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HIGH STRENGTH CONCRETE FOR HIGH RISE STRUCTURES THE WAY FORWARD

by

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<u>Abstract</u>:

The use of high strength concrete (HSC) in structures is increasing worldwide: it is only a matter of time before it makes an impact in Malaysia. While 30 MPa concrete is still the norm, in many recent projects particularly in high rise construction 50, 60 and even 70 MPa concrete has been specified particularly for load bearing columns. The most significant breakthrough in the use of high strength concrete in Malaysia is the Petronas Twin Tower project currently being developed by the Kuala Lumpur City Centre Berhad where 80 MPa (characteristic cube strength) concrete for the lower level columns has been specified.

In this paper the rationale for the use of high strength Concrete in High rise structures is discussed. The need for good materials, well controlled QA/QC and specialist consultancy inputs to achieve the desired product is highlighted. The future prospects for the use of HSC in construction projects is also considered.

HIGH STRENGTH CONCRETE - RECENT DEVELOPMENTS

A few years ago, a characteristic compressive strength of 30 or 40 MPa would have been considered high in Malaysia, but this is now becoming commonplace. Probably the most suitable definition for “High Strength Concrete” is concrete with a compressive strength in excess of the maximum grade specified in national codes and standards, up to the practical upper limit of strength for concrete made with natural aggregates. This is thought to be in the region of 150 Mpa (1). High strength concrete containing normal weight aggregate can be considered as concrete with a characteristic 28 day cylinder strength of 60-120 Mpa (75 - 150 Mpa characteristic cube strength).

Malaysian standards are based on British Standards which cover concretes up to grade 60 (28 day characteristic cube strength). Hence, in Malaysia, high strength concrete can be defined as concrete with a cube strength of 70Mpa or more. However due to the fact that relatively high strength margins are specified in contracts to cope with high levels of variability, most grade 50 concrete may be considered to be high strength. Higher grades (55 and 60) are also more common in precast elements.

The achievement of high strength concretes (> 70Mpa) has been possible primarily through the introduction of two new materials i.e. superplasticisers and Microsilica. Superplasticisers or high range water reducing admixtures were developed in the mid 1970’s. These admixtures enabled very low water/cement ratios to be achieved in concretes without the need for excessively high cement contents, whilst still producing sufficient workability to enable the concrete to be placed using conventionally accepted techniques. Microsilica (or silica fume) significantly increases the strength of the cement paste and when used in combination with superplasticisers has enabled the strength of concrete to be substantially increased, to the point where the mechanical properties of the aggregate become the limiting factor (2).

Much of the development of high strength concrete has been undertaken in the United States, where a large number of high rise structures (particularly in the Chicago and Seattle areas) have been constructed with concretes of characteristic cylinder strengths above 60 MPa (3, 4). Elsewhere, the Japanese Ministry of Construction has funded a four year development programme on the development of advanced concrete buildings using high strength concrete and reinforcement (5). In Norway, extensive research into high strength concrete has been co-sponsored by the offshore oil industry and the Royal Norwegian Council for Scientific and Industrial Research. Over the last five years, this has led to recommendations for the design and use of concretes with strength of up to 105 MPa in Norwegian Standards (6). France has also recently completed a national project on “New Ways for Concrete” that included high strength concrete (7). The ready mix concrete industry in the Netherlands have undertaken their own studies on this material (8).

The use of high strength concrete throughout Malaysia to date has been limited. The barriers to the more widespread application of high strength concrete, in view of the generally positive findings elsewhere, may be ascribed to either a lack of awareness of its properties or lack of confidence by specifiers that it can be used economically and practically in the site situation. This arises both from the lack of interaction between researchers and construction professionals and from failure to absorb the extensive available information into National Standards or Codes of Practice for the use of high strength concrete.

HIGH STRENGTH CONCRETE (HSC) USAGE IN MALAYSIA

Introduction

Several recent projects have given a spur to the usage of HSC in construction in Malaysia. The most significant of these is the Petronas Towers which are part of a massive real estate development on a 100 acre site in Kuala Lumpur city centre and will include office buildings, a retail centre, hotels, residential buildings and substantial public parks, gardens and lakes. The

Petronas Towers linked by a skybridge at mid height and associated retail base and parking facilities are the first developments on the site and due to be ready in the middle of 1996. It consists of 216,901m^2 of total floor space, 88 levels, (6 Basement and 82 superstructure) rising to a height of 450m above street level. It will be the tallest building in the world on completion in 1996 (9,10,11). This is the first project in Malaysia where such high strength concrete (>80 Mpa) has been specified. Other projects where HSC has been used include Wisma Consplant, KTM Flyer Bridge, Port Klang Wharf and Menara Public Bank in Johor Bahru and these are discussed below.

