CONCRETE PRACTICE

IN IRELAND

2015

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in June 2015

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Concrete Practice in Ireland 2015

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CONTENTS

FOREWORD

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Chairman, Irish Concrete Society

The Proceedings recorded in this volume relate to the *Concrete Practice in Ireland 2015* symposium, organised by the Irish Concrete Society. It took place at University College Dublin on the 18th June 2015, attracting almost 150 participants and spanning a wide range of interests in the subject of Concrete Practice.

The publication of this volume provides a state-of-the art review of Concrete Practice in Ireland in 2015. It may be placed with previous volumes from past Concrete Practice in Ireland symposia to give a record of the developments in materials, regulations, construction, production, design and research over the past fifty years. The existence of those past proceedings is due to the foresightedness of the late Professor J. (Seán) W. de Courcy and University College Dublin. It was they who initiated the symposia series in 1965, thus establishing an important benchmark for the industry. The Irish Concrete Society now willingly takes up the baton to continue the symposia for this and future generations.

Following the opening address, seven papers were presented and discussed. The subject matter included materials, production, design, construction and research. The collected views gathered and recorded in the symposium's proceedings will help to guide progress in the field of Concrete Practice over the next decade.

The Irish Concrete Society is indebted to all those who contributed to the success of the symposium, in particular to the organising and scientific committees, the authors of papers, the sponsors and all those who participated.

December 2015

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OPENING ADDRESS

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Deputy Vice-President for Global Engagement,
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Opening the proceedings, Mark Richardson spoke of the context of the symposium, the legacy of 'Concrete Practice in Ireland' (CPI), and the 'giants' of concrete practice who laid the foundations of the CPI series. He then reviewed the topics discussed at the first CPI symposium to seek issues which might still have relevance to concrete practice today, despite the elapse of 50 years.

1. CONTEXT

The origins of the CPI 2015 symposium lie in a series of decennial conferences that were held from 1965 to 1995 at University College Dublin. The key figure in the concept of taking a snapshot of current practice and recent developments, documented at ten-year intervals, was Prof. J.W. de Courcy. He was fortunate in having an able lieutenant in Seoirse Mac Craith, who joined UCD in the 1970's from Ove Arup and Partners and who soon became a member of the 'CPI team'. A decade later another 'Arupian' joined the CPI squad when I manned the sound recording desk at CPI 1985, in a period when I was lecturing part-time at UCD, while throwing a bit of science at the phenomenon of carbonation of concrete. It was an inspirational time to be a researcher at UCD, for we were also fortunate to have Tom Duggan as an occasional lecturer to our degree level students. The three 'greats', de Courcy, Mac Craith and Duggan were photographed together during a visit to the University by the eminent civil engineer Prof. Ben Gerwick (Figure 1). These were my great teachers. My current work takes me to China occasionally, allowing me to learn more of the concept of *dashi* ('master'). How fortunate I was to have Prof. 'Sean' de Courcy in the role of *dashi*.

Professor de Courcy died in 2004 and the decennial CPI series was paused in favour of a tribute symposium to his memory in 2006. The speakers at that event each held a special place in Sean's life and times. The speakers, their topics and affiliation, presented in Table 1, give some sense of his interests. An obituary in The Irish Times on July 3rd 2004 noted his wide interests and that "it was appropriate that John de Courcy should have died in the month in which the 100th anniversary of Bloomsday was celebrated." The tribute symposium to Professor de Courcy's memory was fittingly held at a time when Prof. J. Owen Lewis was Dean of the UCD Faculty of Engineering and Architecture. Owen, a past Chairman of the Irish Concrete Society, was a member of the UCD School of Architecture, where Sean presented many of his most memorable lectures on the theory and design of structures. The 2015 CPI symposium marks another milestone, with the CPI torch being passed from UCD to the Irish Concrete Society.

Figure 1 Prof. J.W. de Courcy, Prof. Thomas Murphy (UCD President, 1972-1985), Prof. Ben Gerwick Jnr, Mrs. Martelle Beverly Gerwick, Tom Duggan, Prof. Patrick Leahy (UCD Dean of Engineering and Architecture, 1974-1979), Seoirse Mac Craith.

2. THE 'GIANTS'

Sean de Courcy

Prof. J. W. de Courcy was born in Sligo in 1918. He studied under the Jesuits in Co. Limerick before entering UCD in 1934. He graduated with First Class Honours at the remarkable age of just 19 years! Following graduation he commenced his engineering career in Patrick J. Sheahan's office in Limerick. His starting wage was £1 per week. Following a period with Limerick County Council he moved to the United Kingdom in 1945. This fateful move involved joining the British Reinforced Concrete Engineering Company (BRC). When told that the best they could offer was £6 per week, Sean quietly smiled to himself and roguishly indicated 'sure it will have to do'! Of course it was not long before Sean's talents were harnessed by BRC to set up an Irish operation. He set up the office in 1950 at 52 Fitzwilliam Square, Dublin 2 - then and now a fashionable address, where a consultant might quote for services in guineas rather than pounds. His Irish BRC office proved to be a major hub for structural engineering in the 1950's, where many of Ireland's top engineering graduates worked with the master. His interest and scholarship in reinforced concrete structures was was now firmly established and was marked by the milestone of conferment of a Master of Engineering (M.E.) degree at UCD in 1959.

The next decade was a period of change for Ireland, for BRC and for Sean. BRC had a system engineering approach. This became less popular in Ireland during the 1960's as business shifted to in-house designs by structural consultancies. Sean turned his eye towards academia and UCD was fortunate when he came onto staff in 1964. His hallmark foresightedness was evident just a year later when he presented a paper on durability to CPI1965.

Table 1 Programme of the Concrete Practice in Ireland tribute evening, 2006

CONCRETE PRACTICE IN IRELAND:		
A TRIBUTE TO THE MEMORY OF PROFESSOR J. W. de COURCY		
Thursday 23rd February 2006 7.00 p.m.		
Theatre G.32, UCD, Earlsfort Terrace, Dublin 2		
Reflections		
The life of Sean de Courcy	*Seoirse Mac Craith*	*UCD*
Inspired by the material, inspired by the man	*Colm Bannon*	*Irish Cement Limited*
Structure, space and architecture	*Yvonne Farrell*	*Grafton Architects*
Concrete in Ireland – stretching the boundaries	*Joe O'Donovan*	*Roughan & O'Donovan*
Concrete sculpture	*Jean Greene*	*Sculptor*
In conversation with Sean	*Eamonn Cannon*	*NUIG*
The archive	*Catherine de Courcy*	

"Durability is a slow burner!" he remarked, when I commenced my research on durability 20 years later. That first research meeting was in his UCD Merrion Street office where another burner was ever-present. A kettle sat over a Bunsen burner allowing Sean to offer visitors a chance to share his partiality to black coffee. It was a single item beverage menu. Henry Ford would have been proud.

Sean's lectures to undergraduates, national and international conferences were a delight. His earliest memory in UCD was of being allocated a Structural Theory and Design lecture to a combined class of architecture and engineering undergraduates. In the event of any questions, he was advised by a senior colleague to tailor his answers to the discipline of the student.

"How will I know if the questioner is an architecture or engineering student?" Sean enquired.

"For heaven's sake man, just look at the student's tie!" came the somewhat dismissive answer.

Fashion styles certainly changed over the subsequent two decade but Sean's consistently excellent lecturing craft ensured that he became the most respected engineering lecturer to the architecture students during his 24 years on staff. In a rare honour for an engineer, his dedication to architecture education led to his election as an honorary member of the Royal Institute of the Architects of Ireland in 1988. Sean's work with students is further recognised and commemorated annually through 'de Courcy student awards' in both the UCD School of Architecture and the Irish Concrete Society.

Sean ensured that the quality product formed through the CPI1965 symposium was carried forward through CPI1975 and CPI1985 with the same high standard. It was with some pride that he invited a government minister to chair a session in 1985. Minister for Labour, Ruairi Quinn, was a former student of Sean de Courcy.

It is fitting to record at this symposium, where the torch passes from UCD to the Society, that both Sean and Tom Duggan were founders of the Irish Prestressed Concrete Association in 1960, which later became the Irish Concrete Society.

Seoirse Mac Craith

The CPI series was safely carried forward when Seoirse Mac Craith undertook organisation of the CPI1995 symposium. Seoirse's debut in CPI, following a tradition, was a paper on concrete durability, presented to CPI1975.

Seoirse was a painstaking researcher, famed for his attention to detail. He left no stone unturned, no avenue unexplored, when chasing down the veracity of a little known fact unearthed during his researches. He delighted in uncovering previously unknown connections between people, events, buildings and structures, which had a particular curious impact on concrete practice in Ireland. As with Sean de Courcy, his cultural interests were wide, which allowed him bring fresh and interesting perspectives when lecturing on traditional civil engineering topics. His project students once constructed a concrete harp! His interest in concrete was total and his studies ranged from the creation of hitherto undocumented historical records to experimentation with novel materials. Elegant concrete specimens made with natural coral aggregate (the source of which he always kept secret!) had pride of place beside piles of carefully catalogued photographs of Irish concrete structures.

He worked quietly and determinately to ensure the success of the many and varied undertakings that he graciously oversaw in respect of engineering education and research. I felt that this was somewhat at odds with the characteristics of a 'crank', yet he admired cranks. The conundrum was explained when he revealed his viewpoint: "A crank is a small lever that causes revolutions!" His impact on concrete practice in Ireland was indeed revolutionary.

Seoirse's role was pivotal in growing the intellectual capital, in a step change, of the Irish concrete industry. He oversaw, as Course Director, a series of pioneering advanced concrete technology courses in the 1990's through collaborations between the Institute of Concrete Technology, Irish Concrete Society, UCD and FÁS. This involved the planning, organisation and execution of 180 contact hours per programme. The scale of the undertaking may be gauged when one considers that any one expert contributor to the advanced level programme lectured for typically 2 hours on their specialist topic. He sourced experts across the concrete industry and academic institutions in Ireland and the United Kingdom. Over the course of the various programmes he must have persuaded over 100 people to share their expertise. An amazing logistical feat in the days before e-mail! These courses led to the swift ramping up of a cohort of highly qualified concrete technologists in Ireland who later collaborated on standards development and innovation in an-increasingly technically complex industry.

Tom Duggan

Each CPI symposium was graced by the presence of the tall man, Tom Duggan. In many ways he was 'the consultant's consultant' when it came to issues with concrete practice in Ireland – before and after the concrete was poured. The breath of his knowledge on concrete was unrivalled in Ireland and his opinions on concrete practice were always delivered clearly, succinctly and with forceful persuasion. His forcefulness on issues of concrete practice that he cared greatly about matched his sense of conviction when advancing his views on the merits, or otherwise, of Irish rugby's adventures on the international field of play. This deep knowledge of concrete practice, combined with his innate wisdom and articulate expression, ensured that Tom's contribution to public lectures or discussions, such as at the CPI series, stayed in one's memory long after the event.

Perhaps it was the simplicity of his messages that made them so powerful. He chastised those whose first reaction was to order the coring of slabs for core strength testing when the cube results were a few notches low: "Never ask for a test to be done until you know what you will do with the answer!" he memorably commented.

Tom's association with the UCD CPI series was very natural. Not only was it unthinkable that such a national gathering on concrete practice would be complete without him, but he also had a long association with UCD as an occasional lecturer. A generation of UCD civil engineering graduates were fortunate to have Tom's printed notes on concrete practice on their bokshelves when they got their first job. The notes – prepared on the first generation of word processors – were carefully updated each year to reflect changes in standards and the introduction of notable innovations which met his approval, such as controlled permeability formwork.

3. LESSONS FROM THE PAST: CPI 1965

Plus ça change, plus c'est la même chose

The primary purpose of the decennial CPI symposia is to provide the industry with an opportunity to take a short period away from busy professional lives and to reflect as a group on the longer term trends emerging in the industry, the lessons from the past and the areas of key focus in which we can beneficially innovate together. It is interesting to reflect on selected topics raised at the first symposium which may have relevance 50 years on. A collage of topics and opinions is presented in Figure 2.

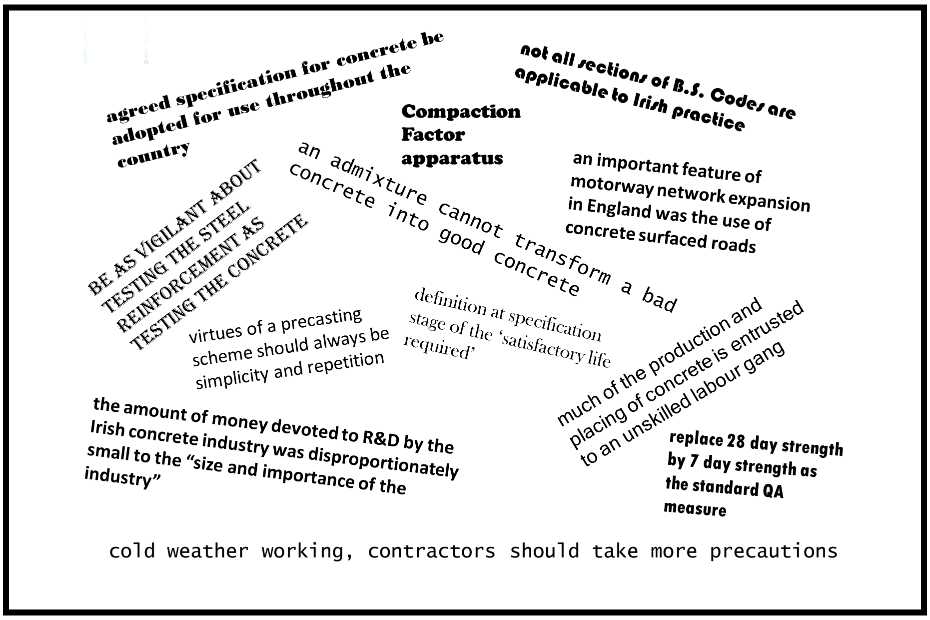

Figure 2 Collage of enduring topics and opinions presented at CPI 1965.

It is clear from a closer review of the topics in Figure 2 that the industry has certain recurrent issues. It is hoped that by highlighting the lack of progress on some of these issues over the intervening 50 years that the participants at CPI2015 will commit to recording a satisfactory resolution by CPI2025. Uppermost is the issue of training and certification of operatives who test, place and cure concrete on site. Other proposals and issues, presented in this section, are worth reflecting on.

A proposal was advanced at CPI1965 that an agreed specification for concrete be adopted for use throughout the country. It is disturbing that even in 2015 many concrete producers must waste staff resources addressing specifications that refer to long-since withdrawn standards and, too often, ambiguous specifications.

Notes of caution were advanced in respect of standards documents. For example it was observed that not all sections of British Standard codes were applicable in Ireland. Equally designers at CPI1965 were cautioned about the use of the L/d ratios in common use, which could lead to excessive deflections. It is interesting to note that before the next symposium (CPI1975) the new design code, CP110, was pushing slab depths up by about 25 to 50mm because of serviceability concerns. Working from first principles was recommended where appropriate. In some ways this viewpoint has found its way into the presentation style of the Eurocodes, decades later. One must wonder, however, if practitioners in 2015 are sufficiently embracing first principles when using the Eurocodes or are instead trying to template them into in-house design manuals.

Novel materials will always have a battle gaining acceptance in our industry. In 1965 the hot topic in this regard was additives and admixtures. Those attending CPI1965 were advised of "......the dangers associated with the promiscuous use of additives!" by one speaker and that "......inclusion of an additive at preliminary specification stage was an unwarranted admission of defeat, even before work began on site!" by another. Technological developments in the intervening decades has shifted opinion to a point where concrete without an admixture is the exception rather than the rule in 2015. However we can still agree with another statement from 50 years ago: "...an additive cannot transform a bad concrete into good concrete."

An increase in the amount of research on concrete and constituent materials in Irish universities and other institutions was encouraged but funding levels were heavily criticised. For example, several speakers called for research on Irish constituent materials with admixtures, because performance in practice with Irish cements was different to published performance of the same admixture in concrete made with English cements. Significant differences in aggregate properties were determined when testing Irish aggregates in comparison with values for concrete aggregates published in the British Standard codes. This required research to furnish the industry in Ireland with relevant alternative data. However several speakers at CPI1965 were heavily critical of the amount of money devoted to R&D by the Irish concrete industry. They noted that this was disproportionately small to the "size and importance of the industry." It was reported that total national investment in building research was 0.1% of the industry's annual output. Corresponding figures in Britain and continental Europe were up to 20 times higher, ranging from 0.5% to 2%. The opinion, from CPI1965, that the quality of applied research for the concrete industry would be as good as the industry allowed it to be, through its level of support, has interesting resonance with Prof. Roger West's paper to CPI2015, 50 years later.

The National Development Plan (2000-2006) was a period of commendable coherent investment in Ireland's national infrastructure. A significant part of this was the transformation of the national primary roads into an excellent network with many significant stretches of motorway. Alas the fine work done by the Irish Concrete Society in making an earlier case for concrete roads was not successful. Life cycle costing did not win out against first cost for pavements. It is doubly regrettable that the voices from CPI1965 were not heeded. At that time a speaker noted that an important feature of motorway network expansion in England was the use of concrete surfaced roads. Given its competitive first cost and greatly reduced maintenance costs, he hoped that Ireland would adopt this approach as traffic densities increased. An opportunity missed to date but perhaps a more enlightened view might be reportable at CPI2025?

We still do a lot of 28 day cube testing of concrete strength today as a quality control measure. Is that effort disproportionate in relative terms to the resources we invest in quality control of steel? That topic arose 50 years ago also – it was argued that engineers and architects should be as vigilant about testing the steel reinforcement as they are about testing the concrete.

The 28 day cube testing of concrete strength raised its head in another context also: it was recommended that a process be commenced to replace 28 day strength by 7 day strength as the standard QA measure. Today we must again question whether or not 28 days is the appropriate benchmark for concrete. The jury is still out on the topic of optimal age – or ages – for testing.

There was interesting discussion and information on mix designs. 'Nominal mixes' (volumetric) were noted as being in their dying days at CPI1965. 'Designed mixes' were becoming popular, based on 'specified works strength' plus 2 standard deviations. These were only used if the minimum cement content exceeded 400 lbs/cu yd (237 kg/m^3) and the maximum was less than 900 lbs/cu yd (535 kg/m^3). Today we have many more approaches, some still in their infancy: designed, prescribed, standardised prescribed, equivalent performance, performance-based, proprietary. However our demands are also much higher: in 1965 it was apparent from the discussions that manufacturers regarded 'normal strength' concrete as averaging 3,500 psi (24 N/mm^2) and 'high strength' concrete as averaging 5,000 psi (35 N/mm^2) at 28 days. Interestingly, details of mix designs for concrete used in the Kish Bank Lighthouse revealed the use of different mixes for different exposure conditions. A harbinger of today's EN206 exposure class approach to mix composition constraints for durability, perhaps?

A curious factor noted in the CPI1965 proceedings was the use of the Compaction Factor apparatus in one project to measure consistency. One might ask why it has not gained a place as a routine test method in the intervening period. Will it – like cement itself – have its most glorious days centuries after its first introduction to construction on our planet.

Our use of technology today – notably information technology – is often in a context which mimics previous manual practice. An idea advanced at CPI1965 was that the design load assumed would be embossed in concrete slabs to facilitate change-of-use investigations over a structure's lifetime. Perhaps we might revisit this idea 50 years later as we embrace Building Information Modelling (BIM). Surely with BIM and a Global Positioning System (GPS) we could now allow an investigator to call up the record of the load assumed in the design of a beam, slab or column, merely by holding their mobile phone in proximity to the element?

Climate change was not an issue at CPI1965. Nevertheless extreme weather conditions were not unknown to the delegates. Surely the 'Big Freeze' of 1963 – the worst winter in over 200 years – was fresh in their minds when a contributor to the symposium made a plea for contractors to take more precautions in respect of concreting in cold weather but that "...on the whole they tended as a class to be confirmed optimists in these matters!"

Precast concrete was a topic for discussion in CPI1965, as indeed it is in CPI2015. Some sound advice was advanced. It was noted that the virtues of a precasting scheme should always be simplicity and repetition, especially repetition. However the reality was that designers often lost sight of these virtues and rendered projects uneconomic for precasters. Worse again, projects were priced on 'typical' details, that became less and less typical as the project proceeded. We have moved on in that regard by 2015, given the impressive statistics around the penetration of the Irish precast industry in export markets.

Durability was a live topic in 1965, as it is in 2015. It was reported that the greatest threat to durability was inadequate cover to reinforcement. The effect of chlorides was alluded to in that structures in coastal areas had steel corrosion rates 50% higher than similar structures in rural areas. In a very far-seeing contribution, Prof. de Courcy recommended a novel approach to the concrete durability process involving definition at specification stage of the 'satisfactory life required'. Why, he asked, should an urban multi-storey office block be structurally in its prime at age 25 years if that age also represented the onset of functional senility? He was clearly years ahead of the rest – it is only in the last decade, 40 years later, that the concept of 'satisfactory life required' has found its way into the daily life of designers and specifiers through the Eurocodes and European Standard EN206.

Very significantly, at CPI1965 the statement was made that that .. "even today so much of the production and placing of concrete is entrusted to an unskilled labour gang." It was recommended that formal training of those working with concrete, covering all aspects of site practice, be introduced. Many have tried and failed to address this in the intervening 50 years. Let us commit to seeing this resolved by CPI2025!

4. CONCLUDING REFLECTION

How fortunate we are to have had such 'giants' building the CPI legacy for us since 1965. The concrete industry in 2015 is poised for new growth as we emerge from the dark days of recession that have recently been so devastating for the many fine people and enterprises that formed our concrete and construction industry a decade ago. Let us build on that legacy and draw inspiration from those who contributed to the wisdom recorded in CPI proceedings over the decades.

> "We are like dwarfs sitting on the shoulders of giants. We see more, and things that are more distant, than they did, not because our sight is superior or because we are taller than they, but because they raise us up, and by their great stature add to ours."
>
> John of Salisbury

de Courcy, Mac Craith and Duggan: *Ar dheis Dé go raibh a n-anamacha.*

SESSION A-1

CONCRETE

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Roadstone Ltd.

Sessional Chairman
M.G. RICHARDSON, B.E., M.Eng.Sc., Ph.D., M.ICT, C.Eng F.IEI
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Abstract

This paper looks at the developments in ready-mixed concrete in the period since the symposium was last held in 1995. The paper covers aspects of the market, production overviews, developments in constituent materials, sustainability issues and standards; and makes some concluding points on the state of affairs of our concrete industry today.

1. INTRODUCTION

Described as the “world’s favourite construction material”, (Tosterud, 2015) ready-mixed concrete is a staple construction commodity that has survived and thrived since Roman times. Concrete has continued to develop in the intervening millennia, particularly so over the last few decades when its technical, economic and ecological benefits have come to the fore. Noted as being the second most used material worldwide (after water) its permanence and resilience can be attributed to its simplicity, adaptability and its amazing properties allied to the fact that for its mass it is a relatively inexpensive, cost effective, durable, strong, sustainable and long lasting building material.

Concrete is strategically important to the Irish construction industry and to the national economy generally. Primarily an indigenous material, concrete continues to be part of both our lives and our environment and it makes a largely hidden and unnoticed, but significant contribution to the Irish economy. It provides jobs, downstream revenue, taxes, infrastructure, commercial, industrial and educational facilities and homes that are strong, energy efficient and low in maintenance. While the development of concrete may seem to be slow compared with some more modern industries such as the Information Technology sector, it nevertheless continues to evolve, improve and excite.

Despite a serious economic and industry downturn over the last 7 years, the Irish ready-mixed concrete industry has seen steady developments in many fields including: concrete composition, rheology, materials and engineering capability. A new and more explicit emphasis on “greener” and value engineered concrete mixes is also apparent, with increased use of secondary cementitious materials and the use of more sophisticated batching systems in the production phase. These developments have not affected a revolution of change but have resulted in the steady and sustained delivery of a product which is structurally, aesthetically, environmentally and commercially viable and valuable to all industry stakeholders, the general economy and our environment. Over the last 20 years Ireland has seen a proliferation of concrete buildings and structures which deliver excellence in concept, design, construction and use of materials on a par with any other country in the world. The quality of entries to the Irish Concrete Society Annual Awards along with other similar architectural and engineering events and accolades, affirm this excellence.

Concrete is essential to the built environment and our industry has to continue to be imaginative in refining its design, composition and use, through ongoing collaboration and work practices with other technologies, innovators and academia. Avenues for development of concrete include;

- Nanotechnology
- BIM modelling
- Use of new admixtures, cements and additions
- Microbiological self-healing concrete
- Incorporation of recycled materials
- Improved sustainability characteristics

Together with ongoing product innovation these will contribute to the future long term success ofboth the next generation of concrete and concrete pioneers.

2. MARKET OVERVIEW

It is generally accepted that the construction industry operates in a cyclical nature and historically the concrete sector, within the general construction industry has been well geared to facilitate and cope with minor fluctuations in annual or periodic demand. The level of growth and momentum experienced from the period of the late 1990's up until 2008 saw unprecedented demand for concrete and other construction materials, fuelled primarily by the housing boom of the time. Post 2008 saw a dramatic and sudden fall in activity and demand within the industry, with output falling by up to 70% from the peak periods of 2007/2008. This resulted in closures, rationalisation, job losses and posed considerable challenges to those that survived the building recession.

Even in the busy years prior to the downturn concrete production capabilities had inherent over-capacity, and while the sudden and severe drop in concrete demand resulted in a slight easing of this over-capacity (through closures and "mothballing" of plants), the effective capacity of the sector has not been reduced significantly and there still remains a clear imbalance between concrete output and demand with readymix concrete utilisation at only 27% of capacity (Table 1).

Table 1 Estimated readymix concrete capacity in Ireland (InterTradeIreland, 2012)

Capacity			Current	Capacity
Republic of Ireland	**Northern Ireland**	**Total**	**Output**	**Utilisation**
8,960,000 m^3	3,000,000 m^3	11,960,000 m^3	3,200,000 m^3	27%

The suddenness and the degree of volume reduction in concrete consumption in Ireland has been far more dramatic than the experience of other concrete industries across Europe for the same period as can be seen in Figure 1 below.

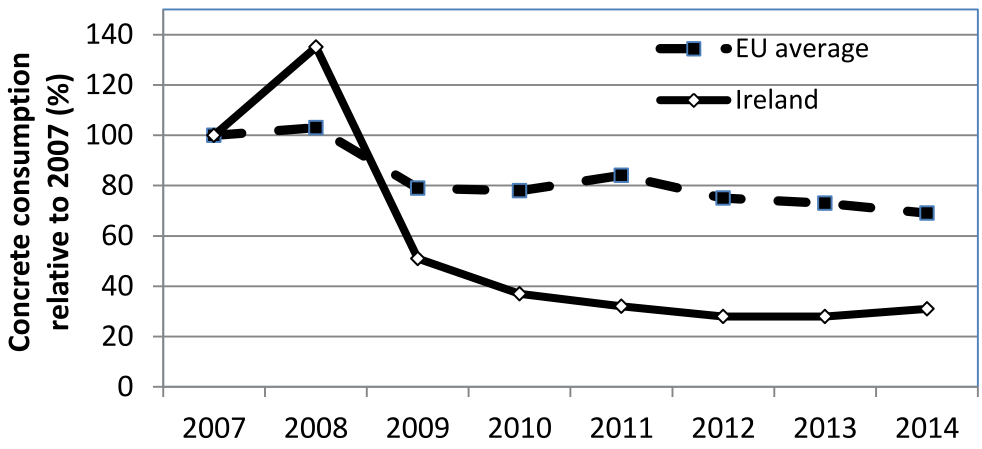

Figure 1 Concrete production, using 2007 as a datum (ERMCO, 2014)

On a more positive note, the recent broad consensus is that demand, activity and confidence within the concrete industry has gained momentum and continues to improve, showing strong medium term prospects. Recent data from the Irish Central Bank (2015) predicts average construction growth of 8.5% for the next two years, while the Ulster Bank's Purchasing Manager's Index in January 2015, illustrated in Figure 2, suggest that the construction industry, and therefore the concrete industry by extension is showing continued and sustained signs of growth. The recessionary period has led to a re-calibration of the concrete sector leaving a much leaner, more sustainable and innovative stakeholder base that is well positioned to adapt to, and take advantage of, the industry's recovery.

There are signs however of a two tiered recovery with a substantial portion of the recovery situated in the greater Dublin area (GDA) and along the east coast, compared with a much slower upturn in activity in the other regions and cities.

Continuation of the concrete industry's recovery will not be achieved by the efforts of the concrete sector or construction industry alone. Growth and prosperity can only be promoted by increased government capital spending on infrastructure, social housing and agriculture incentives along with the continuation of PPP schemes, sustained foreign direct investment and ease of access to funds for builders and home-owners. Addressing the geographically imbalanced recovery is also important. To ensure an even and sustainable national recovery for the industry necessitates increased Government expenditure on construction projects in the less developed regions outside the GDA.

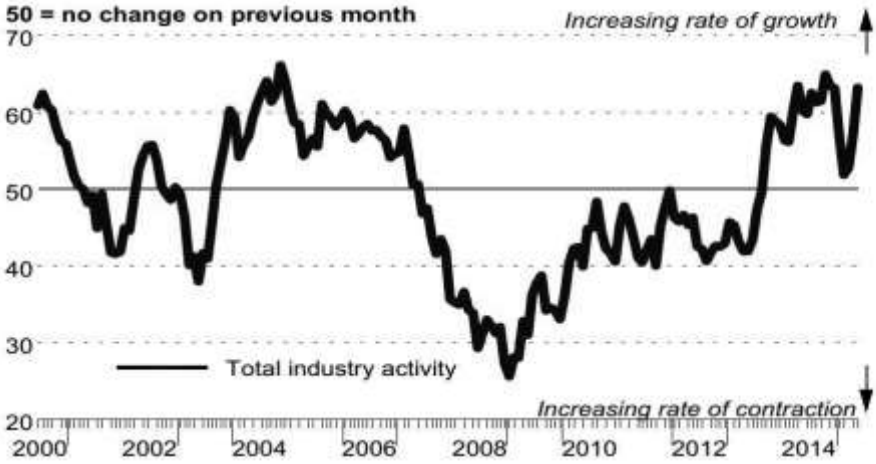

Figure 2 *Monthly construction activity (Ulster Bank, 2015)*

3. PRODUCTION OVERVIEW

One of the positive outcomes of the pre-2009 construction boom period was the investment by some concrete producers in modern concrete production facilities with state-of-the-art wet batching plants (in many cases) that incorporated sophisticated computerised batching systems and software. These modern plants have high output capabilities which can cater for large continuous pours and, more importantly, peak periods of demand such as early morning and "Friday" pours. Many of these plants are integrated with the other aspects of concrete production such as stock control, mix design input, quality control statistical analysis, planned maintenance and delivery logistics. They also provide an increased level of batching accuracy and have impressive recording capabilities.

Figure 3 *Modern twin wet batch plant*

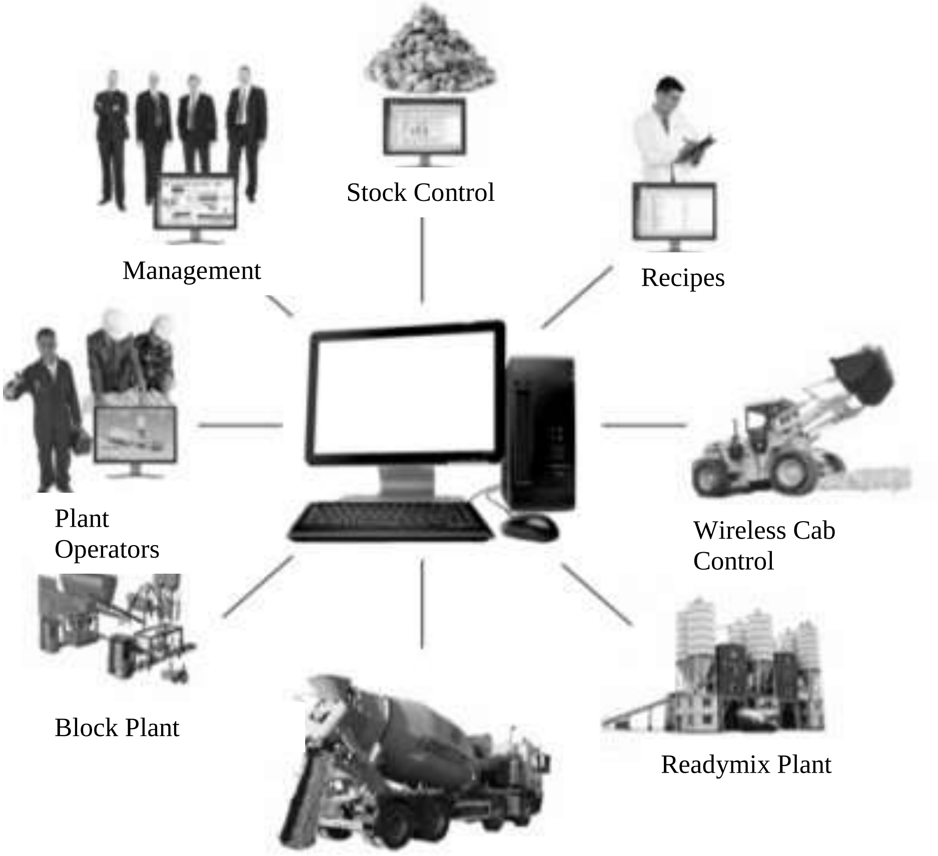

Figure 4 Integrated batching system

Historicially, the majority of concrete in Ireland was produced in dry batch plants, however with the addition of these new wet batching plants across the country the percentage of concrete produced via wet batching is now nearer the levels of other European countries, as illustrated in Figure 5.

Since 2008, concrete producers have become leaner, more sustainable and cost conscious, and employ value engineering in all aspects of concrete production. Their emphasis has been primarily focused on optimisation of concrete production to ensure a competitive yet compliant product. A summary of the key focus areas of optimisation is presented in Table 2.

Of all the areas of concrete production, Health and Safety (H&S) is considered to be the primary issue for concrete producers. Safety is a culture and a core value and keeping people safe is now widely recognised as a vital priority for our industry. The construction industry has seen vast improvements in site safety over the last five years and this concentrated effort is also prevailing in the concrete production sector. The two most commonly used indicators for H&S statistical analysis are Lost Time Incidents Frequency (LTI/FR) and Lost Time Incidents Severity (LTI/SR). Recently available data from the European Ready-mix Concrete Organisation (ERMCO, 2014) shows that the incident figures for Ireland for both these parameters are extremely good when compared with similar industry statistics across Europe (Figures 6 and 7). The Irish LTI/FR is on a par with the average EU figure for LTI/FR but more importantly the Irish LTI/SR is the lowest across all countries canvassed. This shows that while our number of safety incidents is on a par with our peers our accidents are far less severe in their nature. New data gathered by ERMCO for the period 2011 to 2013 concentrates on concrete manufacturing and does not include transportation as the vast majority of concrete is transported by independent hauliers across Europe and reliable figures for H&S are difficult to obtain. The Irish statistics are very encouraging and they reflect the increased focus and importance that is being directed to H&S within the sector. Most importantly the Irish concrete industry recorded no fatality during this period (or since).

