENT SHUTTERS, ABBEY THEATRE,
DUBLIN.

Cladding

The aesthetic possibilities of precast concrete as a self-finished material in building is probably the aspect of it which has most excited the architectural profession. In some cases it forms part of the basic structure, in others, it is simply cladding or curtain walling material. The most spectacular example of the architectural use of precast concrete in recent years has been the new American Embassy. Shockbeton of Holland made the units which are of a very high standard of precasting. It is perhaps a reflection on the Irish precasting firms that this show-piece contract was allowed to go abroad. The building on the other hand serves as a useful standard for comparison with our own efforts in this field.

Some examples of cladding have been mentioned already in the Esso and Sugar Company buildings. The Intercontinental Hotel in Dublin may not be to everybody's taste as a building but it is certainly a pre-caster's dream. There are three types of cladding panel and only one type for the 279 spandrel units in this contract.

Cannock's store in Limerick has a non-structural precast concrete facade. This is made up of mullions in white concrete and exposed aggregate infilling panels. The shuttering for the mullions was formica faced to give a smooth finish and all reinforcement used was galvanised. A special travelling trolley on the floor was used for erecting the units and the whole operation went very smoothly. The new Hainault office block at St. Stephen's Green, Dublin, is another example of concrete curtain walling (Figs. F9a and F9b).

There are only two basic types of unit in this building. The units are really large window frames 10' 9" x 4' 8" weighing about 1½ tons each. The outside or exposed part of the unit is made with a special mix of red Proudstown rock crushed to an ½" maximum size with yellow sand and ordinary grey cement. This part of the mould was made of moulded fibre glass to give a consistently good standard of finish. The units, after demoulding, were washed with a dilute hydrochloric acid to remove surface cement. After a thorough washing with water Inertol was brushed on to darken the colour and give it a permanent "wet" appearance. The units are supported off the main structure and held at the top by galvanised loops over steel pins cast into the floors. An interesting feature of this design is the use of open drained joints between the units. This type of joint was developed by the Building Research Station in England as an alternative to the mastic filled joints normally used.

Systems

"There are now some two hundred systems extant, the materials used in almost every case being the same, their differences lying only in the details of their construction. The author ventures the hope that by the use of such constructions they will find the solution of many problems not so easily or cheaply solved by the ordinary methods." History certainly repeats itself. The above quotation is from a paper on rein-

forced concrete by Mr. A. R. Galbraith to the Institution of Civil Engineers of Ireland on the 2nd March, 1904. The situation with regard to system buildings as we know them to-day is equally confusing. There are now not less than 300 systems on the market in Britain alone. In Ireland there is only a small number of systems available and the size of the market here should tend to keep the number being used fairly small.

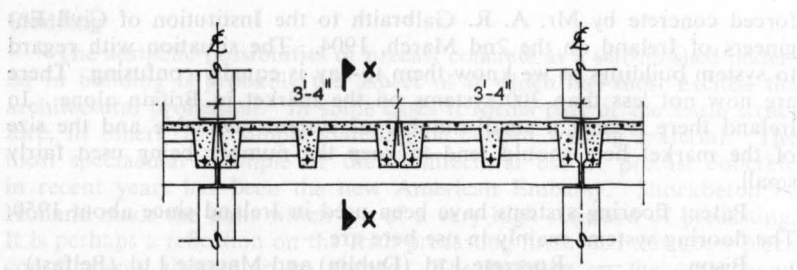
Patent flooring systems have been used in Ireland since about 1950. The flooring systems mainly in use here are :—

Bison	—	Roecrete Ltd. (Dublin) and Macrete Ltd. (Belfast)
Arrow	—	Riversdale Products (Killucan)
Dowmac	—	Dowmac Ltd. (Warrenpoint)
Omnia	—	Crestestone (Dublin)
Filigree	—	McGurk Concrete Ltd. (Dublin)
Spancrete	—	The Galway Tile Co. (Galway)

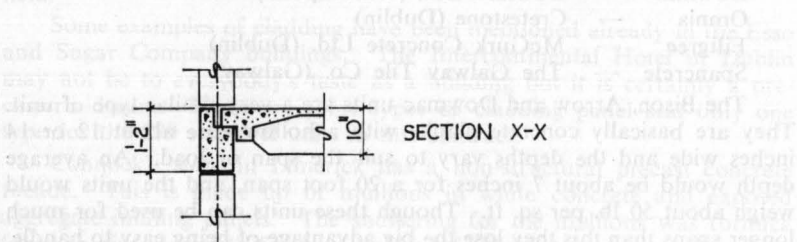
The Bison, Arrow and Dowmac units are a very similar type of unit. They are basically concrete planks with a hollow core about 12 or 14 inches wide and the depths vary to suit the span or load. An average depth would be about 7 inches for a 20 foot span, and the units would weigh about 50 lb. per sq. ft. Though these units can be used for much longer spans than this they lose the big advantage of being easy to handle. Spans over 30 feet are seldom encountered except for roofs. They are used mainly in conjunction with structural steel frames or block wall supports.

Most of the larger span units are prestressed on a long line stressing bed and the basis of the patent in each case is based on the method of forming the hollow core. Bison use an inflatable rubber mould, Arrow use a mechanically expandable steel core, and Dowmac use closely spaced stressed wires wrapped in waterproof paper. All these companies manufacture wide slabs up to 7 feet 6 inches in width using multiple cores and these can weigh anything up to 3 tons for a 20 foot span slab. The Omnia, Filigree and Spancrete systems use a patent plank or rib at about 2 feet centres to support hollow infilling concrete blocks. These systems rely for their structural strength on the composite action of the in situ concrete topping, and they require temporary support until the topping has achieved its required strength.

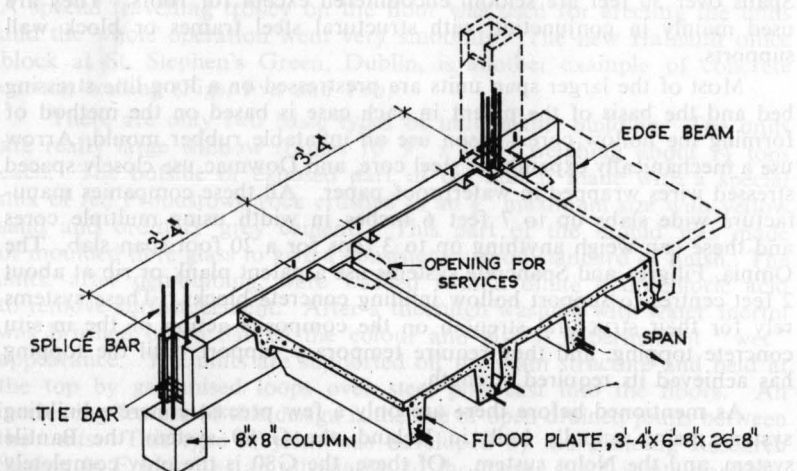
As mentioned before there are only a few precast concrete building systems being actually built in Ireland, the G 80 system, the Bantile system, and the Nolos system. Of these, the G80 is the only completely precast multi-storey system being built here at the moment. It was first introduced here as part of the new College of Technology at Kevin Street (Figs. F12a and F12b). About 200,000 sq. ft. of G 80 have been built to date. The Kevin Street contract was for 92,000 sq. ft. in two blocks five storeys high. The contract time for the erection was nine months and an extra tower crane was placed on site for erection purposes. The system is based on a 6' 8" module and the structure consists of rows of 8" x 8" columns at 6' 8" centres, supporting edge beams and corridor beams. These beams in turn support the ribbed floor plates 3' 4" wide



CROSS SECTION THRO' FLOOR PLATES



SECTION X-X

FIG. F12 (a). G80 SYSTEM
TYPICAL DETAILS.

by 10" deep which span up to 26' 8" in multiples of 3' 4". Connexions are made by means of projecting reinforcement from beams and slabs with in situ concrete. The column connexion is achieved by grouting the projecting bars from the column below in the socket cast into the

next column above. A series of adjustable raking props is used to brace each floor as it is being erected and grouted. The concrete quality for the units and the grouting is 6,000 lb. per sq. in. at 28 days.

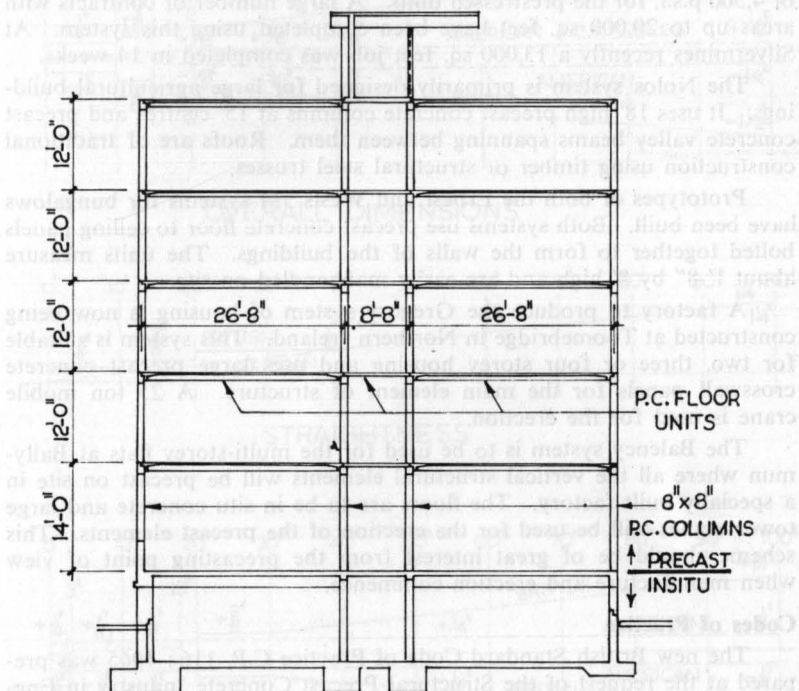


FIG. F12 (b). G80 SYSTEM,
TYPICAL CROSS-SECTION,
KEVIN ST. COLLEGE OF TECHNOLOGY,
DUBLIN.

The Bantile system is confined to single storey buildings and based on the use of a precast concrete pitched arch. Precast concrete walling panels are used between frames; the roofing and other elements are carried out in the traditional manner. Two basic units, a column or post unit and a rafter unit comprise the arch. The columns are 7" x 5" reinforced or prestressed, spaced 6' 6" apart and cast into in situ concrete footings. The rafters are bolted to the columns and pin jointed at the apex.

The maximum span available at the moment is 32' 6". There is a range of 1' high or 2' high walling panels available and these are simply dropped into slots cast into the sides of the posts. The units never exceed

7 cwts. in weight and rafters are simply erected by tractor with an extended 20' jib. The larger units are prestressed. Rapid hardening cement is used and the concrete is vibrated using an external vibrator. All units are steam cured to achieve a 24 hour casting cycle and a release strength of 4,500 p.s.i. for the prestressed units. A large number of contracts with areas up to 20,000 sq. feet have been completed using this system. At Silvermines recently a 13,000 sq. feet job was completed in 14 weeks.

The Nolos system is primarily designed for large agricultural buildings. It uses 18' high precast concrete columns at 15' centres and precast concrete valley beams spanning between them. Roofs are of traditional construction using timber or structural steel trusses.

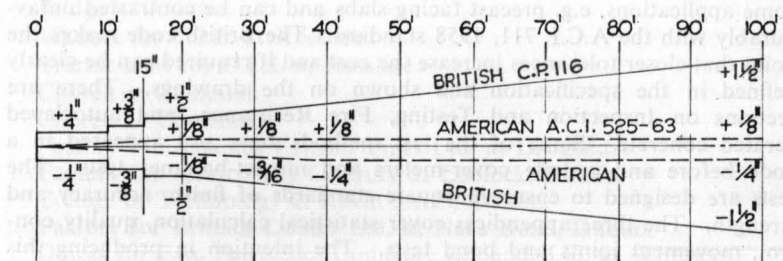
Prototypes of both the Erbest and Wests 5M systems for bungalows have been built. Both systems use precast concrete floor to ceiling panels bolted together to form the walls of the buildings. The units measure about 1' 8" by 8' high and are easily manhandled on site.

A factory to produce the Gregory system of housing is now being constructed at Toomebridge in Northern Ireland. This system is suitable for two, three or four storey housing and uses large precast concrete crosswall panels for the main element of structure. A 25 ton mobile crane is used for the erection.

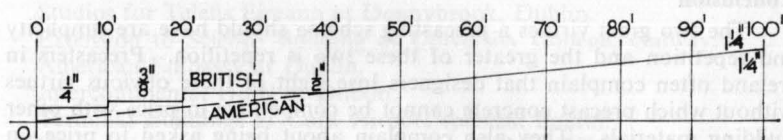
The Balency system is to be used for the multi-storey flats at Ballymun where all the vertical structural elements will be precast on site in a specially built factory. The floors are to be in situ concrete and large tower cranes will be used for the erection of the precast elements. This scheme should be of great interest from the precasting point of view when manufacture and erection commence.

