

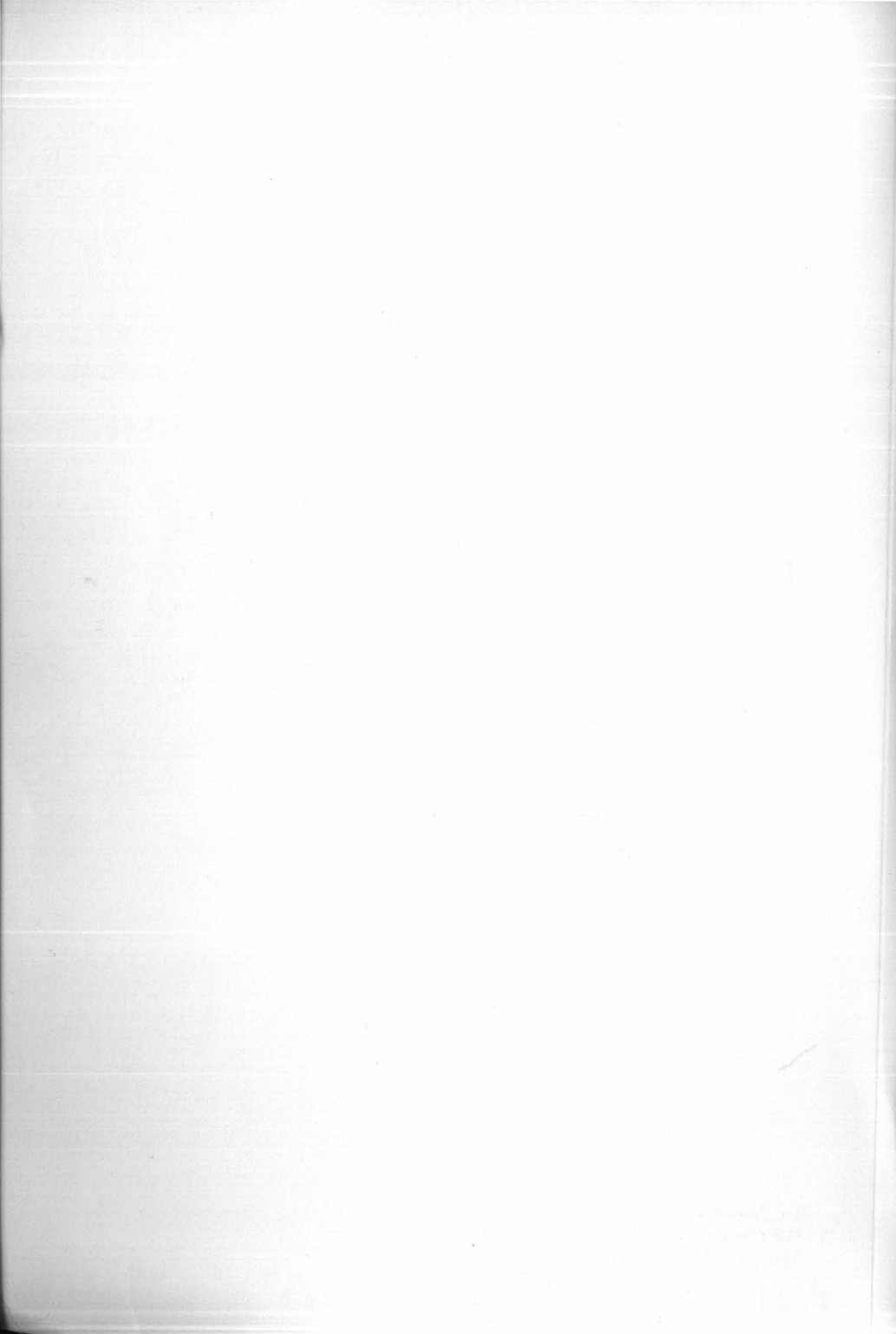
CONCRETE PRACTICE IN IRELAND 1995

SYMPOSIUM

MAY 1995



UNIVERSITY COLLEGE
DUBLIN



CONCRETE PRACTICE

IN IRELAND

1995



**Proceedings of a Symposium
held at University College Dublin
in May 1995.**

Published by
Department of Civil Engineering,
University College Dublin.

Papers and discussion of the Fourth Symposium 'Concrete Practice in Ireland', held at University College Dublin, Republic of Ireland, 10-11 May 1995.

Symposium Organiser: Seoirse Mac Craith.

Irish Practice in Engineering

No. 6: Concrete Practice in Ireland 1995

ISBN: 1-898473-54-4

Editor: Mark G. Richardson.

Previous publications in the series 'Irish Practice in Engineering':

No. 1: Concrete Practice in Ireland 1965

No. 2: Structural Steelwork in Ireland 1967

No. 3: Concrete Practice in Ireland 1975

No. 4: Concrete Practice in Ireland 1985

No. 5: Aspects of the Irish infrastructure - present condition and future needs - 1990

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FOREWORD

MR. AODH DOWLEY, B.E., M.S.

Head of Department,
Dept. of Civil Engineering, University College Dublin.

The Proceedings recorded in this volume relate to the fourth decennial Symposium in the "Concrete Practice in Ireland" series. The symposium was held at University College Dublin on the 10th - 11th May 1995.

The publication of this volume provides a state-of-the-art-review of concrete practice in Ireland in 1995. Additionally it may be placed with the three previous volumes to provide a record of developments in thought, technique, regulation and materials in the concrete industry over the last forty years. The existence of these important records of contemporary practice did not happen by chance. They are the result of the farsightedness of Professor J. W. de Courcy who initiated the series in 1965 and who established their importance as benchmark symposia through the success of the subsequent meetings in 1975 and 1985. His advice was sought by the organisers of the 1995 event who were also grateful to him for presenting a thought-provoking opening address.

The structure of the four symposia has remained unchanged. Seven papers cover different facets of concrete practice with authors, chairpersons, lead speakers and rapporteurs chosen for their expertise and diverse perspectives. This standard format, far from indicating any lack of imagination on the part of the organisers, illustrates the qualities of durability and continuity which are inherent in concrete artefacts of the highest quality!

The Department of Civil Engineering at University College Dublin is indebted to all who contributed to the success of the 1995 symposium through their attendance, authorship of papers, chairing of sessions or participation in discussion. We are especially grateful to Mr. Seoirse Mac Craith to whom the 'baton' of the Concrete Practice series was passed and whose organisation of the event ensured that the previous high standards were maintained.

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OPENING ADDRESS

Professor John W. de Courcy.

M.E., C.Eng, Hon.F.I.E.I, F.I.Struct.E., Hon.F.I.C.T., Hon.M.R.I.A.I

Opening the proceedings, Professor de Courcy stated that he was honoured to be invited to offer, as it were, a prologue for Concrete Practice in Ireland. He wished to consider where we had come from in the last 40 years since the period covered by this series of symposia began, and then, particularly as this was the final 20th century symposium in this series, consider where we may go in the 21st century.

In 1955, we were making very good concrete in Ireland. The age of thin shell roofs was in full swing, prestressed concrete was well established, although its early exponents were still circling around it with a wariness appropriate to their limited experience; virtually all concrete was being made on site; cement was simple, extremely good, and consistent; aggregates were basically as sound as they are now, although washing sometimes required an imposition of will; interesting precast concrete was being used for particular works, with the vast preponderance being purpose-designed rather than off-the-shelf standard units. Fair-faced, self-finished, often unpatterned, in-situ concrete was the delight of some architects, and could all too frequently be a disappointment.

In a second primary aspect of the time, we did have, wisely, our own standards for cement and aggregates, but for concrete, reinforced concrete design, loading norms, and for official approvals generally, we accepted the wisdom of British practice. There were the rare innovators who might appeal to American standards on some particular topic but they were very much the exception to the rule.

In a third primary aspect, formal education in concrete design and technology were almost totally limited to undergraduate programmes, with very occasional resort to the short courses offered in England by the Cement and Concrete Association at Fulmer Grange, and the Building Research Station at Garston. Seminars in the field of building in Ireland were almost non-existent, and in general I believe there were no short courses of any kind relating to concrete in Ireland in 1955.

On the site, there was no formal training for concrete workers. A pivot of the concreting gang was the "man at the mixer", a shrewd observer of mix proportions and arbiter of the water content. Mixing by volume was still widely practised, and that was a process of many peculiarities.

Tower cranes, concrete pumps, off-site or ready-mixed concrete, all were virtually unknown, and the mushroom growth of industrialized precast concrete system construction was still many years in the future.

These apparent shortcomings did not imply that the period was a dark age of concrete. Far from it! Apart from the deep building recession of the 50's, the concrete industry was energetic and highly competent in 1955. And very many structures designed and built at that time are in service today with generations of useful life ahead of them.

How then has our concrete practice developed in Ireland during the last forty years? Perhaps we might distinguish four strands of development, if indeed we can tease them apart.

The first strand is Europe. In 1955, the frameworks of rules and regulations governing concrete and reinforced concrete were nationally parochial. Countries such as France, Germany, Britain, United States of America, USSR, shared a more or less common philosophy, but their official regulatory documents were sacrosanct. Those of one country could not be appealed to in another as a matter of right, and an international will did not exist for harmonisation.

In Ireland, North and South, we paid little attention, in general, to international differences of opinion, as we followed the British rules, even at times when an anomaly arose, such as basing the testing of aggregates largely on Thames Valley flint, a material unknown in Ireland as an aggregate. However, the rules generally served us well, and our building was sound, if perhaps rarely over-adventurous.

Now, under the influence of Western Europe, we have entered, in the Republic, into international discussions, as an increasingly well-informed, knowledgeable, and industrious member of the transnational community; and we are feeding into its literature our own views as to what we should like European standards and regulations to be. It is probable that in 1955 there was no engineer, architect, or technologist from the Republic on any British concrete committee, let alone on any committee based in mainland Europe. We are now capably represented on a wide variety of European committees, both in design and technology, helping to establish harmony between national practices; and indeed some of our engineers are even now occupying important positions in transnational European bodies and organizations. We have also replaced a number of the British documents, on which we relied, with local documents, more appropriate to our own practice.

In a second strand, education, any who has watched the development of education in concrete here since 1955 must be awesomely impressed with the opportunities that have increasingly been given to designers, technologists, contractors and manufacturers. Seminars, short courses, single lectures, all of high quality, have proliferated, and have been warmly supported.

Research into concrete matters is now vigorous in many centres throughout the whole country.

In the Republic, the Institution of Engineers, the Irish Concrete Society and its predecessor, the Irish Prestressed Concrete Association, the third level academic bodies, FÁS, the Construction Industry Federation, have played their part. The recent encouragement of the Institute of Concrete Technology in Britain, through the very successful extension of its programme on Advanced Concrete Technology to an Irish centre, has added an extra dimension to our potential in the understanding of concrete as a material.

The third strand is the ongoing enrichment of our perception of concrete in structure. The annual awards of, in particular, the Irish Concrete Society for excellence in building produce, year after year, admirable accomplishments in all modes of reinforced concrete and structural blockwork. The structural and aesthetic design of our bridges, which has always been a matter

of pride in Irish concrete practice, is now on a par with the best the world can offer, always, of course, recognising that our terrain and traffic requirements rarely make the same dramatic demands on our skills as might be experienced in some other countries.

These comments lead inevitably to the fourth strand in our development - excellence in design remains mere artistry until the structure is built, and then if it is built clumsily and inefficiently, all the design excellence in the world cannot produce a great completed building. It is the finished building, whatever purpose it serves, that comes to judgement, and it is, I believe, the experience of all of us that the contractors in Ireland and their staffs are those who actually show us in three dimensions just how our overall perceptions and skills have developed in the last forty years.

I am at this juncture very conscious that I am speaking in a celebratory way to an Irish audience. To speak in this manner to an audience of several nationalities would be, perhaps, somewhat impolite, and maybe brash!

If all this is where we have come from, where now are we going? What should we be looking out for? What should we be anticipating in the dialogue that our buildings must unceasingly hold with their environment as they make their way towards the year 2100?

May I again use four headings and offer just some ideas?

Firstly, in the area of economics: the precise professional significance of design life must be determined; whole life costing of buildings, including maintenance, will be recognised as normal, using some design life as a basis. Improper economic pressures on the rate of building will, hopefully be resisted. Flexibility of function will be a factor in design; and conservation of older buildings will be closely examined.

Secondly, regarding the quality of what we build, we might distinguish two aspects, structural quality and visual quality. Other things being equal, we now know enough about structural theory and loading - not absolutely I hasten to add!! - but enough to ensure an adequate structural response from all our ordinary buildings. The emphasis instead will be on durability. The use of sacrificial concrete in marine structures may receive some attention. Cover to reinforcement will be addressed, and more effective cover, including a successful campaign against carbonation, will be a major advance. All concerned will probably be eventually persuaded that site practice requires formal training. The proper and just training of the concrete worker as a craftsman of pride will come, and will greatly influence our work.

For the visual quality of concrete building, we should see architects and engineers studying, coming to terms with, and using surface textures and treatments and profiles, both broad-brush and detailed, that are appropriate to our climate, producing surfaces that will consequently offer a quiet vitality to older buildings rather than the down-at heel, unkempt, dull and stained elevations we sometimes see today. Think for a moment that one of the most admired river bridges in Dublin, still serving a full modern function, is an arched masonry design by Vallancey, built in 1768 and so now about 230 years old. What could be done then can be done now.

Thirdly, speaking of processes: we will surely see a move towards more factory-based precasting, both for individual projects and for mass-production. Our precast concrete industry is of high quality and, generally, has a large potential. The mass-production of industrialized building elements must come back into favour, despite the damage done to it twenty-five or so

years ago. I believe this resurgence will be founded on a so-called "open system" using basic mix-and-match elements rather than on the competition of introverted closed systems, which must suffer in a small country from the frustration of short production runs.

In this area of processes, may I mention two uses of mass concrete. Clearly we have, at present, the materials and the ability to manufacture concrete blocks of high and consistent quality; and we shall be building on this to maintain and develop our widely-recognised skills in structural masonry in concrete. If this medium offers visual excellence, it will become a mainstay of the building industry in Ireland. As a second application of mass concrete, which I offer for debate, perhaps a little idiosyncratically, but soundly on the bases of appearance, durability, and cost - that we should be considering the principle of the mass concrete arch for the numerous small span bridges we shall require in our overall roads programme. The arch might be adopted not only in-situ, but also as precast in the form of factory-made voussoir units.

Under the fourth heading, may I mention materials. Quite obviously the world-wide study of cement will continue. While a continuation of the regime that has worked so successfully in Ireland for the last fifty years would be no harm, world research in this field cannot be ignored. I have no doubt whatsoever that we shall benefit from this research, but that at the same time, our technologists will protect our local reputation, and we shall never be required to risk our buildings to imperfectly-proven materials. One cannot overlook, for instance, in our history, the abuse of high alumina cement, or the rise and fall of calcium chloride.

The other basic material is aggregate. Here in Ireland we shall, hopefully, continue to rely on our abundant natural aggregate sources, even while we sympathise with some of our overseas cousins who are being forced towards very peculiar aggregates, because primarily of the paucity of the natural sources available to them. Let us be grateful for our good fortune!

So then, where do we stand today? This symposium comprises seven important papers and a critical audience. The proceedings of the symposium should, therefore, provide a fair idea of where we stand today. I, for one, am looking forward to finding out!

SESSION A

STANDARDS, CODES AND REGULATIONS FOR CONCRETE

N. V. TORPEY, C.Eng, F.I.Struct.E, F.IEI
National Standards Authority of Ireland.

Sessional Chairman

N. M. RYAN, M.A.I., C.Eng, F.IEI, F.I.Struct.E
Department of the Environment.

Abstract

This paper deals with the standards, codes, regulations and relevant legislation of significance to the practice of construction in concrete in Ireland. Its scope in time is the period 1985 - 1995, with some reference to likely future developments, and it deals with documents prepared in Europe, Ireland and Britain.

1. BACKGROUND.

1.1 Introduction.

This is the fourth of the decennial symposia on 'Concrete Practice in Ireland' which have occurred regularly since 1965. These symposia reflect the significant events of the preceding decade and we are fortunate in having a continuous record of the national developments in the general subject of concrete technology now with this symposium covering a total period of forty years. It is appropriate to acknowledge that we in Ireland are probably unique in Europe in having such a record, and its value should be recognised.

It is also appropriate to mention that the topics of *standards* and *codes* (with slightly varying titles) have been the subjects of the first paper in the symposia so far held, reflecting a continuing interest in the subject, and a desire to record the current state in an activity which has rarely been inactive and that is now moving at an ever increasing pace. Much of what is said in this paper has its parallels in the other major structural materials of *masonry*, *steelwork* and *timber*, without unfortunately the valuable backdrop of the recorded proceedings of their own symposia, such as is available for concrete.

This paper has the subtitle the *practical realisation of a harmonised Europe* and this is considered in the light of the current work, both national and European, which has as its agreed aim a harmonised Europe.

The purpose of this paper is to review the significant events of the period 1985 - 1995 and to discuss tentatively the likely shape of future developments. References to future developments are made recognising the fact that reporting the past involves the exact, if

unexciting science of hindsight with mere human fallibility as a hindrance, while the future involves the exciting if doubtful pursuit of prophecy, or its more prosaic and secular relative, prediction, in which opinions are many and of equal validity.

It is necessary to immediately dispel any assumption of completeness in this review since the programme of standards work in Europe is substantial and many topics will be referred to only in passing. The pace of this work shows no signs of slackening and national standards drafting work also continues, if a reduced activity. It is also necessary to dispel any assumption that the subtitle of this paper *the practical realisation of a harmonised Europe* is any more than an indication of the willingness on the part of the countries of Europe to achieve this purpose. The goodwill of the nations of Europe is clearly in evidence in the work to be described but this does not necessarily imply that the preparation of the large corpus of standards currently in hand will introduce *uniformly applicable practice* in Europe, at least in the immediate or short term future.

It is necessary also to realise that being prepared are the *first editions* of European standards, which with revisions and other developments will be with us for the foreseeable future. Taking these ideas of *first editions* and *uniformly applicable practice* into account, they have the effect that many European documents are published somewhat tentatively, or experimentally, as *European Prestandards* rather than *European Standards*, and national standards and other documents will continue to exist for some time to come. It is also appropriate to point out that large and all as the work programme of preparing European Standards is, there will be a continuing need for strictly national standards documents for the foreseeable future, at least in some areas.

The wide range and the on-going development of European activity is a continuing and relentless factor in standards work. It is the object of the national standards bodies to try to keep abreast with the pace of European activity and to form the focus for the national input into the gradual harmonisation of Europe.

As a general point of introduction, it is perhaps desirable to mark our position in time and place and to record that:

the period under consideration has seen important developments take place in the preparation of standards, codes, regulations and legislation in both Ireland and Europe, the continuing effects of which will be with us for the foreseeable future, and will have an increasing effect on concrete practice;

it is now essential that we consider ourselves an integral part of Europe, with all that this implies for our historical closeness to Britain and to British influence on our industry, and to our historic and easy acceptance of their documents. There is no alternative therefore to the development of national mechanisms for making agreed input into European discussions. The attitude of saying 'me too' to a British proposal in Europe is not an appropriate response, unless supported by knowledgeable Irish comment. A part of the purpose of this paper is to describe the level of authority and responsibility we now have for our own concerns.

It follows that the technical input and the organisation of that input which we have not needed to make in the past, due to the ready availability of British documents, now assumes an importance and an urgency which it is sometimes difficult to impress on interested parties in Ireland. Irish technical opinion must now be generated and transmitted to Europe, and one of the purposes of the NSAI is to facilitate this.

In the corresponding paper to the 1965 Symposium the need for an Irish code for concrete was referred to by John Gwynn who said '*...it appears unlikely that any advantage would be obtained by the adoption of an Irish Code of Practice (for concrete). It is possible, however, that the introduction of an Irish Loading Code might be considered advantageous...*'. The reference to a proposed Irish Loading Code was in the context of Irish wind speeds, and the effect of wind loading on the design of building structures. In the sometimes unsatisfactory way that events turn out it is instructive to note that in the intervening thirty years, an Irish Code for concrete has been published but not one for loading.

By the time of the 1975 symposium, CP 110 had been published some three years, with the comment recorded by James Harrington '*...It is a considerable time since the introduction of any standard relating to concrete... has caused such a volume of comment and controversy...*'. CP 110 was replaced by BS 8110 in 1985. The relatively short life of CP 110 is noted, as is the continuing desire to retain its predecessor, CP 114, which has the support of its, if now ageing, adherents and if now available under the relatively anonymous title *Recommendations for the permissible stress design of reinforced concrete building structures* and published by *The Institution of Structural Engineers* in London.

In the 1985 symposium the documents recorded by John Scannell included the Irish codes for Concrete and Masonry, then being prepared. These were duly published and as important national documents they have shown their need for attention by way of revision and amendment.

2. LEGISLATION.

2.1 Legislation in Ireland.

The enactment of the following pieces of Irish legislation is recorded.

The basic and long signalled piece of legislation was the *Building Control Act, 1990*. This Act empowered the Minister for the Environment to make the *Building Regulations, 1991* Order and the *Building Control Regulations, 1991* Order introducing the Building Regulations; these came into operation on June 1st, 1992. The Regulations formalised in legislation the basic rules which historically had been used by at least some parts of the construction industry.

However, it was the publication of the *Technical Guidance Documents, 1991* which gave the event more immediate importance by providing for the first time official recognition, if in a circumscribed way, to the numerous standards and codes of practice and other documents of common knowledge and use.

For an industry not specially noted for its effect on the Legislature, or for the Legislature's attention to the technical affairs of the construction industry, the period also saw the passing of the *Local Authority (Multi-storey Buildings) Act, 1988* and the making of various Ministerial Orders by its authority. The origin of this legislation lay in the events of early 1987 when gas explosions occurred at Raglan House and Dolphin House in Dublin. The subsequent reports by consultants appointed by the Department of the Environment and by a Task Force contained numerous recommendations. It is noted that of the 33 recommendations contained in the Task Force report dealing with the general problem identified, only two referred to building structure. It was, however, these two recommendations that the legislation addressed, some have felt somewhat unnecessarily. The preparation of this package of legislation was discussed at length by many Irish engineers who themselves made recommendations, without, however, complete success in having them acted upon.

Finally under the *European Communities Act, 1972*, the Minister for the Environment made the *European Communities (Construction Products) Regulations, 1992*, which came into operation on January 1st 1993. The purpose of the regulation was to give effect to the Construction Products Directive. These Regulations were subsequently amended in 1994.

2.2 Other documents.

While not strictly part of the topic it is appropriate to record the publication in 1991 of the report on *Alkali-silica reaction* prepared by a joint working party of the *Institution of Engineers of Ireland* and the *Irish Concrete Society*. This report deals with the means to be adopted to minimise the possibility of alkali-silica reaction in concrete in the circumstances of Irish practice. The opinion has been expressed that reports such as these remove from the Irish concrete industry the need to follow British practice which may be of no great relevance to Ireland (a thankfully rare occurrence). In any event, reports such as this have great value in European discussions, and may be regarded as one example of Irish technical input into these discussions which is and will be a continuing part of our work in the future.

2.3 Legislation in Europe - European directives.

The adoption of a number of European Directives is recorded.

Construction Products Directive (89/106 EEC) (CPD). This is the fundamental European document relating to construction products. It is dated 21 December 1988 and deals with the approximation of laws, regulations and administrative provisions of the EU's member states relating to construction products. The CPD requires the member states not to impede the *free movement, placing on the market, or the use in their territory* of products which satisfy the provisions of the CPD. The CPD is a complex document and the manner of its application causes some continuing discussion among those involved in Europe.

To satisfy the provisions of the CPD construction products must be of such a standard as to enable the construction works into which they are incorporated to meet the six *Essential Requirements*, which are:

Mechanical resistance and stability

Safety in the case of fire
Hygiene health and the environment
Safety in use
Protection against noise
Energy, economy and heat retention

The CPD requires that *'the construction works must be designed and built in such a way that...the essential requirements can be satisfied...for an economically reasonable working life.'* Each of the six essential requirements have been elaborated in six *Interpretative Documents* (ID 1-6) which were published by the EU Commission in February 1994.

The effect of the CPD on the Building Regulations is in Part D *Materials and Workmanship*. In this Part, the expression 'proper materials' is used and such materials are defined as those which bear the CE mark in accordance with the CPD. The CE mark indicates that a product bearing it can, in use, comply with the CPD. The coming into operation of the CPD does not mean that all of its provisions are in effect; many of these, particularly in the area of construction products compliance criteria are still under active discussion in the Commission and elsewhere.

There appears to have been relatively little technical discussion in Ireland among engineers of the Interpretative Documents, but one in particular which appears to have great potential significance is ID 3 *Health hygiene and the environment*. It requires the works to be designed and built in such a way that the works will not be a threat to the hygiene or health of the occupants or neighbours. Annexes IA, II and V of this ID deal respectively with the *air quality* of the indoor environment, *water supply* and the *outdoor environment* and requires the 'pollution from building materials' to be controlled. The wording 'pollution from building materials' is used in ID 3. For those of an imaginative disposition, it can be sobering reading.

ID 3 has significance for the very wide range of naturally occurring and industrial residue materials (eg aggregates, slags from metal smelting and industrial pozzolans, and ash) currently used in the European concrete industry and referred to in the European standards now being prepared. It is essential that the matters dealt with in this ID be

considered *seriatim* in the event of concrete (or its constituents) of 'anonymous origin' being proposed or presented for use, possibly with price as the only or principal criterion of consideration in the 'brave new world' of the open markets in the future.

There are six Directives in the area of public procurement, and these are:

The Supplies Directive (93/36) EEC
The Works Directive (93/37) EEC
The Remedies Directive (89/665) EEC
The Utilities Directive (93/38) EEC
The Utilities Remedies Directive (92/13) EEC
The Services Directive (92/50) EEC

These directives have an influence on industry and services generally, and introduce the requirement for 'transparency' (or the dissemination of information) in the granting of contracts. The combined effect of the directives is to require the reference, as they exist, to European Standards or European Technical Approvals in contracts.

3. STANDARDS PREPARATION - BACKGROUND.

3.1 ISO Standards.

The International Organisation for Standardisation, ISO, has its headquarters in Geneva and is the world-wide standardising organisation. However, its influence on the topic in hand is limited and what there is of it is considered in the context of the work of CEN. A formal agreement exists between ISO and CEN, called the 'Vienna agreement', the purpose of which is to avoid the duplication of effort which could arise if the two organisations were to progress their work programmes in isolation from each other.

3.2 Standards preparation in Europe - CEN.

The European standards organisation, and the focus of what follows, is the *Comité Européen de Normalisation* (CEN) and is the international organisation responsible for the preparation of European standards. Legally, it is an international association established under Belgian law and was registered as such in 1976. The earlier history of CEN goes back to the 1960s when it was first established. It now exists as a non-profit organisation of a scientific and technical nature and its headquarters are in Brussels.

The full members of CEN are the national standards organisations of the EU and EFTA countries, a total of eighteen; the Irish member is the NSAI. With the demise of the Soviet Union and the political changes which followed in central and eastern Europe, the countries of Poland, the Czech Republic, Hungary and others have now become 'CEN Affiliates', and these are being joined by some Mediterranean states, Turkey and Cyprus being examples, making a current grand total of 28 members in all.

3.3 CEN - BTS 1.

The organisation of CEN standardisation activities is shown in Annex 1. In some technical areas CEN has established Technical Sector Boards (BTSs) and the first of these is BTS 1 which deals with *building and civil engineering*. BTS 1 is responsible for approving the work programme and monitoring the progress of the Technical Committees (TCs) in its area. The primary authority for the preparation of draft ENs is delegated to an individual TC. BTS 1 regularly reviews the work programmes of the TCs to achieve the optimum efficiency in and co-ordination between them. In the particular case of concrete the relevant committees are

- TC 51 Cement and building limes
- TC 104 Concrete (performance, production placing and compliance criteria)
- TC 125 Masonry (*only in part*)
- TC 154 Aggregates (*only in part*)
- TC 177 Prefabricated...AAC components
- TC 178 Paving units and kerbs
- TC 227 Road materials (*only in part*)

TC 229 Precast concrete products
TC 250 Structural Eurocodes (*only in part*)

Other TCs deal in a less obvious or peripheral way with concrete or its properties or uses eg,

TC 50 Street lighting columns
TC 89 Thermal performance of buildings and building components
TC 127 Fire safety in buildings
TC 166 Chimneys
TC 167 Structural bearings
TC 288 Execution of special geotechnical works
TC 297 Free-standing industrial chimneys
TC 298 Pigments and extenders
TC 303 Floor screeds and in-situ floorings in buildings

Taking the preparation of one new European Standard as a work item, the total number of work items at present in hand in the TC structure is over 9000. At present about 400 completed European Standards are being completed per annum, and it is clear that many years of work are before us before a complete body of European Standards becomes available to industry. The rules applied to this activity are given in outline in Annex 2.

4. CEN - WORK PROGRAMME.

4.1. CEN - current published standards and future work programme.

TC 51 Cement and building limes

This TC was set up in 1973, and its Secretariat is in the Belgian Standards body, IBN. Its work programme is easily the most developed of the important CEN committees dealing with concrete and its constituents.

Its published European Standards are

IS/EN 196:Part 1:1991 Methods of testing cement - Determination of strength
IS/EN 196:Part 2:1991 Methods of testing cement - Chemical analysis of cement
IS/EN 196:Part 3:1991 Methods of testing cement - Determination of setting time and soundness
IS/EN 196:Part 4:1991 Methods of testing cement - Quantitative determination of constituents
IS/EN 196:Part 5:1992 Methods of testing cement - Pozzolanicity test for pozzolanic cements
IS/EN 196:Part 6:1989 Methods of testing cement - Determination of fineness
IS/EN 196:Part 7:1990 Methods of testing cement - Methods of taking and preparing samples of cement
IS/EN 196:Part 21:1990 Methods of testing cement - Determination of the chloride, carbon dioxide and alkali content of cement
ENV 197-1:1993 Cement - Composition, specifications and conformity criteria - Part 1: Common cements
ENV 197-2:1995 Cement - *Conformity evaluation* (being prepared)

The technical matter about cement and its makeup is that in international discussions questions of the *cement content of concrete* can have very different implications in different countries in view of the widely varying *constituent contents of cement* in Europe. This has an inertia effect and discussions on the durability aspects of concrete can be heavily influenced by national experience of cement production and use.

TC 104 Concrete - performance, production placing and compliance criteria.

This TC was set up in 1981 and was the development of an earlier TC 94 *Ready mixed concrete*. TC 94 was absorbed into TC 104 on its inception. Its Secretariat is in the German Standards body, DIN. Its published European Standard is IS/ENV 206:1991 Concrete - performance, production placing and compliance criteria.

This committee deals with the European rules for the specification and construction in structural concrete and in that sense is a parallel committee to TC 250/Subcommittee 2 which prepared Eurocode 2. Liaison between the two groups is maintained.

The major part of the work of TC 104 is the development of ENV 206 into EN 206. This is a large and complex task, which the TC has allocated to Subcommittee 1 and which has in turn set up numerous Task Groups to help in particular parts of this work, i.e., *Durability, Chemically aggressive environments, Conformity criteria, Strength classes, Additions, Precast elements, Curing, Test methods, Alkali silica reaction, and Attestation of conformity*. The test methods for concrete will be (or be based on a development of) the ISO tests prepared by ISO TC 71.

The other functions of TC 104 are allocated to other Subcommittees and Working Groups as noted in Annex 3.

At the most recent meeting of TC 104 in Berlin the matter of time scales was discussed and it was agreed that prEN 206 would be available for Enquiry in August 1996, and for Formal Vote a year later. It was also agreed that ENV 206 should not be withdrawn until EN 206 has been made available. At the same meeting a report from the group preparing the proposed EN for *Silica fume* was presented and it showed that the drafters are taking the topic *Health hygiene and the environment* described in ID 3, into account. The significance of this point has been referred to earlier in the context of the CPD.

TC 125 Masonry was set up in 1987 and its Secretariat is in the British Standards body, BSI. It has so far published no European Standards. This TC deals with the entire range of masonry materials and test methods and so much of its work has little effect on the concrete industry as such, but it is responsible for:

- Aggregate concrete masonry units (dense and lightweight aggregates)
- Manufactured stone masonry units
- Lintels (*includes concrete as a material of manufacture*)
- Masonry mortar

These documents have, of course, a substantial effect on the concrete masonry industry, and are the object of considerable attention from Ireland. We are also keeping a close eye on the test methods for the compression testing of units, with a view to ensuring that our current satisfactory practices can continue. The drafts have been distributed for CEN Enquiry and will be distributed for Formal vote, it is expected, this year, or early next.

TC 154 Aggregates was set up in 1988 and its Secretariat is in the British Standards body, BSI. It has so far published no European Standards.

This TC grew out of the discussions in TC 104 which recognised the need for ENs for aggregates. It is responsible for:

- Aggregates for mortar
- Aggregates for concrete
- Bituminous bound aggregates
- Hydraulic bound and unbound aggregates
- Lightweight aggregates
- Test methods (36 items)

Some of the work items in this TC have been distributed for CEN Enquiry in the recent past, and it may be expected that the Formal vote will take place next year, but actual timings are uncertain as discussions are active and continuing.

TC 177 Prefabricated reinforced components of autoclaved aerated concrete or lightweight aerated concrete with open structure. This TC was set up in 1989 and its Secretariat is in the German Standards body, DIN. It has so far published no European Standards.

Its programme of work includes:

- Prefabricated reinforced autoclaved aerated concrete components
- Prefabricated lightweight aerated concrete building components.
- Test methods (16 items)

This work is about half completed; it may become a matter of greater Irish interest than at present if the manufacture of these products develops commercially in Ireland.

TC 178 Paving units and kerbs. This TC was set up in 1989 and its Secretariat is in the British Standards body, BSI. It has so far published no European Standards.

Its programme of work includes precast concrete paving units and kerbs, together with clay and natural stone products.

TC 227 Road materials (only in part). This TC was set up in 1989 and its Secretariat is in the German Standards body, DIN. It has so far published no European Standards.

Its very large programme of work includes *materials for concrete roads*, and *cement bound materials* and *surface characteristics*.

TC 229 Precast concrete products. This TC was set up in 1989 and its Secretariat is in the French Standards body, AFNOR. It has so far published no European Standards.

Its programme of work is divided between *products for which the stability requirement is in conjunction with other dominant requirements* and *products for which the stability requirement is not dominant*. Its topics include many of the smaller precast concrete products familiar to the concrete plants here, as well as such products as cattle slats and hollow core floor units. It also deals with the performance criteria and testing of glass fibre reinforced cement.

TC 250 Structural Eurocodes (only in part) This TC was set up in 1990 and its Secretariat is in the British Standards body, BSI. It took over the work of preparing the Eurocodes which had been initiated in the (then) EC Commission in the late 1970s.

Its published European Standards are:

IS/ENV 1992-1-1:1992 Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings

IS/ENV 1993-1-1:1993 Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings

IS/ENV 1994-1-1:1993 Eurocode 4: Design of composite steel and concrete structures - Part 1-1: General rules and rules for building

IS/ENV 1995-1-1:1995 Eurocode 5: Design of timber structures - Part 1-1: General rules and rules for building

IS/ENV 1996-1-1:1995 Eurocode 6: Design of masonry structures - Part 1-1: General rules and rules for building

Besides the Eurocodes mentioned, the work of TC 250 most likely to be of interest include:

Eurocode 1: Actions on structures

Eurocode 7: Geotechnical design

The current work programme of TC 250 is given in full in Annex 4, a discussion of which could readily absorb the time available for these remarks; it is desirable to note, however, that close liaison is maintained between this TC and others in the structural design area, to ensure that the published ENs from all TCs will have coherent design rules between them. The National Eurocode Advisory Committee (NEAC), set up some years ago jointly by the NSAI and the DoE advises on all matters related to the Eurocodes.

5. STANDARDS - IRELAND.

5.1 Introduction.

If all of the foregoing can be categorised under the general description of what there is to know, it is necessary to ensure that as far as possible those who need to know can be informed. A part at least of the information transfer exercise is in the presentation of papers such as this.

Emphasising a point which may be obvious, it should be clear that the scale and scope of the work in Europe is far in excess of the resources available to the concrete industry generally in Ireland, or to the NSAI, to take more than a relatively minor part in some of that work. While this is as befits our size of country, it is nevertheless important to identify the critical topics in which we have an interest and the capacity to express that interest in Europe, and to concentrate our resources there. On the general question of the availability of resources, all countries have difficulties whether manpower or finance, or both.

5.2 Standards activity in Ireland.

(Some historical background to general standardising activity is given in Annex 5.)

During the period up to the 1970s there was little or no international activity among the national standards bodies in the area of standards for concrete, and the use of British Codes, CP 114 and later CP 110 for the structural use of concrete, associated necessarily with an amalgam of Irish and British Standards for the materials used in concrete became the practice with which Irish engineers became familiar over time.

It is, however, appropriate to refer to the CEB *Recommendations for an international code of practice for reinforced concrete*, of 1964 as an example of non standards body activity. This code has been referred to in an earlier symposium in this series.

In the 1970s, the impact of the work of ISO together with the then existing work of CEN began to be felt. At that time the ISO Technical Committees for *Concrete*, *Cement* and for *Masonry* were active, and the longer term effect of that work could not then be foreseen. However as the membership of the ISO committees was largely composed of west European countries, including Ireland, it began to be felt that CEN would be a more focused and regional forum for the development of standards than ISO, whose standards tended to be rudimentary and for world-wide application.

With these international developments as the immediate prompt, it was decided to establish an advisory committee in the (then) IIRS, Standards Division to review the work of a series of international committees. The committee called the *Concrete Consultative Committee* (CCC), was set up in 1979 to advise on national and international matters relating to concrete and its constituents, and also masonry, particularly concrete masonry. Its advice over the years has been invaluable in our international discussions and it has also offered general advice in the preparation of our national codes for masonry (IS 325) and concrete (IS 326) and on nominations to CEN committees and of receiving reports and offering national policies to those nominated.

Subsequently, other Consultative Committees have been set up covering *timber*, *fire safety*, the *construction industry*, the *environment*, and the *Eurocodes*, all of which have broadly similar advisory functions.

The membership of the CCC consists of engineers drawn from the Universities, Industry, Consultancy, the DoE, and appropriate semi-State organisations. We were fortunate, in the early days of the CCC, to have the services of Prof J W de Courcy in the chair, whose knowledgeable advice and long experience was of great benefit in our discussions. Indeed, it would not be appropriate to deal with this subject without acknowledging the support of the relatively small number of Irish engineers who have given fulsomely of their expertise in national discussions to ensure that the input into the preparation of the numerous Irish and European documents has taken relevant Irish practice into account. Our thanks are due to them all.

On an organisational note, it should be recorded that IIRS Standards Division became the National Standards Authority of Ireland (NSAI) on 21 January 1985. In addition to its European liaison in standards drafting and certification functions, the NSAI incorporates the Irish Agrément Board (IAB).

Mention has been made of the preparation of IS 325 and IS 326. The origin to the preparation of these two codes lay in the early discussions of the CCC in the course of which it became clear that the need for Irish codes for these subjects would become ever more pressing in view of:

- the international work then commencing, which in the absence of Irish codes, would proceed without formal Irish input;
- the preparation of the Building Regulations which if they were published with references to British Codes only, would have given *carte blanche* to the acceptability of materials complying with British Standards while giving no recognition to indigenous materials complying with Irish Standards;
- the need to codify design rules for concrete block masonry (in the case of IS 325) and (in the case of IS 326) to reflect the results of the *Irish Concrete Society's* study which showed that the durability parameters for concrete given in the relevant tables of BS 8110 were not appropriate to Irish concrete supplied from ready mixed concrete plants.

Before publishing these codes, it was clear that the text of a proposed Irish Code would not be prepared *ab initio* and would be similar for the great majority of the text to the corresponding British Code. In correspondence between the two standards bodies in 1983, their helpful response referred to their '*policy to encourage ... countries to take over British standards...*'. In the event IS 325 was published in 1986 and IS 326 in 1988 with forewords which reflected the fact that they were virtually identical to the BS counterpart and produced in this way by agreement between the two bodies.

5.3 European Standards - input from Ireland.

The NSAI in its national procedures seeks to inform Irish interests of CEN activities; to encourage the nomination of Irish experts and delegates to appropriate committees, and to establish a mechanism for making policy and receiving reports from Irish nominees.

Irish representation in the CEN committee structure is given in the NSAI *Standards catalogue* and includes nominations to most of the TCs mentioned, together with nominations to many of the subcommittees and groups of experts.

The NSAI seeks to keep itself informed of developments in Europe, particularly at the time of initial drafting of European Standards, when influence is likely to be most effective. This is normally done by discussing the topic in hand in an NSAI committee with the appropriate Irish nominee and arriving at a national view which can then be brought to Europe.

