# CONSTRUCTION OF KLCC TOWER #2 — THE WORLD'S TALLEST BUILDING

Yang, Wan-Su*

## 1. INTRODUCTION

The KLCC petronas towers which are 446m high above ground are 92 story twin buildings with a total of 98 stories including mezzanines and mechanical penthouse floors. Architectually, the tower is cylindrical in shape with 16 circular columns spaced along the perimeter. The Facade between columns has alternate pointed projections giving unobstructed views through the glass and stainless steel curtain wall on all sides (Fig. 4).

The central core of the tower houses all elevators, exit stairs, and mechanical services.

The Malaysian Building Code requires that the structural core have two solid walls surrounding and seperating the stairs; two walls run east-west and one wall runs north-south. The core is 23m square at the base, rising in four steps to 18.8 m by 22 m at the top. Inner walls are 350 mm constant thickness while the outer wall varies from 750 mm to 350 mm (Fig. 3). The construction contract calls for completion in 27 months or by June 1996 and the core has to be cast at each level in a four and half day cycle using a self-climbing form system. This paper describes the construction of one of the the twin towers, Tower #2.

## 2. STRUCTURAL SYSTEM OVERVIEW

Cast-in-situ concrete is used in deep friction barrette foundations supporting a continuous mat under tower. Structural steel is used for the long span typical floor beams supporting concrete-filled metal deck slabs. Structural concrete is used in foundations, in the central core, in the sixteen perimeter tower columns and variable-depth perimeter ring beams, and in twelve smaller perimeter columns and ring beams around the bustle. Outrigger beams link core and perimeter frame at levels 38 through 40 for additional stiffness. The typical floor framing plan is shown in Fig. 3.

### Foundations:

The site is underlain by the Kenny Hill formation of stiff residual soil common to Kuala Lumpur

* Architectural Structures Professional Engineer, Technical Adviser Samsung Engineering & Construction Co.

with limestone bedrock beneath. Distance to bedrock varies dramatically across each tower from 60 to more than 160 meters below the lowest basement level with isolated cavities at the Kenny Hill limestone interface.

Since foundations bearing on limestone were impractical, concrete barrettes were used in friction to gradually distribute loads in the Kenny Hill. The tower mats are 4.5m deep.

The foundation work was contracted separately from the super-structure construction. Prior to the contract for super-structure construction, the barrette and mat foundation work had been completed by another local constructor.

According to the foundation constructor, about 13,000 cubic meters of concrete in each mat was cast in one continuous 2 day's operation, and insulating styrofoam panels covered the top to limit temperature variations to 25℃.

### Column, Beam, Corewall and Slab:

There are 16 tower and 12 bustle concrete columns that begin with 80 MPa concrete at the base and change to 60 MPa and 40 MPa at higher levels. Tower columns vary in size from 2400 mm diameter at the base to 1200 mm at the top. In the bustle, eight of the 12 columns vary from 1400 mm to 1000 mm in diameter. The setbacks at levels 60, 73 and 82 are made by sloped columns over three story heights. Above level 84, steel columns and ring beams support the last few tapered floors and the pointed pinnacle.

Haunched ring beams vary from 1150mm deep at ends to 725mm at midspan. The central core of tower is 23m square at the base, rising in four steps to 18.8m by 22m. Inner walls are a constant 350mm while the outer walls vary from 750mm to 350mm.

In a compromise between stiffness required to balance the different loads on the perimeter columns and the core, the outriggers are used with three levels of relatively shallow beams connected by a midpoint post.

The tower floors are typically composite metal deck with concrete fill varying from 110mm in offices to 200mm on mechanical floors. The floors comprise wide-flange beams at spans up to 12.8m, and with limited depth of W18 or shallower to provide room for ductwork.

## 3. HIGH STRENGTH CONCRETE COLUMNS AND WALL

High-strength concrete improves structural efficiency, adds the advantage of a reduction in column sizes and increases the lateral stiffness of building.

Barrette concrete is 45 MPa cube strength, equivalent to 5.5 ksi cylinder strength. Mat concrete is 60 MPa cube strength for a gradual transition to the 80 MPa concrete in the tower column.

Concrete columns, ring beams and core wall use 40 to 80 Mpa cube strength concrete. For the required strength, the concrete mixture is relatively rich and contains silicafume. The mixture has a high heat of hydration, so to keep the predicted peak temperature under 90℃ (194℉), mixing water was chilled to 10℃ (50℉), aggregates were sheltered as feasible, and cement was stockpiled and allowed to cool several weeks, rather than being used warm from the mill. Sample mix designs and plots for the required concrete strength are shown in Figure 5 and Table 1.