Codes of Practice

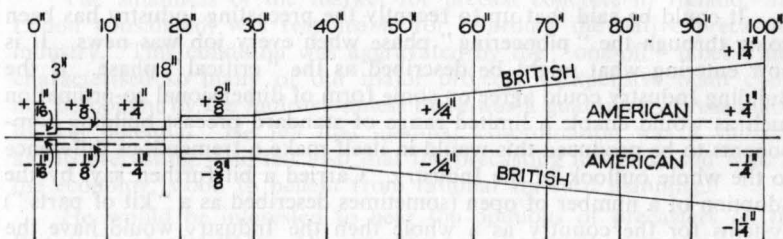
The new British Standard Code of Practice C.P. 116 : 1965 was prepared at the request of the Structural Precast Concrete Industry in England who had long felt the need for such a code. The code extends its recommendations to every aspect of the structural use of precast concrete and puts great emphasis on quality control through all stages of the manufacturing cycle. The code has not been closely studied by the industry here as yet and the general attitude to it was cautious or non-committal. Whether it should be incorporated in specifications in much the same manner as C.P. 114, and C.P. 115, will have to be considered by the designers here. The code has been drafted on the assumption that the process of design and manufacture would be under the overall control of a fully qualified and experienced engineer and is designed for his guidance. The code is divided into eight sections with three appendices. The Materials and Design Sections incorporate much of C.P. 114 and C.P. 115. High alumina cement is permitted and there is a separate section allotted to its use. A feature of the materials section is the new recommendations on cover which takes into consideration the factors of environment and grade of concrete used. The section on workmanship is likely to start some arguments. An attempt is made to codify surface finishes, and tolerances for precast units are recommended (Fig. F13).



OVERALL DIMENSIONS



STRAIGHTNESS



CROSS-SECTIONAL DIMENSIONS

BRITISH STANDARD CODE OF PRACTICE
C.P. 116, 1965

A.C.I. STANDARD FOR THIN SECTION P.C.
CONCRETE (A.C.I. 525-63)

FIG. F13. RECOMMENDED TOLERANCES
FOR PRECAST MEMBERS.

Some designers feel that the tolerances recommended are too large for some applications, e.g. precast facing slabs and can be contrasted unfavourably with the A.C.I. 711, 1958 standard. The British code makes the point that closer tolerances increase the cost and if required can be clearly defined in the specification and shown on the drawings. There are sections on Inspection and Testing, Fire Resistance, and autoclaved aerated concrete. Some of the test methods have not appeared in a code before and include cover-meters and impact-hammer tests. The tests are designed to ensure adequate standards of finish, accuracy and strength. The three appendices cover statistical calculation, quality control, movement joints and bond tests. The intention in producing this code is that it should become the manufacturers' bible. Whether it will be adopted as such in Ireland remains to be seen.

Conclusion

The two great virtues a precasting scheme should have are simplicity and repetition and the greater of these two is repetition. Precasters in Ireland often complain that designers lose sight of these obvious virtues without which precast concrete cannot be competitive in price with other building materials. They also complain about being asked to price on the basis of "typical" details which tend to become less and less typical as the job progresses. There is one case recorded where in a contract valued at about £15,000, the number of different types of unit rose to over 100.

It could be said that up to recently the precasting industry has been going through the "pioneering" phase when every job was news. It is now entering what might be described as the "critical" phase. If the Building Industry could agree on some form of dimensional co-ordination such as would enable a limited range of standard precast building components to be produced this would in itself make a tremendous difference to the whole outlook of the Industry. Carried a bit further, say, by the adoption of a number of open (sometimes described as a "kit of parts") systems for the country as a whole then the Industry would have the guarantee of a continuous demand for the product over the years which is the most essential element at present lacking. Until such forward planning is a reality in Ireland it is difficult to visualise or predict what the future of the industry is likely to be. One can only hope that these favourable circumstances will eventually come about and that the full potentialities of this new material will in time reach the stage of development in Ireland that has already been achieved in other countries.

Discussion

MR. LYDON introduced his paper.

He showed seventy-two slides illustrating systems, details of precast concrete construction, and completed buildings, following generally the sequence of his paper. The examples of completed work were as follows:

Footbridge at Mizen Head.

Mr. Price's prestressed bridge at Poyntzpass (drawing).
 Bridge at Avoca.
 Viaduct for C.I.E. at Rosslare.
 Transit shed for C.I.E. at Rosslare.
 Church at Coilldubh.
 Church at Cootehill.
 Factory for Asbestos Cement Pipes Ltd. at Drogheda.
 Factory for Messrs. Fry-Cadbury at Coolock, Dublin.
 College of Technology at Kevin Street, Dublin.
 Factory for Brittain Dublin Ltd. at Naas Road, Dublin.
 Offices for Esso Petroleum Company (Ireland) Ltd. at Stillorgan.
 Dormitory Block at St. Brendan's Hospital, Dublin.
 Offices for Comhlucht Siuicre Eireann Teo. at Dublin.
 Office Block for Hainault Investments Limited at Dublin.
 Studios for Telefis Eireann at Donnybrook, Dublin.
 Extension to Science Building at University College, Galway.
 American Embassy at Dublin.
 Intercontinental Hotel at Dublin.
 Terminal Buildings at Cork Airport (precast floors).
 Williams' Supermarket at Clonkeen Rd., Dublin (38' 0" long roof units).
 Typical Bantile system buildings.
 Typical Nolos system buildings.
 School at Ballyfermot, Dublin.

The smallness of the market for precast concrete in Ireland, Mr. Lydon considered, was responsible for retarding the native precasting industry. This condition was aggravated by the "one-off" label which characterised so many of our major projects. Expensive plant could not be bought by the industry unless there was a guarantee of reasonable market potential. He felt that modular co-ordination was a valuable aid to precasting. He felt also that the precasting industry, and with it, the economy, stood to benefit from rational forward planning.

He would be interested to hear the opinions of precasters on the British Standard CP116. He considered it as virtually a manufacturer's handbook, to be used where the manufacturing processes were controlled throughout by qualified engineers. The section on tolerance was, he felt, particularly worth discussing, both for its own content and as a comparison with the rather more exacting American demands in this aspect. In his opinion, the British tolerances were too large.

MR. D. MacGREEVY, chairman of the Building Advisory Council, opened the discussion. He dealt with the significance of precast concrete against the background of the constant pressure on governments for low cost housing, schools, and other social buildings. The building industry, whose direct responsibility this was, had while meeting the demand, to take into account the necessity of better conditions of employment for labour. The cost of skilled labour demanded that it be used intensively where needed, and with minimum waste. The hazards attending traditional site operations were to be avoided. These consider-

ations, inter alia, led to the present tendencies of concentrating skilled labour in offsite production, and of seeing site work in terms of mechanization and unskilled labour, with a maximum reduction of wet trades above damp-proof course level.

Where the size of a project justified the use of industrialized building methods, there would obviously be competition for supremacy between the traditional and newer materials, between steel, aluminium, timber, and the cement products. This contest would be complicated by the existence of both open systems, and closed systems backed by their sponsors' claims. He felt that the enterprise and initiative of the promoters of a closed system were sometimes more compelling in the adoption of a particular system than the superiority of that system to its rivals. His comment could apply, more generally, towards materials also, and some people believed that what he might call the cement lobby was at present the most successful in this matter.

Industrialized building was by no means new but he considered, that in the light of the present world population explosion and the tremendous increases current in the rate of scientific progress, it was still in its infancy. Modular co-ordination would play a large part in the development of new methods, and must be considered as an instrument of prime importance in the progress of architectural design. The tributes paid by various foreign delegates at the CIB congress on industrialized building, held in Copenhagen in the summer, to Irish initiative on modular co-ordination had been gratifying. The present Symposium offered an opportunity to congratulate An Foras Forbartha on their work in this field.

The development of precast concrete appeared inevitable, especially in the light of the high standard of Irish cement. He felt prompted, however, as a layman, to question the merits of concrete vis-a-vis other materials in such matters as durability and structural stability. He, in his work as a quantity surveyor, was familiar with the problems of demolition which sometimes arose in clearing sites, and had heard some startling accounts of reinforcing bars being removed from old concrete as a powder. He asked what life span might be assumed for a reinforced concrete structure in Ireland, where, as he said, it sometimes rained, and he questioned as a layman the prudence of assuming that concrete specified to be waterproof would in fact be waterproof. He wondered whether reinforcement always had to be steel; and whether useful research might not be made into the use of a material such as high tensile plastic wire.

He felt that, in the context of the national building programme, it was essential that the country should be free to question methods and materials and, where necessary, to change an opinion without loss of face. Mr. Lydon's paper, by its excellence, stated a strong case for concrete, but it could be most revealing to hear an equally clear paper from him on the essential qualities, and the advantages and disadvantages of reinforced concrete as a structural medium.

One must commend his emphasis on the importance of simplicity

and repetition in design. If designers did not submit to that obvious discipline, there was a real danger that their work would not only inhibit but bring discredit to the growth of industrialization. He considered that it was essential for progress in building that all connected with it should realise that the divorce between design and construction which had characterised the main bulk of architecture since the Renaissance was intolerable, to the point of criminality, in terms of contemporary building and our economy.

MR. J. McCULLOUGH complimented Mr. Lydon on his paper and more generally on his contribution through his work to the development of precast concrete in Ireland.

Mr. McCullough was particularly interested in the problems of high-rise housing. In so far as they were precast concrete structures, they should be governed, if British standard practice was being followed, by CP116. However, it was customary practice in the design of load bearing reinforced concrete walls, and European experience, particularly in France and Denmark, justified this, to use much less reinforcement than the minimum required by either CP116 or CP114. In fact these walls were virtually unreinforced. As such, the design criteria of CP111 : Structural Recommendations for Load-bearing Walls had perforce to be adopted. This was, to him, an anomaly, which should be corrected by amending CP116 to include direct recommendations for walls of this type.

He regarded the section of CP116 on the treatment of joints, possibly the most difficult aspect of design, as too sketchy. Research was needed into the weather-proofing of joints in precast multi-storey buildings. The open-drain joint was used in many systems, sometimes with a mastic sealer. He felt that the reliability of the sealer could not easily be established. The height of the upstanding edge of the walling unit was another point of controversy. One had to steer between the danger of leakage with an upstand too low, and the risk of damage to the unit in handling, with an upstand higher and therefore more fragile. This problem was being examined on the Ballymun project, in two ways. A full scale comparison was being made between weather conditions at Ballymun, and those at Nantes, in France, where high-rise blocks of the Balency type being used at Ballymun were already in use. Also, model tests under simulated conditions of wind-blown rain were being arranged.

Mr. McCullough, although agreeing with Mr. MacGreevy that concrete should not be awarded an uninvestigated monopoly for low-cost housing, observed that in his opinion there was no doubt that concrete was, at the present time, the most likely material for all main vertical structural surfaces in this type of work; all the main systems at present were, he said, based on structural concrete.

It appeared clear, however, that schemes justifying the use of elaborate closed systems, and he would place the minimum size of such schemes at about half the size of the Ballymun project, were most unlikely to be numerous in Ireland. For this reason, one might expect the progress of industrialized building in this country to be based on the development

of a modular system of small units, amenable to many different arrangements. He saw the necessity in this of an agreed system of modular co-ordination and a nationally-agreed and rational code of bye-laws. The unit system was, he felt, applicable either to skeletons or to whole buildings, and even to foundations.

The Balency system which was being used in Ballymun was unusual in two respects. The floors were all cast in situ, and all the walls, both back and front as well as cross walls, were structural. The use of in-situ floors permitted greater planning flexibility, reduced the difficulty of joints and made the structure more monolithic, took up tolerances, reduced floor reinforcement, facilitated services, and, perhaps most important, reduced transport costs. Precast floor units were usually the heaviest single components. It had to be accepted that the use of structural concrete for front and back walls limited the architect's choice of elevational treatment. It was not normal in the Balency system to use non-structural infilling panels.

Mr. McCullough felt that Mr. Lydon should possibly have qualified his statement that the Ballymun units were being made on the site. In fact, the road transport and handling necessitated in moving the units from the stockyard to the building sites proper introduced costs which the precise connotation of "on site" might preclude.