5.4 European Standards - future impact on Ireland.

Cement The specification of Portland cement has changed little over the years, except in the case of *additions*. In the 1938 document no additions were allowed; by 1963, the then version of IS 1 permitted '*...additions not exceeding 1.0 % of the clinker ...may be interground...*'. ENV 197-1 permits up to 5 % of '*...minor additional constituents...*', and this is the document on which the current IS 1 is based. It may be taken that the specification for CEM I will not change in the future and it is likely that the ENV 197-1 will be developed into a full EN, with the consequent withdrawal of IS 1.

The pervasive use of 'pure' Portland cement (CEM I) in Ireland, is by no means the case in all west European countries. Of the 17 west European countries for which figures are readily available, eight (Austria, Belgium, France, Greece, Luxembourg, Netherlands, Portugal and Spain) produce less than 40 % of their total cement production of 80×10^6 tons in the form of CEM I. A further five countries (Denmark, Finland, Germany, Italy and Norway) produce less than 75 % of their total cement production of 70×10^6 tons in the form of CEM I. In the UK about 95 % of production of 14×10^6 tons is in the form of CEM I. Ireland, Sweden and Switzerland report 100 % of their production of 9×10^6 tons in the form of CEM I. It should, however, be added that CEM I is easily the biggest single category of cement produced in Europe, comprising about 52 % of total production.

The economic desirability of Ireland's position in such a listing is a matter for some thought and perhaps revision. Some change in this situation may arise if, as is possible, the range of cements normally available to the concrete industry in Ireland expands to include *Portland fly-ash cement*. This development, should it occur, would provide Irish industry with a further small step towards the broader European practice. To be considered with great caution, however, is the prospect of market niche emerging for some of the wide range of the other cements included in ENV 197-1; their use will require care since some of these cements are of limited historical availability and current experience of their use may be very geographically localised; their constituent components may require to be assessed. The properties of concrete made with such cements may be very different from the properties conventionally experienced here.

Aggregate There is an obvious need for clean, durable aggregates in the concrete industry and IS 5 has sought to ensure this over the years. Ireland has an abundance of sources of such material, a situation which does not apply uniformly in Europe. As an indication of the pressures on the availability and supply of *new* materials in Europe, the draft specification will accept that aggregates may include *dense blastfurnace slag*, *china-clay wastes*, and *recycled*

concrete. It is expected that classes of aggregate, to be chosen by the user which preclude the use of such materials, will be included in the published specification.

The current stage of discussions in TC 154 are that normal density and heavy weight aggregates are being dealt with first, and lightweight aggregates later. Some test methods are reaching agreement.

It can be reported that the sieve sizes will change as noted in Annex 6.

Mixing water In the case of mixing water a situation exists in Europe which is similar to that for aggregates. As an indication of the potential difficulty in the European water supply industry, the prEN 1008 *Mixing water for concrete* (currently being prepared) will allow the use of industrial waste water (subject to testing to establish suitability). A draft for formal vote is expected shortly.

Other materials Other materials including *admixtures, fly-ash, silica fume, pigments and extenders, curing compounds, grouts and sheaths for prestressing concrete, and sprayed concrete* are discussed in TC 104 or its numerous subgroups. It is not expected that unpleasant surprises for practice here will emerge from the discussions for these materials.

While not strictly part of the topic 'other materials', *alkali-silica reaction* is also in discussion in TC 104 and it is expected that the agreed policy on alkali-silica reaction in TC 104 will be published as a CEN Technical Report. This report will include the relevant material from the IEI/ICS report.

Concrete - specification The specification of concrete is a very broad subject and a discussion of this topic in the context of TC 104 material could readily take up an entire paper of such as this. The topic of *durability* is dealt with in the following tables. Some background material is offered in Annex 7.

The durability parameters given in the following table are based on CP 114 and table 3.4 of IS 326 (revised)(to be published later this year) and the corresponding information from BS 8110.

The distinctive difference between IS 326 and BS 8110 lies in the differing grades of concrete as shown in **bold** in the table; the concrete properties at C37.5, C40, and C42.5 grades in IS 326 will be the same as C40, C45, and C50 grades in BS 8110. This difference is a reflection of the differing materials available and statistical approaches used in the two countries, and is an indication of the difficulties in the path of arriving at a European wide specification.

Code	Conditions of exposure	Nominal cover in millimetres				
		1:2:4	1:1½:3	1:1:2		
CP 114	Not referenced	25	25	25		
	Concrete properties					
	Maximum free water/cement ratio	0.58	0.51	0.43		
	Minimum cement content (kg/m ³)	290	360	480		
IS 326:1995	Mild	25	20	20*	20*	20*
	Moderate	-	35	30	25	20
	Severe	-	-	40	30	25
	Very severe	-	-	50+	40+	30+
	Most severe	-	-	-	60	50
	Abrasive	Select to suit service conditions				
	Concrete properties					
	Maximum free water/cement ratio	0.65	0.60	0.55	0.50	0.45
	Minimum cement content (kg/m ³)	275	300	325	350	400
	Lowest grade of concrete	C30	C35	C37.5	C40	C42.5
BS 8110:1985	Mild	25	20	20*	20*	20*
	Moderate	-	35	30	25	20
	Severe	-	-	40	30	25
	Very severe	-	-	50+	40+	30+
	Most severe	-	-	-	60	50
	Abrasive	Select to suit service conditions				
	Maximum free water/cement ratio	0.65	0.60	0.55	0.50	0.45
	Minimum cement content (kg/m ³)	275	300	325	350	400
	Lowest grade of concrete	C30	C35	C40	C45	C50

The current European information on this is given in ENV 206, and is as follows:

ENV 206	Maximum free water/cement ratio	0.65	0.60	0.55	0.50	0.45
	Minimum cement content (kg/m ³)	260	280	300	300	300

This is unsatisfactory for use in Ireland as it is based on the use of 32 mm aggregate, and does not take the properties of Irish materials into account. The Irish annex to ENV 206 refers users to IS 326.

The grades of concrete included in ENV 206, based on cube rather than cylinder testing are 15, 20, 25, 30, 37, 45, 55, 60 MPa.

The future developments on this matter to be published in EN 206 are currently under discussion and the following is an extract from a recent version of the draft. The text and relevant table are as follows:

The values of table 9 refer to the use of CEM I (32.5) and aggregate with the nominal maximum size in the range of 20 mm to 32 mm. The table may be applied for other cements in accordance with EN 197 where permitted by national provision valid in the place of use of the concrete. Different values than in table 9 may be given for other types of cement to EN 197-1 and other aggregate sizes in the provision valid in the place of use of the concrete.

It will be observed that, unlike IS 326 and BS 8110, the grades in this table are not an indication of the mix parameters of w/c ratio and minimum cement content. It is likely that the fixed relationship of grade and mix parameters will not be retained.

Concrete design Eurocode 2 Part 1 together with the other Eurocodes mentioned are currently available for extended examination and its life is in the rules of CEN limited. The conflicting pressures to finalise the document in its EN format within the timespan envisaged *versus* the need to consult appropriately on a document of this character and complexity are widely apparent and appreciated. A short period will be given during which the final published EN Eurocodes and the national codes will coexist; the length of this period will be dependent on agreement with the national authorities.

In the meantime it must be recorded that on the basis of current information, little Irish comment will be brought to the development of the EN Eurocode 2 because of the limited use of the ENV text here. This is a cause for regret as it should be noted that when the EN Eurocodes are agreed it will then be too late to influence their content.

6. CONCLUSION.

As in many activities, one can observe the developments in hand from a pessimistic or optimistic point of view. A pessimistic viewpoint may be that the *practical realisation of a harmonised Europe* is more apparent in the intention than the current reality. However, it should be recorded that *all* CEN members are striving towards a harmonised Europe with as much resource as can be brought to bear. Many industries and companies are investing heavily in the activity and Ireland is no exception to this pattern, at the scale appropriate to our size.

These remarks comprise a far from complete view of the subject in hand. The range of topics merely touched on is large and of importance to the sectors of the concrete industry concerned. While acknowledging this, it must be accepted that some selectivity had to be indulged in in deciding on the content to be discussed.

The developments, both Irish and European, described in the period of this review have formed a watershed. This watershed marks a separation from our old perhaps comfortable ways of using Irish or British documents to a new situation which will involve us in more indigenous examinations of Irish practice, with a view to ensuring that the ENs will reflect our needs. The gradual demise of nationally prepared standards which are in conflict with European Standards must be accepted, for it will happen; it is now only a question of the pace of the preparation of new European documents and the withdrawal of national ones which is in question.

There are a number of final points which form the backdrop to this whole programme to the realisation of a harmonised Europe:

the business we are engaged in is a democracy, and this takes time for consultation and acceptance;

Table 9 - Limiting values for composition and properties of concrete.

Exposure																	
Prescriptive Require- ments	No risk of corrosion or attack	Carbonation-induced corrosion				Chloride-induced corrosion					Aggressive chemical environments			Freeze/thaw attack			
						Sea Water			Chloride other than sea water								
		X0	XC1	XC2	XC3	XC4	XS1	XS2	XS3	XD1	XD2	XA1	XA2	XA3	XF1	XF2	XF3
	Minimum grade ⁽³⁾	C12/15	C20/25	C25/30	C30/37	C30/37	C30/37	C35/45	C35/45	C30/37	C35/45	C30/37	C30/37	C35/45	C30/37	C25/30	C30/37
Maximum w/c ratio	-	0.65	0.60	0.55	0.50	0.50	0.45	0.45	0.50	0.45	0.55	0.50	0.45	0.55	0.55	0.50	0.45
Minimum cement content (kg/m³)	-	260	280	280	300	300	330	350	300	330	300	330	370	300	300	330	350
Minimum air content (%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0 ^{b)}	4.0 ^{b)}	4.0 ^{b)}
other requirements	⁽⁴⁾	Sulfate Resisting Cement										Frost resistant aggregates					

¹⁾ Sulfate resisting cement shall be used when SO_4^{2-} leads to exposure class XA2 or XA3

If provision is made for two levels of sulfate resisting cements in the cement standard, then either moderate or high sulfate resisting cement shall be used for exposure class XA2 (and in exposure class XA1 when applicable) and high sulfate resisting cement shall be used for exposure class XA3.

²⁾ If there is no use of entrained air then the performance of concrete has to be tested according to EN (frost testing) by comparison with concrete for which freeze/thaw resistance for the relevant exposure class is proven.

³⁾ Minimum grade were determined from the relationships between water/cement ratio at strength class made with cement CE 32.5 as shown in Table 10.

those engineers working in countries where there are readily available sources of supply of good constituent materials of concrete might need to note others' problems and express a quite word of gratitude for the providential availability of such materials.

* * * *

The mechanisms necessary to achieve a harmonised Europe are in place. In Ireland there are in place established procedures to respond to CEN developments in many of the areas described. Some at least of the work has been substantially completed and we are, so to speak, at the end of the beginning.

Our new relationships in Europe have been challenging, informative and useful; the experience of having national problems, properly presented, handled with care and sophistication can be very satisfying.

There is no question but that the decade ahead will inevitably be a challenging period requiring authoritative input and decision making. For this an involved, knowledgeable and supportive Irish engineering profession will be essential.

Acknowledgements

The author wishes to acknowledge the assistance of friends and colleagues in the preparation of this paper. Permission of the NSAI to publish this paper is acknowledged.

Annex 1 The organisation of CEN standardisation activities

The organisation of CEN standardisation activities is shown in Figure 1. The senior committee in CEN is the Administrative Board. Under this is the Technical Board which is responsible for '...controlling the standards programme and promoting the programme's execution by the Central Secretariat' (the staff of CEN in Brussels). The Central Secretariat manages the CEN organisation generally and in particular:

advises the Technical Committees on organisational matters and on developments with the EU Commission;

it manages the preparation of the translation of the drafts into the official CEN languages of English French and German after their preparation in the appropriate TC;

it oversees the implementation of the agreed European Standards in each State's standards body.

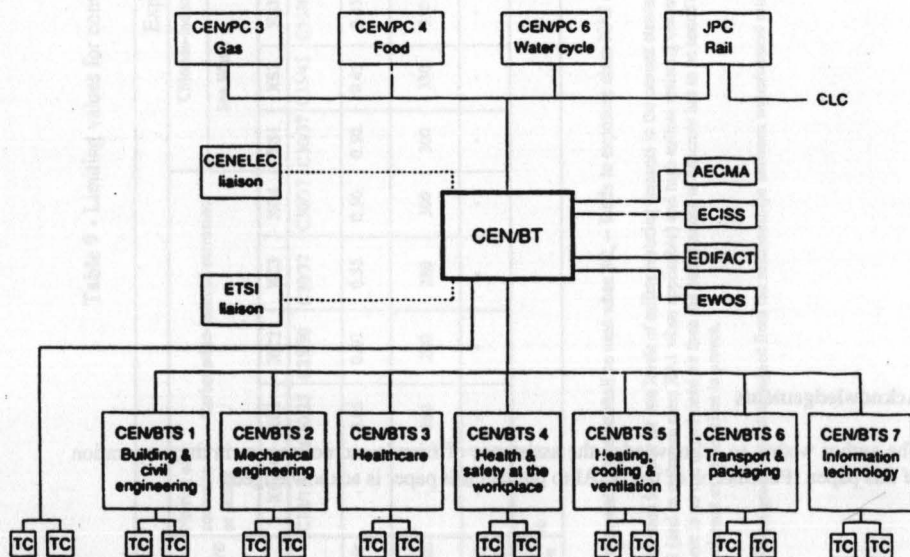


Figure 1: General organisation of CEN standardisation activities

Annex 2 The CEN - rules

Preparation of ENs The drafting of a proposed EN is normally delegated by the responsible TC to a Working Group or a Task Group the members of which are nominated by the National Standards bodies. Because of the costs involved, it is commonly the case that the nominees are drawn from industries or companies which can afford to financially support the experts involved in this work.

When the document has been drafted, it is sent to the TC for approval for distribution for comment among the CEN members. This is called the *CEN Enquiry* and is a commentary period which lasts for six months. It is during this period that the CEN members inform the relevant national committee or interest group of the existence of the draft and seek to ensure that any national comments will be made at the appropriate time. The revision of the draft on the basis of the comments received is normally carried out by the group responsible for the initial preparation of the document. When the content of a revised draft can be agreed, it is again presented to the TC for their approval for distribution for *CEN Formal Vote*. A period of two months is allowed to the CEN members to decide on a 'Yes/No' basis how to respond. The assessment of the formal votes is on the *weighted voting procedure* of the full members. Under this procedure the conditions for the adoption of a proposed EN are:

the proposal must pass by a simple majority, abstentions excluded, and
there must be at least 25 weighted positive votes, and
there must be at most 22 weighted negative votes, and
there must be at most 3 members voting negatively.

As can be seen the system includes 'one-man-one-vote' and 'weighted voting'. It is a procedure that works reasonably and is satisfactory to all sizes of countries.

The number of weighted votes allocated to each country is as shown in table 1.

Table 1: Weighted voting - Member body and number of votes

Country (member body)	Number of votes
Germany, France, Italy, UK	10
Spain	8
Austria, Belgium, Switzerland, Greece, Netherlands, Portugal, Sweden	5
Denmark, Ireland, Finland, Norway	3
Luxembourg	2
Iceland	1

CEN Standstill During the preparation of an EN, the CEN members are required to implement the *standstill agreement*. This agreement obliges CEN members not to take any action which would prejudice the compromises sought, nor to publish a new or revised national standard which is not in line with an existing EN.

Implementation of European Standards The member bodies are required to implement the agreed standard by giving it the status of a national standard, and by withdrawing any conflicting existing national standards.

European Prestandards A *European Prestandard (ENV)* follows the same course in preparation as an EN, except that when an ENV is implemented, the CEN members do not have to withdraw conflicting national standards and there is no standstill imposed on the preparation of national documents. The lifetime of an ENV is intended to be limited, initially to 3 years, and which may be extended. There is a requirement that ENVs be 'made available' by the member body.

Packages of standards CEN TCs produce the results of their deliberations as they are completed by the group concerned, resulting in ENs becoming available for publication in approximately the same sequence. In order to apply some logic to the sequence of publication of ENs, some completed drafts are 'put on hold', pending the completion of other drafts which have been agreed in the TC to form a package of standards.

Annex 3 The TC 104 sub-committees' work items

The work items of the TC 104 sub-committees and Working Groups are as follows

SC 1: EN 206 Concrete (performance, production placing and compliance criteria)

SC 2: Execution of concrete structures Part 1: General rules and rules for buildings (*Formwork, false work, reinforcement, concreting, structures with prefabricated concrete components, tolerances and inspection*) (other parts may cover *Marine structures and Bridges*)

SC 3: Admixtures for concrete, mortars and grouts - (*specification and various test methods; 13 items in all*)

WG 4: Fly ash for concrete - (*specification various test methods*)

WG 5: Mixing water for concrete - (*specification and tests*)

WG 6: Grouts for prestressing tendons - (*specification, grouting procedures and various test methods; 3 items in all*)

SC 7: Sheaths for prestressing tendons - (*various test methods; 5 items in all*)

SC 8: Products and systems for the protection and repair of concrete structure (*64 items in all, mainly test methods*)

WG 9: Silica fume

WG 10: Sprayed concrete This group is asked to consider the subject under the headings
a) *Structural sprayed concrete*, b) *Strengthening of rock*, c) *Surface improvement*, and d) *Repair and upgrading*.

The work on preparing the ENs for *fly ash* and *grouts* is completed and the groups responsible for their preparation have been disbanded.

Annex 4 The current work programme of TC 250

The set of 9 common unified design rules for building and civil engineering works are as follows.

ENV 1991-... Eurocode 1: Basis of design and actions on structures

ENV 1991-1-1:1994 Part 1: Basis of design

ENV 1991-2-1:1995 Part 2-1: Actions on structures - Densities, self-weight and imposed loads

ENV 1991-2-2:1995 Part 2-2: Actions on structures - Actions on structures exposed to fire

ENV 1991-2-3:1995 Part 2-3: Actions on structures - Snow loads

ENV 1991-2-4: Part 2-4: Actions on structures - Wind actions

ENV 1991-2-x: Part 2-x: Actions on structures - Thermal loads

ENV 1991-2-y: Part 2-y: Actions on structures - Accidental actions

ENV 1991-2-z: Part 2-z: Actions on structures - Construction loads and deformations imposed during construction

postponed Part 2-xx: Actions on structures - Actions from currents and waves

ENV 1991-3: Part 3: Traffic loads on bridges

ENV 1991-4: Part 4: Actions in silos and tanks

ENV 1991-5: Part 5: Actions induced by cranes and machinery

ENV 1992-... Eurocode 2: Design of concrete structures

ENV 1992-1-1:1991: Part 1-1: General rules and rules for buildings

ENV 1992-1-2: Part 1-2: General rules - Structural fire design

ENV 1992-1-3:1994 Part 1-3: General rules - Precast concrete elements and structures

ENV 1992-1-4:1994 Part 1-4: General rules - Structural lightweight aggregate concrete

ENV 1992-1-5:1994 Part 1-5: General rules - Unbonded and external tendons in buildings

ENV 1992-1-6:1994 Part 1-6: General rules - Plain concrete structures

ENV 1992-2 Part 2: Reinforced and prestressed concrete bridges

ENV 1992-3 Part 3: Concrete foundations

ENV 1992-4 Part 4: Liquid retaining and containment structures

(postponed) Part 5: Marine and maritime structures

(postponed) Part 6: Massive structures

ENV 1993-... Eurocode 3: Design of steel structures

ENV 1993-1-1:1992: Part 1-1: General rules and rules for buildings

ENV 1993-1-2: Part 1-2: General rules - Structural fire design

ENV 1993-1-3:1994 Part 1-3: General rules - Cold formed thin gauge members and sheeting

ENV 1993-1-4:1994 Part 1-4: General rules - The use of stainless steels

ENV 1993-2 Part 2: Bridges and plated structures

ENV 1993-3 Part 3: Towers masts and chimneys

ENV 1993-4 Part 4: Tanks silos and pipelines

ENV 1993-5 Part 5: Piling

ENV 1993-6 Part 6: Crane structures

(postponed) Part 7: Marine and maritime structures

(postponed) Part 8: Agricultural structures

ENV 1994-... Eurocode 4: Design of composite steel and concrete structures

ENV 1994-1-1:1992:Part 1-1: General rules and rules for buildings

ENV 1994-1-2: Part 1-2: General rules - Structural fire design

ENV 1994-2 Part 2: Bridges

ENV 1995-... Eurocode 5: Design of timber structures

ENV 1995-1-1:1993:Part 1-1: General rules and rules for buildings

ENV 1995-1-2:1994:Part 1-2: General rules - Structural fire design

ENV 1995-2 Part 2: Bridges

ENV 1996-... Eurocode 6: Design of masonry structures

ENV 1996-1-1 Part 1-1: General rules - Rules for reinforced and unreinforced masonry

ENV 1996-1-2: Part 1-2: General rules - Structural fire design

ENV 1996-1-3 Part 1-3: General rules - Detailed rules on lateral loading

(postponed) Part 1-x: General rules - Complex shapes

ENV 1996-2 Part 2: Special design aspects

ENV 1996-3 Part 3: Simplified and simple rules

(postponed) Part 4: Short life structures

ENV 1997-... Eurocode 7: Geotechnical design

ENV 1997-1-1:1994:Part 1: General rules

ENV 1997-2: Part 2: Geotechnical design assisted by laboratory testing

ENV 1997-3: Part 3: Geotechnical design assisted by field testing

(postponed) Part 4: Specific geotechnical structures

ENV 1998-... Eurocode 8: Design provisions for earthquake resistance of structures

ENV 1998-1-1:1994: Part 1-1: General rules - Seismic actions and general requirements for structures

ENV 1998-1-2:1994:Part 1-2: General rules - General rules for buildings

ENV 1998-1-3:1995 Part 1-3: General rules - Specific rules for various materials and elements

ENV 1998-1-4: Part 1-4: General rules - Strengthening and repair

ENV 1998-2:1994 Part 2: Bridges

ENV 1998-3 Part 3: Towers masts and chimneys

ENV 1998-4 Part 4: Silos tanks and pipelines

ENV 1998-5 Part 5: Foundations, retaining structures and geotechnical aspects

ENV 1999-... Eurocode 9: Design of aluminium alloy structures

ENV 1999-1-1: Part 1-1: General rules and rules for buildings

ENV 1999-1-2: Part 1-2: General rules - Structural fire design

ENV 1999-2 Part 2: Rules for structures susceptible to fatigue

Annex 5 Some historical background

The following are some historical notes of some relevance. The first two are examples from the 18th and 19th centuries.

18th century Jonathan Swift's *Drapier's Letters*

I have pressed several of our ... brethren, that the whole corporation of weavers ... would publish proposals ..entering into solemn mutual engagements that the buyer (of such goods) shall have substantial merchantable ware for his money. So that ... if I had reason to complain, the corporation should give me immediate satisfaction. An ignorant customer runs the hazard of being cheated in the price and goodness of what he buys; being forced to an unequal combat with a dextrous and dishonest man in his own calling. Thus our goods fall under a general disreputation; and ... (people) call for English (ware), from an opinion they have (and often too justly by our own faults) that the goodness more than makes up for the difference in price...

The reference to 'merchantable ware' will have, for students of such matters, an interesting parallel in the wording 'merchantable quality' of current legislation.

19th century Ireland was early in the business of constructing railways and our first lines were built in the 1830s in track gauges that varied from 4' 8½" to 6' 2". The difficulties involved in such lack of co-ordination resulted in the Board of Trade asking General Pasley RE, the Inspector General of Railways, to make recommendations to resolve the question. Following General Pasley's report, *An Act for regulating the Gauge of Railways* was passed and became law in August 1846. This Act made it 'unlawful .. to construct any railway for the conveyance of passengers on any gauge other than ... 5' 3" in Ireland', and the existing lines quickly adopted 5' 3" as the Irish standard gauge. While this question may seem far away today, the question of gauge is one which has apparently not yet (early 1995) been resolved in the case of the new Light Rail Transport system (LRT) proposed for Dublin.

20th century In the 1930s, the cement industry here was set up with the legislative support of the *Cement Act 1933*. A requirement of the Act was that cement had to be manufactured to a specification. The specification was published in 1938 by the *Institution of Civil Engineers of Ireland* under the title 'Standard specification for Portland cement; No. 1 of 1938'.

The period of WW II, the 'Emergency' in Ireland (which did not end until earlier this year for of course, very different reasons), saw many difficulties in the supply of materials to the building industry and many examples of 'making do' are widely known and recorded. The Government sought to make the best use of Irish grown timber with the preparation of Irish Standard No. 2:1946 *Timber for building purposes* and was published by the Department of Industry and Commerce, having been prepared by the Building Research Committee appointed in December 1944.

In 1946 the Government passed the *Industrial Research and Standards Act*, and resulting from this legislation the function of preparing Irish Standards passed to the *Institute for Industrial Research and Standards*, in particular the Standards Division of the Institute. For many years thereafter the staff was small in number and only those materials were standardised and those standards maintained for which some national justification existed; for example in the area of concrete, IS 1 *Portland cement* was published in 1949 and subsequently revised in 1953, 1963, 1982, 1987 and 1991. IS 5 *Aggregates for concrete* was published in 1949 and subsequently revised in 1974 and 1990.

Annex 6 The sieve sizes proposed by TC 154

The sieve sizes (in mm) proposed by TC 154 will be as follows:

Mandatory sizes

0.63, 0.125, 0.25, 0.50, 1.0, 2.0, 4.0, 8.0, 16.0, 31.5, 63.0, 125.0 Additional sizes are

5.6, 11.2, 22.4, 45.0, 90.0 or

6.3, 10.0, 12.5, 14.0, 20.0, 40.0

The sizes given in the current IS 5 are as follows:

0.15, 0.30, 0.60, 1.18, 2.36, 5.0, 10.0, 14.0, 20.0, 37.5, 50.0

Annex 7 The durability parameters of concrete - CP 114

The 1948 version of CP 114 included durability parameters as follows:

<i>Nominal mix</i>	<i>Minimum cube strength</i>	<i>Water/cement ratio</i>
1:2:4	3000 lb/in ²	0.58
1:1½:3	3750 lb/in ²	0.51
1:1:2	4500 lb/in ²	0.43
In each case the aggregate is uncrushed and ¾" in size cover is 1".		

Some attempt is made to relate these parameters to modern practice in the table given in 5.4 above.

DISCUSSION.

MR. TORPEY introduced his paper.

He acknowledged the initiative of Professor J. W. de Courcy in establishing the decennial symposia series in 1965 which today provides us with a continuous record of national developments in concrete technology covering a period of 40 years.

He subtitled his paper 'Practical realisation of a harmonised Europe' indicating the willingness of Europe to come together but recognising the difficulties in its achievement. There are many years of work ahead before a complete set of European standards would be available to the industry. In contrast to papers on standards, codes and regulations in previous symposia this paper included a predominantly European perspective. The responsibility we have to generate Irish technical opinion for inclusion in European debates was emphasised - all countries have difficulty in providing resources for European standards development, be it shortage of manpower or finance. In Ireland we can only partake in a fraction of the vast European workload. This requires a focused approach.

The speaker put the topic of concrete into the wider perspective of the European products market. He said that when CEN Technical Committee TC154 (Aggregates) was established in 1988 its members quickly realised that in Europe the use of aggregate in concrete was not the most important market niche for the material. Equally the dominance of CEM I type cement in the Irish market is not reflected in other CEMBUREAU countries. We are likely therefore to see other cement types in the Irish market in time and this indicates the limitations of developing our durability clauses solely for CEM I materials.

He noted that there has been little comment to date on the ENV version of Eurocode 2 and he regretted this.

Looking ahead, the speaker stated that the decade ahead will be a challenging period requiring authoritative input from a supportive Irish engineering profession.

MR. COLM BANNON opened the discussion.

He said that Mr. Torpey's erudite, detailed and concise paper captured perfectly the mood at present in Europe as regards standards - the progress, the problems and, sometimes, the frustrations involved in harmonisation. The European scene had only been mentioned in passing at the 1985 symposium although Mr. Torpey himself had raised many pertinent issues in a written submission. The reliance in this country on United Kingdom documents had been challenged and the strategic significance of European developments for producers and specifiers had been highlighted.

Mr. Bannon reflected on the developments of the past decade - particularly the Construction Products Directive of 1988 and the attendant Interpretative Documents and Mandates to CEN, which showed the route to the marketplace. The strategic significance of the Construction Products Directive had not been lost on the NSAI or Irish industry but their

input to European discussion had not been matched by equivalent enthusiasm by the Brussels bureaucracy. The Interpretative Documents had only been put in place in 1994 and the finalisation of Mandates to CEN has been extremely slow. More worrying, the Commission in a recent policy document suggested that European standards for construction products might be developed with harmonised and unharmonised parts. This is not what the market requires.

Turning to specification, he felt that the move to look beyond the United Kingdom specifications alone to the wider European horizon, in the framing of Irish specifications, was entirely appropriate. For example, concrete could not have been specified with confidence in Ireland, nor made economically, had we adopted the 'durability grades' of BS8110 in 1985. Significant differences exist in materials and practice in different countries. Our approach in framing IS326 should be an example of how to develop European standards - a framework document with national transpositions. This, however, is not the approach that has been taken in ENV206, which contains compromise figures on water/cement ratio, cement content and grade. Flexibility is required.

On the subject of alkali silica reaction (A.S.R.), although an esoteric topic, it is fundamentally important that we have in place our own Irish document since the United Kingdom approach - the 'Hawkins Report' - was totally inappropriate for Irish practice. We also require the Irish A.S.R. document as a contribution to European debate. Interestingly, there is now developing in the U.K. a significant body of opinion that the 'Hawkins Report' should be changed along the lines of the Irish document. He noted that the forthcoming CEN TC104 Technical Report on A.S.R. represents agreement that there will be no agreement on harmonised European A.S.R. guidelines. The CEN report will list the specific documents and approach adopted in those countries which have published guidelines. This further emphasises the importance of national technical documents. Mr. Bannon paid tribute to Professor J. W. de Courcy's contribution as chairman of the Institution of Engineers of Ireland and Irish Concrete Society Working Party which produced the ASR guidelines in this country.

In relation to the high percentage of cements other than CEM I in other European countries, he noted that future trends cannot yet be predicted. The availability of secondary cementitious materials, such as slag for example, may change if new processes in the steel industry reduce the quantity of quality slag.

Referring to the environment, Mr. Bannon stated that he believed that concrete as a sustainable construction material had no equal. This has been illustrated in Dutch life cycle assessment studies. He believed that these findings would be reflected in the future following publication of the ISO 14000 series of standards. These standards will include advice on the calculation of life cycle assessment. Concerns have at times been expressed in relation to concrete and the environment - what is required is collaborative prenormative research to establish facts and figures, rather than reliance on emotive opinions.

Looking to the future, even if we have concerns about the manner of the implementation of the Construction Products Directive, we must contribute to the European debate on standards. They will in time become law. Those who represent Ireland at European level will be listened to. He said that we must identify critical issues and put our scarce resources into these.

In relation to research, Mr. Bannon wished to make a point which was relevant to Mr. Torpey's paper. Two issues need to be looked at. The first is a continuation of the pioneering work of Dr. Peter Strogen of University College Dublin on the microstructure of our aggregates. Great interest has been shown world-wide to the paper he presented on that topic. The second issue is that of recycling concrete. The European Commission is about to finalise, through its Priority Waste Stream Project, a number of strategy documents relating to construction and demolition waste. There are a number of references to recycling. This is something that we should be looking at in Ireland, despite the abundance of aggregates here.

He drew attention to one issue relating to standards that was not covered by Mr. Torpey. This was the matter of attestation of conformity and certification. For example, ISO 9000 is an excellent management tool. Full product certification is a concept which offers great advantages for all and might usefully be applied in the structural concrete area.

In concluding Mr. Bannon observed that Mr. Torpey viewed the current state of European standardisation as the "end of the beginning". Mr. Bannon hoped it was the beginning of the end. It was, however, a dangerous phase - how successful it would be from an Irish viewpoint depended on our commitment to the work of the NSAI in this field. He believed that one of our assets was the size of the country and the consequent relationships which exist between members of the engineering profession and between those in government, industry and private practice. This strength led him to believe that we would achieve even greater success in the next ten years.

PROFESSOR DAVID ORR noted the very limited use of the ENV for Eurocode 2 in Ireland at present. He recalled that when CP110 was introduced the Irish practitioners embraced it more quickly than those in the U.K. He observed that this may be due to two reasons: the high cost of the document and the fact that little encouragement had been given to the third level colleges to introduce it at undergraduate level. Such encouragement had been given in the cases of CP110 and BS8110.

MR. TOM DUGGAN said he believed that the number of standards would continue to increase. For example, the inclusion of matters relating to health, safety and hygiene could lead to a proliferation of standards. He instanced the case of current concern in Germany regarding the use in potable water storage structures of certain release agents which could support microbial and bacterial growth. He believed that in the near future we would see the introduction of standards relating to issues which we have not yet adverted to. On another point he observed that compliance with a standard did not mean interchangeability of the individual products. For example, two cements which comply with the Class I standard can have 28 day strengths that differ by up to 20 N/mm². This move from narrow bands in national standards to the wider ones in European standards meant that one would need to look carefully at the potential for interchanging products that claim to comply with the same European standard. Standards, he noted, are based on compromise. The unrehearsed switch from one product source to another may lead to difficulties.

MR. GERALD McCONNELL noted the reference to glass-fibre reinforced cement under CEN TC229. He enquired whether or not there were developments regarding other types of fibre reinforcements and the position regarding ferrocement?

MR. EAMONN MOORE commented on the impact of changes in standards whereby laboratories find some of their equipment becomes redundant. He asked if we could expect a time lag in the introduction of standards at the turn of the century due to re-equipment needs?

THE CHAIRMAN endorsed Professor Orr's sentiments regarding the lost opportunity in relation to comment on ENV Eurocode 2 although he could understand the difficulty of consultants in terms of cost in design office time. He noted reference to Mr. Gwynn's comments at the 1965 symposium regarding a code for loading. He pointed out that we are making an input into the European code for loading - particularly in relation to wind loading. He said that he found the 'standstill' restriction on the development of local codes when a European code was in preparation to be unacceptable due to the lengthy periods involved in the production of European codes.

MR. BANNON commented on the Chairman's remark on code 'standstill'. He said that in practice some European countries interpreted it differently. For example, French and German cement standards had recently changed whereby they took their favoured aspects of the draft European codes and updated their national codes accordingly. Perhaps a similar approach could be taken in Ireland if necessary. Commenting on Mr. Duggan's concerns regarding wide bands in European standards, Mr. Bannon said that wide bands could be more beneficial than minimum values alone. He instanced the case in the U.K. where cement strengths progressively increased leading to a lowering of cement content with consequent durability problems.

MR. TORPEY replied to the discussion.

The Eurocode documents had been offered to the third level institutions at a substantial discount. He explained the logic of the CEN rules regarding 'standstill' whereby national standards personnel would direct their efforts into European developments. Regarding ferrocement and fibre-reinforced concretes other than glass-fibre, he did not have precise information but understood that work was in hand. In relation to problems which might stem from product interchangeability, he believed that difficulties could be avoided by detailed descriptions. For example cement could be described by strength class - 'CEM I, 32.5' and so on. He accepted that new standards often lead to additional cost as laboratory equipment becomes outdated.

SESSION B

CEMENTS AND SECONDARY CEMENTITIOUS MATERIALS

B. LYNCH, B.E., M.B.A., M.I.EI, M.I.C.T.
Irish Cement Limited.

Sessional Chairman

V. LYONS, B.E., M.Eng.Sc., M.I.EI
Kildare County Council.

1. INTRODUCTION.

It is well known in the industry that the beginnings of cement and concrete date back to beyond 5,000 years BC¹. The empires of ancient Egypt, Greece and Rome discovered and developed cementitious products to build their infrastructure and monuments, examples of which even remain to-day.

The development of current cements is viewed largely in terms of the progress of artificial cements, principally Portland cement, in the last few centuries. In a book published by the Edison Portland Company² in 1926 it proudly states "Every day will reveal new uses for Portland cement; every generation will leave its mark - in cement; every new generation will scan the history and add its own chapter; - that is the Eternal Romance of Cement".

This focus on Portland Cements since the 1800's is primarily due to the progressive improvements in the production process, with, in recent decades, a refined level of process control due to advances in powder technology and also to a high level of quality control associated with the industry. However, due to the introduction of other materials, the use of pure Portland cement has gradually been decreasing, certainly across Europe. It continues to play a predominant role in Irish construction and has performed most effectively. The industry here is now more aware of different cementitious products, but is also cautious of unproven change in this environment.

In this last decade, significant change has occurred in the industry, and this evolution has also affected the cementitious sector. European standards were introduced and have impacted on national standards. Significant market development has also occurred, with the island now regarded more as a single market. Product and process improvements were implemented.

While further change is visible on the horizon, arising partly from the European dimension and partly from the inevitability of the product development life cycle, it is worth reviewing the present position and developments during the last decade. This paper will briefly outline the changes in the cementitious sector and their impact, if any, on concrete.

2. MARKET

2.1 Demand.

The demand for cement products generally reflects the strength of the economy and that of the construction sector in particular. The cyclical nature of construction output is indicated in Table 2.1, summarised from DOE data³, with it seems the cycles reducing in length. Residential output is a major contributor to construction output as is seen from the Table.

	Residential	Infrastructure	Other Sectors	Total
1985	1306	317	919	2542
1986	1313	341	719	2373
1987	1250	297	754	2301
1988	1115	290	783	2188
1989	1250	317	820	2387
1990	1304	366	1171	2841
1991	1312	528	999	2839
1992	1416	499	918	2833
1993	1411	566	810	2787
1994 (f)	1613	469	887	2969
Infrastructure includes Roads, Airports, Ports & Harbours, Tourism, Water Services (excluding R&M) Other Sectors includes Industry, Semi-State, Agriculture, Commercial and other Public (excluding R&M)				

Table 2.1: CONSTRUCTION OUTPUT (£m 1990 Prices)

The estimated market for cement sales in the Republic of Ireland, given in Table 2.2, also reflects similar trends to construction output. This year-on-year change of demand was successfully met by the cement and concrete industry but shifts of this magnitude do cause significant pressures in meeting demand.

Year	Total ('000T)	% Bulk	% Bagged
1985	1299	66	34
1986	1268	65	35
1987	1220	68	32
1988	1288	72	28
1989	1553	74	26
1990	1589	73	27
1991	1460	72	28
1992	1440	72	28
1993	1409	73	27
1994	1600	75	25

Table 2.2: R.O.I. MARKET ANNUAL SALES (Estimated)

2.2 Supply

The demand situation outlined above refers as stated to the Republic of Ireland market. However, even in advance of the Construction Products Directive (CPD) and the Single European Market, the island of Ireland had become a single market for cement. Cement products were traded by a number of companies including Irish Cement and also by Quinn Cement, established in the mid 1980's just North of the border in Co. Fermanagh. Manufacturing capacity on the island is currently just under 3 million tonnes, apart from imported supplies, for a total market demand of approximately 2.5mT.

The 'transitional period' envisaged in the CPD, before full harmonised standards are available, now appears to extend towards the end of the millennium. Construction products can be certified as fit for intended use, in accordance with the essential requirements of the CPD, mainly by obtaining a CE mark through compliance with a harmonised standard (in the case of cement). The Standards Authority and industry are now prepared for this situation but progress at CEN level is slow and publication of the Interpretative Documents was delayed until 1994 by the EU Commission. It is important for Irish producers that Irish products are not disadvantaged by complying with rigorous standards and 3rd party certification schemes while other products claim equivalence but are not independently certified.

2.3 End Uses

It is informative to examine the end uses of cement to understand the main markets for concrete and concrete products. The data in Table 2.3 is estimated for five main sectors in 1990 and 1994 and the primary importance of the residential sector is confirmed in these years of higher market demand, with 1994 figures reflecting the significant increase in house completion's last year at 26863 units⁴. The Agricultural sector's share for 1990 is perhaps unusually high and reflects a surge of building associated with silage and effluent storage. It is encouraging to note that, as these two sectors represent almost two thirds of cement consumption, there has been a significant improvement in concrete specification and workmanship requirements by specifying authorities such as the Farm Development Service and the NHBGS. Continuing advice, information provision and training by the industry is vital to ensure that the efficient use of concrete is achieved in these important sectors.

	1990	1994
Residential	32%	43%
Agricultural	30%	23%
Commercial	14%	10%
Public	11%	12%
Industrial	8%	8%
Other	5%	4%

Note: Individual % rounded to nearest whole number.

Table 2.3: END USE OF CEMENT - BY SECTOR

From Table 2.4 it can be seen that readymixed concrete continues to grow from a product usage viewpoint. This trend is also reflected in Table 2.2 previously. 'Factory produced' ready-to-use mortar and render products have been successfully introduced in the last decade and their use has increased significantly in recent years.