## 4. COREWALL, COLUMN AND RING BEAM FORMWORK SYSTEM

### Core Wall Form:

Self-climbing forms are used to accomplish the cycle time required by the construction program and provide the facility to incorporate all inserts, plates, penetrations, and installations of reinforcement, within the specified cycle. This system provides versatility at required levels for core activities. The forms roll back to allow for cleaning, installation of penetrations, plates and concrete inspection. The system is operated by a hydraulic jack system with various components. Its mast climbs on recoverable pin off brackets and can be set and locked off to accomodate various pour heights. It can climb progressively to allow access to any part of the wall and has lower levels of platforms for inspection of previous concrete pours, remedial work if necessary and access to cast-in plates for the following steelwork erection. This system meets the construction requirement for a four and half day core cycle providing uniform concrete finish quality through-out the project.

The two zone forming system (zone A & B) provides trade continuity, a smaller work force and true cyclic construction without hindrance to zone B form climbing (Fig. 6 & 7).

### System sequence:

a. Form stripping begins, roll back and cleaning of forms after 15MPa concrete strength
a. is reached (12hrs).
b. Rebar cages are prefabricated on the ground, crane hoisted and fixed.
c. Embedments, sleeves and conduits for M&E can begin.
d. Internal forms are climbed to suit rebar, embedments and M&E progress.
e. External forms begin to climb.
f. Forms are progressively closed, aligned, and fixed.
g. Concrete cast.

The changes in wall thickness, wall layout and floor to floor heights can be done form by form or as a complete unit with minimum delay to cycle time.

### Column Form:

The 8 full sets of circular steel column jump forms are used to construct the 16 external columns at each floor and meet with construction requirement for a 4 day cycle providing constant concrete finish quality through-out the project. The forms are constructed in two halves which are key bolted together for pouring and unbolted but not separated for lifting.

Each column form was fixed with a working platform to incorporate all inserts, plates, rebar fixing and concreting (Fig. 8).

construction. The four permanent lifts will be installed and available for temporary use during the construction of the tower.

### Material hoisting system:

The material hoisting system on this project was required to perform in the most efficient manner possible to support the extremely demanding project schedule. The 3 hoist crane and one lift car were integrated as a result of a lengthy and detailed analysis (Fig. 7).

The following cranes were installed.

Tower crane 1 — FAVCO 380D located on tower core
Capacity : 18 ton at 23 meter radius
7.0 ton at 48.5 meter max. radius
Hoisting speed : 140 meter per minute
Self standing height: 36 meter

Tower crane 2 — FAVCO 440D located on tower core
Capacity : 26 ton at 23 meter radius
13 ton at 40 meter max. radius
Hoisting speed : 140 meter per minute
Self standing height: 32 meter

Tower crane 3 — POTAIN MR150 located besides the bustle
Capacity : 4.6 ton at 35 meter radius
2.0 ton at 50 meter max. radius
Hoisting speed : 26 meter per minute
Self standing height: 48 meter

The one lift car was installed on the outside of the tower and this system was provided by the USA Hoist company. This car has a capacity of 4.5 ton and travels at speeds up to 152 meters per minute. This lift is accessed at the concourse level and provides service up to level 73.

## 7. CONCRETE MANAGEMENT, SUPPLY AND PLACING SYSTEM

### Concrete Management and Supply:

Handling of concrete is the major challenge in the construction of the world tallest building. To deal with the quantities like 74000 m3 of concrete, the preparation work, transportation, placing, curing and QA/QC of the concrete became very essential. Ready mix concrete from two on-site batch plant is used for entire project by a local ready mix supplier who provides services of casting and testing of specimens to ensure quality of concrete. The mix designs specify water cement ratios far lower than required to achieve the corresponding specified strength requirments and are very restrictive in terms of workability. Over 35 trial mixes were produced in the selection of the appropriate concrete mix designs. The most suitable of the trial mixes were tested and mockup

### Ring Beam Form:

The 16 full sets of steel jump forms are used for the construction of ring beams. Each component incorporates working platforms, ladders and safety rail fixed to the external side of form (Fig. 9).