MR. A. D. H. MARTIN, while deprecating the introduction of further comment on the Kish Bank lighthouse, felt that, in that project, which he would regard as in-situ, there had been a use of precast concrete which deserved mention. At first, it was intended to construct the helicopter platform and its supports in structural steel. He had, himself, considered the provision of that platform as important, as he thought that helicopters would, at some future time, be in general use in the lighthouse service. However, he was not prepared to accept a Heath Robinson affair of angle iron. The platform was above the lantern and the supports were short, the lantern being only about 4' 6" high, but it was important that they obstruct the light as little as possible. Accordingly a system of 18" x 4" wide reinforced concrete mullions was devised. The 4" dimension represented minimal light obstruction, and the fact that the group of mullions were around the periphery of a circle ensured the rigidity of the platform structure. The contractor, however, recognized that in-situ casting of these columns with top and bottom haunches would be slow, and it was decided that the units be precast. This was done and they were then bolted to the circular shuttering while the sill and head of the lantern opening were concreted, thus tying them into the rest of the structure. The precasting saved probably two to three weeks construction time.

Mr. Martin said that he had been asked about the days' work joints on this project, particularly the underwater joints. These were very carefully made but quite simple. The face of the concrete joint was brushed immediately on stripping, and the surface was later chipped with

a chipping hammer before it became too hard. Waterbars were not used. There had been no leaking.

MR. B. Le C. BYRNE gave some particulars of the policy followed in his firm on the jointing of precast members. Generally they preferred in-situ concrete joints to mechanical connexions. They liked to use in-situ concrete packing when fixing precast columns on in-situ foundations, and favoured the use of an expanding agent in the packing. They were at present examining the use of epoxy resin-based adhesives for scarfed joint connexions in portal frames. Mr. Byrne felt that university laboratory and testing facilities should be used to pursue research in this field of jointing for precast members.

In answer to a comment made by Mr. Lydon, he said that his firm worked very closely along the lines of CP116, and found no difficulty in meeting the tolerances suggested in that code.

Mr. MacGreevy had mentioned the importance of repetition in economic precasting. What would he think of a recent project, costing approximately £15,000 which had 185 different types of unit in it? Design of this kind did not provide much scope for industrialisation.

Referring to another comment of Mr. MacGreevy, Mr. Byrne gave it as his opinion that the durability of concrete structures depended on the quality of the concrete and the cover to the reinforcement. It should be the precaster's aim to provide concrete of the highest quality and reinforcement placed with factory precision.

MR. J. R. McDOWELL stressed the significance of skilful detailing in precast concrete. Careful, well thought-out details with ample repetition were in his opinion even more important than modular co-ordination for the advance of the precast concrete industry. Good details enhanced the durability of the structure through the provision of crack-free joints, and the exclusion of water. Careful consideration of mechanical fixings, where used, could reduce the overall cost of the precast units greatly, as the cost of even the simplest painted steel fixing, was a significant proportion of the total cost of the unit. He felt it was important to remember the isolation of the precast concrete innovator. He could not, as in the days of the traditional trades, rely on a skilled carpenter or bricklayer for a knowledgeable interpretation of his details. Precast concrete details had to be explicit and the manufacturer could offer no more help to the designer than to follow them precisely.

Mr. McDowell considered that the position in Ireland as regards craneage was satisfactory for units weighing up to 10 tons, and particularly when the unit weight did not exceed 5 tons. The position was not so favourable where transport was concerned. A contractor's own fleet of lorries might be too small to handle, sufficiently quickly, the units for a large project, and in comparison with other countries, the facilities for hiring carriers at economic rates were very poor in Ireland. There could be no question here, as in other countries, of a precaster sub-contracting all his transport work to a haulier.

Finally regarding high strength concrete and the attendant problem of deflexion of slender members, Mr. McDowell felt that there was a definite need in Ireland for research into actual E-values for high strength concrete made from Irish cement and aggregates.

MR. LYDON replied to the discussion.

Mr. MacGreevy had mentioned the desirability of experimenting with materials other than concrete. Mr. Lydon agreed with Mr. McCullough in this matter. Concrete was obviously our best material and we had not explored its possibilities fully yet. Until we had, and unless a patently superior material appeared (and he did not know of any at present) we should continue to concentrate on concrete.

Mr. Lydon felt that private firms or enterprises introducing, as it were, package systems were to be commended on their initiative. He frankly felt that the development of a new system, flexible and economic, was outside the normal financial scope of a consulting engineer, and the entry of manufacturers into this field was to be welcomed.

He wondered whether Mr. McCullough's comments about the defects in CP114 and CP116 might not be met, by recognising the codes mainly as guides to good practice, and not binding on an engineer who was satisfied from his own experience to design outside their limitations.

He agreed that the joints were the crucial parts of a precast concrete design. He might add that the exigencies of meeting both the architect's requirements and the architectural requirements (it was accepted that they sometimes coincided) frequently made the joint design even harder.

Regarding the watertightness of the Balency panels, he doubted that French conditions of wind-driven rain would be so serious as those in Ireland, in particular in the west of Ireland. It was significant that when the British Building Research Station wanted to test their open-draining joints, they had chosen the north of Scotland as a site for their experimental station. They had found there that a 3" upstand was adequate.

Mr. Lydon agreed with Mr. McCullough that our precasting policy should move towards smaller units within a modular system. A code of practice or an agreed set of regulations for the whole country would greatly aid this development. It would enable the precasting firms to plan against perhaps a seasonal cycle of stockpiling and delivering, the market being assured. One might quote as a parallel the brick industry in Britain.

The Balency system had great merit in its solution of many jointing problems through the use of in-situ floors. The use of in-situ concrete in a system did, however, draw one's attention back to "traditional" in-situ construction. With the current use of stronger steels and concretes, and the rationalisation of design and detail, reinforced concrete in Ireland could compete for speed with industrialised building methods. In a recent multi-storey project on which his firm and Mr. McIlvenna's organisation had worked in Dublin, the floors had been built at a rate of 15,000 square feet per fortnight (10 working days), including the

columns and walls, and the whole of this work had been in-situ. Such achievements as this were bound to influence adversely the development of precast concrete in Ireland.

Mr. Lydon noticed that Mr. Martin regarded the main structure of the Kish Bank lighthouse as an in-situ job. He, Mr. Lydon, still considered it as precast.

Nevertheless, he did trust it was still in-situ!

He was interested in Mr. Byrne's investigations on jointing and the proposal to examine the use of epoxy resin. The elimination of bars and bolts made this idea very tempting, but he personally would remain uncertain about epoxy resin until serious research into the long-term behaviour of joints made with it had proved its merit. He agreed with the necessity of developing our own research establishments to handle this matter.

In the inauguration of research programmes, and in the vital importance of good detail, he concurred also with Mr. McDowell. Rational design and clear unambiguous details were essential for precast concrete.

SESSION G

CONCRETE AS A FINISHED SURFACE

T. M. DUGGAN, B.E., A.M.I.C.E.I. A.M.Inst., H.E.

Cement Limited

Sessional Chairman :

PROFESSOR D. FITZGERALD, B.Arch., F.R.I.A.I., A.R.I.B.A.

Introduction

The term "architectural in situ concrete" in this report is defined as concrete construction where surface appearance was the subject of conscious effort; it does not include structural concrete designed to fulfil purely functional requirements, even though this may be incidentally exposed.

Facing facts squarely, one can see that only a small quantity of in situ architectural concrete has so far been carried out in this country. Furthermore, even within the limited number of jobs completed, few can be said to be fully satisfying from the appearance point of view. The vast majority are, at the best, successful only to a limited extent, and a large percentage can only be classified as bad. This, of course, does not include the many camouflaged jobs where the initial specifications have been "adjusted," so that the hardened concrete is now (mercifully) hidden behind the traditional plaster or dash.

The most regrettable aspect of many of the in situ failures is that genuine efforts were made to obtain good results. Unfortunately, most of these efforts apparently lacked all appreciation of the special problems involved in obtaining blemish-free surfaces and were probably doomed to failure from the start. This is not intended as a comprehensive condemnation of all work so far carried out; it simply summarises a position where the small number who know what they are doing have shown good results, while the vast majority have failed to varying degrees.

While it may be unfair to focus on a small number of jobs, one must nevertheless reach conclusions on the state of development of architectural concrete in this country. It is hoped that the brief comments given below will summarise the main techniques so far used in in situ concrete.

The office block for Bord Failte in Baggot Street, Dublin is essentially a fully-exposed in situ reinforced concrete frame, with concrete brick in-fill. It is probably the first example of concerted effort in this country by architect, consultant engineer and contractor to produce fair-

faced concrete. Inspection of the work in 1965 clearly shows that the efforts made some five years ago were rewarded by results.

$\frac{3}{4}$ in. mahogany plyform moulds treated with a water-in-oil emulsion were used and great care was taken to eliminate grout leakage. This was almost successful in the columns where adjoining shutter faces were rebated as well as clamped. On the beam soffits no rebated detail was included at the sides; instead the side shutters were bedded in a mastic compound. While no leakage of grout was noted during placing, the appearance of the concrete on hardening suggests that in almost all cases slight loss of mortar did occur at the lower arris and that premature drying of the concrete may have occurred at this point. This has rather spoiled the otherwise good appearance.

The concrete mix used contained a higher than average proportion of fine material and included an air-entraining additive.

A factory for Messrs. Hallmark Cards (Ireland) Limited completed some two years ago features extensive use of preplaced in situ exposed aggregate concrete. The technique was in fact developed as the result of close co-operation between architect and contractor on the job. Basically the procedure was as follows: standard steel wall shutters were filled with $1\frac{1}{2}$ in. to 3 in. aggregate with a small proportion of hand-placed plums of up to 10 in. maximum size. The material was compacted with immersion-type vibrators and subsequently grouted through feed-pipes spaced at 3 ft. c/c vertically in the aggregate. A 2:1 sand/cement grout was used and no additives were included. The forms were removed the day after grouting and the aggregate exposed on both faces of the wall using sand-blasting.

Preplacing of aggregate gives predictable uniformity of the exposed surface and this technique has probably considerable application where a more rugged texture is required in work of reasonably large scale. Aggregate transfer gives results similar in many ways to the above, but has not to the author's knowledge been used in this country. This is rather surprising as it would seem that the elimination of sand-blasting might make for significant saving.

The competition-winning Library Building at Trinity College, Dublin, features extensive use of fair-faced and board-marked white cement concrete. The efforts made to produce blemish-free surfaces here are probably the most sophisticated ever attempted in this country and the results obtained are of high standard and remarkable uniformity. Mahogany-faced plywood was used for the formwork generally and the assembly and detailing of every panel was considered with painstaking thoroughness. Grout leakage was almost completely eliminated by the accuracy of the moulds and particularly by the use of polyester sealing strips at all joints between panels and at all places where panels were fitted to hardened concrete. No special feature was included between separate lifts in the construction of exposed walls—the architects relied entirely on the quality of the concrete and the efficiency of the seal to fully conceal the joint.

Columns were cast with rounded corners and the concrete placed in one continuous operation. The risk of blow-holes at column heads was reduced by applying artificial surcharge to the plastic concrete during compaction. A small piece of timber was placed on the top face of the concrete and loaded (by foot pressure) during the vibration of the final few inches of concrete. This proved most successful.

The choice of the brand of mould oil to be used was made only after a number of experiments on site. The technique is now so refined that three different release agents are used. A straight oil is applied to all horizontal forms including the soffits of beams; water-in-oil emulsion is used on all vertical surfaces and this is supplied in two viscosities so that a uniform light application can be obtained during warm and cool weather. All oils and emulsions were applied by brush.

Normal continuously graded local aggregate was used for the major parts of the concrete. Where very white concrete was required special aggregate was imported from Norway. No additives were used in the concrete and little difficulty occurred in selection of aggregate proportions, etc.

Care in placing and compaction in conjunction with the excellent shutter design are largely responsible for the high quality finishes obtained, and more especially for the exceptional degree of uniformity.

A smooth-finished concrete was specified for the in situ columns and front canopy in the new Opera House in Cork, which is at present nearing completion. On this job timber shuttering lined with thermoplastic sheeting glued to the inner face was used. The corner column detail included a rebated joint and almost complete freedom from grout leakage was achieved. No release agent was used and the concrete was placed to the full height in one operation. Several preliminary trials were made and very little difficulty in obtaining good results was experienced at any stage. The ease with which good results were achieved on this project is quite remarkable but one is forced to consider the possibility that a repetition of the technique might not produce such excellent results.

Aggregate transparency—the slightly mottled reflected pattern of coarse aggregate—was noticed on almost all the columns on this job. It is caused by segregation at right angles to the shutter and is more likely to occur with formwork of low absorbency. It may not architecturally be considered a serious defect and in the particular situation could almost certainly have been reduced by a slight increase in the sand content of the mix.