	1985	1993
Readymixed Concrete	36%	42%
Precast Concrete	29%	29%
Site Mixed	35%	29%

Table 2.4: END USE OF CEMENT - BY PRODUCT

Many firms in the concrete products sector have introduced quality systems certification schemes based on ISO 9002 and this has improved the quality of the products supplied and has increased the confidence of the purchasers and clients. A product-based certification scheme has been introduced by manufacturers for readymixed concrete in the agricultural sector, in conjunction with the Department of Agriculture Food and Forestry. The increased market share of readymixed concrete is a reflection not only of ease of use but also of confidence in the quality of the product by the user.

3. PORTLAND CEMENT

3.1 Production

The production of Portland cement, in this country, using the energy efficient dry process has been well established since its first introduction in 1973 in Platin cement works. Significant investments have been made during the last decade to make the process as energy efficient as possible, both with regard to costs and also from the environmental viewpoint. In addition, incorporation of industrial by-products such as pfa in the raw material stage reduces other raw materials usage. Cost efficient combinations of coal and petroleum coke are used as fuel in both Limerick and Platin works.

The use of additional shale raw materials has enabled a gradual reduction of the alkali level of cement over the past ten years (see section 3.6). The current typical range of 0.7-0.8 Na₂Oeq of NPC is more beneficial, particularly in higher strength concrete using increased cement content levels.

Modern computerised process control systems are used in both works, optimising plant operation, assisting with fault finding, smoothing material variations and thus improving product quality.

A state-of-the-art automatic laboratory system has been recently commissioned at Limerick works. This 'autolab' robotically processes and tests samples of raw meal, clinker and cement

as part of the routine control testing. The results are automatically logged into the process control system for any subsequent action.

High efficiency separators are being introduced in the cement milling stage to improve control of particle size distribution and energy consumption efficiency. The addition of up to 5% of minor additional constituents is permitted by IS1 and this is typically added at the cement milling stage either directly at the mill or by blending after the mill.

Investments in packing and palletising operations have resulted in better pallet handling and improved product presentation.

3.2 Products

The range of cements manufactured by Irish Cement are:

Normal Portland Cement, complying with IS1, which accounts for the largest proportion of sales at approximately 90%.

Rapid Hardening Portland Cement, also to IS1, and mainly used in concrete to provide a faster rate of early strength development because of its increased fineness. This accounts for approximately 10% of the ICL product sales.

Sulphate Resisting Portland Cement, complying with BS4027, which is mainly used in specialist applications where resistance to a sulphate environment is required. The level of tricalcium aluminate (C_3A) level is below 3.5% in this product.

Other Specialised Products

- Normal Portland Cements to a specified fineness and sulphate specification for the fibre-cement industry
- Low Alkali Portland Cement with a sodium equivalent of less than 0.6% mainly for use in exported products.
- Oilwell Cement for the offshore oil industry
- Special Slag Binder for the mining industry

3.3 Standards

The Irish Standard I.S.1 'Portland Cement' has been revised twice since 1985, in 1987 and 1991, and a draft amendment is currently proposed.

The need for the later revisions has arisen mainly due to developments at European level with the publication by CEN of 'prENV197' as a prENormative European standard for cement⁵ and of EN196 series 'Methods of testing cement' as full European standards. NSAI has published this latter series as Irish standards⁶.

It was considered appropriate that Ireland, in common with other European countries, should prepare for the introduction of a harmonised European standard by bringing IS1 in line with

the relevant parts of ENV197-1 'Common Cements' which includes 5 different main cement types:

CEM I	Portland Cement
CEM II	Portland - Composite Cement
CEM III	Blastfurnace Cement
CEM IV	Pozzolanic Cement
CEM V	Composite cement

In all, 25 different cement sub-types are involved. The traditional Portland Cement to IS1 used in Ireland is in the CEM I category. There are no sub-types in this category.

The main changes introduced in IS1 (1991) include:

The introduction of strength classes for cement, with upper and lower limits.

The reference to EN196 for the testing of cement. All tests are now carried out to this standard.

Permission to use up to 5% of 'Minor additional constituents' as defined in ENV197-1.

The introduction of fillers as defined in ENV197-1.

The introduction of requirements for continuous inspection (autocontrol) based on statistical evaluation by the manufacturer as the basis for assessment of conformity as specified in ENV197-1.

The proposed Amendment to I.S.1 would include an additional 52.5 strength class cement and introduce the conformity criteria recently agreed by CEN for certification.

3.4 Certification

Product: NSAI operates a Standard Mark Scheme for cement complying with IS1 and a number of companies now have product certification under this scheme. To bring cement certification in line with the recently published CEN pre-standard ENV197-2, 'Cement-Conformity Evaluation'⁷, NSAI are in the process of introducing a revised set of 'Particular Regulations' which incorporate the provisions of the European Scheme for Certification

This European pre-standard is intended to form the basis for qualification towards the CE Mark for cement and provides for the highest level of attestation of conformity required for compliance with the Construction Products Directive.

The ENV197-2 Scheme incorporates two principal elements:

Factory production control and its assessment

Testing of the finished product (autocontrol and audit testing).

Conformity criteria are verified by NSAI and independent testing carried out at set frequencies on audit product samples.

In addition to the above Standard Mark, both ICL works hold BSI Kitemark Certification for products exported to the UK.

Process: Quality Systems Certification to ISO 9000 has also been a feature of the cement industry and such a scheme contains additional system control aspects that improve quality assurance for users or customers. ICL holds ISO 9002 registration for both of its works.

3.5 Environmental Issues

While cement generally is seen as a necessary and essential component of continued development and renewal of buildings and infrastructure, society's aspirations regarding the environmental performance of industry are becoming more explicitly expressed. The Fifth Environmental Action Programme of the European Union "Towards Sustainability" sets out policies and actions in relation to the environment and sustainable development in Europe. The cement industry, particularly in Europe, is focusing on these issues and successfully attempting to reduce its environmental impact⁸.

In Ireland, ICL has sought to achieve the right balance between environmental performance and the social and economic benefits that cement brings to society. Environmental studies have been undertaken both in respect of new quarries and quarry extensions. ICL is currently pursuing an integrated licence from the Environmental Protection Agency. Economic utilisation of secondary raw materials is practised and this, along with the use of minor additional constituents, reduces raw material consumption, emissions and energy usage.

A reduction in emissions has also been achieved through the use of petroleum coke, a by-product of the oil industry, and installation of energy efficient kiln control systems. Further developments in the area are planned for the future.

3.6 Performance - Cement Properties

Quality control exercised in cement manufacture is influenced by the following parameters:

- Compliance with product standards.

- Compliance with certification scheme.

- Meeting the quality requirements of the customer.

Customers thus receive considerable assurance both from the current standard IS1 and from the Standard Mark Scheme. Inevitably however, market expectations and demands contribute to the setting of more demanding requirements for product quality.

The most widespread cement quality parameters which influence specification and customer preference are likely to include: 28 day strength; early strength development; water demand;

fineness, and alkali content.

However, while absolute levels are of significance, the consistency of the main parameters is of crucial importance to both concrete manufacturers and, ultimately, to clients.

Specific secondary requirements for particular uses also arise and these can relate to performance with admixtures, performance with secondary cementitious materials, performance in high strength mixes and heat of hydration in large sections or pours.

Strength: A gradual increase in 28 day cement strength has occurred in Normal Portland Cement produced at both works over the last decade as indicated in Tables 3.1 and 3.2. This gradual increase, which extends a similar trend reported in the 1985 symposium, has been influenced both by market demand and by the need to comfortably comply with the requirements of a class 42.5 cement introduced in 1991 by IS1. This slow gradual increase allied to minimum cement contents specified by codes of practice has served the industry well from a durability perspective.

The 7/28D relationship has also remained within the range of 70-80%, previously reported, as can be seen in the Tables, reducing somewhat in latter years particularly in Platin as the alkali content of the cement reduced.

Stable 7/28 day relationships of products from each works has enabled concrete producers establish workable control systems based on early age results. Good correlation between mortar prism strength and performance in concrete was previously reported⁹, and has been confirmed in recent testing. Target values are set for relevant chemical and physical parameters, including strength, in quality schemes in both plants, with tight operating ranges also applied. An understanding of the key parameters which influence cement performance enables later age strength levels to be predicted with a good degree of accuracy. Both of these aspects facilitate the operation of an early warning system to customers.

Water demand: The water demand of a cement is measured in the standard consistency test and is a function of fineness. However the water demand of concrete for a given workability is primarily a function of the aggregates, mix proportions and ambient temperatures, with the cement affecting this only to a minor degree. However, at concrete temperatures above 25°C, the loss of workability, particularly in rich mixes can be rapid and thus extra water is required if the concrete is not placed quickly.

Alkali: Alkali levels in cement have become of more interest in recent years following the publication of the IEI/ICS Report¹⁰ (see also section 5). The alkali level of cements produced at both ICL works has been reduced in the past decade as is shown in Tables 3.1 and 3.2. It is expected that this current level of 0.7-0.8 for NPC will continue for the foreseeable future. The alkali value of cement given on test certificates is the "certified average" alkali content that is the average of the last 25 determinations of alkali content carried out on consecutive daily samples.

	2/3D N/mm ²	7D N/mm ²	28D N/mm ²	7/28D %	Fineness (m ² /kg)	Alkalis (Na ₂ Oeq)
1985	30.8	37.9	47.7	80	331	0.96
1986	29.7	37.6	48.4	78	316	1.01
1987	27.4	36.8	48.8	75	319	0.94
1988	27.7	37.4	49.2	76	328	0.95
1989	29.4	38.5	50.5	76	349	0.95
1990	30.4	40.1	51.9	77	356	0.87
1991	23.0*	38.2	50.7	75	331	0.88
1992	22.2*	35.7	51.3	70	297	0.72
1993	23.3*	36.3	51.2	71	317	0.69
1994	22.9*	37.2	53.0	70	318	0.69

* 2D Testing was required by IS1:1991

TABLE 3.1: PLATIN WORKS

Average yearly data for Compressive Strength, Blaine Fineness
and Alkali levels of Normal Portland Cement

	2/3D N/mm ²	7D N/mm ²	28D N/mm ²	7/28D %	Fineness (m ² /kg)	Alkalis (Na ₂ Oeq)
1985	29.0	34.9	43.7	80	298	0.88
1986	29.2	35.5	44.4	80	296	0.94
1987	29.0	36.7	47.8	77	288	0.86
1988	27.8	36.2	47.7	76	294	0.85
1989	27.8	37.0	49.0	76	302	0.80
1990	30.3	39.0	49.9	78	325	0.83
1991	30.4	39.0	49.8	78	348	0.77
1992	26.8*	39.6	50.4	79	345	0.74
1993	27.4*	39.7	50.1	79	358	0.77
1994	25.8*	40.7	52.2	78	348	0.71

* 2D Testing was required by IS1:1991

TABLE 3.2: LIMERICK WORKS

Average yearly data for Compressive Strength, Blaine Fineness
and Alkali levels of Normal Portland Cement

Performance: Performance of cements in customer mixes has been raised, mainly abroad, in the context of the elimination of concrete testing to BS4550 for cement compliance. Cement is used in a wide range of applications and performance in standardised quality control tests may not always reflect its performance in use, particularly for the wide range of cement contents and different placing and curing conditions. However, the use of specific customer aggregates and mixes is advocated to offer a limited guide to performance in concrete and a programme of this kind has currently been commenced by Irish Cement.

4. SECONDARY CEMENTITIOUS MATERIALS

4.1 Introduction

The principal secondary cementitious material reviewed in the Irish concrete context is pulverised fuel ash (pfa), but some reference is also made to microsilica and ground granulated blastfurnace slag (ggbs).

The non-availability of locally produced industrial by-products, such as ash and slag, has been the principal reason for their absence from Irish concrete. The relatively high cost of imported product and industry reluctance, of a practical nature, to intermittent or specialised use is perhaps a secondary factor. The use of microsilica in slurry form in the last decade has grown, where it finds specialist use in industrial floors. GGBS has not been used in structural concrete in this period although it is currently specified as an option for two large civil engineering projects.

However, the commissioning of Moneypoint coal-fired generating station in the late 1980's has resulted in pfa becoming available for use. Irish Cement has contracted with the ESB to take much of the pfa produced and classify it for various uses. Pfa to BS3892 Part 1, which is suitable for use in structural concrete, is available from the Limerick works to the concrete industry. The balance of the ash is used in the cement manufacturing process.

A brief review of the production, properties and uses of pfa is perhaps appropriate at this point.

4.2 Pfa

Production: This is a by-product of the burning of pulverised coal in power station furnaces for the generation of electricity. The very fine coal combusts in the furnace reaching a temperature of approximately 1500°C. The minerals present in the coal melt at this level and pfa is formed when these minerals recombine in spherical glassy particles. The fine ash is recovered from the flue gas stream, before discharge to the atmosphere, in cyclones or, as in Moneypoint, in electrostatic precipitators. It can then be classified into different fraction sizes.

Ash Properties

Composition: Typical compositional ranges for Moneypoint ash are given in Table 4.1 and compared to that given for UK ashes and for NPC.

The pfa consists principally of aluminosilicate glass spheres and contains some iron, calcium, magnesium, sulphate and alkali metals. Carbonaceous particles resulting from incomplete combustion are also present. There may be present some crystalline compounds such as quartz, mullite and iron oxides haematite and magnetite. It is the non-crystalline or glass element that is largely responsible its benefits in concrete. Glass contents range from 45-80%

Element	Moneypoint Ash	UK Range	US Range
SiO ₂	48 - 60	50 - 55	40 - 51
Al ₂ O ₃	17 - 25	24 - 29	17 - 28
Fe ₂ O ₃	7 - 15	8 - 13	9 - 19
CaO	2.5 - 8.0	1.2 - 5.3	1.2 - 7.0
MgO	0.8 - 2.2	1.3 - 2.1	0.8 - 1.1
Na ₂ O	0.2 - 1.0	0.8 - 1.5	0.4 - 1.8
K ₂ O	1.0 - 2.1	2.2 - 3.8	1.8 - 3.0
SO ₃	0.8 - 1.4	0.3 - 1.7	0.3 - 2.8

TABLE 4.1: Typical PFA Compositional Ranges

Pozzolanicity: The principal reaction of pfa in concrete is the pozzolanic reaction between the glass phase of the pfa and the calcium hydroxide from hydration of Portland cement. This affects the longer term strength gain of the concrete, which is inversely related to the calcium hydroxide content. This pozzolanic activity is generally found from 7-14 days onwards at standard temperatures. Products formed from this reaction are further calcium silicates and aluminate hydrates.

The pozzolanic reaction is significantly affected by:

- the amount of glass phase present,
- the ash fineness,
- physical and chemical properties of the Portland cement,
- temperature,
- the quantities of PC and pfa in the mix.

The current version of BS3892 - Part 1¹¹ now requires that the 'strength factor' of a 70:30 blend (PC:pfa) shall be not less than 0.8 of a PC control mortar.

Loss on Ignition (LOI): Residual carbon is found in the ash and this must be controlled within limits as it can detrimentally affect ash performance in concrete. Carbon particles are generally porous and thus have high water absorption capacity. When pfa is heated to 1000°C it suffers a weight loss due to combustion of this carbon. Thus LOI is used as an indirect measure of the % carbon. 6% is the limit specified in BS3892 Part 1.

Fineness: Ash fineness will depend on the ground coal fineness, its hardness and the coal mill and furnace conditions. The average particle size is $20\mu\text{m}$ with a range of $0.5\mu\text{m}$ - $200\mu\text{m}$ possible, though in modern plants the top range is much lower. Fineness can be measured in different ways and the method adopted in BS3892 is wet sieving on a $45\mu\text{m}$ sieve with the limit set being a maximum of 12%.

Density: The relative density of pfa is usually in the range of 2.2-2.5, with Moneypoint ash approximately 2.4.

Properties in Concrete

Water Demand: For concretes of equal slump, a lower water content is normally required when Part 1 ash is used. The amount of the reduction depends on:

- particle size and grading,
- relative cement and ash properties,
- spherical particle shape giving improved rheological efficiency,
- fine aggregate grading.

Reductions found in limited work with Moneypoint ash (both in laboratory and full scale) indicate that it is similar to that quoted in UK literature - Concrete Society TR 40 and BRE "Design of Normal Concrete Mixes". Typical water reductions are approximately 2-3% for every 10% ash in total cementitious content.

Workability: Concrete containing additions generally behaves differently in the plastic state than that using NPC alone. With pfa, the spherical shape of the ash particles produces an overall improvement in cohesiveness and will aid pumpability and allow easier compaction.

Heat Evolution: One of the principal benefits of the use of pfa on large section pours relates to the reduction of the heat of hydration in hardening concrete. The temperature reduction is directly proportional to the % of pfa in the cementitious component for any given 'cement' content. This reduced rate of temperature rise is attributable to the slower rate of hydration of the ash and can thus be of significant benefit in high strength large sections, or large pours, in minimising early thermal contraction. Typical heat of hydration figures at 3D for Limerick NPC/Moneypoint pfa, using Isothermal Calorimeter, are:

Limerick NPC	286 kJ/kg
NPC/PFA (80:20)	238 kJ/kg.

Strength: Pfa will affect the rate of strength gain and the ultimate strength of concrete in which it is used. The rate of early strength gain is slower than that of a PC concrete of similar grade or cement content at standard (20°C) temperature. However, the longer term strength (56, or 90D or later) may match or exceed that of a PC concrete of similar cement content.

It is important to note that the early strength gain of concrete depends not only on the cementitious content, but also on the curing conditions, the mix proportions (w/c ratio especially), the types and sources of materials and particularly on the concrete temperature.

The major influence on the compressive strength differences between a PC concrete and a PC/pfa concrete is the mix design method used. If the latter concrete is designed on a similar 28D basis, early strengths were found to be typically 80-90% of a PC concrete at 3D using Moneypoint pfa¹², with the rate of strength gain from 7D onwards exceeding that of PC concrete.

It is important to note that the strength development of pfa concrete is more adversely affected by poor curing than for a PC concrete, this effect being more pronounced at higher levels of pfa addition - as reported by BRE, based on an extensive laboratory research programme¹³. However, it is suggested that is unlikely to affect the bulk strength of concrete except in slender sections.

Durability: Concrete which uses additions such as pfa has, in many respects, the potential for increased durability compared with PC concretes of the same grade. This is attributable to the pfa pozzolanic effects resulting in reduced porosity and permeability, to continuing hydration (in the presence of moisture) and to the modified chemistry of the cementitious matrix. However, as noted, above PC/pfa concretes are more sensitive to poor curing, and this can affect durability especially in the cover zone performance.

The BRE Report¹³ also found that pfa concretes of equal strength grade to a PC concrete had improved air and water permeability for pfa contents of 15-30% and, from a survey of existing structures, examined carbonation depths were of a similar order to PC concrete and resistance to penetration of chlorides was much higher.

4.3 Microsilica

This product has been used in Ireland in concrete for specific applications since the mid 1980's. It is generally used in slurry form (50% by weight each of microsilica and water and added superplasticiser). This has typically been added to the concrete truck on site for more consistent results.

This material is used in concrete to achieve specific properties such as improved chemical resistance, greater abrasion resistance in industrial floors, and reduced drying shrinkage by reducing the w/c ratio.

4.4 GGBS

The principal benefits offered by the use of ground granulated blastfurnace slag relate to durability properties and reduced heat of hydration. It is these properties, particularly the latter, which influenced the specification of ggbs as an option in two major civil engineering projects which are about to commence. The cementitious components and mix design of the concrete are primarily influenced by strict temperature constraints in the hardening concrete.

4.5 Blended Cements

Blended cements have not been a feature of Irish concrete practice due to the reasons outlined in 4.1. However with the availability of pfa, the introduction of blended cements is a more likely possibility.

A pfa-blended cement could offer both the specifier and the concrete manufacturer advantages. The specifier could achieve in concrete some of the benefits previously listed in 4.2 for certain environmental exposure conditions. The manufacturer would be able to use a reliable single cementitious product produced to a quality scheme.

Though updated British Standards for pfa blended cements are available it is preferable that an Irish Standard is produced to take account of Irish materials and practice.

The DOE 'Specification for Concrete for Highway Works' and Draft IS326 allow the use of pfa in concrete to BS6658 or in a similar fashion to that prevailing in the UK where equivalence at the mixer is allowed.

5. PERFORMANCE ISSUES IN CONCRETE

5.1 Introduction

BS8110:1985 introduced the linkage of strength grade with the durability parameters, introduced in CP110, of minimum cement content and maximum water/cement ratio. Structural concrete was generally specified by strength from a performance aspect and this property is the one that was primarily tested on site or at the concrete plant. Thus this linkage gave assurance to specifiers that these other parameters would also be met.

IS326:1988, based on BS8110, was published by NSAI to reflect more accurately the known performance of concretes made with Irish materials (i.e. cement and aggregates) and to include modifications relating to durability to mix recommendations which reflect Irish conditions and practice. This was established through a survey and study by the Irish Concrete Society of strength, cement content and water/cement ratio relationships in ready-mixed concrete produced in Ireland ¹⁴.

NSAI have circulated for comment and are now about to publish, a revised version of IS326 ¹⁵ that incorporates much of BS5328, again with suitable amendments for Irish materials and practice. This should be a most useful guide to the specification of concrete.

Constituent materials of concrete are covered in some detail in this draft standard and the durability of concrete is also addressed with substantial guidance given for a range of factors, generally on a prescriptive basis.

Recent guidance given in BRE Digest 363, in relation to exposure to sulphate or acid attack, is incorporated in the revised changes, with cement types, minimum cement contents and water/cement ratios recommended for given exposure levels. PFA -blended cements (25-40%) among others are now recommended as giving improved sulphate resistance at higher SO₄ concentration levels (Class 2,3 & 4A).

5.2 Strength & Durability

Cement, as the binder in concrete, is the principal determinant of concrete strength through the water/cement ratio relationship. With the improvements in the cement manufacturing process and market demand for improved concrete strengths, especially at 28 days, cement contents decreased as cement strength increased. The durability requirements established in CP110 and later in BS8110 and BS5328 helped establish acceptable durability parameters for designers.

The various aspects of a cement which affect its performance for a particular end use are complex. The range of concrete products and methods of producing these are constantly increasing and the performance of cement is expected to be all-encompassing. Strength gain characteristics by cement in concrete do play an important role from a structural viewpoint and also from a durability viewpoint. Concrete permeability plays an important role in protecting concrete and reinforcement from premature attack. The pore-filling ability of the cement hydration products is of vital importance in this regard to prevent ingress or delay penetration of harmful materials. Because of the relationship of cement hydration to strength, higher strength concrete does correlate well with improved permeability characteristics. In this regard, the gradual controlled increase in cement strengths of Irish cements and the significant potential later strength gain beyond 28 days has perhaps assisted with avoiding major durability problems associated with increased permeability. The current revision to IS326 should be also of benefit in this area.

However some durability parameters are dependent on concrete characteristics other than strength. Aspects such as chloride ingress and diffusion, heat of hydration and alkali content are related to the material properties of the concrete mix, the construction process and to the service environment.

Recent research on chloride ingress and diffusion of chloride ions to the reinforcement questions reliance on current code recommendations that suggest high grade, low w/c combined with medium levels of cover to reinforcement in providing a long and adequate service life for structures in a chloride environment. It is suggested that a number of alternative options are available for giving increased chloride resistance, including specification of specific mix constituents.

The situation in Ireland has not given cause for major concern to-date but it is important to establish and review the current situation and to consider appropriate recommendations. This review is likely to be put in place later this year by the Irish Concrete Society.

The issue of ASR and Irish concrete is being addressed in another paper for this symposium. As already mentioned in Section 3, the alkali level in cements produced in Ireland has been reduced in recent years and this will help in reducing the risk of ASR in future construction once the guidelines of the IEI/ICS report are followed.

The resulting effects from heat of hydration in concrete have become of greater significance in recent years here due to the increasing strength specified in many structures, the larger scale pours and the method of curing, especially for precast units. With increasing 28 day strengths and fineness, current Portland cements typically generate higher heat of hydration levels in concrete than those of past decades.

This can have beneficial effects on colder weather and smaller sections but can require consideration for larger pours and high strength sections. However the temperature rise is dependent on a number of factors related to the mix constituents and the construction arrangements. Useful advice is given in Ciria Report 91¹⁶ and the use of pfa or ggbs is advantageous in this regard.

5.3 Specifying Durability Performance

European standards should, in future, be expressed as far as possible in performance terms. CEN TC104/SC1 is currently proposing a set of exposure classes in prEN206¹⁷ that relate to specific forms of deterioration i.e. carbonation-induced corrosion, chloride induced corrosion, aggressive chemical environments and freeze-thaw attack. This will facilitate the application of type approval performance tests and criteria. Work is already underway in standardising a number of durability performance tests. Refined methods of durability design are being proposed by some sectors as the way forward¹⁸.

While this aspect is unlikely to arise in the near future or in prEN206, it is accepted that performance tests are also necessary for the different cements classified in prENV197-1 as these have different properties and performance characteristics when used in concrete. Performance tests, when agreed, would provide a mechanism for distinguishing between the various cement types. The current draft of prENV197-1 contains performance tests for strength, soundness and setting time. Additional performance criteria are being considered by CEN/TC51/WG12 for possible inclusion in a future EN197-1. Tests for the following criteria are being currently evaluated: Sea-water and sulphate resistance; Freeze-thaw resistance; Heat of Hydration; Protection of reinforcement.

Until all these performance tests for cements and concrete are in use the following proven parameters are generally recognised as important in specifying a concrete to resist given exposure conditions:

- maximum water/cement ratio,
- minimum concrete grade,
- minimum cement content,
- cement type,
- minimum cover to any reinforcement,
- nominal maximum aggregate size.

Performance in-situ will as always also depend on proper workmanship to achieve full compaction, good finish and effective curing. These aspects are to be specified in a separate Euronorm.

6. CONCLUSION

In this last decade we have added a little more to the development of cement and to its use in concrete.

However, if we are to achieve continued fame for our building heritage in concrete, a clearer

and more complete understanding of concrete and its constituent materials must continue to be a prime objective for the wider industry. Standards generally set only minimum guidelines for usage but the great builders of the past had their own standards of excellence.

Past experience, present expertise and excellence in materials and workmanship should guide our efforts to construct durable concrete structures that benefit both our present and future existence.

Acknowledgement

The author is grateful for the support of management and the assistance of colleagues in Irish Cement Ltd. in the preparation of this paper.

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DISCUSSION.

MR. LYNCH introduced his paper.

He noted that in this fourth symposium in the series cementitious materials occupy a full paper as opposed to being part of a paper on concrete products in general. This reflected the increased role of secondary cementitious materials in the last decade.

He reviewed recent developments in relation to ordinary portland cement. The response of the cement producers to environmental concerns through action at both the plant and in quarrying operations were outlined. Changes in Irish Standard I.S.1 were described. He explained the certification approaches - quality systems certification and product conformity.

Turning to the topic of secondary cementitious materials he noted that pfa was now available from Moneypoint electricity generating station; microsilica was in limited use in industrial environments and ggbs had been specified as an option in two large civil engineering projects. He said that work to date on the cementing efficiency factor (or 'k-factor') of Moneypoint ash indicated a value of approximately 0.4. He observed that blended cements were used widely in Europe but that in the United Kingdom the trend of addition at the mixer was more prevalent. He preferred the European approach and looked forward to the development of an Irish standard for blended cement.

MR. JOHN NEWELL opened the discussion by firstly complimenting Mr. Lynch on his paper. He highlighted a number of points which interested him.

He noted that annual cement sales in 1994 fell 0.4 million tons short of the figure of 2 million tons achieved in the early 1980's. A rise in output towards the end of the 1980's could be attributed to infrastructural developments, including the roads programme. A comparison of the combined 'residential' and 'agricultural' sector figures in 1984 and 1994 showed a decline over the period from 70% to 66%. These sectors were very important to the concrete industry and were heavily subsidized by the exchequer. He therefore observed that any reduction in state support for these sectors would have repercussions in the concrete industry.

An increase of 26% in cement use by readymixed concrete producers in the period under review did not translate directly into increased concrete production - where the volume increase was of the order of 10%. It reflected the use of higher strength concretes and increased cement content levels due to durability concerns. He observed that recently published data had shown the average strength of United Kingdom cements to be 59 N/mm² at 28 days in a range of 53 to 62 N/mm². Comparison with the strengths in this country (Table 3.1 and 3.2) indicated a potential economic advantage for our sister industry in the U.K. He did not agree with Mr. Lynch's comment that cement content affected water demand to a minor degree for concrete of a given workability. Experience with the cement contents of 450 to 500 kg/m³, required for Grade 40 to Grade 50 concretes, with transport distances of up to 30 miles, often in warm weather, was leading to a chemistry in the mixer drum that caused Mr. Newell some concern. Potential difficulties in the circumstances described were loss of workability, lower cube strengths, lower core strengths and increased shrinkage. Cement contents, he remarked, were in part related to cement strengths. Noting the gradual increase in cement strengths reported in the paper Mr. Newell, as a manufacturer, expressed the hope that increases would continue over the next decade and that the "gradual nature" of the increases would be de-emphasized!

He recorded the introduction of ISO9000 series quality systems into the industry and predicted that a national certification scheme for concrete would be in place by the year 2005.

In relation to environmental issues, he stated that members of the Irish Concrete Federation - itself a development of the last ten years - were aware of their responsibilities. The recent establishment of the Environmental Protection Agency would enhance matters.

Turning to the matter of blended cements, he drew attention to the need for better site practice regarding curing with these materials. He wondered if in-situ strengths would decline? If so one would need to consider the impact on the core/cube relationship and partial safety factor for materials γ_m in the codes.

Finally, Mr. Newell observed that the past decade had seen the rise and rise of mission statements. Looking to the quotation from the Edison Portland Company in Mr. Lynch's introduction he suggested that by transposing the word 'concrete' for the word 'cement' in that quotation one could construct a suitable mission statement for the Concrete Practice in Ireland symposia!

MR. EAMONN MOORE enquired why the final setting time was no longer referred to in Irish Standard I.S.1?

MR. EAMONN CANNON wondered if the introduction of blended cements would have an effect on the deformability of concretes?

MR. EAMONN CORCORAN recorded that in one of the forthcoming projects mentioned in the context of ggbs 85000m³ of site-batched concrete would be produced using 30000 tons of cementitious powders. Two thirds of this will be slag.

MR. DENIS WALL observed that concrete grades in excess of 100 N/mm² were now being used on the continent and enquired what was the highest concrete strength achievable in Ireland using normal portland cement?

MR. LYNCH replied to the discussion.

He said that high cement content mixes were a matter of concern to all in the industry. The use of retarding admixtures was worthy of consideration in certain circumstances.

Regarding cement strength, he was aware of manufacturers' concern across Europe where portland cement constituted about half of the use of cement. It was interesting to note, however, that in Germany the largest volume produced was in the lower (32.5) strength class. He felt that controlled development of cement strength had served us well and allowed us to avoid some of the problems experienced elsewhere.

He accepted that the 28 day strengths of blended cements were lower but said that long term strengths were satisfactory.

The removal of the reference to final setting time in Irish Standard I.S.1 was to bring the standard into line with European Standard ENV197-1.

He was not aware of major differences in the deformability of blended cement concretes but it was known that the E-value changed.

He said that the very high strength concretes referred to in the discussion incorporated secondary cementitious materials but that portland cement would be the dominant portion.

SESSION C

MODERN METHODS OF PAVEMENT CONSTRUCTION IN CONCRETE

D. N. PHUKAN, B.E., Dip.Proj.Man., Dip. Avn. Man.
Aer Rianta Technical Consultants.

Sessional Chairman

Cmdt. O. B. WALLACE, B.E., C.Eng M.IEI, MICT
Department of Defence.

1. HISTORICAL DEVELOPMENT.

A contract for the construction of concrete runways at Dublin airport was prepared in 1945 under the auspices of the Department of Industry and Commerce. The contract specification, the oldest in Aer Rianta's files, required the concrete to be consolidated and finished using a "... mechanical self-propelled vibratory finishing machine...". In general all concrete pavements at the airports have been laid using a similar machine running on fixed forms.

This first runway pavement and some subsequent ones were 9 inches thick laid directly on the prepared subgrade. At the discretion of the Engineer a layer of "...stout waterproof paper..." was laid on the subgrade prior to the placement of the concrete. A net P.C sum of 5d (old pence) per square yard was included in the 1945 contract for provision of the paper. The pavement was laid in slabs of 25 feet width and the paving machine was required to be capable of consolidating and finishing the full width in one operation. Longitudinal construction joints were tongue and groove type. Longitudinal contraction joints (dummy joints) with steel tie bars were formed along the centreline of each strip. Transverse expansion joints with steel dowels were formed at 50 feet spacing and transverse contraction joints (dummy joints) were formed at 16' 8" spacing i.e. every third joint was an expansion joint. Thickened edge joints were also specified in the outer edges of pavements and at pavement intersections. The specified cement content was 525 lbs. per cubic yard of finished concrete, which is about the equivalent of 312 kgs. per cubic metre. The 28 day cube strength required was 5,000 lbs./sq. in. which is approximately 35N /mm². One six inch diameter core was required to be cut from every 2,000 square yards of pavement. This core was cured in damp sand for 56 days and was required to have a compressive strength of 4,000 lbs./sq. in. - c. 28 N/mm². The core was also used to check the thickness of the slab. The tolerance for surface regularity of the slab was 1/4" when tested with a sixteen foot straight edge.

As aircraft got heavier runway slab thickness increased from 9" to 10", from 10" to 12" and is currently 370mm. Interestingly even the earliest apron and taxiway slabs - specified by the Department - were 12" thick compared to the 9" runway slab. It should be noted however that according to our records the oldest pavements at Dublin Airport (British Army/RFC) comprised 6" of concrete on 9" of rubble base course.

The use of a base course under concrete slabs was first specified (provisionally) by the Department in 1957. The base course was 3" thick and composed of " ...approved sand-gravel well graded, and containing sufficient fine material and clay to act as binder...".

Lean concrete basecourse was first specified in 1960. The cement content required was 190 lbs. per cubic yard - c. 113 kgs per cubic metre.

A granular capping layer was used for the first time in 1969. This was a 225mm thick layer of material similar to Clause 803 of the Specification for Road Works.

The current Aer Rianta specification for concrete pavement at Dublin Airport is 370mm of C40 concrete on 150mm lean concrete base course and 200mm capping layer to Clause 804 of the Specification for Road Works. At Shannon Airport the corresponding figures are 400mm, 200mm and 200mm due to a combination of heavier aircraft and poor ground conditions. At Cork Airport the figures are 300mm, 150mm and 200mm due to a lighter aircraft mix.

Until recently all the concrete pavements at the airports were laid using fixed form pavers as our specification did not allow for slip forming methods. The fixed form pavers generally comprised a single machine running on rails mounted on the side forms. The concrete would be spread to a uniform surcharge before the machine with a backactor. The finishing machines were normally equipped with either a bank of vibrators or reciprocating paddles which struck off the concrete to the correct level for the machine to compact and finish. In 1987 however the specification for the new runway 10/28 at Dublin Airport permitted slip-forming as an option and included a section on same. The contractor however chose to use the more traditional fixed forming method. The paving train used however was more sophisticated and had more elements than any paving plant previously used at the airports. It comprised a spreader box, two compactor finishers, a diagonal finisher, a brushing/curing machine and travelling tentage. The function of these various machines is explained below. Slip-formed pavement was not laid at any of the Aer Rianta airports until 1992 when this method was proposed by P. Moneley Ltd. and approved by Aer Rianta for the construction of about 14,000 square metres of apron pavement.

The two modern methods of mechanized construction of concrete pavements therefore of which the author is aware and has experience are:

- Fixed form Paving,
- Slip-form Paving.

Both types are very weather dependent. Fixed form paving does allow for a degree of weather protection in the form of travelling tentage which is explained below. This is not as easily deployed for slip formed pavement. In both cases however it is difficult to protect infill slabs from damage by rain and water.

2. FIXED FORM PAVING

In this method stout forms usually constructed of steel are set up on either side of the slab to be poured. A minimum of 24 hours in advance of paving the forms are laid on a bed of low moisture content cement mortar or concrete grade C7.5. If necessary shims are packed underneath the forms also so that the correct level is obtained. The bedding should not be permitted to extend

under the slab. The forms should be secured by using not less than three pins evenly spaced for each 3m length of form. In addition one pin must be fixed at each side of every joint in the forms. Forms should be tightly jointed together by a locked joint, free from play or movement in any direction and they should be cleaned and oiled immediately before each use. The forms should be straight within a tolerance of 3mm in 3m and there should not be a vertical step greater than 3mm between the ends of adjacent forms. The horizontal alignment for forms should be to the required alignment of the pavement edge within a tolerance of ± 10 mm.

Generally there is a rail fixed to the forms to support and guide the paving train. The rails or running surface must be kept clean in front of the wheels of the paving machines. The forms must be of sufficient strength to support the weight and pressure caused by the paving equipment. It is essential that the rail be parallel to the top of the form.

Our experience indicates that the side forms should not be removed earlier than 12 hours after the completion of the construction of the slab. Care is necessary in the removal to prevent damage to the concrete and any projecting tie bars.

The paving "train" which runs on the rails on the side forms consists of a number of separate powered machines which spread, compact and finish the concrete in a continuous operation. The concrete is fed to the train using side tipping or conventionally tipping trucks. The trucks discharge the concrete into the spreader box which is the first element of the train. This machine comprises a hopper which is capable of travelling longitudinally and transversely along the slab and deposits the concrete to a fairly uniform uncompacted density and approximately to the required surcharge. The surcharge at the high edge of the slab would usually be somewhat greater than that at the low edge as the concrete tends to flow to the low edge under the vibration of the paving plant. The spreader can to some extent accomplish this difference in surcharge.

The spreader is immediately followed by a compactor/finisher. This machine is fitted at the front with either rotary strike-off paddles or a bank of poker vibrators. The paddles are mounted on a rotating horizontal shaft running transversely across the machine which strike-off the concrete surface and finely regulate the surcharge. The bank of pokers also performs this function but in addition it provides a significant degree of compaction. At about the centre of the machine there is a vibrating beam which in some cases imparts the final degree of compaction to the concrete. It is our experience however that it is necessary to vibrate the concrete further at the side forms with ordinary poker vibrators after the passage of the machine to avoid honeycombing at the edge of the slab. On some models the leading edge of the vibrating beam can be canted upwards somewhat so that compaction is aided by the downward pressure of the machines own weight. Usually the compactor/finisher incorporates an oscillating finishing beam or a belt which trails behind and imparts the initial degree of regulation to the surface.

During the construction of runway 10/28 at Dublin we found it necessary to have a second compactor/finisher directly following the first in order to get a satisfactory degree of compaction. This was probably due to the fact that the mix had to be quite dry in order to achieve the specified surface regularity - 3mm max. under a 3m straight edge. The vibrating beam on the second compactor/finisher had a stepping action on the leading edge as well as the normal vibrating effect.

The final machine regulation is imparted by either a diagonal or transverse finisher. In our experience we found the diagonal finisher to be more satisfactory. These machines travel on the rails and comprise an oscillating beam which is either set diagonally - at an angle to the side forms - or transversely. After this machine has passed over the slab any final regulation required is applied by hand floating with steel trowels.

The final machine in the train is the texturing/curing machine. The front element of this machine comprises a stiff wire brush which is drawn across the surface of the concrete at a fixed height and which gives it the necessary surface roughness for vehicle/aircraft steering and braking etc. The rear element of the machine comprises a hooded sprayer unit which applies the curing compound to the brushed concrete. The sprayer moves transversely across the slab at a fixed speed and a fixed rate of discharge so that the curing compound is applied uniformly.

The final element of the train is the travelling tentage. This comprises a lattice framework in the shape of a flat tent covered by canvas or tarpaulin. The tentage may be pulled along manually or by the last machine in the train. The purpose of the tentage is to protect the fresh concrete from damage by sun and rain and from the drying effects of wind.

Compacting and finishing machines should at all times be kept in good condition. Rails and wheels must be kept free of concrete or earth and screeds kept free of caked concrete. The speed of travel of the machine should be regulated to give full compaction of the concrete for the full depth being compacted.

The concrete demand for a typical fixed form paver is about 40m^3 per hour.

3. SLIP FORM PAVING

Slip form paving is the process of constructing and finishing concrete pavement between moving side forms. The slab is laid compacted and finished by a single machine running on tracks which is controlled for both line and level using guide wires and sensors. The guide wires are provided along each side of the slab and each guide wire is at a constant height above and parallel to the required edges of the slab - within a vertical tolerance of $\pm 3\text{mm}$ for airport pavements. Additionally one of the wires must be at a constant horizontal distance from the required edge of the pavement in order to steer the machine. The lateral tolerance required on the steering wire is $\pm 10\text{mm}$.

The guide wires are supported from stakes by connectors capable of fine horizontal and vertical adjustment. The stakes are located to coincide with the transverse pavement joints - about 6m apart - or closer if the paving process requires it. The guide wires are tensioned on the stakes so that a 500 gramme weight produces a deflection of not more than 20mm when suspended at the mid-point between any pair of stakes. The ends of the guide wires must be anchored to fixing points which may not be closer to the edge of the slab than the row of stakes.

