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THE CONSTRUCTION OF CRITICAL STRUCTURAL ELEMENTS A NEED FOR A MULTIDISCIPLINARY INTERACTIVE APPROACH

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The Construction Of Critical Structural Elements

A Need For A Multidisciplinary Interactive Approach

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Synopsis:

Increasingly sophisticated structures are being built in confined spaces and within tight time scales. This continues to put new demands on the structural engineer. Critical concrete structural elements like transfer beams, the use of high strength concrete to achieve smaller columns and therefore a better return in lettable space and the introduction of complex architectural designs have extended the use of concrete as a structural material to realms not thought possible in the past. This paper examines the multidisciplinary approach which has been undertaken on a high rise structure in Johor Bahru, Malaysia. It has involved the innovative use of modern day concrete to achieve a defect free transfer structure, for a building in a very confined space. The experience points towards the need for a proper interaction between designers and concrete specialists to best achieve defect free innovative construction elements.

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Dr Peter Gabor practiced in Hungary and Germany before settling in Australia where he worked for a leading firm of Consulting Engineers. In 1988 he joined VSL Prestressing as a consultant both in Australia and Singapore. Since 1992, he has been working as a principal structural engineering with Ranhill Bersekutu, one of Malaysia's leading consultants. His special field of interest is prestressed concrete structures.

INTRODUCTION

Buildings have different structural elements, and the probability of failure of one elements could affect, in different ways, the overall risk level of the building.

In some cases individual elements, such as transfer structures represent the highest risk factor and therefore require special consideration in the design and construction process. In the case of the Public Bank Building, Johor Bahru, the transfer structure can be considered among the most important parts of the building and a special approach, using state of the art methods and technologies in construction was considered beneficial. This involved an organised multidisciplinary interaction which was considered a key element in safeguarding the quality of the concrete, achieving an acceptable product at minimum risk, and using a productive construction strategy (1).

PROJECT DETAILS

General

The Public Bank building in Johor Bahru, Malaysia is located in a very congested site, where long spans and a relatively column free space is an important requirement.

The lower levels, altogether 10 floors, accommodate the banking hall, the carpark levels and mechanical services. The upper 20 levels are typical office floors. The main edge columns are 23m apart thus creating an uneconomical span on the typical floor levels. The 4 x 23m spans are divided by edge columns, which could not be carried down to the foundation levels, since the carpark levels have a different layout.

4 numbers, 23m long 2.15m wide and 4.8m high postensioned concrete beams were therefore designed, to transfer the edge column loads. The 4 beams are carrying approximatively 50% of the total gravity loads of the upper 20 floors. See Figure 1.

Design Procedure

The design procedure can be divided into several stages including preliminary design, detailed design, construction procedures, monitoring and sharing of experiences.

Preliminary design:

- o Recognition of the different architectural layouts.
- o Structural layout.
- o Architectural space allowance for transfer structure.
- o Choice of material.
- o Sizes.
- o Loadpath.
- o Design philosophy.

Design:

- o Calculation of loads.
- o Design of final stage.
- o Check beam shortening and loss of jacking forces.
- o 3 D check of column behaviour.
- o Design of different construction stages.

Detailing:

- o Postensioned cable profile.
- o Bursting reinforcement.
- o Reinforcement detailing.
- o Beam-column joint detailing.

Construction Procedures:

- o Detailing all procedures.

Monitoring During the Construction of the Upper Levels:

- o Concrete monitoring including temperature and strain.

Final Summary and Recommendations for Future Design Procedures:

Without going into the specific design problems, some of the most important points pertaining to the design of transfer structures can be highlighted with this built example.

Design Philosophy

Important decisions were taken in the design towards achieving a realistic target which included:

Designing the beams for the final stage as an almost simply supported structure. The importance of this preliminary decision was later fully supported with the results of the 3D analysis. The main reason behind the decision was the existence of the long blade columns, which are at 45° to the axis of the beams, and represent a very stiff element.

This stiff member provides full end fixity, however will fail under the huge moment component in the blade direction. After this failure, most of the moment goes back to the midspan positive moment. The columns however are designed to carry part of the moment. A time dependent analysis could show that due to microcracks the column stiffness is reduced to approximately 70% and the slow build up of the full load would reduce the effect of failure mechanism to a comfortable level, at which time the structure can tolerate this redistribution, and there will be time to conduct monitoring of the columns. This monitoring is determined and will include visual monitoring, stress monitoring with gauges and deflection checks.

Choice of relatively low prestress level of 2 MPa, helps to avoid large shortening in beams between the stiff supports, which would cause excessive loss in postensioning forces.

Design and detailing were carefully done. The 4 beams were detailed on 26 drawings. Special consideration was given to the choice of reinforcement and prestress cable detailing to match the 3 stage casting concept. This allowed easy placement and minimised the risk of faulty casting.

An extremely important part of the structural engineers works was the specification. The client and the other parties were made aware of the unusual aspects of the construction and about the necessity of extending the usual participants to include an independent materials consultant/technologist. The structural engineer's role in that phase of the project was rather an educational role. The client in this case was experienced and perceptive, and was alerted to the fact that modern day concrete is a much more complex material. While the chemical and physical aspects of hydration is better understood, a larger variety of admixtures are available which can optimise or modify fresh concrete behaviour, to suit the particular structural requirements. It was not possible for a structural engineer to optimise the use of concrete given the variables involved and the complexity of the material. The need for an independent materials consultant to be engaged was therefore emphasised. The contractor's willingness to participate and work closely to implement suggested changes was a critical factor in the work proceeding as expected.

The involvement of the admixture representative was organised jointly by the structural engineer, the materials consultant/technologist and the concrete supplier. They worked on the mix design in conjunction with the supplier monitored the trial mixes and were actively present during the full operation of casting. The close collaboration of the engineer, technologist, concrete supplier and admixture supplier is rather unusual at present, but should be common practice in the future.

Since the beams were cast approximately 40m above foundation level, the construction methodology had to be designed carefully and finetuned after consulting with all the participants. This led to the construction of the transfer beam in 3 stages as shown in Figure 2. Some of the major factors contributing to the decision were:

- Optimising concrete cast volume - construction requirement.
- Minimising back props - construction requirement.
- Optimising postensioned cable profile - structural requirement.
- Avoidance of cold joints within stages and control of cold joints between stages - structural requirement.
- Minimising thermal involvement and cracking - materials requirement.
- Optimising crack formation and location - materials requirement.

In combination, all the above requirements finally impact on structural behaviour and the resulting structural integrity.

Finally construction sequences were well detailed (see Figure 3) including requirements for postensioning and formwork removal. Based on these sequences the construction time table was formulated and constantly finetuned after the experience of each casting.

CONCRETE TECHNOLOGY INPUTS

Introduction

The materials for transfer beam can be summarised as follows:

o Temporary materials: timber formwork, backprops, insulation.

o Permanent materials: reinforcement, postensioning hardware, concrete.

The most uncertain quality of the permanent materials is in the concrete, which increases the risk of failure of the transfer structures. Figure 4 shows the different components, considered during preparation. The above figure shows the sophisticated approach, which was fully carried through, in order to minimise the risk and achieve a high quality product. The detailed approach was only possible with the total collaboration of the participants.

Figure 5 shows the diagram of the participants and the interaction between them.

MATERIALS TECHNOLOGY INPUTS - PRIOR TO CONSTRUCTION

Specification Requirements

The specification requirements with regard to transfer structure included the following:

- Concrete strength of 50 MPa at 28 days with a margin of 20 MPa to achieve the target mean strength.
- Intermediate concrete strength to allow progressive postensioning.
- Slump of minimum 75mm and maximum 200mm.
- Water-cement ratio maximum 0.35
- Fresh concrete temperature not to exceed 35°C.
- Maximum temperature differentials not to exceed 27°C.
- Monitoring of concrete temperature and strain during concrete casting.