The number of manufacturers producing precast concrete architectural units in Ireland is quite limited. Few firms are in fact specialising in work of this type and those who are have developed very definite personal prejudices towards the various techniques available. Thus it is that while the full range of casting methods (described later) is in use in this country, only a very limited number is employed regularly in any one casting yard. For example, face-up casting of cladding panels

using washing and early brushing is an accepted technique with one firm, while in another similar units are cast only face-down. An interesting modification to the normal methods of face-down casting has been developed by one manufacturer. The formwork is coated with a retarder and coarse aggregate spread without the use of any sand-bed. The mould is subsequently filled with structural backing concrete and on maturing the lower surface is brushed, washed and treated with dilute acid to remove any slight laitance on the aggregate surface. This method has been found to give more uniform results than the sand-bed technique, particularly where the concrete units are compacted using vibration.

Overall agreement between manufacturers is evident on quite a number of basic points.

1. High quality timber moulds are most suited to general conditions in this country. It is only occasionally that the number of units justifies the manufacture of special steel or plastic forms.
2. Water-in-oil emulsions are the most satisfactory release agent for quality work using timber forms.
3. Coloured cements should be used with caution where exposed aggregate surfaces are specified. The use of white cement should generally be considered only with the lighter coloured aggregates. Its use with the darker stone gives an exaggerated colour contrast which is in many cases visually unpleasant.
4. The range of commercially available aggregates in this country is rather limited. However, new sources are appearing from time to time and at present a pleasing selection of yellow, green, pink/purple, brown, grey, red and white stone is being used to give a suitable range in both colour and texture.
5. Much of our gravel aggregate reveals the depth of colour only when wet; this appearance can be made permanent by coating with a clear plastic solution which highlights the aggregate exposed on the hardened concrete surface.
6. The relatively small quantity of exposed aggregate required on any job does not make the import of special coloured stone prohibitively expensive.

In Situ Concrete

In Ireland the approach to problems of in situ techniques is frequently marred by unrealistic preliminary estimates of cost. The fact that applied surfacings are eliminated suggests an appreciable saving; in fact (omitting any additional costs for special cements or aggregate), the extra care essential in both the design of formwork and placing of concrete eliminates all envisaged economies. Once this has been acknowledged, many of the difficulties which originate basically in inattention to detail will be eliminated.

In dealing with in situ architectural concrete, the technique broadly divides into six main headings:

- (a) Preliminary design and detailing of concrete.

- (b) The selection and design of form work for the required surface effect.
- (c) The choice of appropriate release agents.
- (d) The exposure of aggregate where specified by either mechanical or chemical means.
- (e) The design of concrete mixes.
- (f) The placing and compaction of concrete.

In most cases the exact method of achieving the required result should be left to the contractor; previous experience and the development of individual techniques are largely his responsibility. The main function of the architect is to ensure that the contractor has full knowledge of **exactly** what is required and of how the required effect may be achieved. This involves discussions at an early stage, followed by site experiments designed to iron out any small problems that may develop.

(a) Preliminary Design :

This includes an assessment by the architect of what is required and involves considerations of colour, texture and scale and their relation to environment, normal viewing distance and lighting. This is basically an aesthetic problem; its introduction here may be justified on the grounds that architects and contractors are in many cases not fully aware of what can and cannot be achieved and consequently do not utilise to best advantage the full potential of available materials and techniques. For example :

1. Construction joints cannot be totally and permanently concealed. It is, therefore, necessary to plan for them and to design them into the structure.
2. Colour in concrete is governed not only by the colour of the cement, but also by the colours of coarse and fine aggregates. This explains much of the "yellowing" of white concrete in Ireland after a few years, when the basically yellow colour of the pit or river fine aggregate shows through the initial surface.
3. For in situ work, the best results are achieved by limiting colour effects to those attainable from the aggregates used with grey, white or black cements, and to avoid the general use of pigmented material. In the writer's view, black cement should be used only after serious consideration of the problems of efflorescence which can prove most disfiguring to concrete surfaces.
4. Surface defects can seldom be completely rectified. The popular idea that sand-blasting or bush-hammering the surface will remove irregularities due to bleeding or segregation has led to considerable expense and disappointment in jobs both large and small.

Architectural concrete probably offers an unequalled challenge to architects. It is quite certain that a greater understanding of concrete

will lead to further development in the field of decorative surfaces if architects, both individually and as a profession, are prepared to experiment in an effort to solve the varying problems of individual clients and buildings.

(b) Formwork

Architectural in situ concrete requires the highest standards of workmanship if satisfactory results are to be achieved. In formwork particularly lies a major portion of the early planning and detailing work. In many cases, an unfair responsibility is assigned to the contractor **without** sufficient guidance to enable him to meet the architect's requirements. It is not within the scope of this paper to deal with the design of formwork from the point of structural strength and deflexion; in recent years a number of research workers have fully studied pressures and loadings on shuttering and their work has given a new insight into its design. (1)*, (2), (3), (4).

From the architect's point of view, the primary consideration in formwork lies in surfaces, assembly details, joint location, release agents and fixing arrangements. The perfect surface finish to in situ concrete is probably both indefinable and unattainable. However, many of the more common defects can be significantly reduced by an appreciation of the frequently conflicting principles involved. That we have generally failed in this field scarcely needs mention; that we are capable of succeeding has been shown by the exceptionally fine work being carried out in building the new library for Dublin University.

While colour is primarily controlled by the characteristics of cement and aggregate, significant changes in colour tone can occur as the direct consequence of inferior shutter design or the use of unsuitable materials. Local dark patches and random streakiness may be the result of either escape of moisture at joints in the formwork or of uneven drying of the concrete. Uneven drying may result from the use of timber of varying absorbency or from the evaporation of moisture through cracks or openings in the forms themselves. For uniform appearance every precaution must be taken to eliminate **completely** any loss of water or grout from the plastic mix and any penetration of air through joints. The use of sponge rubber strips, taping and other sealing methods is generally recommended, but in addition, timber formwork must be prevented from drying before stripping, as shrinkage will allow uneven drying out of the concrete with local darkening effects.

Concrete during compaction is a plastic material and will reproduce the pattern and texture of the form face against which it is cast. Unlimited possibilities are available to those interested in the production of concrete surface finishes direct from the shutter. A wide range of materials can be used, hardboard, plastic, rubber sheeting, insulating boards and steel, to name but a few.

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

Before the final choice of material is made, it is necessary to assess the significance of various blemishes in relation to the texture required on the job in question. Here, a number of conflicting considerations arise. Absorbent surfaces give excellent finishes from a textural viewpoint, with almost total elimination of blow-holes. Unfortunately, the absorbency of formwork leads to concrete of a darker colour, and also gives rise to unpleasant variation in colour with change in porosity. Furthermore, the increase of hydrostatic pressure with depth of plastic concrete gives rise to a corresponding darkening of the concrete where additional water has been taken in by the formwork. Finally, absorbent shuttering can only be used once as the progressive loss in absorbency when re-used produces a corresponding lightening of concrete colour.

Plywood can give extremely erratic results when used for the first time. This is due to the system of veneer-cutting which gives random distribution of sapwood and hardwood with corresponding irregularity in colour. Where uniformity of colour is particularly important, timber of low porosity or treated timber should be used.

Steel shutters have proved very satisfactory from a number of points, but tend to encourage blow-holes; in addition, they are expensive, demand a high standard of maintenance for good results and can create difficulties with leakage of moisture through joints.

Plastic moulds or liners have characteristics similar to steel in producing uniformity of colour in the concrete with increased blow-holes or pock-marking. Where a highly glazed plastic is used, this frequently leads to surface crazing of the concrete, which with time becomes quite noticeable.

(c) Release Agents

In recent years increased attention has been given to the selection and use of mould oils, creams and paints. (5), (6). This has followed the realisation that their influences on surface blemishes in concrete is considerable, and that the use of quality shuttering demands clean release of the form for re-use. There are five main categories of release agents each of which has its own particular characteristics in facing concrete surface finishes :

1. Straight Oils

These are frequently used for treatment of plywood and steel as they give concrete which is uniform in colour with little staining. The surface quality is generally good, but there is a tendency to encourage blow-holes.

2. Water-phased Emulsions

Oil in water emulsions behaves like water and can penetrate the concrete to an appreciable extent. This interferes with hydration, darkens the concrete and gives a surface lacking in durability. **Their use is not recommended.**

3. **Straight Oils with Additive**

The addition of emulsifying agents or fatty acids to the oil can significantly reduce blow-holes without affecting the quality of the concrete. Oils in this category have excellent anti-corrosion properties and are therefore frequently used with steel formwork.

4. **Oil-phased Emulsions**

These are the most suitable release agents for general use. They give uniformity of colour, durability of surface and a minimum of staining and pock-marking. Care should be exercised in their use with steel moulds in view of the risk of corrosion.

5. **Barrier Paints and Coatings**

These are frequently applied to timber surfaces to prolong life and to reduce variations in absorbency. This has the automatic effect of increasing the tendency to blow-holes, but the colour of the concrete is uniform and the surface durable. They are justified economically by the increased life and ease of cleaning of the formwork and where blow-holes are considered a serious defect, release agents in the category 2 or 3 above may be applied subsequently.

Mould oils should always be applied as lightly as practicable and spread as evenly as possible on the formwork. Heavy application may interfere with surface hydration of the concrete and leads to discoloration. Where emulsions are used, these should be supplied ready for application and dilution on site should not be allowed as this frequently leads to instability and subsequent haphazard dispersion of the emulsifier. Almost all manufacturers of release agents supply a wide range of products, many of which are readily available in this country. (See Appendix). Technical assistance is provided and enquiries are generally welcomed.

(d) **Exposed Aggregate**

Decorative surfaces which involve the exposure of aggregate are more widely used in precast work, but they have also found appreciable application in in situ concrete. In Ireland only isolated examples in this category have been noted. Perhaps the most significant is the recently completed factory at Rathfarnham, Co. Dublin, for Messrs. Hallmark Cards (Ireland) Limited. Here selected coarse aggregate up to 10 ins. maximum size was compacted in traditional formwork and subsequently injected with colloidal grout. The shuttering was struck when the concrete was green and the aggregate exposed by sand-blasting. While the technique proved constructionally satisfactory, the appearance has been criticised on grounds of lack of life in the overall texture. This resulted primarily from the use of rather dull aggregate. Six main techniques can be used in this field, but to the author's knowledge, only 2, 3 and 6 have been employed in Ireland:

1. Early washing.
2. Surface retarders.
3. Sand-blasting, tooling, bush-hammering, etc.
4. Acid etching.
5. Aggregate transfer.
6. Preplaced aggregate.

1. Early washing

The simplest method of exposing aggregate is by removing the formwork as quickly as practicable and using wire or stiff bristle brushes and water on the fresh surface. Severe time limitations are imposed using this technique and under average conditions twenty hours between compaction and brushing will be found to be the absolute limit. Exposure of the surface using this method should always start at the bottom as the extra hardening period allowed to this concrete will dictate the depth of exposure possible for the entire surface. This technique is not applicable in many structural units where formwork must be left in position for a reasonable maturing period.

2. Surface retarders

The use of retarders can create problems of uniformity of surface and, furthermore, the period over which they are effective can vary considerably. In practice the surface laitance should be removed as soon as possible. Many contractors now feel that for architectural work mechanical exposure of hardened material gives more predictable and uniform results.

3. Sand-blasting, Tooling, etc.

The mechanical exposure of aggregate in hardened concrete has had only limited use in this country, as the cost involved can be considerable for large areas. The treatment can only be carried out when the concrete is several weeks old, as early tooling only leads to the tearing of whole pieces of aggregate from the matrix and not to the actual splitting of the material which gives much of the interest to the surface.

Grinding is seldom used for large areas of in situ work because of cost consideration. In addition, the normal types of aggregates used in concrete are entirely unsuitable with this technique and in Ireland the choice of aggregate is limited to marbles and some granites. Almost all grinding is limited to precast work in the terrazzo field.

4. Acid etching.

This technique is seldom used for basic exposure of aggregate in in situ work. Its use in this country is confined to the washing of previously exposed surfaces to remove light coatings of cement matrix which may have escaped the primary treatment.

5. Aggregate transfer.

This technique eliminates much of the painstaking control of detail

so vital in all architectural concreting techniques so far discussed. It is, therefore, strange that it has not been used in this country. The process consists of sticking selected coarse aggregate to prepared formwork liners using a water-soluble glue. These liners are subsequently fitted inside close boarded formwork and concrete placed and compacted using normal good practice. On removal of the main forms, the liners are easily removed and a predictable pattern of aggregate is left exposed on the surface of the concrete.

It is important in carrying out this work that precautions are taken to avoid displacement of the aggregate stuck to the liners. Shutter vibration should not be used and care must be taken to prevent immersion vibrators from touching against the liners.

