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# THE PETRONAS TOWERS, KUALA LUMPUR: BENEFICIAL USE OF HIGH STRENGTH CONCRETE

**K. Gurusamy and W.F. Price**

Multi-purpose High-rise Towers and Tall Buildings
Proceedings of the Third International Conference
"Conquest of Vertical Space in the 21st Century"
organised by the Concrete Society London,
7-10 October 1997

TEL

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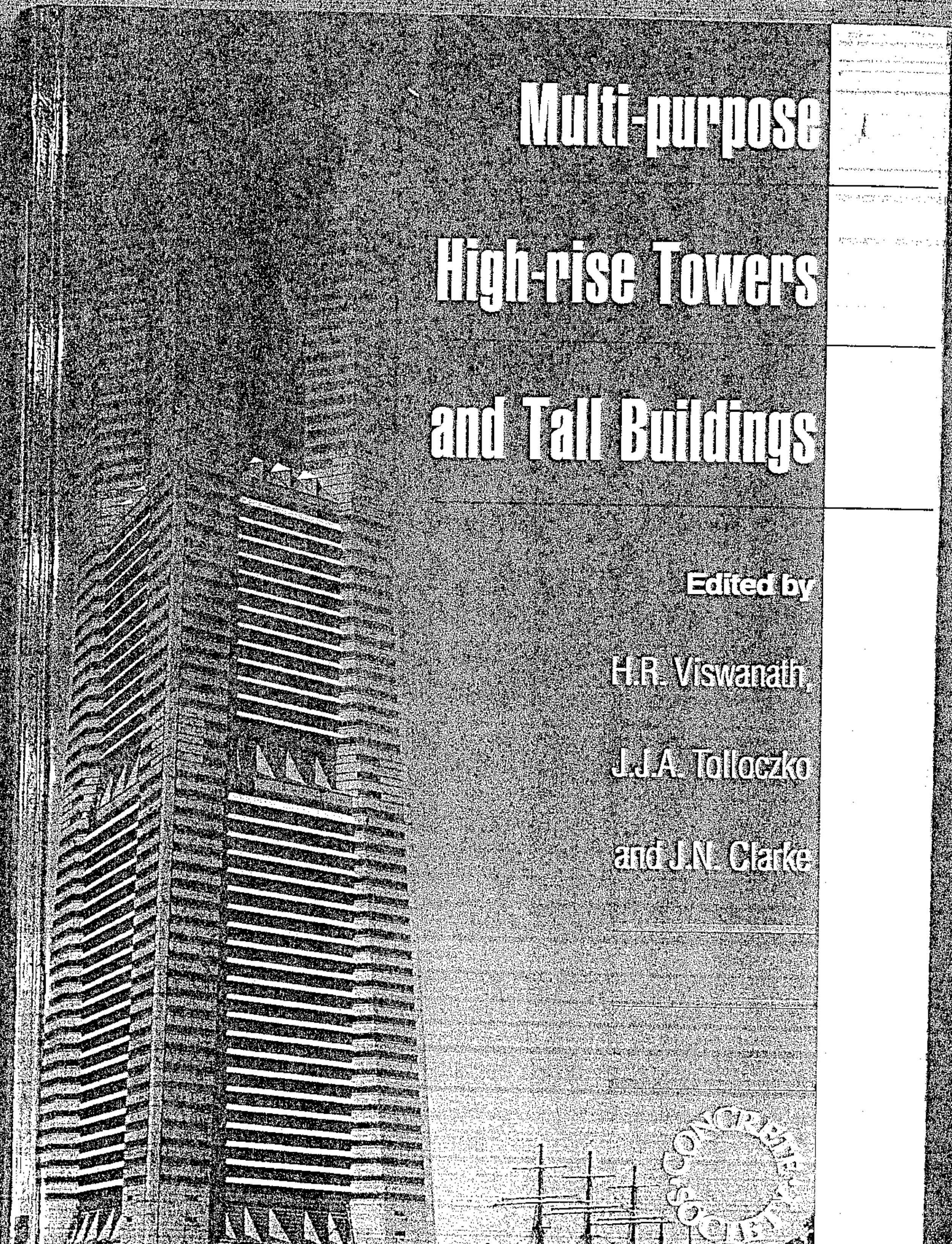

Edited by

H.R. Viswanath,

J.J.A. Tolloczko

and J.N. Clarke

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| To | : | Pioneer Sun-Mix Concrete | From | : | **Ir. Dr. Kriban G.N.** |
| Attn | : | Mr. John Day | File | : | - |
| Fax | : | 03-56313233 | Date | : | **6 December 2001** |
| Copy | : | - | Ref | : | **TESB/mm/01/F110** |
| | | | Pages | : | **12 (including cover)** |

SUBJECT: Presentation Paper

Dear John,

Please find my paper on the Petronas Towers results which is what you need (see page 393) – insitu strength.

