Quality Means Durability and Not Strength Alone! *Smart Concrete*

By: Dr Jackie Voo Yen Lei

INTRODUCTION

CONCRETE, what is it? What was/is its role in the past, present and future? In general, the "non-engineering" personnel would understand concrete as one type of building materials that simply a mixture of cement, water and aggregate. The accuracy of this definition is neither right nor wrong, because for most under-developed and developing countries; like Malaysia, the understanding on the composition of concrete is nothing more than simply the mixture of cement, water and aggregate; whereas for developed countries, the understanding on the composition of concrete is far beyond merely these three components.

For less than a century, the evolution of concrete technology has gone through a drastic change after the Second World War. Modern concrete is becoming a very sophisticated composite as it constitutes the marriage of ground clinker and calcium sulphate (i.e. cement), mineral or amorphous products which have yet to penetrate into the local market; organic polymers, which were engineered using highly technical processes to accommodate specific tasks, and occasionally accompanied by discrete synthetic/organic/steel fibers to exhibit properties that are too ambitious to make dreams come true.

Let's refer to the CEMBUREAU to see what the statistics have got to say about the world cement production in the past, present and future. According to CEMBUREAU, the total world production of cement in the 1900 was about 10 million tonnes, whereas in 1998 the production was 1.6 billion tonnes and the latest reported figure showed 1.87 billion tonne of cement produced in 2003. It was predicted that the global cement consumption will increase to about 3 billion tonnes by 2020 (refer to Figure 1).

It is evident that concrete has become the most widely used man-made material in the world, and it is second only to water as the world's most heavily consumed substances.

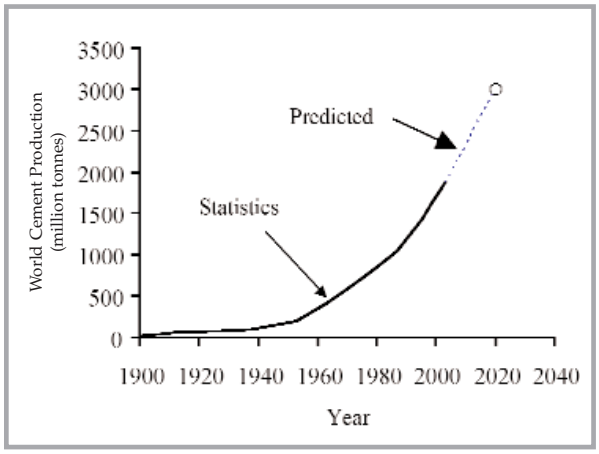


Figure 1 – World cement production, according to CEMBUREAU

Sociologist have taught us that urbanisation will make a society wealthier and thus, directly raise the standard of living through the development of the city and consequently result in a great demand for infrastructures; and thus increase the consumption of cement-concrete.

So, with this drastic increase of cement-concrete production for the next few decades, should the Malaysia concrete industry stick to the 20-30 MPa scenarios, or should it evolve with the contemporary technology? Assuming the industry is willing to move with the times, the next question will be: is the current cement industry or concrete technology of Malaysia ready to face such trends and can the industry cope with the changes?

It must be kept in mind that the development of concrete will result in more choices of concrete in the "menu" with specific property, application and characteristic to cater to specific circumstances. Also, this drastic change will result in the recruitment of more specialised personnel, active input from professors/researchers of local universities, the import of knowledge and the re-evaluation of current design codes and construction methodology.

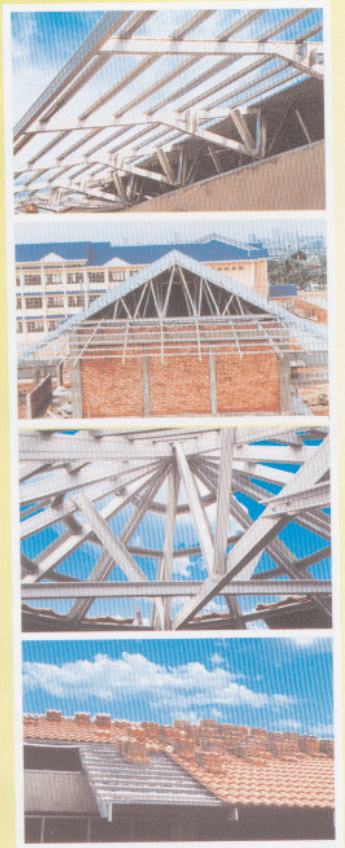
PAST & PRESENT

For a long time, the Malaysia concrete industry has produced so-called "*universal concrete*", which is good enough for universal circumstances and which compressive strength is usually between 20-30 MPa (which is locally known as grade 20 or grade 30).