The stakes should be positioned and the connectors maintained at their correct height and alignment from the day before concreting takes place. The guide wire should be erected and tensioned on the connectors at any section for at least two hours before concreting that section. As a protective measure from traffic etc. the guide wires should be clearly marked at a minimum of 3m intervals.

Slip form paving machines have vibration of variable output and are self propelled. The machine should be of sufficient mass and power to maintain an adequate forward spread without transverse, longitudinal or lateral instability or without displacement.

The concrete is spread in front of the machine using a backactor. The machine used at Dublin Airport had a bank of vibrating pokers at the front which levelled and compacted the concrete initially. Following the pokers there was an auger which helped to spread the concrete laterally and uniformly as the machine passed over and extruded the finished concrete at the rear. This machine also incorporated a machine for automatic insertion of tie bars in the longitudinal joints. At the back of the machine there was a ski shaped float parallel to the centreline of the slab which oscillated slowly from side to side and was intended to give the concrete a fine finish. Like the fixed form pavers however it was noted that a degree of hand finishing was also required.

The concrete mix for slip-forming seems to be very critical and it took a considerable number of trials at Dublin Airport to find a mix capable of satisfactory extrusion. The use of an air entraining agent eventually solved the problem and a satisfactory slab was produced.

The concrete demand for the smaller type of slip form paver is about 40m³ per hour. Larger pavers require in excess of 60m³ per hour which would virtually rule out off site batching and demand a large capacity on site batching plant.

4. CONSTITUENTS OF CONCRETE:

Normal Portland cement certified as complying with I.S.1 current edition is used in the manufacture of concrete for airport pavements.

Aggregates for all pavement quality concrete should be natural materials complying with I.S.5. Once the appropriate gradings have been determined and approved they should not be varied. The extent of crushing of the aggregate, determined in accordance with I.S.5 should not exceed 30 per cent. The Aer Rianta specification expressly requires that the coarse aggregate consists of crushed limestone graded into two sizes:

40mm - 20mm

20mm - 5mm.

In an area such as North Co. Dublin where there is an abundant supply of such aggregates it is preferable to use aggregates with a coefficient of thermal expansion closer to that of the concrete matrix than other heavier aggregates.

Flakiness index when determined by the sieve method described in B.S. 812 should not exceed 35 for any size of coarse aggregate used.

The chloride content of the aggregate to be used, determined in accordance with B.S. 12 should satisfy the requirements given in B.S. 882.

Aggregates from the same source and similar in every respect to the materials proposed for use should have been exposed to natural weathering for a period of at least 5 years without appreciable deterioration.

Additives or admixtures are not normally permitted in the P.Q. mix. As mentioned above however it was found that a small proportion of air entrainment of between 3% & 5% was required for satisfactory slip-forming.

5. MIX PROPORTIONS FOR PAVEMENT QUALITY CONCRETE

The mass of cement in each cubic metre of concrete should not be less than 360kgs, with a tolerance of $\pm 2\%$ in cement content of batches or days output. The water content should be the minimum required to provide the correct workability for full compaction of the concrete to the required density, as determined by trial mixes. The maximum free water-cement ratio should be 0.50. Slump is normally 0 - 25mm.

The proportions of fine aggregate and coarse aggregate are determined from laboratory trial mixes. Each size of aggregate is batched by mass, allowance being made for the mass of moisture in the aggregate. The mass of fine aggregates and the mass of each size of coarse aggregate should be within a tolerance of $\pm 2\%$ of the total mass of aggregate per batch determined following the trial mixes, and the total mass of the aggregate should be within $\pm 2\%$ of the total mass. A typical mix is as follows:

Cement	370 kg/m ³
Fine Aggregate (Natural Sand)	770 kg/m ³
Coarse Aggregate 20mm	780 kg/m ³
Coarse Aggregate 40mm	380 kg/m ³
Water	100 - 175 litres/m ³

Pavement quality concrete should be Class C40 (B.S. 5328). A typical seven day cube strength made from the trial mix is about 58 N/mm². Typical site results of crushing strength from cubes at various ages are as follows:

3 Days	25 - 30 N/mm ²
7 Days	40 - 52 N/mm ²
28 Days	55 - 60 N/mm ²

The in-situ strength of the pavement concrete is determined from cores removed from the pavement. The cores are tested in accordance with the relevant provisions of B.S. 1881. The equivalent cube strength of the cores should be not less than 32 N/mm^2 .

The workability of the concrete at the point of placing should enable the concrete to be fully compacted and finished without undue flow. The optimum workability for the mix to suit the paving plant being used is determined by the Compacting Factor test, or by the slump test, in accordance with B.S. 1881.

Laboratory trials of designed mixes are carried out with the materials from all sources to be used in the Contract. They are repeated if necessary until the proportions that will produce a concrete which complies with the Specification have been determined.

Satisfactory arrangements should be made to transport the concrete, without segregation, from the mixer to the paving plant, and for depositing the concrete in a satisfactory manner suitable to the particular paving plant used. Suitable tarpaulin covers are provided to protect the concrete in wet or very hot weather.

6. PAVEMENT JOINTS.

Regardless of the type of paving plant used the joints are constructed to the same detail. Joints in the surface slab, and lean concrete basecourse are staggered so that they are not coincident vertically and are at least 1m apart. The following are the types of joints commonly used in concrete pavements:

Transverse Joints

Transverse joints are at a spacing of about 6 metres and are normally contraction joints but occasionally may be expansion joints. It is our practise in Aer Rianta not to use expansion joints except at junctions with existing pavements or at changes of direction. Transverse joints should be straight within the following tolerances along the intended line of the joint:

- (i) Deviations of filler board (expansion joints only) from intended line of joint $\pm 5\text{mm}$.
- (ii) The best fit straight line through the joint groove should not be more than 5mm from the intended line of the joint.
- (iii) Deviations of the joint groove from the best fit line should not exceed 5mm.

Transverse joints on each side of a longitudinal joint should be in line and of the same type and width.

Transverse joints have a sealing groove of a depth between one quarter and one third of the slab thickness and about 6 mm wide.

Contraction joints are sawn in the hardened concrete to promote cracks at the required positions. Sawing is undertaken as soon as possible after the concrete has hardened sufficiently to enable a sharp edged groove to be produced without disrupting the concrete and before random cracks develop in the slab. In general sawing should be carried out within 24 hours of the final compaction of the concrete. Sawing operations have precedence on site and sufficient back-up equipment must be available on site in the event of saw breakdown.

The initial saw cut at contraction joints is vertical, approx 6mm wide and extending to a depth of between a quarter and one-third of the slab thickness as mentioned above. Where sawing is carried out before the side forms are removed, the saw cut is taken as close as possible to the edge of the slab and completed to the edge and across longitudinal joints, after the forms are removed.

Expansion/Isolation Joints:

Expansion/isolation joints are formed where new concrete pavement abuts existing concrete pavement or where new pavements are in different directions. These joints are 20mm wide with a soft board filler of a firm compressible material or a bonded combination of compressible and rigid materials. The filler board has a ridged top edge and is of such a depth that the top of the board allows the passage of finishing beams and promotes a surface crack along the line of the joint. The filler board is drilled to suit the dowels (if any) projecting from the existing pavement.

Longitudinal Joints:

Longitudinal joints are either contraction joints or construction joints. Longitudinal construction joints are either tongue and groove joints or plain butt joints - the tongue and groove being the only difference between the two - and they also have a sealing groove. Tie bars are provided in longitudinal joints.

Longitudinal Construction Joints:

Longitudinal construction joints are formed between the adjacent pavement strips. The groove is formed by means of suitably shaped steel moulds fixed to the side forms or in the case of slip formers the mould is shaped to produce the tongue. The concrete must be well vibrated against the mould and the edge of the adjacent pavement strips by means of an efficient poker vibrator to ensure that the T & G joints are perfectly formed.

Longitudinal Contraction Joints:

Longitudinal contraction joints are formed midway between the T & G joints. Like transverse contraction joints these joints are sawn in the finished concrete within 24 hours of the final compaction of the concrete.

Transverse Construction Joints:

Transverse construction joints are formed at the end of each days work or when the concreting operations are interrupted for more than about 30 minutes. They are formed only at the locations of contraction or expansion joints. Where concreting is interrupted between joint locations, the concrete should be removed back to the nearest joint.

Construction joints are vertical butt joints with dowels provided similar to contraction joints. The stop end formwork must be sufficiently rigid to ensure that the joint remains vertical and that the dowels are held in the correct position.

7. JOINT SEALING.

All joints must be sealed to prevent the ingress of moisture which can have a deleterious effect on the slab and the underlying subgrade.

Prior to sealing, joints are widened by sawing and a 5mm chamfer is formed along the joint arris. Prior to permanently sealing the joint is cleaned out by removing any temporary sealing and scouring the sides of the groove by dry abrasive blasting. All dirt and loose material must be removed by air blasting with filtered oil-free compressed air.

A compressible filler strip is firmly packed into the groove so as to provide the correct depth of seal with the top of the seal 5mm below the top of the slab. The groove should be clean and dry at the time of sealing and priming.

Joint sealant may be hot or cold applied material with an appropriate primer if necessary, and is applied in accordance with the manufacturer's instructions. Hot applied sealant is heated in and applied from a thermostatically controlled indirectly heated dispenser with recirculating pump. Hot applied sealant for airport pavements must comply with A.S.T.M. D 3569 (fuel resistant sealant).

The most commonly used sealant at Irish Airports in recent years is a cold applied two-part elastomeric sealant. It has been found that a cold pour material is easier to apply and does not necessitate the use of boilers etc. which are considered a fire risk at airports.

8. DOWEL BARS AND TIE BARS.

Dowel bars are provided in all transverse joints.

Dowel bars in our practice are grade 250 steel conforming to BS 4449 and must be free from oil, dirt, rust or scale. They are straight, free from bends or other irregularities with the ends sawn, or if approved by the Engineer, cleanly cropped with no protrusions outside the diameter of the bar.

Dowels for our pavements are 40mm diameter, 600mm long and provided at 300mm spacing. Other applications such as roads and factory floors would probably be adequately served by smaller dowels at a different spacing. In British Airports they have in many instances dispensed with dowels entirely and rely mainly on aggregate interlock for load transfer.

Dowel bars can be placed by mechanical means but we have never had experience of this and at the airports they have always been firmly fixed manually to the lean concrete base course in the required position prior to the construction of the slab. The dowels are supported on steel cradles in prefabricated joint assemblies.

Dowel bars are positioned at mid-depth from the surface level of the slab within a tolerance of ± 20 mm. They must be aligned parallel to the finished surface of the slab, to the longitudinal joints in the pavement and to each other within the following tolerances:

- (i) Prior to construction of the slab:
 - (a) All bars in a joint should be within ± 3 mm per 300mm length of bar.
 - (b) Two thirds of the bars should be within ± 2 mm per 300mm length of bar.
 - (c) No bar should differ in alignment from an adjoining bar by more than 3mm per 300mm length of bar in either the horizontal or vertical plane.
- (ii) For all bars, after construction of the slab:
 - (a) Twice the tolerances for alignment as in (i) above.
 - (b) Equally positioned about the intended line of the joint within a tolerance of ± 25 mm.

Cradles supporting dowel bars should not extend across the line of the joint.

Dowel bars, supported on cradles in assemblies, when subjected to a load of 110N applied at either end and in either the vertical or horizontal direction (upwards and downwards and both directions horizontally) should not deflect by more than the following limits:-

- (i) Two thirds of the number of bars of any assembly tested may not deflect more than 2mm per 300mm length of bar.
- (ii) The remainder of the bars in that assembly may not deflect more than 3mm per 300mm length of bar.

The assembly of dowel bars and supporting cradles, including the joint filler board in the case of expansion joints should have the following degree of rigidity when fixed in position:-

- (i) For expansion joints the deflection of the top edge of the filler board should be not greater than 13mm, when a load of 1.3kN is applied perpendicular to the vertical

face of the joint filler board and distributed over a length of 600mm by means of a bar or timber packing, at mid depth and midway between individual fixings, or 300mm from either end of any length of filler board, if a continuous fixing is used. The residual deflection after removal of the load should be not more than 3mm.

- (ii) The joint assembly fixings to the sub-base must not fail under the 1.3kN load applied for testing the rigidity of the assembly but must fail before the load reaches 2.6kN.
- (iii) The fixings for contraction joints should not fail under a 1.3kN load and should fail before the load reaches 2.6kN when applied over a length of 600mm by means of a bar or timber packing placed as near to the level of the line of fixings as practicable.
- (iv) Failure of the fixings is deemed to be when there is displacement of the assemblies by more than 3mm with any form of fixing, under the test load. The displacement should be measured at the nearest part of the assembly to the centre of the bar or timber packing.

Dowel bars should be covered by a thin plastic sheath for at least two thirds of the length from one end for contraction joints and half the length from one end for expansion joints. The sheath should be tough durable and of average thickness not less than 1.25mm. The sheathed bar should comply with the following pull out test:-

- (i) Four bars taken at random from stock and without any special preparation are covered by sheaths. The halves of the dowel bars which have been sheathed are cast centrally into 150mm x 150mm x 450mm concrete specimens made of the same mix proportions used in the pavement, but with a maximum nominal aggregate size of 20mm and cured in accordance with B.S 1881. At 7 days a tensile load is applied to achieve a movement of the bar at least 0.25mm. The average bond stress to achieve this movement should not be greater than 0.14N/mm².

For expansion joints a closely fitting cap 100mm long consisting of waterproofed cardboard on an approved synthetic material is placed over the sheathed end of each dowel bar. An expansion space equal to the thickness of the joint filler board is formed between the end of the cap and the end of the dowel bar.

Where dowels are used in longitudinal joints, they should be protected from corrosion for 75mm each side of the joint by a suitable close fitting flexible plastic sheath with a wall thickness not greater than 3mm or by a suitable protective coating.

The position and alignment of dowel bars is checked by measurement relative to the side forms before construction.

After construction of the slabs the position and alignment of the dowel bars may be checked after carefully exposing them in the plastic concrete across the whole width of the slab. During normal construction this is carried out at a rate of one joint per day. After examination of dowel bars the

plastic concrete is removed 500mm on each side of the joint and reinstated to the satisfaction of the Engineer.

Tie bars are provided in longitudinal joints. Tie bars are Grade 460 deformed bars complying with B.S. 4449 or B.S. 4461. They should have Type 2 bond classification. Tie bars must be free from oil, loose rust and scale. Tie bars in airport pavements are 20mm diameter, 900mm long and provided at 600mm spacing. A different size and spacing would be more appropriate for other applications.

Tie bars in longitudinal construction joints should be adequately fixed to side forms. Alternatively the paving train may incorporate a suitable device for mechanical insertion of the bars.

Tie bars in longitudinal contraction joints are placed in position with the centre of each on the line of the joint. Tie bars should remain firmly in position during the construction of the slab.

9. CURING OF CONCRETE.

Concrete is cured by applying a sprayed membrane to all exposed surfaces of slabs immediately after texturing has been applied. The maximum time between batching of concrete and application of curing membrane should not exceed two hours. The curing membrane used is usually resin based and aluminised with an efficiency index of 90%.

10. TRIAL LENGTH.

A trial length of the surface slabs is normally constructed in advance of the main works to demonstrate the materials, plant, equipment and methods of construction proposed. The trial length should be constructed over a period of at least two consecutive working days and it should comply in all respects with the specification. If the trial length fails to comply with the requirements of the specification it is removed and a further trial length constructed.

If the trial length proves satisfactory, the Contractor should not vary the materials, plant, equipment and construction methods except for normal adjustment and maintenance of plant.

The texture depth of the finished pavement is measured using the sand patch test method. The surface to be measured, is dried and swept clean. A known volume of sand is poured into a heap on the surface to be tested and is spread over the surface into a circular patch with the surface depressions filled with sand to the level of the peaks. The diameter of the patch is measured to the nearest 5mm. The texture depth of concrete surface is calculated from the formula $(31,000/D^2)$ mm where D is the diameter of the patch in mm.

No vehicle may run on the surface of the concrete pavement until the temporary or permanent sealing of joints is carried out. No vehicular traffic of axle loading greater than 2 tonnes should run on the finished surface of the pavement within 20 days of completion.

Acknowledgements.

I wish to thank Michael Walsh, Michael Conway and all my other colleagues in Aer Rianta for their assistance in the preparation of this paper. I would also like to gratefully acknowledge the assistance of Padhraic Moneley of "P. Moneley Ltd."

DISCUSSION.

MR. PHUKAN introduced his paper.

He paid tribute to those who had been involved in the construction of Dublin Airport in the 1940's. He noted that our work methods today were merely a development of their techniques and good practice. The machinery of the time were the forerunners of today's sophisticated paving machines. The technique of cutting grooves was not employed, probably because of a lack of diamond saw cutters, but grooves were formed as the concrete was poured.

Airport paving demanded adherence to strict tolerances. These tolerances are set down by the International Civil Aviation Organisation to ensure the safe movement of aircraft.

He explained the concept of the aircraft manufacturer's 'Aircraft Classification Number (A.C.N.)' and the airport authorities 'Pavement Classification Number (P.C.N.)'. The effect of wheel loading is dependant on the subgrade and the minimum requirement is that the P.C.N. and A.C.N. would be equal. A taxiway currently under construction at Dublin Airport has a value of 80 P.C.N. on a subgrade of low characteristics. Operators can compare these values, which are published in Airport Information Publications (A.I.P.), against their aircraft's specification before routing to a particular airport.

Slip-form pavers have only been used since 1992 when the first use of the technique in Ireland was accomplished. However, the slip-form option was included in the specification for Dublin's Runway 10/28 in 1987. The previous absence of slip-form paving from Irish practice was not due to any lack of technical capability on the part of the contractors but was due to economic considerations. Slip form pavers require high minimum volumes of straight runs to be economically viable. Experience in Ireland with slip-form paving has involved use with transverse joints 6m apart. Generally the bay size used in Ireland is 6m by 6m but larger bay sizes have been used in other countries.

MR. EAMONN CORCORAN opened the discussion by agreeing with Mr. Phukan's view that development of paving methodology was a technique of practical refinement rather than basic science. For example, the introduction of better quality control measures.

He commented that he had found concrete to be a rather 'user-unfriendly' material in his 24 years of experience of civil engineering projects involving the production and placing of over one million cubic metres of concrete. The technology for producing and placing excellent concrete has been with us for many years yet we struggle to achieve excellence. His opinion was that the difference between good concrete and excellent concrete was effort and strict quality control.

The specifications and practices for pavement construction in Ireland follow trends in other more developed markets abroad. The reason that we are not world leaders in this area, he believed, obvious: a small construction market by international standards with pavement construction a small part of that market.

Mr. Corcoran noted that despite best efforts to promote the concept of concrete roads for major works in recent times none had been constructed and he feared that this trend would continue. To his knowledge only one primary route project had been put to tender with a concrete option. Life cycle cost had not been taken into account and concrete could lose out on the basis of higher initial cost. He felt that the best prospect for concrete roads would be on projects with long straight runs without the complexity of roundabouts or side roads. The degree of simplicity in dowelled joint details would also be significant.

Turning to the contractor's approach to the topic of the paper, he said that it was important to appreciate the difference between pavement quality concrete and other concretes. Pavement quality concrete has a very low water/cement ratio and a very low slump. Its uniqueness may be judged by the fact that no tracks are left as one walks across the material while it is being laid. The slab itself generally forms 30% of the total cost of the project and so it is only one aspect of the construction process. Other aspects may impose greater constraints on a programme, such as the client's specification; the overall size of the project; specified phasing of various sections of the works; contractual handover of various sections of the works; tie-ins with existing operational runways; availability of plant, equipment and specialist personnel. In relation to this last point he described how their decision to tender for Runway 10/28 at Dublin on the basis of fixed form methods was based on the identification of a partner in the United Kingdom who could supply equipment and specialist personnel for the task. Other constraints included materials supply; weather; the interdependence of one operation on another; financial and cash flow constraints. A problem which was only removed last year was the requirement to pay V.A.T. at the point of entry. The importation of say £2 million of equipment for a contract involved the payment of £0.5 million at the docks and a three month wait for a refund. The impact of such a constraint on cash flow is obvious. The proper management of industrial relations is another aspect.

In relation to slip-forming he referred to Mr. Phukan's comment that in some countries there was reliance on aggregate interlock at joints rather than the use of dowel bars. Aggregate interlock presented advantages in relation to the slip-forming option. Dowels in the transverse joints are not a problem as they can be paved over but longitudinal joint dowels are a hindrance. Attempts have been made to inject bars into the plastic concrete just behind the slip-former. This has been successful for 25mm diameter tie bars but 40mm diameter dowel bars present a greater problem. A second issue was that of slab depth. At the time of the Runway 10/28 tender it was known that slip-forming was successful for 10" to 12" paving but its viability at 16" had not been verified - the stability of the edge was in question. This had caused problems in Canada and in the United Kingdom where miles of concrete had to be sawn off as it did not meet the specified tolerances. The greater availability of fixed-form plant in the United Kingdom - probably about ten sets as a result of the concrete pavement programmes of the 1950's and 1960's - can favour this option over slip-forming in this part of the world. The slip-form process is more capital intensive than the fixed-form method but productivity rates can be up to five times higher. Some slip-form plant can do up to 3000m³ per day. The attendance labour on the slip-form plant would be about one third

of that required for fixed form paving. This would be particularly significant on the continent and in the U.S.A. where labour costs are high, volumes are high and continuity of work for this capital intensive equipment is assured.

Manufacturers are continually improving the automation of these pavers. Economics will dictate the contractor's choice. One must recognise that purchase of a slip form paver is only one half of the issue. The other half involves commissioning the batching and transport capacity to feed the paver and the stockpiling of aggregate. Additionally it introduces a requirement to prepare larger areas of earthworks, fill and ducting work ahead of the paver. This aspect is not necessarily practical in the case of works associated with an airport which remains operational during the works. He was sceptical of some claims regarding world records in relation to concrete paving rates as they did not always take account of the period required to build up sufficient stockpiles of aggregates. He was aware of a project in Canada where stockpiling was in progress for two years before paving commenced!

He outlined the particular requirement in the case of paving for continuity of operations and the matching of capacities between batching, transport and paving equipment. The consequences of a breakdown by one part of the paving train could immediately lead to a situation where up to 25m³ of concrete would need to be diverted until the problem was rectified.

Looking ahead he predicted that most future jobs in Ireland would be done using fixed-form pavers and off-site batching because the size of the contracts would be too small to make it economical to import slip-form pavers. The price of slabs is very sensitive to the cost of cement and the volume of concrete. In relation to road pavements he felt that we were unlikely to see a shift to concrete on major works unless there was a major change in the relative price of cement and bitumen. Greater automation will be introduced in the area of batching, sampling and laying using computer and laser techniques. It is not inconceivable that fully automated plant would emerge reading its co-ordinates from satellite. Labour content would continue to diminish and automation would be further driven by clients' demands for shorter construction programmes. Procurement methods may also change.

MR. MARTIN MANNION addressed the issue of concrete roads. He instanced the durability of forty year old concrete runways and commented that the concrete road was a better option than tarmac when account was taken of life cycle cost. He felt that concrete roads were a viable option and was surprised that there was not more pressure for their use.

MR. TONY MURRAY enquired about the modification to the mix for slip-form paving at Dublin Airport. Was the inclusion of air entrainment to reduce the water/cement ratio or to improve the frost resistance?

MR. BRENDAN LYNCH summarised the findings of the Irish Concrete Society study on roads in the late 1980's. He said that concrete roads could compete with blacktop both on initial cost and whole life costing on road lengths greater than 4 km. He felt that the construction of Runway 10/28 and later the slip-forming of apron sections at Dublin Airport showed from a practical viewpoint that concrete paving was possible in this country. Some held the view that the tender

options on the Northern Cross route were not strictly comparable from a design point of view and that the concrete option was disadvantaged as a result.

He also made an observation on Mr. Corcoran's comment regarding the relative price of cement. The cost of concrete in the Runway 10/28 project represented 30% of the project cost and it involved the consumption of 30,000 tons of cement. Thus he felt that a few pounds difference in the price of cement would have little bearing on the total project cost.

MR. MICHAEL CARR noted that a waterproof membrane had been specified under the concrete and enquired the reason for its use as its presence could promote warping or curling of the slab.

MR. MICHAEL WALSH responded to Mr. Carr's question. He stated that the waterproof membrane was present to act as a slip membrane between the lean mix and the top slab. It also prevented water leaching down into the lean mix.

MS. AMANDA GIBNEY enquired about the economics of using dowel jointing if aggregate interlock systems could be used as an alternative.

MR. TOM DUGGAN commented that one aspect of the blacktop/whitetop road debate was the risk of having a perceived monopoly of any form of construction. This was the case in the Republic of Ireland. In most European countries there was a national strategy of giving a certain percent to one form or the other. This percentage varied widely but the highest standards of each form were encouraged through competition.

THE CHAIRMAN noted that in Baldonnell a runway had been constructed in 1955 to a similar specification to that used by Aer Rianta and it continued to give good performance to day. Recent tests had shown insitu strength of 70 N/mm² which was a tribute to the workmanship. He hoped that we would continue to emulate their feats. The issue of workmanship was a very significant backdrop to all our deliberations on excellence in concrete practice.

MR. PHUKAN replied to the discussion.

In relation to the inclusion of air entrainment in the slip-form mix he said that it was used to improve workability. Air entrainment had also been specified in the top 50mm of the Runway 10/28 concrete but in that case it was for frost resistance. For practical reasons it was incorporated in the full depth of the runway slab.

Consideration had been given to both the flexible pavement and rigid pavement options in the design of Runway 10/28 at Dublin. The design is based on the aircraft characteristics and they found that the flexible pavement would have to have a much greater depth than the rigid pavement. Maintenance aspects also favoured concrete. Thus the concrete option was more competitive. One significant difference, however, between airport pavements and concrete roads was that riding quality and noise were more significant design parameters for road projects.

In relation to aggregate interlock he said that he had studied the joint details used at many airports in the United Kingdom and believed that they were more problematic than dowelled joints. Some authorities currently relying on aggregate interlock may revert to dowelling.

SESSION D

OUR CONCRETE HERITAGE - REPAIR AND PRESERVATION OF CONCRETE BUILDINGS

J. C. WATSON, B.A., B.A.I., C.Eng., M.IEI, M.I.C.E.
Fleeton Watson Ltd.

Sessional Chairman

Prof. R. C. COX, M.A., M.A.I., Ph.D., C.Eng, F.IEI, M.I.C.E.
Trinity College Dublin.

Summary.

The disappointing history of durability of concrete structures with particular reference to corrosion of the reinforcement has led to a branch of the construction industry concerned with repair and preservation. This paper refers to the formalising of repair disciplines and reviews developments in this area over the last decade and considers criteria for repair and preservation.

1. HISTORICAL NOTE.

Cement-like materials have existed for many centuries, indeed, a rudimentary form of lime based mortar was used by the ancient Egyptians and also by the Romans. Since then, their use seems to have fallen by the wayside and was not taken up again until the 18th century, when work which eventually led to the start of the cement industry got underway. In the early 1800's, portland cement was invented and in 1824 was patented by one Joseph Apsdin.

Mortars made with these new cements eventually evolved into concrete, and was identified as a good material with which to encase structural steel as a fire protection measure. The composite use of the two materials continued and recognition of their differing properties prompted experimentation in their use. At the end of the last century this work had reached a stage when, amongst others, the Frenchman Francois Hennibegue produced his 'ferroconcrete'. This is recognisable as the fore runner of reinforced concrete of today.

Hennibegue marketed his system both here and in the U.K. through L. G. Mouchel of London, who in turn franchised construction through specially licensed contractors. J. & R. Thompson of Dublin was one such who built some of the earliest reinforced concrete structures in this country.

2. INTRODUCTION.

Concrete has long been regarded as a durable material and not withstanding some problems of reinforcement corrosion, so too was the composite, reinforced concrete. However the incidence and severity of corrosion increased at alarming rates in recent decades, in some cases appearing within the first year or two of a building's life. This has resulted in the durability of reinforced concrete being seriously questioned.

In his paper 'The Durability of Concrete in Integrity and Appearance,' S. MacCraith (ref. 1) sets out a very detailed schedule of faults. From this it is interesting to note the large proportion of young structures listed, these are for the most part from the building rather than the civil engineering sector.

The acceleration in the rate of corrosion attack generally coincided with changes in the cement industry. The introduction of the dry process of manufacture together with better standards of grinding resulted in a product quality, more akin to that of rapid hardening cement. Also at around that time, Engineers were moving away from specifying concrete by nominal mix proportions to specifying strength requirements. Such a criterion required contractors to 'design' mixes to comply with the strength needs. The concretes thus produced generally had lower cement contents than those specified by mix proportion, this suited the increasingly competitive nature of the industry.

Investigations into durability and the mechanism of corrosion particular to steel encased in concrete have been ongoing for some time and are well documented. A concise resume of the state of the art in this area is set out in a design guide prepared by the Comité Euro-International du Béton.(ref. 2) As a result of this work, attention has been directed to the design, specification and construction of buildings that will not need repair within their designed lifetime. El - Metwally et al (ref. 3) conclude that 'the cheapest and most efficient way to prevent corrosion of the reinforcement is to deal with the problem during the design stage.' However this paper is concerned with the repair and preservation of existing structures rather than the design of new ones.

Returning to reinforcement corrosion, this can almost always be attributed to either carbonation or chloride contamination of the concrete and the mechanisms of this are now well known. The concept of repair therefore is to identify the cause of corrosion and to remove or contain the offending conditions. The structure can then be made good and protected from further contamination.

3. BEGINNINGS OF CONCRETE REPAIR.

The need to repair concrete 'damaged' by whatever means has existed for as long as concrete has been cast. The advent of resins and polymers allowed enterprising manufacturers to produce mortar mixes and admixes specifically directed at repair work. This in turn created an aura of speciality around such work and generated 'experts' who developed their own 'techniques' for repairing the various ills suffered by reinforced concrete.

This situation existed until the early 80's when a working party was set up by a steering group of the Concrete Society of the U.K. with the assistance of FEFRA (Federation of Resin Formulators and Applicators) and the Association of Guniting Contractors. Its purpose was to review current practice in the repair of concrete damaged by reinforcement corrosion. Their report (ref. 4) was published in October 1984 and describes itself as 'a review of the state of the art in a developing field'. This publication was regarded by many as a milestone and marks, I believe, the establishment of concrete repair as a regular sector of the construction industry.

In line with the theme of the symposium, this paper considers the advances that have taken place since then and attempts to review the current state of the art.

4. REVIEW OF PROGRESS.

No new wonder products have emerged in the last decade but there has been significant progress in the development and use of existing materials.

4.1 Cementitious Materials.

In the area of concrete replacement, resin mortars have been almost completely supplanted by cement based products. This is mainly attributable to the differing physical characteristics of resin from those of concrete. Cementitious repair materials are much more in sympathy with their concrete substrate than are resins. Also the cement based products have gradually become more 'user friendly' in all of their various areas of use.

Hand applied mortars are now easier to apply, than ten years ago. Their protective qualities have improved and they can be applied in thicker layers. This is due to improvements in their thixotropic properties, aggregate and additive specification and more recently in some cases, by the inclusion of fibres. Some of these mortars can now be spray applied as well.

Increasingly, Engineers are concerning themselves with the level of protection afforded by repair materials, indeed strength is no longer the only criterion by which they are judged. The aim should be the provision of a low permeability material compatible with the substrate. Material assessment can be confidently made with the assistance of product performance data, certified by laboratories independent of the manufacturers.

Another variation of the formula to have emerged in recent years is the fairing coat, again, protection is the aim. It is polymer rich and applied in very thin layers over the whole or part of the structure. It hides repairs and provides overall protection as well as a good base for final protective coatings. Waterproof slurry coatings are sometimes used for the same purpose but their appearance may not be architecturally acceptable.

A further variation on the same theme is flowing concrete, This is a super plasticised micro concrete, which was developed in the U.K. particularly for the repair of chloride contaminated elevated motorway support structures. In this application very large quantities were involved and hand applied material would have been impracticable. Good watertight formwork is one

of the criteria for the successful use of this material. It being superplasticised, no vibration is required in placing and in common with most cementitious repair materials, is shrinkage compensated and forms an excellent bond with the presoaked substrate.

More recently, another variation to come on our market is a pre blended polymer modified guniting material. This takes a very old technique right up to the minute on the repair scene. Again this allows relatively large quantities of material to be placed quickly and is ideal for the larger repairs. It has the advantage over flowing concrete in that it does not need formwork and is unquestionably the best way to coat a soffit.

All these developments and improvements are aimed at better quality and performance of repair as well as swifter execution. This helps to reduce down or interruption time as well as having a beneficial effect of repair costs.

4.2 Cathodic Protection.

In the late 60's, Engineers were beginning to realise that the presence of chlorides in concrete gave rise to a different and more virulent form of corrosion. It is interesting to note that up to that time calcium chloride was recommended as an additive in the manufacture of concrete to provide early strength. For this reason, it was attractive to precast manufacturers.

As more was learned about the mechanisms of this type of corrosion, it became apparent that a different approach from that of normal rust was required for its repair. The decade just passed has seen significant strides in this regard. No longer is it acceptable to repair corrosion 'spots' in isolation, as this simply moves the 'battery' along the reinforcement to set up another corrosion cell elsewhere. In fact, using conventional repair materials, current practice requires that all contaminated concrete in contact with the reinforcement be replaced, and an effective protective coating to inhibit further contamination be provided. Repair materials are less porous than the concrete replaced, and so the chloride ion penetration rate through it is reduced. Nevertheless consideration must be given to the extent of concrete replacement and the possibility of introducing a chloride impervious barrier such as an epoxy resin bonding layer.

Borrowed from existing marine and pipeline practice, the principle of electrolytic protection was investigated and so systems of cathodic protection were introduced. These were first experimented upon some 25 to 30 years ago in the United States of America where road de-icing salts caused serious corrosion problems on reinforced concrete bridge decks.

Cathodic protection was later taken up in Europe where its use on vertical surfaces was of more interest. This required considerable refinement in anode material before it became a practicable proposition. Ten years ago this was in its infancy. I refer to an article published in July 1985 (ref. 5) which describes Taywood Engineering Ltd. carrying out an early full field trial of cathodic protection in London.

Development of the technique since then has been very rapid. In a similar manner to concrete repair, the Concrete Society of U.K. produced a technical report (ref. 6) on the topic in 1989 followed by a model specification from the same source in 1991.

Expanding the electrochemical principle further, two related systems are being developed, re-alkalisation and desalination (ref. 7):

1. Re-alkalisation reverses the process of carbonation whereby an alkaline solution is introduced into the concrete covering the re-inforcement and restores its pH to a value that protects the steel.

2. De-salinisation reverses the process of chloride ingress and removes it from the concrete. At the same time this process increases the alkalinity of the concrete in the vicinity of the reinforcement.

4.3 Resin Based Materials.

Resin materials, as has already been noted are not now normally used as a bulk repair medium. However, their qualities of adhesion and resistance to abrasion and chemical attack have an important role in flooring, tank and bund linings and the like.

The adhesive qualities principally of epoxy resins are however of value in the concrete repair area. Continuing advances in formulations have produced moisture tolerant materials, these have become available in the last 4-6 years. More recently resins that will bond and cure underwater are beginning to appear. These qualities serve to broaden the scope of the resin's usefulness and to increase confidence in the standard of bond attainable, bearing in mind that concrete does not always have a very low moisture content. Increasing confidence in the improved bond technology is illustrated by plate bonding (ref. 8), a technique for adding reinforcement to a structure. Although known about for some time, it is only recently that Engineers are beginning to specify it in practice. Possibly less critical areas where epoxy and polyester resins have been used with success for some time include 'chemical anchoring,' crack injection and various adaptations of these uses.

4.4 Protective Coatings.

Generally degradation processes go from outside in, requiring the ingress of moisture and active gasses. Coatings which resist such contamination form an important part of the protection and preservation of concrete. However, there is a divergence in the practical effectiveness of the various coating materials available. In the ideal situation, the ingress of liquid water and of carbon dioxide should be blocked, but vapour should be allowed to pass. Each requirement is satisfied to differing degrees by different materials. The solution to the overall problem is, like so many others, a compromise.

All coatings should at least provide resistance to liquid water while more impermeable ones resist the ingress of carbon dioxide. Completely impermeable materials effect a total barrier even to the passage of vapour and as such are unsuitable for coating a 'breathing' material like concrete. Also coatings should be resistant to the effects of ultra violet light and weathering abrasion.

Coatings should be considered as part of the repair and preservation system, a correctly selected product will arrest or substantially impair the onset of corrosion. Modern trends in their formulation are away from solvent based and towards water based products. This is in deference to health and safety requirements as well as to the 'green' lobby.

Protective coatings fit broadly into three categories.

1. Penetrants, or insurface sealers, they are low viscosity materials that line the pores and capillaries in the concrete surface and effectively stop the ingress of liquid water, but not gasses. An example of these materials is silane and siloxane, both very volatile. Water based equivalents are currently being researched.

2. Sealers are unfilled or pigmented polymers, usually acrylic or methacrylics. They are intermediate between penetrants and coatings, and work by blocking the pores of the substrate.

3. Coatings are onsurface films of varying thickness. These materials have 'body' and comprise a binder, pigments, fillers, and a carrier, either water or a solvent. The binders dictate the properties of the compound, anticarbonation, flexibility etc. and are themselves derived from a variety of resins. Currently the favoured materials are, as with the sealers, of the acrylic and methacrylic families formulated with water based carriers. This produces a product that looks like masonry paint and is in fact a high specification version of it. A further improvement on this is an elastomeric formulation which has crack bridging properties and accommodates minor movements of the structure. This material is regarded as offering a good compromise of the desired protective qualities and notwithstanding its higher cost, is being specified more frequently.

5. CONCRETE HERITAGE - REPAIR AND PRESERVATION.

The stock of many and varied reinforced concrete structures and buildings which form our 'Concrete Heritage' do not as we have seen, look after themselves. Like any item of plant or equipment, they need to be maintained and in some cases repaired to keep them in the condition and shape necessary to perform their designed task.

Whilst it might be thought reasonable that a structure should at least survive and remain servicable for its designed life, for reasons already alluded to this is not always the case. Having accepted this, therefore, the owner is faced with the responsibility and expense of carrying out a programme of repairs and maintenance. The extent and cost of this is governed by commercial decisions. The resultant policy will therefore involve the implementation of one of three basic philosophies.

1. Do nothing, other than incorporate measures to protect public safety and accept a reduction in the building's life.

2. Carry out holding repairs to slow down the rate of deterioration and accept the need for further similar repairs from time to time.

3. Carry out a major refurbishment complete with overall protective measures, coating or cathodic protection as appropriate.

No matter what maintenance or repair philosophy is adopted the strategy should be based on a thorough structural survey and investigation to identify the cause, and, as far as possible, the extent of the distress and deterioration. It is only with full information to hand that a logical and correct programme of measures can be specified. When they have been completed the structure can, with reasonable certainty, be said to be sound for a period appropriate to the measures ordered.

Alternatively if a programme of planned inspection and maintenance is implemented from the start of a building's life, this will take into account the quality of the structure and ensure that distress and corrosion from whatever cause will not get out of hand. Preventive and remedial measures can be taken in a timely and programmed manner, thus avoiding major costly repairs. Generally the older structures that still exist today are those that were soundly designed and carefully constructed. They are for the most part works of civil engineering, bridges, dams and the like, and usually away from the influence of sea water. These structures embodied many of the criteria that were to emerge much later from durability studies occasioned by the poor performance of the more carelessly built younger structures.

An example of a good old structure is the Kenmare bridge, built in 1933 and repaired in 1988. The repairs necessary were confined to the splash zone below road level. All the concrete above this level was sound and needed no attention. However when repairs were completed, the whole structure was prepared for and given an insurface treatment of Silane to enhance the structure's own protective qualities.

Many of the early reinforced concrete buildings had their exposed concrete surfaces rendered, presumably to mask superficial imperfections. These architectural features provided excellent protection to the concrete enabling structures, not always of the best quality, to survive. This phase gave way to concrete becoming an architectural feature in its own right and later to the building boom of the 60's and 70's. With these advances came increasing corrosion problems which eventually led to the development of the concrete repair and preservation sector of the construction industry.

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DISCUSSION.

MR. WATSON introduced his paper.

He observed that concrete in building works was often more poorly executed than in engineering works. In addition he felt that poor workmanship was a greater problem than inadequate specification. He supported Professor de Courcy's view that the worker in concrete should be recognised for their craftsmanship. He illustrated his presentation with examples of deteriorated concrete. These examples included cases of very slender units which were difficult to execute and instances where concrete members were cut to accommodate ill-fitting facade units such as window cills.