Petronas Towers

Background

HSC has been used in the foundations, core walls, columns and slabs of the 450m high office development in Kuala Lumpur. The key considerations are as follows:

a) Grade 60 concrete has been used in the massive foundations. Microsilica was used to minimise the cement content and hence reduce the risk of early thermal cracking.

b) Grade 80 concrete is being used in the core walls and columns for the lower third of the building. This then reduces to grade 60 for the middle third and grade 40 for the top third.

c) The concrete is supplied from a ready mix plant adjacent to the job site.

d) The concrete comprises Masscrete cement (a blend of OPC and PFA in the ratio of 4:1) and 5% densified microsillica. The average strength is 99mpa.

e) The coarse aggregate is a crushed granite.

Based on discussions with the ready mix supplier the following general points were noted regarding production of HSC.

i) It is difficult to import aggregates to Malaysia, but the local granite, although tending to be single sized, seems adequate for HSC.

ii) The main problem is with variability of cement.

iii) An OPC/PFA blend called Masscrete was used. It produces more cohesive mixes.

iv) For HSC, mixing times are increased to 2 minutes.

v) The supervision at Senior Level was increased on this project. In addition, QC tests are increased, especially moisture measurements of aggregates/sands and the number of test cubes (8 per 100m^3 compared with 5 per 100m^3 for normal production).

HSC is relatively new to Malaysia and with the exception of the Petronas Towers, its use has primarily been for the manufacture precast concrete. Cement variability is one of the major problems in Malaysia and regular monitoring is needed to enable changes to be reflected in the mix design. Local crushed granite appears to be adequate for HSC.

Benefits Of HSC

Various approaches were considered for the structural framing system of the Petronas towers (1,2). This included the all concrete option, various mixtures of composite steel and concrete structures. In a detailed study of cost, constructibility and practicality it was confirmed that the concrete option was the correct solution. The benefits of the high strength concrete option include:

Structural Efficiency - Columns of concrete and particularly high strength concrete carry vertical loads at a cost per unit load which is a small fraction of that of steel. Using high strength concrete further improves efficiency and adds to the advantage of reductions in member size at lower levels and therefore saving on rentable space. In addition the core and frame provide adequate lateral stiffness without the need for additional structural materials while the core walls serve as fire rated structural members as well as carrying vertical and lateral load.

Constructibility - Cast in-situ concrete can be placed by conventional means and avoids heavy craneage or special rigging to lift large prefabricated building frame elements. This has allowed considerable flexibility to the contractors and maximises use of the skills of the local labour pool.

Occupant comfort - The high average mass density of the towers, lengthens the building period, reducing perceptions of acceleration and improving comfort under windy conditions. In addition the concrete core, columns and ring beams contribute to the damping values providing occupant comfort without the cost and space penalty of special damping devices.

Specialist Consultancy Inputs

Due to the nature of this project being the first super tall structure of its kind and the very limited experience with the use of high strength concrete in Malaysia the contractors were required to demonstrate that the requirements of the project could be achieved prior to actual construction of the structural elements. In this context the author's company were involved in the construction of full size trial columns and rigorous monitoring of concreting materials. All potential problems were identified and brought to the attention of the contractor and relevant changes made.

The client and contractor were made aware of the unusual needs of the project and in particular the use of high strength 100 MPa (80MPa + 20MPa margin) concrete in large diameter columns (2.4m). The potential for high heat of hydration and subsequent cracking of concrete, and stringent QA/QC requirements to achieve consistent concrete were highlighted and accepted as important aspects which needed specialist inputs. Other aspects considered included the need for early age striking of formwork (<15 hours), minimising cracking in corewalls and curing requirements to achieve sound concrete. These inputs have been dealt with in detail elsewhere (11).