Regards,

Ir. Dr. Kriban G.N.
Director

Enc.

# 33 THE PETRONAS TOWERS, KUALA LUMPUR: BENEFICIAL USE OF HIGH STRENGTH CONCRETE

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The use of high strength concrete (HSC) in structures is increasing worldwide and has had a significant impact on construction in Malaysia. The most important breakthrough in the use of high strength concrete in Malaysia is the Petronas Twin Tower project. The project is part of a massive real estate development in Kuala Lumpur City Centre. The world's tallest building has been constructed with concrete columns, ring beams and a concrete core of 40 to 80 MPa (characteristic cube strength) with steel long span floor beams.

The paper discusses the general foundation and structural system of the towers and related benefits of high strength concrete. In particular the pre-construction consultancy input, undertaken by way of trial column construction, to support the use of the high strength concrete, and the requirements for curing, insulation, striking time, strength development, concrete temperature and strain monitoring are outlined. The concreting logistics, construction approach and quality assurance of concrete supply are examined. The future prospects for the use of HSC in construction projects is also considered.

Keywords: Concrete, cracking, high strength, insitu strength, Petronas Towers, PFA, silica fume.

## INTRODUCTION

The Petronas Towers are part of a massive real estate development on a 100 acre site in Kuala Lumpur city centre which will eventually include office buildings, a retail centre, hotels, residential buildings and substantial public parks, gardens and lakes. The twin Petronas Towers are 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 1997. 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 is currently the tallest building in the world. This is the first project in Malaysia where such high strength concrete has been specified. To achieve the completion of the structural frame in approximately 28 months every floor needed to be constructed in approximately 4.3 days thus putting great pressure on the contractor to achieve rapid, delay free construction.

The main structural system for the superstructure and foundation design were selected after a rigorous study and evaluation by the Design and Project Management team. The structural approach in the tower frame combines the most favourable aspects of concrete and steel construction. Structural Steel is used for long-span typical floor beams supporting metal deck slabs. Structural concrete is used in foundations, in the central core, in sixteen tower perimeter columns and variable depth perimeter beams and also in twelve smaller columns and ring beams around the bustle (half height mini tower attached to the main tower). Outrigger beams link the core and perimeter at levels 38 to 40 for additional efficiency.[1]

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The control of production and delivery of high strength concrete was of particular concern for the structural elements. Rigorous trials were undertaken prior to construction to confirm the project specification requirements could be met. These are discussed below and implications for future projects involving High Strength Concrete considered.

## BENEFITS OF HIGH STRENGTH CONCRETE

Various approaches were considered for the structural framing system of the Petronas towers.[1,2] This included the all concrete option and various mixtures of composite steel and concrete structures. In a detailed study of cost, constructability and practicality, it was confirmed that the concrete option was the optimum 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.

*Constructability* - 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.

The scheme which was finally implemented consisted of cast in-place perimeter frame with sixteen columns and cast in-place concrete core. Outrigger beams at mid-height of the structure provided additional stiffness to the structure. The concrete used varies in three steps from grade 80 at the lower floors to grade 40 at the upper floors. Grade 80 is specified up to level 22 for the 2.4m diameter reinforced concrete columns. The floor system consists of a cast in-place concrete slab on ribbed metal deck to act compositely with filled concrete, supported on steel beams.

The perimeter ring beams at tower and bustle were of a tapered construction to overcome the problem of the limited space available. Concrete grades for the ring beams follow the grades in the columns to avoid confusion in the field and possible waste in the concrete pump lines. Each Tower has one central core for all lifts, tower exit stairs and mechanical services. Core design resulted in two virtually solid walls running north-south and one running east - west making the core quite stiff and efficient.

## FOUNDATIONS AND SUBSTRUCTURE

The foundation system of the Towers consists of a 4.5m thick piled raft supported on rectangular friction piles (barrettes) varying in depth from 40m to 110m. The variation in pile lengths was to control predicted settlement under differing thickness of Kenny Hill formation underlain by limestone. The 13,200 cubic meters of concrete in each raft was cast



in one continuous 50 hour operation which therefore avoided any construction joints. Concrete grade 45 was specified for the compression piles. This is a low heat mix and allowed the use of a mix with good workability and slow setting time needed for tremie concreting. The raft concrete is 60 MPa cube strength while the lower level columns in the tower are 80 MPa.

In the case of the Raft concrete (which is really a mass foundation), a highly workable concrete was required to facilitate the pumping, placing and compacting operations. The 60 MPa raft concrete contained 9% silica fume (SF) to achieve the required strength, workability and cohesion without the need for an excessive cement content. The initial temperature of the concrete at pour was reduced by using chilled water for production of concrete at the batching plant, cooling the aggregate by spraying with water and sheltered as feasible and stockpiling cement for several weeks so as to cool rather than being used warm from the mill. This allowed the peak temperature of the concrete in the raft to be maintained below 90°C.[1] It is not clear on what basis this limit was chosen.