## 5. CONSTRUCTION METHOD OF STRUCTURAL FRAMEWORK

The rebar cages for columns are prefabricated on the ground, lifted by crane and fixed into position. The crane lifts and lowers the column form over the previously fitted reinforcement. The column form is closed, bolted up for tightness and its height is adjusted by the screw jacks on the corner of the form before being made ready for concreting (Fig. 10). Since column concrete is poured up to the bottom of the ring beam, the beam forms consisting of box trusses, soffit forms with the external hinged beam form and column beam make-ups are lifted by the crane. The prefabricated rebar cage, including cast-in-plates temporarily tied in position which are ready for final fixing when in location, is lifted into position and fixed. Access to the reinforcement and cast-in plates is unrestricted due to the hinged beam form.

The erection of floor steel beams is carried out at a particular level using small jib cranes mounted on steel beams as shown in Fig. 10. There are two small jib cranes for the tower. The small jib cranes can be handled by tower crane, and positioned in advance of the metal deck essentially on a four zone basis, quadrant by quadrant for the tower. The base frame of the small jib crane is clamped to the top and bottom flanges on both sides of the supporting beams, which are permanent. The jib crane is stepped up to the next floor just in advance of the commencement of metal deck installation. In the worst condition there are a total of approximately 45MT of structural steel in the larger floors towards the bottom of the tower and bustle which requires 48 working hours to complete the steel installation and connections (Fig. 11).

## 6. VERTICAL TRANSPORTATION SYSTEM FOR CONSTRUCTION

### Personnel Movement System:

The continuous and uninterrupted movement of personnel throughout the project is crucial for maintaining the tightly scheduled construction work. Two pairs of lift cars were installed on the outside of the tower (Fig. 7). The system was provided by Alimak.

These 4 cars have a capacity of 3.2 ton (32 passenger) each and travel at speeds up to 90 meters per minute. These lifts are accessed at level P1 and provide service up to level 73.

The one pair of lift cars will be installed to provide service from level 73 to level 84 M3.

The system will also be provided by Alimak. These 2 cars will have a capacity of 2.0 ton (20 passenger) each and travel at speeds up to 40 meters per minute. The project schedule has allowed for turnover of the permanent lift shafts to the lift sub contractor at various stages throughout the columns were cast using the Grade 80 mix designs. Every morning and afternoon after the daily rains, the moisture content of the sand is ascertained by the "Moisture Probe" and "Speedy Moisture Meter". The moisture contents of sand, monitored by the probe are directly transmitted to the computer batching system for adjustments of batch water and sand contents. Temperature control of concrete to a maximum of 35 degrees Celsius is achieved by the use of chilled water (at approximately 10℃ by means of 120 HP chillers and stored in fully insulated 45,000 lit tanks, one unit per plant), sand kept covered to keep moisture content to below 5% to facilitate maximum addition of chilled water, 20mm aggregate sprayed with water(for evaporative cooling in high ambient conditions) and cement below 75℃.

### Concrete Placing System :

Because of the long cycle times required for bucketing concrete to the upper floors of the tower and the high crane usage requirement, pumping has been selected as the main method of concrete delivery for the tower. The equipment required for this operation consists of the following.

- concrete pumps
- concrete pipe lines
- placing booms

The two high pressure SCHWING BP8000HDR-18HP concrete pumps are used to place concrete for the tower. This pump can supply concrete at an excess of 50 m3 per hour at the lower levels and at a minimum of 25 m3 at the upper levels. These pumps are located adjacent to the working platform on the ground level. This allows unloading of two transit trucks simultaneously and minimize traffic congestion on the working platform area.

The one SCHWING BP3000HD-18R concrete pump is used to place concrete for the bustle.

Generally two sets of heavy duty concrete pipe lines are installed from ground level to the placing booms for tower and the third set is standing by for slab casting and emergency use. The 7.0 mm thick, 125 mm diameter pipe lines at ground level is changed to 4.0 mm at the height of 310 meters.

The two SCHWING KVM 31/27-125 booms are used for placement operations on the tower, each with a reach of 27 meters. The one SCHWING KVM 26/22-125 boom is used on the bustle, with a reach of 22 meters. (Fig. 12 for locations of concrete pumps and placing booms.)

## 8. WALL AND COLUMN DIFFERENTIAL SHORTENING

A comprehensive survey is maintained throughout the construction period of the tower to monitor the effect of column and corewall shortening.

The objective of this monitoring is to determine

- The strains in the columns and walls by means of vibrating wire strain gauges.
- The differential shortening between the columns as well as between columns and

– walls by means of precise levelling techniques.