Materials Supply and QA/QC

The potential problems of materials supply and the stringent QA/QC requirements to achieve the desired concrete were recognised by the client Kuala Lumpur City Centre Berhad (KLCC). In this context part of the contractual requirements put the emphasis on the contractor to establish a comprehensive QA/QC plan for the concreting operations.

To avoid problems of concrete supply to a city centre site, a concrete ready mix company was given the contract to erect and operate an on-site concrete plant. Initially two wet-mix plants were established and a third added later. All the concrete could be distributed around the site on internal site roads which meant negligible delay between the plant and delivery locations.

All materials used (i.e.) cement, aggregates and sand were from a single source to achieve greater control.

Quality Assurance

Each contractor was required to operate a quality plan approved by the client. The onsite quality plan for both Towers included checks on the materials suppliers, the concrete producer and concrete delivery.

Aggregates and Sand :	Initial approval including petrography. and Routine grading measurements for organic impurities (sand only)
OPC and Mascrete:	Routine British (BS) and Malaysian Standard Tests (MS) 24 hour strength tests Alkali content. Temperature checks on loading Carbon Content (pfa portion of mascrete)

Admixtures and Silica Fume : Routine BS/MS tests and manufacturing consistency tests.

Concrete Production:	Routine Strength and workability tests Production records check Water temperature checks Concrete temperature checks Tests of elastic modulus, shrinkage and creep General Production Supervision
Concrete Delivery:	Check of delivery docket Re-verification of temperature and slump Strength verification for formwork removal Inspection of finished surfaces

Such a comprehensive checking procedure is critical to achieving consistent High Strength Concrete.

Wisma Consplant

HSC was used to enable column sizes to be reduced. The key considerations were:

a) Grade 55 Mpa was used.

b) The mix was cooled to an initial temperature of 20-22^{0}C

c) Some thermal cracking was observed in the initial OPC mix (<0.1mm), but this was eliminated when microsilica was introduced and the cement content was reduced.

d) Curing was achieved using polythene wraps applied for 7 days.

The main concerns with regard to the concrete were the variability of constituent materials, in particular, the cement and Pulverised Full Ash (PFA). Discussion with the ready mix supplier indicated that while very high strengths have been achieved in batching plant trials (120mpa) this was difficult to maintain. This problem could be partly overcome by establishing a central laboratory to monitor cements and by providing the concrete producer with more regular information. The need for more highly qualified staff to undertake quality control and better control to be exercised if superplasticisers are added at the job site appears to be a significant requirement.

KTM Flyover Bridge

HSC was used in prestressed concrete bridge beam. The key considerations were:

a) Grade 50 ready mixed concrete was used.

b) Workability problems were reported, sometimes associated with delays due to traffic jams-all the admixtures were added at the batching plant.

c) Curing was applied using a water based curing compound.

d) To keep the mix temperature as low as possible, the mix water was chilled, aggregates were sprayed, no fresh cement was used, and production was at either early morning or night.

e) Insulation was used to minimise the risk of early thermal cracking.

f) Additional personnel were used for QA/QC.

Port Klang Wharf

HSC was used to provide durability in a marine environment. The key consideration were:

a) Grade 50 concrete was used to achieve both high strength and durability

b) Problems with slump loss were reported, all admixtures were added at the batching plant and traffic jams are common.

c) The mix temperature was controlled by using chilled water, spraying aggregates, avoiding the use of fresh cement and concreting in the morning or at night.

d) Additional personnel were used for QA/QC.

Menara Public Bank, Johor Bahru

HSC was used in columns. The key considerations were:

a) Grade 60 and 65 MPa used for the columns.

b) The grade 60 MPa concrete gave an average 7 day strength of 74 Mpa and 85 at 28 days.

c) The grade 65 Mpa concrete gave an average 7 day strength of 77 Mpa and 89 at 28 days.

d) On site monitoring indicated peak temperature within concrete of 82.9^0C and 78.8^0C respectively for the grade 60 and 65 concrete. The maximum temperature differentials were 47.5^0C and 35.5^0C respectively for the grade 60 and 65 concrete indicating a high likelihood of cracking.

e) As the heat of hydration peak temperatures was likely to cause loss of compression strength at the mid section of columns an adjustment in mix design was suggested by lowering the cement content (by 100 kg/m^3) and increasing Silica Fume Content to achieve an equivalent strength.