In mass concrete pours, significant cracking can occur due to temperature differentials between concrete core and the surface of concrete.[3] To prevent a large heat loss and therefore large temperature differentials, the designers specified that the top of the raft be insulated using 50 mm thick polystyrene and with the pre-cast formwork panels providing insulation to the sides. The temperature gradient was continuously monitored and measured by means of thermocouples placed at several depths in the raft and temperature differential limited to 25°C. The reason for imposing the latter was driven by the need to achieve crack free concrete but in practice a higher limit could have been allowed as cracking potential is not only dependent on temperature differentials but also restraint and the aggregate type.

## PRE CONSTRUCTION CONSULTANCY

Due to the nature of this project, being the first super tall structure of its kind in Malaysia and the very limited local experience with the use of high strength concrete, the contractors were required to demonstrate that the requirements of the project could be successfully achieved prior to actual construction of the structural elements. In this context the first author was involved in the construction of full size trial columns and rigorous monitoring of concreting materials for the Tower 2 package on behalf of the contractor Samsung-Kukdong-Jasatera Joint Venture (SKJ). Potential problems were identified and brought to the attention of the contractor and relevant changes made where practical. The background to the preconstruction consultancy was dealt with in a previous paper[4] with detailed test results and approach considered below. At the time of engagement, the concrete supply chain, mix design requirements and concrete supply rates had been formalised giving TEL only a limited scope to make significant changes.

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) and low water cement ratio (0.25) 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 input. 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.

## Trial Column Casting

As part of the materials selection several trial columns of actual dimensions were poured and monitored for heat of hydration, strain, cracking potential and durability. The original mix design specified for the concrete was reviewed to minimise the risk of early age thermal cracking and in keeping with the requirements for early age striking of formwork (at 10 to 12 hours). Advice was given on the concrete insulation requirements during casting, use of additives in concrete, the requirements for fresh concrete properties, in-situ strength development particularly at early age and temperature differentials within concrete affecting cracking potential.

The trial columns were of dimensions 2.4m height and 2.4m diameter. Two identical columns were fabricated with the same system formwork as used for the actual column casting. The forms used were 12mm steel in two separate halves bolted together on site. One half of the formwork was removed just under 8.5 hours after concrete casting while the other was removed after 13 hours, for both columns. The column casting was undertaken using pumped concrete in a continuous pour. Both columns took 1.5 hours to pour.

## Concrete Mix

The concrete for the mock up columns was site batched. Two concrete mixes were considered, one PC/SF and the other PC/PFA/SF. Pulverised Fuel Ash (PFA) was introduced into the second mix by using masscrete supplied by Associated Pan Malaysia Cement (APMC). According to APMC product literature, masscrete contains approximately 20% by wt of PFA interground with PC. The mix therefore approximated to 460/69//35/PC/PFA/SF mix, i.e. a 12% PFA replacement. The concrete mix designs are shown in Table 1.

A slump test and temperature measurements were carried out for each concrete batch before the concrete was placed. The slump was between 190-220 mm while the fresh concrete temperature ranged from 32°C-35°C.

Table 1. Concrete mix design

| Item | Column 1 PC/SF | Column 2 PC/SF/Masscrete |
|---|---|---|
| PC (kg/m³) | 505 | 184 |
| Masscrete (kg/m³)* | - | 345 |
| Silica fume (kg/m³) | 30 | 35 |
| Water (litres) | 134 | 152 |
| C. Aggregate (kg/m³) | 1000 | 1006 |
| F. Aggregate (kg/m³) | 750 | 728 |
| P300N (Retarder) | 1.00 | 0.8 |
| R1000 (Superplasticiser) | 9.06 | 8.48 |
| Slump (mm) | 220 | 220 |

* Note Masscrete is a proprietary name for a preblended PC/PFA cement at a nominal 20% PFA replacement.