The target locations for instrumenting the vibrating wire strain gauges are street level, level 19, level 38, level 45, level 58, level 70 & level 80 with a total of 119. The primary means of gauge placement is direct embedment in the concrete by pre-attaching the gauge to the rebar of the structure (Fig. 13). The strain change in tension or compression is measured as a change in the resonant frequency of vibration of the wire. The read-out box used in conjunction with the vibrating wire strain gauge converts the measured frequencies so as to display the reading in microstrain. This monitoring will be continued even after the completion of the construction.

The target locations for precise levelling techniques to determine the differential shortening between columns as well as between columns and walls are located at the two mechanical floors, level 38 and level 84 mezzanine with a total of 16 locations. Relative vertical displacements are being measured using the precise levelling techniques on the walls and columns to investigate the differential shortening between columns as well as between columns and walls. Targets are attached to each column or wall to be monitored as soon as practicable after the forms are removed. Lines at 10mm spacing are engraved on these target plates made of copper which corresponds to the range of the micrometers on the level. A precise measurement of 0.1mm is obtained with estimation to 0.01mm by the precise level. This measured differential shortening will be referenced to a datum column. Only differential displacements will be monitored, hence all surveys will be relative to a selected survey target. By cumulating above data as construction proceeds, the total effect will be reevaluated by a column shortening program which follows the approach of

"Column Shortening in Tall Structures - Prediction and Compensation." 1 An example of column shortening monitored during the construction is shown in Fig. 14.

## 9. STRUCTURAL SYSTEM AND PROPOSED ERECTION METHOD OF SKYBRIDGE

The 50 meter long, 2 story high skybridge connecting the two towers commands a good view and allows high occupancy levels 40 - 43 to be evacuated via a pair of stairs at each tower. The designers, however, had to account for anticipated along-wind and crosswind movements. Such movements were considered in designing of a two-hinged arch supporting a pair of two-span continuous girders. The arch springs from supports at the 29th floor, rises skew to the mid span of girders at the level 41. The skybridge main body is composed of the walkways framing at level 41, 42 and roof framing at level 43 with beams moment connected to pipe columns that bear on the girders. Continuous expansion joints occur through levels 42 and 43 to each side of the bridge midpoint.

Allowance has been made for longitudinal movement of the towers both towards and away from each other using expansion joints at the tower edges equipped with a steel plate hinged to the bridge and bearing on a sliding pad. When the towers move toward each other, the arch angle steepens, the legs rotate on spherical bearings at the spring points and the bridge floor slightly humps. A centering pin between the crown and the girders holds the bridge in position.

The following skybridge erection criteria is given by the design engineer.

— Wind load on the skybridge per wind tunnel tests is 1.5 kPa (about 30 psf) on both
— the walkway walls and on the individual legs.
— The legs vertically against the tower will have multiple tiebacks and will be lowered
— to final position only when the air is calm.
— Towers each move up to 320 mm at level 41 for maximum wind conditions, so they
— could move apart up to 640 mm, or together 640 mm.
— If towers move out-of-phase in their long axes, they could offset up to 640 mm, and
— any structure connecting them would swing a bit less than 1 degree relative to the
— tower itself.
— If towers move sideways the same direction, there will be an angle change between
— tower wall and connecting bridge.
— As towers move, any cable stretching between tower and bolted-up arch leg would
— experience a change of horizontal distance of up to 320 mm which mean it is
— essential that the temporary bridge end connections to the towers allow guided in-out
— slip, horizontal end rotation and vertical end rotation.

The brief proposed erection method of skybridge is as follows.

— Step 1—The column mounted strand jacks are installed at two towers and these are then utilised to install two preassembled end blocks in approx. 100 mm above final position at level 42 and level 43.

— Step 2—The bottom legs are preassembled, installed and fixed vertically at level 29.
— Step 3—The central block and top legs are preassembled, lifted and located to their
— final level to match the installed end blocks.
— Step 4—The end blocks are horizontally shifted in the final location and spliced to
— the central block.
— Step 5—After the bottom legs held temporary are inclined towards skybridge center
— Step 4—The end blocks are horizontally shifted in the final location and spliced to
— line, positioned in final orientation and the central block splice welds are completed,
— Step 4—The end blocks are horizontally shifted in the final location and spliced to
— the skybridge is lowered by 100 mm on to its bearings on level 41. Immediately
— Step 4—The end blocks are horizontally shifted in the final location and spliced to
— before contacting the inclined legs, discrepancies in relative levels and/or out of plane
— Step 4—The end blocks are horizontally shifted in the final location and spliced to
— alignments are shimmed.