He reviewed developments in Europe over the last decade which have had or may have an influence on concrete practice in Ireland. He noted the successful claims which were being attributed to some new techniques but cautioned that some further experience was required before accepting the validity of the techniques. He also noted the recent emergence of a calcium nitrate-based product which may inhibit chloride attack.

Turning to examples of our concrete heritage he instanced St. John's Bridge, Kilkenny; Mizen Head Bridge; structures at Ardnacrusha; the Regional Hospital, Ennis; Terminal Building, Dublin Airport; shell roof at Donnybrook Bus Depot; Dominican Church, Athy; Busarus; Stack 'D', Dublin Port; dam at Innishgarra; prestressed bridge at Youghal; West-Link Bridge; East Stand, Lansdowne Road; and the Parkgate Street telephone kiosk, now re-located in Dawson Street.

MR. JACK O'LEARY opened the discussion by complimenting Mr. Watson on his paper which, he said, provided a comprehensive overview of the current situation. He felt that developments in repair technology over the last ten years, as outlined in the paper, were a result of our better understanding of deterioration mechanisms. He reviewed the electrochemistry of corrosion and observed that the damage which we could see, and which we repaired, was at the anode. One must however tackle the cathode also and this introduces the concept of total protection.

Ten years ago one might have used an epoxy material to repair the anode but corrosion often recommenced rapidly. On the one hand the epoxy materials were not always compatible with

the concrete but the protection of the cathode from oxygen and moisture ingress was not always dealt with.

Nowadays we tend towards the use of cementitious materials - flowing concrete for large scale repairs and mortars for small scale aesthetic repairs. He said that he had experience with flowing concrete on the Kenmare Bridge repair project. In relation to total protection a number of strategies were possible. Firstly, one could endeavour to keep the concrete dry. This could be achieved for example in a bridge deck by the use of a waterproof layer on top and by sealing the underside through the application of silanes. The beneficial effects of silanes are perhaps not as great as were claimed ten years ago but they have a significant role in the total protection process. Indeed they are also being specified on new works.

In the case of a deteriorated pier one might consider cathodic protection. In this instance the anode is effectively external and all of the reinforcement becomes the cathode. The metal consumption, such as it is, occurs in the battery. The theory is perfect but the practical application of the cathodic current is problematic, be it by conductive paint or by precious metal mesh embedded in a cementitious overlay. Acid generation at the contact points can lead to problems in maintaining the integrity of the conductor.

Looking to the next ten years he felt that the main repair methods would be by flowing concrete, repair mortars - which are likely to further develop in quality - and coating of urban buildings. He felt that cathodic protection and the desalination/re-alkalisation techniques would find little general application in our market.

MR. EAMONN CANNON enquired about the importance of continuity in the case of a cathodic protection system. He believed that one could create a problem if one specified cathodic protection and then found that not all of the reinforcement formed part of the circuit. He felt that this was a fundamental weakness in its application to reinforced concrete. He described a system he had seen while engaged on a concrete offshore platform project. This structure had axial prestressing for durability reasons and considerable reinforcement in thick sections. The cathodic protection system included cabling between prestressing ducts and the reinforcement.

He also asked about dealing with the case of old bridges which did not include top waterproofing layers.

DR. ROGER WEST added to the discussion on cathodic protection by describing research underway at Trinity College Dublin into 'smart structures'. This concept involved cathodic protection with feedback monitoring of the structure so that only the required current would be generated in the protection system.

PROFESSOR DAVID ORR enquired about the life expectancy of repaired structures.

MR. MARK PRENDERGAST enquired about stress patterns in repaired structural members and the extent to which the repair contributed to the load capacity.

MR. DENIS WALL asked about the degree of success achievable in colour matching of fairing coats with the original structure where local repairs were carried out. Could one achieve success with local repair or would one have to consider the entire panel?

MR. JOHN GWYNN asked if plate-bonding had been used as a repair strategy in Ireland.

MR. JACK O'LEARY responded to Mr. Cannon's questions. He noted that a different situation pertained if one specified cathodic protection from the start of a project. It required less current because it was not being driven against the corrosion current. The use of cathodic protection as a repair method on prestressed or post-tensioned structures was not possible due to the danger of hydrogen evolution on the prestressing strand. He agreed that absence of continuity could create more problems than it would solve.

In relation to old bridges he said that sealing up an old structure by epoxy coating, for example, could potentially create problems if chlorides were present and anaerobic corrosion developed.

He noted that stress-relieving measures on a bridge could include the use of temporary props or alternatively the slowing down of traffic or diversion onto a reduced number of lanes.

MR. WATSON responded to the discussion.

He said that properly executed repairs should exceed the life of the concrete to which they are bonded. The crucial parameter was therefore the life expectancy of the main structure.

Repairs were not expected to carry load. They would only carry load if extra load was applied over and above that which was on the member prior to repair. In cases where a damaged element was unable to support the loads acting on it one would instigate stress-relieving measures prior to repair and design the repair to provide the required load capacity.

He said that aesthetic repairs usually involved work on an entire panel rather than a local repair. One reason for this was the degree of absorption of patch repairs which differed from the original concrete. Repairs which looked satisfactory in dry conditions might not be satisfactory in wet conditions.

He said that plate-bonding had been used as a repair strategy in Ireland.

PROFESSOR J. W. de COURCY in a written contribution stated that his understanding of Mr. Watson's valuable presentation is that he has dealt principally with the slow environment-induced degradation of concrete and reinforcement and deterioration of surface quality. He has not discussed the repair of stress-induced cracking, which introduces the further need for various other decisions that do not arise in the area he has covered. Whilst it would be unreasonable to expect a further dissertation in the context of the present symposium, it is clear that the author could make another significant contribution to the literature with the knowledge he has in the overall field of repair. A paper on this matter to an appropriate body would be very welcome and would, most usefully, complement his present presentation.

SESSION E

DURABILITY ISSUES IN THE SPECIFICATION OF CONCRETE.

M. G. RICHARDSON, B.E., M.Eng.Sc., Ph.D., Eur.Ing., C.Eng. M.IE, MICT
Department of Civil Engineering, University College Dublin.

Sessional Chairman

Prof D. M. ORR, M.A., M.A.I., Ph.D., Eur.Ing., C.Eng, F.IEI, M.I.C.E.
University College Cork.

Abstract

The background to the current method of specification in Irish practice for durable concrete is reviewed and contrasted with the emerging trend towards performance specification. Design to meet performance criteria will require quantitative assessment of durability-threatening phenomena and developments over the last ten years in the understanding of deterioration mechanisms are outlined. Future trends in the specification of durable concrete in Irish practice are indicated.

1. INTRODUCTION

Twenty five years ago, in a commentary on concrete durability Halstead (1971) concluded that there were no bad materials, only bad designs : "..... there are no bad soldiers, only bad officers". 'Design' in this context was all-encompassing and included the aspects of workmanship. Halstead argued that concrete of a given quality would serve its purpose as long as the exposure conditions in service did not exceed the material's design limits. This statement of the position is reasonable but the difficulty for specifiers lay in translating unquantifiable durability loads into specific design limits - cover, cement content, water/cement ratio, aggregate size, cement type - via definitions of exposure condition which were broadly descriptive. Few structural engineers would feel confident determining the area of tensile reinforcement required in a beam if their knowledge of the expected structural loading was restricted to a description of it being "moderate" or "severe" ! Extensive research since the time of Halstead's paper has, however, brought closer the day when durability loads will be accurately quantified.

The overall approach to durability design has remained unchanged for many years but refinements have been continuing. This includes the introduction of 'national durability grades'. The issue of alkali-aggregate reaction (AAR) has additionally become a factor in concrete specification in Ireland (although no occurrences of AAR have yet been reported).

Durability concerns have always been a factor in the design and specification of reinforced concrete structures despite the colloquial association of 'concrete' with 'permanence'. The first symposium in this series was addressed by de Courcy (1965) on the topic and Mac Craith (1985) reviewed the condition of Irish concrete in service at the third symposium, ten years ago. Research on durability issues continues apace and the translation of the fruits of research into future European and Irish concrete practice is currently in train. The impact of this knowledge may eventually change our approach to specification for durability.

2. CURRENT APPROACH TO SPECIFICATION FOR DURABILITY

2.1 Background

The approach to durability specification currently employed in concrete practice in Ireland continues to be of a prescriptive nature. Nevertheless Irish practice reflects up-to-date thinking on specifying for durability through the incorporation of principles, materials and limitations which are based on current research and experience.

The achievement of durable structural concrete has traditionally been linked to cement content. Prior to 1960 the cement content required to achieve specified strength was considered adequate for durability also. In selected instances of severe exposure the engineer would exercise judgement in specifying a higher cement content than that required for strength alone. Developments in the 1960's included increases in the strength of cement, refined tolerances in mix design and batching procedures, and increased efficiency through greater employment of statistical methods in quality control. The net result was the attainment of comparable concrete strength grades with lower cement contents. Water/cement ratios were appreciably higher than a decade before and this led to higher permeability concretes. Concern for the serious implications regarding durability were voiced by the Concrete Society. The problem was addressed in Code of Practice CP 110:1972 which included durability recommendations for a range of exposure classes. The recommendations took the form of limits on cement content and water/cement ratio.

The heightened awareness among designers of the need to specify for durability as well as strength led to anomalies. Specifications often included redundant parameters with the result that the producer's range of possible mixes included those which made inefficient use of materials. Additionally the range included mixes which satisfied the designer's intention regarding strength but not the durability requirement. This problem was overcome by the introduction of the 'national durability grade', first proposed in a paper by Deacon and Dewar (1982).

2.2 Adoption of the 'Durability Grade' Principle

The basis of the proposal for 'durability grades' by Deacon and Dewar was a recognition that, on a national basis, concretes manufactured with native materials and cement contents typical of national practice produce a limited range of strengths. A range of strengths will also result from varying the water/cement ratios. Hence charts could be produced indicating the strength range of concrete produced with cement contents and water/cement ratios which were typical of national practice. Furthermore for a given grade of concrete the 'CP110' durability parameters of minimum cement content and maximum water/cement ratio would be known. This would allow specification for durability by strength, which in any case is the performance criteria by which

concrete is assessed. Unwittingly, this new system would bring concrete practice regarding durability back to the pre-1960 situation whereby strength specification embraced durability considerations. In this instance, however, strength followed durability rather than the other way around!

The 'national durability grade' concept was endorsed by the Irish Concrete Society's Durability Sub-Committee, who set up a programme to determine the 'deemed to satisfy' grades for Irish practice. Determination of the appropriate 'deemed to satisfy' grades was achieved by the Irish Concrete Society through a survey of the trade associations concerned with concrete production. The recommendations of the Irish Concrete Society were presented to the National Standards Authority of Ireland Concrete Consultative Committee and the 'deemed to satisfy' grades were incorporated in Irish Standard I.S.326:1988.

The relationship between variables is illustrated in Figure 1 for the case of concretes without admixtures. The need to monitor the stability of the curves used in the determination of national durability grades was emphasised by Corish (1987).

It may be noted that the prescriptive approach used in Irish concrete practice at present is based on consideration of durability-related parameters as opposed to consideration of the deterioration processes themselves.

2.3 Developments in mix specification.

The specification of concrete in Ireland has been influenced by British Standard BS5328 and the implications of this standard's revision into four parts is being considered in the context of a revised I.S.326 due for publication shortly.

The revision of BS5328:1981 has been extensive. It has been replaced by four parts which were issued in 1990 and 1991. A major change was the introduction of a new category of mix: 'designated mixes'. Such mixes, related to the concrete's end use, may only be supplied by a plant with third-party quality assurance.

The revision to I.S.326 will take account of the revision to BS5328 with suitable amendments for Irish practice.

2.4 Alkali-Silica Reaction.

2.4.1 Implications for Irish Specifiers.

Damage due to alkali-silica reaction (ASR) continues to be reported in many countries but these occurrences are very widely scattered. In Europe some countries have only recently identified damage due to ASR in their structures while others have yet to experience the problem. The situation is still developing and the specifier of concrete in Ireland must be cognisant of the need to minimise the risk of damage due to ASR in future works despite the fact that no ASR damage has been reported in Ireland to date.

The issue of alkali-aggregate reaction, specifically alkali-silica reaction (ASR), was raised at the previous symposium by Bannon (1985). He noted that no cases of damage to concrete due to

alkali-silica reaction had been identified in the Republic of Ireland. No specific recommendations were in place for the guidance of the specifier in Ireland at the time and Bannon indicated that a need existed for the development of screening tests for aggregates. He noted that test methods appropriate to one region were not necessarily capable of reliably predicting the reactivity of similarly classified aggregates from another region.

Figure 1 shows the range of characteristic strengths at 28 days applicable to cement content and water/cement ratio (Irish Concrete Society 1988).

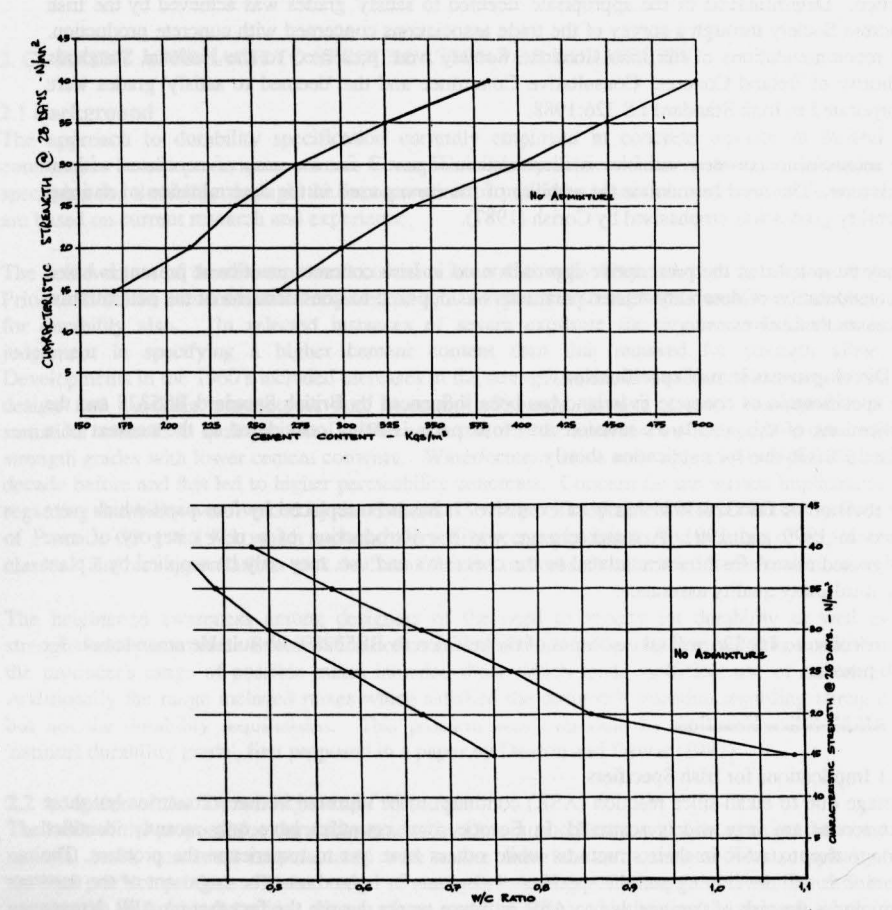


Figure 1. Range of characteristic strengths at 28 days applicable to cement content and water/cement ratio (Irish Concrete Society 1988).

Following a recommendation in a paper by Bannon(1987) to the Institution of Engineers of Ireland (IEI), the Irish Concrete Society (ICS) and the IEI established a joint working party to develop a specific approach to the management of the AAR threat through guidance for specification of future works.

The Working Party took account of international research and of their experience with Irish materials and practice. A questionnaire was issued in 1989 to seek information about any possible occurrence of significant alkali aggregate reaction (AAR) in existing structures in the Republic of Ireland. The response was representative of those responsible for the design, construction and maintenance of concrete structures. No damage was reported other than one instance in which hardened concrete in an industrial environment was damaged by spillage of hot alkali solution. This one case is thought to have been attributable to thermal shock rather than to AAR.

Guidance and model specification clauses for practice in the Republic of Ireland were drawn up and presented in the Working Party's report -IEI/ICS (1991). The report is an interim document to be amended in the future in the light of any significant research findings. The guidelines are referred to in the Department of the Environment (1991) 'Specification for Structural Concrete for Highway Works' and in the current revision to the Code of Practice for the Structural Use of Concrete, I.S.326.

2.4.2 Recommendations and guidance for practice in the Republic of Ireland.

2.4.2.1 Overview.

The philosophy of the specification is that potential damage from ASR may be minimised by controlling, in the following order, one of three parameters:

- exposure of the structure to moisture;
- potential reactivity of the aggregate combination;
- alkali content of the concrete.

A flow chart summarising the procedures is presented in Figure 2.

It may be noted from Figure 2 that no precautions against ASR need be taken if it is considered that the possible occurrence of ASR is acceptable in the structural element under consideration.

A recommendation of convenience, based on control of the alkali content, is also included for concretes with a nominal cement content of 360 kg/m³. This frequently applicable recommendation is intended to obviate the need for lengthy evaluation of the ASR threat on projects where it would not be appropriate. This is explained more fully in Section 2.4.3.

2.4.2.2 Consideration of aggregate reactivity.

Although no cases of damage due to AAR have been identified in the Republic of Ireland, the detrimental role of flints and cherts in damaging alkali silica reaction (ASR) in other countries has been significant. Chert is present in significant quantities in aggregates derived from Carboniferous Limestone in this country. Research to date has therefore concentrated on the characteristics of cherts.

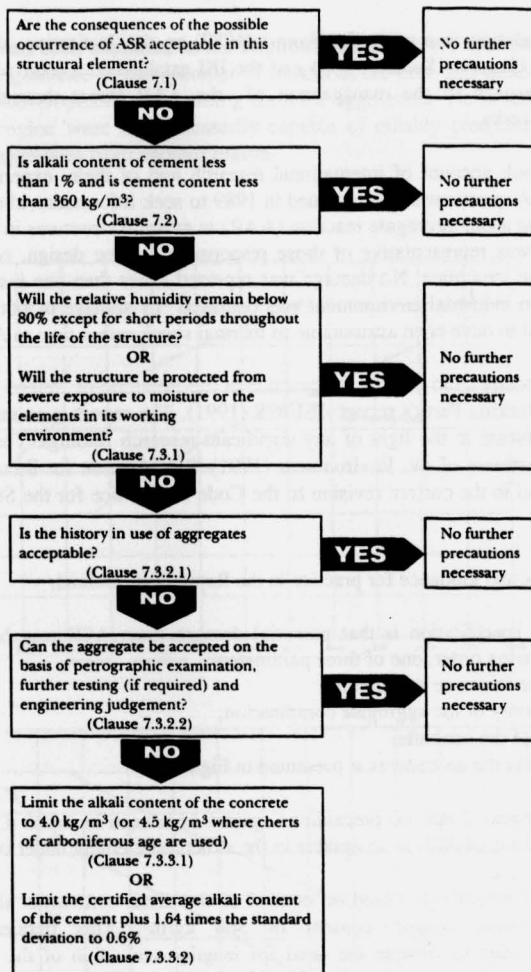


Figure 2. Flow chart for assessment of possible risk and measures to minimise the risk of damage due to ASR in Irish practice. (from Institution of Engineers of Ireland/Irish Concrete Society 1991).

Strogen (1993) reports that the term 'chert' embraces a range of materials whose reactivity towards cement differs by orders of magnitude. He suggests that older cherts - including the Carboniferous and Lower Palaeozoic cherts of Ireland - have properties which lead to very low probability of significant reaction. The study by Strogen included investigation of the X-ray diffraction properties of Irish cherts and flint specimens from England (Figure 3). This latter group included aggregates which were known to be potentially reactive. The Irish cherts were found to be more crystalline than the flints and, by implication, less likely to be reactive. Strogen argues that the different characteristics of Irish cherts and English flints are influenced by the varying ages and thermal histories of the aggregates.

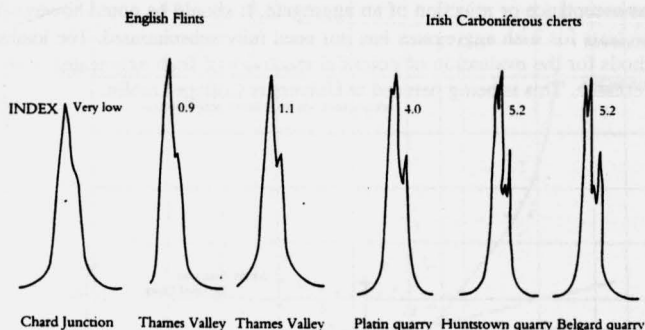


Figure 3. *Diffractometer traces around 68° for three typical English flints and three carboniferous cherts from the Dublin area (from Strogen (1993)).*

Four mineral groups have been identified internationally which may contain potentially reactive constituents. Other than the mineral group which includes those found in chert (microcrystalline quartz, cryptocrystalline quartz and chalcedony), the other mineral groups commonly associated with ASR are extremely rare in this country. These groups include opaline silica, cristobalite, tridymite, volcanic glass and highly strained quartz. Aggregates which can lead to another form of AAR - alkali-carbonate reaction - have not been identified in sources used for the production of structural concrete in Ireland.

In the absence of acceptable standard tests for the assessment of alkali reactivity of Irish aggregates, the satisfactory history of previous use of an aggregate is relied upon. If the history of satisfactory use is not available or applicable further evaluation is required. Specifiers are referred to selected ASTM tests. These tests are not definitive for Irish aggregates but may assist in the engineering judgement of acceptability.

Underlying the 'satisfactory history of use' option is a recognition that there has been little change in the nature of aggregate sources used during the last fifty years and that at times during this period cements with a relatively high alkali level were in use. The absence of reported damage due to ASR in these concretes may allow a specifier to rely on history of previous use to determine the acceptability of an aggregate for use in new works. This option would not be applicable where new quarried sources are being exploited, where new combinations of fine and coarse aggregate are introduced or where cement contents exceed those previously employed.

If satisfactory history of use is not applicable the specifier is advised to carry out a petrographic examination - for example in accordance with ASTM C295-85. If potentially deleterious mineral groups are detected at levels above guidance limits in the IEI/ICS report further evaluation may be required. The report suggests that ASTM C227-87 (Figure 4) and ASTM C289-87 (Figure 5) may be helpful in the acceptance or rejection of an aggregate. It should be noted however that the applicability of these tests for Irish aggregates has not been fully substantiated. The identification of suitable test methods for the evaluation of potential reactivity of Irish aggregates is seen as an important area for research. This is being pursued at University College Dublin.

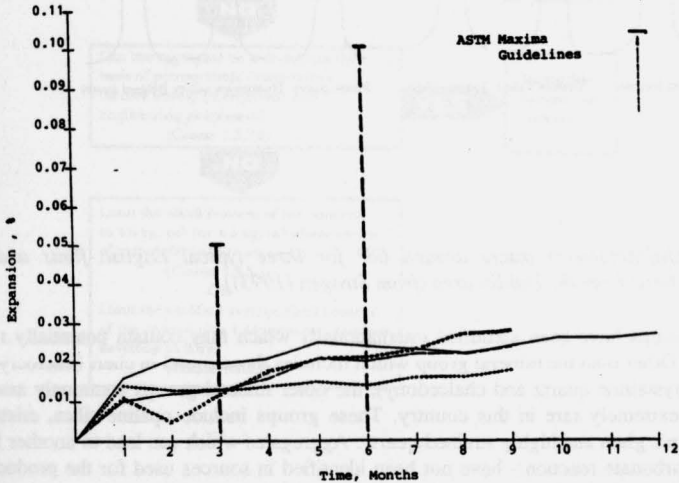


Figure 4. ASTM C227 graph with example of results from Irish practice (from Bannon (1987)).

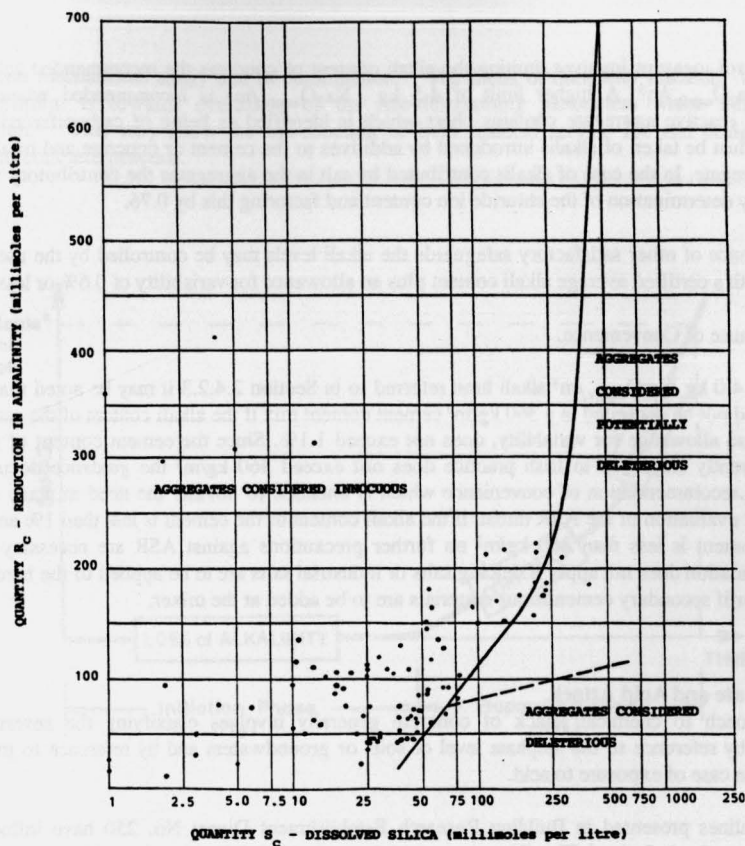


Figure 5. ASTM C289 graph with example of results from Irish practice (from Bannon (1987)).

2.4.2.3 Limiting the alkali content.

The guidance document considers limiting the alkali content of the concrete or cement as the ultimate step in the process if the other options are not applicable (see Figure 2). Limits on the alkali content of the concrete depend on the aggregate type.

The alkali content of the concrete is defined as the product of the cement content and the certified average alkali content of the cement. The certified average alkali content of the cement is defined as "the average of the last 25 determinations of alkali content carried out on consecutive daily samples". An allowance for variability of 1.64 standard deviations is included.

If the control measure involves limiting the alkali content of concrete the recommended value is $4.0 \text{ kg Na}_2\text{O}_{\text{equiv.}}/\text{m}^3$. A higher limit of $4.5 \text{ kg Na}_2\text{O}_{\text{equiv.}}/\text{m}^3$ is recommended where the potentially reactive aggregate contains chert which is identified as being of carboniferous age. Account must be taken of alkalis introduced by additives to the cement or concrete and of alkalis in the aggregate. In the case of alkalis contributed by salt in the aggregates the contributory value is found by determination of the chloride ion content and factoring this by 0.76.

In the absence of other satisfactory safeguards the alkali levels may be controlled by the use of a cement with a certified average alkali content plus an allowance for variability of 0.6% or less.

2.4.3 Clause of Convenience.

Given the $4.0 \text{ kg Na}_2\text{O}_{\text{equiv.}}/\text{m}^3$ alkali limit referred to in Section 2.4.2.3 it may be noted that this limit would not be exceeded in a 360 kg/m^3 cement content mix if the alkali content of the cement, including an allowance for variability, does not exceed 1.1%. Since the cement content of many mixes currently employed in Irish practice does not exceed 360 kg/m^3 the guidance document includes a recommendation of convenience which is intended to obviate the need in many cases for further evaluation of the ASR threat: if the alkali content of the cement is less than 1% and the cement content is less than 360 kg/m^3 no further precautions against ASR are necessary. The recommendation does not apply if deicing salts or industrial salts are to be applied to the hardened concrete or if secondary cementitious materials are to be added at the mixer.

2.5 Sulphate and Acid Attack.

The approach to chemical attack of concrete generally involves classifying the severity of exposure by reference to the sulphate level of soils or groundwaters and by reference to the pH level in the case of exposure to acid.

The guidelines presented in Building Research Establishment Digest No. 250 have influenced concrete practice in Ireland. This Digest was withdrawn in 1991 following the publication of BRE Digest No. 363. Further discussion of this new guide is presented in Section 3.6.

3. DEVELOPMENTS IN DURABILITY RESEARCH

3.1 Concept of Design Life

The concept of designing structures for a specified 'design life' was alluded to forty five years ago in Code of Practice CP3, Chapter IX (1950). More recently the concept has been elegantly illustrated by Tuuti (1982) - Figure 6. Rostam (1984) describes the design life as the recognition of possible technical life with economic considerations. This concept of a notional life for concrete structure was presented by Somerville (1986) and his paper attracted considerable discussion. Dr. Somerville is currently co-ordinating a project on the quantification of residual service life of concrete structures. This project involves accounting for the effects of

deterioration mechanisms singly and in combination. The focus of durability research world-wide at present is towards evaluation of the rate-determining parameters which influence deterioration. This may allow the introduction of both residual service life and design life concepts to concrete practice.

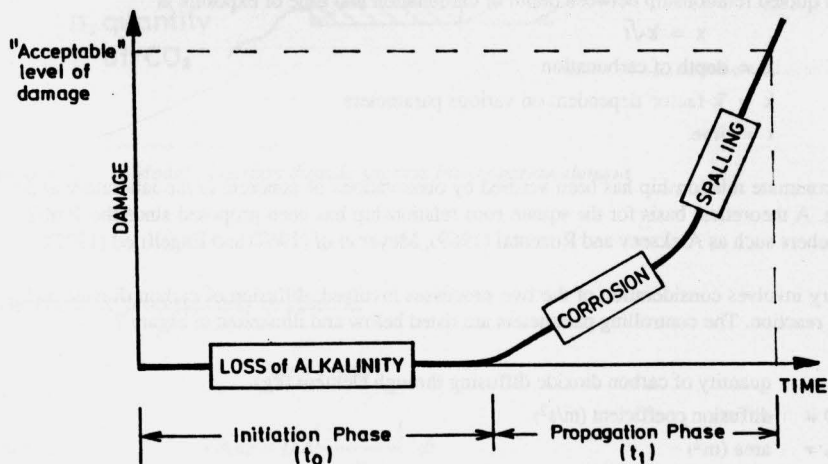


Figure 6. Concept of 'design life' for structures (after Tuuti (1982)).

3.2 Alkali-aggregate reaction

The extensive published research on alkali-aggregate reaction - which Idorn (1992) noted has now exceeded 10,000 pages! - has yet to produce definitive predictive models. A measure of the difficulty is that in excess of forty test methods have been proposed but their reproducibility has been disappointing. This is probably due to the varying geological histories of aggregates throughout the world despite common petrographic classifications. Development of prediction models will, therefore, be even more difficult.

The problem of harmonisation has been examined by CEN Task Group CEN TC104/SC1/TG9. Their report, under the editorship of Mr. Philip Nixon, is currently in preparation. Recognising the major differences in geology and climate across Europe the Task Group did not seek to produce harmonised specifications. Instead guidance on principles are being presented. Broadly,

specifications throughout Europe seek to control one of the three contributing factors outlined in Section 2.4.2.1. Local guidance rules on implementing these principles vary throughout Europe.

The direction of future specifications of concrete with respect to the ASR threat is unclear. Harmonised specifications for specific aggregate types may yet emerge.

3.3 Carbonation

The often quoted relationship between depth of carbonation and time of exposure is

$$x = k\sqrt{t}$$

- where x = depth of carbonation
- k = 'k-factor' dependent on various parameters
- t = time.

This approximate relationship has been verified by observations of concrete in the laboratory and in service. A theoretical basis for the square root relationship has been proposed since the 1960's by researchers such as Alekseev and Rozental (1969), Meyer *et al* (1967) and Engelfried (1977).

The theory involves consideration of the two processes involved: diffusion of carbon dioxide and chemical reaction. The controlling parameters are listed below and illustrated in Figure 7.

- n = quantity of carbon dioxide diffusing through element (kg)
- D = diffusion coefficient (m/s²)
- A = area (m²)
- r = concentration of CO₂ at surface (kg/m³)
- r_x = concentration of CO₂ at depth x (kg/m³)
- c = amount of alkaline material available in unit volume of concrete to buffer carbon dioxide (kg/m³)
- t = time.

The diffusion process is governed by Fickian diffusion. Thus, using standard sign convention we may state:

$$dn = -DA \frac{r - r_x}{x} dt$$

or
$$dn = DA \left| \frac{r - r_x}{x} \right| dt$$

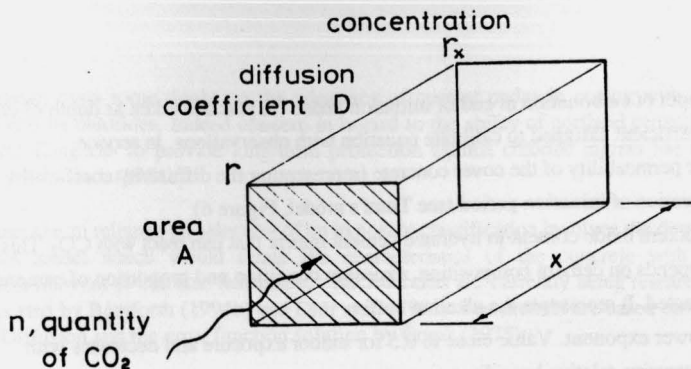


Figure 7. Model of carbon dioxide ingress into concrete element.

The chemical processes may be stated as:

$$dn = c A dx$$

Hence
$$c A dx = DA \left| \frac{r - r_x}{x} \right| dt$$

and
$$x dx = D \left| \frac{r - r_x}{c} \right| dt$$

By integration we may solve for x . In addition it may be assumed that the carbon dioxide concentration at the depth of carbonation will be zero.

Thus
$$x = \sqrt{\frac{2Dr t}{c}}$$

The application of this theory to practice has been explored by Parrott (1994). The relationship derived above is restated as follows, using the notation of Parrott:

$$d = \frac{ak^{0.4}t_i^n}{c^{0.5}}$$

- d = depth of carbonation at end of initiation phase (in practice taken as depth of cover)
- a = coefficient assigned to calibrate equation with observations in service
- k = air permeability of the cover concrete (representing the diffusivity coefficient)
- t_i = duration of initiation period (see Tuuti's model, Figure 6)
- c = calcium oxide content in hydrated cement matrix that can react with CO_2 . This depends on cement composition, exposure condition and proportion of cement reacted. It represents the alkaline buffer.
- n = power exponent. Value close to 0.5 for indoor exposure and decreases with increasing relative humidity.

Parrott further proposes a relationship for " t_p " the duration of the propagation period. This is discussed further in Section 3.7.

The approach suggested by Parrott allows specification for carbonation durability to be approached in a rational manner optimising concrete cover and permeability to suit the particular circumstances of the project. Satisfactory permeability may be achieved by alternative combinations of cement type, curing regime and water/cement ratio which are less limiting than the current prescriptive approach. Alternatively the specification could be based on relevant performance characteristics - for example insitu air permeability values - which would be monitored during construction.

3.4 Chloride Ingress

The damaging effect of chloride ingress, and the difficulties associated with effective repairs, are by now well documented. Specifiers using IS326 would, therefore, classify exposure conditions in which concrete structures are exposed to chloride ions as 'very severe' or 'most severe'. While some comfort may be derived from being seen to classify at the more onerous end of the range it is interesting to view an alternative classification system to that of IS326 and BS8110. The alternative was drawn up by Taywood Engineering Limited on the basis of their extensive experience in the field of concrete durability and is illustrated in Figure 8.

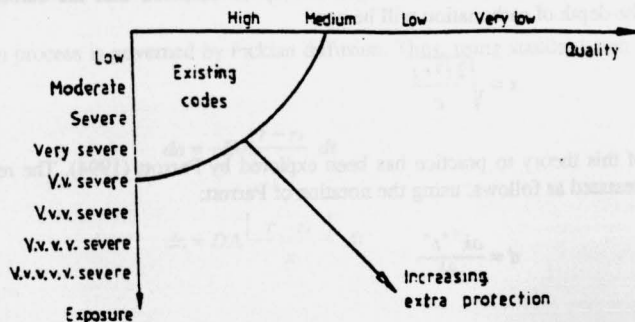


Figure 8. Alternative exposure classification system (from Browne 1986)

This diagram casts some doubt on the adequacy of current codes in coping with the durability threat posed by chlorides. Indeed concern in regard to the ability of portland cement concretes in the United Kingdom to provide long-term protection against chloride ingress has recently been voiced by Bamforth (1994b).

The alternative to reliance on selection of an exposure classification involves the development of a predictive model which would relate the characteristics of the concrete with the material parameters relevant to chloride resistance. Such models are currently being researched and have been reported by Bamforth (1994b) and Dhir *et al* (1991). The models are based on Fick's Second Law of Diffusion and the error function solution by Crank (1975) :

$$\frac{C_x}{C_{sn}} = 1 - \operatorname{erf} \frac{x}{2(D_{ce} t)^{0.5}}$$

where C_x = chloride concentration at depth x
 C_{sn} = notional surface chloride level
 D_{ce} = effective diffusion coefficient
 t = time of exposure
 erf = error function

A nomogram relating C_{sn} , D_{ce} , cover and design life was developed and is illustrated in Figure 9. Nomograms relating D_{ce} and concrete grades may be developed. Performance-based specifications could then be based on the effective diffusion coefficient.

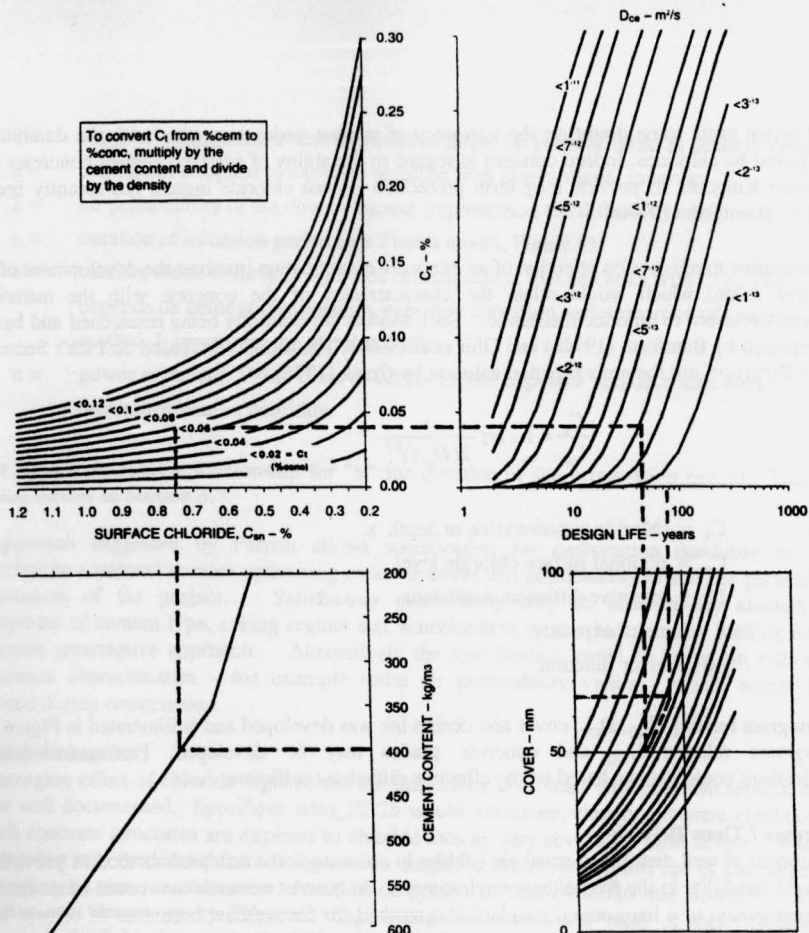
3.5 Freeze / Thaw Behaviour

Entrainment of well distributed small air bubbles in concrete is the accepted method of providing increased durability in the freeze/thaw environment. In current research two issues arise: firstly, the development of a harmonised standard test method for freeze/thaw behaviour of cement and concrete; secondly, the accurate assessment of air entrainment in fresh concrete.

Price (1994) reports that a drawback of the current situation is that the mean total air content by volume of fresh concrete at the time of delivery is the parameter currently specified and assessed. However, this parameter, on its own, does not guarantee protection from freeze/thaw damage as it does not take account of air void size and distribution. Test methods which take account of these deficiencies are being developed.

3.6 Sulphate and Chemical Attack.

Sulphate attack of concrete is a chemical process but is generally distinguished from other forms of chemical attack because its effect is that of damaging expansion as opposed to one of dissolution. A succession of Building Research Station / Establishment Reports have charted advances in knowledge and experience on resistance to sulphate attack - Digests No.90, No.250 and, the current digest, No.363.