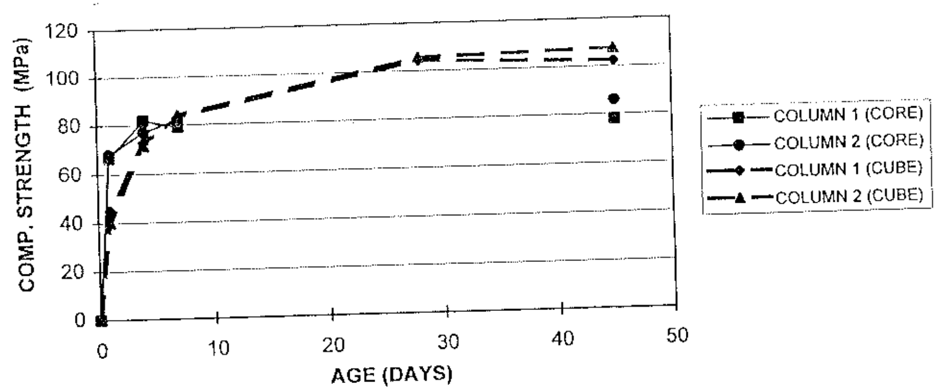
## Concrete Strength

The structural concrete strength specified was 80 MPa with a 20 MPa margin which meant a target strength of 100 MPa had to be obtained at 56 days. Determination of compliance with strength requirements at ages greater than 28 days is a common feature of successful high strength concrete construction worldwide. A water/cement ratio of 0.25 was specified for this grade. This was achieved with a combination of PC/PFA and Silica Fume as discussed above. Due to the fast track construction programme, formwork striking was required at early age (between 10-12 hours) at a minimum strength of 15 MPa. Tests were therefore conducted to ascertain early age strength development and in this context in-situ strength was measured and compared to cube strengths to consider the advantage of strength gain with temperature.

Concrete cube samples were taken for compressive strength testing at 12 hours, 16 hours, 24 hours (1 day), 4 days, 7 days and 46 days. The concrete cubes were made, stored and tested at the site laboratory. The results shown in Fig. 1 show that the target cube strength was met.

The in-situ strength of concrete as measured by testing drilled cores were compared to standard cube testing. The results at 12 to 14 hours, for both Columns 1 and 2, are considerably higher compared to standard cube compression strength as expected. The later age insitu strength indicates that there is very little continued strength development, though in all cases the design strength requirements were met. The significance of this is further considered below.

The early age strength development showed acceptable performance. The standard cube sampling and testing gives a conservative estimate of the in-situ compressive strength and the 15 MPa strength requirement is exceeded after 8 hours. Stripping of formwork can therefore proceed comfortably between 10 and 12 hours for this grade (80 MPa) concrete assuming proper curing had taken place. It was recommended that these tests be repeated for the 60 MPa and 40 MPa concrete to be used at higher levels of the structure and that a pull off or fracture test could be used to estimate in-situ strength for formwork removal.




Note: Column 1 (Grade 80, PC/SF)
Column 2 (Grade 80, PC/PFA/SF)

Fig. 1. Core and cube strength results

## Concrete Temperature, Strain and Cracking Potential

The early age strain and concrete temperature were monitored for a minimum of 7 days in the columns. The strains were monitored automatically with a data logger which measures period and apparent strain of vibrating wire gauges (VWG's). Thermocouple temperature readings were also recorded on a data logger. The significant monitoring data is summarised in Table 2. Temperature data is also plotted in Fig. 2 showing differences in peak temperature between the two concrete mixes used.

Table 2. Significant strain temperature monitoring data

| | Column 1<br>PC/SF | Column 2<br>PC/Masscrete/SF |
|---|---|---|
| Concrete placement temperature | 32-33°C | 33-35°C |
| Peak temperature | 91.6° at 29 hrs | 87°C at 26.5 hrs |
| Temperature rise per 100kg cementitious materials | 11.6°C | 9.8°C |
| Temperature to below 35°C | after 8 days | after 8 days |
| Max. temp. differential | | |
| Centre to corner | 57.5°C at 27.5 hrs | 52.9°C at 33 hrs |
| Centre to top middle | 44.6° at 29 hrs | 32°C at 40.5 hrs |
| Centre to side | 34°C at 43.5 hrs | 30°C at 43 hrs |
| Max. bulk temperature (tb) | 82.7°C | 79.7°C |
| Induced strain (microstrain) | | |
| Centre to corner | 146 | 118 |
| Centre to top middle | 113 | 71 |
| Centre to side | 86 | 67 |
| Maximum restraint* | 0.27 | 0.24 |

* This is maximum internal restraint due to temperature differentials at the centre of the column.

In column 1 cracking first appeared approximately 14 hrs after casting, at the top of the column at position CR1 (see Fig. 3) and was initiated by the removal of the 50 mm polystyrene insulation at approximately 13 hours, during the heat up phase. The removal of insulation produced a sharp cooling gradient. The maximum differential temperature occurred at the top corner of the column where cracking initiated. Fig. 3 shows the crack patterns observed approximately 23 hrs from the start of casting. At this stage the outside face has cooled while the interior is still heating up and expanding in volume giving differential temperature induced cracking on the exterior surface. The crack widths ranged from a maximum of 0.9mm to less than 0.1mm. The examination of the top surface of column 1 at 23 hours after casting also confirmed a crack right across the column diameter, of crack width 0.25 to 0.55mm. Early age exterior cracks tended to close during the cool down phase.