## 10. CONCLUSION

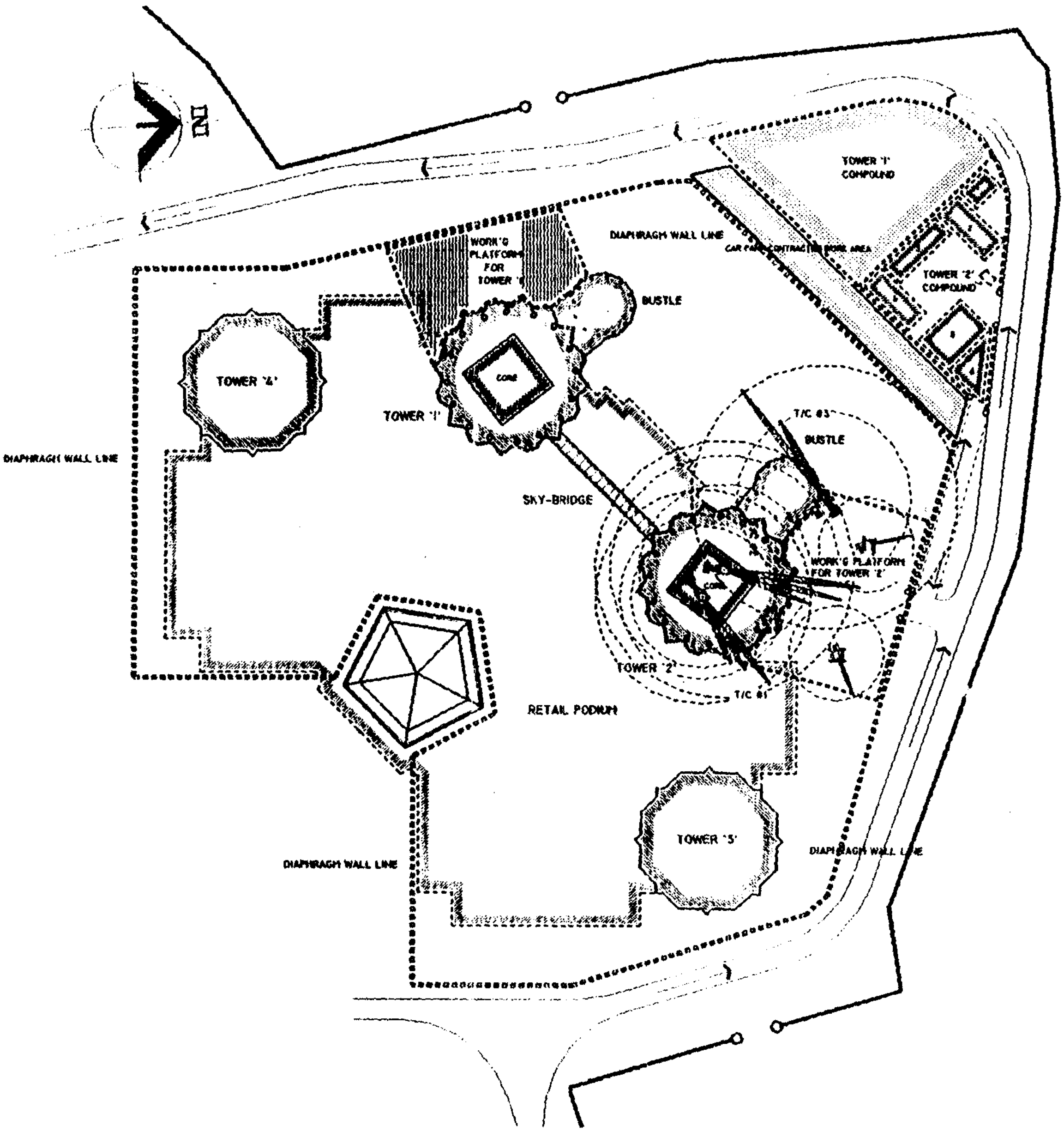
The construction of KLCC Petronas Towers, the tallest buildings in the world is currently proceeding (Fig. 15). State-of-the-art technology available is being utilized for this project to meet the tight schedule presently planned for June of 1996. If completed, these twin towers will no doubt give a great deal of prestige and pride to the owner, designer, builder and all the parties involved. Their devotion to this monumental project will be long remembered in history.