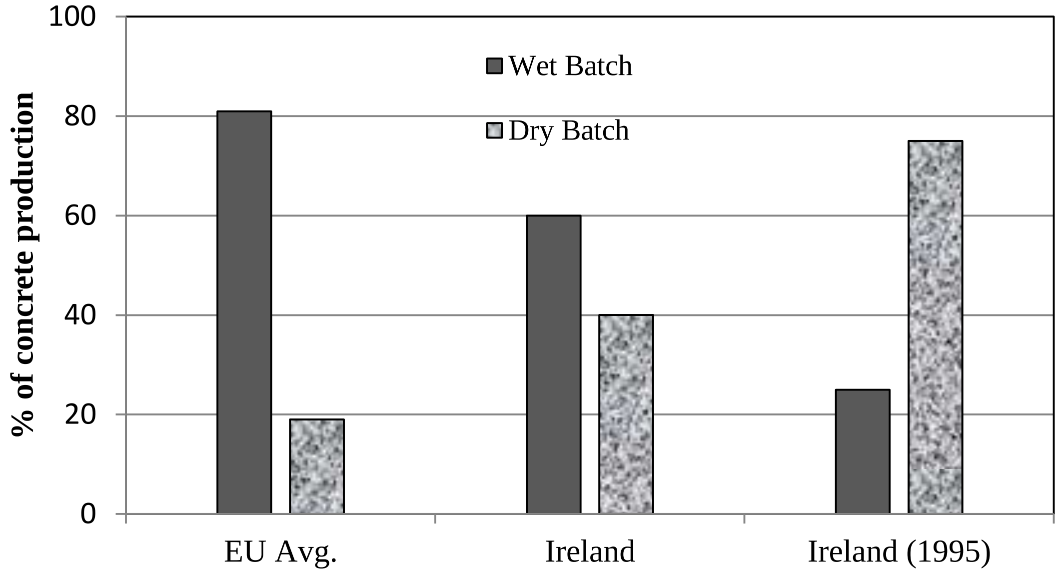

Figure 5 Method of concrete production (ERMCO, 2014 and author's data)

Table 2 Key focus areas of optimisation

Area	Action
Health and Safety	Zero target for fatalities
	Increased efforts to reduce the number and severity of incidents and accidents
	Provision and enforcement of PPE
Mix design	Value engineered mixes whilst meeting conformity obligations
	Adding value and identifying solutions for both customers and producers
Materials	Prioritisation of local aggregates and development of manufactured sand
	Admixture development
	The combination of cement and additions in varying proportions
Plant	Investment in new plant
	Introduction of fully automated and integrated batching systems
	Central despatch in urban areas
Transport	Use of artic mixers
	Two axle trucks for urban work
	Pumi/Pump Trucks
	Fleet Telematics - Truck Tracking to maximise fleet and delivery efficiency

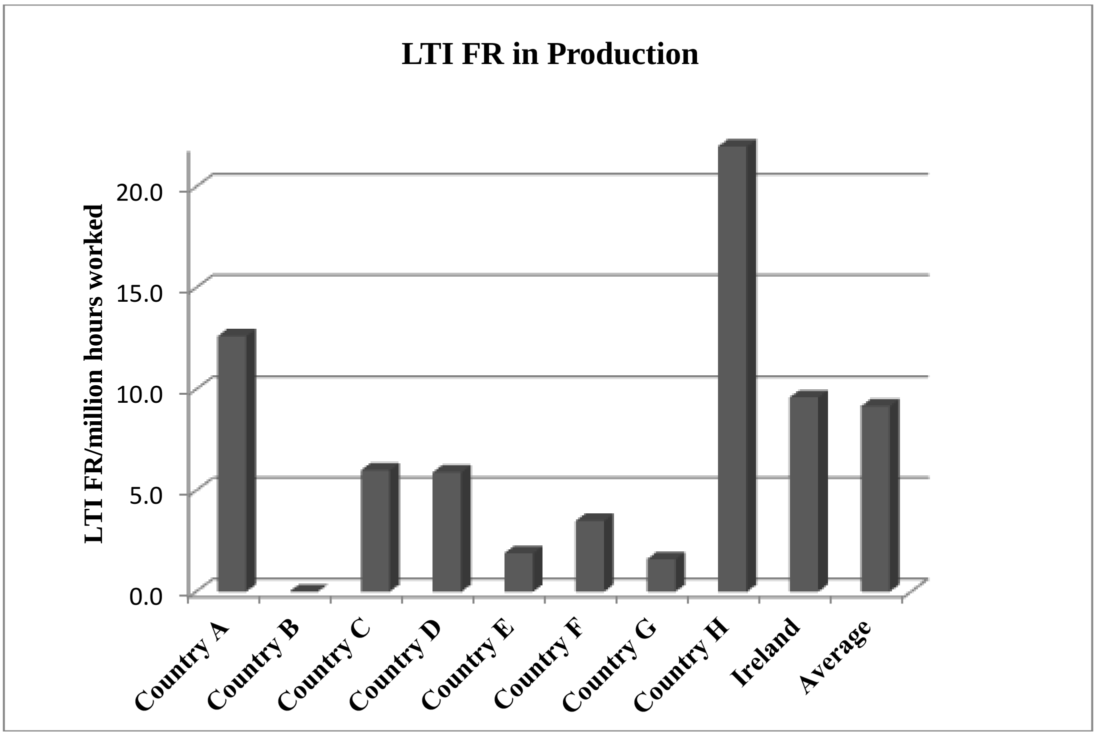

Figure 6 *Lost Time Incidents of Frequency in 2013 (ERMCO, 2014)*

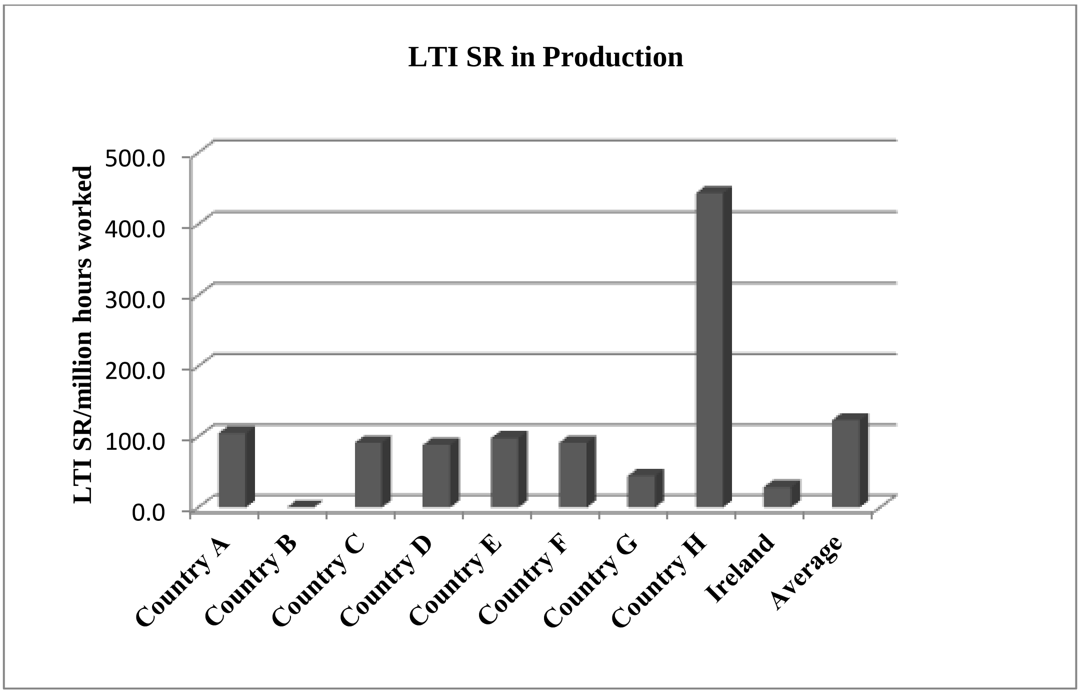

Figure 7 *Lost Time Incidents: Severity in 2013 (ERMCO, 2014)*

The purpose of good concrete mix design is to produce a usable concrete that meets the specified requirements in both the fresh, wet and hardened phases, by selecting and proportioning available materials, using the most economic and sustainable means. There is no one perfect mix design for all jobs, however there is always a suitable mix design for each job. While different concrete producers have different mix designs for a particular application based on the type of aggregates, cements, additions and admixtures used, the common denominators for all mix designers are that the concrete mix must be: Placeable– Compliant – Economic.

There are many types of mix design methods available ranging from the old and trusted methods such as the BRE 'Design of normal concrete mixes' (Teychenne, 1997) and the 'Basic Mix Method' by Owens (1973) to much more modern methods. These include software packages which more recently involve the use of "Packing" tools that incorporate not only the grading of the coarse and fine aggregates, but include allowance for the shape and density of the materials to maximise the packing potential of the aggregates to achieve as dense a mix as possible.

Whichever method of mix design is employed by the mix designer, the basic requirements for designing a good concrete is that they must:

- Know the various materials being used and their capabilities
- Work to a standard / specification
- Ensure that it is compliant and verifiable
- Ensure the mix is placeable and suitable for the particular application
- Make sure the concrete mix is consistent

Over the last forty years, the strength class of the concrete produced in Ireland has steadily increased, reflecting changes to standards, specifications, methods of execution and design criteria. Where once it may have been the norm to use volumetric mixes such as 8:1 for house foundations it would not be uncommon to see C25/30 being used for the same purpose today. Similarly, concrete grades for agricultural applications have steadily increased over the intervening period. This is not due to a more conservative or less sustainable approach to concrete production but could be attributed to improvements in materials generally and new standards and regulations. These changes reflect an industry that is prepared to embrace change when required and one that is open to development. More recent data shows that in general, Ireland is producing higher strength classes of concrete, predominantly in the strength classes C35/45 compared to the various strength classes produced by our European colleagues (ERMCO, 2014), as illustrated in Figure 8.

Complementing the above data is the fact that the average cementitious content for concrete in Ireland is 300 kg/m^3 while the European average for what is effectively a slightly lower strength class being produced (ERMCO, 2014) is 318 kg/m^3.This reflects positively on our capabilities to optimise on concrete mix design and also highlights the contribution of good quality aggregates, cement, additions and admixtures used in the production of concrete in Ireland.

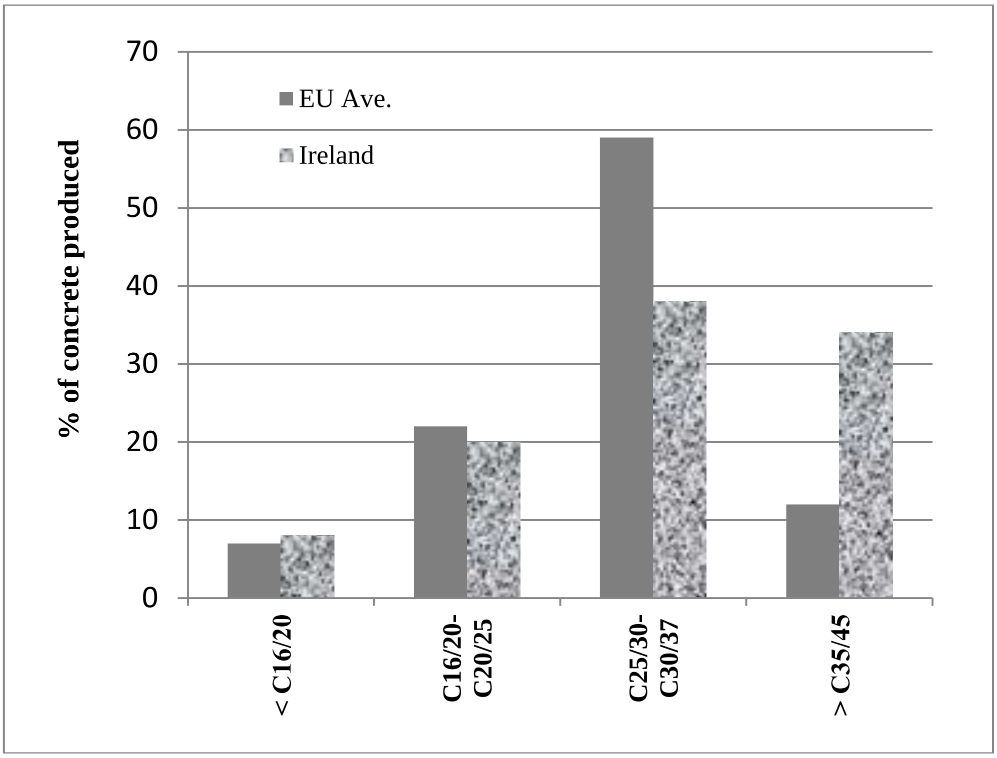

Figure 8 Percentage of concrete produced by Strength Class (ERMCO, 2014)

4. DEVELOPMENTS IN CONSTITUENT MATERIALS

Concrete continues to evolve and improve and one of the main changes in both the R&D and production phases of concrete development is the ongoing improvements in material constituents. New methods of extraction, quarrying and processing of aggregates, new cement types, use of additions and next generation admixtures combine and contribute to the slow but important development of concrete. While the concrete industry is an active participant in this evolution and producers continue to embrace new technologies and innovations, tangible changes may seem slow in appearing and it could be said that the Irish concrete industry is quick to learn but slow to change. However we must accept that we are in a phase of evolution not revolution and these attributes of caution reflect a conservative approach to concrete design, production and use that takes due cognisance of the genuine need to ensure it is designed and produced correctly whilst recognising the consequences and the risks of getting it wrong. While change may be constant in our industry it is wiser to be quick to learn and be somewhat slow to change rather than slow to learn and quick to change.

4.1 Aggregates

The Irish concrete industry is extremely lucky in so far as it is self-sufficient with excellent quality indigenous aggregates for the production of concrete. These aggregates, fully compliant with the relevant material standards such as I.S. EN 12620 (NSAI, 2002a) and SR 16, (NSAI, 2002b) have had a trouble-free history of use in readymixed concrete with no instances of aggregate related concrete degradation problems such as Alkali Silica Reaction, Alkali Aggregate Reaction etc.

The only note of concern regarding aggregates for concrete in recent times has been the reduced availability (in some regions) of natural sand that is within reasonable distance of concrete batching plants to facilitate economic use. This potential problem for concrete producers has largely been engineered out by substantive improvements in the development and increased use of manufactured sand (as opposed to natural washed sand). This development has been extremely successful and enhances the sustainability of the concrete producer. The production of manufactured sand involves the up-cycling of what was a heretofore surplus and largely unusable material from quarrying operations, in the form of a 6mm grit into a product with increased value which is an excellent fine aggregate for concrete production. Manufactured sands are made within the quarry where in the vast majority of cases a readymix plant is also located. This availability and proximity reduces the need to import sand from external sources and reduces transport costs.

The use of recycled aggregates is in its infancy in Ireland. While these type of aggregates can be used (with limitations) in concrete production in accordance with I.S EN 206 (NSAI, 2013) there is, as yet, little demand for their use from industry. This scenario is likely to change in the future, with the increased demands of projects using BREAM and LEED assessment methods likely to drive the increased demand for recycled aggregates.

Lightweight Aggregates to I.S. EN 13055 (NSAI, 2002c) are not produced in Ireland and are usually imported from the UK or Europe. Similar to Recycled Aggregates there has been little demand for this type of aggregate and the limited use of it is primarily confined to specialist projects and products where weight of concrete members is usually the primary concern.

4.2 Binders

4.2.1 Cement

The majority of cement used in present day ready-mixed concrete production in Ireland is CEM II / A-L with a proportion of CEM II / A-V also in use. These CEM II cements have been in use over the last ten years and have replaced a CEM I type cement that was traditionally used prior to 2006. The change in cement type was primarily driven by the needs of the cement industry to enhance the environmental performance of both the cement and the production process. For concrete producers (and their customers), the change from CEM I to CEM II was a seamless one that had no negative impact on the performance or compliance characteristics of the concrete being produced. While the CEM I cements are still available and are used extensively by the precast industry, their use in ready-mixed concrete is confined to occasional applications and projects. Other types of cements such as CEM I-SR (Sulphate Resisting Portland Cement) and CEM III Blastfurnace cement are also available but, like CEM I, have limited demand and use.

4.2.2 Ground Granulated Blast Furnace Slag (GGBS)

GGBS is most commonly used in Ireland as a bulk, stand-alone Type II Addition that is added and combined with CEM I and CEM II/A cements at the mixing stage of concrete production, in the same proportions as factory blended Blastfurnace cements.

While it is used in general construction and in architectural projects, a large market for GGBS has evolved from the wind energy industry where it is used in large quantities in the construction of bases and foundations of turbines as a means of reducing the risk of thermal cracking. Some limitations to its use are known with some contractors reporting slower setting and delays to formwork striking times in winter where large proportions (>50%) of GGBS are incorporated in the concrete.

The inclusion of GGBS in concrete in Ireland is driven by economic, aesthetic, technical and environmental considerations. GGBS is manufactured in conformance with I.S. EN 15167-1 (NSAI 2006) and used in concrete in accordance with the National Annex to I.S EN 206. Specific suitability for the use of GGBS with a limited number of cement types is also established in the National Annex to I.S EN 206 using the equivalent concrete performance of combinations concept up to a maximum slag content limit of 70% by weight. While there is no experience in Ireland of the use of the k-value concept for GGBS, it is general practice that when GGBS is used as an addition to replace CEM I and CEM II cements in concrete it is done on a direct substitution basis at lower replacement levels.

4.2.3 Fly Ash

The technical benefits of using fly ash (Pulverised Fly Ash) in concrete are: improved workability, reduced bleeding, reduced heat evolution and heat of hydration, and improved resistance to chemical attack. Fly Ash is known to produce concrete with a darker colour and with delayed setting times in winter when large percentage replacements are used. Additionally certain admixtures including air entrainers may be influenced by the carbon content of particular fly ash and generally require compatibility verification via trial mixing before use.

Extensively used as a secondary cementitious product in the UK, across Europe and in the US, fly ash is used in concrete production in Ireland on a limited scale. The standard for fly ash is I.S EN 450-1 (NSAI, 2012) and general suitability as a Type II addition is established for its use using the k-value concept according to I.S. EN 206 with certain restrictions on the maximum amount permitted for each category of fly ash. The current use of PFA in concrete in Ireland is limited due to low market supply of certified material, however the fly ash which is available is extensively used in the production of cement.

4.2.4 Silica Fume (Microsilica)

Silica fume, also known as microsilica is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production. The main use for Silica fume in accordance with I.S. EN 13263-1 (NSAI, 2005) is for high performance concrete in specialist applications. The benefits associated with Silicia fume are: high and ultra-high compressive strengths up to 300 N/mm^2, increased abrasion resistance and reduced permeability. The nature of its fine particles mean that it is often shipped and stored in slurry form to reduce Health and Safety risks. This Type II addition is relatively expensive and its use is normally confined to applications where either high early and/or ultimate strengths are required or where an enhanced chemical resistance is a needed.

4.3 Water

Water is the most used substance in the world and it is getting scarcer and more expensive each year. A current and relevant local example of this is the Government funded investigation by Irish Water and Dublin City Council into pumping water from the Shannon region to serve the greater Dublin area in order to satisfy increasing water demands. Often the forgotten constituent of concrete, water is becoming one of the most important sustainability issues for our industry and has been dubbed by some as the new ‘Carbon’. The production of $1m^3$ of concrete requires on average 250 litres of water when the wash water for ready-mix trucks, plant mixers and yards is included. Therefore a yearly production rate of (say) 3 million cubic metres of concrete would require 750 million litres of water, equivalent to the annual water requirement of a town with a population of 18,000 people.

Conservation, harvesting and recycling of water is the norm for the concrete industries in the UK and the continent and this is now becoming more common practice for the Irish concrete industry as well. A joint technical visit by the Irish Concrete Society and Concrete Society Northern Ireland Branch was conducted in 2015 to Belfast's Titanic Centre. It was noted that the Concrete Plant recycled 100% of water on site with zero discharge. Further benefits of a more sustainable water management scheme are: improved early age strength with "grey" water (HulusiOzkal and Dogan, 2015) reduced and cleaner discharge when water is treated, lower pumping costs, savings on cement and sand and savings on water charges. While this water conservation and management practice has started in Ireland on a limited scale we must commit to improvement in "grey" water management and to reducing our dependence on virgin water for our concrete manufacturing processes.

4.4 Admixtures

Admixtures are now an intrinsic part of concrete and our concrete industry. Their improving chemistry and technology greatly enhance both the wet and hardened properties of concrete, give optimisation opportunities for the designer, producer and contractor and they contribute to sustainable construction.

Use of admixtures manufactured in accordance with I.S EN 934-2 (NSAI, 2009) is now standard practice for all concrete producers in Ireland. What was once perceived, by some, as an unnecessary constituent, their use was forbidden in a lot of specifications unless specifically approved and permitted by the Engineer. It is now accepted by the industry that admixtures produce a more sustainable concrete with improved performance characteristics, and although their use is still primarily driven by concrete producers (and admixture producers) nowadays it would be very unusual not to have some kind of water reducing admixture in a concrete mix.

Admixtures have developed significantly over the last twenty years as a result of the more demanding requirements of the concrete industry and improved technologies within the admixture industry. In Ireland twenty years ago the main requirement of an admixture was for basic water reduction and this was achieved by the use of standard lignosulphonate based plasticisers which gave approx. 8% water reduction. Subsequent to this further water reduction capability was achieved by the use of Naphthalene and Melamine based plasticisers which achieved approx. 12% water reduction. In the last ten years the biggest change in admixture development and use has been the introduction of PolyCarboxylicEthers (PCE's) which have dramatically improved the performance characteristics by achieving lower w/c ratios, reduced cement contents and improved strength performance, while extending the water reduction capabilities further. Now we see the development and introduction of the next generation of concrete admixtures/superplasticisers in the form of PolyArylEthers (PAE's) which claim to improve early strength, give outstanding water reduction and reduce the stickiness of the concrete (Kluegge and Aykan, 2015).

In an effort to produce the 'perfect' concrete the demands of the concrete producers over the last number of years have changed from a mere singular requirement of basic water reduction to the need to achieve a troika of parameters from an admixture i.e. good water reduction (up to 20%), increased workability (approx. 150mm slump) with extended workability retention (2 hours min.). This "tailoring" of concrete is being achieved with the refinement of PCE admixtures taking into account the chemistry of the particular cement and the type of aggregates being used.

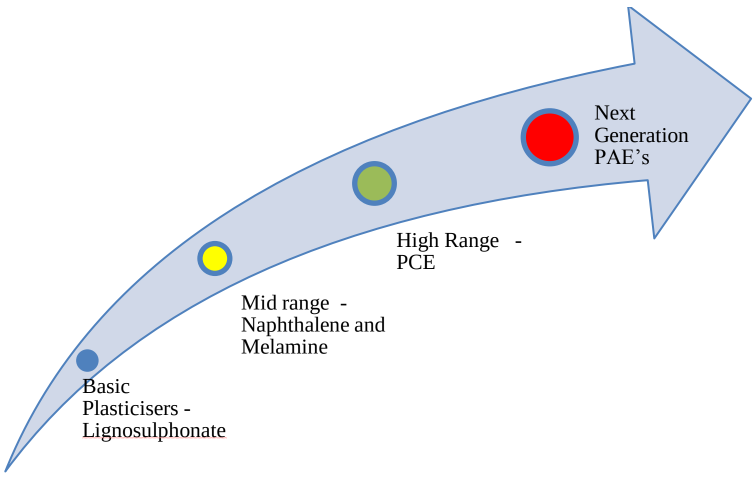

Figure 9 Plasticising admixture development over time

While the Irish concrete industry has moved with the times and incorporated these admixture developments, with a marked increase in the use of mid to high range plasticisers and superplasticisers over the last ten years, we still lag behind in general admixture use compared with our European counterparts. This could be attributed to a number of factors:

(a) reluctance of Engineers to specify these products,

(b) a reluctance by contractors to use the improved performance and placing characteristics of admixture enhanced concrete, such as self compacting concrete (SCC),

(c) the use in general of concrete of a lower consistence class, see Figure 10.

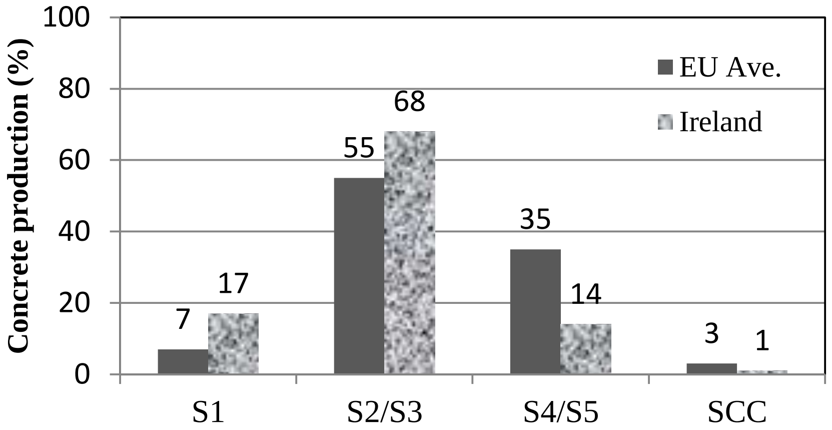

Figure 10 Percentage of concrete produced by Consistence Class (ERMCO, 2014)

4.5 Additives

Additives, as opposed to admixtures and additions, are constituents added to a concrete to improve or enhance the performance properties over and above those properties of a normal standard concrete mix. Their use could be seen as up-grading of concrete as they usually involve a degree of added value to the concrete product. The two most common types of concrete that incorporate additives are Fibre Reinforced Concrete (FRC) and “Architectural” Concrete.

Recent years have seen the increased use of the various types of FRC that include Polypropylene, Macro-Synthetic and Steel fibres. Primarily used in slabs, yards, residential paving and shotcrete, the inclusion of these fibres can increase tensile and flexural strength, improve durability, reduce plastic shrinkage cracking and can save considerably on cost and time for the contractor. Steel fibres are particularly suited to large industrial type ground bearing floors as they can completely replace traditional mesh reinforcement, and the concrete is commonly placed using laser screed technology.

More recent developments have also seen the growth in use of “Architectural” concrete with increased demand for coloured, polished and decorative concrete, particularly in applications such as residential floors, public buildings and outdoor recreational areas. The author believes there is substantial potential for growth in the use of pigments in concrete, due to a general trend towards higher use of decorative concrete which are proven to provide sustainable, hard wearing, low maintenance surfaces.

5. SUSTAINABILITY

The last decade has seen considerable focus on sustainability across all parts of society. The construction and concrete industry is no different. We have seen a steady push for “greener” concrete allied to more sustainable construction. We tend to forget that concrete is already a well-established sustainable material through its longevity of use; what could be more sustainable than a structure that is designed for a 100 year service life and that will probably last twice that time with minimal (and in some cases no) maintenance? This is unlike many large scale steel structures which require a ten year painting/protection regime. We must also remember that to a large degree, concrete can be a net consumer of waste by the potential use of:

- cement made with alternative fuels
- slags and ashes which are by-products of other industries
- recycled water
- recycled aggregates & demolition waste

As the development of thought on sustainability develops into a more nuanced balance of economic, environmental and social factors, concrete has a number of very positive messages relating to its performance in service. These include:

- Extremely economic. Cost 3c / kg
- Thermal mass and occupier safety and comfort
- First phase finishes that require no further coatings or treatments and are light reflective and energy saving
- Low/no life time maintenance
- Value engineered design through the availability of a range of strength and material options at the design and manufacturing stages

- Use of admixtures lowering both the water and cement requirement
- Its low CO_2 impact. The average embodied CO_2 of a tonne of concrete is approx. 100kg.
- Longevity of the finished product – 100 year design life
- Re-use or conversion of buildings at end of life or alternatively recycling 100% of demolition assets
- The very low production energy requirement for concrete and its constituents. (Figure 11)

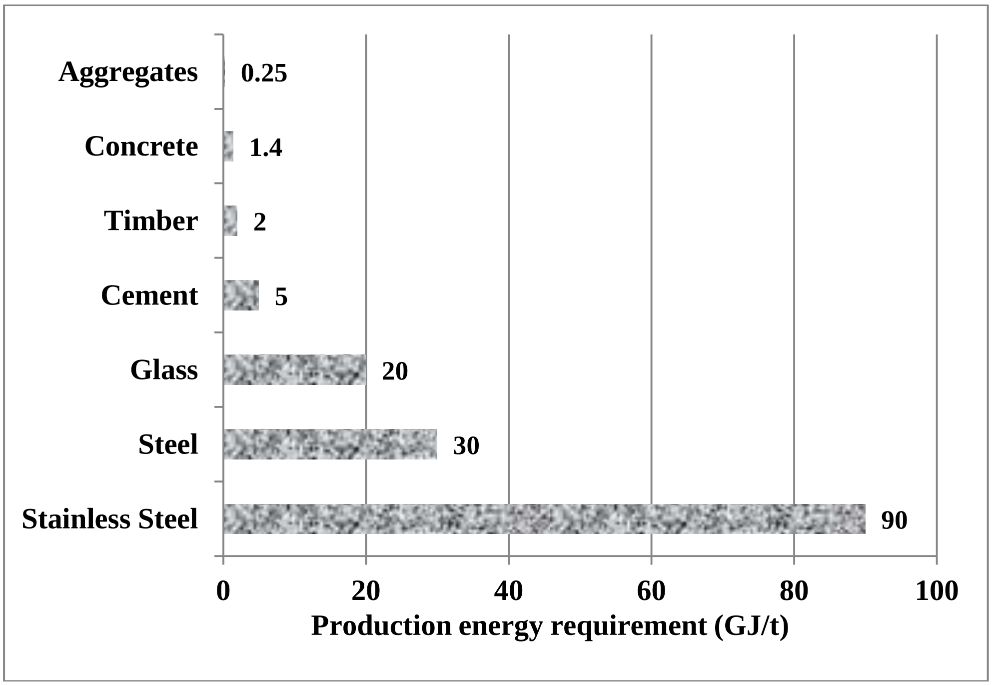

Figure 11 Production energy requirement for selected construction materials

Concrete is produced locally using indigenous materials supporting the local community and economy and it also has a multiplier effect in that it contributes to the economic growth and development of our towns and cities, and by creation of general infrastructure.

Some notable current concrete sustainability initiatives at a European level that are likely to impact on the Irish concrete sector include:

- A new Responsible Sourcing Scheme for concrete by the World Business Council for Sustainable Development / Cement Sustainability Initiative (a group of international organisations in the cement and concrete sector), that is intended to show transparent sustainable and responsible sourcing of materials to customers. This scheme is expected to be recognised by environmental assessment schemes such as LEED, BREEAM, Greenstar, DGNB and HQE.
- The provision of a concrete sectoral Environmental Product Declaration (EPD) scheme with industry specific calculation tools.

6. STANDARDS

The most significant change in concrete related standards over the last 20 years has seen the replacement of National Standards such as I.S. 326 (NSAI, 2004) and BS 8110 (British Standards Institution, 1997a) with pan European (CEN) Standards along with their complimentary National provision/National annexes across all the key areas of concrete construction including design, production, materials, execution and testing.

The new standard for concrete - I.S. EN 206 (NSAI, 2013) was first published in 2002 and it has since been revised in 2008 and 2013. This new standard contained significant changes in its format for specifying and ordering concrete with completely new terminology included for compressive strength class, consistence class and exposure class. It also provided new conformity criteria and the manufacturer was given clear responsibility for conformity via new production control and testing requirements. The standard also provided clear and concise guidance on the responsibility attributed to each of the key stakeholders i.e. specifier, user and producer.

I.S. EN 206 is the primary standard for concrete and all other concrete related standards such as design (Eurocodes), materials, testing and execution refer back to this standard for specification and production of concrete.

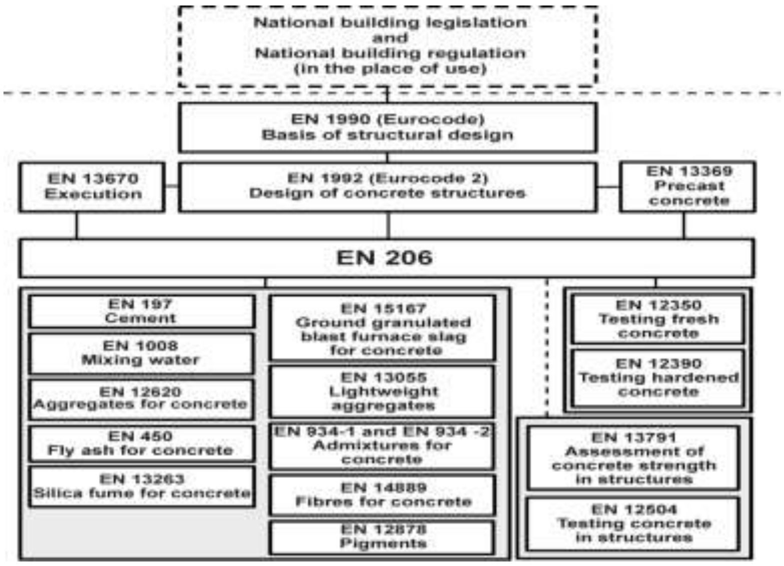

Figure 12 Concrete Standards hierarchy (NSAI, 2013)

In drafting EN 206, CEN Technical Committee TC104 (Concrete and related products).and the European concrete producers recognised that a harmonised standard for concrete was not feasible, due primarily to substantial variance in climatic and geographic conditions along with differing historical methods of use in each country. This recognition led to the philosophy of a pan European standard incorporating National Provisions that would allow for, and accommodate such variances. This resulted in EN206 becoming a non-harmonised standard unlike most other most other construction product standards which are harmonised across Europe.

While the old standards served the industry well for many years, the development of these next generation CEN standards along with their accompanying National Annexes allow for a more country specific means of specification and compliance. The inclusion of National provisions which take into account the different climatic and geographic conditions and traditions and experience of each country / region, allow for the concept of establishing suitability for a particular material or process on the basis of satisfactory historical use in that particular country.

While the co-existence of both the old and the new standards has long since passed, unfortunately the transition between standards has not been without its difficulties. Old and obsolete standards continue to be used which leads to ambiguity in the exchange of information. Apart from any potential legal ramifications arising from such a scenario, the possibility of using an incorrect specification and the delivery of an inappropriate concrete for a particular application is of utmost concern while this practice continues. It would be in the common interest of all concerned to ensure that:

- National Annexes must take precedence in each national platform and should be used in each country. I.S. EN 206 and the Irish National Annex should be the only standard in use for concrete in Ireland.
- Use of other national annexes such as BS & DIN and other foreign national provisions should be avoided.
- Obsolete standards such as BS 5328 (BSI, 1997b), which is still commonly specified, should not be specified.
- Cherry picking of different (and often conflicting) limiting values is not permitted. Avoid the "cut and paste" syndrome.

Further development of our concrete standards is already being investigated with a new approach to concrete specification via "Specifying Durability by Performance". This is a new concept for durability design of concrete structures, involving the introduction of Exposure Resistance Classes. It is a potentially significant and revolutionary change in so far that the durability performance of concrete will be embedded in the specification (Eurocode 2). The concept has general tentative approval of most EU countries but is expected to take many years for full development due to the need for comprehensive modelling of the new system and the establishment of adequate and robust test methods.

7. SUMMARY

Concrete is essential to the Irish economy and to the built environment. All our lives are positively affected by the use of concrete in multitude of ways such as construction of renewable energy projects, infrastructure and roads, agricultural buildings, schools and hospitals, reservoirs and dams, waste water facilities, airports and homes.

Major points highlighted in this paper include:

- For concrete producers and the construction industry generally, safety is a culture and a core value. Keeping people safe is a vital priority for all of us.
- The Irish concrete market is seeing a slow yet steady recovery, albeit presently biased towards the greater Dublin area.
- Concrete producers who have weathered the storm of recession are well positioned and geared for the increased activity and growth opportunities ahead.

- Our industry's recovery can be fuelled and sustained by growth in government capital spending on infrastructure, housing and agriculture, along with the continuation of PPP schemes, FDI and access and availability of funds for builders and homeowners.
- Informing key decision makers of the long term sustainability attributes of concrete is essential.
- Improved management of our water resource is imperative.
- Use and adherence to Irish Standards and National Annexes should be mandatory.
- Irish representation on CEN and other European industry related committees and groups must be encouraged, as participation, involvement and feedback will prove informative and productive.
- Innovation, optimisation and development of concrete must continue with an ongoing eye on best practice across UK and Europe.

Acknowledgements

The author wishes to acknowledge the time afforded by his employers Roadstone Ltd. in researching and preparing this paper. The assistance of Mr. Henry Kerr and colleagues in the Irish Concrete Society in finalisation of the paper is also gratefully acknowledged.

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DISCUSSION

MR. CROWLEY introduced his paper. He spoke of how concrete binds us together as an indigenous industry that makes a positive contribution to society. He noted that 70% of the world's population live in concrete buildings. Concrete was essential to the economy and therefore was a fair barometer of the construction industry generally.

Recovery, evident after eight years of decline, was being served by an industry which had emerged from the recession leaner, more sustainable and innovative – well poised to take advantage of economic growth. Reviewing trends in production (Figure 1 in the paper) he explained that the peak was significantly influenced by the agriculture sector at the time. He especially drew attention to Ireland's improved performance in respect of health and safety. Safety culture was now well-established as a core value. Referring to Figure 7 in the paper he noted that Ireland was best-in-class in Europe from the viewpoint of least severity in lost time incidents – 'Country B' had not returned data. He explained how information technology had led to several innovations. It had allowed the development of 'central dispatch', particularly in urban areas, with up to five plants being organised from one centre. Automated and integrated batching systems allowed optimisation of production and delivery, stock control, mix design, maintenance, reporting, conformity requirements, and transport. In respect of transport, fleet telematics had greatly improved efficiency and safety. Efficiency was evident, not least in reduced fuel consumption. In respect of innovations in transport he instanced the introduction of twin axle trucks in urban areas. Regarding changed trends, it was interesting that truck mounted pumps were now in great demand.

He spoke about the introduction of manufactured sand – made from the former waste stream of 6 mm material, which hitherto was not useful as it made the concrete 'gritty'. In respect of additions, he characterised the market demand as GGBS, high use; PFA, low use; microsilica, no use! Speaking of the significance of 'grey water' he pointed out that, in addition to environmental benefits, its use can result in savings on cement content and sand content. Acknowledging the benefits of admixtures, now used in 99% of ready mixed concrete, he noted that their extensive use was producer-driven. He was surprised that specifiers were not driving its use more, given the clear benefits to concrete. He encouraged greater use of self-compacting concrete. Looking to the future, he expected development of admixtures as internal curing and self-healing agents. Turning to additives, he predicted that steel fibres would replace mesh reinforcement in ground bearing floor slabs, such that the concrete producer would become the 'reinforced concrete producer'! He noted the benefits of fibre reinforcement: reduced structural member size, reduced crack width, high fracture energy, improved freeze-thaw resistance and elimination of plastic cracking.

Regarding future market innovations, he noted that Ireland was way behind the curve compared to the USA on offering architectural and decorative concrete. In respect of specification, the innovation in the next 10 years would be performance-based specifications. In its infancy, the concept required development of accepted mathematical models of durability phenomena and accelerated durability test methods.

He drew particular attention to concrete's sustainability credentials:

- Net consumer of waste,
- Excellent thermal mass characteristics leading to energy saving over the building's lifetime,
- First phase finishes, requiring no further treatment,
- Light reflective,
- Very economic at <3c/kg of concrete,
- Very low CO_2 impact. He contrasted the misleading soundbite of '750 kg CO_2 per tonnne of cement' with the more relevant statistic of '75 kg CO_2 per tonne of concrete',
- Long serviceability life,
- End-of-life re-use through conversion for change of use or recycling. He instanced the redevelopment of the Aviva Stadium where the existing stands were demolished and the material was entirely re-used on site.

In respect of European sustainability initiatives he spoke of the adoption of a Responsible Sourcing Scheme for concrete, a concrete sectoral EPD scheme with industry specific LCA indicators and promotion of the "Concrete Initiative" to engage with key industry, governmental and EU Commission stakeholders on the concrete industry's contribution to sustainable construction. The Initiative is a joint initiative involving Cembureau, ERMCO and BIBM.

In conclusion he urged a balanced recovery based on a mix of government investmest in infrastructure, public-private partnerships, foreign direct investment and investment by the construction industry. The need for funds at competitive rates for builders and home owners was also required.

MR. JOHN REDDY raised the issue of the requirement for concrete to be tested on site by those with competency in respect of identity testing. He noted the introduction of 'Safepass' on site and asked if we could expect a 'Concrete Pass' to be a feature of practice. This could be regulated by the concrete producers who could then ensure that competent personnel were sampling and testing concrete on site. Equally he expressed concern that the placing and finishing of concrete was not a recognised trade. In the course of his reply MR. CROWLEY observed that there was a shortfall in the standards document in that the level of competency was not specifically defined. However a lead on competency in respect of working with concrete had been taken in continental countries, such as Germany, where the concrete batcher and sampler were required to have a certified level of education in respect of concrete competence. Regarding Irish concrete standards he acknowledged that 'competency' was not specifically defined but that progress on education was being made. Legally however it was a grey area, given that the definition of competence was so vague. MR. BRADLEY noted the work being done on two levels by the Irish Concrete Society and the Irish Concrete Federation. The ICS Basic Concrete Technology course modules were targeting the graduate engineer audience and similar professionals. The ICF in consultation with SOLAS had submitted a proposal earlier in 2015 for the development of an apprenticeship scheme for concrete operatives. MR. STRATTON SHARPE spoke of great efforts in the past to address the issue of training and qualification of concrete operatives. He spoke of failure to get it approved in the past and welcomed the unceasing efforts to see this to a successful conclusion. MR. RICHARD BRADLEY spoke in appreciation of the previous efforts by Mr. Sharpe, Past Chairman of the Society, and noted how current work on this topic has included a review of findings by a delegation from the Society who did fact-finding in Sweden in the 1980's. He assured the Sysmposiun that this was a key area of focus by the Irish Concrete Society. In an invited response MR. BRIAN O'ROURKE, Chairman of the Society, spoke of the obvious deficit that exists at present: high quality production of constituents for concrete and high quality of production of concrete, yet a lack of a requirement for formal education and training of those dealing with concrete on site. He elaborated on the Society's plans to address this, which involves three half-day training sessions, leading to preparedness for participants to sit the Stage 1 level examinations of the Institute of Concrete Technology. He expressed the hope that this would lead to recognition and retention of skilled operatives in the industry.

PROF. ROGER WEST raised the issue of the increased use of steel fibres in Irish concrete practice over the next decade. He agreed with Mr. Crowley on the advantages of using fibres in respect of crack control but sounded a note of caution of the use of steel fibres in structural elements as an aid to ductility resistance in advance of changes in test methods. Current 'displacement' tests were based on monitoring pull-out performance and not ductility. While fibres could contribute to shear resistance, there was a need for more research and a change in international test methods before Irish designers and specifiers should replace 8mm reinforcement at 150 mm centres by steel fibres. MR. CROWLEY agreed and emphasised the benefits that he spoke of were in respect of ground bearing slabs.