PROCEDURE FOR DEFINING CONCRETE PERFORMANCE REQUIREMENTS

1. Select design life (e.g. 75 years) and drop a vertical line
2. Select cover (e.g. 65mm) and project a horizontal line
3. At the intersect from 1 and 2, project a curve, parallel to the nearest curve, to cross at the 50mm level
4. At the intersect of 3 with 50mm cover, project a vertical line
5. Select C_{sn} based on cement content (e.g. 400kg/m³) or from local knowledge
6. Project a vertical line from C_{sn} to the threshold level (e.g. 0.06%)
7. At the intercept with the selected threshold level, project a horizontal line
8. The intercept of the vertical line from 4, and the horizontal line from 7 defines the maximum acceptable value of D_{ce}

Figure 9. Nomogram for evaluation of parameters in chloride diffusion prediction model (from Bamforth 1994b)

This year, 1995, marks the completion of a 25 year exposure trial of concrete specimens buried below the water table of a sulphate-bearing soil in Northbrook Park, West London. Final analysis of the results will not be available for some time but interim results based on specimens tested after 15 years exposure have assisted in the understanding of sulphate attack. These interim results were influential in the revision of BRE Digest No.250 and its replacement by No.363. The new Digest includes guidance on requirements for concrete exposed to attack from acids in excess of pH 2.5. Research has allowed modification of the basis requirements by taking into account such matters as:

- member geometry
- permeability of soils
- hydrostatic head relative to concrete thickness
- degree of precarbonation prior to exposure
- water table level.

Development of a performance test for sulphate resistance of cements is also being pursued in the context of a harmonised standard for cements. The test is currently based on the measurement of expansion of mortar prisms stored in sodium sulphate solution or sea water. It is intended that the test would allow replacement of the current prescriptive approach (cement type and mix limitations) dependent on classification of the aggressiveness of the environment (Priest 1995).

The exposure classification system related to specific degradation mechanisms proposed by CEN TC104/SC1 includes three classes of exposure related to sulphate and chemical attack. Parameters included in the classification system include :

- SO_4 in water
- Total SO_4 in soil
- pH
- CO_2 aggressive in water
- NH_4^+ in water
- Mg^{++} in water.

Final analysis of the Northbrook Park trials together with developments on harmonised European standards will influence the approach to chemical attack in future works.

Meanwhile, research into forms of chemical attack specific to certain industrial processes are also continuing - for example O'Donnell *et al* (1995) - with a view to enhancing the durability of concrete in these industry-specific environments.

3.7 Corrosion Propagation

Early proponents of the 'design life' approach to durability management assumed that only the initiation phase could represent the design service life. This conservative assumption was based on the difficulty of accurately predicting that part of the propagation phase during which the

structure remained serviceable. This difficulty may be overcome by consideration of the relevant corrosion mechanism and designing appropriately.

Parrott (1994) has illustrated such an approach in the case of carbonation-induced corrosion:

$$t_p = \frac{CD}{CR}$$

where t_p = time to visible cracking
CD = corrosion depth which causes visible cracking
CR = corrosion rate.

Illustrative examples, derived by Parrott from many published results in the literature, are:

CD = 100 μm

CR = 0.3 $\mu\text{m}/\text{year}$ at 50% relative humidity

CR = 5 $\mu\text{m}/\text{year}$ at 80% relative humidity.

Further refinements, which would take account of the diameter and geometry of the reinforcement cage, may emerge.

4. THE FUTURE: PERFORMANCE CRITERIA AND ASSOCIATED TEST METHODS?

The continuing development of our understanding of deterioration processes, as illustrated by the developments over the last ten years outlined in Section 3, will provide the opportunity for a more rational approach to the specification of concrete than that currently in place. Such an approach is commended by Dewar (1985) who recognised his 'durability grade' proposal as a "practical expedient". Bamforth (1994a) points out that specifications reliant on empirical recommendations are only valid as long as material properties are unchanged.

The difficult task of producing a harmonised European standard for concrete (performance, production, placing and compliance criteria) has been ongoing since 1981. A number of approaches to the classification of exposure conditions have been debated. The desirability of harmonising exposure classes in the general European standard EN206 with the design code EC2 is also recognised despite its complication of an already complex process. Harmonisation does, however, provide an opportunity for the adoption of current research findings in a coherent engineering approach. It also provides the impetus for change which should not be lost. The arguments in favour of performance-based specifications backed up by predictive models and tests are therefore worthy of consideration.

5. CONCLUDING REMARKS

The traditional approach to durability design and specification has been refined in the ten year period under review but not significantly changed. The introduction of guidance for specifiers in respect of ASR has added to the list of checks but the overall approach remains a prescriptive one. Over the ten year period research into the phenomena which threaten the serviceability of concrete structures have yielded significantly greater understanding of the parameters influencing the rate of deterioration. Meanwhile, European standards harmonisation is promoting an alternative to our traditional approach. This alternative method is driven by the desire to specify on the basis of performance criteria wherever possible.

The traditional approach, with its all encompassing methodology, may lead to overdesign or alternatively it may cause localised serviceability failures when even the most conscientious specifier may be 'caught out'. The alternative option, based on quantitative models and identification of specific durability threatening processes, may satisfactorily address the shortcomings of the traditional approach. The introduction of artificial intelligence should enhance such considerations.

The approach to durability being advanced by CEN sub-committee TC 104/SC1, involving exposure classes related specifically to deterioration mechanisms is a logical development of our increased understanding.

Some practitioners may cast a cynical eye on the development of complex numerical models for the analysis of deterioration mechanisms and look forward to their further 'development' into simplified rules which may bring us full circle back to the traditional approach! However, a cultural change is taking place in the concrete industry away from specifications reliant on empirical knowledge and towards the adoption of performance criteria. This should lead to economies and better use of diminishing resources. The specifier can better harness the expertise of the producer by stating what is required of the concrete in service rather than stating the 'height' of the 'hurdles' to be jumped in the assessment of fitness for a marathon! Nevertheless, change will be slow to implement and, of course, there will be instances where specifier and producer are happy to employ the traditional approach.

Advances in specification for durability since the third Concrete Practice in Ireland Symposium in 1985 are a welcome result of increased cognisance of deterioration mechanisms. Further advances in our understanding of these phenomena, coupled with a general move towards performance specification, may lead to even greater change before the next symposium in the series. The translation of these advances into the practical realities of concrete practice in Ireland offers an opportunity for enhancing the reputation of concrete.

If I may extend Halstead's analogy, quoted in my introduction, we may yet turn every good soldier into a good officer!

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DISCUSSION.

DR. RICHARDSON introduced his paper by indicating that it would cover developments over the past ten years in relation to specification for durability and would also look forward to the possible introduction of performance-based specifications which was an emerging issue. This latter topic was covered by reviewing developments in durability research over the past ten years in so far as this work could be related to future specification methods.

The roots of recent durability failures were traced through the changes in cement and concrete strengths over the preceding decades. The response of the industry to these issues were charted through changes in codes of practice and specifications.

The contrast between current procedures for the design of structural members to resist stresses induced by load and design methods for durability was highlighted in a manner which indicated a lack of precision in the case of durability considerations. Possible methods of reducing this degree of imprecision through the development of mathematical models were outlined.

MR. TOM DUGGAN opened the discussion by noting that our intellect in regard to the problem of durability was strange - when confronted by a situation to which we believe there is no solution we regard it as a fact. When we begin to suspect that the situation may have a solution we regard it as a problem and then we endeavour to solve the problem. This is evident in the case of durability and was reflected in the approach outlined in the paper. He did not believe that we have an absolute solution nor that one would emerge in the next ten years.

Although durability was writ large in the minds of specifiers he remained to be convinced that it was writ in the same size lettering in the minds of those who actually build. He recalled that Professor de Courcy had once noted that what really mattered was not what was done in research or was written in the specification but what was finally translated into a three-dimensional model of all that had gone before.

He instanced three issues. Firstly he reminded the symposium that concrete in the structure was not the same as concrete in the cube. Strengths in the structure would be lower than cube strengths but we recognise this by modifying our design stresses. Secondly he noted concerns about control of water/cement ratio on site yet in the structure the water/cement ratio increased from the heart of the member to the surface. He illustrated this by reference to Swedish research which showed highest water/cement ratios in the cover concrete - where durability issues were most important. Some believed that we had a solution to this problem, others just took it as a fact. He challenged them about what they were going to do about this if it was a 'fact'. Thirdly he drew attention to the frightening evidence of low covers published in late 1994 in the magazine 'Concrete'. A survey in the United Kingdom comprised 250 measurements and revealed many cases where specific covers were not achieved in practice.

The problem of design for loading has been solved. The durability issue has not been solved. He believed that what we could do at this stage was to check the impact of various parameters on the resistance of concrete to certain aggressive environmental features. Research has already shown that by adjusting various parameters the overall durability may be enhanced. The next problem is one of translating enhanced performance from laboratory-scale studies to the large scale reality of site concrete.

He noted some reservations he had about accelerated tests but recognised their role. He felt that there was a need to take cores from concrete in service which could be directly compared with laboratory concretes of the same mix. The effects of bleeding influence all site concrete pours but few laboratory-based ones because of difference in scale. Another issue on site but not in the laboratory was the sympathetic vibration of forms - modern forms were not as rigid as heretofore and were more prone to sympathetic vibration. This had the effect of drawing water and fine particles to the surface. He observed the growing trend in higher workability concretes and wondered if the reintroduction of the 'podger' would be more appropriate than the use of vibrators. This might lead to more durable concretes by reducing the variability of water/cement

ratio from the heart of the member to the outside. The problem of curing was another issue which differentiated site concrete from laboratory concretes. He did not believe that our site concrete was cured as well as it should be - or could be.

The introduction of the durability grade concept was a very significant step forward as it made those involved in the production and use of concrete aware of the need for control of durability parameters. However he urged a review of the durability grades which were arrived at eight years ago as there remained the need to take account of changes in admixtures and, perhaps, changes in cement.

He believed that it must be possible for researchers to determine reliable predictive models for the onset of corrosion propagation and damage in structures. The work of many experts in this field had shown the way ahead but how this is to be translated into performance on site is a key question. He believed that we were at the threshold of coming to grips with the totality downstream of the concept of durability but urged that we not be carried away with advances to date and success based on less than perfectly defined parameters.

Looking ahead to the year 2005 he felt that our attention would be more directed to the quality of cover concrete on site. The next 'Concrete Practice in Ireland' Symposium would perhaps include a paper on controlled permeability formwork which was not relevant to this review of the present decade because its use was isolated to date.

He looked forward to the day when we would see durability quantification in the same first division league as we have brought stress analysis.

MR. KEN QUINN asked if there was not a case for specification of surface coatings of concrete for durability as in the case of steel structures. He recognised that this may sound like heresy to the purists but he said that it was a practical alternative to many of the problems we encounter today.

DR. ROGER WEST said that site practice was all-important in the production of durable concrete. He felt that there was a greater need for supervision on site by those who had been educated in the importance of the durability-related parameters already well known to researchers, designers and specifiers. Worthwhile mathematical modelling of durability phenomena was not possible if site supervision was lacking.

PROFESSOR J. W. de COURCY commented that although a study of structural steelwork could indicate the role of surface coatings he preferred to compare concrete with brick or stone. Many masonry structures had been in service without coatings for very long periods and he believed that the same should be possible with concrete.

He then referred to the concept of 'design life'. The practical reality of 'design life' should be in the form of a contractual relationship between designer and building owner or financier. It did not of course mean that the building would be unserviceable at the end of the 'design life' as may be implied by the illustration of Tuuti's concept. Durability beyond design life was likely in reality. It should be viewed as a contractual period during which the building would be durable.

MR. NIAL TORPEY invited the Irish Concrete Society to review in the future the durability grades offered and published in Irish Standard I.S.326. Developments at European level indicate that the concrete grades which we may have to live with in the future are grades 30, 37, 45, 50 and 55. We need to review how our own concrete practice would fit in with these grades.

DR. EAMONN CANNON felt that our role as engineers was to mediate between complex materials, complex environments and complex human beings - all play their part in the attainment of durability. He therefore had difficulty with the absolutism and determinism as expressed sometimes in mathematical formulae. Formulae play their part but it is important that they be kept in context. There are so many uncertainties attached to the individual parameters of the formulae that one must recognise their role as being limited to the indication of trends. The dangers of regarding formulae as providers of certainty are ones which we must be conscious of. For this reason he did not share the same objections to simple statements in codes on durability issues as those indicated in the paper.

MR. BRENDAN LYNCH commented that we must also recognise the changes taking place in the industry. In the past the builder was the prime mover and was concerned to produce a structure to be proud of and that would stand the test of time. Changes are now happening with, for example, designers and specifiers on the one side and the introduction of management contractors on the other side. He praised their introduction of certified systems to improve quality. He felt that performance-based specifications were down-the-road somewhat and so he endorsed the comments regarding enhanced site supervision at this stage.

MR. TOM DUGGAN took up the point about surface coating of concrete for durability. He saw this approach as an admission of defeat. Coatings were not permanent and they were expensive. An expert at a recent seminar in Dublin had quoted a figure of £80/m² for a coating guaranteed to protect the structure for 10 years.

THE CHAIRMAN commented that much had been said in the discussion about site practice but he did not feel that this sufficiently recognised the whole process. Undetected errors in design offices would also compromise durability. He also said that research into durability of concrete was vital since developments would not occur in practice unless there was adequate research to encourage change.

DR. RICHARDSON responded to the discussion.

He saw no reason why surface coatings could not form part of the performance-based approach. For example, in a particular environment the pertinent durability parameter might be surface permeability and the required value might demand the use of a surface coating. Alternative methods might be available, such as controlled permeability formwork, but surface coatings could be part of the solution.

In relation to the comments on site supervision he saw a direct link between mathematical modelling of durability and the issue of site supervision. Supervisors need targets - for example, one usually found that formwork for member section sizes was invariably accurate because it was possible to check both the target and the achieved dimensions. Rather than hope that supervision would by its presence encourage good concrete practice why not add the additional tool of

quantifiable targets for durability-related parameters? A range of non-destructive tests already exist for checking aspects such as cover and surface permeability.

In relation to 'design life' he hoped that this would emerge as a notional concept to assist prudent and economical design. It should be a means of determining the time parameter 't' in performance formulae. He expressed the hope that it would not merely be adopted by insurers and others who might use it in a manner which made it another millstone for designers in the increasingly litigious world that they must practice in.

He agreed that a review of the data on which the durability grades of I.S.326 were based would now be timely. The manner in which this was assessed 10 years ago by the industry in co-operation with the Irish Concrete Society was a model worth repeating.

Finally he addressed the issue of the relevance to concrete practice of mathematical models. His view was that all mathematical models in the world of engineering should be viewed merely as aids to the designer and specifier. They provide assistance in reaching a sound engineering judgement. He hoped that the formulae and concepts presented in the paper would be viewed in that context.

SESSION F

DEVELOPMENTS IN PRECAST CONCRETE

C. O'DEA, B.E., M.Sc., M.B.A., C.Eng. M.I.EI, M.I.Struct.E.

Techrete Limited.

Sessional Chairman

K. N. QUINN, B.Sc., C.Eng, M.I.C.E., M.A.S.C.E., F.F.B.

John Graham (Dromore) Ltd.

Abstract

This paper reviews the developments that have taken place in the industry structure. The main product areas are reviewed and where possible likely future trends are discussed.

1. INTRODUCTION.

This paper will review the development of the industry in Ireland in recent years and examine the product range that is now available and what might be the trends for the future.

2. INDUSTRY DEVELOPMENTS.

Pre-cast had an image problem that is fading rapidly and is being replaced by a new awareness of its scope and flexibility in an industry that has become more specialized and quality orientated. High rise system buildings in grey, pre-fabricated concrete, do little for the product. This was not just the fault of the industry, designers and developers must also share the blame. The industry was perhaps, at times, not providing due consideration to workmanship but there were also many new ideas being explored, sometimes without the appropriate research and investigatory work such as joint design, development of tie forces, water penetration, behaviour of sandwich panels etc.

These factors and indeed changing architectural styles resulted in a fairly major downsizing of the industry as designers stood back from the product to re-think it and consider other applications. Surprisingly this was not the case in Western Europe where although a change took place in building styles the industry remained busy and strong. In industrial terms we have probably witnessed a major shake out and we have lived through the early growth of a new pre-cast industry.

What are the differences? For one the industry is much more specialized. It is now unusual to find a pre-caster offering the full range of products. Typically they will concentrate on a more

limited portfolio, devoting the necessary time and attention to that range. A huge change of emphasis on quality and quality systems coinciding with the general thrust for ISO 9000 in operations. A much improved awareness and research back-up on jointing and assembling of pre-cast concrete and indeed a significant change in the style of buildings. It is fair to say that we are witnessing the growth of a new and different type of pre-cast industry - a more informed and more specialized one and that the notion of high volume, high repetition is no longer the only criteria for use of the product.

3. INDUSTRY STRUCTURE IN IRELAND.

One of the significant developments in the industry in recent years has been the formation of the I.P.C.A. (The Irish Pre-cast Concrete Association).

One of the primary reasons for the formation of the associations was to ensure that the pre-cast sector of the industry could collectively respond to the commercial and technical needs of the specifiers and purchasers of pre-cast. The members are committed to delivering a professional service and currently there are eight members providing between them the broad range of structural products in the market place.

The member companies all have the support of in-house design and a progressive attitude towards new products and developments. The publication 'Pre-cast Concrete Building Regulations Guide' produced by the I.P.C.A., has been very well received and is used extensively as a guide by consultants and the industry in designing to meet the building regulations. It deals with the issues of stability, tie forces, support details for slabs etc. and it is the intention of the association to produce further publications which will give similar advice and guidelines for other pre-cast elements.

4. FLOORING SYSTEMS

4.1 Hollow Core Flooring:

The most rapid growth of all product areas has probably taken place in the use of pre-cast flooring (see Appendix 1). Pre-cast flooring is now the accepted norm in many building types. Typical hollow core sizes range from 150mm up to 300mm and there is now a 400mm hollow-core slab available, capable of spanning up to 16m clearspan for car-park construction.

Considerable investment has been made in plant and equipment and at least 95% of all hollow-core flooring is now machine produced in extruded form.

4.2 Double Tee:

Double tee flooring is still a very competitive element for a long span flooring where the self-weight of the unit must be kept to a minimum. It is an extremely elegant form of structure and is optimum in its use of materials. It is interesting to note that various forms of special double tee structures have been used on some notable recent buildings in the UK such as "The Inland Revenue in Nottingham", "The Scottish Office in Leith" and they are also proposed for "The New Parliament Buildings". There are other issues involved in these buildings such as

conservation of energy and the heat sink concept but the chosen form would suggest that the double tee type structure, although perhaps not a high volume one, will remain with us.

4.3 Wide Slab:

This system of a thin slab of concrete with upper projecting reinforcement or inverted beam is in effect a permanent shutter with tension reinforcement incorporated in the plank. It does offer the versatility of combining both pre-cast and insitu construction. Some propping may be required on a temporary basis on longer spans. In parts of Europe this is a particularly popular form of construction and an interesting application is the combination of two slab sections welded through their centre re-enforcement to effectively provide the shuttering for vertical walls.

4.4 Pot & Plank or Block & Plank Flooring:

These systems are of domestic scale and can be man-handled into position. They are ideal for short-span flooring and have great potential in the housing market. They are used extensively in the UK, where many ground floors are suspended because of the problems with heaving clay. Just recently the I.P.C.A. has set about improving awareness in the market place of the potential quality improvement in housing from the use of pre-cast floors and we can expect to see growth in the use of the product.

5. PRE-CAST CONCRETE FRAMES.

These can be considered under two headings (see Appendix 2):

- a) Industrial, Single Story Frames.
- b) Multi-story, Pre-cast Frames.

The former can be further sub-divided into:

- a.1) Portal Frames.
- a.2) Beam & Column Frames.

The form of the portal frame has changed over the years and the most recent trend is to joint the rafter section to the portal leg at contra-flexure point along the rafter i.e. above the haunch connection of the rafter. This is a little cumbersome for installation but results in a very efficient use of material. The rafter pitch is in the order of 7 degrees and surprisingly big spans can be achieved. A record portal of 35m was installed in Naas last year.

Column and beam frames are available with rafter pitches of 4 and 6 degrees and are the more common industrial frames. These have been used up to spans of 30m with perhaps an optimum about the 18m span. Sections are reinforced or prestressed depending on manufacturers preference. The competitiveness of concrete industrial frames depends to a degree on the fluctuating price of structural steelwork, which is the generic competitor, however, the client would be well advised to give consideration to aspects of durability, maintenance and fire protection which are intrinsic to the concrete system and not always apparent on preliminary cost comparisons.

5.1 Pre-cast, Multi-storey Frames:

Pre-cast, multi-storey frames are now used extensively, particularly in the new office parks. There is more flexibility in the industry to supply these in non-standard forms and also with a combination of steel and concrete. An interesting idea is shown on (see Appendix 3) where steel and concrete are combined to provide a clear zone for services and eliminate the problems encountered with downstand beams. Beam/column connections are either corbel or steel bracket type. Whereas concrete corbels are used extensively in Europe, we tend to use steel, shear connectors at beam/column interface. These are in the form of projecting solid steel billets or box sections and are quick and simple to install. Column heights have extended in single lift and although four floors would be generally considered the maximum height for a single column, a six storey column has been manufactured in one piece.

6. PRE-FABRICATED STAIRS/WALLS.

Pre-fabricated stairs have grown in popularity, very much as a natural add-on to the above. There are now two fully flexible, hydraulically operated, stairmoulds in the country.

The use of pre-cast walls for core areas or as party walls between apartment units has not yet become the practice in Ireland. This would seem to be a logical development in the future. If the volume is in the right order, then battery moulds can be used and a self-finished wall can be provided at a competitive cost. It is likely that we will see some developments in this direction in the future.

7. CLADDING.

The traditional finishes of exposed aggregate and sand blasting have been replaced by lightly etched and rubbed surfaces to simulate natural stone. The term 're-constructed stone' is now used extensively to describe concrete cladding and for both sandstone and limestone, a very good match can be achieved. One of the more interesting developments has been the use of complex and ornamental shapes which do much more to exploit the potential of re-constructed stone (see Appendix 4). Concrete cladding is now seen as a new medium and there are recent examples where it has been chosen ahead of natural stone, not because of its cost differential but because of its own intrinsic characteristics, durability, scale, speed and texture. The range of finishes has also improved to include polished concrete and tinting of concrete to provide a range of colours along with a mixture of treatments within the same element.

7.1 Faced Panels:

The use of facing materials has become increasingly popular. Stone faced panels can be installed at the speed of pre-cast panels and are designed in accordance with BS 8298 (about to be superseded). The restraint system (see Appendix 5) is through stainless steel dowel pins, thus ensuring a mechanical connection and no dependence on adhesion. This system has been used on buildings such as "Georges Quay, Harbour Masters Place" and the "Sweepstakes Building".

7.2 Durability & Weathering:

High quality cladding should not require any maintenance for 10 years, unless it is located in a heavily polluted atmosphere. Good quality silicones or silanes acting as waterproofers, help in the run-off of water and keeps the building clean for longer than would otherwise be the case. If we recognise that concrete cladding does require some maintenance and if it is carried out at reasonable intervals, then the building appearance will benefit tremendously. Concrete cladding is a dense, durable material and the tendency is to give much more thought to the potential run-off of water on buildings and potential dirt gathering areas.

8. G.R.C. (GLASS REINFORCED CONCRETE).

G.R.C. is widely used in the construction industry throughout the world as a building, cladding material and for associated architectural components. G.R.C. products normally have a wall thickness of between 10mm and 20mm and this results in low component weight - typically one fifth that of pre-cast concrete - although G.R.C. products retain the appearance and feel of a structurally heavier, denser material. Earlier panels were cast either with ribs or as sandwich panels. In recent years we have seen the introduction of the stud frame (See Appendix 6) the essentials of the system are that the stud frame section provides the lateral stiffness to the G.R.C. panel. A single skin (no ribbing) is connected at regular intervals by flex anchors which allow in plane movement but no out of plane movement. A typical cross section through a cornice unit is attached showing the scope that exists in shape and method of attachment. The last 10 years would also have shown an increasing trend towards placing the design responsibility with the pre-caster. Typically the consultant will now prepare outline drawings backed up by a detailed performance specification with the pre-caster taking responsibility for the structural design. For wall cladding there is a trend to go one step further and try and pass full envelope responsibility to the pre-caster i.e. that the package will include the responsibility for the wall, windows and other performance criteria such as water tightness, vapour tightness, insulation PVC's etc. This trend will continue with increasing demands on the design/drawing office of the specialist sub-contractor.

9. BRIDGE BEAMS.

The standard range of 'M' beams and 'T' beams has been broadened in recent years to include both 'Y' beams and 'U' beams (see Appendix 7). The choice of beam will be influenced by the aesthetic, as well as the structural, efficiency of the element. Spans of up to 36m have been achieved and it is surprising that pre-cast beams have not been used more extensively in the current phase of road construction. They are extremely efficient and give comfort to the designer in knowing exactly where strand is located and that it is adequately protected. By suitable selection of the beam element and some modifications to the outer beams, simple and elegant forms can be achieved, as witnessed on some of the most recent motor-way bridges.

The 'Y' beam came about as a natural evolution from the increased spacing of the 'M' beams. Once the idea of leaving a joint width emerged, the opportunity was taken to improve the cross section. The 'Y' beam allows more access to the pre-caster and a simpler reinforcement set up. The 'U' beam was developed both for its shape and efficiency. Each 'U' beam,

although more expensive than the single beam, is in comparative terms a double beam. On some recent projects the design has been extended to include for partial continuity over supports with these beam systems.

10. WATER TANKS.

There are two proprietary systems available in the market place using circular tanks. The tanks are formed using vertical segments which are either reinforced or prestressed. A proprietary insitu stitch is poured between elements and these, when in place, are stressed circumferentially using external prestress. Diameters up to 30m and height of 7m have been achieved. The system is fast and efficient and a good competitor to insitu and steel tanks. An interesting development would be the use of different finishes to these tanks either in texture, colour or banding which would improve appearance at a relatively small incremental cost.

11. EARTH RETAINING SECTIONS:

11.1 Earth Retaining Structures:

The proprietary reinforced earth system has shown significant growth in recent years and must now account for a sizeable share of embankment work. Designers have become more adventurous in the use of the section using a range of finishes.

Traditional retaining walls are also available in short segments but are not in great demand.

12. SPECIAL STRUCTURES.

Probably the most significant use of special structures is in grandstands. Recent stand roofs would include "Fairhouse" and "Leopardstown" racecourse. At Leopardstown the roof beams were suspended from diagonal macaloy bars demonstrating again the scope for mixing the two material to the best advantage. Step units for stands have been formed frequently in pre-cast concrete and for the new stand to Croke Park these have been scaled up considerably to spans of 15m incorporating both the downstand as well as upstand section.

Pre-cast segmental bridge construction has been used in Belfast for very large box sections with integral deck segments where match cast in the factory and then post-tensioned segmentally on site.

13. FUTURE DEVELOPMENTS.

The trend in Europe is to place more and more emphasis on a systems approach to pre-casting. As we move further and further from multiple standard sections the business becomes one of efficiently controlling changing logistics i.e. ensuring efficient co-ordination between design, component sourcing, moulding, storage, delivery etc. using both 'critical path' and 'just-in-time' analysis. The trend is to take the industry further and further from a site

operation and more toward the factory discipline. Likewise, pre-cast elements are being analysed according to a pareto analysis to identify those components that have some commonality. It is true, that what might first seem non-repetitive, will have many repetitive sub-components with scope for mechanisation. Appendix 8 shows some equipment that is being introduced to the industry whereby hydraulically adjustable tables and moulds will facilitate more efficient casting of a large number of units.

Scarce and expensive people's skills are in the trade and this will have two influences:

1) An increasing demand for off-site pre-fabrication due to the constraints of site labour.

2) A pressure to optimise the use of human skills in the factory so as to produce at minimum cost.

Fully computerised, automatic batching plants are now common place. We will see more emphasis on the transportation of the concrete to the mould place, the placing of the concrete in the mould and compaction techniques etc.

APPENDICES.

Appendix: 1. Types of Floor Slabs.

Appendix: 2. Precast Frames.

Appendix: 3. Flitch Beam.

Appendix: 4. Ornamental Concrete.

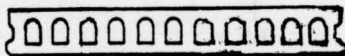
Appendix: 5. Stone Restraint.

Appendix: 6. Stud Frame Panels.

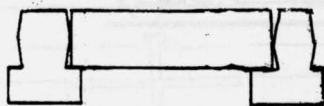
Appendix: 7. Bridge Beams.

Appendix: 8. Hydraulic Moulds.

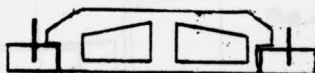
Appendix: 9. Sandwich Panels.



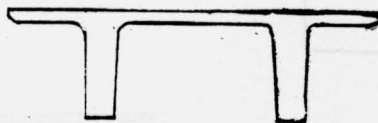
HOLLOW CORE.



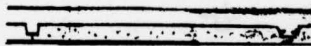
Precast + Plank.



Precast + PBT.

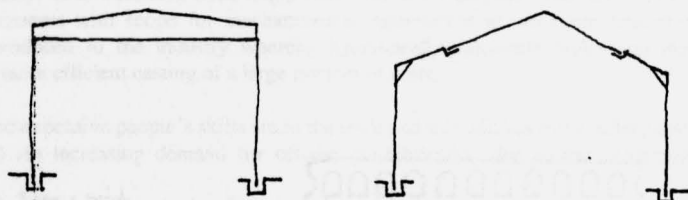


DOUBLE 'T'

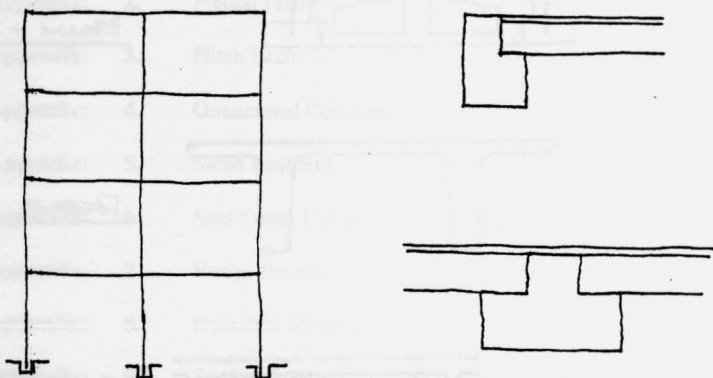


COMPOSITE.

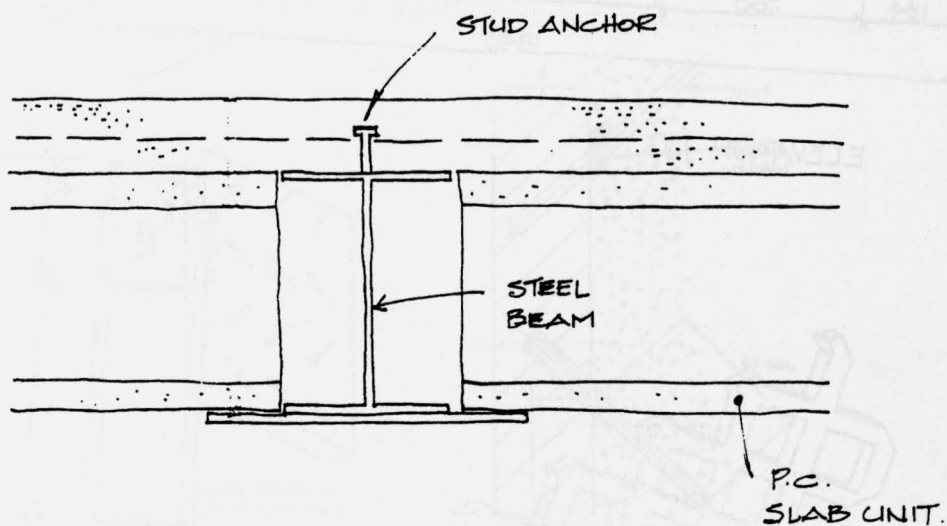
Appendix: 1. Types of Floor Slabs.



SINGLE STOREY

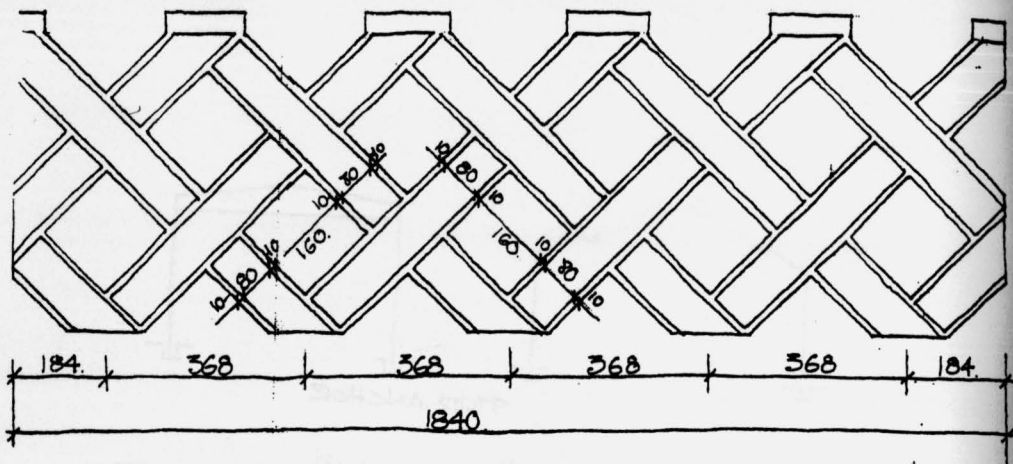


MULTI STOREY

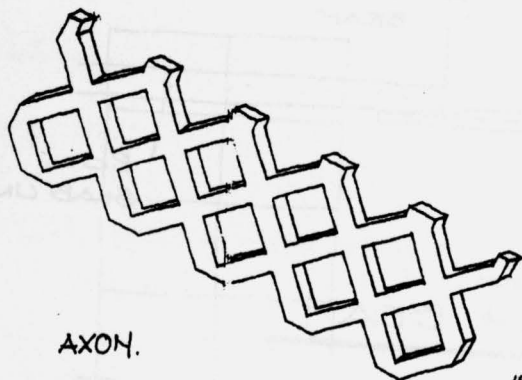


FLITCH BEAM

Appendix: 3. Flitch Beam.



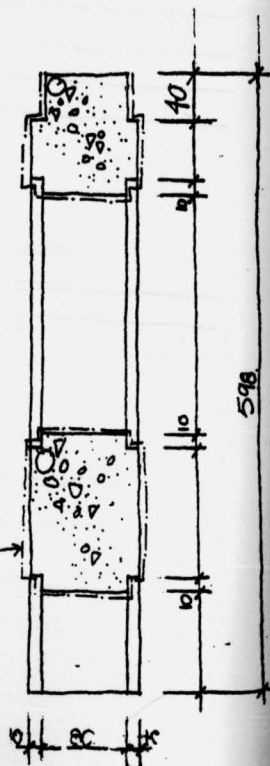
ELEVATION 1:10



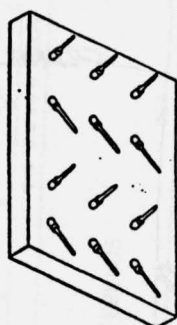
AXON.

INDICATES FINISHED FACE

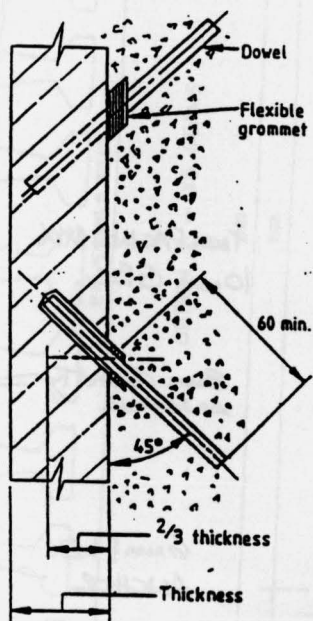
SECTION 1:5



GN.

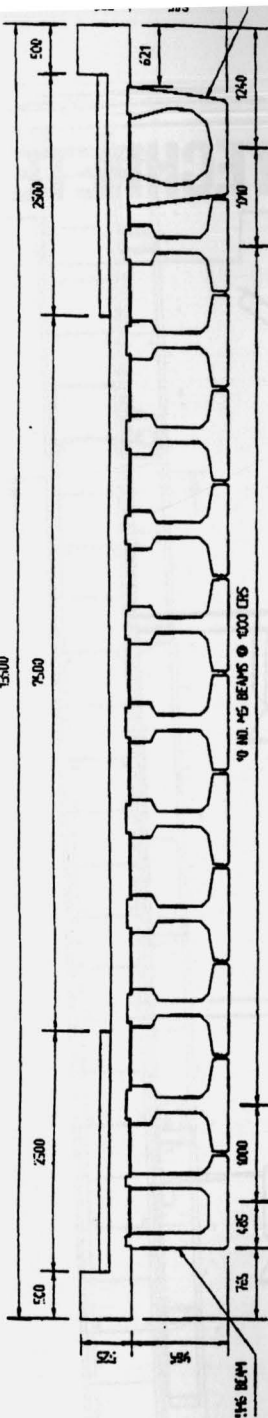


Dovels inclined in opposite directions



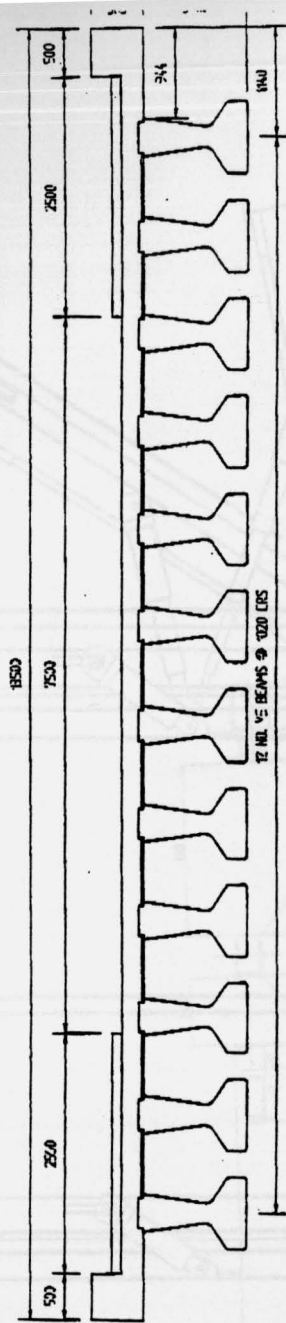
All linear dimensions are in millimetres.

Appendix: 5. Stone Restraint.