In the case of column 2 although the temperature differential results exceeded the normally accepted limits for granite concrete (of 27.7°C) cracking did not initiate at the exterior top corner of the column, nor had it propagated down the column. This was because the high differential temperatures developed at very early age do not have sharp gradients and benefited from early age creep relief. The theoretical limiting temperature differential is



based on assumed external restraint factor of 0.36. This will be significantly lower for columns as the underlying section of column concrete cast earlier will have retained heat at the time of a typical column cast. Insulation at the top of the column was also not used in this case. The visual examination of the column confirmed that no thermal induced cracking had occurred on the external surface of the column.

The additions of flyash to the column 2 concrete mix delayed the heat development (i.e. maximum temperature differential occurred on the cool down phase, rather than in the heat up phase as for the PC concrete used in Column 1), and slightly lowered the critical temperature differentials within concrete; both these have resulted in a lower probability of cracking in the concrete by comparison with the column 1 concrete.

The strain profiles did not indicate any cracking strain relief during the concrete cool down phase for Column 1 and 2. In other words no internal thermal cracks formed during the concrete cool down. The strain results indicated heat up phase exterior cracking in Column 1 which was consistent with the visual results.

The cracking in trial Column 1 was primarily caused by differential temperature induced strain. The probability of cracking in Column 2 was reduced by the use of PFA.

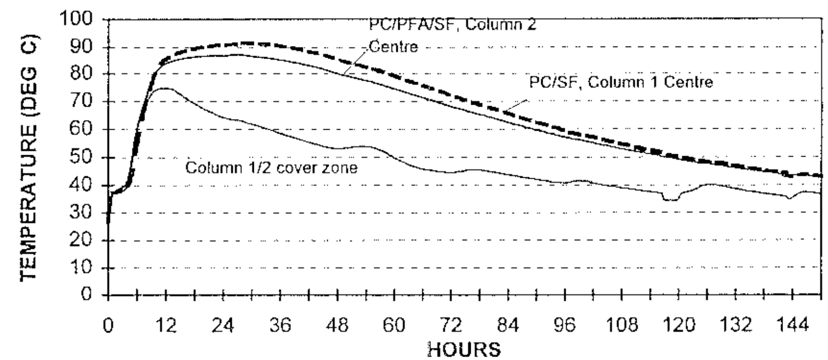



Fig. 2. Temperature profile within the centre and cover zones of a 2.5m diameter high strength concrete column

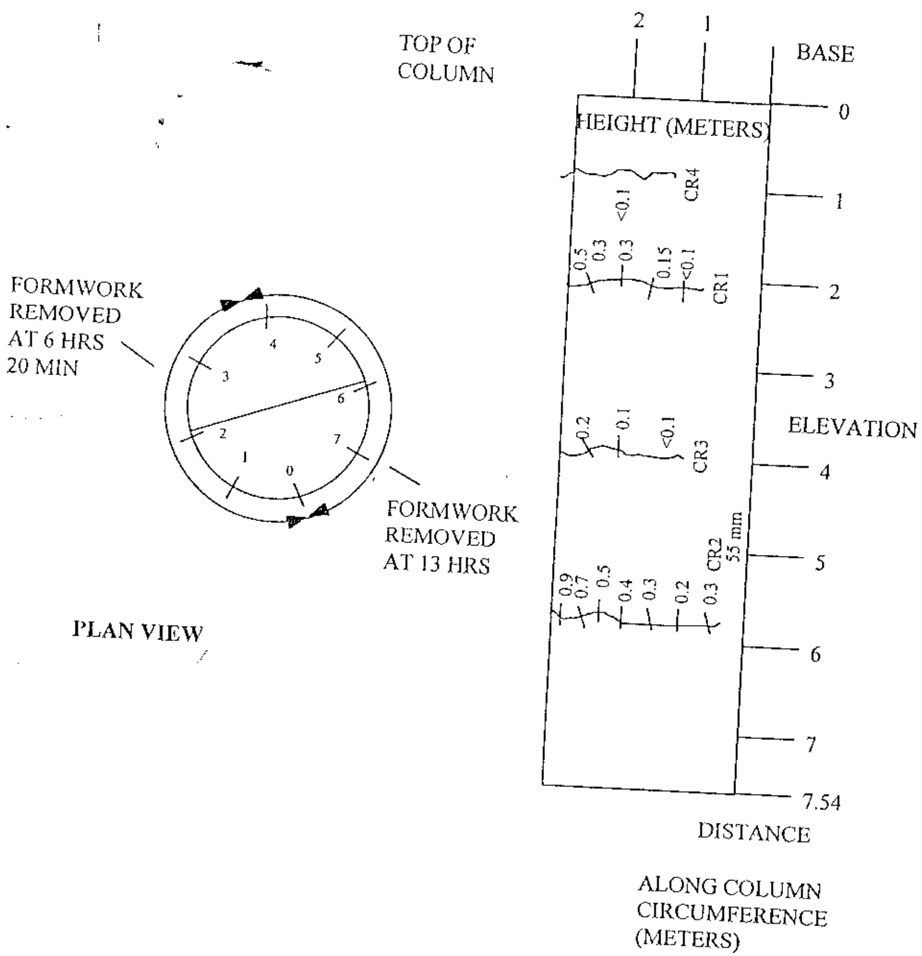



Fig. 3. Visual survey of column 1 cracks (23 hrs after casting)