Strength

The target strength requirement was relaxed from a 28 day strength to a 56 day strength for the transfer structure. This was adequate from a structural point of view taking into consideration the loading sequence on the structure. The 20 MPa margin was relaxed to 7.5 MPa based on concrete trial mix results, which contributed to limiting the early age heat rise.

Mix Design

Due to steel reinforcement congestion in the transfer structure, the target slump was increased to 225mm with a 200mm minimum to achieve a flowing concrete to ease placement. The incorporation of silica fume into the concrete allowed reduction in the ordinary portland cement content to reduce the early age heat rise. Careful selection of superplasticiser and set retarding admixtures were necessary to give the necessary workability and setting time. A procedure was established to test the slump of each truck load of concrete on site and then re-dose the superplasticiser on site as necessary to give a +200mm slump. By involving all parties in this procedure there were no disputes during casting on slump matters.

Temperature

Concreting was undertaken during the night to ease delivery to the site which was on a busy main street, and also allowed the delivery of concrete at between 25°C - 28°C. Ice was used at the batch plant to minimise the fresh concrete temperature. A water chiller was not available at the batch plant and batching crushed ice was the most practical and cost effective means of lowering the batched concrete temperature. Based on calculations it was considered essential for concrete to be supplied at <30°C to minimise the risk for crack development in the transfer structure. By involving the materials consultant, designer and contractor at the planning stage the contractor appreciated the benefit of lowering the batched concrete temperature, including the extra concrete cost, as opposed to placing concrete at 35°C.

Water to Cement Ratio

The maximum water to cement ratio was slightly increased from 0.35 to 0.4 (calculated by including the silica fume in the cementitious content and water in the admixtures). This alteration was assessed as not significantly changing the material performance of the concrete.

Concrete Temperature and Strain Monitoring

The actual monitoring to be carried out was decided by consensus cost/benefit interaction between the designer, contractor and materials consultant to achieve an adequate concrete.

Pour Operation Plan

The materials consultant produced a brief pour operation plan for the contractor. This document assisted all parties involved in the casting to plan in a systematic manner and assess contingency plans such as standby placement techniques during concrete pump break down, night time concreting and concreting under wet conditions.

Transfer Beam Construction

Significant construction details included the following:

a) The transfer beam layout and staged casting sequence are shown in Figures 1 and 2.

b) The time of casting is listed below:

Beams 1 & 2	Stage 1	Day 0
Beams 3 & 4	Stage 1	Day 5
Beams 1 & 2	Stage 2	Day 18
Beams 3 & 4	Stage 2	Day 19
Beams 1 & 2	Stage 3	Day 31
Beams 3 & 4	Stage 3	Day 32

This also included the completion of 2 floor levels connected with the beam.

c) Curing of the transfer beams was adequately achieved by the formwork and concrete already cast below for casting Stages 2 and 3. There was no curing to the top surfaces as this was considered not practicable (nor necessary) for the construction process.

d) Thermal insulation was by the plywood formwork and the concrete already cast below for casting Stages 2 and 3. There was no insulation to the top surface as it was not practicable for the construction process.

The insulation philosophy was to allow the heat to escape in order to minimise the bulk temperature rise from the heat of hydration.

IN SITU CONCRETE TEMPERATURE AND STRAIN MONITORING

Locations

The monitoring locations selected to representatively evaluate the early age material performance of the transfer beams were:

a) The mid span vertical plan of two out of the four transfer beams.

b) Thermocouple positions as per Figure 6 on two beams.

c) Vibrating wire strain gauge positions on one beam as per Figure 6.

Duration

The monitoring started at the time of placing the concrete and continued until approximately 14 days.

Predicted Early Age Thermal Induced Cracking Likelihood

The Stage 1 concrete casting (0 to 2000mm high) was expected to be free of external and internal cracks. The Stages 2 (2000mm to 3500mm high) and 3 (3500mm to 4800mm high) concrete castings were expected to have internal cracks formed as a result of the increased restraint from the concrete being cast onto the already cast concrete of the earlier stage casting of the transfer beam below. Although cracking was not expected to be significant in width, additional crack control reinforcement was placed in the beams by the structural engineer for extra control.

Concrete Temperature Test Results

Typical thermocouple data obtained is shown on Figure 7 for the temperature profile at the mid span of Beam 2 (see thermocouple positions indicated on Figure 6).

Significant concrete peak temperature monitoring data results were:

a) The peak temperatures for all the pours were similar ranging from 74°C to 80°C (see Table 1).

b) The peak temperatures occurred at the mid section of the beams as expected (ie mid depth and center).

c) The peak temperature time after casting ranged from 24 hours to 43 hours. This variation in time was a result of the pour depth (1.3 to 2.0m) and casting duration.

d) The peak temperatures recorded were consistent with the predicted peak temperature of 78°C.

Significant concrete temperature differential monitoring data results were:

a) The maximum temperature differential ranged from 28°C to 37°C (see Table 1). In all beams this differential was between the mid depth and center position to the top corner.

b) The predicted maximum temperature differential was 32°C. In general all results were similar with one result at 37°C.

The overall temperature movement of concrete during the heat of hydration heat up and cool down is given by the bulk temperature variation. The main cracking concern is during cooldown as the bulk temperature cools from its peak to ambient conditions. The bulk temperature profile across a section of concrete approximates a parabolic curve.

Significant monitoring data results were:

a) The maximum bulk temperature varied between 70°C and 75°C (see Table 1).

b) The predicted maximum bulk temperature was 75°C.

Concrete Strain Test Results

Typical Stage 1 casting data obtained from the vibrating wire strain gauges is shown on Figure 8 which gives strain with time, and Figure 9 which gives strain versus temperature. This data was for the gauge at 100mm up from the bottom in the mid span of Beam 2 for the Stage 1 casting. There was no evidence of any cracking on the strain temperature graph however, the early and final postensioning was detected by the sudden strain relief after approximately 60 hours and 160 hours respectively.

Typical Stages 2 and 3 casting data obtained from the vibrating wire strain gauges is shown on Figures 10 and 11 which gives the strain versus temperature. This data was for the gauge at 750mm below the top surface in the 1500mm deep beam, at mid span of the Stage 2 casting. Cracking was detected by the change in slope of the cooldown curve when the concrete had cooled to about 47°C. Cracking was also detected in the Stage 3 casting. In general, the crack occurrence was as predicted prior to casting the beams.

The strain relieve noted due to postensioning indicates the beneficial effects of postensioning and the importance of the right timing for this to take place.

Restraint Factors

The slope of the strain-temperature curve from recorded data (eg Figure 11) provides a value of in situ thermal contraction coefficient (α_i) at the gauge location. The free thermal contraction coefficient (α_f) is the value obtained for concrete which is free to contract without restraint.

The α_f for the concrete used in the transfer beams has an assumed value of 10 microstrain/^{o}C based on theory (2, 3).

The restraint factor R, is given by:

$$R = 1 - \frac{\alpha_i}{\alpha_f} \quad \text{.......... Equation (2, 1)}$$

Significant comments on R values are:

a) Stage 1 had low restraint of +0.1 and +0.06. The predicted restraint was to be less than +0.15. Theoretic restraint values were expected to be less than +0.1 to +0.2 (2). The measured restraint in Stage 1 was therefore consistent with the expected performance and no internal cracking occurred.

b) The partial postensioning gave a reduction in restraint (Figure 12) however, the restraint before and after postensioning was the same which indicated the measured data was postensioning and not a crack.

c) Stage 2 restraint varied from -0.15 (bottom) to +0.32 (middle). The predicted and theoretical value was 0.5. Cracking was detected in the middle (Figure 11) and the subsequent strain relief resulted in a reduction in restraint from +0.32 to -0.25.

d) The Stage 2 restraint at the horizontal construction joint to Stage 1 below was -0.15, indicating a net 'prestress' effect rather than restraint of +0.4 as expected. The prestress was created by the faster rate of cooling of the middle and top horizontal concrete layers, by comparison with the bottom concrete layer, giving tension in the top/middle and compression in the bottom. The horizontal layered construction sequence has produced a cooling phenomenon whereby the cooling 'prestress' has more than offset the concrete-to-concrete restraint at the bottom. Cracking therefore did not initiate from the horizontal construction joint upwards into Stage 2 but has occurred in the middle to top portions of Stage 2. This phenomena has been noted elsewhere (4).

e) Stage 3 restraint varied from -0.08 (bottom) to +0.33 (top). Cracking was detected in the top. The horizontal layered cooling of the Stage 3 concrete resulted in tension in the top/middle and compression at the bottom as per Stage 2 discussed above.