6. Preplaced aggregate.

Preplacing of aggregate followed by grouting and subsequent sand blasting has been widely developed in Scandinavia as the patented "Naturbetong" process. The technique demands the use of a special non-shrinking grout and has not been used in this country; however, modified methods of preplacing have been developed and used with success on at least one project (already referred to).

(e) The Design of Concrete Mixes

For many years concepts of minimum cube strength, water/cement ratio and associated basic principles dominated the field of mix design. More recently, considerations of quality control and realistic prediction of strength variation have reached prominence among larger contractors. This is being dealt with in some detail in other papers, and in this report it is intended only to discuss briefly the special problems of mix design which influence appearance.

Earlier workers largely overlooked the effect of mix characteristics on appearance. Full significance of this factor was masked by the more serious effects of formwork surfaces, release agents, etc. Recently, however, it has been found that mix proportions have a marked effect on uniformity of colour and on the incidence of blow-holes. Unfortunately, no simple answer exists as conflicting considerations arise. One main principle has, however, become clear—**mixes for "straight-from-the-form" concrete should differ basically from those used for exposed aggregate surfaces.**

Straight-from-Form Surfaces

The most recent research suggests that a continuously graded aggregate of large maximum size combined with a fine sand produces appreciably superior results. The exact proportion of sand cannot be specified to cover all types of work, as this factor is dependent on the type of blemish considered most disfiguring. For example, the high sand content reduces colour variation and a low sand content reduces the incidence of blow-holes. If a compromise is required, i.e. the minimum of all defects, the sand content should be the minimum

required to prevent segregation in the circumstances. A rich workable mix should be used for best results and while no definite cement content can be specified, it has been shown that many of the more common defects become more noticeable with a change in aggregate/cement ratio from 3 to 6.

Some of the main blemishes in the surface finish of the concrete are given below, with outline suggestions on adjustments that can be made to mixes with a view to reducing the likelihood of their occurrence.

The term "sand-runs" is used to describe areas of rough texture in otherwise good concrete. They are caused by the migration of water along the plane of the formwork. This is basically a form of segregation occurring only when non-absorbent formwork is used. They are more likely to occur in cold weather when concrete remains plastic for a longer period of time.

Crazing describes the occurrence of relatively closely spaced fine cracks as the result of relative shrinkage of the surface of the concrete relative to the main volume. It is more likely to occur with mixes having a high aggregate cement ratio and low strength. These mixes have a low resistance to any stresses that develop due to differential drying or thermal conditions or to the non-reversible surface shrinkage, which can occur due to carbonation of free lime by carbon dioxide in either the air or water.

Plastic cracking includes cracks which begin very shortly after the concrete has been compacted and result basically from additional settlement within the mix. Settlement of aggregate relative to cement is of only slight significance but the movement of all solids relative to the water in which they are suspended can be appreciable. This produces a bleeding—the appearance of water on the upper surface of the concrete. It is interesting to note that the degree of bleeding varies little with total water content; a low slump concrete compacted by vibration will bleed almost as much as a highly fluid hand-compacted concrete. Restraint of this relative movement due to aggregate interlock, friction against forms or restraint by reinforcement causes a build-up of rising water under the restrained coarse particles. Where this occurs near vertical surfaces it appears as a slight horizontal crack. These cracks are generally more noticeable near the top of lifts where the weight required to overcome frictional resistance is less. This phenomenon has frequently been reported in this country in road slabs where in some cases a reflected pattern of reinforcement was quite noticeable on the surface.

It is extremely difficult to classify plastic cracking as a special feature and it is frequently confused with surface shrinkage cracks. Cracks that become noticeable with rapid surface drying have frequently originated as plastic cracks and have simply been aggravated by the increased stresses caused by differential shrinkage. True plastic cracking is a feature of concrete without appreciable tensile strength; it is aggravated at low temperatures, which allow longer time for move-

ment within the concrete and is reduced by any measures (such as air-entrainment) that reduce bleeding. The use of absorbent shuttering which induces water migration towards the forms rather than vertically almost completely eliminates plastic cracking.

Blow-holes or pocking are, as already pointed out, influenced by every aspect of concrete practice, but under the heading of mix design, it has been suggested that a reduction in the surface index of aggregates produces a corresponding reduction in these blemishes. Therefore, where it is desired to reduce this phenomenon one should design the workable mix with a water/cement ratio reduced to the minimum by selection of appropriate aggregate.

Exposed Aggregate Surfaces

It is generally agreed that the most pleasing effects are obtained when the surface displays a maximum amount of coarse material. It is also true that the aggregate exposed should be of one size or at least have a restricted grading. Thus, mixes that fulfil structural requirements and give best results for "straight-from-the-form" concrete will not give the most satisfactory results where the aggregate is subsequently exposed. In addition, where normally graded coarse and fine aggregates in the usual proportions are used, there is a tendency for non-uniform distribution of the larger particles, which is unsatisfactory.

Gap graded mixes with a high percentage of coarse aggregate have proved most satisfactory in this field, and give at the same time excellent strength characteristics with low creep and shrinkage. The use of entrained air is recommended as the improvement in workability and reduction in the risk of segregation are of considerable benefit in mixes in this category. In the design of such mixes workability will generally be lower than for normal continuously graded material, but this is unavoidable in view of the need to keep sand content low. This does not present any serious problems when mechanical compaction methods are used. In America typical mixes for work of this type include about 25 to 30% of sand by volume of total aggregate.

(f) Placing and Compaction

The primary requirement for uniform results in in situ concrete lies in the development of a system of placing and compacting the material. In general, concrete should be placed continuously and at as high a rate as possible, consistent with obtaining full compaction. It is particularly important that this fact be borne in mind when designing the structural aspects of the formwork. Vibration should be used continually and care taken that immersed vibrator heads do not come in contact with the forms. It is a mistake to allow any head of concrete to build up in the formwork before commencing vibration, even if full compaction can be so obtained; the head of loose concrete will trap air on the face of the concrete and increase the occurrence of blow-holes.

Conclusion

In a country dominated for many years by clauses specifying mixes by the traditional 1 : 1½ : 3 and 1 : 2 : 4 methods, it has been unreasonable to expect a sophisticated approach to the design of mixes specifically for architectural purposes. Prestressed concrete has created an increasing need for high strength concrete and has resulted in better control and greater appreciation of the meaning of mix design. The next stage undoubtedly lies in the wider understanding of the factors controlling surface finish as outlined above, with the certainty that greater application will be made of concrete as a decorative medium.

Precast Concrete

It is, of course, obvious that any of the methods used for in situ concrete can be applied in precast work. In addition, however, a number of specialised techniques have been developed and used in Ireland for the precasting of architectural concrete, and this section of the report deals with this field. It is not intended to include descriptions of the various decorative building blocks, etc. available, but to concentrate on the larger cladding units and the heavier structural precast items and the techniques used in their manufacture.

As previously emphasised, the problems of colour must be carefully considered in relation to local and national environment. In our own country, where grey skies are an accepted feature, bright colours can look garish and should be avoided. Colour itself depends both on aggregate and cement, but the relative importance depends on the surface treatment. Where aggregates are exposed, cement colour is of less significance and current opinion favours colour derived from natural stone rather than from pigmented cement. (White cement is not regarded as a coloured cement in this context).

The production of plain coloured panels using coloured cement is probably the most difficult of all decorative finishes and its use should preferably be restricted to profiled slabs.

The manufacture of precast textured panels can be divided into two main categories :

1. Face-up casting.
2. Face-down casting.

Casting face-up has the decided advantage that all treatment may be completed with concrete in a plastic state and a visual assessment of appearance can be made while the possibility of easy adjustment still exists. In panels where aggregate is not exposed, surfaces of considerable character may be obtained by rolling, combing or scraping the smoothed and compacted material. The only problem with this technique lies in maintaining a uniform colour between panels, but local variation can to a large extent be concealed by the logical placing of repetitive panels so that contrast between adjacent units is kept to an absolute minimum.

The exposure on face-up panels is generally carried out on plastic concrete by tilting the unit shortly after casting, and spraying water while brushing. Manufacturers differ in the details of this technique, and their procedures are frequently influenced by the relative costs of normal concrete and any special aggregates required on the surface. For example, where total thickness is relatively small, a uniform mix may be used throughout the unit. Alternatively, with heavier units or expensive facing aggregates two separate mixes cast integrally may be appreciably cheaper. A third method used involves the compaction of a facing mix from which all coarse material has been omitted. This is subsequently covered with a layer of largely single-size aggregate which is vibrated into the mortar. This allows any irregularities to be corrected at a very early stage and is particularly useful where aggregates with contrasting colours are used. Panels cast using this technique are sprayed and brushed in the normal manner.

It is of importance to consider problems of exposed aggregate units where adjacent faces have a similar finish specified. First, it may be desirable that the exposure of aggregate is stopped slightly back from the edge so that a clean arris is obtained. Alternatively, a semi-rounded corner with irregular lines may be more suitable. There is the additional problem of obtaining a similar appearance from adjacent surfaces when one of them is form-finished and the other trowel-finished. There will generally be a tendency for less aggregate to show on the upper (trowelled) surface, but this can be corrected by experiment. Almost complete success in this field was obtained in the precast columns cast for the Telefis Éireann Studios at Montrose, Co. Dublin. Here it was found necessary to scatter additional aggregate on the trowelled surface and compact it using a minimum of surface tamping.

Face-down casting is widely used in the manufacture of large units in industrialised building systems. In many cases, tiles, mosaic or other facing material is laid in the bottom of the mould and the concrete units cast subsequently. While this method of casting is the only one where profiled slabs are being produced, the manufacture of exposed aggregate surfaces suffers from the disadvantage that it is not possible to visually assess the quality of the work until the concrete has matured.

Aggregate exposure on face-down surfaces may be carried out by wire-brushing or by the use of retarders, as already described for in situ work. The sand-bed technique has been specially developed for precast work, and is a development of aggregate transfer applied to horizontal surfaces. The procedure consists in spreading a uniform layer of sand in the bottom of the mould. Aggregate is spread on this and bedded in position. A layer of 3:1 sand/cement mortar is then spread to cover the aggregate and the mould is immediately filled with concrete in the normal manner. On stripping, the sand can be brushed and washed from the lower surface leaving the decorative aggregate exposed. The sand-bed technique is normally limited to aggregate of at least $1\frac{1}{2}$ ins. which is hand-placed in position. The degree of aggregate

exposure will depend on the thickness of the sand layer and the depth to which the aggregate is embedded.

Failures which have occurred in Ireland using this technique have, in the main, resulted from the precise placing of aggregate, which has produced an irritatingly forced symmetry of the panel texture.

Conclusion

All of the casting techniques described above have been used in Ireland. Unfortunately, only a very limited number of organisations has made a study of the subject, and this has led to an appreciable amount of inferior work completed without a basic understanding of technical aspects of the work.

Specialist precast firms have produced quality work and have in general used to the full the facilities available. The range of aggregates commercially available on the Irish market has relatively limited colour variation and this has presented problems in obtaining variety. This position is improving with the increased demand for particular colours, and aggregate suppliers are always prepared to develop un-worked pits if an assurance of demand for the material is obtained. In addition, there is an increasing realisation that the expense involved in importing the relatively small quantities of special aggregates for any job is by no means prohibitive.

APPENDIX

Release Agents

This list classifies a selection of the proprietary liquids and creams considered suitable for use with architectural concrete, and which are available in Ireland. As continuing developments are occurring in the field of mould oils, it is recommended that the firms mentioned be consulted for more extensive data.

1. Straight Oils

Coray 40	Esso Petroleum Co. (Ireland) Ltd.
Carnea Oil 21	Irish Shell & BP Ltd.
Mould Oil Nos 6 and 10	Castrol (Ireland) Ltd.
Oil No. 393	Greenmount Oil Co. Ltd.
Rubex 100	Mobil Oil Co. (Ireland) Ltd.
9611 : 735 Oil.	Caltex (Ireland) Ltd.

2. Water Phased Emulsions

Oil in water emulsions should not be used where appearance of the concrete is of importance.

3. Straight Oils with Additive :—emulsifiers, surfactants, fatty acids, etc.

IL 1384, R 133, R 136.	Esso
Mould Oil Nos. 1 and 2	Castrol
Oils Nos. 481 and 519.	Greenmount
Shell Oil P 5	Shell
Tecrex 23	Mobil Oil
9209 Mould Oil F	Caltex

4. **Oil Phased Emulsions**

Duckhams Z1 and Z2 (low viscosity)	Reliance Bearing & Gear Co. Ltd., Dublin
Mould Oils Nos. 4 and 5	Castrol
Mould Oil No. 11 (low viscosity)	do.
Oil No. 148	Greenmount
Oil P.W. 5	Shell
R. 134	Esso

5. **Barrier Coatings**

Mobilcer C	Mobil Oil
Mould Fluid No. 9	Castrol

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* These publications may be obtained free of charge on application to the Technical Advisory Department, Cement Limited, 19 Lower Pembroke Street, Dublin 2.