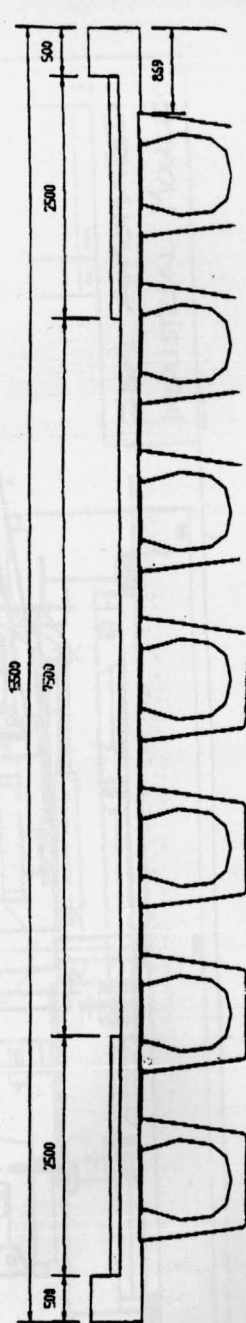


OPTION 1A - M6 BEAMS WITH UMS EDGEBEAMS

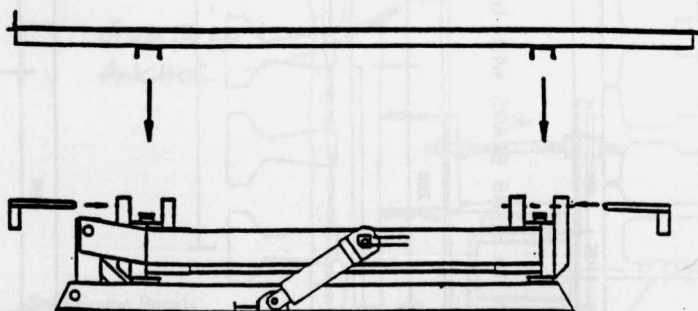
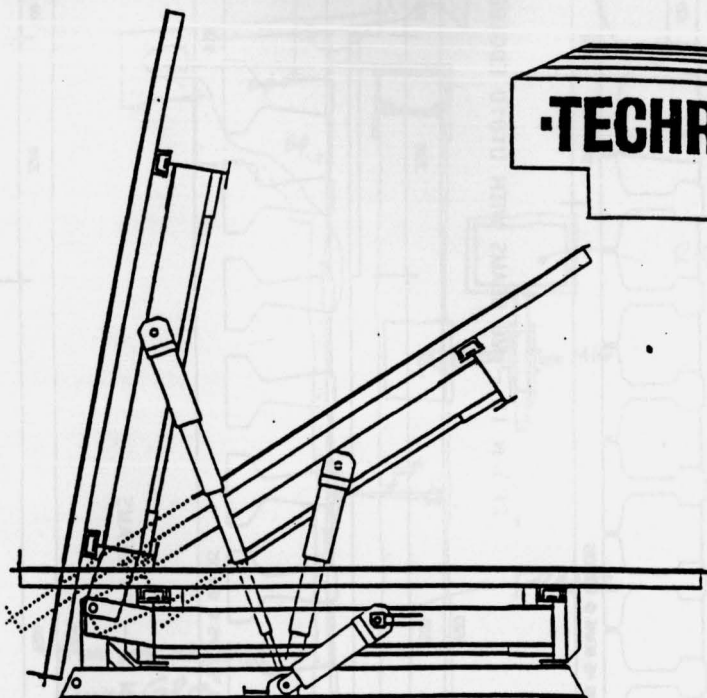
OPTION 1B - M6 BEAMS WITH U1010 EDGEBEAM



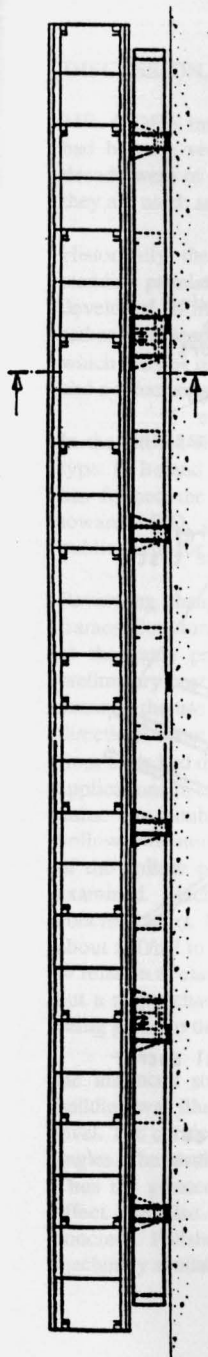
OPTION 2 - Y5 BEAMS



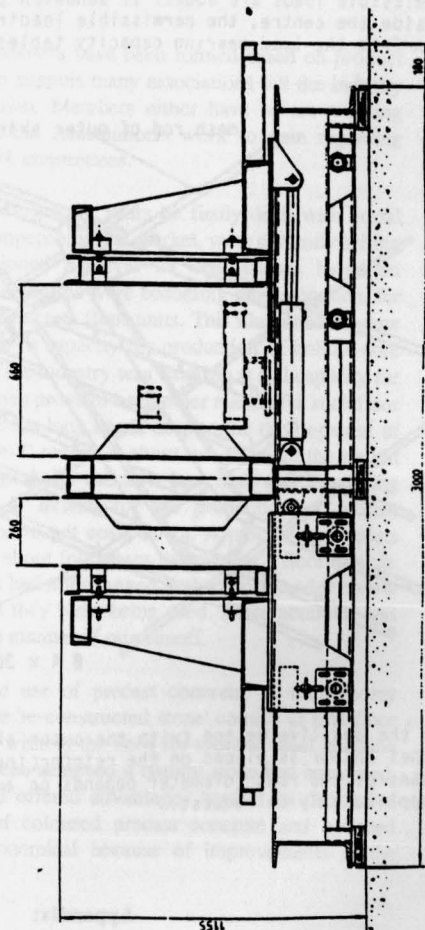
Appendix: 7. Bridge Beams.



Appendix: 8. Hydraulic Moulds.



Appendix: 8.

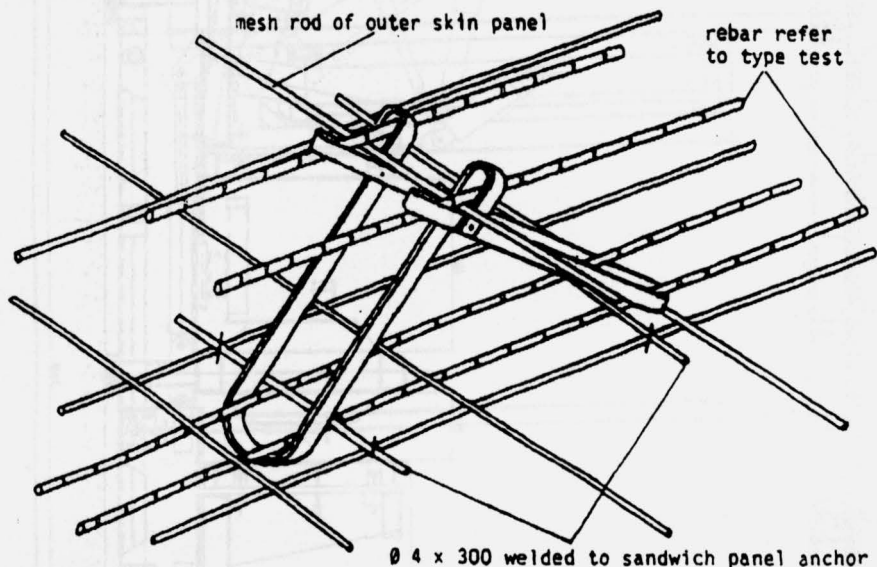


SEMI AUTOMATED
INDUSTRIAL MOULD

Sandwich Panel Anchor

(positive)

A sandwich panel anchor is subjected not only to vertical force (the deadweight of the outer skin) but also a horizontal force from the wind and obstructed curvature. For this reason, the permissible loads are shown separately on the tables overleaf. Any desired number of anchors can be used with a minimum spacing of 22.5 cm apart, so that the permissible loads are added. If sandwich panels anchors are installed outside the centre, the permissible loading is reduced; this will be seen from the load-bearing capacity tables in the technical specification.



In the positive method (with the outer skin at the top) the sandwich panel anchor is placed on the reinforcing mat and locked beneath it by means of two rods (diameter depends on anchor type).
Supplied only on request.

DISCUSSION.

MR. O'DEA introduced his paper by noting that while some sectors of the precast industry had become very specialised it was not a high technology industry. Thus changes over a decade were of the following nature: modifications to products; significant changes in the way they are used; and a complete change in the way the industry is structured.

Historically, the precaster was a multi-product company producing floor slabs, double tees, cladding panels and producing systems which they encouraged designers to use. The industry developed an image problem. Quality suffered and precasters were seen as system producers rather than bespoke designers. Designers and developers often used the products in a manner which did not reflect well on the industry. There has since been a down-sizing of the industry and a refocusing on specialised quality products.

In the United Kingdom many associations of precasters have been formed based on product type. In Ireland the market is not large enough to support many associations but the industry has formed the Irish Precast Concrete Association. Members either have or are working toward I.S.O. quality certification. He outlined the Association's work to date regarding publications for designers and their work on C.E.N. committees.

Reviewing changes in product areas over the previous ten years he firstly dealt with portal frames. Structural steelwork portal frames, the competitor in the market, were currently selling at the same price as ten years ago. He cautioned however on comparisons based on preliminary cost only. Hybrid steel and concrete structures were becoming more common, for example the use of steel flitch beams and precast concrete floor units. This illustrated the new directions being taken by the industry. The industry's capacity for production of hollow core floor units had doubled over the last ten years and the industry was working at full capacity for applications in urban renewal schemes. Housing may prove to be another market for such floor units. The 'double-T' section remains competitive for long spans despite the development of hollow core units spanning up to 16m. The 'double-T' section is about two-thirds of the weight of the hollow core unit and retains aesthetic appeal. Its use as a heat sink was also being examined. Mechanisation had been introduced in Ireland for the production of precast concrete stairs. Further volume growth is required to get costs down. A precast stairs costs about £80/m² to £100/m² to produce at present - about four times the rate for a flooring unit. In relation to cladding units, the basic constituents had not changed in the period under review but a major change had occurred in the way that they were being used. More attention was being given to the exploration of geometry and the manner of rain runoff.

He instanced some noteworthy examples of the use of precast concrete. A multi-storey building was illustrated which incorporated a wide 're-constructed stone' cornice at first floor level. The cornice supported the brickwork above without the need for stainless steel relieving angles. The resulting cost saving could not have been achieved if natural stone had been used. Thus the greater strength of the precast material offered advantages beyond its decorative effect. He also showed examples of the use of coloured precast concrete and polished concrete. Polished concrete was now more economical because of improvements in the machinery available.

The use of polymers for curing GRC units was replacing the use of moist cabinets. Examples were given of GRC cladding units which incorporated finished windows, thus illustrating the increasing scope for precasters to offer wider specialist sub-contract services.

The development of 'Y beams' and 'U beams' in the bridge beam product area was noted. A moratorium is currently in place in the United Kingdom on the use of post-tensioned bridges following the collapse of three insitu bridges. Quality control regarding tendon location and grouting was always a problem. The precast sector had no such difficulties and currently Irish precast concrete producers were exporting to the U.K. market in the supply of bridge beams.

Looking to the future he believed that the precast industry must look to the systems engineering approach. Graduates of systems engineering would be required to redirect the industry away from concrete technology issues and the concept of site operations to the concepts of factory discipline - benchmark dates, 'just-in-time' analysis etc. He believed that cost reductions of up to 60% were possible if such an approach were adopted.

MR. MARTIN MANNION opened the discussion. He said that despite its widespread use precast concrete is seen by many as a very specialized industry. Designers have no reservations with regard to specifying it but they are in general not prepared to design precast concrete units and structures. Many designers blindly rely on manufacturer's tables and data and do not check from first principles. This attitude may stem from the lesser emphasis placed on precast concrete in undergraduate courses. The aspects of design for handling, joints and continuity require further elucidation. The onus was on designers and on educators to enhance appreciation of precast procedures. He quoted Jan Bobrowski: "If you cannot build it, you have not designed it!"

He noted the increasing demand for precast concrete components. These may be used in virtually all forms of structure as for example: industrial and commercial buildings; maritime works; agricultural structures; bridges and tunnels.

He reviewed advantages and disadvantages in the use of precast concrete and concluded that in general the advantages are predominant.

He firstly dealt with the advantages:

- The mixing, placing and curing of the concrete is carried out under factory-controlled conditions.
- Repetitive reproduction of standardised units leads to reduced costs.
- Site assembly can take place in inclement weather including cold. This allows precast concrete to be competitive with structural steel and also structural timber, and since concrete is relatively cheap, the precast approach is likely to be more economical.
- In general semi-skilled labour is adequate for assembly. Thus operatives can be recruited and quickly trained to carry out such activity.
- Shrinkage problems are alleviated since maturing takes place before the components are built into the structure.
- Easier to achieve better surface finishes.
- Factory cast service ducts avoid the necessity for laborious setting out and for shuttering on site.

- Earlier occupancy is more likely, thus leading to a quicker return on capital outlay.
- Many of the units will possibly be lighter due to better quality control on mixes and on the use of castellation. This leads to savings on the overall structure.
- Some precast components may be used as an aid in the construction process. For example, precast concrete floors provide an immediate working platform.

Turning to disadvantages he noted the following:

- Probably the greatest disadvantage of precast concrete is the difficulty in achieving the continuity and rigidity that is inherent in in-situ concrete. To overcome this disadvantage it is necessary to give special consideration to joints and to tying requirements at the design stage, and to pay particular attention to these aspects during construction.
- Transportation difficulties, including delivery restrictions due to traffic controls.
- Handling and placing may require greater capacity plant than normal.
- Design must include for handling stresses in addition to the final stresses.
- Precast members will generally be handled, transported and erected at an early age. Thus it may be necessary to use higher strength concrete. While this would not be a disadvantage with prestressed units it would be with normal reinforced units.
- Precast concrete is likely to be more expensive than in-situ due to factory overheads and transport costs. However, these will generally be offset by savings in labour and time.

Turning to specific aspects of the product areas covered in the paper he noted that precast concrete ranges from the smaller architectural and structural units like cappings, sills and lintels, through stairs, floor slabs and portal frames, right up to such large structures as bridges and offshore rigs.

The technique of precast concrete for structural purposes was originally applied to the manufacture of floors and roof slabs. Hollow units are normally the cheapest form of precast concrete suspended floor for simple straight spans, with beam or wall supports, up to a maximum span of 20m. Precast hollow floor units are available in a variety of sections such as box planks or beams; T, I and channel beam sections. Economies which can be reasonably expected over the in-situ floor are:

- 50% reduction in the volume of concrete;
- 25% reduction in the weight of reinforcement;
- 10% reduction in the size of foundations.

Other systems include Double tee construction; wide slab; and domestic type floors using precast prestressed beams with infill blocks.

In relation to precast concrete frames he said that the overall concept of a precast concrete frame is the same as for any other structural framing material. Single or multi-storey frames can be produced on the skeletal or box frame principle. The single-storey frames are either of the portal or beam and column form. Most precast concrete frames are produced as part of a "system" building. Such building is less flexible in its design concept than purpose made structures, but since presently there is a wide variety of choice of systems available, most design briefs can be fulfilled without significant modification of the original concept. Single-storey precast concrete frameworks are directly more economical than structural steel frameworks, especially when fire protection and painting is taken into account. Design optimisation and improving manufacturing is leading to their use over larger spans. He

speculated that the precast industry would soon face significant competition in the frame market from glue-laminated timber sections. The current world glut of structural steelwork would continue to pose a significant competitive threat, as would steel's advantage at spans in excess of 35m. He also saw the restriction of multi-storey precast concrete frames to four or perhaps six storeys as a limiting factor.

One of the more widespread uses of precast concrete is for cladding panels. These have excellent architectural appeal since they can be supplied with a variety of finishes including stone, marble and slate facing. In general manufacturers supply advice and support, from conception to completion, thus alleviating problems associated with the various stages, as for example, transportation, handling and fixing of the units. He noted that the structural design must consider the supporting arrangements in addition to the gravity and wind forces acting on the panel. Also allowance must be made for the effects of deflection, and for shrinkage and thermal movements. He instanced an example of a building that he was familiar with which was clad in precast concrete but which was totally devoid of aesthetic appeal. Many users of the building blamed the concrete for its ugliness. Concrete, however, was what you put into it from the viewpoints of design, manufacture and construction. The building in question was constructed over twenty years ago. He was greatly impressed by the examples of recent work illustrated by Mr. O'Dea which showed what designers and precasters were now capable of.

Among the various other uses of precast concrete he included bridges, water tanks, earth retaining structures, agricultural structures and grandstands. Bridge spans of up to 30m are relatively easy to attain and tank diameters up to a similar dimension have been achieved. He particularly noted the extensive use of precast concrete in the agricultural sector. Although the units themselves were small in scale the industry itself was a big one.

He complimented the Irish Precast Concrete Association on their excellent publication regarding precast concrete and the building regulations. He expressed the hope that clients would recognise the excellence of precasters in their chosen product sector and be wary of precasters who lacked experience in certain sectors but who might tender for work in any sector.

He expressed surprise at the apparent lack of extensive use of precast concrete in bridge works associated with the current roads programme. He felt that precast concrete's advantages in bridge work had not been fully recognised.

On a more positive note he instanced the complimentary use of precast concrete, in-situ concrete and steelwork in the construction of Mizen Head Bridge in 1908 and 1909. This fine structure, he believed, pointed out that no one method or material was necessarily superior. The combination of materials and methods could often offer the best solution.

In conclusion he complimented Mr. O'Dea and his colleagues on the significant advances that they had brought to the industry, so much so that Ireland was now exporting precast concrete units. This was a magnificent achievement which bode well for the future.

MR. NICHOLAS RYAN was very impressed by the illustrations of coloured precast concrete units shown during the presentation of the paper. He said that the technology had clearly

moved beyond reliance on fine and coarse aggregate alone for colour contribution. He wondered what new techniques had emerged to make possible the range of examples illustrated and how durability of the surface could be ensured.

MR. BRENDAN LYNCH wished to comment on the agricultural sector. He said that there had been some problems with precast units over the last ten years but that these had been resolved. There was now a new specification for single slats and gang slats. Turning to the housing sector he mentioned that research was currently underway to ascertain the advantages of the thermal value of concrete as a heat store linked to solar heating.

THE CHAIRMAN noted that Mr. Mannion had instanced transportation as a potential disadvantage of precast concrete. On the Belfast Cross-Harbour Bridge project, however, his company had transported 1000 precast units weighing from 60 tons to 90 tons and this had been done with little difficulty. The use of the balanced cantilever method of construction had also been advantageous in dispensing with the need for propping.

MR. O'DEA replied to the discussion.

The colouring of product was still predominantly achieved by natural materials. Pigmentation was however used to achieve blue and red colouring. Many of the sands used to achieve colour were sourced internationally. The premium for importing these materials was about £20/ton. The paving industry also used pigmentation and adequate research results existed to indicate that durability would be achieved. Fading of darker colours was inevitable and it was important that the designer and client were aware of this. Allowance for fading could be made by the geometry and multi-coloured nature of a facade. The use of coatings - say silanes or siloxanes - were useful in minimising the growth of algae by reducing the period during which the concrete was moist. He felt however that light coloured panels should be avoided in cities and in parts of the west of Ireland where algae were airborne. He also stressed the importance of detailing for water runoff.

SESSION G

CONCRETE RESEARCH IN IRELAND - AN OVERVIEW

Prof. S. H. PERRY, Sc.D., F.I.EI, F.I.C.E., F.I.StructE., F.I.H.T.

Department of Civil, Structural and Environmental Engineering,

Trinity College, Dublin.

Sessional Chairman

P. T. PIGOTT, B.E., M.Sc., Eur. Ing., C.Eng., F.I.EI., A.M.A.S.C.E.

Office of Public Works.

1. INTRODUCTION.

At present, all indications are that the construction industry is coming out of the recent recession, with a distinct up-turn in activity. However, partly because tight margins continue to prevail and partly because of the increasing emphasis being placed on efficiency in the use of materials (tied in with the growing awareness of the need to minimise damage to the environment) there is a continuing need for a better understanding of the ways in which concrete, both materially and structurally, behaves. Increased efficiency, and economy, in the case of concrete require the implementation of new practices, materials and design codes. The development or assessment of these new practices and determination of their suitability to Irish conditions requires research.

Often, a specific job will require a contractor or material supplier to undertake research into a specific problem. However, not only can the time taken to acquire this new knowledge delay a project, very often the new knowledge so acquired is either lost once the job is completed, or not available in a form to benefit others. One of the critical roles of the third level education sector, the universities and advanced colleges of technology, is a co-ordination role and, above all else, the dissemination of the results of experimental and theoretical research. Also, the very nature of university research means that programs of co-ordinated study can be undertaken, often over several years, and the results so obtained published in a form that allows application to a wide variety of problems. Without doubt, the advent of new materials, more elaborate and material efficient structures and new codes of practice has led to the need for more knowledge. These, taken together with improved experimental facilities, both in the universities and in some research establishments, has led to a considerable growth in the volume of research undertaken in the general field of concrete.

In this brief overview, the recent and current research in the university sector is summarised; in Section 3 the role of the research institutions, their efficiency and the controversial issue of funding is touched upon. Finally, the most effective summary of recent work undertaken in the professional/university sector might be best noted through a study of the list of references.

2. CONCRETE RESEARCH

2.1 Mix Design, Workability and Durability

University College Cork (UCC) has been consistently involved in research in this field, as far back as 1920. More recently, considerable study has been conducted into the use of limestone fines (Orr and Slattery 1991, 1993). Considerable work in this area has also been undertaken at Trinity College, Dublin (TCD), in particular, into aggregate recycling, polystyrene aggregate concrete and the areas of workability and rheology, (Mulheran and O'Mahony, 1988; Perry, Bischoff and Yamura, 1986; West, 1990).

University College, Dublin (UCD) is involved in research relating mainly to durability. This work includes the study of carbonation, alkali-aggregate reactivity and oxygen diffusivity measurement as an alternative to permeability-based measurements (Richardson, 1988; de Courcy and Ryan 1992). Queen's University, Belfast (QUB), also, has undertaken work in this field. Their research has involved the development and use of equipment to assess in-situ strength and permeability (durability) as well as studies of in-situ durability of bridges (Basheer, 1990; Basheer, Montgomery and Long, 1990). University College, Galway have also conducted work in the area of mix design (Cannon, 1992), while a study of Concrete Quality Control is being conducted on an ongoing basis.

2.2 Reinforced Concrete

There has been a significant amount of work done in this general area over the years. In TCD research topics have included fire, piles, impacts, corrosion and the loading of laterally confined columns (Perry and Harty, 1992; Perry, Armstrong and Harris, 1987; Perry and Cheong, 1993; Fahey, 1989). Both UCC and The Dublin Institute of Technology (DIT) have conducted work on external reinforcement (Orr and Kiely, 1990). UCD is undertaking research into joint detail optimisation for concrete pavements, while QUB are conducting much research in this area, most notably into flat slab punching shear, shear strength of continuous beams, patch repairs and steel-concrete-steel sandwich construction, as well as yield-line analysis (Montgomery and Murray, 1990).

2.3 Prestressed Concrete

Since the late 1950's, much research has been conducted in the field of prestressed concrete from the early work on impact resistance and flexural strength at University College, Galway (UCG) and the 'Speedwell' tests at QUB (Bennett and O'Keefe, 1958/9; Sidwell et al, 1969-75) to more recent research. In more recent years, TCD has undertaken research mainly in topics related to bridges - deflections, weigh-in-motion, jacking, computer programmes - but also relating to columns with lateral prestressing (O'Brien and Flanagan, 1993; Dixon and O'Brien, 1991; O'Brien, 1991; Cheong and Perry, 1991). UCC has conducted research on partially prestressed beams and on computer programmes using the Magnel Diagrams approach (Orr, 1986).

2.4 Masonry

TCD has worked on foundations subject to subsidence for masonry buildings (Burland, Mansour and Perry, 1988; Mansour, Burland and Perry, 1987), while DIT was involved in the testing of wall panels for IS 326. UCC has been involved in masonry-related work including

the Study of laterally loaded panels (Orr and Mannion, 1992; Orr, 1992). UCG has worked in this area also (O'Dwyer, 1991).

2.5 In-Service Behaviour Studies

Studies of this nature have been underway at UCD for many years (MacCraith, 1990). Recent studies have concentrated on the monitoring of movement cycles in buildings. At TCD, work is ongoing relating to Precast Segmental Arch Culverts (Orr and O'Neill, 1993).

QUB has been involved in the monitoring of masonry bridges under abnormal loads, as well as the condition of circular prestressed reservoirs (Cleland, Rankin and Aston, 1990).

2.6 Miscellaneous University Research.

In TCD, work has been conducted in the areas of concrete in marine environments, impacts due to explosions, early age behaviour and bamboo as a substitute to steel reinforcement in Africa. Also, TCD has conducted studies into the compressive strain rate effects of concrete at high strain rates and the stress-strain behaviour of laterally confined columns (Bischoff and Perry, 1986; Bischoff and Perry, 1991; Perry and Cheong, 1991).

QUB are undertaking research into silage effluent attack on concrete. UCG have conducted work in the area of moisture movement and time-dependent effects (Cannon, 1994; Murray, 1995).

2.7 Commercial Research.

Undoubtedly, a considerable amount of research is undertaken commercially investigating the manufacture and behaviour of individual products. This is sometimes reported in fair detail in promotional and sales brochures. However, this information is rarely available in a form that allows the work to be incorporated into wider studies.

3. LOOKING AHEAD.

3.1 Funding and Co-ordination.

Currently, funding derives from four principal sources: in the Republic, the European Union (EU) and the Government through Forbairt are the main sponsors of research with some input from industry; in Northern Ireland, research finance is available from the EU, the Science and Engineering Research Council, the Department of the Environment (NI) and industry. With the continuing enlargement of the EU, it is questionable whether funding from that source can be sustained at the present level - estimated to be as high as 2/3 of all funding at present. Thus, even to maintain the present 'indifferent' support, it will be necessary to seek out alternative sources of finance.

A number of new sources of finance are possible, these include:-

- o a "construction levy";
- o more finance from industry;
- o a government "flexi-fund";
- o increased funding from the International Fund for Ireland.

A "construction levy" has operated in a number of countries. A set percentage of the capital cost of all projects could be directed to a fund for construction-related research, including research into concrete. Even if a fraction of 1% were to be levied, a significant amount of research could be financed. With an industry worth £4bn in 1994, a levy of 0.1% would give £4 million pounds per annum available for research.

Seeking finance from industry, in which tight margins apply and business is largely cyclic, is not easy. However, industry unquestionably derives significant benefit from the research undertaken in the educational Institutions. In particular, manufacturers of cement, admixtures, fibres, polystyrene and other products with uses in concrete all benefit. Additionally, manufacturers of concrete products, such as roofing, cladding, concrete furniture or precast elements could also benefit significantly from increased involvement in the research side of the industry.

Funding is generally available for specific topics in particular fields; it can be argued that a 'flexi-fund' providing additional funding to miscellaneous projects not covered currently would be of use.

The emergence of the International Fund for Ireland as a significant source of finance will serve, hopefully, to further research into concrete on a cross border basis.

Currently, it is evident that between the various institutions, there is little overlap in the topics under research. It is possible that this is merely a fortunate side-effect of the overall lack of funding sources, in that the few financiers (such as Government Agencies) are in a position to monitor any duplication. However, if the Institutions are to widen the range of finance sources, there would be a need for some type of co-ordinating mechanism say, for example, a "Concrete Research Forum" meeting on a regular basis under the auspices, perhaps, of the Concrete Society. This would serve, also, as evidence of a co-ordinated approach which would be encouraging to an industry considering research funding.

3.2 Future Research.

Amongst the many possible topics are:-

- o **Admixtures:** More research is required into the suitability and optimisation of admixtures for Irish conditions.
- o **Lightweight Concrete:** This is in common use in other countries but has yet to 'catch on' here, despite its apparent advantages. As such, research is required into its compatibility with Irish conditions.
- o **Cement Replacements:** Pulverised Fuel Ash is in reasonably common use abroad but has not yet found much use here, despite the high availability of it from ESB generating stations. A large-scale test-case is required in a fully-operational application, to be monitored during and after construction.
- o **Reinforcement:** Further research is needed into fibre reinforcement, particularly in relation to flat slabs.

- o **In-service Behaviour Monitoring:** The research institutions need to take a more active part in the monitoring of structures in-situ. While this is currently being conducted to a limited degree, more is required to aid our understanding of the behaviour of concrete structures. This necessitates increased co-operation with local authorities, contractors and owners.

3.3 The Role of the Research Institutions.

Teaching

The research undertaken by educational institutions' allows them to impart practical experience to their students, as well as disseminate the commercial and theoretical benefits attached to it. Thus, research is useful to industry on two counts: firstly, industry gains from the knowledge and information gleaned from the research; also, potential employees gain better training.

Information

With a fast changing situation caused by the need for harmonisation of construction practice across the European Union, we are seeing many new Eurocodes, often on a different basis to our own older codes, and these can lead to problems and, occasionally, confusion within all branches of the industry.

The Universities and research institutes can contribute some of the manpower and time needed to digest this "torrent" of new information, as well as the all-important skills needed to update industry. In addition, universities have a role in disseminating information relating to their own research and, also, in keeping industry "up to speed" and aware of developments on the international scene.

Testing

Significant investment has gone into the facilities of the Research Institutions in recent years in order to enable them to compete for EC stimulated research projects and funding as they came on stream. These laboratories can also serve industry in a commercial capacity, particularly where sophisticated measurements on a 'one-off' basis are called for. Generally, university laboratories are more suited to R and D work rather than repetitive 'standard' testing (cube-crushing, etc.).

Sponsored Research

Commercially-sponsored research leading to the development of new structural forms, materials, methods or equipment needs to increase if practice in Ireland is to keep apace with development abroad. In particular, assessment of the suitability of new materials such as admixtures, reinforcements or additives to Irish conditions needs study on a continuous basis.

Acknowledgements.

I wish to express my deep appreciation to Don Keigher for the substantial amount of research and assistance that he has undertaken in the production of this paper; also, my thanks to Julie Sutton for undertaking the typing.

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DISCUSSION.

PROFESSOR PERRY opened his paper by noting that it was not exhaustive. Twice as many papers from the various universities could have been included. A trend which emerged was that our focus is more on research into the material aspects of concrete than its structural behaviour. This perhaps was not a bad thing as structural research demanded very expensive facilities which perhaps did not require duplication with other centres. As an example of cost he instanced a bridge research project which he undertook at Imperial College. It involved a one-tenth scale model of an urban interchange. The cost was £250 000 at 1970's prices. Such expenditure would probably represent an unacceptably high proportion of total research funding in Ireland to be justifiable.

He went on to detail the research being carried out under the seven headings listed in the paper. In relation to commercial research he noted that the results tended to be reported in promotional material only. He regretted that the results were not carried a little further and disseminated more widely. He identified possible topics for future research and spoke of the role of the research institutions.

Looking to the future he indicated the need for greater co-ordination of our activities, attention to funding issues and the need to publicise what the research institutes were achieving and what they could and should be doing. A problem was a view in this and many other countries that conventional civil engineering could be taken for granted. It was difficult to generate enthusiasm at government level for investment into materials such as concrete. Public perception of concrete was that it was not a glamorous material despite the excellence of its use.

He called for co-ordination by interested societies, research institutes and private companies to address the issues of long term funding. He elaborated on the possible sources of funding outlined in his paper. The "flexi-fund" would be administered by professionals and would fund wider topics which single industries could not support alone.

Turning to the dissemination of results he suggested that more regular seminars on concrete research in Ireland be held. He wondered if the Irish Concrete Society would become involved in an annual publication of Irish concrete research.

MR. GERALD McCONNELL opened the discussion.

He said that Professor Perry's paper provided a clear and succinct overview of concrete research in Ireland, had indicated the need for research, the factors driving it and the factors which must sustain it for the national good. He congratulated Professor Perry for his achievement in the last decade in organising the construction of a new civil engineering laboratory at Trinity College Dublin which includes a facility for heavy structural testing. "Go n-éirigh an bóthar leis!", he declared. He wished this as a salutation and not as a call for Professor Perry to produce this phenomenon in the heavy structures laboratory!

Mr. McConnell then gave a personal perspective of the points raised in the paper. He illustrated cases to raise awareness of the need for research including the technology of house construction for areas of the world disadvantaged by climate and economy. He likened research to any construction activity. It involved an input in the form of materials, a process of design and construction, and an output: the product. The element of time was also present. He saw durability as the global issue which must be right from the start. Strength and stiffness would come along as part of the process but durability could be threatened at any stage.

He echoed Professor Perry's comments on the value to industry of the universities and higher institutes in their role as educators. He felt that, in research, our laboratories should be a workshop for ideas. The human resources, in the form of the high calibre students which we currently attract enabled high quality work to be achieved at low cost. He would be disappointed if those outside of academia had a very narrow view of research, believing it to be a marginal activity limited to specific objectives. He would welcome a construction levy to boost research activity which would benefit all concerned. He instanced an example from Israel where the researchers were being invited to share their expertise with Albania, Ethiopia and other countries.

Describing the range of elements possible in reinforced concrete he drew attention to the thickness of elements. Referring specifically to thin elements he stated that in Ireland we have yet to fully exploit shape in structures. The first ferrocement boat was constructed in 1848. It is still durable. The museum where it is housed in Paris will celebrate the boat's 150th anniversary shortly. In Ireland we have yet to fully embrace this technology. Fibre reinforced composites were developing rapidly.

Testing machines had developed greatly and had moved away from the awkward time consuming machines of two decades ago. The machines were now modular and could produce results with a rapid turnaround. Servo-controlled systems can be controlled to produce a strain environment, a load environment or a position environment. This is done through

feedback control using computers. We can now make journeys into the mechanical behaviour of structures in ways that were impossible twenty or thirty years ago.

In materials we can look beyond the elastic state in our designs and see the plastic response. Our test equipment allows us to identify the load/deflection response of structures and components up to a brittle response or with load paths that go beyond this - ductile stiffening behaviour, ductile stable, ductile unstable or violently unstable behaviour. He illustrated what was now possible through an example of tests on timber sections and concrete using a servo-controlled system in U.C.D. Our great reliance on the concrete cube crushing machine has allowed us to lose sight of the material's behaviour. Cube crushing machines lead to a machine-dependent failure which gives little insight into the fracture of the cube. Modern test equipment allows us to investigate failure closer to that which is relevant.

He referred to the work of Johansson, Hillerborg and Wood and to the influence of boundary conditions of slabs. Failure in tests on a circular simply-supported slab occurred at four times the load at which yielding was expected to occur. We should be exploiting these areas where load could be carried 'for free' as it were.

Turning to imperfection-sensitivity, he noted that some structural forms behaved in a manner which was disappointing - their load capacity on test was much lower than might be predicted by theoretical computer analysis. We could not claim to have no experience of such phenomena - the collapsed cooling towers at Ferrybridge and box girder bridges were examples.

He questioned whether or not those of us involved in concrete recognised the need for continued development in concrete structures. He instanced the case of a reinforced concrete hyperbolic paraboloid structure built in the 1960's. Elaborate timber formwork was required which was disposed of after the pour. The concrete itself incorporated some thick sections. Timber hyperbolic paraboloid structures, on the other hand, were now being built to cover similar floor areas to that concrete structure. The timber members, including laminated plywood sections, were only marginally larger than the formwork for the concrete shell!

Finally he noted the need for the greatest collaboration possible.

THE CHAIRMAN, before proceeding to open the floor for further discussion after the lead speaker, called on invited contributors to address the symposium on the topic of research into concrete at the following institutions:

Dublin Institute of Technology, Bolton Street;

Queen's University, Belfast;

Trinity College Dublin;

University College Cork;

University College Dublin;

University College Galway.

CONCRETE RESEARCH AT THE DUBLIN INSTITUTE OF TECHNOLOGY, BOLTON STREET.

Mr. G. Corcoran, B.A., B.A.I., M.I.E.I.

Mr. Corcoran said that the projects undertaken at the Dublin Institute of Technology, Bolton Street, covered a wide range of topics.

An example of a project undertaken was a project entitled "Determination of the compressive strength of masonry with blocks laid on flat", (Project Director: Mr. O. McNulty; Project Managers: Mr. R. Mahoney and Mr. J. Kindregan; Research Assistant: Ms. M. Whelan) completed in 1987. This project was initiated by the Concrete Masonry Panel and funded in conjunction with the National Board for Science and Technology.

Another project funded by the National Board for Science and Technology and the Industrial Development Authority was entitled "An investigation into the early prediction of 28 day strength of cement", (Project Director: Mr. O. McNulty; Research Director: Dr. G. Bonner; Research Assistant: Mr. A. Fitzsimons) completed in 1986.

He reviewed the topics of short term final year projects and noted that over 70 concrete-related projects had been completed over the past decade. He mentioned two projects from the 1994/95 class as examples of the work being undertaken which was of interest to industry. The first was entitled "Electrochemical desalination of reinforced concrete" and dealt with potential disadvantages of the application of this new technique on structures such as bridge piers. The second project was entitled "Shear enhancement of cantilevered concrete beams". This project was in the context of the absence of reinforcement in the overhang of a ground beam. These two projects were examples of practical issues which would be of interest to the wider industry.

Other topics covered in final year projects over the last four years included: recycled aggregates; pfa concretes; effect of temperature on the bond strength of epoxy-coated reinforcement; shear in corbels; strengthening by concrete overlays or steel plates; torsional behaviour in fibre-reinforced beams; precast concrete column and beam connections; impact loading of polystyrene-rubber aggregate concrete; moment redistribution; diagonal tension shear cracking; shear connections in composite reinforced concrete; bentonite as a partial cement replacement; residual strength of soffit-repaired concrete beams; concrete parabolic arches; shear capacity of prestressed hollowcore floor units; shear reinforcement in high strength concrete beams; acid attack; shear in dowelled joints; strength and stability of air-entrained concrete; biaxial bending strength of reinforced lintel block beams.

He echoed Professor Perry's comments on his disappointment that the results of research projects were not immediately finding their way into the industry and he expressed the hope that this would change.

CONCRETE RESEARCH AT THE QUEEN'S UNIVERSITY BELFAST.

Dr. D. J. Cleland, B.Sc, Ph.D., C.Eng., M.I.C.E., M.I.Struct.E.;
Prof. A. E. Long, B.Sc, Ph.D., D.Sc, C.Eng., F.I.E.I., F.I.C.E., F.I.Struct.E.

1. INTRODUCTION.

The Civil Engineering Department has well-equipped laboratories and computing facilities which allow a wide range of structurally related concrete projects to be undertaken. Nine members of staff are active in areas of research relevant to Structural Engineering and most have experience of concrete related research.

The main areas of research are as follows:

- (a) Model testing of structures,
- (b) Full scale testing,
- (c) Structural Analysis,
- (d) Durability of materials,
- (e) Concrete coatings and repair.

2. MODEL TESTING OF STRUCTURES.

The group has a long tradition of experimental research in concrete structures and has gained a reputation for expertise in experimental modelling of structures. The aim of most of this work is to devise more efficient design solutions.

One current area of research has been concerned with providing a better understanding of the stresses in flat slab structures in the vicinity of edge columns. With funding from EPSRC and collaboration with the University of Durham, reinforcement strains have been measured using sophisticated internally gauged reinforcing bars to establish the exact criterion for failure and from that a more reliable prediction of the failure capacity.

The same technique for measuring strain is being used to study the stresses in the anchorage zone of simply supported reinforced concrete members. Supported by EPSRC and industry, this research has particular relevance to the bridge assessment programme; specifically the aim is to determine how the shear capacity is influenced by the anchorage detail.

Another research project is investigating shear failure in reinforced concrete continuous beams. Much earlier research has concentrated on simply supported beams subjected to point loads whereas, in reality, most beams are continuous and subject to uniform loading. The aim

of the project is to determine if the current design approach, based on simply supported beams is appropriate.

3. FULL SCALE TESTING.

While model testing is efficient and the research at Queen's has placed emphasis on it being realistic, there is a need to determine if the models behave in the same way as real structures. This is illustrated by a research project which has just begun to investigate the in-plane effects in composite concrete/metal deck floor slabs. Laboratory model tests are being carried out in conjunction with full-scale tests on the Cardington Steel Frame. This EPSRC supported research will provide information on the degree of enhancement to the ultimate capacity relative to that normally assumed in routine design.

As far as research on bridges is concerned, initial tests were carried out in the early 1980's in collaboration with DoE (NI) Roads Service to determine the transverse load distribution characteristics of M Beam bridge decks. This subsequently led to a joint research project on the strength of the deck slabs which allowed the reinforcement to be reduced to less than a third.

More recently, along with Dundee University another grant has been received from DoE (NI) and EPSRC to monitor a multi-span masonry arch bridge over the River Lagan in Belfast. The opportunity arose because exceptionally large loads were crossing the bridge during construction, nearby, of a new glued segmental bridge.

4. STRUCTURAL ANALYSIS.

The above experimentally based research is complemented by extensive studies on computer methods of structural analysis.

A difficulty in applying computer solutions to plastic methods of structural analysis for multi-storey frames is that the result is sensitive to the choice of hinge position. However, a method has been developed to find automatically the most critical hinge positions.

Research is also underway to devise computer methods for the yield line analysis of slabs and plates. Again the solution is sensitive to the yield line pattern chosen, but this time non-linear optimisation is being employed to determine the critical solution. The EPSRC has provided funding for the development of both of these computer based projects.

Mesh generation and analysis of CAD stress models using the finite element method has also been sponsored by EPSRC. The end product of the research is a fully automatic hexahedral mesh generator and this has received considerable outside interest; currently FEGS, the Cambridge FE software company, is developing a commercial version. Dimensional reduction and detail suppression in stress analysis models is the subject of further research.

5. DURABILITY OF MATERIALS.

Over the past 20 years staff at Queen's have built up an international reputation for the development of insitu testing techniques; the 'Limpet' for strength testing and the 'Clam' for permeability testing. A further in-situ test to measure chloride diffusion in concrete is being developed.

Air and water permeability remain a central theme to the work at Queen's. High quality measurements can be made using the latest version of the equipment; the AutoCLAM. However, an important issue with permeability measurements is the manner and the extent to which they are affected by ambient conditions and moisture gradients in the concrete. This is being investigated, with support from EPSRC, and involves collaboration with researchers at Heriot-Watt University.

Another important durability area is acid attack on concrete. This is a particular problem where effluent from silage attacks the structures used to contain it; often leading to highly polluting leakage of effluent. EPSRC are sponsoring research to study the mechanism of attack and to investigate ways of reducing it. The Agricultural Research Institute for Northern Ireland and the School of Chemistry at Queen's are partners in this work

An important means of reducing the permeation characteristics of concrete is often considered to be effective curing. The various methods generally used to improve the curing are being studied; included within this is Controlled Permeability Formwork.

6. CONCRETE COATINGS AND REPAIRS.

An alternative method of improving durability is to apply a hydrophobic coating to the surface. Research at Queen's has sought to quantify the extent to which the characteristics of the concrete can be improved in relation to deterioration mechanisms such as chloride induced corrosion and freeze-thaw action.