Strictly speaking, the design of a concrete structure is done by experienced or qualified structural engineers. Unfortunately, very often, what the current structural engineers understand about concrete is the material's 28 days compressive strength and who know very little about the paramount importance of concrete durability. It has no doubt that the knowledge of 28 days compressive strength of a concrete is the fundamental parameter to demonstrate a calculation that will allow the construction of a structure that is safe, but, the issue on whether the concrete will keep its mechanical properties during the whole designed life span remains lack of proper justification.

For instance, many examples show that concrete which have a sufficient 28 days compressive strength loses most of their functionality due to the structures facing environmental agitation that has not been adequately conceived in the design.

The use of concrete of a higher strength (40-50 MPa) began to be specified for columns in high rise building. This type of concrete was first known as the high strength concrete (HSC) during the 1950's. Over the years, the name of these high strength concrete has been changed to high performance concrete (HPC) because these concretes have more characteristics than simply as a high strength cementitious composite.



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In general, high performance concrete is when the well-known "*universal concrete*" is upgraded with additional supplements such as the more commonly used fly ash and superplasticiser. Besides in the enhancement of its megapascal, HPC has a much lower porosity and consequently makes it a more durable material that perform better under extreme conditions such as aggressive environments and chemical attacks.

HPC is becoming more popular, especially in the field of high rise building, off-shore structure, oil platform, bridge and precast industry. In 1998, the highest building in the world is a concrete high rise building built in Malaysia – the Petronas Towers, which uses HPC that has a compressive strength of 60 MPa. Other examples where HPC has been actively used is in precast line manufacturing, such as Hume Industries (M) Berhad and OKA Concrete Industries Sdn. Bhd.

It has been realised very recently that HPC is more ecologically friendly than "universal concrete" because the HPC can support a given structural load with less cement. Moreover the life cycle of HPC is estimated to be two to three times higher than that of usual concrete.

In Malaysia, the acceptance of HPC is nevertheless relatively slow, but it is progressing steadily and it will continue to progress because personally, I think it is about time for the designers and developers to receive a wake up call, to acknowledge that the value added concrete is not merely in its serviceable long-life, but also its socio-economic sustainability. Quality means durable, not just strength alone!

FUTURE

For decades, concrete is the fruit of a simple technology; and today it is mastered by the essence of "pure science". The emergence of scanning electron microscope (SEM) and other advanced instrumentation have progressively improved the philosophy of concrete microstructure behaviour up to the nano-scale. As the industry moves into the era of computing technology and incorporating the essence of complex laws of physics, chemistry and thermodynamics; it will result in a rapid progression in the science of admixture, particularly for concrete and optimisation on the rheology of binders. No more guess work! No more trial and error!

The binders of tomorrow will contain less and less conventional ground clinker and will feature increasingly complicated mineral products with the aim to make more durable concrete rather than simply megapascal gainer. Some of the most widely used binders are fly ash, blast furnace slag and silica fume. Today, fly ash is a relatively common material that can be obtained from many local suppliers whereas silica fumes are still in it's infant stage.

Interesting development on chemical admixture of tomorrow will be more and more specific in its application. Today, concrete admixture: superplasticiser, air entrainer agents, anti wash-out admixtures, waterproofing material, etc, have become the most important recipe to make stronger and more durable concrete. For instance, some promising superplasticisers are able to maintain slump levels for at least 1-2 hours and gives a minimum slump of 200 mm. Another example is concrete with water/binder ratios as low as 0.12, which can be achieved without deteriorating its workability.