Discussion

MR. DUGGAN introduced his paper.

When he had first been invited to present a paper to the Symposium on concrete as a finished surface, he had wondered why an engineer, and not an architect, had been selected. It had seemed to him that a paper involving architectural interpretation would have come more logically from an architect. He had recognised, however, on reflection that the subject called for a mutual appreciation of each other's viewpoints and intentions by architects and engineers; and this fact, combined with a realisation that the development of techniques and the actual production of the concrete normally falls to the engineer rather than to the architect, now seemed to him to make the choice of an engineer more easily understood.

Precise communication between the architect and the engineer, and between them and the contractor was essential in using architectural concrete. Frequently, the giving of inadequate terms of reference to the contractor, both as regards concrete mix design and the detailing of formwork, had led to poor quality work and to the dissatisfaction of both the architect and the contractor.

The traditional methods of specifying concrete in Ireland, mentioned in earlier sessions of this Symposium, had brought their own range of problems. It was customary to lay almost total emphasis on minimum strength. Little attention had been paid to variation, the presence of which was of course one of the bugbears of any fair-faced concrete job. It has been noticeable that on jobs where a section of the work called for fair-faced concrete the remainder of the concrete had improved out of all recognition through the development of a logical system for the demanding part of the work and the spread of this system without effort into the remainder of the concrete.

In commenting on the weakness in practice, he had to emphasize that there had of course been some outstanding examples of close co-operation in architectural concrete in this country, and the result had justified that co-operation.

Mr. Duggan then showed a series of slides, saying that he had chosen both the slides and the supplementary comments he would make on them with a conscious decision to lean more towards honesty than towards what people might like to hear. His comments represented his own personal opinion. If they brought down on him the combined wraths of the architects, engineers and contractors, he hoped that even that would be considered an achievement in giving architectural concrete recognition in this country.

The buildings illustrated by Mr. Duggan were as follows :

The Intercontinental Hotel, Dublin

Individually the wall panels were well textured, but the lack of an interesting aggregate made them a little dull. Grouped together

the panels showed an unpleasing lack of uniformity. The mullions on the front elevation were, he felt, too narrow for the size of aggregate exposed on their surfaces.

The Bank of Ireland, Coolock

A pleasing use of good quality white concrete frames and fascias. Some parts of the same job looked like precast cladding panels, but were actually formed with mortar on concrete block walling. He was not certain whether this was a correct architectural interpretation.

Office Blocks of Messrs. G. & T. Crampton, Dublin

The uniformity of the exposed aggregate panels was good. Due to the size of the aggregate, however, it was hard to appreciate from a normal viewing distance that this was exposed aggregate. This might be considered a defect.

Bord Fáilte Éireann Offices, Dublin

The first determined effort at architect—engineer—contractor co-operation in the field of fair-faced concrete in Ireland was represented by this building. It was pioneering work, and actually showed improvement between its own earlier and later stages, the work near roof level being better than further down. Some bleeding had occurred, to the detriment of the appearance of some of the frame but the general result reflected the care that had been taken.

Studios for Telefís Éireann, Dublin

The precast exposed-aggregate columns were excellently conceived and made and were considered as up to the highest international standard of workmanship.

Opera House, Cork

The fair-faced concrete work on this project had been conscientiously done. Mr. Duggan did not know what terms of reference had been given to the contractors, or what they were paid to achieve, or in fact what the architect had wanted. He did not intend therefore to be taken as criticizing, in saying that the finished work had many haphazard visual variations. These could have been avoided with a little extra care, which might of course have represented extra cost.

Church at Mayfield, Cork

The quality of the concrete blocks, cast by the contractor on the site, using Ennis spar as aggregate deserved praise.

Offices for Aer Lingus, Dublin Airport

The fair-faced concrete columns at the ground floor showed bleeding defects and non-uniform colour of the concrete. The colour variation might have arisen as a result of overall settlement of coarse particles within the wet concrete of a single lift with a consequent migration of very fine material towards the top of the lift. An air-entraining agent could have been useful to obviate this variation.

The concealment or statement of construction joints was another problem revealed by this building. It was very difficult to conceal them totally, and a frank statement of them appeared preferable.

Boiler House for University College, Dublin

As in an earlier example, one should, before criticizing, question the terms of reference. This building gave the impression that external renderings were intended. If it was intended as fair-faced concrete, then the results would have to be classed as inadequate. There was considerable patching, segregation, and bleeding and staining due to haphazard application of mould oil.

Office Block for Irish Life Assurance Company, Cork

An interesting feature of this project was the use of columns, visually unimportant in the finished building, as full scale experiments for the main bulk of the fair-faced work. Mr. Duggan considered the full scale test as invaluable. The aggregate transparency which occurred could probably have been lessened by adding a plasticiser or increasing the W/C ratio slightly. This would have had the effect of reducing the compactive effort and consequently the pumping action between the aggregate and the formwork.

Library Extension for Trinity College, Dublin

The fair-faced concrete in this project was outstanding in quality. It was originally intended that the column surfaces would be bush-hammered, but the architect decided when he saw the columns finished that the surfaces were too good to be further treated.

Offices for Comhlucht Siuicre Éireann, Dublin

The cladding panels were formed with exposed Connemara marble aggregate face-down. Single-sized material was used and this gave a definite texture which a uniform large-to-small grading of aggregate would not give. An interesting refinement was the use of an exposed aggregate size gradually increasing with the height above street level at which particular panels were to be used, so as to give a uniform appearance as seen from the street.

Factory for Hallmark Cards (Ireland) Ltd., Dublin

The use of pre-placed aggregate up to 10" in size and its subsequent exposure by sand-blasting was the technique in this project. The extremely rough texture obtained was apparent, and a merit of this technique was the visual control which was possible throughout.

Mr. Duggan also showed slides illustrating:

- the use of black and white aggregate with normal cement;
- the use of white aggregate with red cement;
- the use of aggregate made from broken bottles;
- the difference between the results obtained from plastic-faced and absorbent-lined formwork;
- the use of clear glaze applications;

precast storey-height walling panels for a factory in Dublin; 150 square foot walling panels for the Asbestos Cement Pipe factory in Drogheda.

the use of the aggregate-transfer technique in precast panels;

Regarding the use of coloured cements, Mr. Duggan felt that restraint was important if garishness was to be avoided. The same danger lay also, he felt, in the use of any dark aggregate with white cement. On the whole, it appeared preferable to him, even with the limited range of coloured aggregates available in Ireland, to seek for colour through a combination of those aggregates with grey or white cement, bearing in mind the dangers inherent even in these.

In conclusion we should recognise that our problems were not unique but were being met and tackled all over the world. We had much work in Ireland of which we could be justifiably proud, and critical appraisal of that work, and our work generally, could not fail to lead us towards better techniques and away from the mistakes we were now making.

MR. D. W. CRONIN opened the discussion.

The members of the Symposium were indebted to Mr. Duggan for putting together a great deal of common sense about the whole problem of concrete finishes. He regretted that Mr. Duggan had found it necessary to point to the need for conscious efforts in regard to concrete finish, but undoubtedly this was necessary. It was clear that both the newcomer to concrete surface techniques and the expert who had already been through the fire could find valuable guidance in Mr. Duggan's paper.

Mr. Cronin thought that an architect's comments on the buildings described might be, as it were, an interesting counterpoint to Mr. Duggan's melody.

In the Bord Failte Éireann office block, the area of the in situ frame made up only a small part of the total facade area and for that reason failed to make a confident and major statement. According to his view the frame tended to suggest that it had not been finished, unlike the other materials close by.

Regarding the Sugar Company building, he felt that the panels were rather coarse and possibly self-conscious. He wondered whether there was not something fashionable about these panels and, if so, whether the building might not date very quickly. Perhaps it would weather to more substantial effect.

The concrete work in the United States Embassy building he regarded as an excellent strong statement, confident, a major function of the structure and likely to improve on weathering. In the Telefis Éireann building there were large panels which he would consider more successful than the columns which appeared to him to be timid, a little decorated and may be even trivial or titivated. Contrary to Mr. Duggan's view, he believed the Intercontinental Hotel to have been a successful

exercise in the use of the large panel. They were a good colour, rather self-effacing and quietly satisfactory. He was sorry he had been unable to see the Trinity College work, but he joined with Mr. Duggan in admiring it.

Mr. Duggan had in his paper rightly pointed to a failure to appreciate the problems involved as the root cause of poor results. One must agree with his comments regarding the cost of in-situ work and the absence of a saving through the omission of plaster. In this context, it was worth recalling that while value for money was not the only criterion, it was a very necessary one, and that whereas an architect might rightly refuse to design a cheap building for a client, it was his duty to see that his client got an inexpensive one.

Mr. Cronin observed how very right Mr. Duggan was in what he said about colour. Limit was the rule, and discipline was essential. The colour sense displayed in the greater number of new buildings dismayed Mr. Cronin, for, as he said, the hand of an architect lay heavily upon them. He felt that Mr. Duggan's comment on surface defects was too wide in scope as not all systems of concrete surfacing denied complete rectification. As a final comment on the paper, he would like to have seen included a strong injunction to experiment, to simulate conditions as closely as possible, for this he considered as an invaluable and indeed an essential exercise.

For his own part, Mr. Cronin acknowledged the limitation of his practical experience in concrete as a finished surface to exposed aggregate design. He explained that his architectural philosophy was quite opposed to what he knew as veneer building. Within this classification, which included the fixing of surface tiles and mosaics and the hanging on of cladding units, could be found the worst excesses of what Le Corbusier had called an unhappy state of retrogression in architecture. Again he quoted Le Corbusier as saying "architecture being the masterly, correct, and magnificent play of masses brought together in light, the task of the architect is to vitalise the surfaces which clothe these masses, but in such a way that the surfaces do not become parasitical, eating up the mass and absorbing it to their own advantage."

Though one might not be the author of that thinking, and might not have isolated out the root concept for oneself, Mr. Cronin suggested that one was not thereby released from trying to follow it.

The Hallmark job was the result of looking about for an indigenous material with structural and emotional potential, emotional, because we were told that the business of architecture was to establish emotional relationships by means of raw materials. No one with roots in Ireland could gainsay the pre-eminence of concrete; it was our primary building material. Prompted by his Clients' request for the major use in their factory of a material which would give the building a distinctively Irish character, and encouraged by the co-operation and experience of his Consulting Engineer and his Contractors, he commenced experiments which ultimately led to the constructional techniques described

by Mr. Duggan in his paper. The result had been a structural material, fully disciplined by shuttering and capable of reinforcement; yet displaying a texture both decorative and rugged in scale, with exposed finishes available on all sides at will.

Mastery of the construction joint technique had taken some time, because through oversight, work on this had not been included in the experimental programme. However, it had eventually been discovered that by breaking the arrises of the earlier pours quite harshly near the construction joint planes, the later pours could be concreted in such a manner as to render the joints imperceptible (his experience on this project incidentally made him disagree with Mr. Duggan's contention that construction joints must always be exposed deliberately). The aggregate was exposed by sand-blasting which was started 14 to 18 hours after placing, depending on temperature, and where the aggregate was exposed on interior surfaces, a polyvinyl acetate clear spray was applied as a dust proof.

Mr. Cronin wondered whether perhaps the history of the Hallmark job did not give the lie to Mr. MacGreevy and Mr. Lydon in their adverse comments about architects. Alternatively, of course, it was possible that the job was one of the exceptions proving the two popular rules: that architects did not adequately brief their Consulting Engineers, possibly because they were unaware of hidden potential in materials and techniques; and that architects sometimes denied the very requirements of architecture itself. He did not propose to offer a general answer.

MR. J. DALY congratulated Mr. Duggan and Mr. Cronin on their honesty which he felt contrasted very favourably with the reluctance of some earlier speakers to identify the location of faults which they had described.

He would like to hear some discussion on surfaces obtained with continuously-moving formwork, which had not been mentioned so far in the Symposium.

He would also like to hear more about materials which could be applied to concrete surfaces for one purpose or another, and in particular, more about the various silicone preparations. The Electricity Supply Board had painted the outside surfaces of their chimneys at Ringsend, Dublin and Marina, Cork, with three coats of 5% dilute solution of sodium silicate. This had given a pleasing effect and was functioning very well as a sealant in locations where there was grave danger of both saline and flue gas attack. Tests made before painting the stacks had indicated that absorption of the solution by even a good dense concrete was satisfactory, and he understood that a steeple-jack's report of the top sections of the chimneys showed the concrete as sound as when it had been cast ten years earlier. Whether the sodium silicate solution was or was not responsible for this might of course be argued, but the existence of the satisfactory achievement, from whatever cause arising could not be denied. The Marina chimney was soon

to be replaced by a taller stack, and he felt it would be of definite interest to examine the concrete being removed to see what, if any, trace of the original solution remained. There was room without doubt in modern practice for a good concrete sealant at an economic price, for non-wearing surfaces.