MR. JIM MANSFIELD alerted the symposium to the issues of standards for execution in concrete. He observed that the standards for execution in steel were much more specific. He extended this point to note that the steel industry and the timber industry were very coherent in their approach to publications and other information tools used by specifiers and designers in the application of their materials. The concrete industry was less so. MR. O'ROURKE speculated that the difference resulted from differences in respect of consequence. Consequence classes for steel structures could involve anything from the entire structure to a detail, which implied the need for a higher level of certification of a welder than a concrete operative. Mr. Mansfield noted that the concept of 'consequence class', as considered for example by Committee TC135 (steel), was not a feature of discussion by Committee TC250 (Structural Eurocodes).

MR. BRENDAN LYNCH expressed concern over the level of education of engineering graduates in respect of certain aspects of an increasingly sophisticated industry. The pace of change in respect of standards, even over the last ten years, was significant. He instanced the publication of an Irish Standard for the execution of concrete some years ago. He suspected that few graduates were familiar with it. The reality was that many were now behind the times in respect of their knowledge and often only updated their knowledge of current standards and practice after the event, when a problem arose. This was an issue of education and training that went beyond the scope of just the Irish Concrete Society. In response PROF. ROGER WEST noted the competing demands on the time that engineering students spend on topics ranging from environmental engineering to hydraulics, geotechnics, structures and transportation engineering. He instanced the case of Trinity College Dublin where concrete technology was covered in Stages 2 to 5 of the programme. The graduate courses included core and optional modules on concrete ranging over from sustainability to durability. While praising the Irish Concrete Society concrete technology courses, which benefited graduates, he drew attention to significant resources being supplied to third level institutions from the Steel Construction Institute.

MR. JOHN REDDY noted the welcome development of a concrete sectoral Environmental Product Declaration (EPD) scheme. There was a good story to be told about concrete and its carbon footprint, especially compared to the steel industry. He requested further details. MR. CROWLEY elaborated on developments through the European Concrete Platform, following European standards for the development of EPD's. He predicted significant developments within the next 12 months.

MR. PETER DEEGAN, in an invited written contribution, summed up the last ten years of concrete practice in Ireland ....:

- it was when our domestic market reached an all time high, and an all time low,
- it was when our market grew from the island of Ireland to Britain and beyond,
- it was when a piece of Ireland built the 2012 Olympic village in London, Hinkley Point Nuclear, motorway bridges from Devon to Edinburgh and Crossrail, a wee piece buried as tunnels,
- it was when CEM 1 became 2 and 2 became 3 and concrete became green,
- it was when strength became maturity and slump became consistency,
- it was when we discovered SCC and PCE and PAE.

and looked forward ten years ....

- longer spans,
- thinner sections,
- stronger blocks,
- all made with an eco friendly concrete that will self heal!

SESSION A-2

AGGREGATES FOR CONCRETE

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Abstract

This paper reviews significant legal, technical and market issues that have recently influenced the current shape of Ireland's extractive and aggregate industry.

1. INTRODUCTION

In any discussion on aggregates for concrete, it is necessary to have a basic understanding of the nature of the extractive industry and its actors. The mere act of extraction is a legally complex issue, being both a development work and use, and is contained within a wider and even more complex legal definition of quarrying. Extractive operations, generally large rural developments with the potential for environmental impact and social nuisance, are necessitated by societal need for infrastructure and many of the foundational elements of modern civil society, such as health services, waste and water management, as well as roads, housing, schools etc. It is commonly held that the human requirement for aggregates is only surpassed by that for water.

In 2004/5, during the original quarry registration process (Planning and Development Act 2000, No. 30 of 2000, s.261 as commenced on 28th April 2004), c.1,600 sites registered with the outcome then being acceptance of circa 1,200 sites warranting registration as existing or having an enduring right to exist. More recently, planning authorities identified and examined circa 2,200 extractive sites (deemed material in planning terms, Planning and Development Act 2000, No. 30 of 2000, s.261A outturn as of August 2012). While over half of these sites are either dormant or abandoned, there are still a substantial number of extractive sites, perhaps up to 1,000, in operation or capable of immediate recommencement in the Republic of Ireland.

Industry estimates that circa 90% of output emanates from just 500-600 sites, with many of those sites being seasonally operated pits, and that concrete product manufacturing occurs on 300-350 sites, the vast majority of which are within quarry complexes. The industry make-up includes multi-national companies, nationally and regionally important companies, and an abundance of small family run companies with just one or two sites under their control generally operating within a 30 kilometre transport radius. An award-winning integrated facility is illustrated in Figure 1.

Figure 1 Award winning integrated facility (Kilsaran International)

In economic terms, this collection of large and small operations might be described as a loose oligopoly with strong competition evident across the country with minor regional variations accountable for by traditional economic factors. Competition should be a positive benefit to both the industry itself and the customers of the industry when quality standards are high and conformity enforced. Unfortunately, the ‘Celtic Tiger’ years put enormous pressure on the industry to supply ever increasing amounts of material, and resulted in the promotion of many operators who were opportunistic, with little regard to sustainability, and, particularly, the environment.

To put those heady years in context, during the ‘noughties’, the average EU consumption of aggregates was estimated by UEPG (European Aggregates Producers Association) as 7.5 tonnes per capita per annum; by 2007, with Ireland reaching an estimated 30-35 tonnes per capita per annum supplied by a professional industry and an ever increasing number of semi or completely unregulated ‘pop up’ sites, with whom the professional industry was expected to compete.

The nature of Irish infrastructure, population demographics, and rural house building suggests the usage of aggregates related products should naturally be above the EU average, possibly as much as twice it. Volumes remained high, only slightly down on 2007, to the end of 2008 due to a farm grant scheme (Farm Waste Management Scheme, Dept. of Agriculture, Fisheries and Food) which ended on 31st December 2008. This scheme benefitting rural operators, and the professional industry could maintain operations, but the economic cliff happened for the aggregates and concrete industries in 2009 and may only have stabilised, on a national basis, in the last 12 months, with Dublin and Cork picking up somewhat in that period.

Overall, UEPG estimates a contraction in output of over 70% for aggregates and over 80% for concrete over those years with few operators leaving the industry. There are now probably still more (potential) quarries in the Republic of Ireland than are in Great Britain where the traditional market is five times greater.

Market issues (dealt with in more detail in Section 4) and other legacy issues from the ‘Celtic Tiger’ years of high levels of house building have seen recent regulatory changes which tighten accountability in the professional services industry, and which will result in more appropriate accountability in the construction material supply industry, including aggregates and concrete.

Certification rather than opinion is demanded, and certification only comes from confidence in what has been supplied. Standards are being reviewed and, where necessary, improved following reasoned consultation and debate, often as a customer confidence inducing measure, as well as to improve on old practices. Professional industry welcomes these improvements as an opportunity to address the competitive balance with the ‘pop-ups’ and has participated in each and every relevant national technical committee, generally under the auspices of the NSAI.

CE marking became mandatory from 1st July 2013 and has still to properly take hold and be enforced. Again, certification necessitates that all of the construction industry gets to grips with this fundamental requirement for many of the standard products. More often than not, it is not a question of product non-compliance with standards but is one of incorrect designation and even ignorance of the Euro Norme equivalents (IS ENs) of older but equivalent Irish Standards (often long since withdrawn). The market will sort this out quickly as non-compliant declarations are not tolerated, and should lead to supplier disqualification at pre-construction materials pre-approval stage.

So, this is an industry coming out of recession with lots of challenges but with a core professional industry embracing change and seeking a level field of competition.

2. EXTRACTION

The Republic of Ireland’s planning system substantially began with the Local Government (Planning & Development) Act 1963, No. 28 of 1963, which commenced on 1st October 1964. On the basis of the registration process, circa 70% of sites claim authorisation by virtue of existence prior to 1st October 1964, thus not requiring permission for development thereafter under Part IV, s.24 of the planning legislation, accepting existing works and uses as not requiring permission. This is not as unusual as it might appear as many sites were opened along the routes of the regional and other roads built in the 1950s and early ‘60s when opening a new pit was more desirable than hauling materials any great distance, given the lack of infrastructure and suitable transport. Despite being open to challenge on the basis of the doctrines of intensification and abandonment developed primarily in the period 1978-1999, many of these authorisation continue to form the main, or only, authorisation for some sites, even some of the most substantial sites.

These authorisations have been reviewed recently and the 1963 Act amended (s.261A review 2012, following ECJ C-215/06, 3rd July 2008). The review was primarily within the context of possible offences against both EIA and AA legislation. The former relating to European Communities (Environmental Impact Assessment) Regulations 1989, S.I. No. 349 of 1989, giving effect to the Council Directive of 27 June, 1985 (No. 85/337/EEC, O.J. No. L175/40, 5 July, 1985) and the latter to European Communities (Natural Habitats) Regulations 1997, S.I. No. 94 of 1997, giving effect to Council Directive No. 92/43/EEC of 21 May 1992. There have also been reviews of all planning permissions since 1964, as well as a significant number of developments which have operated without either ‘pre-63’ or permission, i.e. completely unauthorised. This has resulted in a process of regularisation where authorisations have been found deficient, and decisions warranting enforcement action against those sites without any authorisations, and those who failed to enter a regularisation process (where required to).

It is commonly held that crushed rock accounts for 70% of output with sand/gravel accounting for 30%. There has been a small amount of recycled aggregates used in recent years, generally in fill materials, though current shortfalls in nationally agreed criteria for ‘end of waste’ status, as required by national (European Communities (Waste Directive) Regulations 2011, S.I. No. 126 of 2011, Art. 28) transposing the European Union Waste Framework Directive (2008/98/EC), Art. 3(1), restricts the current usage in any form. A small amount of dredging of marine aggregates (sand/gravel) occurs at times, with that material processed in substantially the same fashion as land derived gravel.

The term ‘quarrying’ is defined in planning legislation (Mines & Quarries Act 1965, No. 7 of 1965, now repealed, and more recently Planning & Development Act 2000, No. 30 of 2000, as amended) and is applied to both traditional rock quarries and sand/gravel pits, though the nature of these operations are materially different. Rock quarries normally require the use of explosives to perform the act of extraction, a requirement which is legally materially different from mere excavation of resources, requiring permission if not included in the site authorisation(s). Quarrying is a wide term and includes all extraction, processing, storage of materials and the resources themselves; extraction alone is the scheduled activity under the EIA Directive and transposing regulations.

To begin the extraction process, the area to be blasted will have been stripped of soil, and checked for the presence of archaeology during that process or through previous trenching under licence (National Monuments Act 1930, No. 2 of 1930, as amended, s.26) or other methods. Topsoil and sub-soil is managed, generally separately with the eventual site restoration in mind, under the Waste Management (Management of Waste from the Extractive Industry) Regulations 2009, S.I. No. 566 of 2009, giving effect to the provisions of Directive 2006/21/EC of the 15 March 2006.

Blasting practice requires a degree of design to ensure both a safe and economical blast, which will generally involve rows of shots being separately detonated in a series of mini blasts so that the resistance to each element of the blast is minimised, all within the space of fractions of a second. A typical blast will likely result in a blast rock pile of 15-20,000 tonnes, greater still in larger quarries with longer faces to blast. Blasting is an art form and not to be taken for granted, as mistakes can see fly rock thrown hundreds of metres instead of just dropping close by the blasted face. Therefore, the attention of the driller is needed in identifying potential geological anomalies which would serve as impediments to a safe blast. The process is illustrated in Figure 2.

Whether in the form of blast rock, or sand/gravel directly excavated from a pit face, this won material is screened and put through a primary crusher, generally in close proximity to the face where mobile machinery is used. This both cleans the won material of extrinsic contaminants and then processes it to manageable size for further screening and processing.

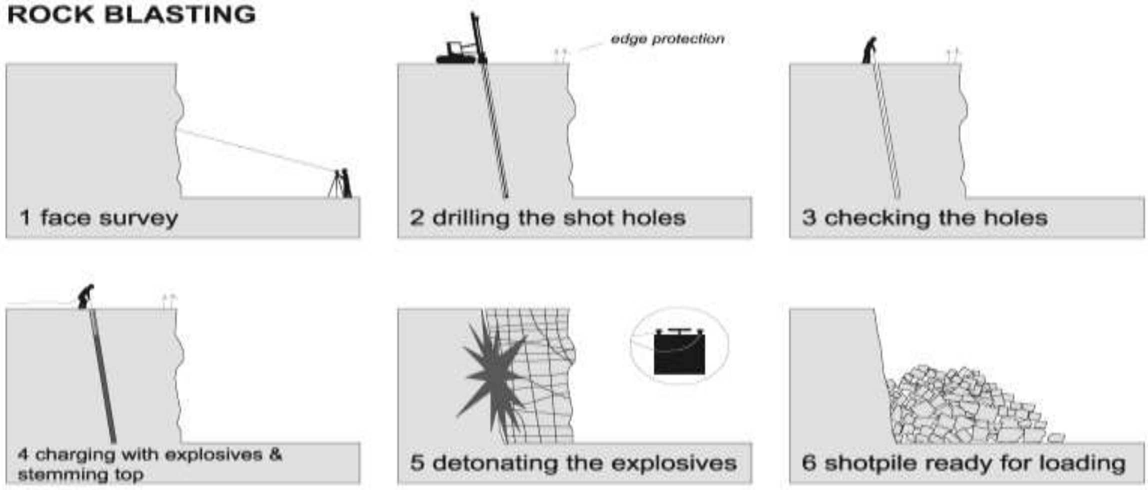

Figure 2. The blasting process in a rock quarry (Roadstone Ltd.)

It is through this onward processing that the proposed uses (markets) for the eventual aggregates must be anticipated and the appropriate screens and crushers incorporated to achieve the required grading of each product.

An intimate knowledge of the geology is also required to inform the choices of equipment and crusher type (e.g. jaw, cone or impactor types), indeed it is a matter for consideration on whether or not to exploit the resource in the first place and the type of plant installed. The product requirements are more a choice of configuration and the extent of plant required. A typical production process is presented in Figure 3.

Whether blast rock or gravel, the won material is first handled using large capacity excavators to load dumpers or conveyors which carry the materials to the first screener and primary crusher. As internal site distances increase, the use of conveyors provides better value than the alternative cost of numerous dumpers, and this is likely to become a feature of larger sites where haulage distances can be upwards of one kilometre. Conveyors and screening is illustrated in Figure 4.

Production processes seek to maximise the yield from the resource generally while achieving crushing on all faces of the particulate. Thus, screens are used to split the resource into different sizes with different uses for each size as a product or feedstock for the next phase of further processing. Undersized and flaky material is recirculated and further crushed down and/or shaped to yield a useful product, preferably not generating excessive fines.

Many quarries produce fill materials only; clearly, this does not involve the very significant amounts of plant required to make single sized aggregates for use in products such as concrete. As such, quarrying for fill only does not normally result in large quantities of crushed rock fines (6.3mm - 0). Where single sized aggregates are produced, this will result in undersize and fines by-product arising from shaping processes; sites such as these normally add manufacturing of concrete and/or macadam to site activities if not already in place which beneficially use this clean, fully crushed fine material.

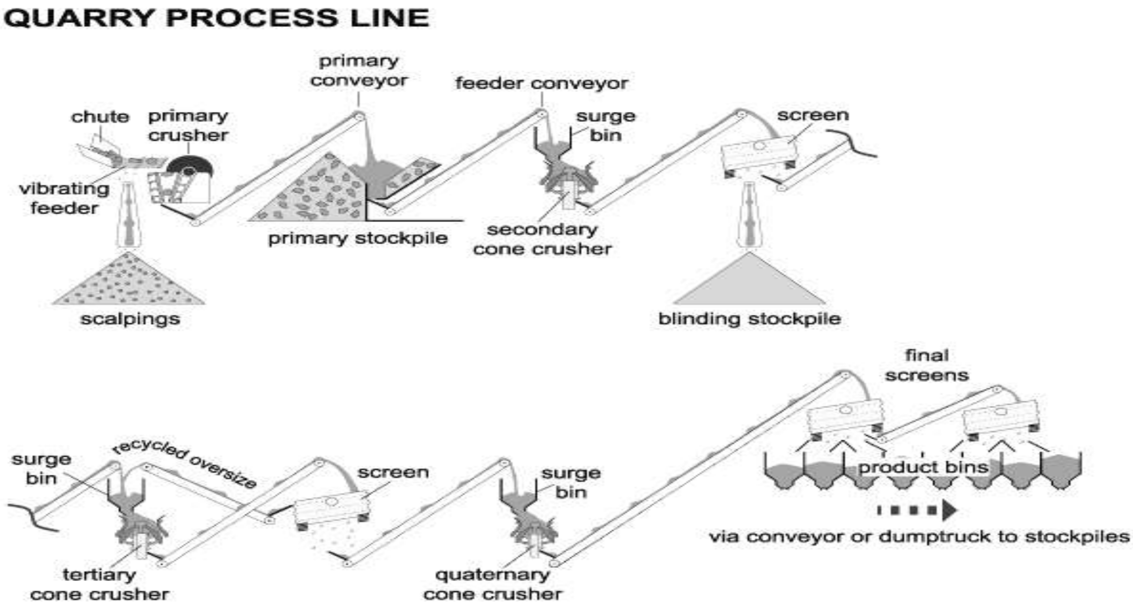

Figure 3. Typical production process for a full range of products (Roadstone Ltd.)

To produce a full range of aggregate sizes naturally involves very sophisticated crushing and screening processes, perhaps producing single sized aggregates in seven different nominal sizes in addition to the more basic range of fill, capping and drainage materials. Clearly, this also requires significant technical knowledge not just in terms of production management but equally in terms of quality management which substantially informs the production set-up.

It is important to note that the secondary screening, post primary crushing, means that all downstream aggregates should be perfectly clean of clays. It is from this point of processing that we consider the inherent geology for the particular end uses as we wish to consider them in connection with concrete.

Figure 4(a) .Large capacity conveyor of c.1km length (B.D. Flood Ltd.)

Figure 4(b) Mobile screening post primary crusher (Roadstone Ltd.)

3. GEOLOGICAL CONSIDERATIONS

Ireland's rich and varied geology is normally considered in terms of both the solid rock geology and the overlying unconsolidated sediments overlying the solid rocks, and deposited either during or since the last Ice Age. Three great rock groups exist here, namely (i) igneous rocks (formed within the earth such as granites in Leinster and basalt of Antrim), (ii) sedimentary rocks (formed from either the weathering of earlier formed rocks, for example the sandstones of Cork, or by precipitation in water, for example the limestones of central Ireland), and (iii) metamorphic rocks (formed by heat and pressure related forces within the Earth, for example, marbles, quartzites and schists as in the rocks of Connemara). The most common rock type in Ireland is the limestone found in the Midlands, which is of the order of 300-360 million years ago (the Carboniferous Period).

Thus, once knowledgeably assessed and developed, there is undoubtedly an abundance of good quality rock for engineering and construction purposes within economic distance of the point of production. While sand is often in short supply along the eastern coast, elsewhere there is generally a mixture of rock and overlying quaternary resources available across the country so as to allow cost efficient concrete production everywhere. In places, different rock formations may lie on top of each other making the proving of resources more technically challenging and development more intricate.

Environmental issues have the effect of sterilising many significant sources of gravel, e.g. for visual impact or habitats issues, and this has added to what is becoming an acute shortage within reasonable transport distance of the Greater Dublin region, where a third of the concrete market exists. The more recent development of 'NIMBYism' is also a considerable force in determining where resources can be exploited.

With regard to the eastern coast, including the Greater Dublin region and up to Louth, the need for sand has resulted in the transportation of supplies from further afield, distances of perhaps 60 kilometres which adds substantially to the production cost of the finished concrete, as well as logistical issues for manufacturers. It is possible and technically sound to manufacture sand from rock but it is also expensive and energy intensive, and is a matter of cost: benefit analysis for those in that predicament with security of supply a major concern.

The primary source of geological information in Ireland is the Geological Survey of Ireland (GSI) which generates, maintains and shares very significant databases on the geology of the country. Geological heritage has become a notable new issue in the last decade as a consideration for development proposals, with many geological heritage sites now enjoying the protection of County Development Plans. Nevertheless the GSI maintains a general outlook that, in principle, overall knowledge of geology increases through responsible extraction. GSI has a complete database of rock and an increasing database with regard to quaternary resources (sand/gravel).

For development purposes, this has led to the creation of the Aggregate Potential Mapping database where resources are identified on a county by county basis, and announced public infrastructure development and other factors are added into a matrix leading to an overall index of potential for development. Once maintained and updated, this is a useful resource, though it is not exhaustive (yet) and the matrix is subject to certain assumptions which can easily become outdated. However, the resource mapping on its own is of great interest to quarry operators.

The GSI also maintains a quarry directory (Geological Survey of Ireland, 2014), which includes data on quarries which provided responses to a questionnaire; while also useful, it is incomplete as many quarries did not respond and, thus, needs to be a ‘living document’ (as it primarily is meant to be, and is in soft copy for this reason). The Environmental Protection Agency also maintains a partially completed database on extraction sites, on foot of its role under the Extractive Waste Regulations.

Rock types which are typically not suitable for aggregate production include weak or strongly foliated rocks such as mudstones, shales, slaty mudstones, argillaceous siltstones, argillaceous limestones, schists etc.

It is fair to say that until the pyrite issue arose (Section 4.1), resource proving primarily concentrated on the resource’s physical attributes, namely strength, cleavage, water absorption and general soundness, generally avoiding weak rock in this manner. Unfortunately, some weak rock deposits were still developed and used as construction materials.

Other economic issues considered during feasibility studies include the cost of development, depth of overburden, development consent application(s) costs, planning authority costs including development contributions (under s.48 and 49, formalised development contribution schemes from March 2004 onwards), and local road network capacity for the development. The presence of so many ‘pre 63’ sites has to date overcome many of these economic concerns for many operators, and provided a history of use over decades for many of these sites which testified to the quality of the resource. In my opinion, many of these sites have failed to provide for the replacement cost when those historical resources run out, and may face closure at that point.

Following on from the pyrite issue, all responsible operators employ the professional services of a highly competent professional geologist, experienced in quarry matters and *au fait* with product requirements (physical and chemical), advising and reporting on appropriate development and use of the resources. The role of the professional geologist is now being incorporated where appropriate into certain Standard Recommendations for products on the Irish market, a move which is welcomed by the professional industry. Standard Recommendations are in place for many products on the Irish market, officially guidance for product use but effectively fulfilling the role of a National Annex to the Irish version of the European Standard (I.S. EN), where applicable, as managed by the National Standards Authority of Ireland (NSAI).

The professional geologist will properly analyse and interpret available data and report on the quarry as a whole, identifying any variability in the resource (on area or depth basis), perhaps identifying some areas as being better than others for certain products or processes. Product conformance is a matter of testing finished stockpiles of product, which has gone through the cleaning actions of the crushing and screening processes; thus, a rock sample from the quarry face is not to be taken as representative of the finished product, particularly where significant processing has occurred.

Recent issues have necessitated deeper technical appraisal of potentially deleterious materials which may be vulnerable to swelling on their own or in the presence of sufficient quantities of certain chemicals. In this regard, of primary interest are the sedimentary mudstones which can form part of otherwise perfect sedimentary rock and current wisdom is to cap the percentage of such deleterious elements at a low level so as to ensure the overall soundness of important products, e.g. materials for use as fill under concrete slabs and for use in concrete itself.

Many sedimentary rocks lie beneath gravels derived from those rocks, with the pressures of glaciation having effectively substantially diminished the potential reactivity of those gravels. The cleanliness of those gravels is the greatest issue for the economic feasibility of extraction and processing, as gravels may often contain upwards of 15% silt. Processing must, therefore, involve finer screening than blast rock, and additional washing, and the economic handling of those silt arisings.

Silt arisings from washing processes, where required, may result in large amounts of process wash water which needs to be recycled by circulation through settlement lagoons or by special de-watering plant which releases most water immediately with a resultant heavy sludge being pumped to storage, preferably placed as part of a site restoration process. All of these processes add to the cost of production of the finished aggregate so double handling is to be avoided if at all possible at all stages of processing and manufacture, adding complexity the processing set-up.

4. MARKET ISSUES

The last decade has seen issues arise which have resulted in a significant diminution of confidence in the construction industry's professional standards, and some of these issues have been traced to the construction materials sectors including aggregate and concrete products. While only a very small number of quarry and concrete operators have been implicated in quality issues to date, and some of the complex quality issues relate at least in part to poor standards and often poor client specification and site practice, the entire quarry and concrete industries has come under the spotlight and is proactively involved in national debate on appropriate specification improvements.

4.1 The Pyrite Issue

Pyrite is a very common mineral generally occurring as veins, coarse crystals or finely disseminated (framboidal) crystals and whose occurrence in Ireland is similar to the global norm. Pyrite is the most common and abundant iron sulphide mineral and is composed of iron and sulphur. Where the crystal size is fine, the pyrite tends to be most reactive (framboidal pyrite) and is more prone to degrade in contact with air and water, which leads to the generation of iron sulphate and sulphuric acid. Where the rock contains calcareous minerals, the acid reacts with this to form gypsum which has a greater volume than the pyrite, leading to an increase in the volume of the material (swelling).

It is worth noting that many rock types do not contain elements such as calcite or dolomite and such swelling will not occur. However, in weak mudstones and shale, this expansion can fracture the rock allowing air and water penetration leading to further exposure of more pyrite resulting in further reaction and expansion. With strong rock (such as limestones, granites, sandstones, greywackes, basalts, rhyolites etc.), only surface pyrite may react, as the aggregates will not fragment and the degree of expansion will be negligible.

Around 2006/7, issues arose in the wider Dublin area with regard to the occurrence of heave below concrete slabs, leading to cracks and structural failure of floors and walls in manners not evident in traditional failure mechanisms. Upon investigation, it was attributed to the placement of unsatisfactory fill containing significant levels of reactive pyrite beneath concrete slabs, substantially or entirely from five quarries in the Greater Dublin region. Potentially, several thousands of houses have been affected to a greater or lesser degree.

This led to an immediate review of the applicable National Standards Authority of Ireland (NSAI) guidance to the standard I.S. EN13242, in that case SR21, to which was added Annex E to deal with the revised specification for what is commonly called hardcore for use under slabs (see below). Annex E gives recommendations for specifying material properties and recommendations for procedures for production of unbound granular fill (commonly known as hardcore) for use under concrete floors and footpaths. The material proscribed by Annex E 2007 contained little by way of fine material, theoretically limiting the potential for swelling of the material, as well as providing room within the void space of the compacted material for any swelling that might occur. It also provided for mandatory chemical testing of the aggregates with appropriate limit values.

This material proved difficult to manufacture so few quarries offered it at that time. Additionally, engineering reason suggests that a complete grading envelope incorporating fines will yield a better structural solution, as long as the chemical quality of the source meets the 2007 Annex E chemical criteria. The result was that the market evolved to where National Road Authority (2013) specification Clause 804 with the chemical requirements of SR21 Annex E 2007 was the structural fill of engineering choice beneath concrete slabs. Over time, the NRA itself amended its own specification to introduce more demanding specifications for materials in close proximity to concrete and steel, resulting in Clauses 808 and 809 respectively (effectively Clause 804 type material with increasingly stringent chemical requirements). Thereafter, there was something of a further move by specifiers to opt for Clause 808 in place of Annex E material.

In parallel, the pyrite problem was deemed so significant that a formal investigation was carried out by the department with responsibility for building standards and controls, leading to the publication of the Dept. of the Environment, Community and Local Government (2012) report on the problem. Special NSAI Committees were formed to deal with the identification of pyritic induced heave in dwellings and the development of a specification for replacement material for use during remediation works; this led to the publishing of I.S.398 Parts 1 and 2, dealing with inspection, diagnosis and remediation of pyritic induced failures in housing.

As the work of that committee ended, the NSAI Aggregates Panel, a sub-committee of the Roads Committee, began work on other requirements of the Pyrite Panel Report, namely a ‘cradle to grave’ approach to traceability for such fill materials, requiring the NSAI Aggregates Panel to carry out both a further review of the material specification SR21 Annex E and the development of a Code of Practice with regard to the ordering, supply, acceptance and placing of SR21 Annex E material. With regard to the latter, this Code of Practice, which is currently in draft form and awaiting public consultation later in 2015, will be published as I.S.888, and will place traceability requirements on the builder, supplier and any intermediary with regard to the ordering, transport and placing of SR21 Annex E materials.

As an additional confidence measure, and as I.S. EN 13242 is a harmonised standard and, therefore, subject to the requirements of the Construction Products Regulations, Ireland voluntarily moved from attestation level 4 (self-certification) to level 2+ (requiring independent auditing by a notified body) of the factory production control procedures required by the standard.

4.2 The Concrete Block Issue(s)

More recently, issues of concern have arisen with regard to the supply of concrete blocks in a number of areas of the country, from a small number of suppliers, but with a particularly clear failure mechanism in the Greater Dublin and east coast market, with concrete block failures prior to and post construction. In this particular case, the otherwise very reputable company involved is dealing with the issue but it has undoubtedly added to concern with regard to quality standards generally, as the failure could be directly traced to the blocks in this case.

Elsewhere, failures of weathered gables of houses in Donegal following the severe winters of 2009/10 and in Mayo in similar conditions have added to concerns not only with regard to quality of products, but also to the correct specification of products and appropriate specification of renders, and indeed the leaving of blocks un-rendered for long periods of time during extended construction periods.

As previously touched on, the transition to CE marking has not been as consistent among suppliers as the industry might have wished even though the confusion was a matter of designation rather than product performance. Aggregates must be designated with respect to the Euronorme, e.g. I.S. EN 13242 SR21 Annex E and not to the NRA specification, e.g. NRA Clause 808, which is effectively a private client specification and which may deviate from the Euronorme on that basis.

Concrete blocks for use in dwellings in the Republic of Ireland must be 7.5N/mm^2 Category 1 blocks to I.S. EN 771-3, prepared and tested in accordance with I.S. EN 772, and carry attestation level 2+, as set out in the durability requirements of SR325 (where Category 1 is specified). Masonry is required to be designed in accordance with various Department of the Environment Building Standards Technical Guidance Documents, Euro Code 6 and SR325, as appropriate.

However, a difficulty arises for both customers and specifiers, concerned at recent issues, in that there is no appropriate chemical test for blocks that will identify propensity to fail. The approach has to be a reliance on the quality of the input materials, especially the aggregates as specified in SR 16 and SR18, both of which are currently under review. It is noted that cementitious binders require CE marking to attestation level 1, which is the highest standard, due to the reliance of concrete on the cement matrix for its very existence.

As of now, attestation level 4 applies to aggregates bought in by the concrete manufacturer for the manufacturing of concrete products; own processed aggregates do not require CE marking as it is the finished concrete product that the manufacturer is putting on the market, and therefore requiring CE marking, where a harmonised standard exists.

Harmonised standards exist for most products but not for that of readymix concrete, so Irish manufacturers engage in a voluntary scheme of certification to I.S. EN206, which should be specified in all cases.

The discussion now requires review of the key parameters of the aggregates standards and standard recommendations in place and under review in Ireland at this time.

5. STANDARDS AND STANDARD RECOMMENDATIONS

The following discussion of standards, and particularly that of the Irish Standard Recommendations (SRs), appears to concentrate on the specification for fill under concrete floors. This is merely a reflection of the evolution of the current review of all of the standards as many of the changes made to the fill specification are now to be reflected in the aggregates for concrete specification.

When the reviews of the specifications are completed, it is just as important that construction industry stakeholders, specifiers, contractors and suppliers, are made aware of and become familiar with the current requirements, including those proposed for traceability, lest problems of the past get repeated.

5.1 Hierarchy of Standards

The European Community requirement for standardisation of products is primarily aimed at freedom of movement of goods, enshrined in the EC Treaty on the Functioning of the European Union (TFEU), Art.34-36. This has meant the withdrawal of long established Irish Standards (I.S.), and the need for acquaintance with the adopted appropriate Euronorme (European standard) in the form of Irish Standard Euronormes (I.S. ENs). The European standards are reviewed periodically, generally following a five year period of implementation, and changes to a European standard will occasionally necessitate a review of associated national references to the document and guidance on the use of the European standard. Indeed the entire suite of European aggregate related standards is currently out for review and member state comment will be considered by the NSAI aggregate standards later in the year.

These adopted standards (I.S. ENs) typically provide for additional national requirements through the use of a National Annex to the standard. This mechanism has been used sparingly with regard to construction products, though this has led to necessary reliance on knowledge of additional mandatory requirements for products on the Irish market arising through Department of the Environment Building Standards Technical Guidance Documents and standard specific Standard Recommendations, the latter effectively acting as the National Annex (as will have been gathered from the discussion above).

Thus, when looking at conformity to a product, one should look at several documents to ensure that the manufacturer is declaring values, and meeting threshold values where required, in accordance with all necessary requirements.

It should be noted that this has the effect of expanding the list of declared properties normally required under CE marking arrangements; indeed the failure to make the appropriate statutory declarations is a very important issue for the purposes of materials pre-approval and/or sign-off as it is difficult to see how this can be remedied post construction where the information is unknown at the time of supply.

5.2 Testing of Aggregates

Each standard sets out the requirements for the regimen of factory production control testing appropriate for the product in an annex, and which must be met or exceeded by the factory production control procedures of the manufacturer, save any intensification of required testing arising from other regulatory sources, e.g. SR21 Annex E imposes a higher frequency of certain tests which may be relaxed by the professional geologist once the resource characteristics are well known and documented.

It should be appreciated that testing frequencies, expressed in days, months etc., refer to production days, months etc. and not to calendar days, months etc. Thus, for example, a weekly requirement arises after every five production days within an overall longer period of time. This is set out in EN16236, the 2013 version of which was withdrawn but a draft version is out for public consultation at this time.

While large quarries have almost continuous or at least very regular production of many products, and so will have very regular testing of the required parameters, smaller quarries often produce in large batches of particular products before adjusting limited plant to make a different product. This results in the smaller producer having test results appropriate to their method of manufacture but which may look a little out of date; this would, most likely, be an incorrect assumption as the standards do not seek re-testing of existing stockpiled material, just the testing of new production to the required regimen.

Thus, a small operator may produce a large stockpile of, say, SR21 Annex E material in January, sufficient for sales of such material over the entire year, test appropriately at that time and then not re-test the slowly diminishing stockpile, which is not further added to by new production. Given current demand, this is not at all unreasonable as testing costs are substantial when output is low.

In legal terms, the improvement of a product specification does not constitute an acceptance that the old specification was deficient. However, when issues arise, and some changes are mandated in one area, it is reasonable to have those improvements included in associated areas, unless there are valid reasons for non-inclusion. The pyrite issue detailed above, leading to now multiple reviews of SR21 Annex E, has resulted in a tightening of the physical and chemical parameters for compliance under that specification. Upon review of the specification for aggregates used elsewhere, certain or all of, the changes to physical and chemical requirements, other than grading which is a different issue related to the material's engineering properties, suggest a simple reasoning that much of the same basic set of tests should be required for all uses, i.e. the identified causes of the pyrite problems should be excluded from critical uses of all aggregates. This is not unreasonable, and per above, is not legally indicative of any past issues with regard to product quality.

The benefits of this approach does, however, have effects which might be seen as beneficial to the customer but with economic cost. It will mean additional testing, and associated costs, for processors of materials which have never been implicated with respect to inferior quality products.

In my opinion, given the level of unauthorised extraction operations which exist in Ireland and all that that entails, the requirement for higher technical compliance cannot be seen as anything but a positive move which the vast majority of operations have nothing to fear, other than the attendant costs. Professional, responsible operators will already know the answers to these technical questions though perhaps without the frequency of testing that will be mandated into the future.

Thus, certain regular chemical testing of all mineral resources seems inevitable into the future, and that any one such set of results may form the basis of compliance with several product specifications (or otherwise inform where limits differ), depending on the diversity of the product range of the site. This somewhat mitigates the cost of inclusion of such testing in a uniform manner across several specifications but does result in a cost to sand pits not producing fill for under concrete slabs or themselves not producing concrete products, a common enough situation and which resource is highly unlikely to contribute to concerns as described.

The key chemical tests to be applied are Total Sulphur and Acid Soluble Sulphur (both tested in accordance with BS EN 1744-1) with petrographic (microscope) analysis required if Total Sulphur is >0.1% to see the nature of the rock material and the nature of any pyrite present.

5.3 IS EN 13242 – Fill under Concrete Slabs

As before, SR21 provides guidance on and is effectively the national annex to I.S. EN 13242: 2002 + A1:2007 -Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction. In particular, Annex E of SR21 sets out guidance for specifying aggregates for unbound fill (hardcore) for use under concrete floors and footpaths.

The deliberations of I.S. 398 had established the nature of the aggregates which had given rise to pyritic heave and it was accepted that a combination of high active pyrite content, as determined using measured acid soluble sulphate and total sulphur content, in combination with high levels of deleterious mudstone were the key parameters responsible for the pyritic heave problems observed. Clearly, control of these parameters was essential to the success of any revised specification.

The key 2007 changes, grading aside, had been the highlighting of the need for chemical testing to identify the nature of the sulphur compounds and hence potential for pyritic action, present in the product.

SR21 Annex E 2014, while contained within an overall revision of SR21, was the key driver of that more recent review. Originally, SRs 16, 18 and 21 were to be reviewed and combined in a 'super SR 60' but the need for clarity with regard to this material, given the problems which had arisen, required that it would continue to stand alone, effectively ending the benefits of any integration of standards into a super SR.

So, the current version of this Standard Recommendation is that of 2014 and this made significant changes to the 2007 version, previously alluded to above. In particular, the grading of the 2007 Annex E was removed in favour of the grading envelopes which appear for rock and crushed gravel in the National Road Authority (2013) Specification for Road Works, Clauses 804 and 805 respectively, and which reflected sound engineering reason with regard to achieving the best compacted result, based on using clean and chemically sound aggregates. Thus a 0-32mm grading was favoured in place of the previously recommended combination of 4-40mm blinded with a 0-6mm.

With the key parameters identified, the tight control of those specifics would ensure that any future material to the current standard had nothing in common with material which had failed previously, i.e. the materials were totally different. Consequently, deleterious mudstone was capped at 10%, when assessed by a professional geologist with professional discretion on how to arrive at such a visually difficult quantum for rejection. As above, preferred grading envelopes were incorporated which included the first acceptance of crushed gravel for this particular use.

A suite of testing was adopted for the in-depth analysis of aggregates with all but the most minimal of Total Sulphur (>0.1%), with precautionary limits set for Acid Soluble Sulphate (0.2%) on foot of such detailed analysis.

The key aggregate strength parameter, the Los Angeles Abrasion Value, was reduced to an absolute 30 as exists in the NRA specification; the reproducibility of this test is large enough to exclude a perfectly good aggregate depending on what test house is used and should be applied with caution and statistical certainty.

In Annex E only, Magnesium Sulphate Soundness testing has also been incorporated as a requirement to measure aggregate durability whereas it was previously only required by SR21 in the instances where the aggregate water absorption was above 2%. Additionally for Annex E, water absorption was capped at a maximum of 2% in an effort to ensure greater durability. Unfortunately, this has resulted in the omission of previously acceptable sources, with no identified problem material.

In overall terms, while there really is no such thing as a totally pyrite free material, materials complying with the tightened specification are deemed entirely satisfactory for the particular specified end use, having addressed all known parameters which led to pyritic heave failures. The complete specification is set out in Tables E.1 and E.2 of the current SR21.