**Curing and Insulation**

The steel (12mm) forms on the sides of the column provide no significant insulation. Insulation of the column sides and top surface was not considered essential based on the trial Column 2 performance (i.e. no cracks observed). It was also concluded that inappropriate use of insulation i.e. removal before the internal temperature of concrete had peaked can increase the likelihood of cracking and no insulation was applied during construction. The columns were covered with a roll on applied curing membrane immediately after formwork removal.



**Summary**

The trial column casting, monitoring and assessment indicated that concrete used in the column which included masscrete (i.e. PFA replacement ) had a marginal benefit as regards early age thermal cracking, PFA reduced the risk of early age thermal cracking occurrence and propagation by:

- slowing down the rate of heat generation
- reducing the peak heat of hydration temperature
- reducing and delaying the maximum differential temperature

Formwork stripping could be carried out comfortably between 10 and 12 hours for this grade (80 MPa) concrete for both concrete mix designs investigated. Significant considerations are:

- in situ concrete compression strength exceeds 15 MPa
- standard cube sample compression strength exceeds 15 MPa
- a relationship of in-situ to standard cube compression strength was developed which showed the extent of increase in in-situ strength gain at early age
- steel formwork removal does not influence thermal crack occurrence as the steel gives no insulation
- the formwork removal will need to prevent excessive surface concrete tearing during removal particularly if removed too early.

Insulation of the column sides and top surface was not considered essential based on the trial column 2 performance (i.e. no cracks observed). Inappropriate use of insulation can increase the likelihood of cracking and is therefore best not used.
Further recommendations were made included the following:

1) The initial target mean compressive strength of 20 MPa above the 80 MPa grade should be relaxed to allow lower a cement content and hence lower peak temperature. The margin requirements were never relaxed but the 80 MPa strength compliance of the concrete mix was assessed at 56 days rather than 28 days.
2) Relaxation of the water/cement ratio requirement of 0.25. In practice a 0.27 water/cement ratio was used.

## MATERIALS SUPPLY AND QA/QC

The potential problems of materials supply and the stringent QA/QC requirements to achieve the desired concrete were recognised from the outset 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 delays between the plant and delivery locations.

**Materials used**

All cement came from APMC plant in Rawang including masscrete which is an interground blend of PC with PFA (20%). The PFA is from the TNB power station in Kapar. The coarse aggregate was a 20-25mm crushed granite which came mainly from the Golden Plus quarry in Ampang about 10km from site. The sand was obtained from Puchong, extracted from a large stock of tin mine sand and delivered after processing. All chemical admixtures were supplied by Master Builders Technologies (MBT), this included Silica Fume, a Conventional retarder (P300) and a conventional Superplasticiser (R1000). These were later reviewed for pumping requirements.

**Mix Design**

The concrete mix design was aimed at producing a cohesive pumpable mix with a target slump of 200mm and a characteristic 56 day strength of 80 MPa. The contract specification limited the water cement ratio to 0.25 for grade 80 MPa concrete. This was later relaxed to 0.27. The requisite mix was achieved by incorporating PFA (masscrete) and chemical admixtures. Strict control on all materials ensured a consistent concrete which in general met the specification requirements. The Grade 80 concrete was supplied to Towers 1 and 2 from April to December 1994.

**Quality Assurance**

Each contractor was required to operate a quality plan approved by the client. The first author was intimately involved in establishing the onsite quality plan for Tower 2 over the period March 1993 to February 1994 which included checks on the materials suppliers, the concrete producer and in establishing the contractors own supervision team. In general the following were undertaken.

- Aggregates and Sand: Initial approval testing including petrography and routine grading measurements for organic impurities (sand only).
- OPC and Masscrete: Routine British (BS) and Malaysian Standard Tests (MS)
  24 hour strength tests
  Alkali content.
  Temperature checks on loading
  Carbon content (PFA portion of masscrete).
- 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.

## INSITU STRENGTH

In column 2, approximately 12% of the Portland cement is replaced by PFA and even though the total cementitious content is slightly higher than in column 1 (564 kg/m$^3$ as opposed to 535 kg/m$^3$) the peak temperature is 7°C lower.

In conventional concretes the use of PFA at levels of 25% or greater can produce a significant reduction in heat of hydration. However, at low replacement levels (such as column 2) any reduction in temperature is less likely to result from the lower heat of hydration of the PFA.