Another part of the work is concerned with repairs to existing structures which have already deteriorated. Many special materials exist for making surface or patch repairs. An extensive study has been aimed at providing information about the optimum conditions for an effective repair.

CONCRETE RESEARCH AT TRINITY COLLEGE DUBLIN.

Dr. R. P. West, B.A., B.A.I., M.Sc., D.I.C., Ph.D., C.Eng., F.I.E.I., Grad I.Struct.E., M.I.C.T.

1. INTRODUCTION.

While the School of Engineering has had many achievements over its 150 year life, it is in the last ten years that the most significant strides have been made in the different facets of concrete technology. The appointment of five new academic staff members with an active interest in concrete has resulted in the development of a vigorous and specialised team of researchers. As Head of Department, Prof. Simon Perry spearheaded the program to fundraise for a new structural testing facility which has recently been fully equipped and fitted out.

The objective of this brief paper, which is being presented by the author on behalf of his colleagues, is to review the existing facilities and to highlight the main concrete research activities within the Department.

2. FACILITIES.

The new structural test hall is a unique facility which was purpose designed by the academic staff. It enables the staff to engage in research which comprises small and large scale concrete testing. Over its 250m² on each floor, it houses a large demonstration area and seminar rooms on the upper two floors, a 6m high test hall on the ground floor and a modern concrete laboratory in the basement.

As well as facilitating the customary testing procedures for fresh and hardened concrete, specialised equipment exists in the concrete laboratory for attrition testing of aggregates (using the Los Angeles machine), a rapid analysis machine for the determination of the cement content of fresh concrete, a two-point workability machine for assessing the rheological parameters of fresh concrete and temperature matched curing apparatus.

The test hall itself houses a wide range of heavy testing equipment including:-

- a 15m x 10m x 900mm deep heavily reinforced suspended concrete slab with holding down pockets at 1m centres;
- a 10 tonne overhead gantry crane running the length of the laboratory;
- a 6m x 6m void at ground floor level to allow the vertical movement of specimens between the basement and the ground floor using the gantry crane;
- two 7m wide x 5m high 300 tonne capacity internal-reaction testing frames;
- a 100 tonne capacity 6m high dynamic push-pull rig;
- a complete Amsler twin-hydraulic 10,000 psi system with 12 no. 90 tonne hydraulic jacks;

- a Losenhausen 300 tonne concrete testing machine;
- impact testing facilities over a drop height of 16m.

3. COMPLETED RESEARCH PROJECTS.

A short list of the principal research projects which have been completed in recent years is given in Table 1 and they are summarised very briefly here.

The response of concrete on a micro and macro scale to high velocity impact was the subject of a lengthy research program culminating in a comprehensive treatise on the effect of high strain rates in concrete (Dinic and Perry 1990, Perry and Bishoff 1990, Bishoff and Perry 1991).

A similarly thorough treatment of active and passive confinement of concrete and the subsequent ability of concrete to effectively develop plasticity with three dimensional compressive stress states was published (Perry and Cheong 1991, Cheong and Perry 1991, Cheong and Perry 1993).

Several research programs on the anchorage and bond characteristics of bamboo made a valuable contribution to progressing building construction in this area (Kankam, Ben-George and Perry 1988, Kankam and Perry 1989).

Many European countries are significantly more advanced than Ireland in the recyclability of their concrete buildings when they exceed their useful life. O'Mahony (O'Mahony and Mulheron 1990 and O'Mahony 1991) published her finding following many years of research into the use of recycled concrete as an aggregate in new structures, particularly in road sub-bases.

A comprehensive study into the physical and chemical properties of Irish pulverised fuel ash as produced at Moneypoint power station was conducted in the late eighties. Many hundreds of cubes were also made from dozens of different mixes to ascertain the quality of Irish pfa in comparison to its UK counterparts (Udekwe 1989).

Impact loading	Dynamic response to impact and high strain rates in concrete	Prof. S. Perry
Confinement	Development of three dimensional stress states in active and passive confinement	Prof. S. Perry
Bamboo reinforced concrete	Anchorage and bond in bamboo reinforced concrete	Prof. S. Perry
Recycled concrete	Recycled concrete aggregate	Dr.M.O'Mahony
Pulverised fuel ash	Chemical properties and concrete properties of Irish pfa concrete	Dr. T. Glynn

Table 1: Completed Research in Recent Years

4. CURRENTLY ACTIVE RESEARCH PROJECTS.

Due to the many projects currently under active research, this section will be subdivided into five separate categories, namely Fresh and Hardened Concrete, Concrete Design, Concrete In-Service and New Materials. While it will not be possible, nor indeed desirable, to describe each one in detail here, the main topics will be afforded a terse explanation. In each section the principal researchers are also identified in Tables 2 to 6.

4.1 Fresh Concrete.

A list of the main research topics in this area are given in Table 2.

The influence of thermal history on the early age strength development of concrete is being modelled non-linearly and remote sensing of temperature matched cubes can optimise the stripping of formwork and transfer of prestress times (O'Brien et al 1992, O'Donnell et al 1993).

The carefully controlled retempering of fresh concrete to replace evaporated water in cases of delayed placement has been shown not to be detrimental to the hardened concrete (West 1990). This has been confirmed by diagnosing the fresh concrete using the two-point workability test, an improved prototype of which was designed and built at TCD (O'Leary 1993, West 1994). The rheological parameters of any fresh concrete (including those with pfa, fibres, lightweight aggregates, etc.) can be ascertained with a high degree of confidence using a computer to log and statistically process the results.

The precise mechanism of plastic shrinkage cracking in exposed flat slabs is under study using a wind tunnel to mimic the actual recorded site conditions in Ireland.

Early thermal effects	Early thermal effects and temperature matched curing	Dr.E.O'Brien and Dr.R.West
Concrete rheology	The two-point workability test and diagnosing fresh concrete	Dr.R. West
Concrete retempering	Limited and non-damaging retempering	Dr.R. West
Plastic shrinkage	Plastic shrinkage cracking in flat slabs	Dr.R. West

Table 2: Current Research into Fresh Concrete

4.2 Hardened Concrete.

The main research topics are summarised in Table 3.

A technique for estimating the residual strength of concrete after fire damage using colour classification of the damaged sample is being developed (Kinsella 1995).

The dynamic response of steel-concrete composite sections has been the subject matter of a significant study over the last few years (Broderick and Elnashai 1994). The conclusions

reached were that partially encased composite columns offer significantly improved rotational ductility.

Several bamboo reinforced concrete tanks have been designed and built in the laboratory at TCD based on co-operative research with the University of Kumasi in Ghana. These were successful insofar as crack widths were minimised and sealed autogenously very soon after use (Gunna 1994).

Fire resistance	Change in colour vs determination of strength	Dr.T. Orr
Composite structures	Dynamic loading of composite structures	Dr.B. Broderick
Structural elements	Large scale testing of structural elements	Dr. B. Broderick and Dr.R. West
Bamboo reinforced concrete	Bamboo reinforced tanks for the third world	Dr.R. West

Table 3: Current Research into Hardened Concrete.

4.3 Concrete Design.

The principal areas of current research in concrete design are presented in Table 4.

A novel design using a concrete ring beam as part of a man-hole cover was tested by reacting against the heavily reinforced concrete floor in the test hall (Delaney 1995). During the test the man-hole cover failed, not the concrete beam !

Using grillage and three-dimensional finite element models of bridge decks, the prediction of shear stresses above bearing supports and the determination of the neutral axis of the edge cantilevers is complemented by experimental monitoring of real bridges (Keogh and O'Brien 1994).

Also on the topic of bridge design, a numerical model has been developed to allow the use of optimisation techniques to predict shrinkage and creep at early ages in prestressed concrete bridge decks. The model can be modified in response to on-site measurements which has proven successful in predicting long term deflections of Irish bridges (O'Brien and Flanagan 1993).

Of the different schemes used for the design of corbels in precast concrete construction, an optimisation procedure is being used in their design with a view to conducting full-scale tests in the laboratory.

Ground anchors	Ground anchors for concrete bridges	Dr.T. Orr
Man-hole covers	Novel concrete ring beam design of man-hole covers	Dr. B. Broderick
Bridge deck behaviour	Grillage and finite element analysis of bridge decks	Dr.E.O'Brien
Bridge deflections	Predicting deflections in prestressed bridge decks	Dr.E. O'Brien
Corbel design	Optimising corbel design in precast concrete	Dr.R. West

Table 4: Current Research into Concrete Design

The popular subject of expert systems has been successfully used to conduct preliminary design of concrete framed buildings (Harty and Ryan 1992, Harty and Danaher 1994).

The computer software uses knowledge-based systems to harmonise rules of thumb and codified rules in concept design, allowing three-dimensional visualisation of the resulting structure (Harty and Dillon 1991).

Finally, O'Brien and Dixon (1995) have recently published a comprehensive book on concrete design which utilises examples to the current version of EC2.

4.4 Concrete In-Service.

This series of research topics are all related to practical concrete problems which have arisen in the field. They are summarised in Table 5.

The stresses in segmental concrete culverts have been measured in-situ using vibrating wire gauges and the readings compared with predictions calculated using a soil-structure interaction model (Orr and O'Neill 1993).

The actual settlement of concrete piles in the new Cusack Stand at Croke Park have been monitored to better understand pile group behaviour and the interaction of the piles with the ground.

The collapse mechanism of a concrete bridge during the recent Los Angeles earthquake has been compared with numerical finite element dynamic models of the concrete structure (Broderick and Elnashai 1995). This showed that a simple design alteration unexpectedly changed the failure mode from flexure to shear.

A project to acquire truck axle weights by monitoring strain gauges placed on the soffit of calibrated bridges is part of an international scheme for Weigh-in Motion using bridges. Portable data logging equipment mounted on Irish concrete bridges has provided information regarding truck velocities, axle spacings and numbers and, of course, axle weights. This will

be especially useful for remotely monitoring trucks which may exceed the new EU limits on axle weights (O'Connor and O'Brien 1995, Dempsey and O'Brien 1995).

Tunnels	Stresses in segmental concrete culverts	Dr. T. Orr
Piles	Monitoring of settlement of concrete piles	Dr. T. Orr
Bridge failure	Numerical analysis of bridge failures under dynamic loading	Dr. B. Broderick
Weigh-in motion	Weigh-in motion on concrete bridges	Dr.E. O'Brien
Cathodic protection	Smart cathodic protection and computer modelling of same	Dr.E. O'Brien
Sulphates in pipes	Corrosion of pipes due to industrial sulphates	Mr. P. Johnston

Table 5: Current Research into Concrete In-Service

As a solution to the problem of just how much current should be supplied to a structure which is being cathodically protected, a smart feedback system has been developed which optimises the desired potentials. This keeps the entire structure within safe bands of applied current, thereby avoiding the problems of hydrogen embrittlement or reinforcement corrosion (O'Brien, Kelly and Foley 1996).

In the disposal of chemical waste into concrete pipes, strict limits are placed on the allowable concentrations of sulphates. This projects aims to investigate the mechanisms of deterioration and its rate, depending on sulphate ion concentrations which may allow a more rational approach to the control of industrial waste.

4.5 New Materials.

For a summary of these topics the reader is referred to Table 6.

A patent has been taken out in Sweden for a novel type of reinforcement which is composed of interlocking Wireballs, which are spheres of 80mm diameter spun out of thin wire. Six drooping rings are attached strategically to improve the overlap between the Wireballs. Preliminary tests at TCD (Levins 1994, West 1994) indicate good ductility post-failure in short columns with a high degree of confinement evident. Potential applications include uses in the mining industry where access is limited and any energy absorption requirement such as in impact, explosion or earthquake.

Wireballs	Novel spherical reinforcement for columns and energy absorption	Dr.R. West
Paper waste in concrete	Flexible and energy absorbing concrete using waste from paper recycling	Dr.R. West

Table 6: Current Research into New Concepts

The waste material from the paper recycling industry has been used in dry-lean concrete with promising results. The resulting concrete appears to have residual tensile strength, energy absorption characteristics and elastic recovery after failure (McDonnell 1995). This 'spongy' concrete is currently being investigated for long term durability .

5. SUMMARY AND CONCLUSIONS.

In this short summary of the concrete research activities of the Civil Engineering Department at Trinity it is difficult to do anything other than mention cursorily those topics which are under investigation. For further details the reader is referred to the abbreviated list of publications in the next section, although some topics which are in their embryonic state are, as yet, unpublished. In either event, the principal researchers as indicated will be happy to deal with any correspondence.

Finally, as in all research, both theoretical and practical, there is a desperate need for funding to conduct extensive and penetrative investigations and the author feels strongly that a greater participation from Irish industry could assist considerably in harnessing the research potential of young Irish researchers.

6. ACKNOWLEDGEMENT.

The author would like to thank all of his colleagues mentioned in the paper, to numerous to mention individually, for making the research information available.

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CONCRETE RESEARCH AT UNIVERSITY COLLEGE CORK.

Prof. D. M. F. Orr, M.A., M.A.I., Ph.D., Eur. Ing., C. Eng., F.I.E.L., M.I.C.E.

1. INTRODUCTION.

The Structural Engineering Laboratory at University College Cork has a total floor area of approximately 600m².

The laboratory is equipped with a number of testing machines, including a 300 tonne Amsler column testing machine, a 200 tonne compression testing machine, a 6.7 tonne universal testing machine and a recently acquired electronically controlled concrete testing machine suitable for testing concrete specimens and masonry blocks. The laboratory also has facilities for producing concrete and mortar.

Over the past decade research on concrete structures and materials has been carried out on the following topics:

- (a) externally bonded reinforcement,
- (b) limestone fines in concrete mixes,
- (c) masonry of solid concrete blocks,
- (d) prestressed concrete beams.

2. EXTERNALLY BONDED REINFORCEMENT.

Reinforced concrete beams and slabs may be strengthened by gluing steel plates onto the tension face of the concrete structural member. When this is done there are difficulties in predicting the contribution that the bonded plates make to the flexural strength of the reinforced concrete member because ripping or peeling off of the plate can occur before the full strength of the steel plate is developed. Even when the yield strength of the steel is achieved, the member may be lacking in ductility due to the sudden parting of the plate from the concrete. Also, a beam may not have the shear strength to carry the load which the increased flexural capacity would permit.

Tests carried out indicated that external shear reinforcement can be used to inhibit ripping failure, to increase shear strength and to enhance the ductility of tee-beams which are strengthened in flexure by external reinforcement bonded with epoxy resin adhesive. The tests also indicated that conventional reinforced concrete design procedures may be used to determine the external flexural and shear reinforcement required, provided that additional shear reinforcement is located near to the ends of the flexural plate^(1,2).

3. LIMESTONE FINES IN CONCRETE.

Crushed limestone fines tend to be rich in filler sized (less than $75\mu\text{m}$) particles, which raises the question as to whether this quarry by-product is suitable for use as a fine aggregate in concrete. The results of an investigation which included a 3^4 factorial experiment, indicated that crushed limestone fine aggregate produces concrete with enhanced strength up to an age of at least three months, which does not depend on the presence of filler sized particles, but only on the presence of limestone fines instead of natural sand. It was concluded that fine, but not necessarily very fine, particles of limestone act as crystallising nuclei and thereby accelerate the hydration of Portland cement and also promotes the formation of additional gel products. There is some evidence to indicate that the strength enhancement associated with limestone fines diminishes at greater ages^(3,4,5).

4. MASONRY OF SOLID CONCRETE BLOCKS.

Masonry is a traditional building material, the use of which goes back very many centuries; within Europe, Ireland has its own distinctive masonry practices. Unlike structural concrete which has kept pace with modern developments in design methodology and materials technology, the understanding of the structural behaviour of masonry is based on traditional practices and empirical relationships. In many European countries the principal form of masonry is of clay brick, and internationally there is a concentration of research and development for this type of masonry.

In Ireland, concrete blockwork is dominant in masonry construction, with some 200 million concrete blocks being used annually. The behaviour of this type of masonry has been relatively neglected internationally and in some of its characteristically Irish forms, little if any data on its fundamental structural behaviour exists. Within Europe, the design of masonry structures is based on empirical rules determined from experimental research carried out in various countries where masonry materials and construction practice are different from those used in Ireland. It is therefore desirable to have a technically sound basis for Irish masonry practice, so that this practice will be permitted under European rules. It is also advantageous to move forward from empirical rules to a more fundamental application of the principals of mechanics to the behaviour of masonry. Furthermore it is desirable that Irish masonry practice should be developed so as to increase productivity and improve quality assurance. In this connection work has been carried out on the strength variations in solid concrete masonry blocks^(6,7) and masonry of solid concrete blocks laid on face^(8,9,10,11).

When laying standard solid concrete blocks on face, masons tend to remove the centre portion of the bed in order to facilitate the levelling of the blocks, thus contact between block and mortar bed is not achieved over the full width of the joint. Using a shell bed joint, formed with the aid of a template to control the dimensions of edge strips of mortar, has been shown to be practical and the effect of shell bed construction on compressive strength of the masonry has been investigated experimentally.

Work is currently in progress on the tensile bond strength of bed joints in concrete block masonry and on the strength of laterally loaded concrete masonry panels.

5. PRESTRESSED CONCRETE BEAMS.

The existence of a linear relationship between the reciprocal of prestressing force and eccentricity was recognised by Magnel as being the basis for a useful aid for the design of prestressed concrete cross-sections. Magnel's original diagram for use in selecting prestressing force and tendon location, which was introduced in the 1940's, is applicable to homogeneous prestressed concrete beam design. The concept was extended to composite sections using the transformed area approach, and details were derived for applying the method to composite prestressed concrete T-sections, for a construction sequence in which the prestressing force is applied in two stages. The method may be applied to any construction sequence, including taking into account differential shrinkage stresses in composite sections. The transformed area approach allows any combination of materials to be dealt with in a composite section. With the aid of interactive computer graphics, the method can be used to develop quickly the design of a cross-section which meets design criteria expressed in numerical terms and which also meets with visual approval as to its suitability for concreting^(12,13,14).

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CONCRETE RESEARCH AT UNIVERSITY COLLEGE DUBLIN.

Mr. G. McConnell, B.A., B.A.I., M.Sc., C.Eng., M.I.EI.

1. INTRODUCTION.

Research work in concrete at University College Dublin over the last decade by Professor J.W. de Courcy, Mr. S. Mac Craith, Mr. G. McConnell and Dr. M. Richardson has focussed in three main areas:

- (a) Mechanical strength and stiffness of hardened concrete small scale structures and components.
- (b) Durability studies of hardened concrete. The main emphasis has been on understanding of the carbonation process and corrosion of reinforcement.
- (c) Studies of in-situ performance of existing structures.

The Test Facilities in the Laboratories in UCD comprise:

1. Strong floor at Belfield.
2. Large test rig with computer controlled 25 tonne servo-controlled Instron actuator.
3. 60 tonne servo-controlled Instron universal testing machine with automatic recording of response.
4. Avery Dennison Cube Crushing Machine.
5. Computer data logging and processing.
6. Oxygen diffusion meter.
7. Miscellaneous standard accessories.

The following sections give examples of the research work which has been completed in the period under review.

2. MECHANICAL STRENGTH AND STIFFNESS OF HARDENED CONCRETE SMALL SCALE STRUCTURES AND COMPONENTS.

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CONCRETE RESEARCH AT UNIVERSITY COLLEGE GALWAY.

Mr. E. Cannon, B.E., Dip. Ing., D.I.C., M.Sc., C.Eng., M.I.C.E., M.I.Struct.E.

1. AREAS OF RESEARCH.

Area of Research	Aspect
1. Bridge deck behaviour	Load sharing
2. Time-dependent effects in concrete	Creep, shrinkage
3. Non-linear analysis of structures	Non-linear $\sigma - \epsilon$ relationships; Interface slip.
4. Composite steel-concrete structures	Design to Eurocodes; Ultimate behaviour.
5. Computer applications in the design and analysis of structures	Fortran; AutoCAD; Spreadsheet; Structural analysis packages (ENCAD, QSE)
6. Computer-aided learning	Tutorials - for design of elements and complete structures to National and Eurocodes
7. Durability testing of concrete structures	Investigation of 60-year old reinforced concrete bridge.
8. Blast resistant design of structures	Petrochemical plant, Scotland
9. Masonry arch structures	Strength assessment

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O'Byrne, C., 1988, "The monitoring of creep effects in a prestressed concrete bridge of box-girder construction".

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Ó'Monacháin, C., 1994, "Modh maitriseach an righnas mar ghléas anailíse neamhlíni ar bhíomai comhchodacha de chruach agus de choincréit" (Application of the matrix stiffness method in the non-linear analysis of composite steel-concrete beams).

Murray, D., 1994, "Evaluation of time-dependent effects in concrete".

2.2 Final Year Projects (representative selection only):

- 1986 Computer based yield-line analysis of slabs under trapezoidal loading.
- 1987 Fire Base - a prototype knowledge system for the design of buildings to the draft fire regulations (1987 - *McGrane Computing prize*).
- 1988 Computer-aided design of retaining walls.
- 1990 Structural masonry to BS5628.
Computer aided design of beams, columns, slabs to BS8110.
- 1993 The testing of aggregates for concrete.
A study of concrete testing standards.
Comparison of EC2 with BS8110.
- 1994 Design of Sports Stadia.
- 1995 Application of spreadsheets (EXCEL) to the design of reinforced concrete building projects.
Grillage analysis of walls subject to hydrostatic loading.
Masonry arch bridges: a study of methods of assessment.

2.3 Publications: other.

Cannon E.

Non-linear analysis of a simply supported composite beam having shear connection only at the ends - with reference to Wostrack Traglastversuch SV2 Report, Fachgebiet Stahlbau, Universität Kaiserslautern, Germany, June 1991.

SATTLER 1: Ein allgemeines Berechnungsverfahren für Tragwerke mit elastischem Verbund - Programm 1.

Report, Fachgebiet Stahlbau, Universität Kaiserslautern, Germany, Dec. 1991.

Suirbhé ar Dhroichid i gCathair na Gaillimhe.

Report, Galway Corporation, 1990

Composite Construction: Design for Serviceability - I

ESDEP Lecture - European Steel Design Education Programme (SCI) 1994.

Composite Construction: Design for Serviceability - II

ESDEP Lecture - European Steel Design Education Programme (SCI) 1994.

Cannon, E., et al.,

Eurocode 4: Composite Structures in Steel and Concrete: Short Version.

Draft commissioned by TCII of the European Convention on Constructional

Fachgebiet Stahlbau, Universität Kaiserslautern, Germany, Nov. 1991.

Structural systems: - Buildings: Special single-storey structures.

ESDEP Lecture - European Steel Design Education Programme (SCI) 1994.

Steel construction - economic & commercial factors: the European Building Market

ESDEP Lecture - European Steel Design Education Programme (SCI) 1994.

Cannon, E., et al. (Editors)

WG10 Composite Construction.

WG14 Structural systems - Buildings

WG15A Structural systems - Offshore

WG15C Structural systems - Miscellaneous

WG5 Computer-aided design and manufacture

WG1A Steel construction - economic & commercial factors

ESDEP Lectures - European Steel Design Education Programme (SCI) 1994.

3. LECTURES PRESENTED

Cannon E.

Concrete mix design.

Concrete properties, specification and compliance.

Interpretation of concrete cube results.

IEI/Irish Concrete Society Course: Concrete - Materials, Specification, Production

Galway, Jan.-Feb. 1992.

Eurocodes 1, 2 and 3 - Basis of design for concrete and steel structures
IEI Seminar: The Structural Eurocodes: Concrete and Steel
Dublin, April, 1992

Structural Monitoring
Institute of Concrete Technology / Irish Concrete Society
Termonfeckin, April, 1993

Eurocodes 1, 2 and 3 - Basis of design for concrete and steel structures
IEI Seminar: The Structural Eurocodes: Concrete and Steel: Update
Dublin, Oct., 1993

ESDEP: A European Engineering Resource
UK launch of ESDEP, Queen's College, Cambridge, June 1994

Moisture movement - $\sim$ thc, phenomena of shrinkage and creep
IEI / Irish Concrete Society Course: Concrete Technology - Recent Developments
Dublin, Oct. 1994

4. CONCRETE LABORATORY EQUIPMENT.

4.1. Aggregates.

Sieve analysis equipment with associated sampling equipment. Apparatus for determination of bulk density, relative density, flakiness, aggregate impact value.

4.2. Mortar.

Vicat apparatus. Le Chatelier apparatus. Tensile testing cement briquette moulds.

4.3. Concrete.

Concrete mixers (pan and Winget types); scales.

Apparatus for Slump, Compacting Factor and Vibro-Consistometer tests.

Moulds - cube, cylinder and beam; cylinder specimen capping equipment.

Electromagnetic vibrating table.

Curing tanks (including accelerated curing).

Concrete cube testing machine; concrete prism testing machine.

PUNDIT ultrasonic concrete strength testing machine; concrete test hammer.

Demec gauges; Vibrating wire strain and temperature measuring meter; creep rigs.

Drying oven.

Prestressing jack.

4.4. Structures testing: general.

Denison, Instron testing machines; Dartec servo-hydraulic actuator.

Data logging equipment.

THE CHAIRMAN thanked the contributors from the research institution and invited further discussion.

PROFESSOR DAVID ORR acknowledged support received for research from certain companies but found that, in general, industry did not respond well to approaches regarding research. In relation to dissemination of information, he believed that the limiting of seminars to concrete research would not provide sufficient scope for conferences - other countries such as Australia had broadened the scope of their research meetings to embrace other materials.

DR. ROGER WEST noted the enthusiasm which existed within the research institutes and expressed the hope that practitioners would be open to co-operation on site with researchers in order that ideas may be developed.

MR. EAMONN CANNON made an observation based on his involvement in recent years in European programmes on structural steelwork educational aids. It brought into focus for him the reality of our future in Europe and this applied to concrete as much as to other materials. In dealing with the European dimension we are dealing with long-standing but differing European engineering cultures. The material in the Eurocodes is drawing on all of these cultures and not just from the British one which we frequently refer to. He spoke of the dangers of Irish engineers possibly becoming de-skilled: perhaps using Eurocodes but not fully understanding the aspects that have led to particular clauses. He saw the research area as one means of keeping engineers in touch with developments.

MR. BRENDAN LYNCH believed that the Irish Concrete Society would look at the issues raised in relation to dissemination to the industry of information on research in Ireland. The concept of bi-annual research meetings or use of the Society's Newsletter would be looked at.

PROFESSOR J. W. de COURCY noted the reference to work on the potential variability of strength of concrete blocks within a bale. He believed that the researchers involved would be interested to learn of variations in the Young's modulus of prestressed planks in a research project in the Cement and Concrete Association caused by a mini-climate which resulted from the method of stacking.

MR. NICHOLAS RYAN responded to the issues of European harmonisation. He noted particularly the need for more research into the effect of water/cement ratio and cement content on durability of Irish concretes. We had gone some way on this topic but further work would be valuable in the context of ENV206.

MR. TOM DUGGAN called for closer collaboration between industry and researchers so as to develop a better appreciation of aspects of concrete which could only be learned from full scale monitoring. He looked for a conduit through which researchers would be made aware of projects coming on site: perhaps there was a role for the Irish Concrete Society in this?

THE CHAIRMAN closed the discussion by noting that it was clear that there were talented individuals and sophisticated equipment available in the research institutes. Industry needed to be more aware of this. He also felt that the clients needed to be more involved and he included government as a client.

SESSION H

GENERAL REPORTS

Sessional Chairman

A. DOWLEY, B.E., M.S.

University College Dublin.

The following members of the Symposium gave personal viewpoints reports on the sessions:

- Session A: **J. Harrington, B.E., C.Eng., M.IEI, F.I.Struct.E.**
Session B: **M. Prendergast, Dip.Eng., B.Sc.(Eng.), M.Sc.Eng., M.IEI, M.I.Struct.E., M.I.Weld.**
Session C: **A. Gibney, B.E., M.Sc., M.IEI.**
Session D: **J. Gwynn, B.A., B.A.I., Eur.Eng., C.Eng., F.IEI, F.I.Struct.E.**
Session E: **B. Smith, Afl.IEI, M.I.C.T.**
Session F: **B. Mulligan, B.E., Eur.Eng., C.Eng., F.IEI, M.I.Struct.E.**
Session G: **E. Moore, F.T.C.**

MR. HARRINGTON said that Mr. Torpey's paper gave us a background, dealt with the legislation and the development of the European standard system through C.E.N. It dealt with the input of Ireland in relation to standards and regulations and also the impact of these developments on Ireland. The paper serves as a reference to the documentation that we will have to be aware of, become familiar with and live with. Mr. Torpey had indicated the significance of I.S.326 in that it had been necessary to break with U.K. practice in some respects. He also stated that concrete had no equal and undoubtedly in doing that he must have been taking into account his affiliations.

Mr. Bannon, the lead speaker, indicated that there was a possibility of European codes in both harmonised and unharmonised streams but that this should not be accepted. He advised us to be vigilant in relation to the final documentation that has to be implemented. We had heard comments that the use of EC2 at this stage is not widespread in Ireland. It was suggested that this may be due to the cost of the documents. Mr. Harrington commented that he believed that the code was not being used due to the cost of the implementation.

The precision of standards was addressed. Compliance and interchangeability was not a factor that was necessarily acceptability.

A new loading code, EC1 was in the process of preparation. Mr. Harrington referred to a building he had designed some time ago. The structure included a roof, the loading on which was 70% attributable to wind load. The introduction of the new code in 1972 put this structure outside code limits. He expressed the hope that under EC1 the structure would come back into code limits.

Queries had been raised in relation to glass and other fibres, and to additives. The issue of redundancy of test equipment by the new standards had also been raised. Mr. Harrington believed that it would be possible to phase in these changes in a manner which would be commercially viable as test houses updated their equipment.

He expressed the hope that commentaries on EC2 and EC4 would be provided to complete the picture regarding the topics in Mr. Torpey's paper. He welcomed the statement that "what there is to know is being provided and those who need to know can be informed". Information is the key to what we have before us and what we have to do. We need to be informed on matters such as our new raw materials for concrete. He recalled the difficulties he had thirty years ago getting definitive information on the chemistry of the hydration of cement as he prepared notes for undergraduate students and that was a time when, to quote Professor de Courcy "cement was simple"! Nowadays cement was not so simple and many other ingredients besides water could find their way into the mix. This highlights the need for ongoing research. The possibilities of using recycled concrete and other waste materials in new concretes demand that we be certain that we will not be revisited by some of the problems which we had with durability of concrete in the past.

In the past he had taken a very conservative line on additives. He no longer found it necessary to be cautious on that topic but he did have to be cautious on the use of any material which influenced the composition of concrete. There had been a tremendous advance in concrete in the recent past and no doubt this will continue but we must be vigilant. We must be aware of what is happening in other European countries but be alert to the possibility of European legislation heading us in a direction we do not want to go.

Mr. Harrington drew attention to the last paragraph of the paper and assured Mr. Torpey that the requirements that he asked for are around: the input from industry is available, the evidence is there that it has been offered before and it will be there to assist in the time ahead.

MR. PRENDERGAST said that the Session B paper covered all aspects of the cement industry over the last ten years. Changes had occurred both in the product and in the cement itself. Changes in the industry included the introduction of a robotically-controlled laboratory at the Limerick plant. Undoubtedly this showed the way ahead and the next ten years would see this technology reaching the testing regimes of the concrete manufacture also. Changes in the product were prompted by comments from industry.

The main end use of cement over the last ten years was shown to be in the agricultural and housing sectors which currently account for 66% of production. The more visual end use of public spending accounts for 12% but questions were raised about the prominence of this sector in the future. The importance of the housing and agricultural sectors were therefore apparent.

In relation to secondary cementitious materials, it was recognised that these would be important aspects of future practice in Ireland. Research was required into their use in an Irish context.

He noted that durability had been a major topic of the two day Symposium and that it had received attention in Mr. Lynch's paper also.

The topic of the maximum strengths that were achievable was raised. In Ireland maximum strengths of concrete were not as much of an issue as elsewhere. High performance concrete was not as much an issue in Ireland at present: our high strength concretes would be in the 50-60 N/mm² range. The issue of deformability of concrete had also been raised.

It had been noted that in relation to the end use of cement the consumption of cement had gone up yet the volumes have not changed that much. This was generally due to the durability aspects that had to be taken into account.

In concluding, he said that the paper should provide food for thought on what would happen in the next ten years.

MS. GIBNEY said that the paper in Session C had begun by describing pavement construction work at Dublin Airport in 1945. Today's construction methods were essentially a refinement of the older methods. Changes have, however, taken place in the pavement make-up. These have largely been as a result of heavier aircraft loading. The current Aer Rianta specification for Dublin - 370mm of C40 concrete on 200mm capping layer to Clause 804 - are based on pavement classification number and the ground conditions. The paper also indicated the differing specification for Cork and Shannon which experience a different traffic mix and also different ground conditions.

The methods of pavement construction were also reviewed. Mechanisation has increased. Fixed-form paving and slip-form paving were described as were the components of a paving train. The fixed-form paving method was currently preferred by Aer Rianta due to difficulties associated with the insertion of dowel bars in longitudinal joints when slip-forming. In addition the slip-form paver required 40-60 m³/hour of concrete and this requirement implied site batching. Plant costs were also higher. The benefits of slip-form paving included considerable time savings, however the volume of work in this country at present probably does not justify the method. This would change if more concrete roads were built but one opinion expressed at the Symposium was that this would not occur unless a significant difference in cost occurred between bitumen and concrete. Fixed-form paving and off-site batching were likely to continue to be the norm.

The aspects of mix parameters and jointing were dealt with in detail. It was observed that unreinforced joints are generally used in the United States of America but that problems had been encountered in the United Kingdom with this approach. Mr. Phukan believed that U.K. practice would revert to the details which included reinforcement. Ms. Gibney commented that more research into the topic of aggregate interlock would be worthwhile before unreinforced joints were dismissed: the cost saving could be considerable. She noted that while the paper had referred primarily to airport pavements much of what was covered could find applicability in the area of concrete roads.

MR. GWYNN said that in his opening remarks to Session C the author referred to reports on the causes of deterioration of reinforced concrete structures, and to the Euro-International design guide for durability, but said the paper would be confined to the repair of existing structures.

He observed that reinforcement corrosion due to carbonation or chloride contamination is the principal cause of deterioration, and noted that structures were now showing defects at relatively early stages in their design life. He attributed this partly to the introduction of modern processes of cement production which gave increased concrete strengths, encouraging reduction in cement content, and to construction defects, some of which he illustrated with slides.

He said that to carry out repair successfully, the source of the corrosion must be identified and the causative condition removed. He recalled the introduction of resin repair materials by specialists, and the review by the U.K. Concrete Society in 1984 which established concrete repair as a regular sector of the construction industry. He described how cementitious materials have replaced resins because they are more in sympathy with the concrete substrate, have good protective qualities and they can be applied thickly and easily. The materials can also be certified independently.

He mentioned the use of a thin polymer-rich fairing coat, which provides a base for the final protective coat. He also referred to the use of flowing concrete, a super-plasticised micro-concrete poured into watertight formwork, which is used where large repairs are necessary. Another material suitable for large repairs is polymer modified gunite, which is particularly advantageous for soffits. A number of slides illustrating these the use of these repair materials were shown.

He dealt briefly with cathodic protection, and referred to the only example in use in Dublin. He mentioned that other electrochemical protection systems are being developed which are intended to restore alkalinity adjacent to the reinforcement.

He referred to the development of moisture-tolerant resins with good bonding properties, which, while not suitable for bulk repair, have applications for underwater repair, crack injection and bonding of reinforcing plates to concrete surfaces.

He also described the development of protective coatings which are capable of resisting ingress of water while allowing vapour to pass. Ideally, passage of carbon dioxide should also be prevented, but completely impermeable coatings are unsuitable for protecting concrete. He characterised coatings as penetrants, which include silane and siloxane, sealants, which include acrylics, and are intermediate between penetrants and coatings, and coatings, which are surface films of appreciable thickness. A coating is now in use which has crack-bridging qualities.

He concluded his paper with a brief discussion on the philosophy of maintenance and repair, particularly in relation to the economic consequences of the scheme adopted.

He completed his presentation with a number of slides, some of structures dating from 1910, others recently constructed, which illustrated good construction. Although some of the older structures required remedial work, they constituted part of our concrete heritage.

The lead speaker in the discussion referred to the electrolytic cause of reinforcement corrosion. He mentioned that repair materials have improved over the last 10 years, referring particularly to flowing concrete. He said that silane can be used to keep a structure dry, but that water penetration elsewhere must be prevented, or else the silane application is ineffective. He mentioned that silane is sometimes used on new structures.

He said that cathodic protection is best, but there are problems in ensuring that the cathodic current passes throughout the structure, and referred to failures of cathodic protection systems in the U.K. He commented that desalination and other systems to restore alkalinity are still laboratory studies. Reference was made in the discussion to cathodic protection systems installed in reinforced concrete North Sea platforms, in which methods were adopted to ensure connection between reinforcement and prestressing cable ducts, and the question was raised about possible problems if there was failure to ensure that all reinforcement was connected to the protection system. In reply the lead speaker said cathodic protection should not be applied to post-tensioned cables to avoid possible embrittlement, but that incomplete connection of the reinforcement could give rise to problems. Mention was made of research work in T.C.D. on "smart structures", in which only sufficient current is used to prevent corrosion.

The matters of use of stainless steel; the stressing of repairs; matching of repairs to existing concrete appearance; and the repair of bridge soffits were also discussed.

The chairman closed the session with a brief review of the bridges referred to by the author, and presented a heritage list of concrete bridges.

MR. SMITH summarised the paper presented in Session E. He said that the paper had reviewed the current position in relation to specification for durability in Irish concrete practice. Particulars of changes that had occurred over the last ten years were presented and these included the emerging topic of alkali-silica reaction.

Current understanding of durability phenomena were discussed and this led on to the topic of mathematical modelling of these phenomena. The possibility of a move to performance-based specifications in the durability area over the next ten years was raised and the author had questioned the wisdom of continuing with our current prescriptive approach. These matters had been taken up in the discussion.

The importance of site supervision was mentioned as a significant factor in the production of durable concrete.

MR. MULLIGAN noted that, as an undergraduate, he had been told that one of the advantages of concrete was its formability to almost any shape. He had been reminded of this quality during the presentation of the Session F paper. The quality control achievable in precast factories allowed the mouldability of concrete to be exploited to its limits.

The author of the paper had spoken about the image problem suffered by the precast industry in the past. Perhaps this had occurred because sometimes people had failed to appreciate that quality comes at a price - in finance and in effort. Pre-tender collaboration between the specifier and precaster was essential. Early visits by the specifier/designer to view trial panels or the first panels cast were to be encouraged so that standards could be agreed.

The degree of specialisation in the industry today had been outlined in the paper. These ranged from high volume, high repetition off-the-shelf products to tailor made high quality elements particular to one project. The disciplines required were different. If one were intending to specify precast the reasons for doing so must be very clear.

The formation of the Irish Precast Concrete Association was to be welcomed. Standards in the industry can vary widely and if the I.P.C.A. could address this successfully it would allow specifiers to have increased confidence in precast concrete generally.

He was pleased to see that drainage now received careful consideration at an early stage. This had been the main problem as precast panels tried to grow old gracefully.

Tight tolerances in precast work were very unforgiving of poor workmanship. This could lead to durability problems. He wondered if the approach used for structural steelwork structures of 'life to first maintenance' might run in parallel for concrete with the design life concept.

In concluding, Mr. Mulligan called for close collaboration between all of those involved in precast concrete works - designers, specifiers, precasters and main contractors.

MR. MOORE said that Professor Perry's paper had identified the need for more commercial research, possible future research topics and the key aspects of funding and dissemination of research. In relation to attracting funds for research in concrete we needed to overcome the lack of a glamour image to concrete which made it unattractive to potential funders - including those in the political arena. Perhaps we could do something about that. The professions might make better arguments for funding. The possibility of a construction levy had been raised. The dissemination of research findings was most important and suggestions had been made regarding a bi-annual forum or publication update.

Mr. Moore said that he found the paper to be thought-provoking and envy-making! It was thought-provoking in how succinctly the arguments had been put forward. It was envy-making in that Professor Perry now had excellent facilities in place at his College.

The lead speaker had outlined the role of the universities and the key aspect of research. The current position regarding test equipment, behaviour analysis, and information technology were covered. The question must always be asked: are we getting the best out of our concrete?

The listing of current research in the third level institutions was reviewed.

The need for research institutions to approach industry for funding was mentioned in the course of discussion but one speaker had noted that his experience had not been as successful in this regard as it might have been.

The search for knowledge through research to assist us in the design and construction in concrete can occur at different levels. Mr. Moore put forward a personal view that research into matters concerning workmanship and the methods and techniques of concreting would be of as much benefit as the high level of research on the design side.

He looked forward to the newer third level institutes taking their place in the research life of the country.

MR. DOWLEY closed the Symposium by expressing his thanks to Professor de Courcy for initiating the series in 1965 and to Mr. Seoirse Mac Craith for organising the 1995 Symposium.

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