According to Professor P. C. Aïtcin (2000), who is one of the earlier researchers in the development of ultra high-performance concrete: the concrete of the future will be ecologically sound, and it will increasingly embrace greener environmental philosophies. He stated that contractors and designers must understand that the modern concrete will have lower water/binder ratio and more durability is needed. Contractors and designers have to realise that what matters is not the cost of 1 m^3 of concrete but rather the cost of 1 MPa or 1 year of life cycle of a structure. Once this concept is understood, the construction industry will start to move forward.

In the mid 1990's, French researchers, Richard and Cheyrezy (1994, 1995) developed an ultra-high strength high-performance concrete known as reactive powder concrete (RPC) which has a compressive strength over 200 MPa. When this concrete is confined in a thin-walled stainless steel tube, the triaxial effect will augment the concrete to reach a compressive strength of up to 375 MPa. By replacing the sand with fine metallic powder, the compressive strength increases to 800 MPa, which is stronger than BHP-Billiton structural steel.

The fiber reinforced RPC is a unique material (some people termed it as the *smart concrete*) with possibilities for use in a wide range of structural and non-structural applications due to its superior strength, high durability and enhanced ductility. Enormous benefits have been reported for the application of RPC, such as the fiber reinforced RPC used in the prestressed girders without any conventional stirrup in the web regions which serves as highway traffic-bridges or pedestrian bridges (Voo, 2004). The beauty of this technology is a smaller, lighter and improved durable member. In terms of construction and management effort, the construction time and labour costs may also be decreased significantly.

When RPC was first announced in the mid 1990's during the construction of the world's first RPC structure, the Sherbrooke pedestrian bridge in Canada, the cost of 1 m^3 of RPC shocked many engineers who still compares to the cost of 1 m^3 of the universal concrete and HPC. 1 m^3 of RPC was approximately RM 3,500, which is at least 20 times more expensive than conventional concrete. The continuation on the development and optimisation of RPC has made it currently possible to produce similar kinds of RPC at a cost of RM 1,500 and I believe in the near future similar types of RPC can be produced for RM 1,000-1,200. In some applications when durability and compressive strength are key factors, reactive powder concrete can compete with structural steel that cost over RM20,000/m^3.

To date, many landmarks have been mounted world-wide using this newly developed technology, such as the Sherbrooke Footbridge in Canada (1997), Cattenom Cooling Tower in France (1998), Seonyu Footbridge in South Korea (2002), Sakata Mirai Footbridge in Japan (2002), Shawnessy Light Rail Train Station in Canada (2003), Yamagata Footbridge in Japan (2004), Shepherds Gully Creek Bridge in Australia (2004) and Bridge of Futur in USA (2005).

Although many past and on-going studies, conferences and workshops have been conducted internationally, and yet, the demand of RPC as durable building material has yet to be established in Malaysia.

The implication of RPC is to provide more architectural opportunity and innovative space to future engineers, architects and even builders in the industry. Very often, structural designers are limited by the Codes on what "*universal concrete*" can and cannot do. The versatility of RPC provide the modern architects with nearly infinite potential to create structures with perfect finishes, or even unlimited complex shapes that are light without sacrificing its durability and ductility. Perhaps, it's time to think outside the square!

I believe that the critical barriers which prevent the rapid introduction of these *smart concretes* into the Malaysian market are the lack of enabling technologies or stakeholders to support the cost-effective commercial production, industry liabilities and institutional barrier.

CONCLUSION

Sooner or later the designers of tomorrow's concrete will realise that the design and placement of concrete cannot depend solely on material strength alone. Instead, the concept of "durability" should be the key factor for the success of sustainable development. I feel that if local experts are able to find some semi-industrial applications which makes RPC more competitive, it will lead to more affordable contracts implementing this type of promising material in the concrete technology of tomorrow. By all means, the evolution of tomorrow's concrete technology should proceed forward with the objective to provide a greener and ecologically sound environment for our future generations. ■

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Talk on "MS 1314:2004 Precast Concrete Piles"

By: Ir. Dr Jeffrey Chiang Choong Luin

Date : 24 July 2004
Time : 9.00 a.m. to 12.30 noon
Venue : IEM Conference Hall, Bangunan Ingenieur, Petaling Jaya

Introduction

The talk, which was organised by IEM Civil & Structural Engineering Technical Division, commenced at 9.30 a.m., with 37 participants having registered, and after having their morning tea and refreshment. The then Deputy Chairman of the Technical Division, Ir. Li Thang Fai, who was chairing the proceedings, gave a welcoming address, and introduced the speaker.