The limitations on cement hydration discussed above also reduce heat output and many high strength concretes produce less heat pro rata to the content of cementitious material than more conventional concretes.[7]

In the case of a binder containing Portland cement, PFA and silica fume, there is another factor leading to limited hydration. Both PFA and silica fume are pozzolanic materials and react with free lime. However, due to its extreme fineness, silica fume is much more reactive and will readily exhaust the available lime (produced by the Portland cement) by preferential reaction before the PFA can react. Consequently, hydration of PFA is significantly inhibited this further reducing heat output.

Concretes containing pozzolanic materials often respond better to high internal temperatures than Portland cement concretes in terms of strength development.[5,6] This may be the cause of the slightly higher insitu strength in column 2.

**Discussion of Data**

During the construction and testing of the trial columns, there were some concerns expressed as to the development of insitu strength.

Core strengths indicated that whilst the early age strength was in excess of that measured using standard cubes, at later ages the core strengths were 24% and 20% lower than the cube strengths for columns 1 and 2 respectively (Fig. 1).

This is consistent with the effects of high internal concrete temperatures on concrete strength which accelerate early strength development at the expense of longer term strength. In high strength concrete, however, this effect is exaggerated by the possibility of self desiccation. At low water/cement ratio's the amount of available internal water in the structure is small. This may act to inhibit continued cement hydration and hence longer term strength development.[8] The standard test cubes by contrast have abundant available (external) water for hydration.

Fig. 4 shows all the insitu core strength results at 46 days taken in the column. The equivalent cube strength at 46 days is included for comparison.

The cores tests were at the following locations in the column:

- Outer ( surface) cores 100-250mm from the surface
- Middle cores 540-740mm from the surface
- Inner cores 900-1350mm from the surface

The results indicate a further reduction in strength between the outer core and inner cores which is probably due to temperature effects. This is consistent with the fact that the temperature rise at the core of the column was much higher than at the outer zones of the column. In the case of PC/SF concrete (columns) the peak temperature at the core was 92°C as compared to 75°C at the surface. Also the bulk temperature at the core and surface were 83°C and 69°C. The equivalent values for the PC/SF concrete was 7°C higher than the PC/masscrete/SF (column 2). The strength at the middle of the section and the core of the column are similar as the temperature variations between these locations is relatively small.

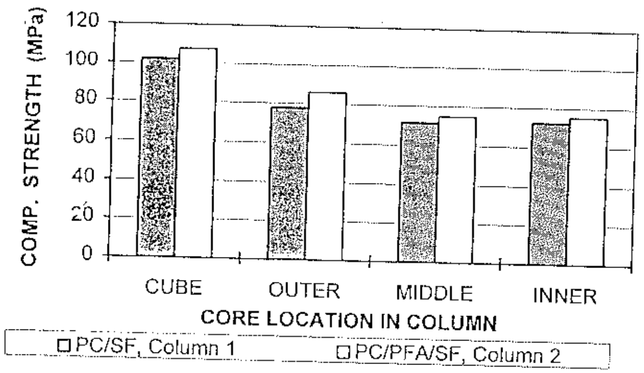



Fig. 4. Insitu Strength (46 days)

**Insitu Strength Measurement**

Whilst the removal of cores from a high strength concrete structure is a direct means of determining insitu strength, it is not always the most convenient method. Alternative non destructive methods, appropriate to use with high strength concrete can also be considered. Of these both temperature matched curing and pull out tests have been shown to correlate will with core test results.(8,9)

The rate of development of insitu strength in the trial columns for the Petronas Towers and elsewhere often exceeds that of the standard cubes. The use of an appropriate technique for rapid non destructive measurement of the insitu strength would enable this early strength development to be utilised in construction (i.e. for determining times for removal of formwork and falsework).(9) This in turn would lead to the potential of reduced floor to floor cycle times.



**Design Considerations**

The differences between the actual insitu strength of concrete structures and the values obtained from standard concrete test specimens are recognised in many codes and standards. A materials partial safety factor is introduced to take account of these differences. Such factors consider:

- differences in compaction between the structure and the test specimen
- differences in curing history (this will also include the effects of the early age heat cycle)
- variability of concrete properties and the effects of construction technique.

Currently, BS 8110(11) includes a materials partial safety factor of $\gamma_m$=1.5 to account for these differences.

However, such factors were developed for conventional concretes, when dealing with high strength, low water/cement ratio concretes, current factors may not be applicable. The additional effects of self desiccation and inhibited hydration may lead to relatively lower insitu strengths compared to standard test specimens. Additional research is required to confirm or otherwise the applicability of current materials factors.

## CONCLUDING REMARKS

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 in high rise construction to be economical and of reasonable size saving rentable space. It permits construction using relatively simple equipment and skills of the local workforce. However, successful construction required increased attention to Quality Control and Assurance.