Unfortunately, SR21 2014 was prepared without consideration of possible issues relating to radon gas. The subsequent implementation of the Department of the Environment, Community and Local Government (2014) National Radon Control Strategy identified the necessary reconsideration of Annex E grading envelopes, where concerns were expressed that the all-in grading envelopes were substantially inferior to a grading absent fines for the collection of radon gases to a passive radon sump, e.g. under all ground floor slabs of dwellings. Once that hypothesis is accepted and a gas permeable fill re-inserted into Annex E, then the chemical requirements of any blinding material for over gas permeable fill must also be provided for, for completeness.

This has led to the draft amendments to SR21 Annex E 2014, currently at the public consultation phase, where the proposed grading envelopes include adjustments to provide for (a) structural fill (same grading envelopes as per 2014 document), (b) gas permeable fill (grading envelope equivalent to that included in Annex E 2007) and (c) blinding layer (6.3-0mm), thereby ensuring the same chemical requirements and other soundness criteria are applied to all materials necessary to achieve the end use. Thus, the key proposed changes to the grading envelope will lead to significant additions to Table E.2.

Additionally, the definition of deleterious mudstone has been clarified as mudstone of a sedimentary origin, thereby ensuring that certain metamorphic resources are not unnecessarily rejected as unsuitable. This aspect is to be subject to further debate between an expert joint committee of the Institute of Geologists of Ireland and Engineers Ireland.

5.4 IS EN 12620 Aggregates for Concrete – SR16

IS EN 12620: 2002 + A1: 2008 is the key standard and national requirements for aggregates used in concrete products, including blocks and pre-cast products. Thus, all constituent aggregates must comply with this standard first, as the finished product compliance depends on such compliance of the key ingredients. As a more refined quarry product, this involves more processing, normally necessitating a background of higher technical competence not generally (previously) required with fill material production.

Originally to be incorporated into the 'super SR 60', SR16 will now remain as a stand-alone Standard Recommendation, whereas multiple uses under various standards might have been simultaneously identified for a single product type under the integrated approach.

Following the then thought finalisation of SR21 2014, SR 16 became the priority agenda item of the NSAI Aggregates Panel, though of late priority was again shared due to the radon issue detailed above. Now, a draft SR16 2015 is about to go to public participation and is likely to include proposals to incorporate many of the physical and chemical criteria tightening measures and thresholds incorporated into SR21 2014.

Most importantly, it will provide for the resource assessment by a professional geologist in the same manner as SR21 now does, which is of no real additional burden to quarries already producing SR21 Annex E materials or manufacturing concrete to IS EN 206 using own processed aggregates, but it will be a new issue for stand-alone pits producing sand for sale to others for such manufacturing ends.

It is worth noting that the current Acid Soluble Sulphate limit of 0.2% in SR16 effectively rules out the use of recycled concrete, which runs counter to the green agenda. This may yet be revised for this particular source of secondary aggregates, perhaps for selective use in readymix concrete only. The European standard has optional Acid Soluble Sulphate limits of 0.2% and 0.8%, the latter being suitable for recycled concrete and which was adopted in the UK, where 20% of aggregates are from secondary sources.

In my opinion, the proposed additions to SR16, including the incorporation of many of the appropriate changes to SR21, will further ensure that only robust material is used for the production of concrete and concrete products and that all sources of material must be properly assessed by a professional geologist who must certify the material for the particular use.

Based on market issues which have arisen in relation to concrete blocks in Donegal, and which remain to be resolved, industry opinion is that freeze thaw issues are at least partially responsible, particularly following severe weather conditions in the winters of 2009/10. To that end, aggregates must comply with the relevant provisions of the standard, including Table F.1 which lists categories for a range of climates.

While related, this is not to be confused with other requirements or limitations with regard to freeze thaw of finished products, e.g. concrete blocks, contained in other standards and standard recommendations.

5.5 IS EN 13139 Aggregates for Mortar – SR18

The current version of the standard is that of 2002 and the standard recommendation dates back to 2006. The standard specifies six preferred nominal sizes for aggregates, but the commonly used sizes in Ireland for three classes of use are masonry mortar (0/2 grading), render/plaster (0/2 grading), and floor screeds (0/4 or 0/8 grading). Sulphur content is capped at 1% Total Sulphur with Acid Soluble Sulphate at 0.2%, similar to SR 16.

Degree of coarseness is defined based on the percentage passing the 0.5mm sieve and may be categorised at CP (coarse), MP (medium) or FP (fine), the latter category only an option for 0/2 aggregate size.

The key change to SR18 arising from the current review will most likely be the incorporation of the professional geologist requirement, already present in SR 21 and also likely to be incorporated into SR 16. This will be a new development for suppliers not involved in the supply of other materials.

6. CONCLUSIONS

The past decade has seen reviews to standards and guidance in relation to aggregates used in or in association with concrete, some scheduled and some forced by market issues. Industry views the changes arising from these reviews as having little impact on the established professional industry, but they will result in additional cost on foot of additional certifications and traceability requirements; however, the amount and value of such material in a standard dwelling is not such as to have a significant impact on build costs. Customers must accept this as an acceptable aspect of material quality assurance and certification.

These measures are necessary to re-establish confidence with users and the public, the ultimate customers. However, supplier controls/certification is just one part of a necessary solution; specifiers and builders need to be equally aware of appropriate uses of products, limitations on use and traceability upon receipt from the supplier.

The technical changes are overall probably a touch excessive in that some sources which have never been indicated as having quality issues may be excluded on a minor parameter, particularly in the supply of fill under concrete floors and footpaths. However, the market issues which arose were of such significance as to warrant clear and bold steps to overcome market resistance, which resolutely refused to see that just a small number of suppliers were called into question, not an entire industry with a long tradition of producing good quality material.

It is important that the provisions of the Building Control Regulations and those relating to CE marking are implemented in every situation, without exception, so that properly certified materials are used in accordance with the standard recommendations and other regulatory instruments.

Only professional operations with obvious technical ability should be considered with materials pre-approved where possible; there is little point looking for the paperwork when the floor is poured or the building constructed.

Price alone is not a justification for material approval and use.

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DISCUSSION

MR. SMYTH introduced his paper. He provided further background to the make-up of the extractive industry in Ireland today. About 70% of current sites can attest to having been in existence on 1 October 1964, predating planning laws. A process of regularisation for the purpose of environmental control was instigated in 2004/2005. A European Court of Justice ruling in 2008 led to a situation where retention could not be granted where EIA or AA offences had occurred. A once-off regularisation process was negotiated based on the failure of government to transpose the law correctly. Interestingly it emerged that 2,200 sites could potentially be identified in Ireland, compared with 1,200 across England, Scotland and Wales. In practice about 90% of output comes from about 600 sites in Ireland. These comprise sites of varying scale from multi-nationals to regionally significant to family run small firms to opportunistic sites (‘pop-ups’). The pop-ups’, based on mobile plant, were a common feature of the boom times. In economic terms it would be described as a loose oligopoly. The market is very competitive: currently the Irish product sells for about half that of the equivalent in the U.K. Concrete production in Ireland is based around about 350 sites, most of which are on quarry sites.

He spoke of the excellent databases maintained by the Geological Survey of Ireland but emphasised the need for professional geologists with relevant experience when analysing a quarry. Such experts were vital when trying to identify likely sources of conforming processed end product when analysing variability within a quarry, based on rock samples. Variability down through the benches were also difficult to analyse, requiring geological expertise.

Introducing the market issues, he noted that problems that arose primarily stemmed from 'Celtic Tiger Economy' days. At that time construction reached a stage where it was 25% of the economy or at least twice sustainable levels. Construction of dwellings peaked at twenty per thousand of population per annum, whereas a sustainable level is about eight. A significant issue was pyrite. He cautioned that there is no such thing as pyrite-free material. It is a question of degree. By way of context he also pointed out that the pyrite problems stemmed from about five sites out of 1000. However they were very busy sites.

Outlining the current position in respect of Standards and Standard Recommendations (SR.16, SR.18 and SR.21), he echoed the earlier comments of Mr. Crowley that it was essential to keep abreast of the current documents and not to specify anything related to out-dated versions.

MR. JIM MANSFIELD commented further on the Construction Product Regulations and their relationship to sustainability and the life span of buildings. He felt that this was an area where research was needed to provide specific advice in respect of the upgrading of buildings already in use.

SESSION A-3

CEMENT AND ADDITIONS

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Abstract

This paper reviews developments in cement and additions in the period since the symposium was last held in 1995; including market developments, production, products, standardisation, performance and sustainability.

1. INTRODUCTION

While concretes and mortars based on cementitious materials date back to earliest times, industrially produced cements with which we are familiar today were invented and patented in the early 1800's. Since that time the development of sustainable economies and societies has been predicated on a secure supply of cement. The emergence of new nations has generally featured the establishment of national utility providers followed by national cement companies, a path followed by the fledgling Irish state in the early part of the last century when the establishment of Ireland's first cement plants in the 1930's followed on from the ESB's construction of the major hydro-electric power station at Ardnacrusha in the 1920's.

The modern cement and additions industry in Ireland employs over 2000 people directly and indirectly and comprises four fully integrated major cement manufacturing facilities in Meath, Westmeath, Limerick and Cavan, significant import/grinding stations in Dublin and Waterford and a number of other import and export facilities. In Northern Ireland there is one fully integrated cement plant in Co. Tyrone and further terminals for cement import and export.

Cement production in Ireland has always been at the cutting edge of manufacturing technology and the twenty year period since this symposium was last held has seen that trend continue. During this period significant changes have occurred right across the industry, from processes to products to markets, and from standardisation to applications and uses. The driving force behind many of these changes has been the sustainable use of resources, energy efficiency demands and carbon reduction strategies, themes which will be fundamental to our industry for the 21st century.

Continuous investment and improvements in both process efficiency and product performance have provided the platform for new product applications, which in turn has driven developments in standards. These investments have also allowed the industry penetrate new export markets. In the last decade alone over €300 million has been invested by the sector in Ireland (CMI, 2014a).

This paper outlines developments in the sector and their impacts on concrete practice in Ireland.

2. MARKET

2.1 Demand

Demand for cement is considered a bellwether for the construction industry and cement consumption is generally viewed as an important national economic indicator. The economic cycle experienced over the past decade has had a marked effect on the development of the cement sector in Ireland. Figure 1 summarises construction output in Ireland from 1970 to the present and clearly indicates a sustained period of strong growth from the mid 1990's followed by a sharp fall resulting from the post 2007 economic crisis.

The pattern evident in construction output is reflected closely in cement consumption, both by volume and consumption per capita as demonstrated in Figure 2 and Figure 3.

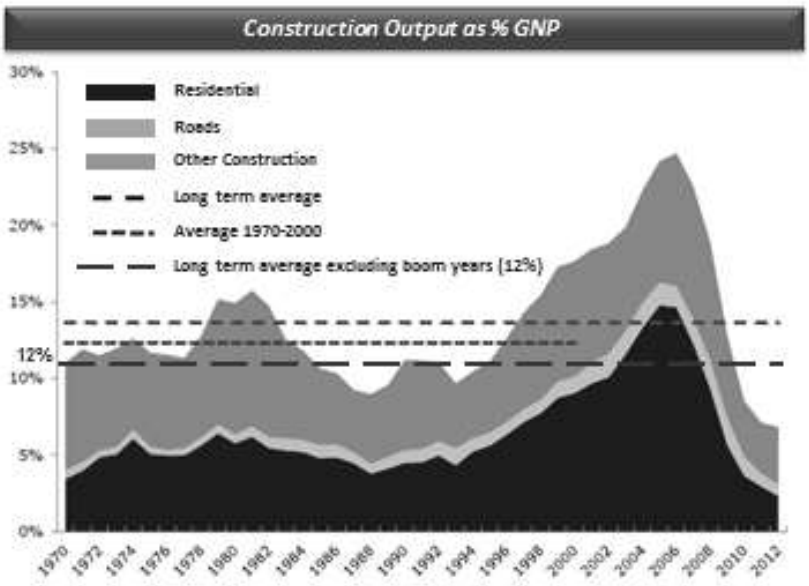

Figure 1. Irish Construction Output as a percentage of Gross National Product (Goodbody Economic Research, 2013)

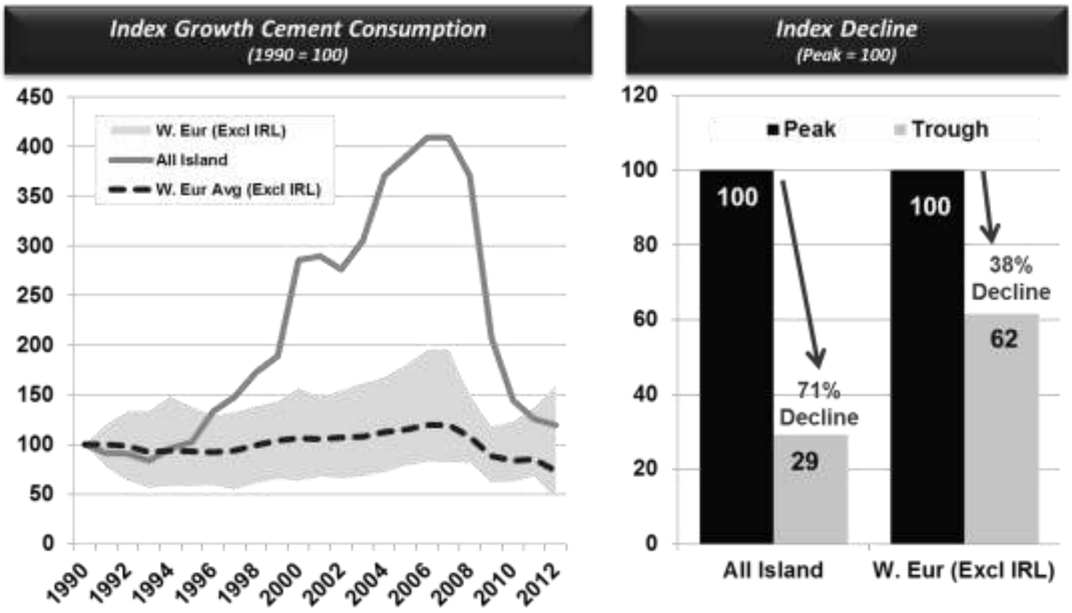

Figure 2. Total Cement Consumption (Republic of Ireland + Northern Ireland) versus Western Europe, and Peak to Trough Decline indexed to 1990 levels
(EUROCONSTRUCT, 2014 and International Cement Review, 2013)

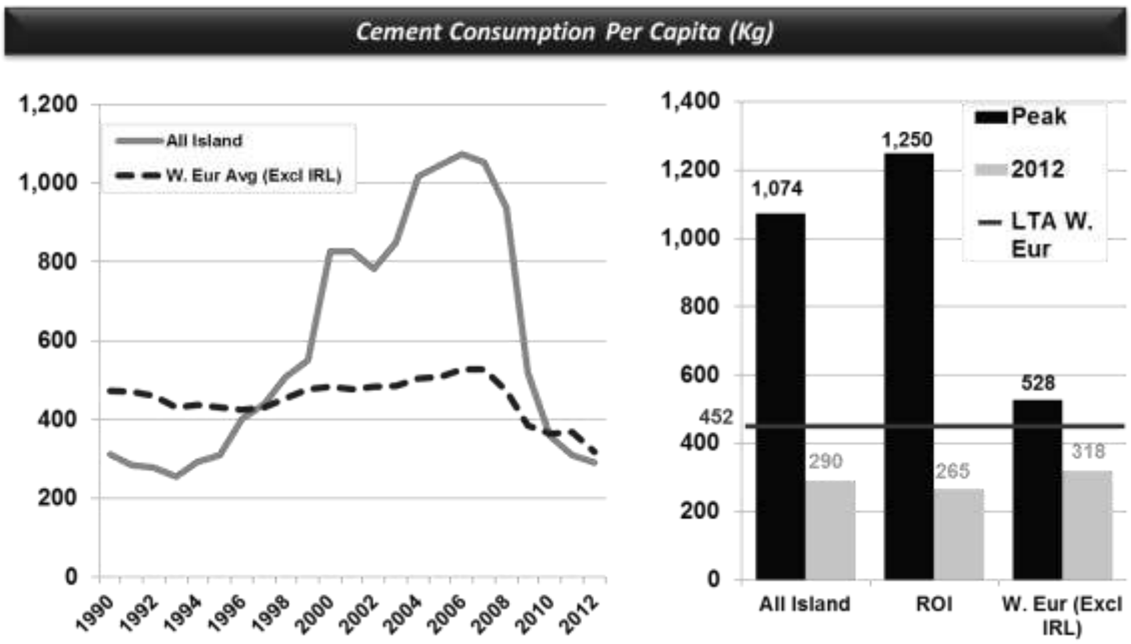

Figure 3 Per Capita Cement Consumption (Republic of Ireland + Northern Ireland) versus Western Europe and Peak to Trough Decline
(EUROCONSTRUCT, 2014 and International Cement Review, 2013)

While the construction market in Northern Ireland experienced a similar cycle during this period, the extent of growth and severity of contraction were not as extreme as that experienced in the Republic of Ireland.

2.2 Supply

The growth in cement demand between 1995 and 2007 resulted in new entrants to the market, expansion of existing facilities and the importation of cement, clinker and slag. Quinn Cement built a new production line in 2000 in Ballyconnell, Co. Cavan; in 2002 Lagan Cement developed a new plant near Kinnegad in Co. Westmeath; while Irish Cement installed a third kiln in their Platin facility in 2008. Various projects to increase capacity were carried out on the existing production lines in Platin and Limerick (Irish Cement), Cookstown (Lafarge – previously Blue Circle) and Derrylin (Quinn Cement). Noel O'Brien Cement installed a grinding station at its import facility in Waterford while Ecocem also developed an import terminal and grinding station in Dublin for the manufacture of GGBS and Blastfurnace cements during this period.

In the years leading up to 2007 demand (estimated by Cement Manufacturers Ireland, unpublished data) was such that, despite increased capacity and full production at domestic plants, approximately 1 million tonnes of cementitious materials per annum were being imported.

Post 2008 a reduced level of cementitious imports continued, largely unground slag and GGBS which are not produced in Ireland due to the absence of an indigenous steel industry. Smaller volumes of cement, including white cement are still imported. Bulk white cement is mainly used by precast concrete manufacturers, particularly in the 'face/surface mix' of products where particular finishes are required. Various companies have imported bulk and bagged white cement, from a variety of sources, over the past two decades.

2.3 Export

The sharp economic downturn and subsequent drop in cement demand post 2007 resulted in excess capacity in the industry in Ireland. The focus of the sector switched to export opportunities, mainly in the UK, the Benelux and other European markets. Irish Cement Ltd. acquired grinding stations in Belgium to which clinker is exported, and developed a network of cement import terminals in the UK which are supplied from both Platin and Limerick. Quinn Cement Ltd. developed an import terminal in the UK servicing the London market while Lagan Cement acquired a cement import terminal in the Netherlands. Lafarge supplied various sister plants with cement and clinker from Cookstown. Third party export supply contracts were also secured by companies in the sector during this period.

2.4 End Use

Like most developed economies, the demand for cement in Ireland, in volume terms, is largely for bulk deliveries. The breakdown of sales (estimated by the Cement Manufacturers Ireland, unpublished data) is typically in the range 80-90% bulk cement to 10-20% bagged cement.

As discussed above, overall construction output has fluctuated greatly over the past two decades, and Figure 1 highlights the role of house building in the dramatic increase and subsequent fall in output. Figure 4 demonstrates the peak to trough impact by sector in greater detail relative to European averages.

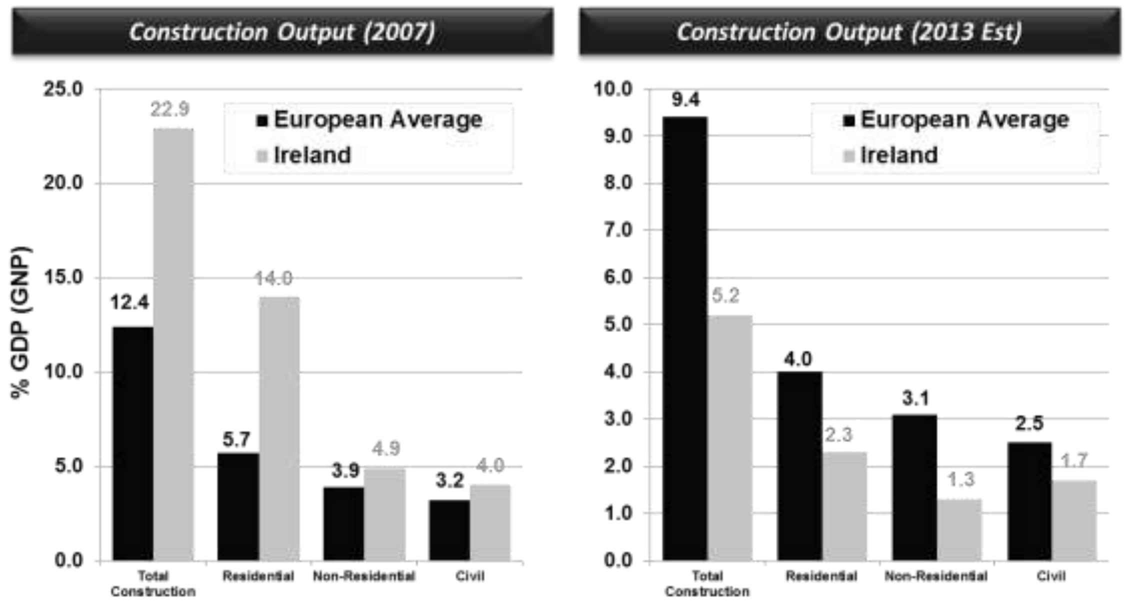

Figure 4 Irish and European Construction Output by Sector
(Goodbody Economic Research, 2013)

Residential construction accounts for the largest proportion of cement end use (>40%); however infrastructure, non-residential building (public, commercial & industrial) and agriculture are also important market segments. Specific policy led building programmes such as the Farm Waste Management programme in 2008 had significant regional impacts on cement sales.

Another feature of the economic downturn was the change in market end use, with repair, maintenance and improvement (RMI) increasing as new building activity decreased. This change, which is illustrated in Figure 5, also helps explain the reduction in cement demand as RMI activity is much less cement intensive than new build.

Cement products are predominantly supplied to the construction sector however other smaller markets such as the mining sector, which consumes slag binders, were not affected to the same degree by the domestic economic cycle.

3. CEMENT

3.1 Production

Since the installation of the first 'dry process' plant in Ireland in the early 1970's the Irish cement industry has been among the most efficient national industries in Europe. Industry developments outlined in Section 2.2 have reinforced this position. Specific recent technological improvements have included:

- Kiln burner and pre-heater tower developments to enable co-processing of alternative fuels.
- Materials handling equipment installation to incorporate alternative raw materials; i.e. overburden and/or fly ash as a source of silica, substituting shale.
- Installation of vertical roller mills to reduce electrical energy requirements.

- Development of materials handling equipment and grinding and blending technology to produce CEM II cements.
- Use of X-Ray diffraction (XRD) to improve monitoring of clinker mineralogy and cement quality.

3.2 Products

The single most important development in the cement industry in Ireland over the past decade has been the introduction of CEM II cements to the market. For 70 years prior to 2006 the main cement produced in Ireland was CEM I, previously known as Normal Portland Cement. Following company level product development programmes, CEM II cements were introduced between 2006 and 2008 and quickly grew to account for over 80% of the market. Irish Cement, Lagan Cement, Lafarge and Noel O'Brien Cement currently produce Portland Limestone cement (CEM II / A-L) while Quinn Cement produces Portland Fly-ash cement (CEM II / A-V). Quinn Cement use fly ash from the coal fired power station in Kilroot, Co. Antrim for the production of CEM II / A-V. Irish Cement Limerick Works utilise fly ash from Moneypoint, Co. Clare as an alternative raw material in clinker production and as a minor additional constituent in cement.

The key driver for the development of CEM II cements in Ireland was the improvement of the environmental performance of the industry and specifically the reduction of carbon emissions per tonne of cement. This is described in greater detail in Section 5.

To communicate the change from CEM I to CEM II cements to construction professionals, with respect to concrete performance, Cement Manufacturers Ireland commissioned the German Cement Research Institute (VDZ) to produce a detailed report (CMI, 2008) on the strength and durability performance of CEM II cements.

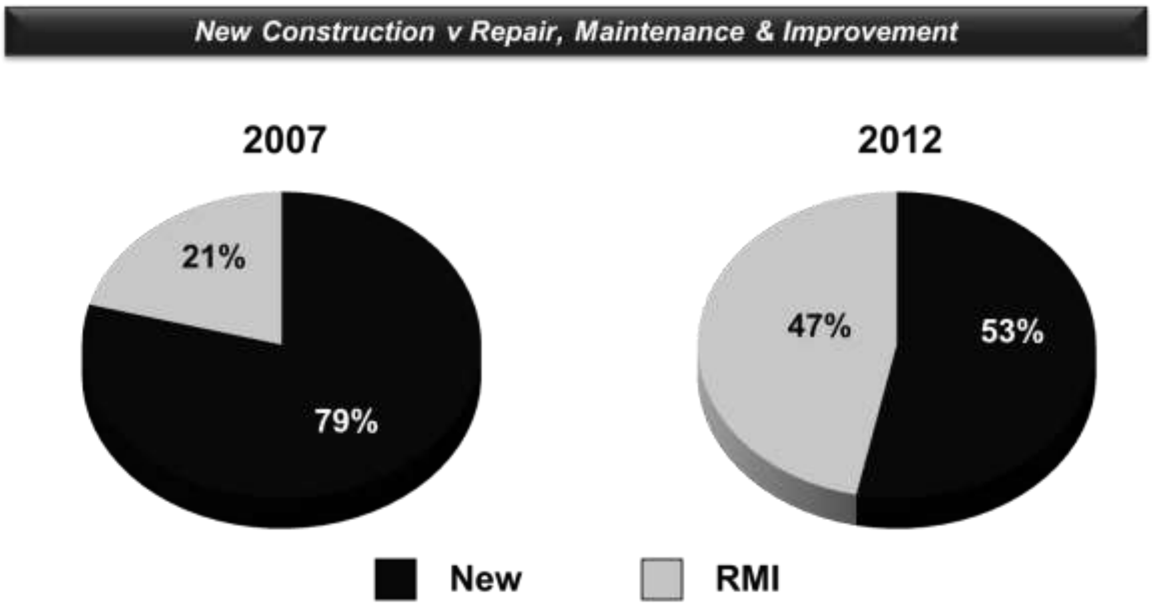

Figure 5 New Construction and Repair, Maintenance & Improvement – 2007 v 2012 (EUROCONSTRUCT, 2014)

This report, in addition to the work carried out by the industry in Ireland was considered by NSAI and other national specification bodies, and national concrete standards were revised and updated to include CEM II cements for general use in concrete.

CEM I is still produced and is largely used by pre-cast concrete manufacturers who require higher early strength to facilitate de-moulding of elements. More recently, CEM III Blastfurnace cements have been supplied to the market by Irish Cement, Lagan Cement, Lafarge and Ecocem. CEM I-SR3, previously known as Sulphate Resisting Portland Cement is also produced by Irish Cement Ltd.

3.3 Standards and Certification

The harmonised European standard EN 197-1 (NSAI, 2011), has been in use in Ireland since its formal introduction in 2000 and has undergone one revision in 2011. This revision included two main changes; updating Annex ZA to meet the requirements of the Construction Products Regulation relating to CE marking, and the inclusion of Table 2 'The Family of Sulphate Resisting Cements'.

A further revision of EN 197-1 is currently underway and is expected to be formally published by 2017. This revision, if approved, should include the introduction of ten new cement combinations to Table 1 'The Family of Common Cements'. The new cements under consideration are 'tri-blend' cements, containing clinker with a combination of two other approved and commonly used constituents (limestone/ fly ash/ slag). These new products have been subjected to a substantial, cross laboratory pre-normative testing programme at a European level.

The introduction of any cement or addition with new classification to the Irish market requires approval by an expert committee in NSAI, who assess its specific suitability for use in concrete in Ireland, before inclusion in the National Annex to I.S.EN 206 (NSAI, 2015).

3.4 Performance

The introduction of new cements and the increased use of secondary cementitious materials (or additions) combined with significant growth in the range of available admixtures in Ireland has resulted in increased flexibility for designers of concrete structures and producers of concrete. Numerous options are available to provide concrete with a variety of fresh properties and to meet a range of strength and durability classes.

For bulk cements the traditional 28 day strength parameter, measured in accordance with EN 196-1 (NSAI, 2005) is still of greatest importance in the market. The most commonly used bulk cements in Ireland typically have a 28 day mortar strength of between 55-60MPa.

Fineness (Blaine) values for bulk cement are generally in the range 3500-5000 cm^2/g. CEM II / A-L bulk cements tend to have higher Blaine values than the traditional CEM I cements they replaced, on a like-for-like strength basis, due to preferential grinding of limestone in the cement milling process. The advances in grinding aid technology, including strength enhancing grinding aids have improved cement performance and assisted with the smooth transition from CEM I to CEM II cements.

4. ADDITIONS

4.1 Introduction

I.S. EN 206 (NSAI, 2013) defines additions as ‘finely divided inorganic constituents used in concrete in order to improve certain properties or to achieve special properties’. Two types of additions are defined, categorised as ‘Type I’ and ‘Type II’.

Type I ‘nearly inert’
- Limestone

Type II ‘pozzolanic or latent hydraulic’
- Ground Granulated Blast Furnace Slag (GGBS)
- Fly Ash
- Silica Fume (Micro-silica).

One of the most significant changes in the concrete market in Ireland over the past decade has been the increased use of additions, particularly ground granulated blastfurnace slag (GGBS). Traditionally the only secondary cementitious material used in Ireland was fly ash, which was available from the coal fired power stations in Moneypoint and Kilroot in Northern Ireland. Available fly ash is used extensively in cement production, however smaller volumes are used in concrete products. Silica fume or microsilica is also used in small volumes in specialist concrete applications

IS.EN 206 provides rules for use of additions in concrete via three methods:
- k-value
- Equivalent Concrete Performance Concept
- Equivalent Performance of Combinations Concept.

A notable development in concrete practice in Ireland over the past decade has been the revision of the National Annex to I.S.EN 206 to establish specific suitability for the use of CEM II/A cements with additions.

4.2 GGBS

Ground Granulated Blastfurnace Slag (GGBS) is a co-product of the pig iron manufacturing process. Slag is tapped from the blast furnace and quenched with water. This rapid cooling produces granulated slag which has latent hydraulic and pozzolanic properties. In certain steel plants slag is air-cooled and sold as aggregate. The granulated slag is ground to form GGBS, which is used with cement in the production of concrete. Like cement, the performance of GGBS in concrete is influenced by its chemical reactivity and how finely it is ground. Performance of GGBS is also dependent on the compatibility of the cement with which it is used.

GGBS was originally imported by Irish Cement in the 1970’s and 80’s for the production of slag blends for mining applications. GGBS was first specified in structural concrete in Ireland in the 1990’s during the construction of the Jack Lynch Tunnel, primarily to reduce heat of hydration in large tunnel segments. It was subsequently specified by the National Road Authority (NRA) on bridges, mainly to assist in diminishing the risk of chloride ingress in splash zones.

In 2003, Ecocem opened a facility to import and grind slag, followed by Noel O’Brien Cement in 2010. Irish Cement, Lagan Cement and Lafarge currently import GGBS.

The harmonised European standard for GGBS is I.S. EN 15167 (NSAI, 2006). In ready-mix concrete GGBS is normally used at up to 50% by mass of cement however, the use of up to 70% GGBS is permitted in Ireland. Higher percentages are sometimes used in certain geotechnical and mining applications where low early strength gain is required. The National Annex to I.S. EN 206 sets out, in Annex NE, the conformity procedure for the use of GGBS. This procedure is a version of the Equivalent Performance of Combinations Concept where combinations of CEM I and CEM II/A cements tested with 50% and 70% GGBS in accordance with I.S. EN 196-1 (NSAI, 2005) must meet the 42,5N cement strength class requirements.

4.3 Fly Ash

Fly ash is a co-product of coal fired electricity production. The burning of pulverised coal produces fine, glassy, spherical ash particles which possess pozzolanic properties. This fine ash, or fly ash is recovered by filters from the flue gas stream before discharge to the atmosphere. In Ireland there are two coal fired power stations, Moneypoint and Kilroot. As described previously, fly ash from these facilities is largely used in cement manufacture as an alternative raw material for the production of clinker or in the substitution of clinker at the final grinding stage of cement manufacture.

Some fly ash is, however used as an addition in the production of concrete and concrete products in Ireland. Due to its pozzolanic properties, fly ash can assist in certain concrete applications such as reducing heat of hydration and enhancing chemical resistance. Its spherical particles can assist with the flow of fresh concrete and reduction of water cement ratios. I.S. EN 206 and the National Annex set out details for the use of fly ash in concrete in Ireland using the k-value concept.

4.4 Silica Fume

Silica fume (micro-silica) is a co-product of silicon metals production. It is a very fine powder which is often supplied in slurry form. The use of silica fume in Ireland is generally limited to specialist applications such as high strength concrete or concrete exposed to highly aggressive or abrasive conditions. I.S. EN 206 provides details of the rules for use of silica fume.

5. SUSTAINABILITY

The importance of concrete to modern civilisation is such that, after air and water, it is the most used substance on the planet. Therefore cement, the glue that makes concrete possible, is manufactured in nearly every country in the world. Sustainable cement manufacture relies on the local availability of calcium and silica bearing minerals, principally limestone, in abundant supply.

The modern cement industry in Ireland has grown significantly over the past eight decades and has continuously invested in ‘Best Available Technology’. Some examples of recent process and product improvements undertaken by the industry were outlined in Section 3 and it was noted that the key driver for many of these developments was improved environmental performance. This investment has ensured that cement plants in Ireland are among the most efficient in Europe and has provided the platform for sustainable development of the industry. Cement companies have been in a position to adapt to volatile economic circumstances in Ireland by turning to export markets to secure jobs, including many jobs in rural areas where the cement plants are typically located.

Cement production accounts for 3% of Ireland's carbon emissions (CMI, 2014a). Each cement plant operates under the EU Emissions Trading Scheme (EU ETS). Cement sector emissions, which are regulated centrally under the EU ETS are not included in Ireland's national targets for carbon reduction, set by the EU.

Production of cement results in carbon emissions arising from de-carbonation of limestone (c.60%) and fuel burning (c.40%). Process improvements and product development have focussed on resource efficiency, energy efficiency and clinker substitution. Specific reductions of the order of 20% have been achieved for some products since 1990 (CMI, 2014a).

5.1 Resource Efficiency – Alternative Fuels and Raw Materials

Cement production is energy intensive and coal, petcoke and fuel oil have been the traditional fuels used by the industry in Ireland. Over the past decade, equipment and systems have been installed to replace imported fossil fuels with locally available alternative fuels. The most widely used alternative fuel in Ireland is solid recovered fuel (SRF) – manufactured from unrecyclable residues of paper, plastics, textiles etc. The industry is also utilising solvents and meat & bone meal as fuels. In 2014 over 30% replacement of fossil fuels has been achieved and the industry has publicly committed to replacing 50% of fossil fuels by the end of 2017 (CMI, 2014b).

The use of alternative fuels in cement production is referred to as co-processing. Co-processing is the simultaneous recovery of energy and recycling of materials from residual wastes that would otherwise require disposal. This diversion of waste from landfill avoids the generation of further greenhouse gases such as methane. The replacement of fossil fuels reduces the industry's carbon profile while ash from the burning of alternative fuels is fully consumed and incorporated into cement products as part of the manufacturing process. Cement Manufacturers Ireland expect that in 2015 over 200,000 tonnes of alternative fuels will be used by cement plants in Ireland.

Traditionally the silica component required for dry process clinker production was sourced from quarried shale. In Ireland, overburden from the limestone quarries and fly ash from power stations are now used to substitute a portion of this silica. This has been made possible by investment in specialist materials handling equipment and research and development in raw material chemistry. The key benefit from the use of alternative raw materials is the reduced requirement for quarrying virgin materials.

5.2 Energy Efficiency – Thermal and Electrical

The manufacture of cement requires thermal energy to heat the calcium and silica bearing raw materials to 1450^{o}C to produce cement clinker. In modern production processes the raw materials, or raw meal, is progressively heated as it passes through a pre-heater tower to approximately 900^{o}C. This pre-heating is achieved through a combination of burning and recirculation of hot gases. Consequently the thermal energy required in the kiln is reduced. Nonetheless, gas temperatures in the burning zone of approximately 2000^{o}C are required to ensure that the raw meal reaches 1450^{o}C, at which point the key minerals in cement clinker are formed. Developments in process design have seen pre-heater towers get taller and kilns get shorter. Recirculation of hot gases also contributes to a lower thermal energy input requirement during the milling of raw meal. Cement plants in Ireland operate kilns with pre-heater towers which incorporate 4-5 stages of pre-heating. The average thermal energy needed across the EU to produce a tonne of clinker in 2012 was 3770 MJ (World Business Council for Sustainable Development, 2015). The weighted average in Ireland is 3538 MJ (CMI, 2014a), confirming that the industry is operating at best practice standards.

Cement manufacturing utilises electricity to crush and grind raw materials, to transport large quantities of materials and gases, and to grind clinker. Over 50% of the electrical energy required in cement production is used in milling raw materials and clinker. The application of vertical grinding techniques, mill separator technology and variable speed drives reduces the electrical energy requirement throughout the cement production process. Modern vertical mill technology has improved electrical efficiency by up to 30% (CMI, 2014a).

5.3 Clinker Substitution

Approximately 40% of carbon emissions associated with traditional cement production arises from fuel burning while the remaining 60% (process emissions) result from the de-carbonation of limestone. To address this, CEM II cements which replace a portion of clinker with finely ground, unburnt limestone and/or fly ash, were developed by each of the cement manufacturing companies in Ireland. This approach is in line with international best practice where clinker is substituted with locally available, approved materials. The cement industry is a high volume business and security of supply is critical for sustainable development. Cement plants in Ireland are located on abundant limestone reserves while fly ash is also locally available from power stations in Moneypoint and Kilroot.

In the concrete industry the use of additions in accordance with the National Annex to I.S. EN 206 as outlined above results in indirect clinker substitution at the concrete mixer.

It should also be noted that during the lifetime of a concrete structure, carbon dioxide in the air reacts with hydrated Portland cement clinker in concrete. This process is known as re-carbonation. Studies have shown that, from the production of 1 tonne of cement, at least 75kg of the carbon dioxide released during de-carbonation of limestone in the kiln, is re-absorbed over the use phase of concrete structures in Ireland (Fitzpatrick *et al.* 2015). CEMBUREAU (2013) have estimated that the application of certain recycling practices can result in up to 25% of the originally emitted carbon dioxide being re-carbonated.

6. FUTURE DEVELOPMENTS

While predicting the future is always challenging, there are some distinct trends which can be projected:

- Between now and 2050, the Irish population is projected to increase from 4.6 million to between 5.0 and 6.7 million (Irish Water, 2015).
- Population growth is expected to be largely concentrated in highly developed urban centres.
- Mitigation against climate change, and adaptation to climate change effects, particularly rising water levels, will require innovation in construction and building technology.