Talk on "MS 1314:2004 Precast Concrete Piles"

The talk was presented by Tuan Haji Yahya bin Haji Ariffin, the Director of Certification, IKRAM Quality and Certification Institute. He has also served as the Chairman of the Technical Committee for the revision of MS 1314, formed and directed by the Industrial Standards Committee (D) of SIRIM Bhd. The co-speaker for this talk was Ir. Yue Kam Fatt, the Secretary of Working Group 4 of MS 1314:2004.

The background and issues, the formation and working of the various working groups and the scope of work involved were presented briefly.

MS 1314: Precast Concrete Piles was first published in 1993 as Part 1, and followed by Part 2 in 1996. Both Parts 1 and 2 were developed based on JKR Standard Specifications for Precast Concrete Piles in Building Projects (JKR 20709-0182-91). In general, the concrete piles currently produced in the market are those that comply to JKR Specifications, MS 1314 Part 1:1993 and MS 1314:1996, as well as those categorized as 'commercial grade' piles.

In the newly revised MS 1314:2004, effort has been made to harmonize the requirements of JKR Specifications, MS 1314 Part 1:1993, MS 1314:1996, and also to introduce a new standard grade 'S' for RC piles to provide the minimum requirement for the 'commercial grade' piles.

The new MS 1314:2004 is divided into 7 parts as follows:

- Part 1 : General Requirements and Specification
- Part 2 : Method for Determination of Bending Strength of Precast Concrete Piles (bend test)
- Part 3 : Precast Reinforced Concrete Square Piles (RC piles) – Classes M, J and S
- Part 4 : Precast Pretensioned Spun Concrete Piles (Spun piles) – Classes A, B and C
- Part 5 : Precast Prestressed Concrete Square Piles – Classes X, Y and Small Piles Classes PCS-1 and PCS-2
- Part 6 : Small Reinforced Concrete Square pPiles – Small Piles RCS-1 and RCS-2
- Part 7 : Guidelines to the Installation and Load Testing of Precast Concrete Piles

MS 1314 Parts 1 to 5 are currently being printed and Part 7 is still under deliberation. Part 6 is in the stage of getting Ministerial approval on the revised standard. Tuan Haji Yahya contended that MS 1314:2004 will provide a wider choice of selection of concrete piles produced by local Malaysian concrete piles manufacturers.

Some of the technical details presented include the following:

- Reduction of cement content of commercial grade piles from 450 kg per cu. m to 420 kg per cu. m, which was claimed to satisfy international material tests. Experimental results from the many series of tests undertaken at IKRAM were used as the basis for this reduction.
- Under MS 1314:Part 3 (RC piles), the minimum steel content is reduced to 0.8%, for class S piles. This mainly caters to commercial grade piles, to ensure no steel content below 0.8%. A technical report from Sweden was cited, to support this reduction, together with detailed calculations, signed by a professional engineer.
- Reference was made to MS 1314:Part 1, Clause 1.3, where the professional engineer has the responsibility to select the appropriate pile for suitable applications.
- The basis of the 'f' factor was explained, with regards to determining the cracking moment, with respect to ultimate moment. It is the ratio of ultimate moment (at installation/handling) to the cracking moment (which is defined as when 0.5mm cracks appear in the piles due to bending).
- The thickness of mild steel plate for pile joints are now smaller for RC pile class S, i.e. 6 mm thick for 200mm and 250mm piles, and 9 mm thick for 250mm, 275mm, 300mm and 325mm piles.