As economic pressures increase in the centre of major cities 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 and consider incorporating the existing international experience into national codes. Extensive materials pretesting, combined with preconstruction trials (preferably supervised by a specialist consultant) have been shown to produce benefits in terms of demonstration of the practicality of high strength construction.(11) This also enables potential construction difficulties to be resolved before full scale construction is undertaken. This approach to high strength concrete construction has been applied to successful projects worldwide.

Lack of guidance in current design codes acts against the continued exploitation of high strength concrete technology. One issue highlighted during preconstruction trials for the Petronas Towers is the relationship between the strength of the concrete in the structure and the strength measured on standard laboratory specimens. Continued investigations in Malaysia(12) are examining this issue.

## ACKNOWLEDGEMENTS

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## REFERENCES


1. Thorntun, C.T. et al, High strength concrete for high rise tower. *ACI Conference, Singapore, November 1994, SP149-43.*
2. Hashima Hashim and Witherill, M., High strength concrete for KLCC Twin Towers. Paper presented at *CONCET 95 'Trend, Innovation, Durability and Appraisal of High Performance Concrete' Kuala Lumpur, June 1995.*
3. Bamforth, P.B., Mass Concrete. *Concrete Society Digest No. 2, 1984.*
4. Gurusamy, K. and Paull, R.J., Petronas Tower 2 project (KLCC). Mock up columns, temperature and strain monitoring. *TEL Report 1303/94/6827, February 1994.*
5. Bamforth, P.B., In situ measurements of the effects of partial Portland cement replacement using either fly ash or ground granulated blastfurnace slag on the performance of mass concrete. *Proc. Inst. Civ. Eng., Part 2, Vol. 69, Sept. 1980, 777-800.*
6. Dhir, R.K. et al, Investigations of the engineering properties of OPC/pulverised fuel ash concrete, strength development and maturity. *Proc. Inst. Civ. Eng., Part 2, Vol. 77, June 1984, 239-254.*
7. Smeplass, S. and Maage, M., Heat of hydration of high strength concretes. *Proc. Symp. 'High Strength Concrete', Berkeley 1990, ACI SP121, 433-456.*
8. Price, W.F. and Hynes, J.P., Insitu strength testing of high strength concrete. *Mag. Conc. Res., Vol. 48, No. 176, Sept. 1996, 189-197.*
9. Price, W.F. and Hynes, J.P., Non destructive testing of high strength concrete. *Proc. Symp. 'Utilisation of High Strength/High Performance Concrete' Paris 1996, 637-644.*
10. British Standards Institution, *Structural Use of Concrete, Part 1: Code of Practice for Design and Construction.* BSI London BS 8110: Part 1: 1997.
11. Gurusamy, K., The Petronas Towers: The worlds tallest buildings. *Concrete in Australia, V. 22, No. 2, July 1996.*
12. Gurusamy, K., Telekom headquarters: Early age thermal cracking behaviour and insitu strength development of high strength concrete columns. *TEL Report 1303/96/8257, April 1996.*


# 34 THE JANUS TOWER, HANNOVER

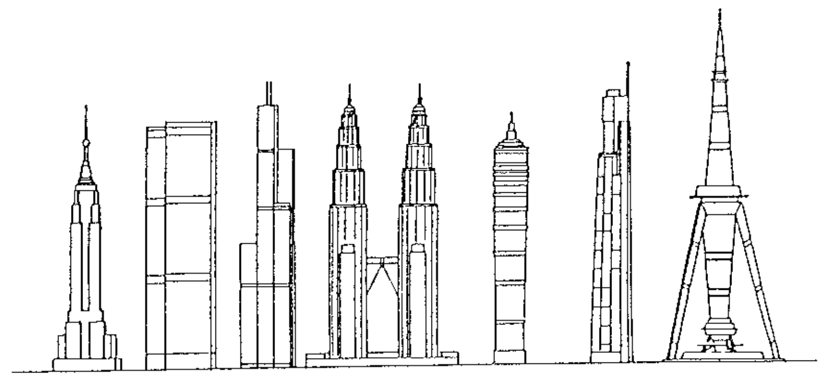
K. MEWES
Vision 1996, Düsseldorf, Germany

Janus: Roman god of the gods, the gateway, the beginning and the end. Protector of the house. Representation by a gate or a double-faced head.

The - Janus Tower - shall be sign and symbol as well as beginning of an architecture for the purposes of environmental protection and power-self-supply.

Sun, wind, water, geothermal energy are the keywords for the self-supply with energy. Furthermore the idea of a selfsupporting building shall be determined resp. symbolized by water-recycling and internal wasterecycling.

Solar cells in annular arrangement in front of the floors, two in turbines, rainwater reservoirs and geothermal energy facilities ensure the utilization of our inexhaustible natural energies.



1. Well-known tall buildings compared to the Janus Tower

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