Cement and concrete will play an important role in managing resources and providing solutions to deal with these challenges.

Developments in the cement industry in Ireland are in line with the European Cement Association's (CEMBUREAU) 2050 roadmap for carbon reduction (CEMBUREAU, (2013). This roadmap predicts a 32% reduction on 1990 levels with conventional technology and projects an 80% reduction on 1990 levels with breakthrough technology.

Improvements already implemented by the Irish industry utilising conventional technology have been outlined in this paper. The cement industry in Ireland is also supporting the European Cement Research Academy (ECRA) on a range of breakthrough technologies including research on carbon capture. Research and development into a wide range of novel cements and clinkers are at various stages of progress in Ireland and throughout Europe. Further advances in process technology are expected in areas such as waste heat recovery and unpublished data from Irish Cement Ltd. indicate that approximately 25% of plant power requirements can be generated onsite.

Technology in the manufacture and application of cement and additions will continue to advance throughout the next decade along with all aspects of concrete practice in Ireland. However, as we look towards the next decade, the fundamental importance of safe, robust, durable and affordable concrete structures to society, from the simple foundation to the awe-inspiring building will remain.

Acknowledgements

The author wishes to acknowledge the assistance of colleagues in Irish Cement Ltd. and Cement Manufacturers Ireland in the preparation of this paper.

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DISCUSSION

MR. BRADLEY introduced his paper. He drew attention to the topic of cement consumption per capita as an important national economic indicator. In Ireland during the Celtic Tiger Economy period it peaked at 1100 kg of cement per capita, which was a similar figure to that pertaining in China over the last decade. Putting that in context, he noted that China had consumed more cement since 2010 than the USA had consumed in the entire 20th century! Comparing with the Middle East, he revealed that Qatar is currently consuming almost 3000 kg of cement per capita.

He spoke of the smooth transition from a market dominated for over 70 years by normal Portland cement (or CEM I cements) to a market now dominated by CEM II cements. Product development, driven by environmental considerations, led to the introduction of Portland limestone and Portland flyash cements in the period 2006-2008. About 80% of sales are now CEM II and the vast majority of readymixed concrete is produced from CEM II.

The harmonised standard EN197-1 is currently being revised and the 2016 version should see an increase in the number of permitted cements from 27 to 37. However changes to practice in Ireland will require establishment of specific suitability through the NSAI consultative committee.

Regarding additions he noted that Ireland was leading the way in allowing the use of additions with CEM II/A. Many countries still did not permit this.

While speaking about sustainability he referred to economic, social and environmental considerations. The ubiquity of concrete is such that it is imperative for us to produce and use the material in the most sustainable manner possible. The environmental innovations in Irish cement production has allowed entry to export markets, which has sustained employment during harsh economic times. Many of these jobs are in rural areas. It is estimated that over 2,000 jobs are either employed directly or indirectly by the cement industry. Cement accounts for about 3% of Ireland’s CO_2 emissions. The industry in Ireland is one of the most efficient in Europe due to extensive investment. The key area of focus currently for the industry is the increased replacement of fossil fuels with alternative fuels.

He drew attention to recarbonation and research on the topic at UCD, on which a paper was published in 2015. De-carbonation of limestone involves the release of CO_2 but this is recarbonated into concrete – the phenomenon of carbonation known to many specifiers. The UCD research found that 75 kg of the CO_2 driven off in the de-carbonation process is reabsorbed during the use phase of the building. Other international studies have shown that up to 25% of the CO_2 can be reabsorbed depending on how the concrete is used at the end of life. The studies are ongoing.

MR. JOHN REDDY acknowledged the work done by the Irish Concrete Society Durability Sub-Committee and their role in the introduction of GGBS to Irish concrete practice in a progressive way. He noted that combinations at the mixer in excess of 50% GGBS were permissible, unlike in other countries which were more restrictive.

Looking to future developments in the introduction of additional cements to the European market, such as geopolymer, CSA and super-sulfated cements, he noted that there seemed to be a perpetuation of constituent-based criteria in the definition of a cement type. He felt that we should now be moving to performance-based requirements, rather than reliance on prescription of constituent percentages. Currently less than half of the 27 available cements in Europe are given specific suitability in Ireland. In the course of his reply, MR. RICHARD BRADLEY noted that there were natural restrictions in the cements that could be produced in Ireland, due to availability of materials. Regarding constituent requirements in new cements, the ten proposed new cements had known constituents – they were tri-blends of clinker, limestone and either slag or flyash. Nevertheless a lot of complications arose in the process of introducing these. CEN TC51 had recognised this and so has agreed on procedures for the introduction of new cements to the market. A technical report on this is due to be published in the next year.

MR. COLUM McCAGUE, in an invited written contribution, noted that he was attending the symposium as a representative of the UK cement industry. He had come to learn more about the Irish cement and concrete industry with a particular interest in the current industry status in respect of technical specifications and sustainability. He found that Mr. Bradley's paper, and the earlier paper by Mr. Crowley, demonstrated how Irish concrete practice remains in the front-line, while Irish representatives are proactively engaging in standards development and technical activities at the European level. The transition to modern plant, processes and widespread use of CEM II demonstrated clearly that sustainability is a priority for this industry. In the past decade, the implementation of EU legislation and product standards has brought many challenges for our industry across Europe. Continuing the current ethos in Irish concrete practice should ensure that the Irish cement industry can thrive this coming decade and beyond. He thanked the organisers for an insightful and well-structured event.

SESSION B-1

DEVELOPMENTS IN PRECAST CONCRETE

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Abstract

This paper examines the developments in precast concrete covering the decade from 2005 to the present day. It examines briefly the economic downturn and the effect this had on both the domestic and export precast markets and how companies who had the foresight to invest in increased mechanisation, product development and technical support prior to the recession, were better equipped to survive the tumultuous intervening years.

The paper reviews the trends in the main product areas and highlights the step changes that have taken place in the industrialisation / mechanisation of certain products and how this has been made possible by the use of 3D modelling, its integration with robotics and CNC machines and the carousel production system.

Reference is made to the ever increasing demands on health and safety, quality and sustainability and the positive response of the industry to these demands.

1. INTRODUCTION

The past decade has been a most interesting one for the construction industry as a whole but in particular for the precast industry. It was a decade during which Ireland experienced its greatest period of growth in the construction industry followed by the greatest decline. Although the journey through the economic downturn was a turbulent one, the precast industry has come through the recession with a confident and optimistic outlook. Damaged somewhat no doubt by the very sharp decline of sales in Ireland but thriving on the export market to the UK which has experienced rapid growth since 2010 and surpassed the €100 million mark in 2014. For an industry that was once fragmented, lacked scale and financial strength, it is now very focussed and a significant employer and exporter. Precast companies boast some of the most modern factories in Europe and have the technical resources to support them. Enterprise Ireland has acknowledged that achievement and has played a major role in supporting the export strategy. The significant growth in the home market up to 2007 was a major positive and facilitated investment in and mechanisation of the industry.

The decline in the home market in the past number of years has been on a scale that would anticipate a text book ‘shake out’ and closures within the industry. Fortunately the industry, using the strengths it had gained up to 2007 focused its attention on the export market and the Irish Precast Industry has now established itself as being a key and competent supplier into the UK market.

We are indeed fortunate that the UK construction industry, which also experienced a downturn post 2007, has been in a strong recovery mode for the past number of years and this demonstrates the benefits of operating in these two, sometimes contra cyclical markets.

The growth of exports from 2010 to 2014 is illustrated in Figure 1 and it is fair to say that although the exports have not replaced the volume decline in the Irish market, they have certainly been the major contributor to sales in the past few years.

This is quite an achievement by the industry particularly given the exchange rate over the past number of years, as illustrated in Figure 2. Post 2007 sterling weakened relative to the Euro making exports less competitive. One can see that much of the export growth was made during a period of a less favourable conversion rates.

There are some very interesting business lessons to be learnt from this period. Foremost is the underlying lesson that the foundation of that growth is based upon product development, technical support skills and heavy investment.

The more significant product developments, reviewed by category in this paper are:

- Twin walls and wide slab floors
- Load-bearing structures and external cladding
- Bridge beams
- Architectural cladding and GRC
- Car parks
- Tunnels

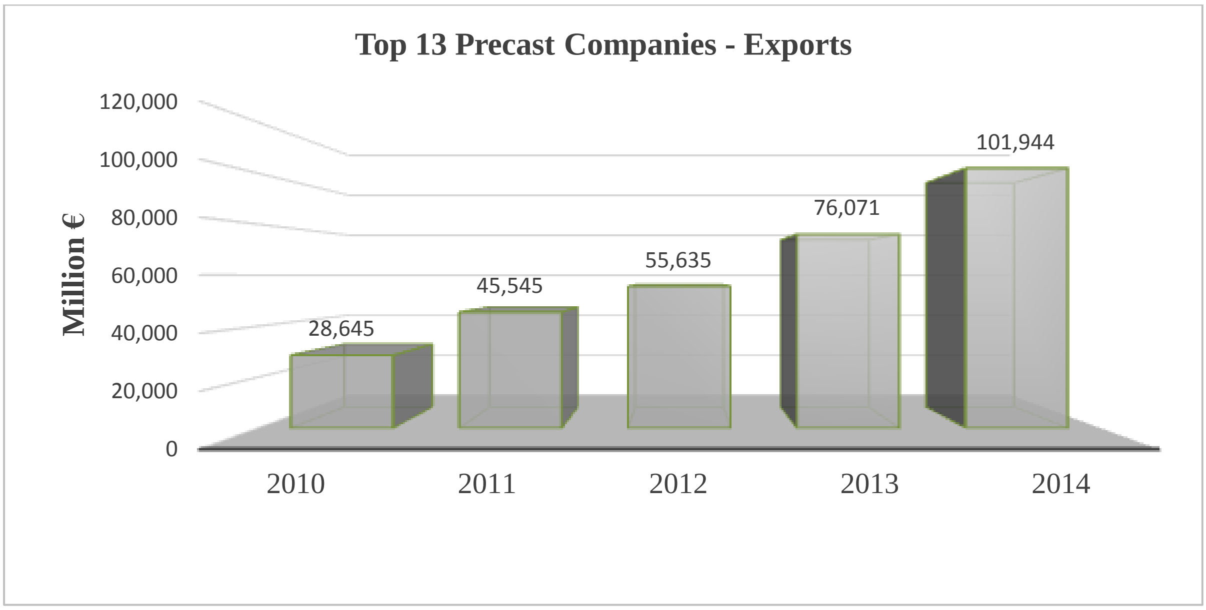

Figure 1. Precast Export Growth 2010 – 2014 (Enterprise Ireland, 2015)

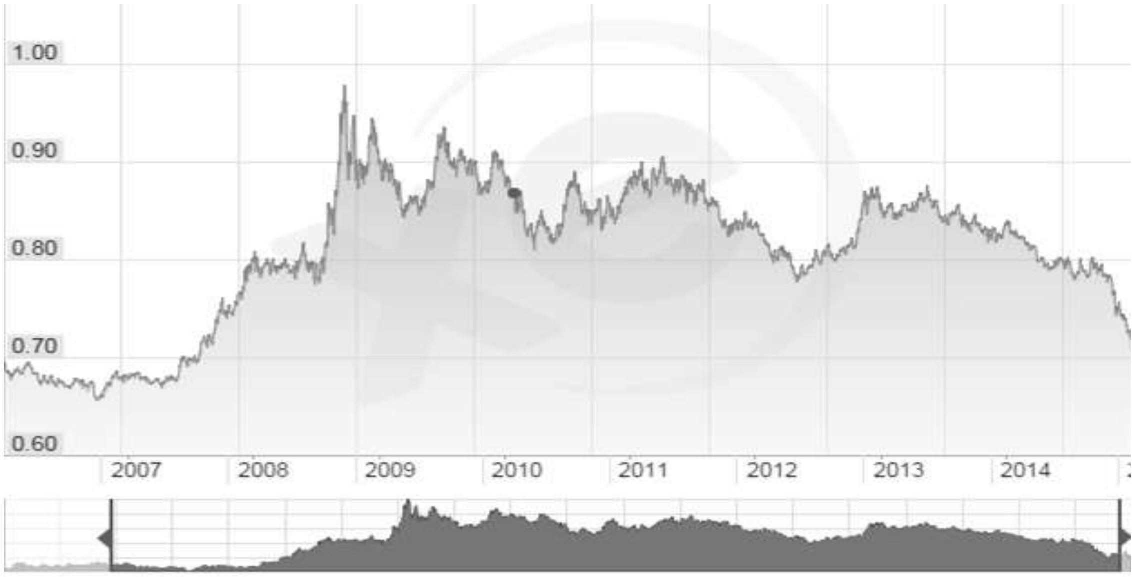

Figure 2. Exchange rate variation with time, Sterling per Euro 2007-2014 (www.xecom)

2. TWIN WALL AND WIDE SLAB FLOORS

Twin wall is formed by connecting two thin precast concrete leaves by a lattice structure, as illustrated in Figure 3. Each leaf is 65mm thick and has an ex-mould finished face. The two leaves are connected by a lattice steel truss and the core infilled with insitu concrete. The walls are used typically in conjunction with an Omnia floor plate which has a similar leaf thickness but with steel lattices built in to provide the main tension reinforcement in the slab and to also provide the plate rigidity for handling.

This is a clever product insofar as it is makes best use of the strengths of precast and insitu construction producing a very flexible composite form of building. It is also adaptable to the most modern techniques of automated production. The production processes encompass the main technological advancements that have recently taken place in the industrialisation of precast manufacture. For many years the structural steel industry has seen the benefits of combining 3D computer drafting with CNC machines which can precisely execute the designed detail. 3D modelling and computer aided manufacture have combined to manufacture highly complex interfaces and do so with accuracy and efficiency.

That same thought process has now been transferred to particular components of precast concrete and software such as “Tekla” and “Nemetschek” are used in the modelling of 3 dimensional precast structures with added intelligence to manage the production planning and material scheduling.

This technology is combined with a carousel system which is essentially an arrangement of moving moulds, and work stations are arranged around a key activity such as mould assembly, addition of components, addition of reinforcement etc. As illustrated in Figure 4.

Each station can have varying degrees of automation. Mould cleaning is done mechanically as the mould travels through a tunnel of rotating wire brushes. Setting out is done by laser or ink plotter. Edge forms are magnetic and put in place using robotic arms. Concreting is by machine using screw or belt discharge with exact quantities of concrete.

This type of manufacturing system cannot handle all varieties of panels but where there are fixed parameters such as a planar surface and a standard leaf thickness then this technology is extremely efficient and accurate.

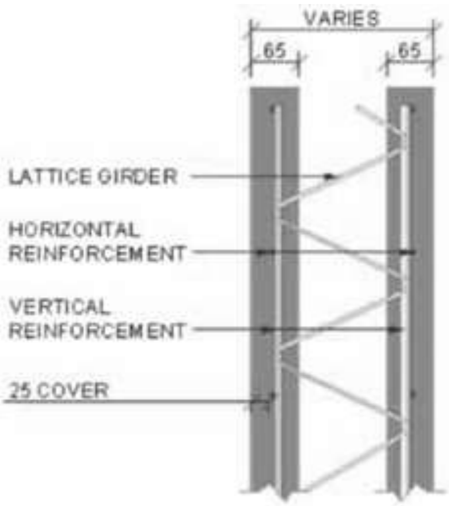

Figure 3. *Twin wall section (adapted from www.doppelwand.com)*

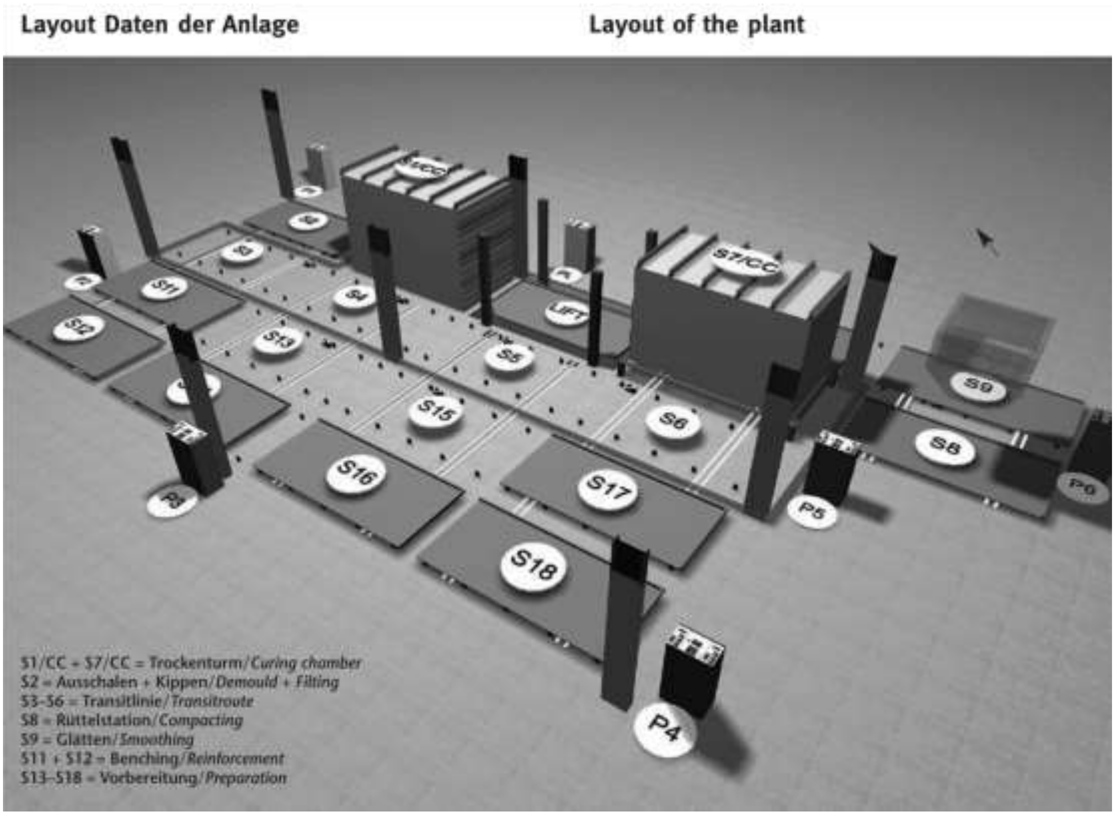

Figure 4. *Carousel System of Production (from BFT International, 2005)*

The finished surfaces are all ex-steel mould and ready to receive a finishing treatment.

Once concreting has taken place the moulds / tables travel to a lift which elevates them into a curing chamber. The curing chamber is environmentally controlled to optimise curing times. The production process for the twin wall has a further piece of mechanisation worth mentioning and that is the rotating rig, illustrated in Figure 5. In order to form the twin leaf structure one hardened face is lifted by suction pads, rotated through 180º and lowered into the fresh concrete leaf of the opposing face.

Figure 5. Rotating Rig

This method of construction has been used extensively throughout the country and one large example is at Spencer Dock in Dublin where internal walls and floors were all formed using this system and combined with an external architectural sandwich panel to complete the building. Currently there are three carousel plants in Ireland.

One of the larger UK frame contractors is using the floor plates in a novel way to form flat slabs. The technique used is to have all of the bottom reinforcement requirements cast into the floor plate. The floor plates are then landed onto temporary supports. Transverse reinforcement is spliced for the bottom layer reinforcement and top reinforcement put in place. Turn around times for a floor of 4/5 days are being achieved. The system does require very advanced planning as all attachments or inserts to the slab must be known and detailed several weeks in advance. Advanced planning is becoming part of the reality of modern construction in any event.

3. LOAD BEARING STRUCTURES AND EXTERNAL CLADDING

The use of precast as a total solution for residential buildings grew hugely in popularity during this period. What might have been traditionally constructed using load bearing block work and precast hollow core floors was increasingly replaced by precast external and internal walls with flooring systems being either hollow core or wide slab. The walls are typically cast on flat steel tilting tables or battery moulds and the external panels are sandwich panels finished in reconstructed stone or a facing material of brick or with an applied textured finish. There are numerous examples of this form of construction, many in the 8 to 10 storey range.

The advantages of the system are significant with off site prefabrication of all of the main structural elements. Prefabricated bathroom pods have been made extensively with this system.

Figures 6 and 7 illustrate a typical load bearing external wall being installed and the associated connection detail. There are a variety of solutions to detailing the junctions to accommodate the required tie forces.

Figure 6. Internal view of load-bearing sandwich panels on site

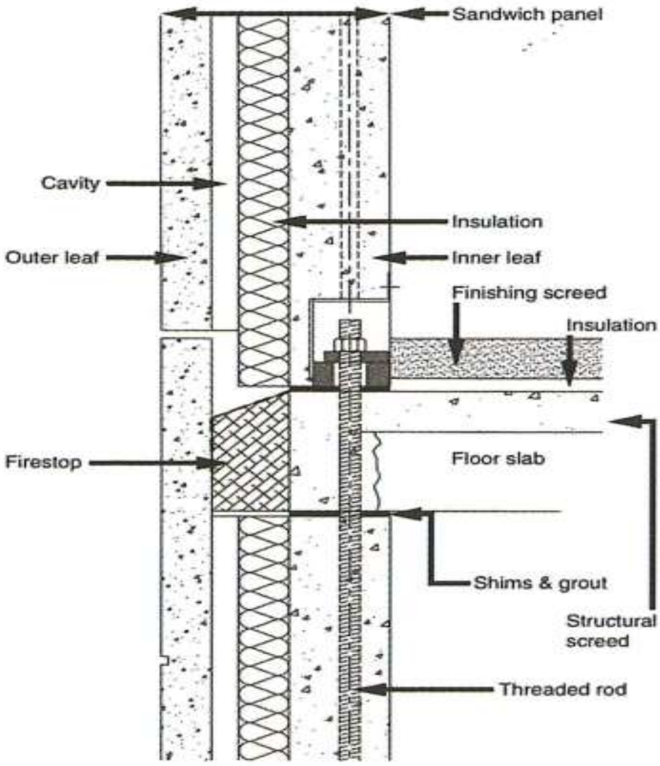

Figure 7. Typical detail section through panel-to-panel connection using threaded rods

One of the maturing aspects of the industry has been the ability of a number of precasters to combine to provide the total solution. In an age of specialisation it is unlikely that a single precast company will provide the full product range and the most efficient solution is likely to be perhaps two to three precast specialists combined with one installation crew to give the best results. Featherstone Prison in the north of England is an interesting example of this cooperation (Figure 8) where four precasters provided the mixture of precast elements required.

Research has shown that structural screeds are not essential to the creation of diaphragm floor action provided the appropriate grouting and tie reinforcement is in place between floor plates. This has further speeded up the floor to floor construction rates for these buildings as they are not dependent on the cycle time for the structural floor screed.

Figure 8. Featherstone Prison, panel being installed

4. BRIDGE BEAMS

The Irish Government's 'Transport 21' scheme, the purpose of which was to develop the road network and transport system, covered the period 2005-2015. It had allocated approximately €34 billion for the provision of this infrastructure to include extensive road programmes, extensions to rail networks and grants to airports. This has driven the motorway programme throughout Ireland and has dramatically improved the routes from Dublin to the provinces. Ireland can now boast a direct link from Dublin Port to Northern Ireland via the port tunnel and M1 Motorway.

Precast bridge beams have played a major part in the speed of construction that was achieved for these projects. During that time the manufacturing capacity grew considerably in Ireland and beam profiles were modified and developed. These developments increased spanning capacities from 35m towards 50m.

One such development to help achieve these spans is the "W" bridge beam. Figure 9 shows a cross section through the W profile bridge beam which will now span up to 50m and techniques are being developed to create a continuous precast bridge by post tensioning on site. This is a demanding product category. The size and weight of the product results in significant transport issues coupled with the need for just-in-time deliveries.

The industry has demonstrated that it can meet these demands and surprisingly for such a large product the industry has established itself as a key supplier of bridge beams into the UK market. These demands have furthermore driven innovations in the transport and logistics industry.

This is a product where the customer requires certainty in relation to delivery and fit. The industry has responded by, for example, carrying out trial erection mock ups and taking full control of transport logistics, as illustrated in Figure 10. There are now three main suppliers of bridge beams in the industry with one having the capacity to produce 2kms of beams per week.

5. ARCHITECTURAL CLADDING AND GRC

The discipline referred to as "façade engineering" has grown considerably in the last number of years. This is partly due to the increasing complexity of façades but mainly due to the greater demands on the performance of the wall to meet the requirements for sound attenuation, thermal resistance, fire resistance and the elimination of cold bridging. There has also been a trend to combine architectural concrete with curtain walling systems with the precast performing the functional role of solar shading to the building.

This has led to very tight requirements in the design of fixings and the accuracy of units. This is a consequence of combining units with very different manufacturing and installation tolerances (precast versus curtain walling) but with high repetition it is possible to achieve significantly better tolerance with precast than those specified in BS 8297 (British Standards Institution, 2000).

Technology has also benefited the creation of complex moulds formed using robotics and CNC machines. Figure 11 shows a 3D profile being carved robotically on to a timber base from which the working mould is formed.

Thus in a similar way to the earlier review of "Twin Wall", the 3D modelling of complex facades and the option to link that to the robotic machine has facilitated the manufacture of profiles that would simply be economically impractical otherwise.

Also advancing at a great rate is the 3D interface of all external components. Many projects will now have a dedicated person or consultant who will regularly superimpose / integrate the various 3D models and carry out a clash check between components. The cost savings from this technology will be significant as there is still considerable waste in construction related to reworking and modifying components on site.

There has been an increasing trend to incorporate ancillary trades into the precast panel. This is all to do with the objective of keeping site operations and crane lifts to a minimum. There is thus a demand for installation of the windows into the panels at the precast works and the attachment of panel insulation and the casting in of cable trunking. Full scale mock ups and testing for wind and water penetration is quite common (Figure 12).

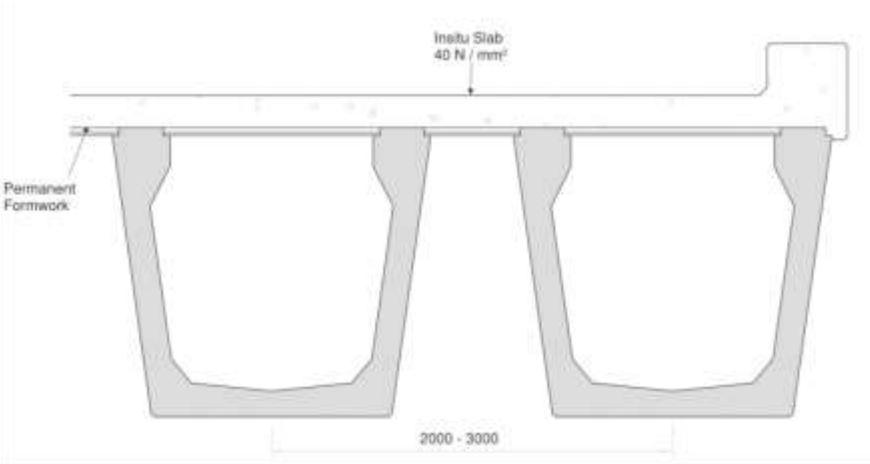

Figure 9. *Cross Section through a W Beam*

Figure 10. *Transport logistics – long span precast beams*

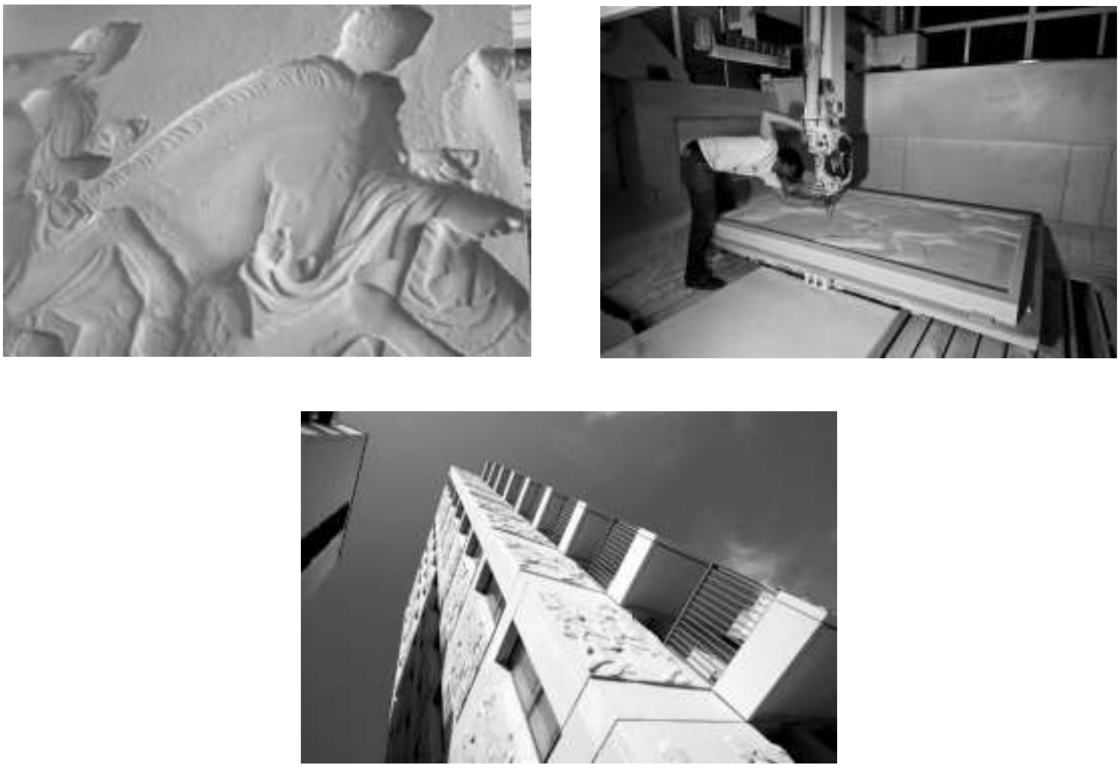

Figure 11. Use of CNC machine in mould formation for complex facade finish

Figure 12. Ludgate Panel on Test Rig

GRC continues to be a popular product for lightweight cladding. It has limited tensile strength and is typically strengthened using ribs or stud frames. Stud frames were historically fabricated from cold formed sections but more recently aluminium stud frames have been used on some projects and this simplifies durability issues. Spray equipment has improved making it possible to spray larger returns and complex shapes. GRC has also been used extensively as permanent formwork for bridge beam decks.

6. CAR PARKS

The past decade has seen new cars registered in the state drop from a peak of 180,754 in 2007 to a low of 54,432 in 2009. These figures have fluctuated in the intervening years but have increased steadily from 2012 onwards with 92,361 new cars registered in Ireland in 2014.

With these new cars comes increased traffic volumes coupled with an amplified demand for additional parking facilities. In towns and urban areas, space is at a premium and new developments rarely have the luxury of designating acreage to surface carparks, favouring instead the multi-storey option.

Multi-storey car park developments have been used extensively. Commonly the design is either of a split level or flat deck type and are generally a column and deck structure. Multi-storey car parks are generally made up of beams, spandrels, columns, hollowcore, wall panels and stairs and are constructed using a column and deck system (Figure 13).

The use of hollowcore in multi-storey car parks has generated clear spans of up to 16.2m. This has reduced the use of vertical columns and can permit 3 car parking spaces between each column, thus, increasing capacity of the area. It furthermore facilitates spacious turning circles.

There have been continuous improvements in jointing techniques which have resulted in composite action between floors and beams.

Efforts are continuing to minimise beam depth effectively. This reduces the depth of the services void which in turn reduces the height of the building. Composite beams are frequently used to achieve this, although the final loading capacity is not achieved until the screed is applied.

Precast frame developments have been mainly in the area of jointing connections. Proprietary cast-in shoes are now available to create reinforcement continuity. These are contained within the plan area of the column and can be used to create base fixity for cantilever columns and provide tie and load transmission connections at upper levels. Likewise concealed projecting steel connectors are available for beam / column junctions with the male and female parts cast into the column and beam respectively. This eliminates the need for projecting concrete corbels but can attract a price premium.

Figure 13. Multistorey Car Park During Construction

7. TUNNELS

This is a relatively new segment to the industry. One of the most impressive and visible developments in Ireland are the increase in construction of road tunnels in the past ten years. The most significant project was the Dublin Port Tunnel, completed in December 2006. Large sections of the Port Tunnel were lined using precast segments.

These segments are cast to extremely tight tolerances and follow-on projects have included the supply of precast segments to the "Crossrail" project in London, currently under construction.

8. QUALITY AND SUSTAINABILITY

Ten years ago the position in the industry generally was such that having an EN ISO9001 certification for your quality management system was sufficient to satisfy most clients requirements.

Since that time two fundamental things have changed:

a) World opinion on sustainability and its importance in construction has undergone dramatic change.
b) Clients have become far more demanding in relation to the qualifications of their supply chain members.

The net effect of all of the above is that health, safety, quality and environment have gradually become integrated and most companies now consider them jointly. Further necessary certifications followed.

The first of these further certifications that became necessary was OHSAS 18001 Occupational Health and Safety Management System. This has been driven by the very poor record that the construction industry had in terms of its safety performance and all of the main players in the industry were insisting that their supply chain engage with improvement of their safety performance.

Two further qualifications then became desirable as a result of the focus on sustainability and the way particularly the precast industry impacted on the environment. These are EN ISO 14001 Environmental Management System and EN ISO 50001 Energy Management System. These of course apply to both on and off site activities and in particular precast factories including treatment of effluent and consumption of water and fuels.

In July of last year CE marking to EN 14992 became a requirement for a significant number of precast products and it became necessary for the industry to embrace this process.

For those companies that engage fully in the process BES 6001, Responsible Sourcing of Construction Products (Building Research Establishment, 2014), began to draw together all the threads of the supply chain suppliers to the precast industry.

In addition to this some of the main developers and contractors began to introduce various forms of separate accreditation with the objective being to reduce the amount of work required in prequalification etc. These are such systems as Achilles and Construction Online. These have only had varying degrees of success as not all the players have joined or in some instances have joined different systems. This places quite a heavy burden on a Precast Contractor if they wish to try to satisfy all their customers. Some rationalisation of this is becoming inevitable.

There is no doubt in the past 10 years the industry has improved its position in relation to quality and sustainability. It has begun to focus on its impact on the environment and trying to minimise it.

9. CONCLUSION

The industry has emerged from a very deep recession in surprisingly good shape. It is now recognised as having built a distinctive competence in precasting which is recognised in the UK as well as in Ireland. The trend towards off site fabrication will continue to grow and the challenge for the industry is to sustain and grown the export market as well as serving a recovering home market. Past investment in plant, people and R&D has been crucial and there is a commitment in the industry to continue to invest and build an even stronger precast industry.

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DISCUSSION

MR. O'DEA introduced his paper. Speaking of the very sharp decline in the Irish market during the recession, he noted correlation of his estimate with those of earlier speakers at the Symposium, quoting figures of a 70% to 80% decline for many products. In the case of the precast industry however he said that some would estimate it as high as 95% for some product areas. Thankfully the response of the industry, to respond to rapid growth in the UK market, was successful and all members of the Irish Precast Concrete Association in 2007 are still in the business and enthusiastic about the future. Looking at trends in export growth (Figure 1 in the paper) he said that the intention was to continue growing this sector, rather than retreating fully to the Irish market only, as it recovers. Further support for this approach was the interesting pattern whereby economic activity was often counter-cyclical between Ireland and England or Scotland. Recent success was achieved despite an unfavourable swing of about 10% in respect of the impact of exchange rates on pricing.

The basis of success was both technical innovation and competitiveness. He went on to describe in detail the innovations outlined in the paper, including twin walls, lattice slab floors, wide slab floors, production processes, load-bearing structures, external cladding, bridge beams, architectural cladding, GRC as lightweight cladding and permanent formwork, car parks and frames. He described the carousel system of production, of which there were now three in the country. He noted a shift whereby the precaster was no longer going to simply supply an element that formed part of a wall – the new requirements were pushing us towards a situation with sandwich panels that the precaster needs to supply the entire wall unit. There had been significant development in respect of bridge beams and Ireland had become a key supplier to the U.K., with one supplier shipping up to 150 loads a week across the Irish Sea.

He noted the need for full scale testing facilities of precast units in Ireland. Currently this work is being done for Irish companies in U.K. labs. He suggested that this could represent an opportunity for Irish universities.

Turning to quality and sustainability, he echoed the comments of earlier speakers regarding the achievement of significant success in improved safety statistics, for example through the use of certification to OHSAS 18001. Many Irish precast companies had been involved in the London Olympic projects. There had been one fatality – one too many – but still a measure of great improvement on past records, given the combined scale of the Olympic projects. This contrasts with the current situation in Qatar as they build for the Olympics. The system was rigorous with security checks going onto and off site that were more onerous than that when going through airports. Random drug and breath tests for alcohol were a feature. There was a system of ‘yellow’ and ‘red’ carding. Red cards were permanent – no access was granted to site again irrespective of the person’s role in the company – erector, director, owner or whatever. He attributed the successful impact on reducing accidents and incidents to the fact that the industry believes in it.

He praised the work of the Irish Precast Concrete Association, a very-well run organisation. Founded in 1991, it initially focussed on marketing. The focus had now moved to training, health and safety, environmental issues and transport. A measure of its strength was the way it had survived through the recession, a time when anything regarded as non-essential activity gets cut out.

Concluding his presentation, Mr. O’Dea noted the very good progress in product development and a step change in production efficiencies, helped by 3-D software. The companies have geared up and now have strong technical support within companies. This has led to the growth in export markets. Meanwhile customers in Ireland have choice from an industry of scale and critical mass, which is what the customer wants.

MR. RICHARD BRADLEY noted the recent developments in 3-D printing. He wondered if this might be a feature of future practice in Ireland, through the precast industry. MR. JOHN REDDY spoke of research on the topic at Loughborough University and the production of a bus shelter by 3-D printing, based on a design by Norman Foster. The Chairman, MR. SHANE SANTRY speculated that it might be a significant topic for discussion at the next symposium in ten years time.