Early Age Thermal Crack Likelihood

The strain and temperature monitoring confirmed there was no early age thermal cracking in Stage 1 transfer beams casting. the stages 2 and 3 had early age thermal cracking on cool down at the top/middle.

The early age strain induced within the concrete from early age thermal behaviour can be calculated from the strain gauge and thermocouple data of restraint and temperature change at a unique location. Using a theoretical equation (2) the induced strain at the locations where cracking was detected can be calculated below:

From Gauge E as per Figure 11,

Peak temperature = 77°C

Approximate temperature at cracking = 47°C

Restraint (R) = +0.32

Induced strain $= 0.8\, R \propto \Delta T$
$= 77$ microstrain

where ΔT is the temperature change during cool down and 0.8 takes into account creep relief.

The cracking is consistent with the tensile strain capacity of concrete of about 80 microstrain (2).

POST CONSTRUCTION MONITORING

Further strain gauges have been placed in the beams and major columns, allowing a continuous monitoring of the 3-dimensional structural system during construction. Parallel to the above readings, deflection checks will be carried out as well. The results obtained will give a better understanding of the time dependent behaviour of the transfer beams, which could give further help in future designs.

CONCLUSIONS

1 The concrete material performance behaviour at early age was predicted prior to casting the beams with sufficient accuracy to develop a concrete mix and casting procedure to minimise the risk of significant early age thermal cracking.

2 The concrete temperature and strain monitoring of the transfer beam provided data to identify the actual in situ early age thermal behaviour of the transfer beam with certainty, the predicted behaviour was confirmed, and the designer was able to satisfy himself that this critical building element had been constructed free of significant cracks. The contractor was therefore able to continue construction of typical floors above without any delays from evaluation of an uncertain transfer beam condition.

3 The interaction of designer, contractor, materials consultant and concrete supplier in addressing the concrete mix design, placement, construction strategy, material performance and risk of defects on the transfer beams enabled all relevant issues to be addressed in a manner to avoid construction defects. Such interaction does not normally take place in the construction process, and should be encouraged in the future.

REFERENCES

1 P Gabor, Concrete Future a Multi Disciplinary Interactive Procedure; 3rd International Conference on the Concrete Future, March 1994, Kuala Lumpur, Malaysia.

2 P B Bamforth, Early Age Thermal Cracking in Concrete, Institute of Concrete Technology, July 1982, London, United Kingdom.

3 P B Bamforth and W F Price, Construction of Deep Lifts and Large Volume Pours, (Ciri A) Report RP454/1, August 1993, London, United Kingdom.

4 P B Bamforth and W R Grace, Early Age Thermal Cracking in Large Sections - Towards a Design Approach, Asia Pacific Conference on Roads, Highways and Bridges, September 1988, Hong Kong.

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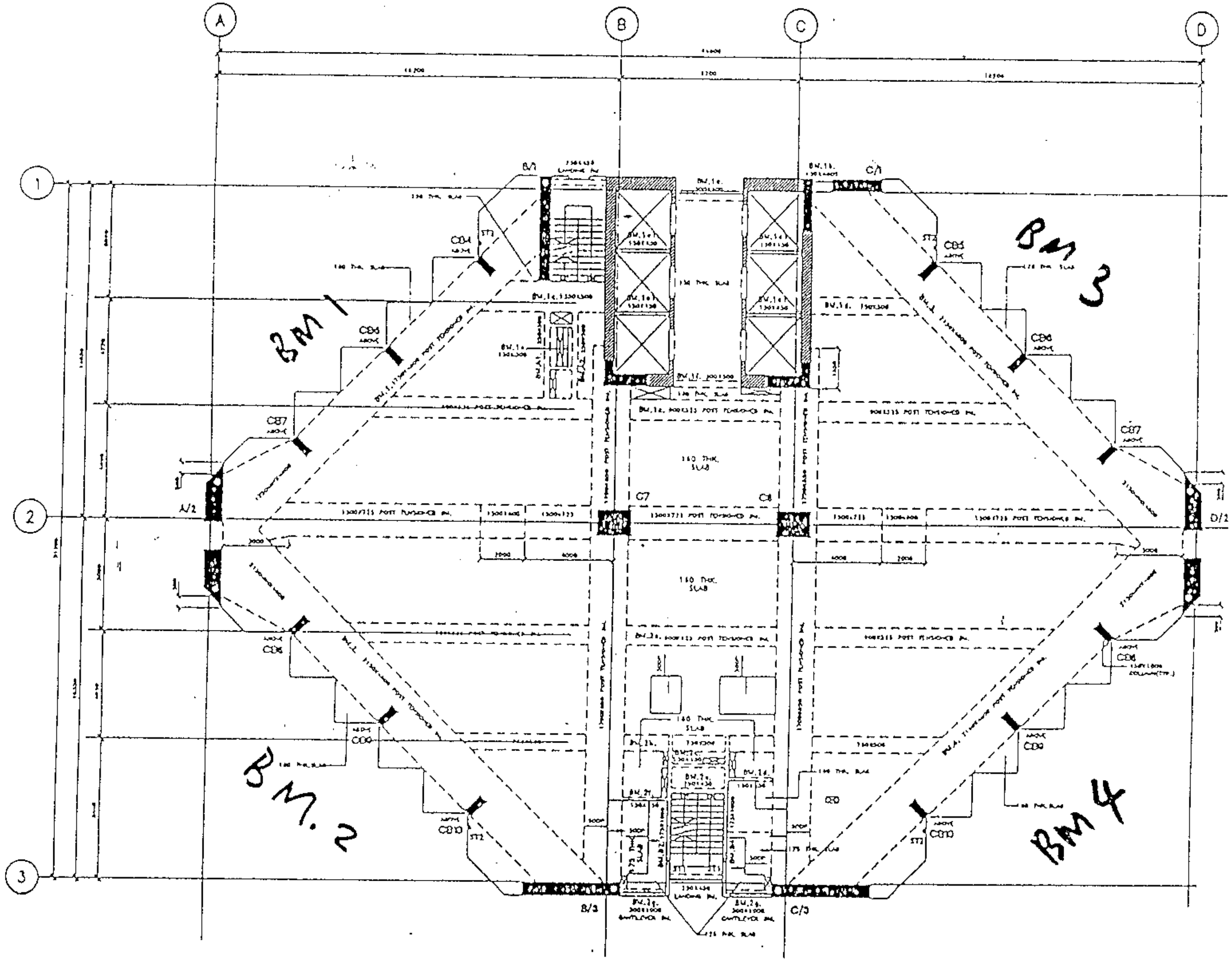