Conclusions

The common theme in all the projects where HSC has been used is the importance of the quality of the materials which make up concrete i.e. the cement and aggregates. Of particular concern is the variability in cement quality which is likely to be accentuated due to the current shortages which has necessitated import of materials. Often in HSC the quality of aggregates can pose limits to the strength which can be achieved. The Petronas Project has however shown that strengths up to 100 Mpa equivalent cube can be readily achieved. A single source of materials for any particular project can help with the quality assurance procedures as any variations can quickly be isolated. Above all the staff responsible for Quality control need to be senior and dedicated to a continuos monitoring of all elements in the production of HSC.

HIGH STRENGTH CONCRETE: OVERVIEW OF PROSPECTS

High strength concrete is being successfully used in the central core, perimeter columns and perimeter ring beams of the Petronas Towers in the Kuala Lumpur City Centre development. High strength concrete permits vertical core and column elements to be economical and of reasonable size saving rentable space. It permits construction using relatively simple equipment and skills of the local workforce.

In a recent survey of the use of HSC for Marine applications undertaken by Taywood Engineering (12) the use of high strength concrete worldwide was found to be increasing (particularly in the Asia Pacific region), but is still not widespread. It was further concluded that there are few practical problems with the actual production of high strength concrete on construction sites and as yet no reported problems with the durability of the material.

From a practical point of view, the main problems with using high strength concrete seem to centre on the rheological characteristics of the material. These influence the placing of the concrete in terms of the amount of vibration required to achieve adequate compaction as well as the need for prompt curing in order to prevent plastic shrinkage cracking. Most high strength concretes are very “sticky” due to a combination of low water/binder ratio and high doses of superplasticiser, this if often compounded by rapid loss of fluidity with time. Additional work needs to be undertaken to address these issues.

The availability of high quality constituent materials (in particular, aggregates) is an important factor influencing the local use of high strength concrete. The reported variability in cement needs to be addressed and is likely to be accentuated due to the current shortages due to the importation of cement from abroad.

As economic pressures increase in the centre of the major cities of Malaysia and rentable space increases in cost, the use of high strength concrete is likely to provide an attractive alternative in the medium term. It is therefore necessary to increase the exposure of local construction professionals to HSC. The lack of codes and standards covering the use of high strength concrete is still perceived as being a major limitation to increased exploitation.

The outcome of the Petronas Towers construction using grade 80 concrete is likely to be influential in the future use of HSC in Malaysia.

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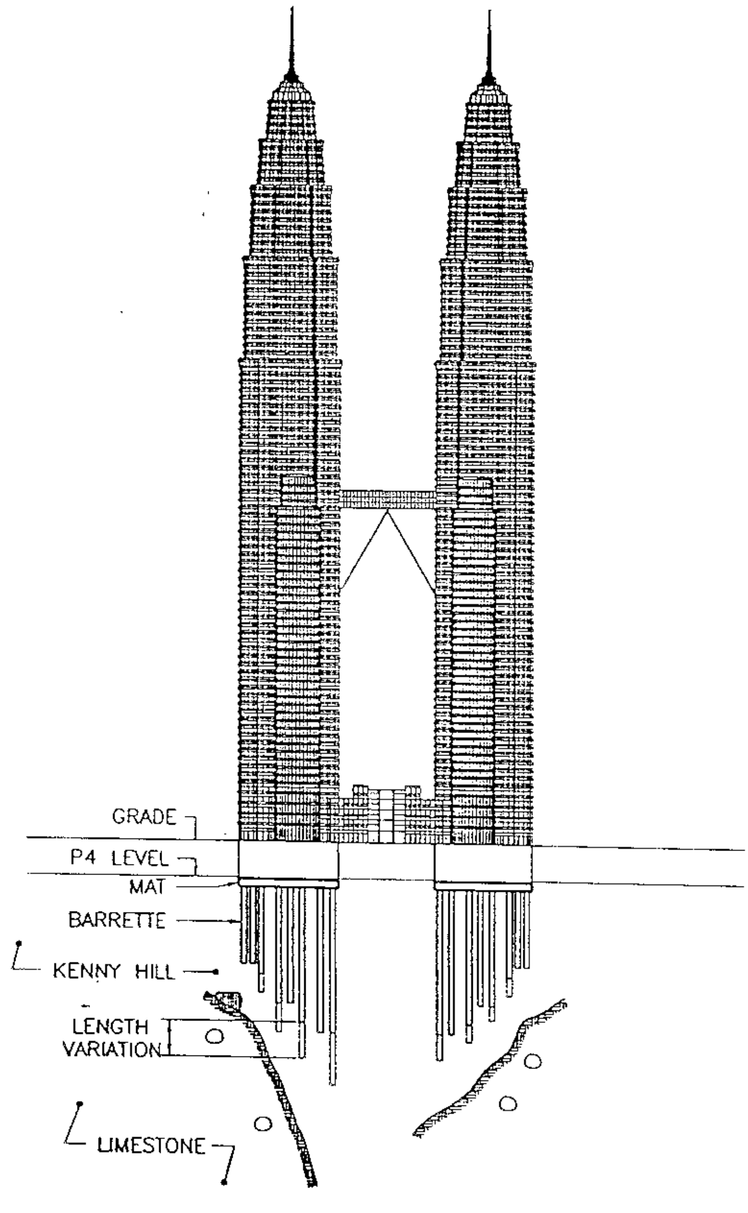