MR. JOHN REDDY queried the relevance of 28 day strength as a continued restriction on concrete practice. He noted how, 50 years ago, Mr. Holloway had proposed to the CPI 1965 Symposium that they adopt 7 day strength as the acceptance criterion. Mr. Reddy now proposed to CPI 2015 that 56 day strength should be appropriate figure. He argued that the key issue in compliance criterion was “did you get the right concrete?” which has very little to do with the construction process and the actual properties of concrete in the structure. This was especially the case in respect of precast elements. Significant changes have taken place in respect of cements – this should be reflected in changes regarding age of compliance testing. He accepted that, in the past, a market dominated by CEM I concretes (or OPC, NPC concretes as it would have been at the time), would have seen relevance in the strength plateau emerging around 28 days. However much has now changed with CEM II cements and additions being more dominant. The strength development curve now stretches out to 56 days, or longer, before the plateau develops. There is a value engineering proposal that the industry should adopt 56 day compliance, leading to rationalisation of building materials. There is a derogation in I.S.EN206 which permits use of 56 day strength for concretes incorporating over 50% GGBS. The precast industry has developed the necessary tools: temperature matched curing, maturity functions and associated charts. He instanced the construction of ‘The Shard’ in London where post-tensioning was carried out using real-time information on in-situ concrete maturity rather than cube strength testing. The opportunities are now here for using such information technology systems. He urged the industry to adopt a revised system, whereby real time strength information would be used to assess the time for loading structures, rather than use of strength values at 28 days as a sole method of compliance verification. MR. MICHAEL BARNWELL, while accepting that the traditional association with 28 day strengths was difficult for some to abandon, welcomed any measures that would speed construction through, for example, earlier removal of shuttering. The reality for many building projects was that ‘time is money’ and any innovations that meant ‘faster is cheaper’ had to be good for our industry. MR. CHRIS O’DEA emphasised the significance of early strength in the precast industry: the need to get elements out a mould at 24 hours and the ability to stress a beam at 48 hours. He also spoke about the issue of creep. This was a significant factor in serviceability and required early information on strengths. MR. TIM MURNANE also spoke of the significance of strength information which allowed removal of back props, thus allowing fit-out to commence. This was more significant than strength testing for compliance. DR. MARK RICHARDSON supported the proposal for consideration of alternatives to 28 day strength testing as the norm. He instances two examples of innovative practice in Germany, each of which involved sourcing materials from a single source. In one case savings derived by reducing safety factors at the design stage, based on the consequent reduction of standard deviation of material properties. In another case the building met stricter environmental footprint criteria by using a concrete mix whose strength compliance was assessed on the basis of 56 day strength. These examples of 'thinking outside the box' demonstrated how Mr. Reddy's value engineering proposal was worth a hearing. MR. DONAL CROWLEY advised that a recent European conference had heard a case being made for 91 day conformity testing! However the reality was that contractors would even find moving to temperature matched curing would be a significant step change for the industry. MR. REDDY returned to his core point: strength at 7, 14, 28 or 56 days for compliance testing had little relevance to the strength of concrete in the structure due to the effects of ambient temperature, section size and other factors. PROF. ROGER WEST disagreed. He felt that knowledge of our materials in Ireland meant that good predictions could be made on 7 day strengths.

MR. CIARAN MURTAGH was interested in the lessons that could be learned by the industry from Mr. O'Dea's experience of collaborative working with clients, both in the United Kingdom and in Ireland. In particular he was interested in the early involvement of the concrete technologist and others in the project. He instanced his experience of working with companies in the U.K. who had adopted Standard B.S.11000 (Collaborative Business Relationships), sustainability charters and so forth and wondered about its possible impact on future best practice in Ireland. In response MR. ODEA spoke of the clients' close involvement in many projects that he has worked on. He instanced their interest in the sub-contractors: some clients have a list of preferred companies that they work with, knowing that they will deliver a quality product. Certain clients, interested in a long term relationship with their suppliers, might appoint you in advance of pricing the job. While this was a feature of many U.K. clients that he worked with, he had also examples of certain clients in Ireland also being close to the action, with attendant positive results in respect of the quality of the finished project. This contrasted with clients who might appoint an investment fund manager to project manage a job. Such an individual would perhaps be more concerned with optimising the rent per square metre than inputting to optimisation of the overall end product. He felt that collaborative working with clients had been taking off successfully in Ireland and would do so again as the economy recovered.

SESSION B-2

DESIGN IN CONCRETE

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Abstract

This paper examines the recent evolution of design in concrete in Ireland, how it is tempered by its external physical, economical and socio-political environments which allow it to continuously reinvent itself as a product of its time despite the fact that its basic properties have not changed in thousands of years. Although the current paper must inevitably reach back to 1995 and beyond, insofar as possible its focus will be concentrated on the ten year period from 2005 to 2015.

1. INTRODUCTION

In the twenty intervening years since the last 'Concrete Practice in Ireland' symposium at UCD, it would be an understatement to say that quite a deal of progress has been made. On the other hand it can be said of concrete, perhaps more than any other man-made construction material '*plus ça change, plus c'est la même chose'* (Karr 1849).

There have been significant developments on the production side in Ireland in the areas of cement, cementitious materials, aggregates, additives and precast concrete. On the design side there have been major changes in design standards with the implementation of the Eurocodes in Ireland coupled with increasing emphasis on the incorporation of durability and sustainability into the design of our built environment. There have also been large strides made in design of concrete elements in an architectural context which celebrate the medium rather than apologise for it.

This paper does not purport to cover every single design development over the last ten years or so, but rather to provide an overview of progress and general trends. As design is such a big word, even when 'narrowed' to design in concrete in Ireland, this paper presents a review focusing on the following:

- Evolution of the harmonised Eurocodes from aspirational ideal to practical realisation;
- The 'seismic' change from IS 326 / BS8110, BS5400-4 and BS8007 to Eurocode 2 and its constituent parts, highlighting any significant differences;
- Primary design issues experienced in Ireland over the past decade;
- Review of four award winning projects in the context of the above design issues;
- Brief look forward to the decade to come – 'Star Gazing';
- 'Back to the Future' case study of innovation and adoption in concrete.

2. EUROCODES

The development of the Structural Eurocodes started in 1975; since then they have developed significantly and are now claimed to be the most technically advanced structural codes in the world. There are currently 58 Structural Eurocodes which comprise a comprehensive set of harmonised standards related to the design of building and civil engineering works.

2.1 Brief History of Concrete and Masonry Design Codes and Standards in Ireland

It would be remiss not to mention the very extensive and detailed review of standards, codes and regulations for concrete presented by Torpey (1995) at the fourth UCD 'Concrete Practice in Ireland' symposium held in 1995. The current paper does not intend to repeat the same body of work but rather provides a codicil to it.

Up until the formal adoption of the Eurocodes and Irish National Annexes within the last five years, structural design in concrete and masonry in Ireland has been closely linked to the suite of British Standards and Codes of Practice.

Table 1 and Table 2 provide a historical timeline over the last century for the design codes applicable to the design of structural concrete and structural masonry, respectively. The last major transition in design standards on these islands was the switch from permissible stress design to ultimate limit state design in the 1970s. In the changeover to the Eurocodes, while challenging in itself, designers have not had to face the same paradigm shift in design philosophy as their predecessors.

2.2 Evolution of the Eurocodes

2.2.1 Motivation

Just four years after the Treaty of Rome was signed in 1957, the European Committee for Standardisation (CEN, *Comité Européen de Normalisation*) was founded in Paris. It was formally established as a non-profit (AISBL, *association internationale sans but lucratif*) standards organisation in Brussels in 1975. Its thirty three national members work together to develop European Standards (ENs) in various sectors to build a European internal market for goods and services and to position Europe in the global economy. CEN is officially recognised as a European standards body by the European Union.

CEN's National Members are the National Standardisation Bodies (NSBs) of the 28 EU countries, FYR of Macedonia, Turkey and three EFTA countries: Iceland, Norway and Switzerland. There is one member per country. The NSB responsible for Irish National Annexes is the National Standards Authority of Ireland (NSAI).

The mission of CEN is to promote the European economy in global trading, the welfare of European citizens and the environment through the provision of an efficient infrastructure to interested parties for the development, maintenance and distribution of coherent sets of standards and specifications.

2.2.2 Harmonisation of Design Across EU

The CPI symposium paper by Torpey (1995) had the subtitle of the *practical realisation of a harmonised Europe*. Although political and monetary harmony across Europe may have been called into question in recent times, harmonisation of design codes and standards has been practically achieved across Europe with the formal introduction of the Structural Eurocodes and the vast and ever growing tranche of Euronorms.

Table 1 Historical timeline, concrete design code and standards in Ireland

Year	Code/Standard	General Comments
2010	All Eurocodes Apply	End of Transition period
2007	IS EN 1992-3:2006 Liquid Retaining Structures	Commencement of transition period from BS 8007 to EC2-3
2006	IS EN 1992-2:2005 Design of Concrete Bridges	Commencement of transition period from BS 5400-4 to EC2-2
2005	IS EN 1992-1-2:2005 Structural Fire Design	Commencement of transition period from IS 326/BS 8110-3 to EC2-1-2
2005	IS EN 1992-1-1:2005 General Rules and Rules for Buildings	Commencement of transition period from IS 326/BS 8110 to EC2-1-1
2004	IS 326:2004	Updated to include provisions of IS EN 206-1
2002	IS EN 206-1:2002 Specification performance, production and conformity	New methods for design/ specification of concrete strength and quality to satisfy durability requirements under specified exposure conditions
1995	IS 326:1995 The Structural Use of Concrete	IS 326 consists of the text of BS 8110: Parts 1, 2 and 3, as amended.
1987	BS 8007:1987	Design of concrete structures for retaining aqueous liquids
1985	BS 8110:1985 The Structural Use of Concrete	Parts 1, 2 and 3: 'Structural Use of Concrete' Replaces CP110
1978	BS 5400-4:1978 Design of concrete bridges	Part 4: Code of practice for design of concrete bridges
1972	CP110 Part 1:1972 The Structural Use of Concrete	Design, Materials & Workmanship Limit State Design introduced Replaces CP114, CP115 & CP116
1965	CP116	Code of Practice for precast concrete
1959	CP115	Code of Practice for prestressed concrete
1948	CP114	Permissible Stress Design
1934	DSIR Code of Practice	Permissible Stress Design
1911	RIBA Report	Permissible Stress Design

Table 2 Historical timeline, structural masonry design codes and standards in Ireland

Year	Code/Standard	General Comments
2010-2014	All Eurocodes Apply	End of Transition period
2013	SR 325	Standard Recommendation (NCCI)
2006	IS EN 1996-3:2006 Eurocode 6 - Design of masonry structures	Part 3: Simplified calculation methods for unreinforced masonry structures - commencement of transition period from IS 325-1/BS 5268-1 to EC6-2
2006	IS EN 1996-2:2006 Eurocode 6 - Design of masonry structures	Part 2: Design considerations, selection of materials and execution of masonry - commencement of transition period from IS 325-2/BS 5268-3 to EC6-2
2005	IS EN 1996-1-2:2005 Eurocode 6 - Design of masonry structures	Part 1-2: General rules for structural fire design
2005	IS EN 1996-1-1:2005 Eurocode 6 - Design of masonry structures	Part 1-1: General rules for reinforced and unreinforced masonry structures - commencement of transition period from IS 325-1/BS 5268-1 & BS 5268-2 to EC6-1-1
1995	IS 325-2:1986 Code of Practice for the use of masonry	IS 325-2 virtually identical to BS 5268-3, amended to reflect Irish masonry practice
1986	IS 325-1:1986 Code of Practice for the use of masonry	IS 325-1 virtually identical to BS 5268-1, amended to reflect Irish masonry practice
1985	BS 5268-3:1985 Code of Practice for the use of masonry	Pt-3: Materials and components, design and workmanship
1985	BS 5268-2:1985 Code of Practice for the use of masonry	Pt-2: Structural use of reinforced and prestressed masonry
1978	BS 5268-1:1978 Code of Practice for the use of masonry	Pt-1: Structural use of unreinforced masonry Limit State Design Introduced
1948	CP111 – Structural recommendations for load bearing walls	Permissible Stress Design

With a view to achieving excellence and better harmonisation, CEN and its sister organisation CENELEC (European Committee for Electrotechnical Standardisation) decided to join forces. This consolidation was formalised by the creation of the CEN-CENELEC Management Centre set up in early 2010 to maintain, strengthen and continuously improve the effectiveness of the European standardisation system.

CEN develops standards in relation to the design of buildings and other infrastructure, such as the Structural Eurocodes and European Standards dealing with the Energy Performance of Buildings (EPB), which provide tools for calculating the integrated energy performance of buildings as defined in EU Directive 2010/31/EU, of particular relevance to concrete-framed buildings given the considerable thermal mass available for exploitation.

Whilst the Structural Eurocodes have become essential tools for design and fulfilment of national building regulations, CEN has also recognised that harmonised European Standards for construction products are also essential for the application of the Construction Products Regulation (CPR - 305/2011). The CPR repeals, replaces and simplifies the previous Council Directive 89/106/EEC known as the Construction Products Directive (CPD) originally implemented to promote open trade within the construction industry across Europe.

CEN supports more than 100 Technical Committees in the construction sector, many of which develop European Standards to assess the performance of construction products and to provide the respective testing and/or calculation methods. These harmonised European Standards provide a means for manufacturers to prepare declarations of performance (DoP) in accordance with provisions of the CPR and to affix CE marking to their products.

The CPR receives brief mention here as it came into force in Ireland on the 1st of July 2013 and will have increasing relevance to construction within and exports from Ireland of concrete construction products and/or their constituents. For example it is the stated policy of the National Roads Authority (NRA) that it "unreservedly expects all those working on NRA funded schemes … to comply with the CPR" and "is currently reviewing its MCDRW (Manual of Contract Documents for Road Works) to identify where issues might arise and is working towards ensuring that all requirements conform to the CPR".

2.2.3 Streamlining Design while accommodating Difference (National Annexes)

The European Commission supports the implementation and use of the Eurocodes in EU Member States (Recommendation 2003/887). The Eurocodes support National Building Regulations and other national requirements for regulated work but remain subservient to them. In many countries including Ireland and the UK, the Eurocodes (or part of them) have replaced the old national codes for structural design, as indicated in Table 3.

The key link between each Structural Eurocode and a country's national regulations is its respective National Annex. National regulations set the appropriate level of safety through Nationally Determined Parameters (NDP), which are flagged in each Eurocode for determination in the relevant National Annex. Each National Annex is a special type of informative annex containing the choices made by a particular country. The body responsible for Irish National Annexes is the National Standards Authority of Ireland (NSAI).

A typical National Annex states the values and classes applicable to that country, provides value(s) where only a symbol is given in the Eurocode and provides country-specific data (e.g. wind and snow loadings). The National Annex selects the procedure(s) to be used when alternatives are provided in the Eurocodes, indicates which Informative Annexes may be used and refers to non-contradictory complementary information (NCCI).

Table 3 Concrete & masonry related Eurocodes and equivalent superseded Standards

Eurocode	Title	Superseded Standards
IS EN 1990	Basis of structural design	BS 8110: Part 1 – section 2
IS EN 1991-1-1	Densities, self-weight and imposed loads	BS 6399: Part 1 and IS 648
IS EN 1991-1-2	Actions on structure exposed to fire	-
IS EN 1991-1-3	Snow loads	BS 6399: Part 2
IS EN 1991-1-4	Wind actions	BS 6399: Part 3
IS EN 1991-1-5	Thermal actions	-
IS EN 1991-1-6	Actions during execution	-
IS EN 1991-1-7	Accidental actions	-
IS EN 1991-2	Traffic loads on bridges	BD 37/01
IS EN 1991-3	Actions induced by cranes and machinery	-
IS EN 1991-4	Silos and tanks	-
IS EN 1992-1-1	General rules for buildings	BS 8110: Parts 1, 2 & 3 and IS 326
IS EN 1992-1-2	Fire resistance of concrete structures	BS 8110: Part 1, Table 3.2 and BS 8110: Part 2, section 4
IS EN 1992-2	Concrete Bridges	BS 5400: Part 4
IS EN 1992-3	Liquid-retaining and containment structures	BS 8007
IS EN 1994-1-1	Composite design – General rules and rules for buildings	BS 5950-3, BS 5950-4
IS EN 1994-1-2	Composite design – General rules – structural fire design	-
IS EN 1994-2	Composite design – General rules and rules for bridges	BS 5400-5
IS EN 1996-1-1	Structural masonry – General rules for reinforced and unreinforced masonry structures	IS 325-1, BS 5268-1 &BS 5268-2
IS EN 1996-1-2	Structural masonry – General rules – structural fire design	-
IS EN 1996-2	Structural masonry – Design considerations, selection of materials and execution of masonry	IS 325-2 & BS 5268-3
IS EN 1996-3	Structural masonry – Simplified calculation methods for unreinforced masonry structures	IS 325-1 & BS 5268-1
IS EN 1997-1	Geotechnical design – General rules	BS 6031, BS 8002, BS 8004, BS 8006, BS 8008 & BS 8081
IS EN 1997-2	Geotechnical design – Ground investigation and testing	BS 5930
IS EN 1998	Design of structures for earthquake resistance (6 parts)	-

An NCCI is a way of introducing additional guidance to supplement the Eurocodes without contradicting them. For example, the NCCI to IS EN 1996-1-1 is given in Structural Recommendation S.R.325 “Recommendations for the design of masonry structures in Ireland to Eurocode 6” (NSAI, 2013). There is currently no Irish NCCI for the design of concrete to Eurocode 2. There are, however, a series of published documents (PD) from BSI which serve as NCCI for design in concrete, with the Irish National Annexes having precedence wherever there is any discrepancy.

2.2.4 Eurocodes Remove Barriers to Design across EU among other Benefits

The general benefits of the Structural Eurocodes identified to date include the following:

- The Eurocodes are claimed to be the most technically advanced codes in the world.
- The Eurocodes are widely used in the construction and civil engineering industry throughout Europe, in neighbouring countries and further abroad.
- Use of the Eurocodes will provide more opportunities for designers to work throughout Europe and further afield.
- In Europe all public works must allow the Eurocodes to be used.

3. EUROCODE DESIGN v BRITISH AND IRISH STANDARDS DESIGN

3.1 Eurocodes for Concrete & Masonry

It is clear from Table 3 that four of the Eurocodes are directly related to structural concrete and four are directly related to structural masonry, with connections to a further twenty-two Eurocodes from ‘basis of design’ to ‘design of structures for earthquake resistance’.

3.2 Eurocode 2 v IS 326/BS 8110 & BS 5400-4

A comparison of Eurocode 2 and the codes it replaces indicates that:

- Eurocode 2 should result in more economic structures than IS 326/BS 8110 or BS 5400-4. Such economic benefits are expected in the long run as opposed to the short term.
- Eurocode 2 is less restrictive than existing codes by providing a more complete range of analysis and design options.
- Eurocode 2 is more extensive than existing codes.

3.2.1 Eurocode 2, Part 1-1: General Rules and Rules for Buildings

This is the principal part which is referenced by the three other parts. For the Irish designer there are a number of differences between Eurocode 2 and IS 326/BS 8110 and BS 5400-4 which make the new Eurocode seem unfamiliar. The key differences are listed below:

(a) Eurocode 2 is generally laid out to give advice on the basis of phenomena (e.g. bending, shear, etc) rather than by member types as in IS 326/BS 8110 (e.g. beams, slabs, columns, etc.).
(b) Design is based on characteristic cylinder strengths not cube strengths – concrete strength classes are designated by uppercase letter C followed by the ratio Cylinder Strength/Cube Strength, e.g. C40/50.
(c) The Eurocode does not provide derived formulae (e.g. for bending, only the details of the stress block are expressed). This is the traditional European approach, where the application of a Eurocode is expected to be provided in a textbook, design guide or

similar publication. The Eurocodes allow for this type of detail to be provided by appropriate NCCI.

(d) Units for stress are mega pascals, MPa (1MPa = 1 N/mm^2).

(e) Eurocode 2 partial factor (γ_m) for steel reinforcement is 1.15 applied to 500MPa (characteristic yield strength of steel to BS 4449:2005) as compared to BS8110 material factor of 1.05 applied to 460 MPa (characteristic yield strength of steel to BS 4449:1997). The former results in a design yield strength of 435 MPa whereas the latter resulted in a design yield strength of 438 MPa. Also, Eurocode 2 and BS 5400-4 have the same material factors of 1.15. Therefore the overall effect is negligible and brings harmonisation to the building and bridge codes.

(f) Eurocode 2 is applicable for ribbed reinforcement with characteristic yield strengths of 400 to 600 MPa. There is no guidance on plain bar or mild steel reinforcement in Eurocode 2, but guidance is given in various NCCI.

(g) The effects of geometric imperfection ('notional horizontal loads') are considered in addition to lateral loads.

(h) Minimum concrete cover is related to bond strength, durability and fire resistance. In addition to the minimum cover an allowance for deviations due to variations in execution (construction) should be included. Eurocode 2 recommends that, for concrete cast against formwork, this is taken as 10mm, unless the construction is subject to a quality assurance system in which case it could be reduced to 5mm or even 0mm where non-conforming members are rejected (e.g. in a precast yard). It is recommended that the nominal cover is stated on the drawings and construction tolerances are given in the specification.

(i) Higher strengths of concrete are covered by Eurocode 2, up to class C90/105. However, because the characteristics of higher strength concrete are different, some expressions in the Eurocode are adjusted for classes above C50/60.

(j) The 'variable strut inclination' method is used in Eurocode 2 for the assessment of the shear capacity of a section. In practice, design values for actual structures can be compared with tabulated values.

(k) In Eurocode 2, the punching shear checks are carried out at 2d from the face of the column and for a rectangular column, the perimeter is rounded at the corners.

(l) Serviceability checks can still be carried out using 'deemed to satisfy' span to effective depth rules similar to BS 8110. However, if a more detailed check is required, Eurocode 2 guidance varies from the rules in BS 8110 Part 2, including for direct calculation of deflections.

(m) The rules for determining the anchorage and lap lengths are more complex than the simple tables in BS 8110 and result in marginally longer laps and longer end anchorages. Eurocode 2 considers the effects of, amongst other things, the position of bars during concreting, the presence of transverse steel providing confinement, welded reinforcement, the shape of the bar and cover.

3.2.2 Eurocode 2, Part 1-2: Structural Fire Design

Part 1-2 gives guidance on design for fire resistance of concrete structures. Although much of this part of Eurocode 2 is devoted to fire engineering methods, the design for fire resistance may still be conducted by referring to tables for minimum cover and dimensions for various elements. These are given in Section 5 of Part 1-2.

3.2.3 Eurocode 2, Part 2: Bridges

Part 2 applies the general rules given in Part 1-1 to the design of concrete bridges. As a consequence both Part 1-1 and Part 2 are required when performing the design of a reinforced concrete bridge.

3.2.4 Eurocode 2, Part 3: Liquid-Retaining and Containment Structures

Part 3 applies the general rules given in Part 1-1 to liquid-retaining structures and supersedes BS 8007.

3.3 Eurocode 2 Less Prescriptive – Pros & Cons

As with all major code transitions the initial reaction of most designers is to seek out equivalency between the old and the new standards to proceed with routine designs, which reflect a naturally conservative approach.

A consequence of the above is that the less prescriptive elements of the codes may appear to 'cloud the issue' rather than present as an opportunity for optimised designs. With the passage of time, however, designers will test the different approaches and explore a wider range of solutions as they become familiar with Eurocode 2.

Although the applicability of Eurocode 2 to a wider range of reinforcement strengths (400 MPa to 600 MPa) is less restrictive, it is anticipated that the characteristic yield strength of reinforcement supplied to the Irish market, and certified by the Certification Authority for Reinforcing Steels (CARES), will be maintained at 500 MPa for the foreseeable future.

3.4 Eurocode 6 v BS 5628/IS 325

In advance of completion of the Irish National Annex, comparative design studies were conducted between Eurocode 6, BS 5268 and IS 325 with the following conclusions:

(a) In general Eurocode 6 was found to be less conservative in terms of compressive design of masonry walls under vertical load than BS 5268 and, to a greater extent, IS325.
(b) Using the 'Recommended' values for lateral bending strengths f_{xk1} and f_{xk2}, Eurocode 6 is significantly more conservative than BS 5628 and IS 325, but as these are Nationally Determined Parameters (NDP) this situation has been redressed in the Irish National Annex and NCCI S.R. 325.
(c) The partial factor (γ_q) for wind loads to be used in Eurocode 6 is set by EN 1990 at 1.5. By comparison BS 5628 and IS 325 equivalents are 1.4 or 1.2 where the wall in question is not essential for the stability of a building.
(d) Accidental damage limitation requirements are not as directly covered by Eurocode 6 as they were in BS 5628 and IS 325. The provisions of IS EN 1991-1-7 should be followed.

4. PRIMARY IRISH DESIGN ISSUES FOR DECADE (2005 – 2015)

4.1 Industry Boom

In the initial quarter of the period under review (2005-2007) there was huge growth in construction and, on the positive side, the production of high quality precast concrete in Ireland reached unprecedented levels.

At the same time the country's road network and infrastructure took shape. In a country not known for its unconventional bridge architecture, several iconic state-of-the-art bridges were designed and constructed. In all of these bridges, concrete, precast or in-situ, prestressed or reinforced, has had a significant part to play.

We now have a selection of cable-stayed bridges which are strikingly attractive, the elegant and subtly extradosed River Erne Bridge and the impossibly slender and shapely Rosie-Hackett Bridge in Dublin to mention a few. The LUAS network and its structures should be a source of pride for designers and commuters alike.

Nevertheless, the pace of construction, which outstripped the industry's ability to regulate itself, permitted the entry of sub-standard and misunderstood materials and products into the construction supply chain.

4.2 Economic Downturn

The second and third quarters of the period (2008-2013) saw the economic downturn take full hold. The shortcomings of the boom became manifest with notorious pyrite contaminations of hardcore and concrete blocks. These were accompanied by famously inadequate fire protection provisions in a few buildings which revealed major deficiencies in the certification regime. These deficiencies were due primarily to occasional lapses in self-regulation on account of the sheer volume of buildings under construction and resulted in disproportionate reputational damage to the construction industry as a whole. The recent introduction of Statutory Instrument No 9 of the Building Regulation in 2014, or BC(A)R S.I.9 2014 is an attempt to reform any perceived shortcomings in the certification of new buildings and structures following the last boom and subsequent downturn.

To be optimistic, the fourth quarter of the period under review (2013-2015) has shown signs of a tentative recovery and the companies that survived are very competitive and prepared to take up the challenge.

4.3 Export Opportunities for Design & Concrete Products

With the onset of the downturn, the pressure to diversify was prevalent among many architectural practices and engineering consultancies which chose to export their services abroad as part of their survival strategy. The timely implementation of the Eurocodes has meant that structural engineers can now ply their trade across the continent and beyond using the harmonised design principles of the Eurocodes. This has allowed consultancies not only to maintain but also to grow their current overseas presence without technical barriers.

Throughout the boom and the economic downturn, quality control was very much at the heart of precast concrete production in Ireland. Although our indigenous precast concrete factories were decimated at the end of the boom, they had not suffered reputational damage which meant they were able to quickly diversify into other markets. In this regard the London 2012 Summer Olympics could not have been more opportune for Irish precast concrete manufacturers to showcase their products.

4.4 Sustainability

In recent years we have witnessed the increasing demand for whole life cycle and sustainable designs of which few, if any, will not include concrete as a key component. In its basic form, concrete has very low energy inputs, it can be produced locally, it is extremely long-lived and it has a high thermal mass which can be harnessed to control and reduce the external energy inputs to the built environment. Cement substitutes can be selected to brighten a streetscape and reduce public lighting costs; equally they can be used to improve durability and reduce a building's carbon footprint *ab initio*.

4.5 Exposed Concrete Structures Impact on Durability

The 'overnight' economic downturn left a legacy of incomplete buildings across the Irish landscape, many of which are in prominent locations. A number of these buildings are of reinforced concrete construction in their 'base structure' state. Almost a decade has passed since many of these structures were abandoned. In the case of the exposed structural precast and reinforced concrete frame of one such building which was placed 'on hold' from 2008 to 2013, it was found that:

- Worst case assumed corrosion rates for exposed reinforcement were not realised meaning that atmospheric concentrations of airborne chlorides were low;
- Low carbonation depths of approximately 1.0mm were typical;
- Increased cover requirements of IS EN 206-1 were met.

From the above it was concluded that the structure had sufficient durability for a design life of over 50 years. It is always dangerous to extrapolate such findings to other buildings in different environments, but it seems that by strictly adhering to the cover requirements of IS EN 206-1 there is the not wholly unexpected but real potential to prolong the life of modern concrete buildings well beyond the 50 year design life inferred by the standard.

4.6 Building Control (Amendment) Regulations S.I.9 2014

It is very early to begin to assess the effectiveness of BC(A)R – S.I. 9 2014 and the question remains as to whether it would have prevented certain failings at the height of the boom when there were simply insufficient 'troops on the ground'. Conversely had BC(A)R – S.I. 9 2014 been in existence it may have proven robust enough to the extent of having had a throttling effect on the boom.

Comments on BC(A)R – S.I. 9 2014:

(a) An efficient design can save a client a considerable amount of money. Where the structure is predominantly concrete, an efficient design can save the cost of the fee on a project e.g. €10M Project with €2.5M Structure Cost and a 10% more efficient design could save €250k in construction costs.

(b) Design is important but BC(A)R site monitoring is critical. However important the design element is, whether that design be extremely tight or with plenty of fat, the fact remains that if a contractor or their subcontractor has priced the job below cost, then cutting corners in construction might be considered 'the best way of making money', with several possible consequences:

    i. Reinforcement cover too low;
    ii. Reinforcement cover too large;
    iii. Bars noticeably in the wrong position;
    iv. Insufficient cube testing.

(c) The BC(A)R 'solution' would be to increase pre-pour inspections from one per week to three or four per week. This could cost the consultant considerably over the period of construction. With such serious quality control issues the consultant could be forced to conduct cover meter surveys thereafter, in order to satisfy him/herself that it is safe to certify.

(d) Certain precautionary measures such as writing clauses into the tender documents requiring the Contractor to produce half-weekly or weekly photographs and reports on reinforcement placement would help mitigate against poor workmanship and oversight

(e) A client who appreciates an efficient design would normally be prepared to pay a little extra on fees to save considerably more on construction. Nevertheless, in the scenario outlined in (b) above, certification under BC(A)R could have a negative impact on the efficiency of a design, when faced with the risk to the design fee presented by poor workmanship. A potential consequence of this is the watering down of the value of design at the expense of certification.

(f) A possible outcome from BC(A)R, therefore, is to put pressure on the consultant to offer a lower design fee in exchange for a conservative design (e.g. thicker slab with 5mm or 10mm of additional cover), resulting in the following:
   - i. Less efficient designs at the expense of increased construction costs;
   - ii. Lower design fees for the consultant;
   - iii. Reduced site monitoring costs (to be offset against the design fee);
   - iv. Reduced need to 'punish' workmanship flaws using extreme measures such as demolition and rebuilding
   - v. A potentially uniform landscape of conservatively designed compliant buildings.

(g) If the BC(A)R requirements are correctly understood from the outset and properly followed over the course of a project, the above 'worst case scenario' may be avoided. The following are key to the success of BC(A)R for all parties:
   - i. Excellent communication between Consultant and Client;
   - ii. Separate design fee within agreed 'design efficiency' parameters;
   - iii. Separate certification fee for commensurate level of site inspection;
   - iv. Tender documents with strong BC(A)R mitigation measures;
   - v. Robust tendering assessment process;
   - vi. Excellent communication between Contractor and Consultant.

5. REVIEW OF ICS AWARD WINNING DESIGNS IN CONCRETE

5.1 Background to review of specific winning designs

In this section a number of Irish Concrete Society (ICS) award-winning designs in several categories are reviewed. These have been selected without any particular bias with a view to illustrating any trends or patterns which have emerged over the period 2004/5 to 2014/15.The review revealed the following:

(a) In its various award categories the ICS has applied strict criteria where projects are awarded depending on the quality and level of entries; in any year where a category fails to satisfy these criteria, the award has not been given.

(b) The Student Award was renamed the Sean de Courcy Student Award at the 2004/5 awards ceremony in recognition of his tireless commitment to teaching concrete technology at UCD, his major contributions as a devotee to design in concrete and as a founder member of ICS.

(c) ICS first introduced the Sustainability Award category in 2006/7 in recognition of the global trend towards more sustainable designs in the face of climate change and the inherent sustainability credits applicable to concrete (see Section 6.3). It appears that from 2008/9 onwards the award has been given on a discretionary basis as opposed to being a standalone category. Since 2006/7, in 7-out-of-9 awards ceremonies, Sustainability Awards (5) or Commendations (2) have been granted with 2010/11 and 2014/15 being the exceptions. The 2010/11 winner of the Overall Award was, however, cited for the high priority given to sustainability considerations. Also, several key aspects of the design of the 2014/15 Overall Award winner had sustainability at their heart. On reflection, both of these projects could easily have merited a Sustainability Commendation or Award.

(d) ICS first introduced the International Award in 2012/2013 in recognition of the contribution of Irish companies to design and construction in concrete on the international stage. The award reflects the increasing emphasis on export of Irish construction services and products kick-started by the economic downturn. In the three year inclusive period 2012/13 to 2014/15, all of the international entries have been constructed in the UK. Perhaps, as Eurocode 2 continues to bed down and as Irish international construction experience continues to grow, entries from further afield will begin to compete in this category.

(e) Winners of the Overall Award in 10-out-of-11 projects were public buildings (5) or infrastructure (5). Privately owned buildings have won the Building and Overall Award just once (2007/8) in the 2004/5-to-2014/15 period and indeed in the twenty years that have passed since the last ICS Symposium. This poses the question for future debate as to why privately owned buildings have not been winning the Overall Award.

(f) An interesting observation is that the vast majority of smaller privately owned buildings, many compelling in their aesthetic appeal, have featured in and won the Elemental Category which has never won the Overall Award. This might go some way to explaining the findings in the previous paragraph.

In the following sections, examples of award winning buildings and infrastructure promoting sustainability, exported services, exported products and optimised design are reviewed.

5.2 Cork Civic Offices – Sustainability Award (2007/8)

In the year following the introduction of the ICS Sustainability Award, the Cork Civic Offices received a commendation in this category for successful implementation of a number of sustainability measures, many of which are now becoming the norm. The project was highly commended for the following:

- Utilisation of the environmental benefits of low energy GGBS concrete;
- Aesthetic integration of environmental services allowing the thermal mass of the exposed concrete structure to produce a natural cooling effect for the building.

The above project exemplifies how the intrinsically sustainable aspects of concrete can be exploited to maximum effect in buildings. Section 6.3 elaborates on the assessment of the sustainability aspects of concrete.

The timely recognition by ICS of sustainability as an award category in its own right has advanced the sustainability agenda in the main award categories and for the Irish construction industry as a whole.

5.3 Lyric Theatre, Belfast – Building & Overall Award (2011/12)

The Lyric Theatre is representative of the year-in year-out delivery of striking buildings in concrete on the island of Ireland since the turn of the century. This building is celebrated for its use of high quality concrete for structural support and architectural impact. Appreciation of the balance between the aesthetic and structural properties of concrete meant that its use was neither over-expressed or denied, creating a natural flow through the building.

The Lyric Theatre has also been highlighted since the delivery of such an impactful project by a committed team of Irish designers has the potential to open up the international market for their services. Indeed, the architectural practice responsible went on to win the ICS International Award two years later and continues to attract high-end international work. With many Irish design and construction companies now having a visibly successful footprint abroad, it is anticipated that the international demand for their services will continue to grow.

5.4 The Copper Box, Olympic Park, London – International Award (2012/13)

The “Copper Box” serves as a very good example of the completion by an Irish company of a high profile project in precast concrete on the international stage. With the Irish construction sector decimated by the downturn, the 2012 London Olympics threw it a lifeline. Coupled with a very strong determination to survive, a number of high-quality precast concrete producers with surplus capacity actively sought out and won a number of significant projects connected to the 2012 Olympics.

The “Copper Box” indoor arena won the ICS International Award in 2012/13 for the technical expertise exhibited in the delivery of a high quality precast concrete solution instead of the original structural steel proposal. The precast concrete design provided a simpler structural solution reducing the mass of steel frame by 130 tonnes and greatly enhancing the overall sustainability of the building. The design, production, exportation and construction overseas of such a prestigious project on time and within budget has succeeded in promoting the technical and production capabilities of Irish construction companies on the global stage.

5.5 Rosie Hackett Bridge – Infrastructure & Overall Award (2014/15)

The Rosie Hackett Bridge is the most recent winner of both the Infrastructure and Overall Award. It has been selected for this review for a number of reasons, namely (i) optimised structural design; (ii) aesthetic appeal, and (iii) sustainability.

(i) Optimised Structural Design
Some of the key structural features of the bridge are:

- Single 47m span post-tensioned in-situ concrete bridge;
- Abutments made integral with the bridge deck to create a ‘portal frame’ in order to minimise horizontal and vertical loading on the existing quay walls;
- Span-to-depth ratio of 1:100, matching anything achieved on the international stage;
- High-strength concrete of Strength Class C90/105 to optimise the design, which is at the upper limit set by Eurocode 2: Part 1-1.

(ii) Aesthetic Appeal
Significant aesthetic features of the bridge include:

- Visual slenderness achieved by the marriage of structural optimisation and three-dimensional contouring of the deck soffit in a high quality in-situ concrete finish;
- Contoured abutments that merge seamlessly with the deck;

- Dual purposing of the flood defence upstand for public seating.

(iii) Sustainability
Among the many sustainability aspects of the bridge, the following are noted:

- Provision of a river crossing of shallow gradient to accommodate low-energy public transport and cycle/pedestrian traffic;
- Use of in-situ concrete to minimise embodied energy and maximise longevity;
- Flow-contoured abutments situated proud of the quay walls to minimise their impact on these historical masonry structures;
- Shallow deck to maintain the navigability of the river channel and provide a hydraulic capacity in excess of that of the existing neighbouring bridges;
- Use of integrated flood barriers to protect the quays.

The latest ICS Overall Award winner is a prime example of the potential of concrete to continue to face and overcome significant design challenges and, despite the relatively benign Irish landscape, for Irish designers to exploit the medium and receive deserved international recognition for state-of-the-art designs in concrete in an Irish context.

6. CONCRETE DESIGN IN IRELAND BEYOND 2015 – 'STAR GAZING'

6.1 Outcome of Less Prescriptive Eurocodes on Future Direction of Design?

For twenty-five years IS 326 / BS8110 provided design engineers with the basic tools for designing in reinforced concrete to a set of prescribed formulas, tables and rules where it could be argued that designing by rote became the norm.

The Structural Eurocodes are set out more on the basis of principles (e.g. bending, shear, compression) as opposed to member types in IS 326/BS 8110 and BS 5400-4 (e.g. beams, slabs, columns). The Eurocodes present an opportunity for engineers to really understand the principles and stretch their designs to the limits allowed in the codes. Although the anchorage length of bars may prove considerably longer in isolation, advantage can be taken of confinement from transverse steel including links or indeed of welding of bars to reduce anchorage lengths.

It is easier to programme Eurocodes in a step-wise fashion. Every aspect of design is covered and not a single formula is left to chance. Alternative methods of analysis are presented for different situations affording greater scope to engineers to optimise their designs.

6.2 New Generation of Textbooks & Design Guides to Come

For the last twenty years there has been an ongoing evolution of textbooks and design guides on the Eurocodes. At the same time National Annexes have only reached a relatively stable state of equilibrium in the last five years. The rush to achieve understandable equivalency of elemental designs between new and old, which was necessary to alleviate any concerns during the changeover period, is now over. To date, however, there does not appear to have been a noticeable shift in terms of a steady stream of more economical designs to the new code.

It is expected that since the bedding-in stage has now occurred, more adventurous textbooks will emerge to encourage design engineers to test the extents of the concrete Eurocodes with a broader focus. These textbooks may promote design economies in terms of shallower span-to-depth ratios and thinner vertical elements as designers become familiar with higher strength concretes and more direct forms of calculation.

6.3 Whole Life Cycle & Implications of BREEAM, LEED, etc.

In the light of pressures on world resources and climate change CEN has been tasked with developing standards which promote the energy efficiency of buildings, including a methodology for calculating the energy performance of buildings, in line with the EU Directive on the energy performance of buildings (2010/31/EU). The CEN Project Committee ‘Energy Performance of Buildings’ (CEN/TC 371) is in charge of coordinating this work, in accordance with EC Mandate M/480.