FIGURE 1: TRANSFER BEAM LOCATION IN PLAN

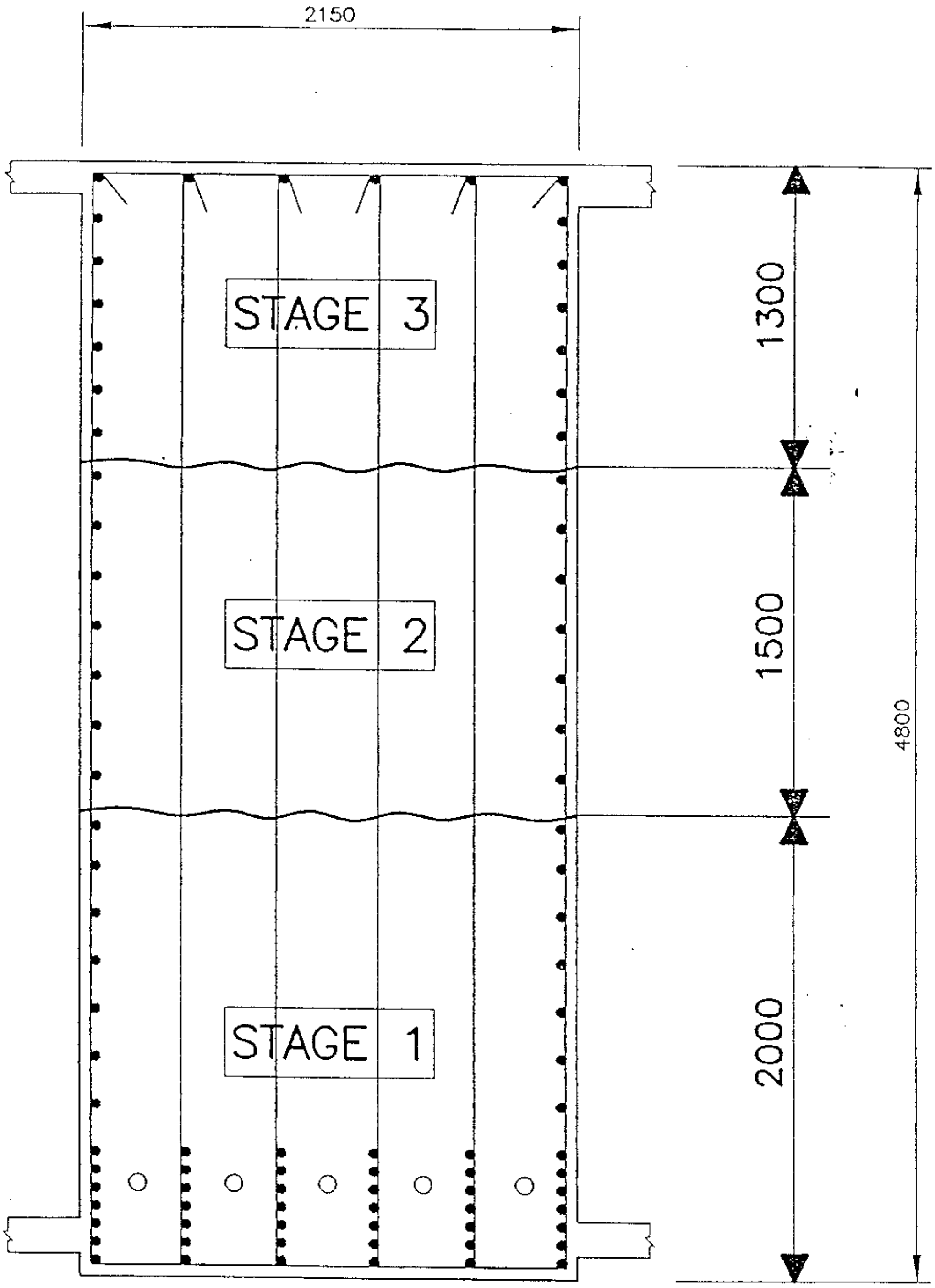


FIGURE 2: 3 STAGES IN TRANSFER BEAM CONSTRUCTION

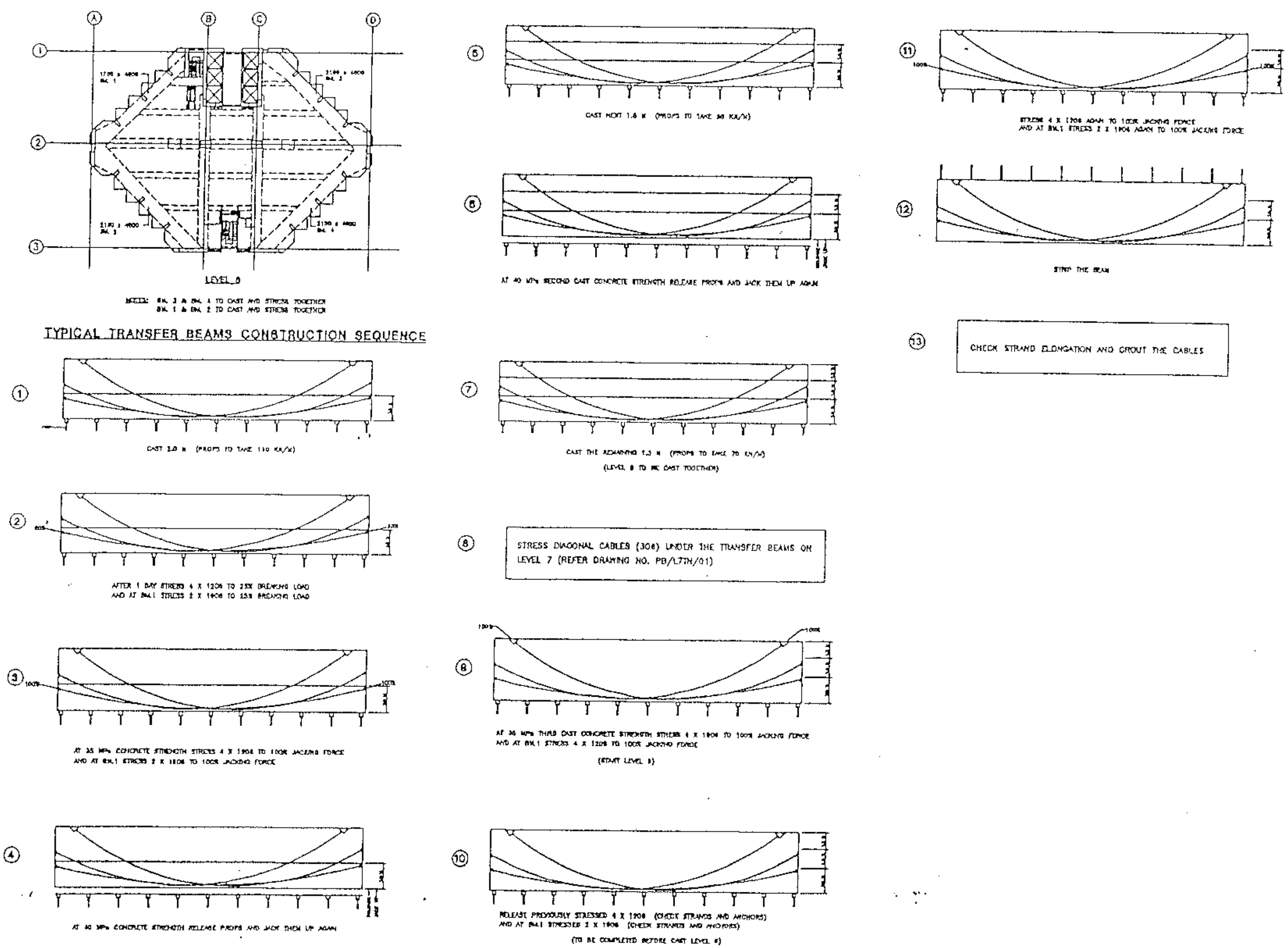


FIGURE 3: CONSTRUCTION SEQUENCE

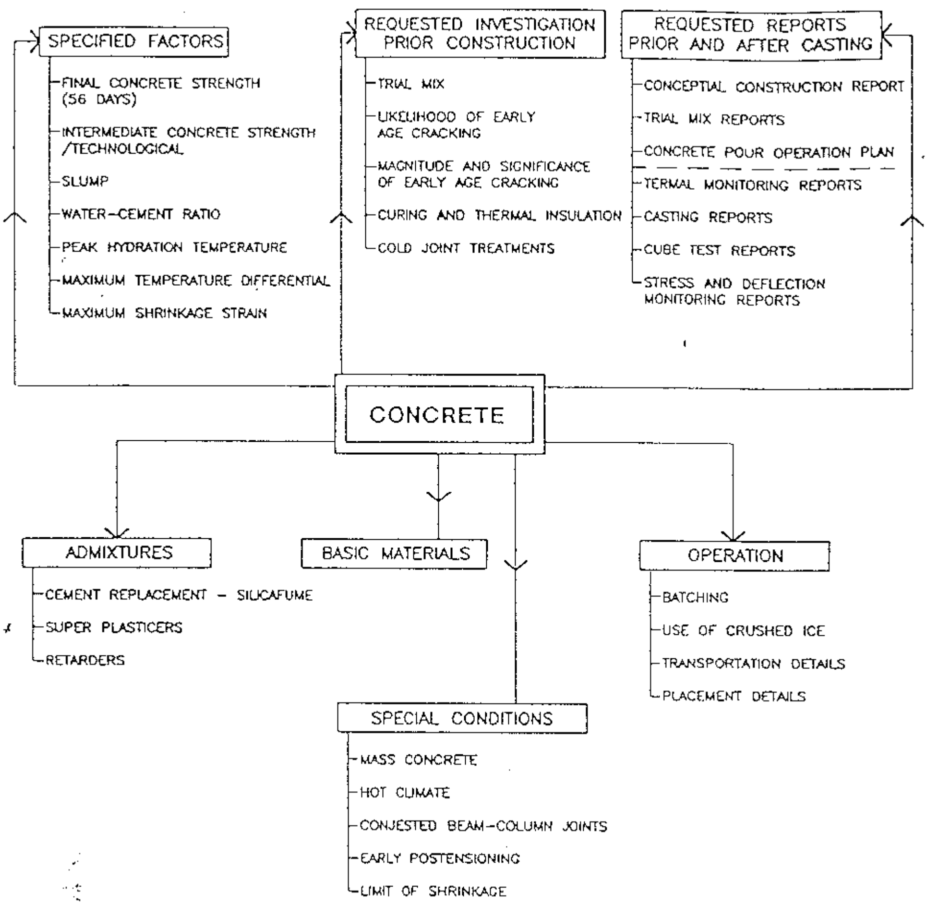


FIGURE 4: TRANSFER BEAM CONSTRUCTION - MATERIALS TECHNOLOGY INPUTS