Regarding the Trinity College columns, he would be interested to learn why, if they were subsequently to be bush-hammered, was so much costly work put into their prior formation as fair-faced concrete.

MR. W. J. L. O'CONNELL speaking, he said, as a rude mechanic refused to accept himself as a complete Philistine, having lived under the ameliorating influence of three painters in the family for many years. He had always considered that the job of the engineer on a large structure was so to design the structure that its shape would be satisfactory for its purpose. The structural lines were then bound to express that purpose, if the engineer was competent. For the past 20 years he had been mainly concerned with bridges and he had had for many years a conviction that in that kind of work in which the scale was enormous, the surface treatment was relatively unimportant. Bridges were usually looked at from a greater distance than other structures, and, for an engineer who knew anything about structural theory, it was, anyway, almost impossible to design an ugly bridge. He had from time to time tried with the co-operation of his architect friends to design board-marked shuttering, but without much success, and he had largely stopped trying.

Mr. O'Connell referred to Mr. Duggan's comments on the Cork Opera House. A great deal of effort had gone into the work done on that job, and he felt that, if the technique appeared to be easy, the principle of *ars est artem celare* should be invoked. He had a great respect for craftsmanship, and the ability of both the foreman and the clerk of works on that job had been abnormally high.

He had in other works, which were purely utilitarian great difficulty in persuading engineering contractors, particularly, so to design the formwork as to produce the kind of pattern which he liked to see. The pattern of board marks on a structure ought to bear some relation to both the shape and the mass of the structure. This was a relatively simple field for development and much remained to be done in it. Rough textured concrete surfaces could be preferable on occasion to smooth surfaces; he personally considered the board-marked soffit of the main entrance canopy at the Cork Opera House to be very attractive.

He did not feel disposed to talk about colour in the presence of architects, particularly at the first session in the Symposium in which the architect had the leading role. He did think, however, that very much more use could be made of colour than had been made. Arising from this and with an eye cast towards Mr. Cronin, he would like to mention a new surfacing technique which had appeared in Italy a few years ago. Assuming that a surface was to consist of, say, 1' 6" square

panels, a long block of concrete 1' 6" square in cross-section was cast, using very high quality variegated marble aggregates. This block was then sliced into thin 1' 6" square slices with a high speed saw, and the slices used, he would emphasise for Mr. Cronin, not merely as a surface treatment, but as a structural lining to the framework. The effect he understood was very beautiful.

In conclusion Mr. O'Connell claiming the privilege of oldest inhabitant, congratulated University College on the success of the Symposium.

MR. A. B. HARMAN said he had noticed an apparent disparity between Mr. Duggan's two comments on construction joints. In the Trinity College library, the architects relied on good workmanship to conceal the joints whereas, generally, Mr. Duggan felt that they should be shown.

Mr. Harman considered that it was safer not to rely on their total and permanent concealment, although he had been most impressed by Mr. Cronin's special exception.

Concreting technique at construction joints was still a subject for debate in engineering circles, e.g. whether or not to use a mortar layer. He himself thought that there were two extremes, both wrong. On one extreme, a layer of mortar, say 3 : 1 or 4 : 1 sand to cement, would be used; such a mortar did not really relate to the mortar content of the concrete and merely formed a plane of weakness. At the other extreme, no mortar layer was used; concrete was placed and vibrated in the normal manner, but because the supervisor did not appreciate that at the beginning of the construction lift or the day's work, some of the mortar in the first mixes would remain to lubricate the mixer drum, some would remain in the dumper, and some on the reinforcement, the concrete reaching the construction joint would in fact be deficient in mortar. A middle-of-the-road approach appeared desirable through use of slightly oversanded first batches, or conceivably through complete omission of the coarse aggregate in the first batch.

The merit of standardising specifications had been mentioned by Mr. Duggan and earlier by Mr. Gwynn. He agreed with them about the value of this, especially in the matter of an agreed specification. It might interest the members of the Symposium to know that the Reinforced Concrete Association had published standard specification clauses on formwork and transporting and handling reinforcement, and would shortly be publishing clauses relating to materials for concrete. Later, they would deal with quality control, but this had been left until last because the Institution of Civil Engineers had also been working in that field, and had published its findings in the document already referred to in the Symposium.

Regarding the use of continuously-sliding formwork, he had recently heard of some American experience in that matter. It was suggested that horizontal markings which were often associated with this technique and which were, by definition, not construction joints, were caused by a

graduation of shading arising from a minute periodic tilting of the form. This could occur through the development of high and variable friction between the sliding form and the concrete. As a remedy for that, it was suggested that removable liners should be placed between the concrete and the sliding forms. The friction between the liners and forms could be controlled and kept uniform. Work on the design of sliding shuttering was always in progress, and it was a field for much individualistic thought.

MR. P. J. MOLLOY showed a series of slides illustrating architectural concrete work in England. Problems in this medium were common to both countries, and he felt that the members might be interested in the solutions shown.

THE CHAIRMAN thanked Mr. Duggan for his masterly summary of the various methods for carrying out work in exposed concrete, which he said was so presented that one could readily see the range of possibilities.

There were clearly two basic ways of making exposed concrete surfaces. One was by the use of very fine shuttering with which, using great care, fair-faced surfaces could be produced free of blemish. The second was based on the exposure of selected aggregates on the surface of the finished concrete. These alternatives existed whether the surfaces were of precast or in-situ construction. He personally felt that grey fair-faced concrete was somewhat uninteresting and would prefer the use of exposed aggregates. He saw cost and, as Mr. Cronin put it, value for money, as important criteria. Costings for exposed concrete surfaces were not always readily available, and the alternative use of mosaic, stone, or marble, where appropriate, should not be dismissed as extravagant without investigation.

Two or three years ago he had obtained comparative prices for mullions in natural stone and in fair-faced precast concrete. The stone had been dearer but only in the ratio of about 4 to 3, certainly not more than $1\frac{1}{2}$ to 1. That gap had now narrowed. The concrete mullions were now 16% dearer whereas the stone costs had increased by only 8%, the reason for this being that labour rates had been rising more quickly than the prices of materials.

In the matter of colour he and most architects liked colour as such, but restraint and discipline were essential, and if the only alternative to brightly coloured concrete was the use of natural grey stone-coloured concrete, he would prefer that. The split block technique was a perfectly rational and economical method of obtaining exposed aggregates for low cost housing, but the terrible results which emerged from the unwise use of the multicoloured units using red and yellow cements made one regret its invention. Coloured cement, he felt, was a tool which in the wrong hands could cause enormous damage to the community, not merely now when selected, but for a hundred years to come. It was fatal to select materials purely for the novelty value of the results obtained.

There was, of course, a wide field open for fine texture and interesting colour within the bounds of restraint and discipline, and this, he felt,

was where true development along the lines of the present paper lay.

MR. A. MOORE, of Mr. S. Kenny's office, in a written contribution, suggested that the difficulties besetting the achievement of good fair faced concrete surfaces in Ireland were due at least in part to the inertia of the contractor. However, much of the trouble came from the fact that the average contractor frequently remained unaware of valuable new materials and techniques, and rarely had the organisation which would allow him to experiment on new techniques himself. The setting up of an advisory and information service which would channel news of useful materials and techniques and the results of world research out to the Irish users of concrete, and which could be called on for specific advice, would do much to raise the standard of our concrete work.

Some of the blame for poor quality concrete work rested with the contractor. Many surface blemishes of the types illustrated by Mr. Duggan were liable to be held as unavoidable, and a matter of indifference, repairs to small surface defects were made haphazardly by unskilled workers with poorly chosen materials, surprise was expressed by the contractor at exception being taken to the use of wire shutter ties embedded in fair-faced concrete. While these attitudes lasted, progress in fair-faced concrete work in Ireland would be slow.

Referring to Mr. Duggan's comments on the Bord Failte building, it had been Mr. Moore's experience that over-sanding a mix did little, if anything, towards a better long-term finish. Rather, the weaker strengths obtained with excessive sand tended to encourage rapid deterioration of the arrises exposed to the elements.

In the matter of high single-lift pours, he had noted that most contractors were reluctant to undertake storey-height pours of columns or walls. That system of concreting had three advantages:

- (a) It gave a better finish on the surface generally due to the pressure of the volume of concrete being poured;
- (b) it eliminated almost entirely the problems of horizontal construction joints and difference in colour due to slight differences in mixing concrete from day to day;
- (c) it required only one handling of the shutter for each wall poured.

He had met arguments of excessive cost being raised to counter these advantages, but he felt that an unwillingness to try was often at the root of such objections.

His firm had had most success with mahogany-faced marine plywood in the forming of fair-faced concrete surfaces. It was their practice to ask the contractor to surface-seal the plywood with a polyurethane varnish, and this had the merit of providing a smooth hard casting surface, at the same time sealing the timber against the ill effects of moisture. That type of panel had the tendency to cause the formation of air bubbles on the concrete surface. The use of excessive quantities of mould oil aggravated this defect. They had found detached shutter linings unsatisfactory. The linings had a tendency to lift after two or

three uses, and as they could not be jointed in a water-tight manner, the main shutter was rapidly attacked by moisture from the concrete.

For filling holes, and "rubbing up" the patches on a concrete surface, they normally required the filling to be made with fine material, using a cork float, the excess material being removed with a damp sponge.

MR. DUGGAN replied to the discussion.

He would bow to Mr. Cronin's architectural interpretation of the work on the Intercontinental Hotel. He would, however, on the other hand, remind him that he had in fact included in his paper a strong plea to the architectural profession to experiment with concrete finishes, and he certainly agreed with Mr. Cronin on that point.

He was, on balance, opposed to the use of applied finishes on exposed aggregate work. Their use often represented an admission of lifelessness in the surface as formed and an attempt to give life to that surface. Rarely was an applied finish an accepted method of producing a finished surface. In this general context, he did not accept sodium silicate as a sealant, although he felt sure that Mr. Daly's strong advocacy of that material would charm those firms which supplied it. The effect of silicate of soda was, he considered, based on absorbency. The better the concrete, the less the absorbency, and in fact the painting of a good concrete surface with silicate of soda would have very little effect.

Regarding the bush-hammering of finished surfaces, it was unfortunately the position that, to get good results from bush-hammering, one had to begin with a very dense well-finished concrete. Bush-hammering was not a method for concealing segregation or other defects.

Mr. Duggan felt he owed an apology to Mr. O'Connell for recording that the work on the Cork Opera House had been regarded as easily achieved. The exchanges which had led to this comment might serve as his explanation. He had as a Dublin man talked to the contractor and clerk of works and commiserated with them on the difficulty of the work they were doing. Their attitude, possibly not wholly technological, had indicated that what might be difficult in Dublin was not necessarily difficult in Cork, and he had tended, with some tact, to accept their equanimity.

He would not agree with Mr. Harman that there was any contradiction in his comments on construction joints. He had said, and still thought, that construction joints were difficult to conceal. In the Trinity College project, the architects, while possibly agreeing with that attitude, had decided nevertheless to rely entirely on the quality of the concrete and the workmanship to conceal the joints. He was not fully convinced that their reliance was justified, especially as regards the long-term behaviour of the joints. It was even more difficult to obviate marginal colour differences between adjacent concretes poured under different weather conditions, and age tended to intensify these differences, rather than soften them.

Mr. Duggan wondered whether there had been a false note struck in

the discussion, in a suggestion that either the architect or the engineer had to dominate in the pursuit of satisfactory surface techniques. Surely we should to-day realise that a good building represented a combined effort by all concerned. He felt that it was unlikely, on any of the outstanding work in this field in Ireland at present, that either the architect or the consulting engineer would lay claim to the prior place. He hoped that he had not given anyone the impression that all the problems in concrete surface technique had been solved. That would be far from true. The development of this technique belonged to the site, not the laboratory, and case-histories were more important than theory.

With reference to Professor Fitzgerald's observations on cost, Mr. Duggan agreed that it was extremely difficult to get accurate costings. So much depended unfortunately upon what one's informant was trying to prove. In his own opinion, the cost of fair faced concrete exceeded marginally the cost of normal structural concrete finished with three-coat plaster work. While on the subject of cost, he would say that mechanical exposure of aggregates, by bush-hammering and other methods, was rather expensive for Irish work generally. It would be more economical for us to concentrate on those techniques which expose the aggregates while the concrete was still plastic.