After a brief insight into MS 1314:2004, participants were served coffee and refreshments at 10.30 a.m. The talk resumed at 10.45 a.m., in which, Ir. Yue Kam Fatt, the Secretary of Working Group on MS 1314: Part 4 (Spun piles), was the designated speaker. He presented the details of some pertinent aspects of MS 1314:Part 4, such as prescribed concrete strength (60 MPa for all three classes A, B and C), yield strengths (4.0, 5.0 and 7.0 MPa, for classes A, B and C respectively), and cement content of 420 kg per cu. m for all classes A, B and C.

Other technical details presented include:

- Concrete strength at transfer of prestress to be at 30 MPa
- The 'f' factor to be of 1.5 (for Class A and B), and 1.8 (for Class C)
- Effective prestress of 4.0 MPa (for normal piles), and 7.0 MPa (for marine piles)
- Minimum clear cover of 20 mm
- Joint plate thickness ranging from 12mm to 15mm

Tuan Haji Yahya continued the talk with emphasis on IKRAM as a quality assurance and certification body for both the government agencies and private sectors.

During the Q&A session, various questions and comments were raised and directed to both Tuan Haji Yahya, and Ir. Yue Kam Fatt, pertaining to application and interpretation of MS 1314:2004. The following are summarised questions posed, and responded accordingly by both speakers:

(1) What are the justifications for a reduction in cement content to 420 kg per cu. m. from 450 kg per cu. m. , especially where high concrete grade piles (e.g. 60 MPa) may be needed, such as in harsh climatic or marine environment?
Ir. Yue Kam Fatt responded by saying that many independent tests were carried out in the laboratory locally and results obtained proved that 60 MPa strength – 420 kg/m3 cement content combination is deemed acceptable.

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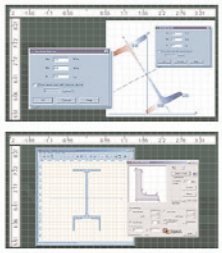

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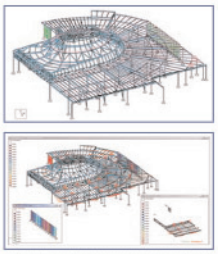

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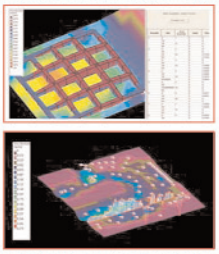

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A follow-up comment was made from the floor to the Technical Committee for MS 1314:2004 in cautioning them that laboratory tests are not true representation of conditions on site. Performance of piles on site may have to be checked and assessed, over a period of time, before such test findings are deemed acceptable.

(2) What kind of tests were carried out on piles to check the requirements for strength and durability of precast piles?
No direct response was made to this query, although Ir. Yue Kam Fatt clarified that concrete grades for piles may have to be increased for severe soil and exposure conditions, since MS 1314:2004 only covers pile exposure to mild and moderate soil conditions. Tuan Haji Yahya commented that MS 1314:Part 1, Clause 1.2(c) has provisions for exposure to severe soil conditions, where compliance to MS 1195:1991 (concrete design standards) is required.

A follow-up comment from the floor: The Clause 1.2(c) provision is not clearly highlighted, or was it added in as an after thought? Tuan Haji Yahya agreed to take into consideration of this comment, in the next revision of MS 1314:2004.

(3) Is MS 1314:2004 a product specification, and not a structural or materials code of practice? The provision is not clearly spelt out on the role and responsibility of engineers in specifying the concrete piles, as part of structural design, particularly Cl. 1.3 (Part 1) – what can be done to rectify this?
Tuan Haji Yahya concurred that MS 1314:2004 is indeed a product specification, and is not to be used as a design code of practice as such. Nevertheless, professional engineers will be held responsible in selecting the right piles for installation and commissioning, as per Clause 1.3 in Part 1. Again, Tuan Haji Yahya promised to re-look at highlighting this aspect in the next revision of MS 1314:2004.

(4) What are the formulas used to determine the cracking moment, and what is the basis of derivation?
Both Tuan Haji Yahya and Ir. Yue Kam Fatt have earlier presented the calculations for cracking and ultimate moments, not in detail, but in a summarized and tabulated form, only for RC square piles (Classes M, J and S) covering steel ratios of 0.8%, 1.0% and 1.2%. Should any participants wish to get detail information of formulas and calculations done, they may contact the TC Secretariat directly at SIRIM Bhd.