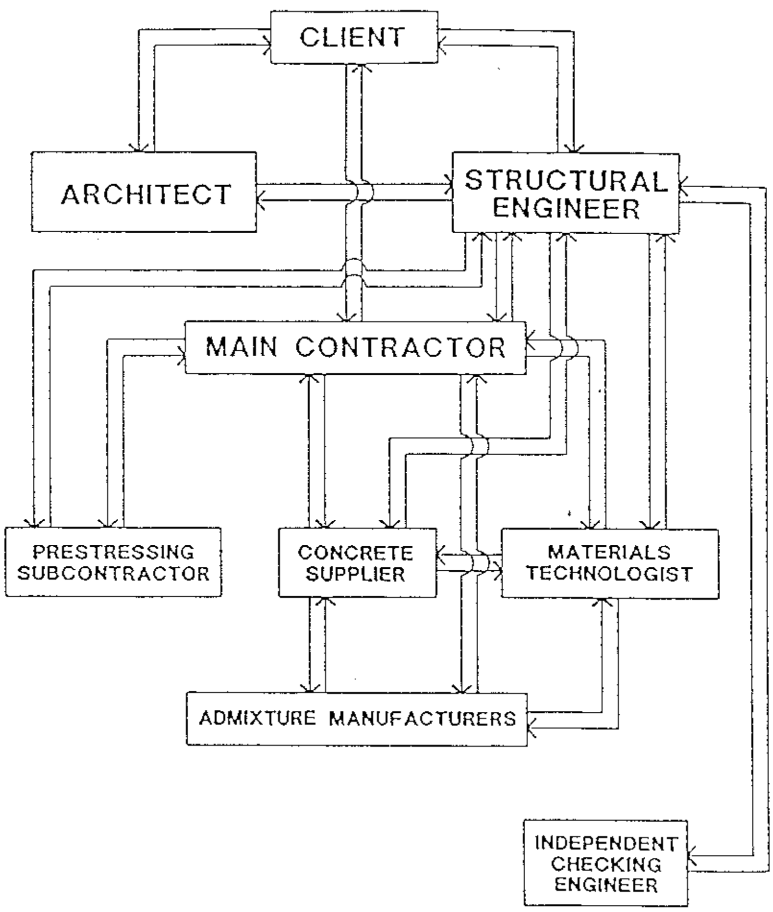
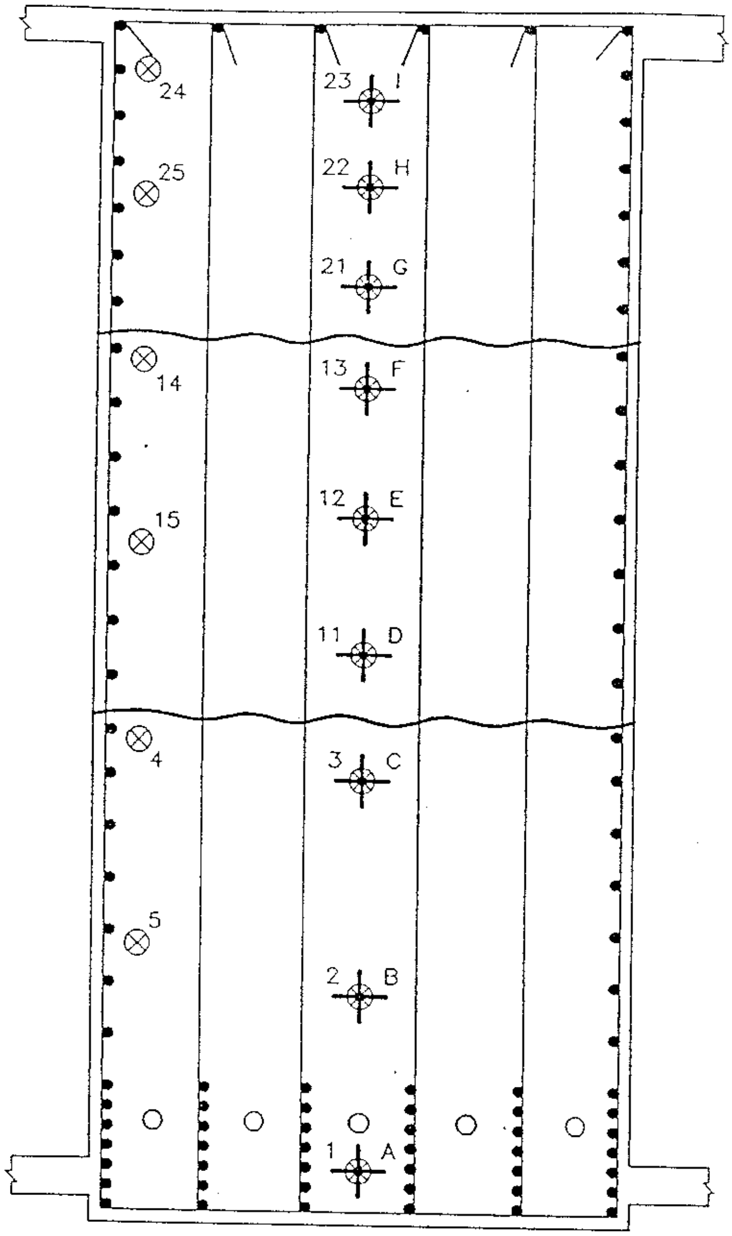


FIGURE 5: HIGH QUALITY STRUCTURAL CONCRETE PARTICIPANTS AND TECHNOLOGICAL INTERACTION DIAGRAM



LEGEND:

— VIBRATING WIRE GAUGE (VWG'S NOS. A TO I)

⊗ — THERMOCOUPLE TYPE 'K' (NOS. 1 TO 30)

FIUGRE 6: MONITORING LOCATIONS (CROSS-SECTIONAL VIEW)