In the matter of split blocks, he wondered whether Professor Fitzgerald had not been slightly hard on their manufacturers. They were undoubtedly manufacturing to meet a demand. That demand might at times be highly unfortunate, he agreed, but he felt that the means to raise its standard lay, through education and example, in the hands of the architectural profession.

In reply to Mr. Moore, the Author agreed that lack of experiment contributed largely to failures in architectural concrete finishes. He felt that it was unfair to attach all the blame to contractors, as one would generally assume that the incentive for experiment would come from the architect or engineer. A willingness to co-operate in experiments was probably the most important point.

Mr. Duggan felt that a misunderstanding had occurred in interpreting his comments on over-sanded mixes. What was really implied was a slight increase in sand content to reduce colour variations, but at no time would one encourage the addition of large amounts of extra sand which would, of course, reduce strength and effect weathering characteristics.

Single high pours were a very important feature in architectural work. Reluctance on the part of contractors to tender for this type of job probably originated in lack of experience in shutter design; this could easily be rectified by the architect or engineer taking a greater interest in this part of the work and providing the contractor with working drawings for form work.

"Rubbing up" was an activity largely frowned upon by the architects. There was plenty of justification for the objections, as in many cases the last state was worse than the original blemish. One had to accept the occasional flaw on even the best jobs, and careful training in repair methods was vital if success was to be achieved. Swiss craftsmen were very skilled in this field, and could reinstate small unsatisfactory areas most successfully. They even went so far as to add a small percentage of white cement to the normal material to compensate for the normal darker colour expected due to more rapid drying out of the replacement concrete.

SESSIONAL REPORTS AND CLOSING DISCUSSION

Sessional Chairman :

**PROFESSOR M. A. HOGAN, B.E., D.Sc.(Lond.), D.I.C.,
M.I.C.E., M.I.Mech.E., M.I.Min.E., M.I.C.E.I.**

Reports summarising the discussions of the first seven sessions were read by the following members of the Symposium :—

- A : Dr. L. F. Stephens
- B : Mr. P. Hayes
- C : Mr. C. H. Clifton
- D : Mr. D. E. Tierney
- E : Mr. F. Clarke
- F : Mr. J. R. McDowell
- G : Mr. D. V. O'Connell

THE CHAIRMAN thanked the reporters for their contributions which had given the Symposium a concise synopsis of the discussions so far. As he had said earlier, a purpose of the Symposium was to bring out subjects for research, and listening to the discussions and the reports, he felt that quite a nice crop of topics had appeared. He would list the following :—

- (a) the use of additives with Irish cements and aggregates, and the influence of mould oils and surface sealers.

Work on these subjects was already being considered at University College, and the Symposium proceedings had emphasised its importance.

- (b) The relationship between 7-day, 28-day, and longer period concrete strengths.

He had not taken out any figures but his impression was that 7-day tests were becoming more numerous than 28-day tests, and the age/strength relationship would accordingly increase in importance.

- (c) The control of workability.

It was evident that the methods at present available needed further investigation.

- (d) Methods of compaction and of storage and treatment of site cubes.

Usually the cube was much smaller in volume than the placed concrete which it represented, and the method in which it was stored could be quite unrepresentative of the conditions obtaining in the placed concrete.

- (e) Joints in concrete structures.

Some members of the college staff had already interested themselves in this subject.

Having dealt with research, the Chairman raised some general points.

Mention had been made of the growing use of ready mixed concrete in Ireland. In this field, there was undoubtedly a need for quality control. It might be of interest to mention that in southern Sweden the ready mixed concrete manufacturers had formed a testing association. This association operated quality control on materials and mixes, and members who were subjected to that control, sold their concrete as a controlled mix.

He had been interested in the references to modular construction. Had they not been made, he would have felt it his duty to raise that subject, not so much because engineers had to be convinced of the utility of modular construction, but because comment on it might attract the interest of other professions, who perhaps required more convincing.

Mr. Duggan had mentioned the University College boiler house. Here Professor Hogan found it necessary to speak very carefully. As chairman of the Symposium he fully agreed with Mr. Duggan that the work on that building should be illustrated. It was good to be objective and show faults where they existed. On the other hand, as a member of the College Building Committee, he felt he should say that their consultants were in no way to blame for matters which had arisen outside their control. The facts were that the boiler house had been a very rushed job, and for a very simple reason. On the one hand, planning permission had been held up for the longest possible statutory period, while on the other, 1200-1400 students were working in Belfield and had to be given heat.

Mr. Duggan in his paper had referred to the importance of experimenting on finishes. Professor Hogan said that he had recently seen, at the new university of Lund, a building which had been erected specially for the purpose of testing finishes. It was, in essence, a great big empty space with a concrete floor, where experimental spraying, "guniting" and other finishing could be carried on.

The Chairman then asked for further contributions to the discussion.

MR. T. J. S. MALLAGH felt that in view of the praise given earlier in the Symposium to Colcrete, he would like to mention his experience of it. On some five or six occasions when he had used it, he had been informed each time that previous poor results had been due to an incorrect procedure at some stage of the process, and that these would not occur again. After all this, cubes cut from Colcrete placed in what was supposed to be finished work had given a best strength of 975 p.s.i. and two results of 350 p.s.i. These were not trial cubes, but were from what was supposed to be finished work.

Mr. Lynam had said that the aggregate must not be coated with mud or any similar contamination. How, one might ask, could the aggregate be kept clear of such contamination if the water in which the Colcrete

was being made was, as it frequently was, laden with silt? Mr. Lynam had mentioned a figure of 4000 p.s.i. on a specially-made test cube made under ideal conditions. Could he say however what results, if any, had been obtained on cores cut from the concrete in the piles which his slides had shown.

In Mr. Mallagh's experience, Colcrete cost considerably more than underwater concrete traditionally placed, and he had yet to be convinced that it was a superior product.

MR. J. G. J. OWENS referred to Mr. O'Leary's comments in Session D on the potential danger of corrosion in small diameter wires in prestressed concrete. Mr. O'Leary had felt that many engineers were suspicious about this matter. Mr. Owens would agree that they were, but in his opinion unjustifiably so. Good concrete was dense and durable, and concrete in prestressed members had to be good, as otherwise its weakness would show up through failure of one form or other when the prestressing force was applied. Further, it was a fundamental of prestressed concrete design that all of the concrete in a member was permanently in a state of compression or near-compression. There was not, therefore, the same tendency towards the development of small cracks that there would be in reinforced concrete. In general it appeared to Mr. Owens that the durability of a prestressed concrete member should not be any more suspect than that of any reinforced concrete member made with dense concrete. The long-term performance of prestressing steel had been given exhaustive study in the research laboratories and in the field. As regards relaxation of steel under stress, long-term laboratory tests, based on an initial age of 100 days, showed virtually no relaxation from the stress at that age to the stress existing up to 20 years later. As regards the vexed problem of the efficiency of grouting in ducts, research and field examination on an international scale indicated that imperfect grouting did not generally lead to corrosion of the stressed wires. Anxiety about this was largely dispelled through reports submitted to the fourth Congress of FIP. The opinion of these reports which factually revealed little damage from corrosion, was that the very exclusion of air from the ducts and the alkaline characteristics of the moisture remaining on them preserved the wires from attack.

Referring to specific jobs, Mr. Owens considered the road bridge at Avoca to be a very satisfying application of standard precast decking units, and an excellent example of what could be done with low cost construction. He had admired the spiral stairway at the Esso offices. He presumed that the central core of that stairway was reinforced concrete. He felt that a core of that type could, with advantage, be prestressed. The detailing and erection of the stairway would thereby be simplified, and, of course, the hole in the core centre could be reduced to 1½" to 2" diameter.

Regarding the techniques of prestressed concrete design and construction at present practised in Ireland, Mr. Owens observed that we were not making use of the technique, now well established, of varying

where desirable the imposed force in members to suit the constructional sequence. This could be done more or less at will, and it could be used to control such factors as handling stresses in elements of prestressed portal frames, and the formation of moment-transmitting connexions in such frames.

MR. T. M. DUGGAN asked permission to clarify his comments on additives, made earlier in the Symposium, as from remarks made to him, he was afraid they might have been misunderstood. Concrete mix design, in his opinion, should never begin by stating the additives which would be used. Design should begin by examining all available aggregates, and devising suitable trial mixes with those selected. Only when that stage had been reached, should the decision to use, or not to use, an additive, properly be taken.

Regarding fair-faced concrete, he did not wish to go on record as attaching blame to anyone for failure to produce perfect results. The future of fair-faced concrete relied on the removal of the idea of blame from any comments on the work as done. Any team which tackled the problem was to be admired, and the better the results, the higher the praise. The subject was difficult, and one's attitude towards a result tolerably less than perfect should be sympathetic rather than harshly critical.

MR. J. H. HARBISON suggested that concrete had to be classed as essentially feminine, in that it was, if treated ungallantly, completely unpredictable and ungovernable. The likeness was enhanced by the high costs involved in providing a fair-faced finish.

He regretted he had been unable to attend all the sessions, but was grateful for the excellent summaries of the discussions which had just been given by the reporters.

The importance of precast concrete had been properly stressed during the Symposium. He wondered, however, whether the quite obsessive interest which existed in finishes had not unduly overshadowed the other obvious and, in his opinion, more important advantages of precasting. Control of manufacture, control of movement of the finished structure (e.g. in the Cadbury factory illustrated earlier) and flexibility in the placing of contracts to accelerate the overall rate of building (e.g. in the Telefilm studios) were very important merits in favour of precasting. These, or other such features, were primary in influencing his decision to precast in any given project. That certain finishes were in fact obtained was in his opinion merely putting to good use the further possibilities of precasting.

Regarding the relative merits of natural stone cladding and concrete cladding he would stress that concrete was not intended to be compared with natural stone. Although they had certain common qualities, they were different materials, and concrete processed to resemble stone could only be considered as a substitute material at best. On the other hand, natural stone was not necessarily a flawless material either;

an examination of the granite facing slabs of the new Belfield blocks would make that apparent.

MR. J. P. O'F. LYNAM in a written contribution stated that he was sorry Mr. Malagh had been so unlucky with Colcrete. After the Symposium had taken place, he had had 6" cores taken from a complete pile crushed with the following results (average of six cores)

Equiv. Cube Strength :	2710 lb./sq. inch
Density :	156 lb.
Grout :	1 part cement; 1½ parts sand
Aggregate :	6" - 2" crushed (i.e. angular).

The lowest strength obtained was 2,252 lb./sq. in.; in this core there was a large piece of aggregate, one face of which lay at about 45 degrees to the axis of the core, and which occupied nearly the complete cross-section of the core; failure occurred along this face. This illustrated Mr. Lynam's point that 6" cores or cubes were hardly large enough to give satisfactory test results.

With regard to the 4000 lb./sq. in. 30" test blocks made in India, Mr. Mallagh would never have described the conditions under which they were made as "ideal" if he had seen them!

With regard to cleanliness of aggregate, Mr. Lynam pointed out that it was usual to clean out bored piles thoroughly with an air lift or similar mechanism, to ensure a good bond with the foundation rock. The amount of material remaining in suspension in the water was insignificant. He had never attempted to "colgrout" in muddy water, but he considered that some reduction in strength would occur.

THE CHAIRMAN then closed the Symposium.

He received with favour the views expressed during the proceedings that private firms should sponsor research. Last Session there were in University College, Dublin, six post-graduate students in Engineering who were receiving outside support, and this form of sponsorship would, he hoped, develop.

A word of warning might be permitted in reply to those who advocated a special concrete research station. It was not easy to find people who wanted to do research, and were capable of doing it. A special station might tend to "spread the butter too thinly" and it seemed advisable not to contemplate a new establishment, until the facilities in the existing laboratories throughout the country were being used to capacity.

Professor Hogan welcomed Mr. Harman of the Reinforced Concrete Association as a valued contributor to the Symposium. His presence as a visitor from outside Ireland had been greatly welcomed by the members.

He extended also a special welcome and word of thanks to Mr. Bill O'Connell for attending and joining into the discussions so freely.

The applause of the members left no doubt that they shared with him in his tribute to Mr. O'Connell and Mr. Harman.

In conclusion Professor Hogan thanked the authors, and the reporters for their cooperation and for the care they had put into their work; and he thanked all those who had contributed to the discussion and thereby to the success of the Symposium. He congratulated the Dublin Duplicating Company on the excellence of their work in the preparation of the printed papers. Of their devotion to duty he could not say enough. It might be sufficient to reveal that while the printing was in progress, he himself had been telephoned as late as 11 o'clock at night to verify a doubtful spelling.

He thanked the firms, and especially Cement Limited, for the book displays which they had mounted during the Symposium. He thought also that as this Symposium had been the first major outside function to be held in the new Theatre Block at Belfield, the members might like to join with him in thanking the Belfield staff, and in particular the catering staff, for their ministrations.

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