Specific standards are being developed by the CEN Technical Committees that deal with ‘Thermal performance of buildings and building components’ (CEN/TC 89), ‘Ventilation for buildings’ (CEN/TC 156), ‘Light and lighting’ (CEN/TC 169), ‘Heating systems in buildings’ (CEN/TC 228).

BREEAM (Building Research Establishment Environmental Assessment Method) was first launched in 1990. It is the leading and most widely used environmental assessment method developed by the Building Research Establishment (BRE) in the UK to help mitigate the sustainable construction aspects of non-domestic buildings and, more recently, communities, multi-residential buildings and homes. BREEAM 2014 has trained assessors who assess the evidence against the various credit criteria and report it to the BRE.

Established in 1993, LEED (Leadership in Energy & Environmental Design) is a green building certification program developed in the US that recognizes best-in-class building strategies and practices. To receive LEED v4 (2013) certification, building projects satisfy prerequisites and earn credits to achieve different levels of certification. Prerequisites and credits differ for each rating system, and teams choose the best fit for their project. There are five rating systems that address multiple project types:

- Building Design and Construction
- Interior Design and Construction
- Building Operations and Maintenance
- Neighbourhood Development
- Homes

BREEAM and LEED methods assess the sustainable performance of buildings across the following areas:

- Management: overall management policy, commissioning site management and procedural issues
- Energy use: operational energy and carbon dioxide issues
- Health and well-being
- Pollution: air and water pollution issues
- Transport: transport-related CO_2 and location-related factors
- Land use: greenfield and brownfield sites
- Ecology: ecological value conservation and enhancement of the site
- Materials/Responsible sourcing: environmental implication of building materials
- Water: consumption and water efficiency

The local nature of concrete's production and the well-integrated supply chain has been an advantage for concrete companies to gain accreditation under BES 6001 - Framework Standard for the Responsible Sourcing of Construction Products. Designers can now easily source accredited material and gain maximum credits in sustainability assessment tools such as BREEAM or LEED. Concrete now receives more credits than other materials – which is an acknowledgement of the breadth and depth of sustainability initiatives that are being delivered within the concrete sector, e.g. in the area of steel reinforcement:

- Eco-reinforcement is a scheme that complies with BS8902 and meets the criteria set by BES 6001;
- The CARES Sustainable Reinforcing Steel scheme established to comply with BS 8902.

A key area where the use of concrete can attract points in BREEAM is through the use of exposed concrete floors as part of a building's heating and cooling strategy (as for example in the Cork Civic Offices project, Section 5.2). This approach works the material hard, as it must not only fulfil the design's structural requirements, but must also satisfy its thermal and aesthetic needs. The resulting savings in operational energy from exploiting the floor's thermal mass are often significant, particularly in environments with a high cooling load. A further benefit is the ability to design out the need for suspended ceilings, avoiding their embodied impacts and requirement for periodic replacement.

In addition to the Energy category in BREEAM, there are also the Health & Wellbeing, and Materials categories in which points can potentially be scored for the appropriate use of concrete. A breakdown of these categories and how they may relate to exposed concrete floors is provided in Table 4.

It can be calculated from use of Table 4 that the correct use of concrete floors alone can contribute over 30% to a building's overall BREEAM rating. There is also has a bonus 10% for innovation; innovative approaches to design in concrete are constantly being tried and executed with the potential to further enhance a building's overall sustainability rating.

6.4 Impact of Materials Evolution on Design & Further Evolution of Eurocodes

The European Commission under EC Mandate M/515 has tasked CEN with revising the existing Eurocodes and extending the scope of Structural Eurocodes, incorporating new performance requirements and design methods. This work is the responsibility of the CEN Technical Committee (CEN/TC 250) in cooperation with stakeholders including structural design companies and the scientific community. This work supported by the European Commission and its Joint Research Centre (JRC).

In 2015, CEN will continue working to develop standards in new areas of structural design and construction materials (such as structural glass, fibre-reinforced polymers and membrane structures).

Table 4 Concrete floor BREEAM ratings (Concrete Centre, 2015)

BREEAM category	Weighting	No. of sub-categories
1. Health & Wellbeing	15%	Six
2. Management	12%	five
3. Transport	8%	Five
4. water	6%	Four
5. Energy	19%	Nine
6. Pollution	10%	Five
7. Waste	7.5%	Four
8. Land use & Ecology	10%	Five
9. Materials	12.5%	Five
Total	**100%**	
Innovation	10%	None

% contribution to overall BREEAM rating

Health & Wellbeing:

1. Visual comfort → Scores up to 2.8% (daylighting, glare, view etc)
2. Safety & security
3. Thermal comfort → Scores up to 1.9% (thermal modelling of design)
4. Water quality
5. Acoustics performance → Scores up to 1.9% (meets acoustic standards)
6. Indoor air quality → Scores up to 5.6% (0.95% for nat. vent. capability)

Energy:

1. Reduced CO_2 emissions → Scores up to 8.1%
2. Energy monitoring
3. Efficient external lighting
4. Low/zero carbon tech. → Scores up to 2.7% (0.54% for night-time cooling)
5. Efficient cold storage
6. Efficient transport systems
7. Efficient laboratory systems
8. Efficient equipment (process)
9. Drying space

Materials:

1. Life cycle impacts → Scores up to 4.8% (based on Green Guide rating)
2. Hard landscaping
3. Responsible sourcing → Scores up to 2.9%
4. Insulation
5. Designing for robustness

6.5 Building Information Modelling (BIM)

Building Information Modelling (BIM) has slowly been taking root in Ireland. It makes use of computer software applications to compile complete and integrated data about a building that can be easily shared among all the parties involved in the design, construction and maintenance of a building. Increasingly, public authorities in European countries may require the use of such electronic modelling technology in the context of public works contracts and design contests.

CEN will establish a new Technical Committee (TC) on Building Information Modelling (BIM), which will enable CEN to adopt a number of existing international (ISO) standards as European Standards. This new TC may also develop standards (or other deliverables) in relation to Industry Foundation Classes (IFC), data dictionaries and information exchange procedures. The adopted standards could be used by designers (engineers and architects) and also by builders and maintenance companies.

6.6 Concrete Durability Rebar Corrosion & Outcomes on Modern Concrete Structures

The question remains as to how concrete structures could be made more durable. The benefits of increased cover to reinforcement alone have been described in Section 4.5 above. Research continues into alternative non-corrodible reinforcement which will not deteriorate over time. Further research is also being conducted in the area of durable polymeric concretes. Another approach would be to go back to basics to develop unreinforced concrete designs for the future which rely on compression to resist the design loads. Indeed, the use of unreinforced concrete in compression was mastered by the Romans and, almost two thousand years after it was built, the Panthéon in Rome continues to be the world's largest unreinforced concrete dome with a span of 43.3m.

Inspiration for the back-to-basics approach came from different quarters on the island of Ireland. In the early 1990s Gordon Millington (former Chairman of the Institution of Structural Engineers Northern Ireland Region, raised the question:

"Why is it that so few arch bridges have been built since the early 1900s as they are aesthetic, strong, durable, and require little maintenance?" (Long, et al 2014)

Development of this approach was given further encouragement by Professor John W de Courcy (1995) in his opening address to the 4th UCD CPI Symposium in 1995:

"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."

In answer to the open question offered by Professor de Courcy, the following section provides a case study of the 'back to the future' innovation and adoption of the FlexiArch^{TM} system.

7. BACK TO THE FUTURE – THE FlexiArch^{TM} BRIDGE

Masonry Arch bridges are one of the oldest types of bridge construction and have been in existence since antiquity. They were originally built of stone or brick but since the mid-20th Century traditional masonry arch construction has been substituted with reinforced concrete, pre-stressed concrete or steel. Introduction of these new materials allowed for the design arch bridges of longer span and shallower profile which could either be cast in-situ, manufactured as precast or prefabricated. The common problem with such bridges is corrosion of steelwork or steel reinforcement, leading to high repair and maintenance costs and reduced longevity. With sustainability being a key driver in modern construction, removal of steelwork or steel reinforcement from the design completely and relying on concrete alone would reduce the embodied energy and extend the life of the bridge almost indefinitely.

Construction of a traditional masonry arch bridge involves centring, resulting in significant temporary works, labour costs and slow progress. If traditional masonry construction could be replaced with a prefabricated flexible arch system with minimal on-site construction costs, then the masonry arch could once more become a viable alternative.

Queen's University Belfast (QUB), in collaboration with Macrete Ireland Limited, has developed an arch bridge system (FlexiArch^{TM}) constructed of precast unreinforced concrete blocks or voussoirs. The precast concrete blocks can be cast individually or together with the insertion of a wedge former. While the second method would appear to save time, the first method is preferred as it allows for better quality control over the voussoirs.

The precision precast voussoirs are cast individually, laid contiguously in a line, tied together at the top with a layer of polymeric reinforcement (the key innovation) and capped with a 40mm in-situ concrete screed to interconnect the voussoirs as shown in Figure 1.

When the flexible arch is raised from its flat bed at the designated lifting points (approximately at the 'quarter' points) as shown in Figure 2 below, the force of gravity causes the tapered gaps to close and hinges form in the screed. During this critical installation stage, the structural integrity of the arch unit is maintained by tension in the polymeric reinforcement and the shear resistance of the screed.

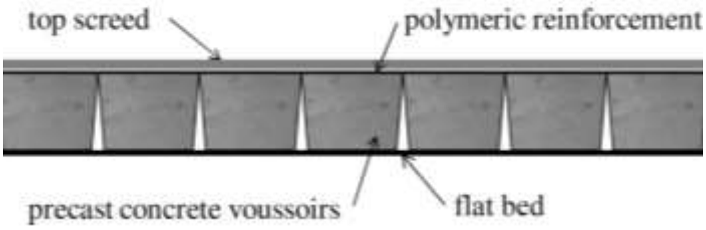

Figure 1. Flat Bed Arrangement of Precast Concrete Voussoirs (McNulty et al, 2011)

Once the unit is aligned on its thrust-block foundations (Figure 3), it can rely on compression within the arch ring to resist its own self-weight and any applied loads.

The key advantages of the FlexiArch^{TM} are:

- Reproducible identical precast unreinforced concrete voussoirs;
- Flat packed transportation allowing energy costs to be minimised;
- Self-contained temporary works solution using polymeric reinforcement layer;
- Speed of Installation comparable with precast concrete/steel beams;
- Standard design methods for conventional arches may be applied;
- An aesthetic, strong, cost-effective and sustainable solution.

Figure 2. Lifting of FlexiArch^{TM} (New Civil Engineer, 2008)

Figure 3. Arch thrust block (Brierley 2010)

The first commercial application was the construction of a bridge on private land in Co Monaghan in mid-2007. For the first highway application three FlexiArch^{TM} bridges were installed one year later on the Newtownabbey Phase 3 Pathway, a new 8km cycle and pedestrian path which crosses the Three Mile Water River on National Cycle Network Route 93 (New Civil Engineer 2008). By mid-2015, more than 50 FlexiArch^{TM} bridges had been constructed in the UK and Ireland.

The Flexi-Arch first won the Construct Award 2009 for Innovation and Adoption for the Newtownabbey project and won the award again in 2013 (Construct Awards 2013). On this occasion the prize was awarded for the restoration of Ashton Bridge by retro-fitting FlexiArch^{TM} units to the bridge soffit (Figure 4). The restored bridge is illustrated in Figure 5. Fourteen 7.4m span FlexiArch^{TM} units were slid into place beneath the existing road bridge dating from 1935, in Tameside Greater Manchester, in the first application of the new technology as reinforcement to an existing bridge.

A further advancement in the flexible arch system has been its evolution towards the double radius arch (Figure 6) to provide sufficient headroom over a dual lane highway or twin track railway (Figure 7).

Figure 4. Insertion of FlexiArch^{TM} (Construct Awards 2013)

Figure 5. Ashton Bridge as restored (Construct Awards 2013)

Figure 6. Double radius FlexiArch^{TM} (Macrete 2012)

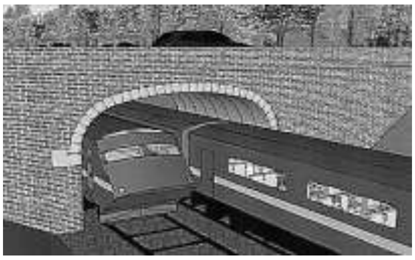

Figure 7. Double radius FlexiArch^{TM} over railway (Macrete 2012)

A recent development in the flexible arch system has been its evolution towards the skewed arch which is significantly more complex but rooted in the same principles as the standard FlexiArch^{TM}. The required skew angle is achieved by varying the step distance between adjacent voussoirs which results in an elongated 'S' shape (Figure 8) when the voussoirs are laid on-the-flat. Again, the arch takes up its correct shape upon lifting (Figure 9).

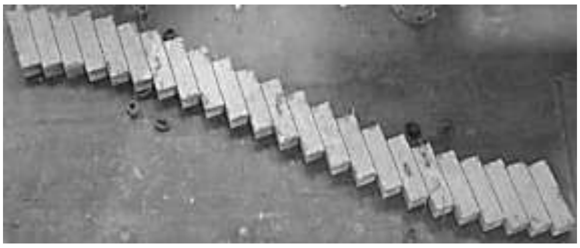

Figure 8. Skewed FlexiArch^{TM} on flat (McNulty et al, 2011)

Figure 9. Lifting of skewed FlexiArch^{TM} (McNulty et al, 2011)

8. CONCLUDING REMARKS

This paper presents a mere snapshot of progress in concrete design in Ireland over the period 2005-2015. We have seen the evolution and perhaps hesitant implementation of the Structural Eurocodes which are now very much at the forefront of European harmonisation.

The concept of 'design in concrete' is so wide and varied that a single conference paper could not begin to cover a fraction of the magnificent potential implied in the phrase. It can also be said with confidence that as the world grows ever smaller the potential for design in concrete appears to grow ever larger.

Acknowledgement

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DISCUSSION

MR. MURNANE introduced his paper. He spoke of the success of the Eurocodes in achieving their intent. The problems attendant on clients commissioning work outside their national jurisdiction and specifying their ‘home’ national codes for work overseas has now been overcome. The Eurocodes themselves have been drafted in a form that presents greater opportunities for creativity in design. There has been a welcome shift from the prescriptive, rule-based style, element by element, that characterised practice heretofore based on the editorial style of British standards. There was some distance left to go on full embracement of the Eurocode solutions – some designers still had a tendency to ‘revert to type’ and checked Eurocode solutions against designs carried out to I.S. 326 / BS 8110.

He lamented the undervaluing of design time by some clients despite the clear evidence of cost-effectiveness. This was particularly a feature of the boom times when speed was everything. He urged the re-education of clients by designers on the value of a changed attitude as we emerge from recession. He also called for rewarding ‘an honest day’s work by an honest day’s pay’, which in practice translates to higher fees than at present. Regarding design itself, he recommended much greater emphasis on flexibility through allowing for change in future use. This would allow functional life to match the existing lengthy material and structural life.

He endorsed the views of other speakers about the need for training of the concrete gang. He noted the competence of many operatives but with lack of formal training there was an increased risk of the material properties in the finished structure dropping below design expectations. He instanced loss of lever arm through incorrect cover to reinforcement.

Reviewing the Irish Concrete Society award-winning buildings and structures, he noted a trend in respect of procurement sector. Publically-funded projects were more prevalent in the number of awards garnered. He felt that private sector clients could learn a lesson from this trend. He noted that the ‘race to the bottom’, from the boom times, had been arrested but designers needed to assert the value of design more, in the context of the private sector projects.

DR. JAMIE GOGGINS, in an invited written contribution, noted overarching factors that need to be considered by all stakeholders in the industry. Major challenges in the past that have been addressed with respect to the performance of concrete are strength and durability. We are now in an era where sustainability is also a key consideration, not just in the choice of construction materials, but in many of our choices today. It is important that when considering sustainability, we address its three pillars – environment, economy and society. This is most evident in the recently published UN Sustainable Development Goals, as defined in Transforming Our World - the 2030 Agenda for Sustainable Development. Similarly, if we consider the most cited papers since 2010 in a high impact factor journal, such as Cement and Concrete, most are focussed on sustainable cement production and/or supplementary cementitous materials.

He urged stakeholders in Concrete Practice in Ireland 2015 to have a positive sustainable impact by focusing on enablers such as BIM, life cycle assessment, smart materials and components. While acknowledging that the list was not exhaustive he elaborated on the examples:

- Building Information Modelling (BIM) – companies should develop comprehensive sets of product/component families for use in common software tools used for BIM and make these easily accessible to the industry. This has the potential to increase market share of Irish concrete products, in particular the pre-cast concrete industry.
- Life cycle assessment – developing a comprehensive life cycle inventory dataset for construction materials and products in Ireland, including cements and concrete; developing a comprehensive database of environmental product declarations for construction materials and products in Ireland, including cements and concrete; setting agreed goals for reducing the global warming potential of construction products in Ireland, including cements and concrete.
- Smart materials and components – use of sensor technology in concrete, which can be used for many applications, such as quality control and assurance; structural health monitoring that can be used for performance based analysis in future decisions about our infrastructure; better control strategies for operating buildings, which may lead to safer, healthier, more comfortable and productive indoor environments, at the same time ensuring the reduced/optimised energy consumption in buildings (e.g. linking sensors embedded in the concrete elements with the Building Management System (BMS) to more effectively utilise the thermal mass of concrete through real-time decisions).

SESSION B-3

CONCRETE IN CONSTRUCTION

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Abstract

This paper addresses the evolution of the concreting industry's practice on site since the last 'Concrete Practice in Ireland' symposium proceedings were published in 1995. The typical practices prevalent in the mid 1990's are contrasted to those in use today. Site activities, practices and methodologies are compared with current trends.

1. DESIGN OF BUILDINGS

Buildings have become larger, taller and more complex over the past number of years. Typically in the 1990's the average concrete contractor was involved in projects ranging in height from two storeys to five storeys. With the advent of globalisation and the free movement of goods and services, commercial activity in all sectors have transformed and magnified, with greater workforces, requiring ever more accommodation space. With this new trend comes increasing challenges to construct these buildings. Weights of building components are being reduced with the advent of technology and new codes, heights of buildings increasing, with this comes more efficient designs but more complex construction tasks to create these ever complex details. Currently the larger contractors will not even raise an eyebrow to buildings currently being designed of 20 storeys high.

Concrete has become more 'trendy' of recent years with more and more concrete elements becoming exposed and used as the finished surface. The advent of the exposed concrete or "Architectural Concrete" as it is better known has led to an evolution in the approach to construction techniques. Everything from the source of materials to the pouring of the concrete needs to be critiqued, planned and carefully considered. This planning and attention to detail along with the shortage of skilled labour and lack of ongoing architectural concrete projects has led to a huge bias or fear from the contracting industry to execute such projects.

However there is no avoiding the fact that current design views exposed concrete as an environmentally friendly product, with low maintenance costs and positive aspects regarding its thermal capacity. In the 1990's concrete was designed by the engineer to form the manaquin for the Architect to "dress up". A brief review of the winners of the Irish Concrete Societys' Annual Awards over the last 20 years serves to demonstrate the radical change that the industry, and the fabric of this country, has undergone as a result of both Public and Private investment.

2. QUALITY CONTROL

The quality of concrete elements poured in recent years would be perceived to have greatly improved over the last 20 years. Without doubt this is due to enhanced technical knowledge and training combined with on-site experience, in Ireland, on technically challenging projects, and on projects of substantial scale that demanded such investment. This experience coupled with the free movement of labour has resulted in a situation where repeats tasks are being completed efficiently and without defects and those involved are benefitting from the experience gained, which results in the quality of future work being enhanced. Early contractor involvement is a feature of construction in recent years. This involvement facilitates the contractors combining their vast knowledge and experience with the detailed technical and creative skills of the design team to create an overall betterment of the construction process. A decision to construct a project involves a considerable financial outlay. Contractors have assisted the construction industry in providing cost effective solutions to construction thus benefiting the overall decision making process.

However the downturn in the industry from 2008 has seen a considerable flight away from construction and little investment, particularly in training. Already the UK has hit crisis point in regards to entrants and training, and there are significant initiatives in place there to address the skills deficit that has clearly affected their delivery of key programmes. We now face the exact problem in Ireland. Construction is viewed as a risky career (not much of a change there), and many of the experienced “hands” have retired or emigrated. With so many other options available to both younger and older people in “cleaner” employment opportunities we really do face significant challenges as the forecast for the industry looks brighter. The industry has moved away from “Main Contracting” in the old sense of the word, with much of the work being now completed by specialist subcontractors. With many of these contractors on their “uppers” it seems that they will be an unlikely source to invest in long term training needs, and it behoves the industry now to plan for these needs.

As with all evolution processes the benefit is accompanied by the burden. Unfortunately the non-productive by-product of enhanced quality of the finished product comes with an ever increasing “paper pile”. The need to record, and detail every aspect of the process combined with more complex construction projects, increasing participants to the contract, and increase in dispute resolution has fuelled the need for paper. The introduction and development of standards has also added to the amount of records to be produced. The construction products regulations introduced in July 2013 sought to overcome barriers to trade within the EU by harmonising technical standards, agreeing systems of assessment and CE marking most construction products. The introduction of these standards and the lack of statutory or professional education for contractors has led to a situation of uncertainty in some instances.

The Building Control Amendment Regulations 2014 has added to the administrative burden on contractors. The regulations require formal inspection and hold points in the construction of a building, this again has added to the paper pile in that contractors have to prove the constructed elements comply with the requirements of the regulations.

3. CIVIL ENGINEERING

The overall approach to bridge design has changed in recent years from articulated bridges which incorporated moving components, to fixed state bridges. As the National Road Authority (NRA) have taken control over the maintenance of many road networks around the country, they have moved towards reducing the maintenance costs associated with the articulated bridges. Moving parts have being significantly reduced with more recent bridge designs. The advent of the public private partnership model of project procurement has also led to the move towards solid state bridges.

Concrete strengths and durability are increasing along with the use of specialist liners. Contractors have become more specialised in this form of construction and a huge factor in their work is the responsibility for the temporary works design. This responsibility for temporary works along with a greater involvement in the mix design process has led to less instances of concrete cracking and spalling. The advent of ever more efficient and technical specifications has its downsides for contractors as engineers are specifying increasing quantities of mix designs, in some cases as much as seven designs for a single structure. The greater quantity of mix designs involves greater trials' for contractors and greater risk of the correct consistency of mix being achieved with the corresponding environmental conditions.

4. IRISH AND UNITED KINGDOM CONSTRUCTION COMPARED

With the recession in Ireland, many contractors had to look for work outside of Ireland in order to maintain their business. Many of these companies travelled to the UK and established a base there. Much has being learned from the experiences gained and exposure to UK work practices. UK formwork contractors tend to be either small formwork contractors working on small development in regional towns or publicly quoted companies working on London's most prestigious landmark buildings. Many formwork contractors in the UK will undertake the full sub and superstructure works from constructing the frame to excavating the basements including value engineering of the design to overall design responsibility including setting out of the structure. Irish formwork contractors generally do not have sufficient turnover to warrant the risks associated with all the responsibility from design through to the supply of concrete, reinforcing, plant and equipment. However a trend is emerging where larger formwork contractors can supply all formwork, construction accessories, plant and equipment necessary however, it is the exception as supposed to the rule.

The risks associated with this approach by the larger formworks operators have come to pass in recent months in the UK. Two of the very large specialist have shut down for various reasons, particularly where they had moved outside their core business and where they had adopted new risks profiles that perhaps they did not fully assess. It seems an unlikely route for Irish formwork specialists to travel.

5. CONCRETE AND PRECAST

The composition of concrete mixes has evolved over the years with the most notable change being the introduction of ground granulated blast furnace slag (GGBS). GGBS has many benefits most notable its "green" credentials however the impact on the construction process has being controversial, with some contractors expressing a reluctance to use the product, to a more holistic approach by others. The GGBS slows down the heat of hydration, thus contractors have expressed concern that the striking of formwork to rising elements in winter months is delayed by generally a day. This delay is generally catered for by ensuring additional formwork is available to cast the next element. Contractors report that the introduction of GGBS to slabs has a neutral affect as formwork is usually not ready for striking within a short period as sufficient rising elements on the next level have to be cast.

Precast concrete has being accepted as playing an important role in the construction of buildings. The benefits of precast have greatly increased with the investment in plant and machinery allowing manufacturers to cast elements which would have being beyond their capabilities twenty years ago. Formwork contractors regularly utilise and work alongside their precast counterparts to create the best overall solution for the project which will enhance productivity and build ability. Traditionally the precast supplier would supply the main contractor, however a trend is developing where the formwork contractor will retain a precast supplier to produce products on their behalf, becoming in essence more like the UK model of precast supply.

One of the real success stories since the downturn has been the ability of the precast industry in Ireland to successfully compete in the UK market. There is no question that the industry certainly worked incredibly hard to maintain its' workforce, knowledge base and sheer existence by delivering and erecting product in the UK and it merits specific mention.

6. PROGRAMME

Ever complex buildings require an increasingly complex software programme to facilitate construction, monitoring and reporting. The computerisation of programmes have brought on the notions of "float, resources, baselines, critical paths, milestones etc." These concepts have filtered their way through the construction chain to the contractor, who must respond and manage the programme and reporting process. This process requires training, new skills and additional management resources. Building Information Modelling is a new concept to the building industry. The BIM model can more easily portray the construction of the building at various timelines in the construction process, and currently the industry, from Clients to design teams to sub-contractors are assessing the delivery of projects in BIM, given the lack of investment over the last 7 years. There is no doubt it is a powerful tool when complete, and the UK has decided it is the way forward on all its Public Contracts. However there appears to be an unwillingness in Ireland to commit to invest in BIM fully just yet, as the industry is just getting up off its knees.

Technology has transformed the delivery of drawings from the old system of printing the A1 drawing and posting six copies, to emailing the drawings with no paper copy. This new method of translating the information to the contractor has being complained of, as last minute changes are being e-mailed and modifications not incorporated into the works as e-mails have being missed. This situation is possibly going to evolve further as the contractor will most likely be given the BIM model and the drawings will have to be created from the model then printed. The overall burden of delivery is increasing for the contractor as risk is shifted, programmes reduced and designs become more complex. However the introduction of IT systems has no doubt led to significant efficiency for all parties. Drawings can be easily amended, paper copies are fewer on site, iPads are becoming the norm for Engineers on site and being "synced" at night-time to "the model", mobile phones can carry all the data for a single project, and yet somehow, we are busier than ever. However as one of those who could never get his desk clear of paper, the advent of the lap-top has been a life changing experience.

7. FORMWORK AND ACCESSORIES

Traditional formwork consisted of solid timber members, primaries and secondary's along with plywood liners, this then evolved into engineered primary and secondary timber members and again into aluminium and steel sections. Economic, environmental and technical considerations are driving the need for alternative materials to timber to be considered which would form the bases of the formwork system. Glass reinforced plastic is used for column forms and bridge deck permanent formwork, along with foundation formwork. Disposable formwork composed of multi laminated paper layers produces a high quality concrete finish in various shapes from circular to hexagonal. Steel formwork systems are utilised to meet the most demanding of engineering projects, tunnel formwork is one such system which has being utilised in apartment construction along with tunnel projects in recent years. Slip form shuttering is commonly used in place of fixed shuttering for long lengths of concrete structures, as can be seen on the interim section of motorways throughout the country. Climbing formwork is an old system which has made a comeback recently, but again used intermittently mainly on high rise structures. The most common formwork system prevalent today is the sectional system comprised of a hard wearing phenolic plywood fixed to a steel frame, also known in the industry as "the pan".

Soffit formwork for floor slabs are generally created with prefabricated "Tables". This system has generally remained unchanged over the past few years, however the method of transporting the table has evolved with the onset of the table hoist in place of "the forks" suspended from a crane. More complex smaller area soffits are still created with engineered timbers. Soffit formwork has become more manageable with the introduction of lightweight sectional systems which can be handled by operatives whilst negating the need to remove the props supporting the slab above.

Chemicals used in the construction process have remained unchanged over the past few years, however the chemical compositions have being modified, generally to improve the product. Contractors have seen a deterioration in the effectiveness of some release agents as more potent chemicals are replaced with more environmentally friendly equivalents. The typical spacer used in the 1990's were concrete pavers, bricks or prefabricated blocks, these products have evolved and plastic spacers have now taken centre stage. The introduction of plastic, has greatly increased the safety associated with protruding reinforcement, with plastic caps and strips now providing adequate protection. New advancements in structural technology include the introduction of thermal breaks for continuity reinforcing in balcony construction, along with shear load connectors for movement joints.

8. LABOUR

EU accession in 2004 accompanied by cheaper air travel has greatly increased the flow of migrant labour into the Irish construction market. This increase in labour fuelled an already heated property market, but greatly assisted contractors who were finding it increasingly difficult to locate skilled local labour. This skilled labour solved one problem but presented another challenge in the form of the "language barrier". To resolve this issue many contractors employ operatives with at least one person speaking both the native tongue and the English language. The foreman, who again is a rare asset, has adapted by learning a few words of the foreign language themselves.

Contractors complain of the lack of structured training for trades within the profession. The state training bodies do not have apprenticeships for steel fixers, or concrete finishers, and as such these operatives must learn on the job. People have a tendency to end up working in the formwork industry and construction industry, rather than having an aspiration and seeing the industry as a clear career path. The work is hard and involves long hours and in some cases a "nomadic" lifestyle moving from project to project. Perhaps what is not recognised is that so many of the "cleaner" industries such as IT, business, finance and retail, have the exact same issues, to a greater extent.

Training has being targeted at the safety element of construction over the past two decades, and rightly so, and little training has being provided within the quality and environmental sectors. Operatives usually learn by trial and error and experience. Professional bodies such as the UK Concrete Society have introduced papers on best practice, but few formwork contractors in Ireland are members of this organisation. The system of education within the sector is left with the experienced personnel to educate the younger operatives with the knowledge they have gained over their career.

9. HEALTH AND SAFETY

The Safety, Health and Welfare at Work Act 2005, General Applications Regulations 2007, and the Construction Regulations 2013 have had a profound effect on the concrete construction industry. The change in the approach to construction and performance of contractors over the past twenty years is akin to the moon landing. Twenty years ago the hard hat was a scarcity, hobnail provided the footware, and personal protective equipment was the exception instead of the rule. Today personal protective equipment is utilised on all projects. Steel-toed and soled wellingtons, glasses and gloves are used for pouring concrete slabs, hi visibility vests are worn by all operatives and mandatory, with goggles for cutting reinforcing bars or concrete.

Formwork construction is a high rise activity, and many accidents have occurred through the years. Unfortunately falls from height remains a major issue in the pursuit of a safe work place. Falling from height is still accounting for 3 in every 10 construction place deaths. From 2005 to 2014 construction deaths in Ireland have decreased from twenty three to eight. Contractors have made consistent efforts to improve work practices helping to ensure a safer workplace for all people involved in the construction process.

A major improvement in safety has being provided by the advancements in temporary works designs. Contractors are now legally obliged to have all temporary works designed by a qualified professional. The reporting of accidents and Incidents to the Health & Safety Authority is also mandatory, and contractors are obliged to notify the authority of near misses. Considerable investment has being made training operatives in safe work practices, with Safe Pass and manual handling now mandatory for all construction workers. Other such training which is regularly under taken by contractors includes, First Aid, Safety representative training, confined space training, Safety Harness training, abrasive wheels and slinging and signalling. Logistics on sites is far better managed too, both within the site boundaries and on entry/exit. Clean efficient vehicles mounted with reversing beacons, auxiliary devices and dedicated inspection platforms are the norm on site, along with professionally trained drivers.

10. ENVIRONMENTAL

Twenty years ago protection of the environment was not a major consideration for contractors, an issue that is documented by the amount of waste that went to landfill., before the costs of such waste were addressed by Government. However, the introduction of statutory laws, mainly originating in Europe, have required a considerable change in approach to the execution of construction projects. Gone is the day where the concrete bottle can be washed out on the ground, dedicated washout zones are now required which filter the harmful chemicals from the waste water. Waste is now required to be segregated, concrete, steel, timber and general waste need to be disposed of in separate waste disposal containers. Spill kits and hazardous waste bins are required to be carried by contractors to dispose of sealant tubes, and release agent drums. Petrol and diesel must be contained within a bunded area, and sealed in a steel airtight can. Dust must be controlled, with local authorities imposing strict limits on the creation of dust. This has required a change in approach to tasks being carried out, concrete cutting saws now have water bottle attachments, grinding disks have air extraction points, and vibration is kept within specified limits.

Breeam and LEED have also moved contractors to carry out more sustainable practices. Materials are now sourced more sustainably. Timber can be procured FSC or PEFC approved, chemicals are required to be labelled and disposed of correctly and water is rationed and metered.

11. THE FUTURE

To take a view on the future of Concrete and the Construction Industry for the next 10 years is a very difficult task, having regard for the turbulent and attritional nature of the business. As we review the position in summer 2015, with clear indications all around us that the business of construction is rising up from the last 7 years of utter devastation, some matters are probably quite certain:

- Those operating within the industry will be very lean and efficient.
- There will be more specialist small contractors and suppliers.
- From suppliers to consultants and everything in-between, they will have professional and highly qualified people within their organisation to meet both Client, risk and statutory requirements.
- There will be less manpower on site, and more prefabrication.
- Precast suppliers will flourish on the back of the investment, achievement and innovation abroad, after the industry collapsed here.
- There will be fewer “big” players within the industry as companies amalgamate.
- Prudent financial management will regulate corporate expansion, not opportunity.

The concern is that in ten years’ time, at the 2025 Concrete Practice in Ireland symposium we will be again discussing:

- The lack of interest among students in being involved in engineering and construction related studies.
- The ongoing and archaic requirement that Higher Level Maths in Leaving Cert is an absolute requirement to study engineering in our Universities, which is undoubtedly related to the 1st concern above.

- The death of the trades in Ireland, through lack of interest emanating from lack of investment, failure to promote the trades as a career, and failure to address the current negative elements of a 4 years trades apprenticeship course.
- The continuing (and perhaps ongoing for an entire generation) negative view of the construction industry following its collapse in 2008.
- The failure of Government to throttle Capital Expenditure into a contra-cyclical programme so that the construction industry faces relatively level demand between private and public equity investment cycles.
- The unfair risks associated the latest ill-judged Government Form of Contract.

As an eternal optimist--and one has to be, to survive this industry-- I do believe that the future is bright and the industry will grow and develop. We have the very best people working within the industry, and with the appropriate changes to entry programmes we can attract young people into it. There is absolutely no doubt that it will continue to be bust or boom cycles for the next 5 years, and that we will not learn from some of our mistakes, at a macro level. However, those who have survived the last 7 years have no aspiration within our own organisations to see the return of the "Tiger" to this country. If our industry is to remain stable and to become attractive it behoves those who control investment to ensure that such investment is timely and targeted to deliver steady growth, within the domestic markets and businesses, over the next 10 years.

Acknowledgements

I would particularly like to thank my colleague Shane Glynn (BSc P Dip.C. Law) for all his assistance throughout the preparation of this paper. I would like to also thank Michael Barnwell (BE Dip Proj Mgt C Eng FIEI) for graciously stepping in, in my absence on the day of the symposium. I would like to thank all my colleagues from Main Contractors, Subcontractors and Suppliers who met together to discuss the current state of the industry in preparation of this paper and who expressed their views so passionately.

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DISCUSSION

MR. BARNWELL gave an overview of the construction industry in Ireland today on behalf of Mr. Aherne. Introducing the overview he indicated that every aspect and developing trend was related to at least one of just three themes: time, quality and money.

The major shift that he drew attention to in the industry was the collaborative approach, whereby the contractor was now engaged in the process from a much earlier stage. While this form of procurement was not practical in all cases, it was a welcome feature in many projects. Another feature in respect of increased efficiencies resulted from a greater degree of added value fabrication off-site. Early involvement in selecting lap length, continuity rebar can make a difference. Some efforts at efficiency were not succeeding, despite their good intent, through impracticality. For example he instanced cases where different concrete strength classes were specified for a single slab. Although possible to achieve, he questioned the true efficiency in that it complicated the process for the contractor in respect of restrictions on stop-end positions. These might offset any savings in material costs.

He welcomed the complex designs and wonderful aesthetics of award winning designs, exemplified by the Irish Concrete Society annual award winners but he cautioned that there was currently a skill set shortage in the construction industry in Ireland. The immediate skillset shortage was a consequence of the effect of the lengthy and deep recession. However he drew attention to a further underlying trend. This was the loss of interest on the part of some of the workforce in entering the tough physical environment of construction. While some complex concrete elements could be precast, there would always be projects where in-situ concrete work was required in difficult situations. Attracting people to the industry for this work was an increasing challenge. Gender balance in the industry was not good and this also needed to be addressed in respect of solving the skill-set issues. In general in could be stated that working conditions on site will need to improve to a new level in attracting and retaining the workforce of the future. Attracting people into the industry is going to be a challenge for the industry that must be met. Equally there will need to be a realisation that some of the trades will no longer provide the level of skill, expertise and quality during to loss of interest in such apprenticeships. Therefore the industry will need to provide new details installed by a workforce of lower skill level, but working under increased level of supervision. A further new element was the need to overcome language barriers. There was increased mobility of labour. Ireland cannot meet its workforce needs and there has been a great increase in proportion of the workforce made up of foreign nationals, notably from eastern Europe. Foremen must upskill their foreign languages to meet the demands of communication with a diverse workforce.

In respect of complexity, he noted that concrete practice in Ireland in 2015 was characterised by much greater bureaucracy than that which prevailed at the time of the previous symposium, twenty years ago. Site colleagues were now somewhat overwhelmed by paperwork and sign-off. However as a counter to this increased complexity was the provision of information technology (I.T.) tools to address the needs. He instanced the greater use of Building Information Management (BIM) and how this heralded the day when significant amounts of information could be accessed on site through tablets and iPhones. All public projects in the United Kingdom will be BIM based from 2016. We were moving to 5-D models with time and facilities management being added to the 3-D element. He expressed the hope that many of the I.T. developments being worked on by software developers would be of direct relevance to the needs of the construction industry.

He pleaded with designers to consider the logistical aspects of construction at the design stage. For example environmental concerns have introduced greater restrictions on working hours, noise levels and dust control, particularly in urban areas. Such changes in construction practice needed to be taken into account at design stage.

He felt that the industry in Ireland, naturally limited in scale compared to larger markets, was punching above its weight. Nevertheless the limited scale reduced the viability for large scale subcontractors, such as the shuttering and concrete sub-contractors who are a feature of U.K. practice. He spoke for example of ‘frame contractors’ who you simply ‘opened the gate for’ and they would do a full concrete frame from foundations to roof, providing their own crains and other logistics. Such specialist contractors can influence design and can provide in-house design teams to support the process. He felt that the greater prevalence of such sub-contractors of scale in Ireland was required to meet future demands in respect of pace.

Given the significance of time in building operations and contracts he noted the increased role of the specialist programmer and planner. Clients were demanding shorter programmes and greater risk was being transferred to contractors in respect of meeting completion date targets. There had been a move from simple bar-chart programmes covering about 30 activities to the need for very complex programmes if targets were to be met. This was another area of skill shortage.