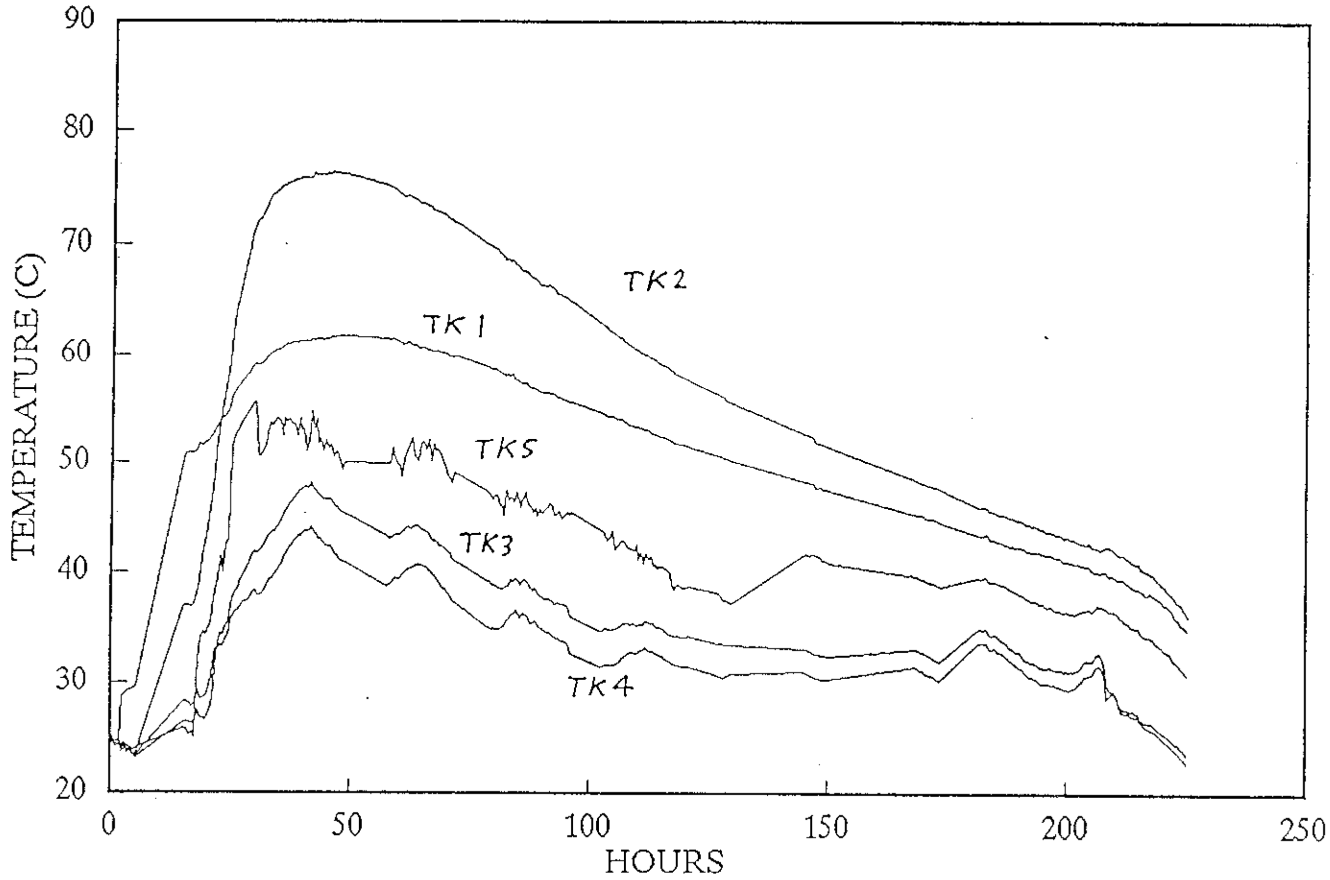


FIGURE 7: TEMPERATURE PROFILE (THERMOCOUPLE POSITIONS 1 TO 5)

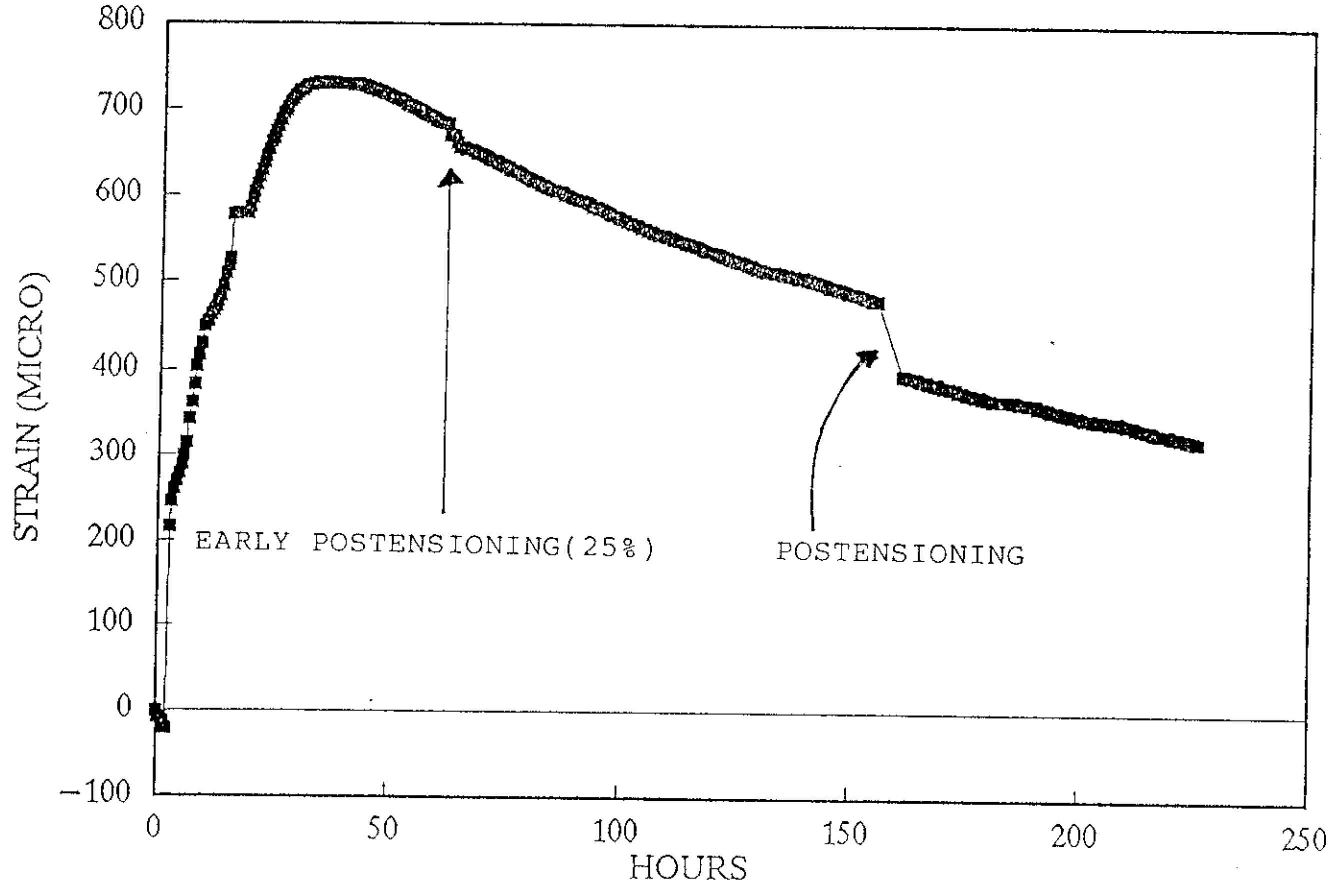


FIGURE 8: STRAIN PROFILE (GAUGE A POSITION STAGE 1 POUR, 100mm FROM SOFFIT OF TRANSFER BEAM)