Figure 2 Elevation including foundation details (Petronas Twin Tower Project)

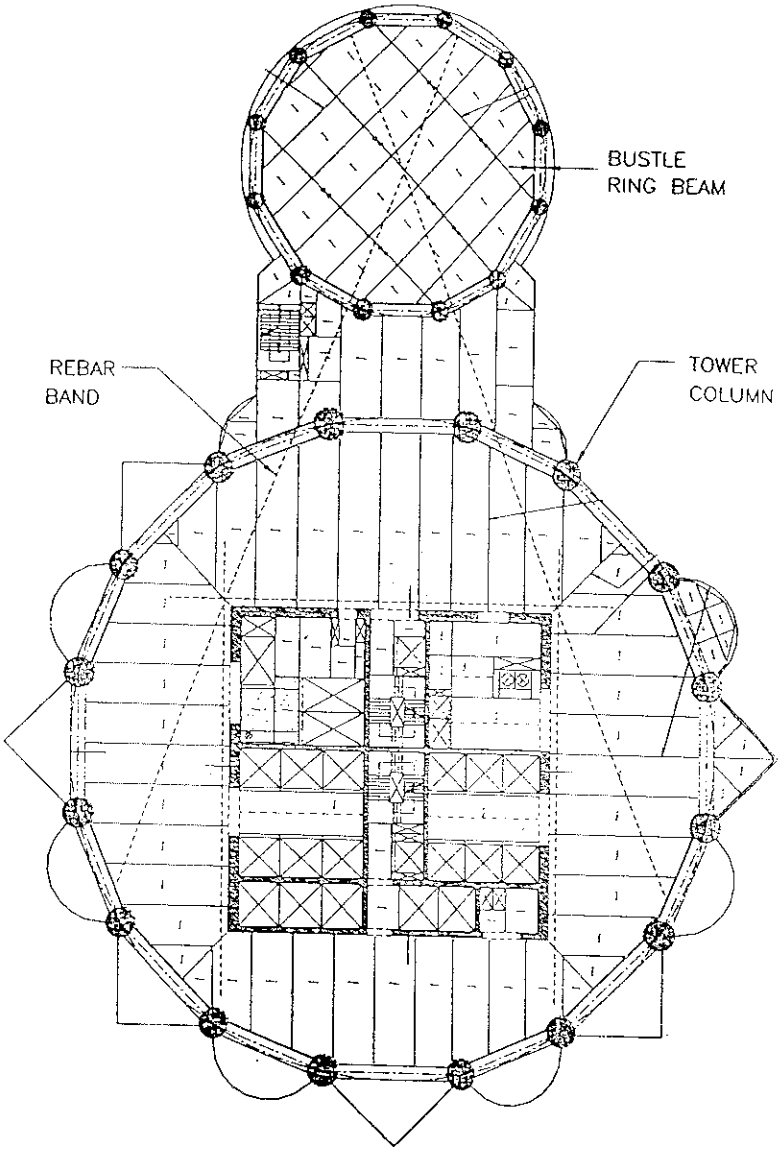

Figure 1 Typical Floor below level 38 (Petronas Twin Tower Project)