He echoed the remarks of previous speakers about the relationship between top quality work and a top quality safety culture.

Developers were demanding adoption of BREEAM and LEED standards in projects, as it enhanced rental income rates significantly. Traceability within the concrete industry must back this up.

MS. CATHERINE O’KEEFE PRUNTY spoke of an increased role for Information Technology on site in the quality control process. The Dublin Institute of Technology School of Construction will soon offer CPD modules for site operatives in the use of digital information on site using tablets and iPads. This should assist in the management of the regular inspections now required.

MR. JOE MURPHY reflected on the need for the industry to work better together. He instanced the recent case of building defects in Priory Hall, where the politicians took the lead, rather than the industry, in formulating a response. This led to further regulations. He noted how the current form of working – at a workstation – was diminishing the degree of personal interaction on discussion of details with the design team. This isolation must surely lead to knowledge gaps. A different approach was required, which would drive the industry to work together. Given that there was this work to be done – ‘*obair in aisce’* – he proposed that the Irish Concrete Society should take the lead in bringing the industry together, given its unique position in the industry, with membership across so many sectors. MR. JOHN O’REILLY supported the role of the Society in this and in the related topic of getting the contractor and design team working collaboratively at the earliest possible stage in the project.

MR. BRENDAN LYNCH noted that there was a great increase in the use of sub-contractors in concrete practice in Ireland today. He linked this aspect with the skills shortage and lack of training in respect of concrete practice on site, which has been commented on at the symposium. This was a cause of concern, given the importance of workmanship to the finished product in our industry. The Irish Concrete Society had found it difficult to attract sub-contractors to membership and training courses, probably due to the small size of the individual companies. He wondered if main contractors would address this by insisting on documentary evidence of competence, in addition to considerations of price. In response MR. BARNWELL elaborated on the change identified by Mr. Lynch. Looking back 25 years, Sisk as a main contractor had identifiable teams of concrete operatives with recognised roles including section leader. This has changed to greater use of sub-contractors. Looking to the future, based on experience in the U.K., he envisaged larger scale sub-contractors who would be taken on to construct the entire concrete frame. Such contractors would wish to have a long-term relationship with the main contractor and so may be expected to bring a highly skilled workforce to the project. However, given the small market in Ireland it would be a business challenge to achieve this. For example the specialist contractors in the glazed facade industry have a limited turnover each year in Ireland due to the size of the market. They cannot take on certain large scale projects. He envisaged that it could be similar for specialist concrete sub-contractors in Ireland. The scale of the industry was a potential problem in respect of investment in training. He agreed with the view, expressed at the Symposium, that collectively we need to come together to make this a more attractive industry.

SESSION C

CONCRETE RESEARCHON THE ISLAND OF IRELAND 2005-2015 – AN OVERVIEW

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Abstract

This paper describes the main themes of research in concrete materials and structures in the period 2005 to 2015, as evidenced by the conference and journal publications of the academic principal investigators in the Institutes of Technology and Universities on the island of Ireland. Remarkably, about 650 papers have been published in total, of which about 100 have been included in the proceedings of the five Concrete Research in Ireland colloquia held in the last decade. Over 400 selected references have been cited here in a theme-by-theme review.

Nomenclature: *AIT: Athlone Institute of Technology; BSE: Back scatter emissions; CPF: Controlled permeability formwork; CPI: Concrete Practice in Ireland; CRI: Concrete Research in Ireland; CIT: Cork Institute of Technology; FEM: Finite element method; Fibre reinforced polymer; GGBS: Ground granulated blastfurnace slag; KPI: Key performance indicators; QUB: Queens University Belfast; NUIG: National University of Ireland Galway; SCC: self-compacting concrete; TCD: Trinity College Dublin; UCC: University College Cork; UCD: University College Dublin.*

1. INTRODUCTION

The brief for this paper was to summarise the concrete research undertaken on the island of Ireland by academia in the decade since 2005, as reflected in learned publications. It is a fact that many academics are unfamiliar with the work undertaken by colleagues in other institutions except when working in the same or associated research areas, so it would be unsurprising if what is described herein is also largely unfamiliar to practitioners. This lack of awareness by academics is primarily because they can only concentrate on keeping up with the plethora of journals in their own immediate research discipline in which they may occasionally spot a paper by a fellow researcher. It is, therefore, apposite that, following the inaugural paper on an overview of concrete research in Ireland at CPI 1995, a series of concrete research colloquia has taken place since, roughly every two years, to keep the academic and construction communities informed as to what emerging research topics were being undertaken, while enabling young researchers to exhibit their work for the first time on a public stage.

In his inaugural address on concrete research in Ireland at CPI95, Prof Simon Perry of TCD stated:[1] "At present, all indications are that the construction industry is coming out of the recent recession, with a distinct upturn 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….there is a continuing need for a better understanding of the ways in which concrete, both **materially** and **structurally**, behaves." So, apart from invoking a sense of *déjà vu*, this call to action is why this paper describes the remarkable array of research work on concrete materials and structures published by academics since 2005, a veritable "who has done what" in Irish academic concrete life. Thus, it is hoped that this paper may be an informative reference source for academics and practitioners alike.

1.1 Concrete Research Infrastructure

It is worthwhile reflecting on the significant developments in the supporting infrastructure for concrete research: In UCD, the move from Earlsfort Terrace to the Belfield Campus in 2007 has led to spacious and flexible laboratory space, while the construction of the very progressive NUIG "live" laboratory building (Figure 1a) recently will be an excellent exposure on how buildings work for years to come. The much publicised conglomeration of DIT properties on to one site in Grangegorman is a very exciting development, as is the planned replacement of the heavily utilised Simon Perry Building (Figure 1b) with the imaginative E3 complex on the main TCD campus. Such investments serve the research and construction sectors well in facilitating continued world class research into concrete, which, given the small size of our two countries, is highly commendable.

Figure 1(a): NUIG Live laboratory (Source: Goggins)

Figure 1(b): Simon Perry Building, TCD, due for demolition

1.2 Concrete Human Resources

In truth, the timescale of most PhD projects, namely four years in total, mitigates against a quick return on investment into an innovative idea. However, with many academic institutions now running integrated Bachelors/Masters courses (which are essential for Chartered Engineer accreditation by Engineers Ireland), opportunities exist for short term pilot research projects with further expertise available through Post-Doctoral Fellowship appointments, both of which are likely to yield more immediate returns on research investment. The list of those who have edited Irish research colloquia in the last 10 years (Table 1) is populated by experts who have many demands on their research time, driven by funding – so if the concrete industry wishes to retain and enhance this expertise, it too must fund research to capture this diminishing resource of academic time. Finally, too often the immense contribution made by the technical staff in bringing the various research projects to a satisfactory conclusion is overlooked, thus that support and achievement should be openly acknowledged and celebrated here also.

Table 1: Details of Concrete Research in Ireland Colloquia, 2005-2014

Year	**Title**	**Location**	**Editors**	**Concrete Papers**	**Total No. of Papers**
2005	Concrete Research in Ireland (CRI05)	UCD	C. McNally	15	15
2008	Bridge and Concrete Research in Ireland (BCRI08)	NUIG	E. Cannon, R.West, P. Fanning	12	53
2010	Bridge and Concrete Research in Ireland (BCRI10)	UCC& CIT	NA.Ni Nuallainn, D. Walsh, R. West, E. Cannon, C. Caprani, B. McCabe	27	76
2012	Bridge and Concrete Research in Ireland (BCRI12)	DIT & TCD	C. Caprani, A. O'Connor	14	88
2014	Civil Engineering Research in Ireland (CERI14)	QUB	S. Nanukuttan, J Goggins	26	86

2. CONCRETE RESEARCH IN IRELAND COLLOQUIA

The original concept for the CRI colloquia was to provide, on a frequent basis, an opportunity for researchers to keep abreast of what concrete research was being conducted on the island of Ireland, and particularly to provide a platform for young researchers to cut their teeth on the dais before taking on international exposure. In this they have been very successful, with 96 papers specifically on concrete research being presented and published at the five events held around the country in the last decade.

The proceedings, which are published formally (Figure 2), are peer-reviewed and the editors, venues and numbers of concrete papers (with the total number of research papers presented also included) are listed in Table 1. From this it can be observed that the Concrete Research in Ireland (CRI) and Bridge Research in Ireland (BRI) series of colloquia merged in 2008 into a joint Bridge and Concrete Research in Ireland (BCRI) due to large overlap in the topics. However, on opening up to other disciplines in 2012, it is the case that there were more papers on Geotechnical Engineering than concrete and, as a consequence, the title of the series came under pressure. The organising committee elected to change the name of the series to the more generic Civil Engineering Research in Ireland (CERI) to be more inclusive, meanwhile forming a new association (CERAI) to oversee the running of these biennial events.

It could be argued that concrete research lost something of its identity when only 14 papers out of 88 were on that specialism in 2012. Incidentally, the peak of a total of 88 papers in 2012 is because that is the largest number of papers that can be accommodated in a two day event which has three parallel sessions. However, as shall be suggested presently, there is a possible solution to the lower concrete presence at the CERAI events, in which there is a strong basis for optimism.

Figure 2. Published proceedings of the five CRI symposia with CPI 1995

3. RESEARCH THEMES

When invited to deliver this paper, the author embarked on a survey of academic institutions to identify who was active in publishing research into concrete materials and structures. Of necessity, only conference and journal publications in the period 2005-2015 inclusive were sought, so books, technical reports and theses are omitted. Any reports on research undertaken in industry were also omitted due to difficulties in sourcing all such documents in a diverse constituency.

All 14 Institutes of Technology and 9 Universities on the island were contacted and, while all but one replied, interestingly, only 8 institutions confirmed that their staff had published work on concrete in the said period. Those individual academics who made returns are as listed in Table 2 and those in bold in that table kindly agreed to act as a conduit in gathering listings of their colleague's work.

What emerged was nothing short of remarkable – there were some 650 papers in total, revealing a highly productive research community. Not only is this proclivity in publication probably unknown to the construction community, it is equally likely that it will be a surprise to the academics.

The distribution of these papers (Table 3) can be broken down into annual returns of conferences (Figure 3a) and journal (Figure 3b) papers. The peaks in conference papers in 2010, 2012 and 2014 can be attributed to the CRI colloquia and notably add considerably to the conference paper output of many academics.

Table 2: List of principal concrete researchers by institution

Institution	Academics
AIT	**Paul Archbold**
CIT	**Brian O'Rourke**, Des Walsh
DIT	**Niall Holmes**
NUIG	Eamonn Cannon, **Jamie Goggins**
QUB	Muhammed Basheer, David Cleland, JF Chen, Oliver Kinnane, Adrian Long, Daniel McPolin, **Sree Nanukuttan**, Des Robinson, Mark Russell, Mohamed Sonebi, Maurice Soutsos, Sue Taylor
TCD	Biswajit Basu, Brian Broderick, Alan O'Connor, Dermot O'Dwyer, Sara Pavia, **Roger West**
UCC	Nora-Aine Ni Nuaillain, **Vikram Pakrashi**
UCD	Paul Fanning, Debra Laefer, **Ciaran McNally**, Mark Richardson

Table 3: Summary of published papers 2005-2014 inclusive by academics on the island of Ireland

Year	Journal	Conferences	Total
2005	13	34	47
2006	9	23	32
2007	9	34	43
2008	10	40	50
2009	26	43	69
2010	14	84	98
2011	17	35	52
2012	37	85	122
2013	31	33	64
2014	23	50	73

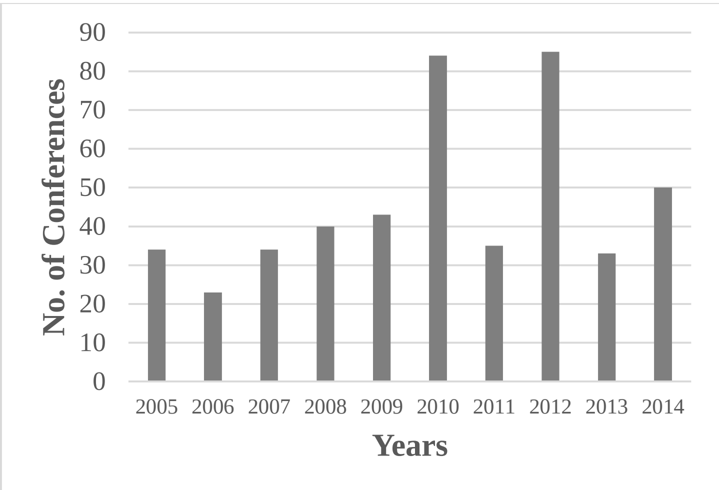

Figure 3(a): Annual output of published conference papers 2005-2014 inclusive by academics on the island of Ireland

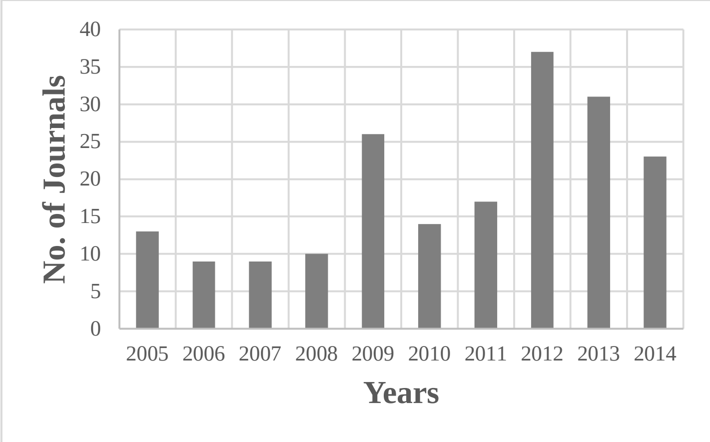

Figure 3(b): Annual output of published journal papers 2005-2014 inclusive by academics on the island of Ireland

The peak in the journal papers in 2009 is unexplained as it exists against an underlying increasing trend from 2006 to 2011. However, it might be speculated that the peak in 2012 is as a consequence of more postgraduates staying on in higher education due to the jobs scarcity during the height of the recession in the construction industry. However, the three year trend of a rapid fall to 2014 may be due to decreasing funding in concrete research, exacerbated by funding being available in other research areas.

The papers which have been published can be categorised into a number of themes, as shown in Table 4, where it may be observed that roughly 25% of the 650 papers appeared in journals, which in typical academic terms is an excellent outcome of which the sector might be justifiably proud. It may be observed that the key materials topics appear to be cement, fibre reinforced polymers, durability and testing, with a range of sub-themes extant in concrete structures.

Table 4: Breakdown of published papers by theme

No	Title	Journal	Conference	Total
1	Aggregates	5	8	13
2	Cements and Pozzolans	16	64	80
3	Mortars and Grouts	4	18	22
4	Rheology	8	14	22
5	SCC	4	17	21
6	Fibres	8	18	26
7	FRP	47	56	103
8	Nanotech	4	3	7
9	Sustainability	3	31	34
10	Durability	17	65	82
11	Recycling	4	13	17
12	Testing	29	66	95
13	Structures	19	79	98
14	Codes and Design	0	9	9
15	Miscellaneous	**-**	**-**	**21**
	Total	**168**	**461**	**650**
	%	**26.7**	**73.3**	

In summarising these themes in this paper, it is not possible to cite all 650 papers; nonetheless, over 400 are reviewed in the sections that follow, where of those papers which were selected for mention, preference is given to journal papers and those presented at the CRI colloquia. Furthermore, when a series of papers describe a progression of research over a number of years, only the most recent is cited.

3.1 Materials

There follows a *précis* of the papers on various research themes in concrete materials:

3.1.1 Aggregates

Following early and important work on chert crystallinity vis-à-vis alkali silica reactivity,[2] topics of interest included how limestone's elastic modulus is considered in EN206,[3] the recycling of aggregate fines,[4] lightweight aggregates[5, 6] and recycled tyres in the form of crumb rubber.[7-9] The importance of aggregate composition in successful self-compacting concrete was also recognised.[10]

3.1.2 Cement and supplementary cementitious materials

A broader outlook on the cement types emanating from Europe[11, 12] and further afield has ensured that there has been very extensive studies of mechanical and durability characteristics of concrete[13] even down to detailed problems such as particle size[14] and the rate of cement hydration.[15] It is inevitable that this involves pozzolans.[16, 17]

So far as pozzolans are concerned, not much work has been done on pulverised fuel ash, reflecting its general unavailability for structural use. Nonetheless, the importance of slow strength development[18, 19] and thus strength prediction has been recognised, while the need for activation of the hydration reactions has also been explored.[20-22]

There has been substantial work done on the effect of ground-granulated blast-furnace slag (GGBS) on the properties of concrete, particularly the work on blends with CEM II/A-L[23] as it informed limiting criteria in mix design in the national annex to IS EN206-1. GGBS is well known to impact on early age strength development[24-27] and durability[28, 29] where the former affects formwork striking times and thus fast-track construction.[30-32] Other effects discussed include resistance to fire and aggressive water.[33-35] Activation of GGBS reactions is also an emerging topic,[36-38] which would facilitate lower clinker use.

Irish research on other supplementary cementitious materials is not extensive but is wide ranging, including silica fume with fly ash,[39, 40] palm oil fuel ash,[41] dolomite powder,[42] peat[43] and, particularly relevant in Ireland, that relating to limestone powder.[44-46] Rice husk ash and metakaolin[47, 48] and reactive powders[49, 50] also feature in this, reflecting world-wide trends in alternative cement exploration. More specific applications in the search for clinker replacement or uses for recycling waste, include expansive cements (as a demolition agent),[51] calcium sulphate,[52] bauxite refinery residue,[53] spent mushroom compost ash,[54] ceramic waste sludge,[55] low-pH cements[56] and, returning to roots, even Roman cements.[57]

One artisan alternative, involving lime[58] has been in vogue in lime hemp concretes[59-68] perhaps recognised more for its thermal and acoustic properties than its strength.

3.1.3 Pastes, mortars and grouts

One cannot easily understand concrete behaviour without having knowledge of paste performance.[69] Lime-pozzolan pastes,[70-71] Bauxsol pastes[72] and the utilisation of carbon dioxide[73] have all been investigated. The effect of superplasticisers,[74-76] neutralised BRR[77] and viscosity modifying agents[78, 79] on the fresh and hardened properties of grout have been considered.

The effect of temperature,[80] loading rate and geometry,[81] water content[82] and curing temperature[83] on mortar strength has also been explored. Results of the addition of polymers and grass silage extract to mortars to enhance properties have also been published.[84, 85]

The durability of mortars in relation to chloride ingress[86, 87] and carbonation[86-88] is also of relevance.

Furthermore, it has for some time been recognised that there are significant advantages in using cement-lime based mortars for conservation and repair of historic stone buildings, harbours, etc.[89, 90]

3.1.4 Rheology

Rheology, the science of flow of materials, is highly pertinent for grout and concrete workability. Admixtures which affect rheology[91] include superplasticisers,[92-94] GGBS,[95] viscosity modifiers,[96-98] silica fume,[98] limestone powder[99] and hybrid fibres.[100] Of course, these also affect other properties, such as surface finish[101] and segregation.[102] One of the practical difficulties is on-site rheological testing which has been broached in a proposal for a hand-held rheological tool which has potential to be both economical and reliable.[103]

3.1.5 Self-compacting concrete

It has been argued that probably the single most significant technological development in the last two decades has been the advent of SCC[104] which has unique fresh properties attendant with the elimination of the risk of non-compaction and thus better strength delivery reliability.[105] The features of segregation resistance, filling and passing ability[106, 107] are well known properties to be assessed, but also enhanced compressive and bond strengths are desirable outcomes.[108] Binder content and type, and aggregate type and size, especially the fine fraction, have a large influence on performance of SCC in the fresh state.[109-111] So also does the presence of viscosity modifiers, supplementary materials such as limestone fillers, rice husk ash and fibres.[112-115] SCC's durability is also impacted through changes to the transport properties, affected especially by segregation.[116-117] There is strong evidence that this has mostly impacted on the pre-cast industry in Ireland,[118] for example in cladding panels,[119] bridges[120] and piles[121] where there are supplementary benefits of not just productivity but also sustainability, health and safety.

3.1.6 Fibres

The utilisation of fibres to enhance tensile strength and flexural toughness of concrete is well known, depending on aggregate size, fibre type, shape, aspect ratio and dosage.[122-124] Although steel and polypropylene are popular for different applications, hybrid and polyvinyl alcohol have also been tested.[125] Some unusual fibres have also been experimented on, including basalt-fibre and grass silage press-cake.[126, 127] It is quickly realised that to have a significant effect on mechanical properties, very high dosages have to be used,[128, 129] improving also, for example, dynamic performance[130] and blast resistance.[131] Furthermore, accepting that fibres are randomly distributed in the cement matrix and, therefore, of inevitably less than optimal orientation, some work to examine forced alignment of steel fibres into planes of maximum stress has revealed interesting results.[132-134]

The use of fibres in more practical scenarios has also been described in a variety of publications. These include pre-cast applications,[135] for example, thin FRC panels,[136] paving flags,[137] slabs[138] and pavements,[139] concentrating particularly on their toughness and impact resistance. The mixing of recycled aggregates and fibres has also been explored.[140]

3.1.7 Fibre Reinforced Plastics

The work in this established research area has mostly been conducted by academic staff now working in QUB. Firstly, the behaviour of concrete beams with bonded thin plates needed to be considered under mechanical and thermal loading.[141, 142] Interfacial stresses are of particular concern,[143-145] including shear deformation effects. The integrity of the bond and, by inference, the incidence of debonding failure, is a focus of this prolific research work.[146-152] Behaviour under dynamic and impact loading has also been investigated[153, 154] and the subsequent damage has been cited, using plastic theoretical and numerical (FEM) models backed up by experimental measurement.[155-162]

The shear strengthening provided by externally bonded FRP plates and how they relate to the internal steel stirrups has been explored, either as soffit plates or U strips.[163-170] Indeed, subsequently useful design guidelines have emerged for shear strengthening.[171]

The use of FRP wraps is usually more appropriate in columns due to the passive triaxial confinement they provide, but they have also been used in beams.[172] The wraps reduce geometric discontinuities, strain, and enhance strength considerably in columns.[173-176]

It has also been shown that enhancements occur in slabs through restraint and improved arching action,[177-179] which has practical application.[180]

Furthermore, FRP has also been shown to be advantageous in resisting corrosion,[181] fires[182, 183] and blast loading.[184]

3.1.8 Nanotechnology

Considering the media publicity surrounding the impact of nanotechnology in many areas of science, there are relatively few publications produced by Irish academics on the sub-theme of nanotechnology in concrete – perhaps an opportunity exists here, though significant capital investment would be required. However, a bibliography of applications[185] and some specific examples in nanocrystal seeding as an admixture[186] and nanosilica in grouts and mortars[187, 188] have been published.

3.1.9 Sustainability

Sustainability, too, is a pervasive topic in which substantial research funding is currently and has historically been available. Much has been written on how to improve concrete in this regard.[189, 190] Sustainable construction is inextricably linked to embodied energy and the life-long carbon footprint of a kilogram of placed concrete as indicators of environmental impact, not only in housing but in RC structures in Ireland.[191-195] This includes how to reduce the carbon footprint,[196] which can involve taking advantage of the natural thermal mass of pre-cast concrete in facades[197] and indoors.[198] The advent of self-compacting concrete, as described earlier, has led to more environmentally friendly concrete when used in the precast concrete industry.[199] Other sustainable pre-cast products include the now well-known flexi-arch system[200, 201] developed in QUB (of which more presently) and the interesting concept of a void formed slab.[202]

Concrete colour has also been of interest[203, 204] now that albedo (solar reflectance) is a recognised property of concrete for reducing the heat island effect.[205] The measurement of solar reflectance has been made easier by the development of a device specifically to quantify, for example, the effect of GGBS, surface finish and weathering on concrete colour.[206]

3.1.10 Recycling

Despite a world-wide impetus to research on this theme, there are relatively few publications in the last decade emanating from Irish researchers. Most work has been on pre-cast products, where in the concrete block market,[207] the use of recycled demolition aggregates has been made, together with paving blocks[208] and flags.[209] These and other concrete products[210] use both construction and demolition waste to develop the "urban quarry" [211] and have now[212] expanded to include ultrahigh performance concrete[213] in a sustainable and innovative manner.[214]

3.1.11 Durability

A useful overview of durability was presented by Prof RK Dhir as the keynote address at the BCRI08 colloquium in NUIG,[215] a theme taken up in many publications. The sustainable aspect of durability[216] has been recognised as of high relevance in relation to limestone with CEM II/A-L cements,[217] to SCC[218] and to CPF.[219] Performance of concrete in marine environments,[220] where exposure site location [221] and the concrete cover zone[222] are important, has also received some attention.

A review of corrosion induction[223] must include spatial variability,[224] established using a probabilistic approach[225] which is useful in whole life costing of bridges,[226] for example. Corrosion also has an effect on seismic behaviour of bridges[227, 228] which is relevant in many parts of Europe, where again probabilistic modelling allows assessment for repair strategies[229] and performance optimisation.[230] Lessons can be learnt from older structures[231] where safety assessment[232] and sustainability due to corrosion resistance[233] are paramount. The estimation or investigation of crack propagation[234] is also vital, whether temperature[235] or corrosion-induced,[236] which is in sharp contrast to another topic - the deliberate induction of cracks due to expansive cements used for demolition purposes.[237]

Surprisingly, considering its prevalence world-wide, carbonation research does not feature large in the publication list. Some work on the effect of climate change[238] and wetting and drying cycles[239] has, however, been published.

The same cannot be said of chloride induced corrosion, where much research has been undertaken, not least in service life estimation[240] and the use of key performance indicators.[241] The effects of duration, conditions[242] and compressive loading[243] on chloride diffusion have been established. Again, a probabilistic approach including spatial variability and safety assessment is necessary for accurate assessment of chloride-induced deterioration.[244-246] Indeed, the effects on chloride diffusion coefficients in these models have been established.[247-249] Finally, the ingress of chlorides through alkali activated slags[250] and the study of chloride ingress into a real bridge[251] are of interest.

A series of papers has also described durability research into alkali-silica reactivity,[252-253] cold weather[254-256] and biochemical attack.[257]

The advantages of corrosion inhibitors, whether in the original mix or surface applied,[258, 259] have been amply demonstrated, including the use of amino-acid[260] and siloxane based[261] inhibitors. The actual performance of inhibitors in bridges has also been investigated.[262]

The performance monitoring and assessment of deterioration of concrete structures[263-264] including bridges,[265-266] whether existing old bridges[267] or repaired ones,[266] and a practical manifestation of this research activity.[268]

It was noted that the ingress of aggressive agencies by ionic diffusion[269] is moisture content dependent,[270] while corrosion of steel can be prevented through cathodic protection.[271]

Novel methods for monitoring durability were developed,[272-276] including those for obtaining pH profiles,[277, 278] covercrete quality[279] and optical sensors.[280] The use of in-situ instrumentation[281-282] in advanced performance monitoring[283] and assessing the state-of-health of structures[284-285] are well established. Improving the quality of monitoring and assessment methods for durability has been pioneered and commercialised at QUB.[286-290]

3.1.12 Testing

With little done on fresh concrete testing,[291] most of the test methods developed concern strength testing using non-destructive testing techniques.[292-295] Early age testing,[296, 297] including maturity testing,[298, 299] is also important, especially in pre-stressing applications.

On the other hand, testing to establish the transport and permeation properties[300, 301] is essential in developing an understanding of the durability characteristics of concrete. In particular, measuring the air and water permeability indices is achieved using the well-known Autoclam.[302-304] Similarly, the testing of chloride migration penetration[305-307] allows the establishment of the chloride profiles with depth from the surface. Other tests involving conductivity sensors, backscatter electron imaging, half-cell, resistivity and scanning electron microscope examination have also been reported in the literature.[308-311]

Novel fibre optic systems have also received a lot of attention including its use for durability monitoring[312] and chemical sensors,[313] used for monitoring corrosion,[314] taking advantage of the electrical properties of concrete.[315] Corrosion monitoring,[316-317] including monitoring pH changes under carbonation,[318] chloride ingress[319] or sulfate attack,[320] can also be achieved using fibre optics, and this technology's versatility is demonstrated by being used also for relative humidity[321] and temperature determination[322] in bridges.[323]

3.1.13 Miscellaneous concrete materials papers

There are some papers of note which do not fall under any of the above categories but which are worthy of mention - these include the BCRI12 keynote paper by Prof A. Long on inspiration for innovative solutions over his forty years of experience.[324] Miscellaneous papers such as pervious concrete,[325] behaviour in a real fire,[326] plasticiser compatibility,[327] plastic shrinkage cracking,[328] KPIs for specifications,[329] intelligent monitoring,[330] predicting concrete drying,[331] organic corrosion inhibitors[332] and an assessment of the new concrete laboratories at NUIG[333] are indicative of the great diversity and complimentarity of interests in concrete materials research. However, Prof R. West, in his keynote address at the CERI14 conference[334] warns of the impact of government cut-backs on the ability of researchers to fulfil their primary role – to undertake and disseminate relevant research into concrete.

3.2 Structures

3.2.1 Beams and columns

Studies on reinforced, pre-stressed beams and columns are not plentiful, but include disparate work on moment re-distribution,[335] transfer lengths in FRP beams,[336, 337] natural frequencies[338] and seismic response.[339] Of increasing interest is the facility to perform real-time hybrid tests[340] where a contemporaneous interaction between the numerical (software) predictions and sensors on real specimens under test informs the next step in the load application to the physical specimens.

3.2.2 Slabs

The effect of arching action on slab behaviour[341] has been much vaunted, especially the now well-known phenomenon of compressive membrane action.[342] This includes work on the serviceability of bridge decks[343] and FRP reinforced slabs,[344-346] where some finite element modelling has also been undertaken.[347]

The behaviour, established using computer modelling, testing and monitoring of hollow core slabs,[348, 349] hybrid pre-cast and in-situ slabs,[350] steel-concrete composite decks[351] and composite reinforcement[352] has also been of interest.

3.2.3 Bridge structures

In parallel with the concrete research papers at the Irish colloquia, many papers on bridges have also been published through the parallel Bridge Research in Ireland colloquia, but only those which were specific to concrete will be reviewed here. The modelling, monitoring and assessment of bridges have received some attention,[353-358] including for impact and seismic behaviour. On the other hand a practical report on the recent design and construction of the replacement of the iconic Mizen Head bridge has also been reported on.[359]

However, a highlight of innovation which is deserving of particular mention is the use of the arch concept in precast applications[360, 361] which has been very successful in practice. The so-called FlexiArch has had much written about it in the last ten years, where one can trace its origins and development.[362, 363] The necessary testing and modelling,[364-368] undertaken over several years, allowed it to emerge from the laboratory onto site. The initial analysis to understand its behaviour[369, 370] and its subsequent promotion as a sustainable solution for arch bridges are noteworthy.[371, 372] Further advancements to include skew and double radius arches[373, 374] demonstrated the concept's adaptability. The case histories published of the FlexiArch's use in practice[375, 376] are just exemplars of the 50 or so arches which have been constructed to date, a testament to careful research and detailed practical implementation.

3.2.4 Structures in practice

There is a strong cohort of papers published on actual structures, including ones on circular tanks,[377] retaining structures,[378] wind turbine towers,[379-381] corbels[382] and façade panels.[383] Indeed, cracking due to temperature in the latter has also been explored.[384, 385] Paving slabs,[386] slabs on grade,[387, 388] block pavements[389] and even precast pile systems[390] have all been investigated.

3.2.5 Design matters

The implementation of new ideas and practices is a necessary part of evolution of design methods. A performance-based approach in the design of reinforced concrete elements[391-393] is a new method, which encompasses topics such as curtailment,[394] beams in flexure,[395, 396] and column design.[397, 398] To accompany these, pioneering ways to teach design in concrete are being found.[399]

3.2.6 Miscellaneous structures papers

As in the earlier case for materials research, several published papers, which did not easily fit into the above themes, were deemed worthy of mention. For example, publications on active confinement,[400] dynamic response during construction[401] allied to identifying natural frequencies,[402] withstanding extreme loads,[403] including blast loading,[404] alternative reinforcements,[405] displacement based design[406] are collectively illustrative of the wealth of research being undertaken into concrete structures.

4. CURRENT RESEARCH FUNDING

Much, though not all, of the research output emanates from externally funded projects and the three principal sources for current projects are private industry, local government and Europe.

There is enormous scope for industry to take further advantage of the expertise, infrastructure and specialised equipment available in higher education institutions. For example, Banagaher Concrete, Banah UK, ECOCEM, Macrete Ireland, Oran Precast, John Sisk and Sons and Techrete are all actively funding projects at present.

Local authorities and local government currently fund through, for example, in Northern Ireland the likes of EPSRC, Invest Northern Ireland, Department of Agriculture and Rural Development while in the south, Enterprise Ireland, IRC Enterprise Partnership Scheme and South Dublin County Council currently fund projects, a list elicited from the respondent researchers.

In Europe, the Horizon 2020 programme has attracted significant funds into Ireland, though many tens of thousands of submissions were made under this new scheme for funding research in Europe, so the success rates may be disappointingly low.

5. CONCLUDING REMARKS

The evidence presented in this paper demonstrates that the academic research sector on the island of Ireland is punching way above its weight with respect to publications. However, there is no room for complacency as the very harsh realities of the European and Irish economies continue to bite. Grants for teaching equipment replacement and modernisation have been absent for many years and funding in Europe for concrete is now extremely competitive and most funding has a strong sustainability angle. But this paper has indicated that there are, perhaps, some salient messages to be heard by the stakeholders in the concrete research arena, thus:

<u>To government:</u> Continue to invest in both research infrastructure and competitive research grant funding and restore funding for essential teaching equipment. Both are needed to educate and train future engineers, concrete technologists and researchers in support of the construction industry revival.

<u>To industry:</u> Employ the best concrete research graduates at appropriate salaries and increase funding for concrete research – without these, future innovative developments are not secure. Researchers have many alternative funding opportunities outside of the concrete industry which one is forced to seek in the vacuum created by the paucity of industry funding into concrete research.

<u>To the ICS:</u> Organise the compilation of an annual Directory of Publications and Research Theses in the area of concrete, open to submissions from both academia and industry and publish this document at the CRI biennial event.

<u>To researchers:</u> Reflect proudly, but momentarily, on our many successes, submit more papers on concrete to CRI and submit an annual return to the ICS directory, should it come to pass. Given the evident extent of concrete research in Ireland, I will leave the researchers

amongst the readers with a thought – how about organising a solitary Colloquium entitled CRI18 in three year's time with enough quality papers submitted for a two day event?

Finally, thank you to the organising committee for inviting me to submit this paper and for organising this event.

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DISCUSSION

PROF. WEST introduced his paper. He noted the considerable body of work done by researchers on concrete materials and structures reviewed in his paper, which of necessity was confined to a survey of academe. Research carried out solely in industry in Ireland was not readily accessible and was not included.

The scale and breadth of research was astonishing. Reviewing output trends, he explained that interest in staying on for a research-based graduate qualification was counter cyclical with the strength of the economy – many talented graduates were attracted to the job market immediately after their undergraduate degree studies when industry demand was strong.

He gave more detail on funding of research and of Ireland's higher education sector, which was half that, per student, compared to the U.K. Praising his academic colleagues, he noted how the evidence from his paper demonstrated that we were punching above our weight. This was all the more commendable given the funding models under which we worked. He expressed concern at the effect of cutbacks in capital and recurrent funding for third level institutions to update their facilities. There has been no such investment by government for 10 years. Thus even basic test equipment portfolios were incomplete. He speculated that not one of Ireland's third level institutions has the full suite equipment to conduct the four consistence tests for self-compacted concrete, unless funded by a research grant.

He explained how the number of students available to carry out self-funded small research projects was growing on foot of the move to 5 year engineering programmes in Ireland. He invited industry to conduct pilot study research contracts using that research capacity.

DR. EANNA NOLAN noted that lack of funding of concrete research was a theme of the paper. He asked about topics in concrete research that were successful in winning research funding at present. In response PROF. WEST reported that the data available to him did not allow him to comment on the relative level of funding on specific topics. Nevertheless, he could comment on the areas that were attractive for funding. These included: concrete batteries, sustainability (EPA), Smart Cities (solar reflectiveness, thermal mass, facade sound absorbtion, cold bridging, and 'greening' of the city). However he had to report that there was no strong driver in Ireland for the key areas to be researched in concrete, backed by a stream of funding. In such circumstances, many who wished to research in concrete were engaged in areas outside this field, due to the availability of funding in other fields – funding they were required to obtain as part of their job. He instanced his own research on sustainability, where he was optimising the performance of concrete that incorporated 97.5% recycled material. Such research was desirable but funding was a big issue.

DR. CIARAN McNALLY drew attention to the critical shortage of civil engineering graduates from Irish third level institutions for the next four to five years. He wondered what measures could be taken with industry to address this situation. PROF. WEST noted that there was never a better time to study civil engineering but significant influencers, including parents of prospective students, were slow to embrace this message. That meant that employers were faced with a shortage of Irish civil engineering graduates for some years to come. To put the stark figure in perspective he gave the example of Trinity College Dublin where a peak of 110 students opting for civil engineering in recent years fell to an intake of just 15 students in recent years. This was mirrored in other Irish third level institutions. He noted the swing to biotechnology. The message was clear: civil engineering needed to demonstrate that it was not a ‘low tech’ industry when compared to biotechnology. The role of the media in addressing this could not be ignored due to the influence of peer pressure.

MR. LIAM SMYTH drew attention to the need for research on the acid soluble sulfate content of aggregates for concrete, as set out in Standard Recommendation SR16, which was set at a level in Ireland that was four times lower than in the United Kingdom, 0.2% compared to 0.8%. Already twenty per cent of aggregates in the U.K. were from recycled sources and he felt that Ireland was disadvantaging its aggregate industry until the issue of the acceptable acid soluble sulfate content was addressed through research. PROF. WEST acknowledged awareness of the issue.

MR. EAMONN CANNON paid tribute to the work of two people who had made a particular contribution to concrete research in Ireland: Roger West and Mark Richardson. He noted how they had built up the level of research on concrete in Ireland with the strength of Simon Perry and Sean de Courcy at their backs in TCD and UCD respectively. Building on the success of the decennial CPI series in UCD, he praised the concept of the more frequent CRI symposia which grew from CPI 1995 and which rotated around the research institutions. He also praised the significant contribution of Adrian Long and Muhammed Basheer in Queens University Belfast, noting the better access to funding for concrete research in the United Kingdom. His sentiments and best wishes for the future of the CPI symposia series were endorsed by the audience.

MR. BRIAN O’ROURKE closed the symposium by reflecting on the ‘health check’ of the industry provided by the papers and discussions. He found the industry to be in rude good health in respect of a lot of aspects: health and safety, planning legislation, standardisation, sustainability and rationalisation. Looking forward to 2025, he noted that the long diagnosed ailment in respect of a deficit in skills training and education for those working with concrete was still an unresolved issue. He urged those present to work together and with the Irish Concrete Society to ensure that this recognised ailment of the industry did not risk becoming a chronic ailment, such that the industry would get together in 2025 with a clean bill of health on this issue.

INDEX TO CONTRIBUTORS