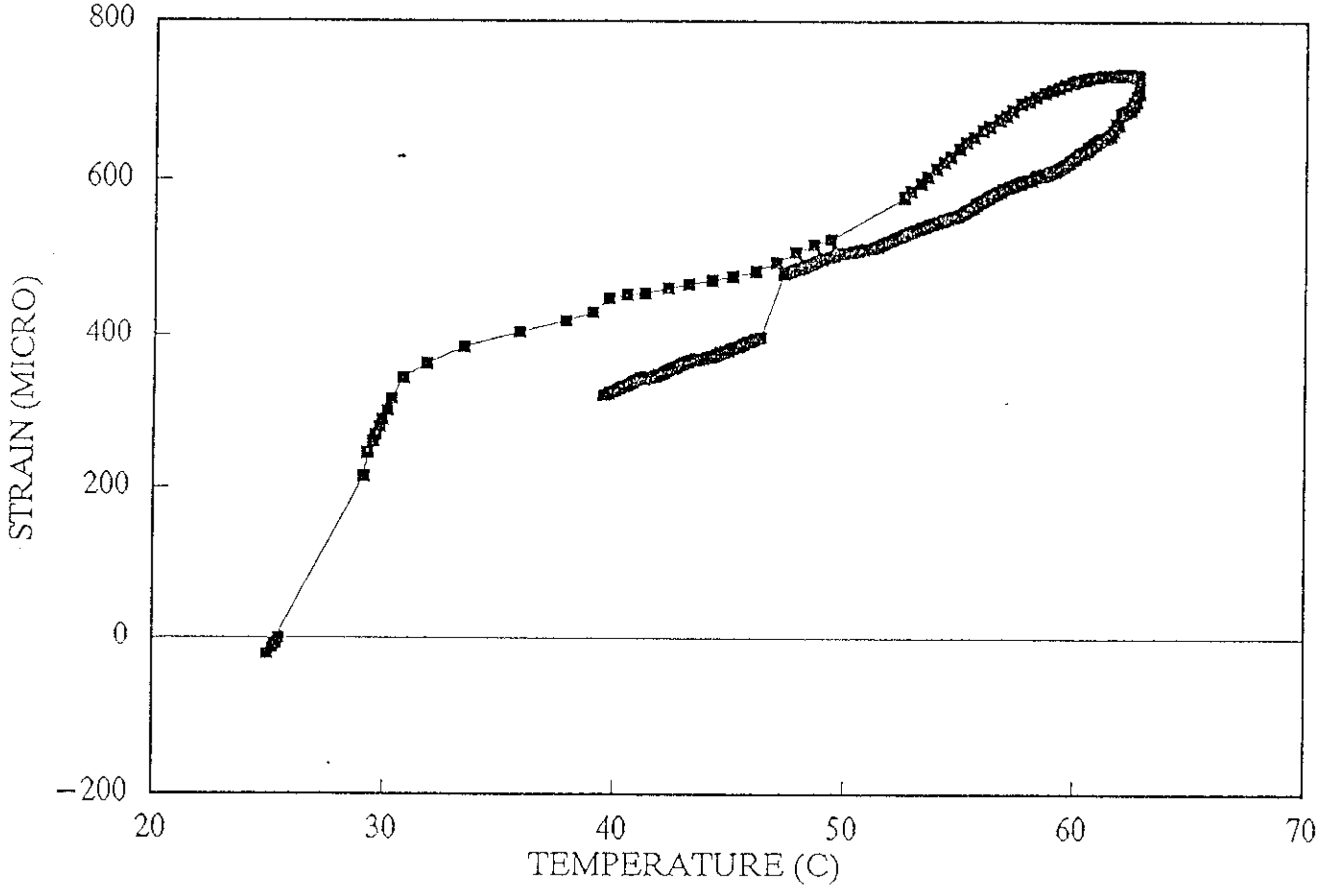


FIGURE 9: STRAIN VERSUS TEMPERATURE
(GAUGE A POSITION STAGE 1 POUR, 100mm FROM TRANSFER BEAM SOFFIT)

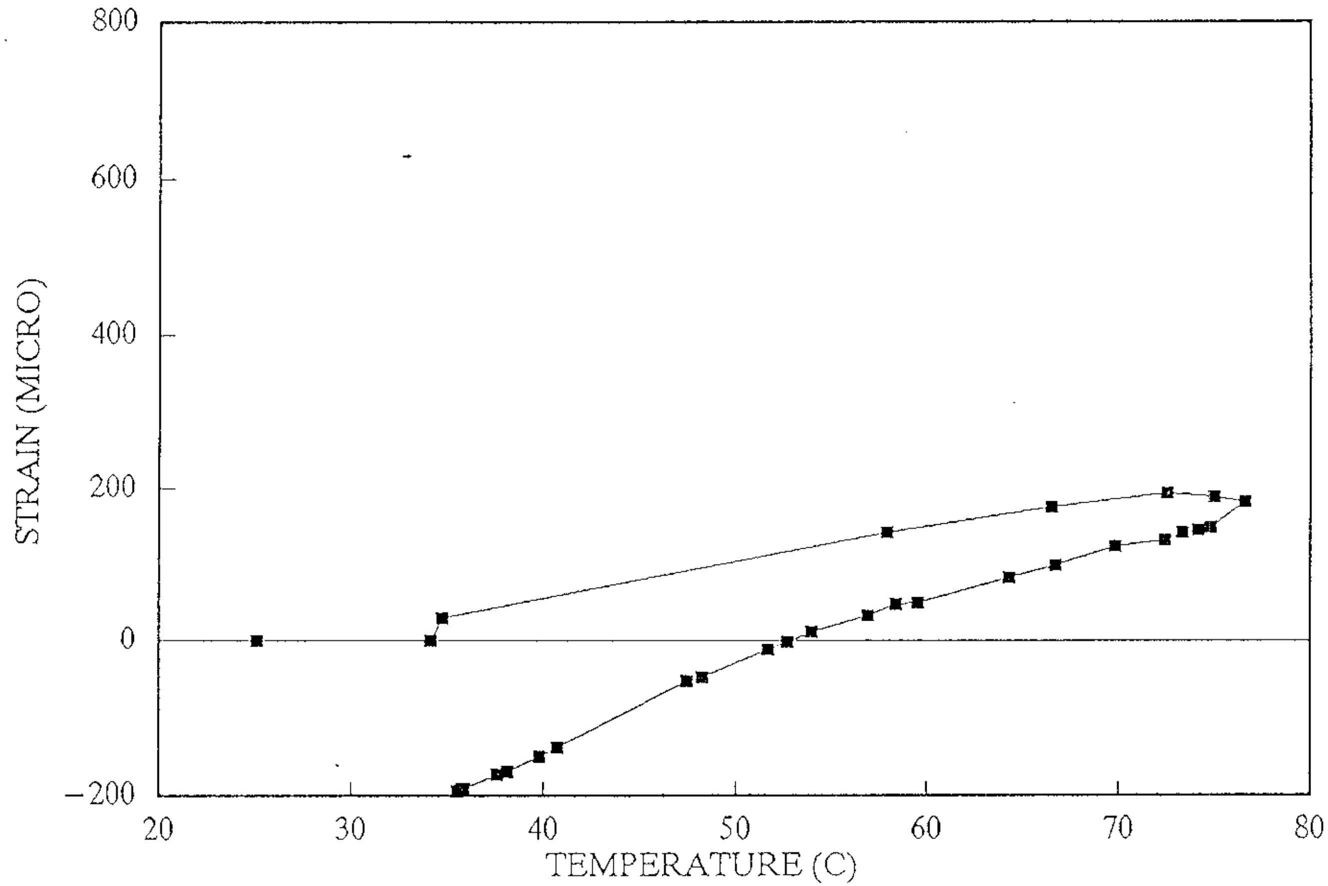


FIGURE 10: STRAIN VERSUS TEMPERATURE
(GAUGE E POSITION STAGE 2 POUR, 750mm FROM TOP OF BEAM)