(5) In high steam and high temperature curing process of concrete piles, i.e. autoclaving (which is of Japanese origin), how are delayed shrinkage and cracks formation controlled or remedied?
Ir. Yue Kam Fatt informed the participants that this method of curing is used mainly for very high concrete grade of piles, such as 80 MPa. Of hand, Ir. Yue could not reply to this question, in terms of cracks and shrinkage control. Ir. Yue will try to obtain further information and convey to IEM. He stated that the maximum temperature used in autoclaving is 180°C at a pressure of 10 bars.

(6) What is the actual definition of cracking moment, and ultimate moment terms as used in MS 1314:2004 in determining the ratio, 'f' factor?
Elaborating further on the presented facts by Tuan Haji Yahya, the THEN IEM C&S Technical Division Chairman, Ir. MC Hee suggested that in BS 8110 and ACI 318, the cracking moment is defined as the moment in structures in which the tensile capacity has been exceeded – in which cracks start to form. On the other hand, the definition of cracking moment in MS 1314:2004 is slightly different, in the sense that it is the moment experienced in structures where a certain crack width has formed. The MS 1314 drafters then back calculated to get the required 'f' factor of 1.5 to 1.8, based on this definition. It would not be correct to relate these 'two' cracking moments as to mean the same thing.

(7) Questions on steel ratio reduction to 0.8% (for commercial grade concrete piles) and the use of 6mm and 10mm thick mild steel plates at pile joints are raised for further clarifications and justifications, were posed to Tuan Haji Yahya – who was informed that Swedish Standards actually specify a steel ratio of 1.2% and not anything less than 1.0% as suggested.
Tuan Haji Yahya referred to MS 1314:Part 7 on installation of piles, in which only qualified welders are specified. He further stated that, not only bend tests but joint tests were also carried out on piles to study the effect on 6mm and 10mm plates, beyond ultimate strength, and no failure in the joints were observed. Tuan Haji Yahya also clarified that the ultimate moment in this case is referring to loading experienced by piles during handling and installation stages, not for structural loading capacity.

He also stated that the recommended steel ratio of 0.8% is only allowed for commercial S grade piles. Steel ratios for other classes of piles (M and J) are maintained at or above 1.0%. Its purpose is to ensure that pile manufacturers should not go any lower than 0.8% for the commercial grade piles – as are prevalent now in the market. Nevertheless, the professional engineers are still given the authority and responsibility to accept or reject piles, which are not deemed acceptable for safety reasons.

(8) In Table 2 of MS 1314:2004, Part 1, a crack width of 0.2mm is allowed for RC piles, and a question arise on whether this is applicable for use in severe soil conditions?
Both speakers suggested that the allowed crack is more for the purpose of handling and installation of piles, i.e. in particular the calculation for engineering Mult and Mcr. This crack allowance is also stated in BS 8110 for concrete design.

In a point of clarification, Ir. MC Hee remarked that the 0.2mm crack width allowance is not acceptable, especially for piles to be installed and commissioned for use in severe ground conditions, where steel reinforcement may be exposed to such elements. The requirement in BS 8110 is applicable only for structural buildings or superstructures.

As time did not permit for the Q&A session to continue, the Chairman of the session suggested that any further queries can be directed officially to the TC Secretariat at SIRIM Bhd, or unofficially to Tuan Haji Yahya and Ir. Yue Kam Fatt personally, who welcome any suggestions which can be used to improve the technical content and presentation of MS 1314:2004.

At the end of the Q&A session, the talk was formally closed by the session Chairman, Ir. Li Thang Fai, who invited the then Chairman of Civil & Structural Engineering Technical Division, Ir. MC Hee, to present tokens of appreciation to Tuan Haji Yahya and Ir. Yue Kam Fatt for their very timely and interesting talks, and their enthusiastic responses to queries from the floor.

The talk formally ended at about 11.30 a.m. ■

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