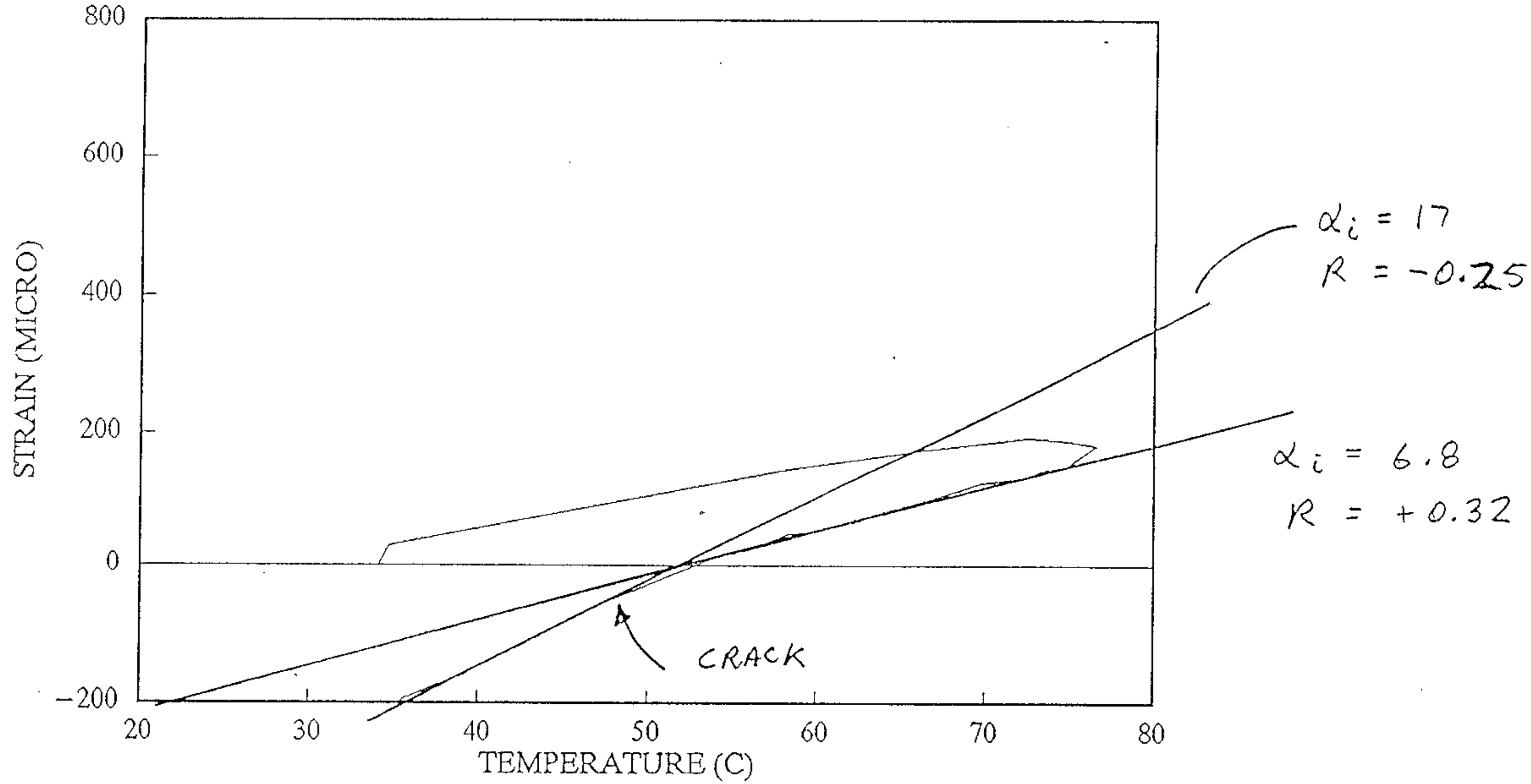


FIGURE 11: STRAIN VERSUS TEMPERATURE
(GAUGE E POSITION STAGE 2 POUR), SHOWING INTERNAL CRACK DEVELOPMENT

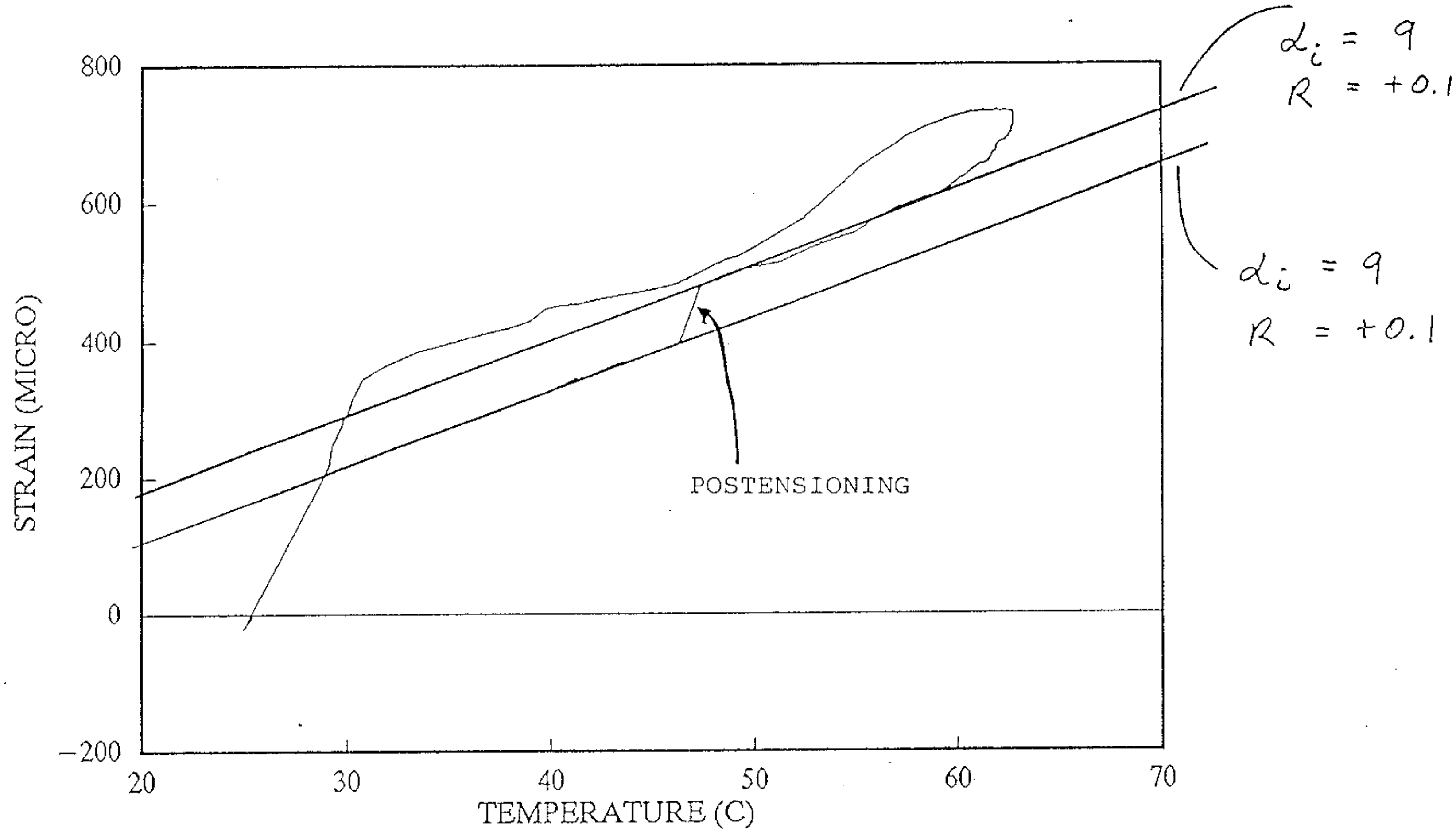


FIGURE 12: STRAIN VERSUS TEMPERATURE
(GAUGE A POSITION SHOWING NO CHANGE IN RESTRAINT AFTER POSTENSIONING)