## REFERENCES

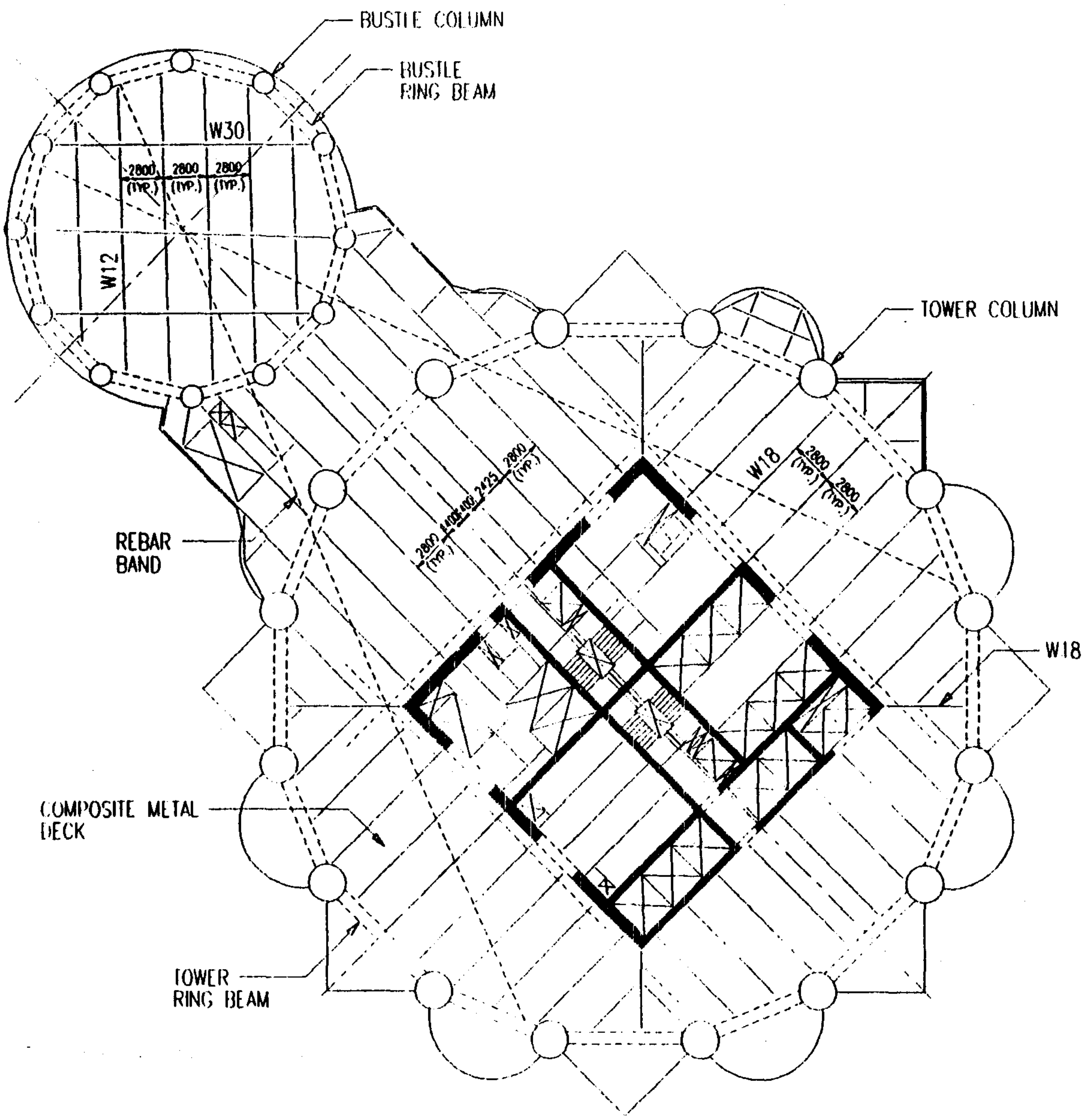
1. Fintel, M., Ghosh, S. K., and Iyengar H. "Column Shortening in Tall Structures –Prediction and Compensation", Portland Cement Association, Skokie, IL., 1987, 35pages.

2. Robinson, R., "Malaysia twins: High-rise, High strength," Civil Engineering, ASCE, New York, NY, July 1994, page 65

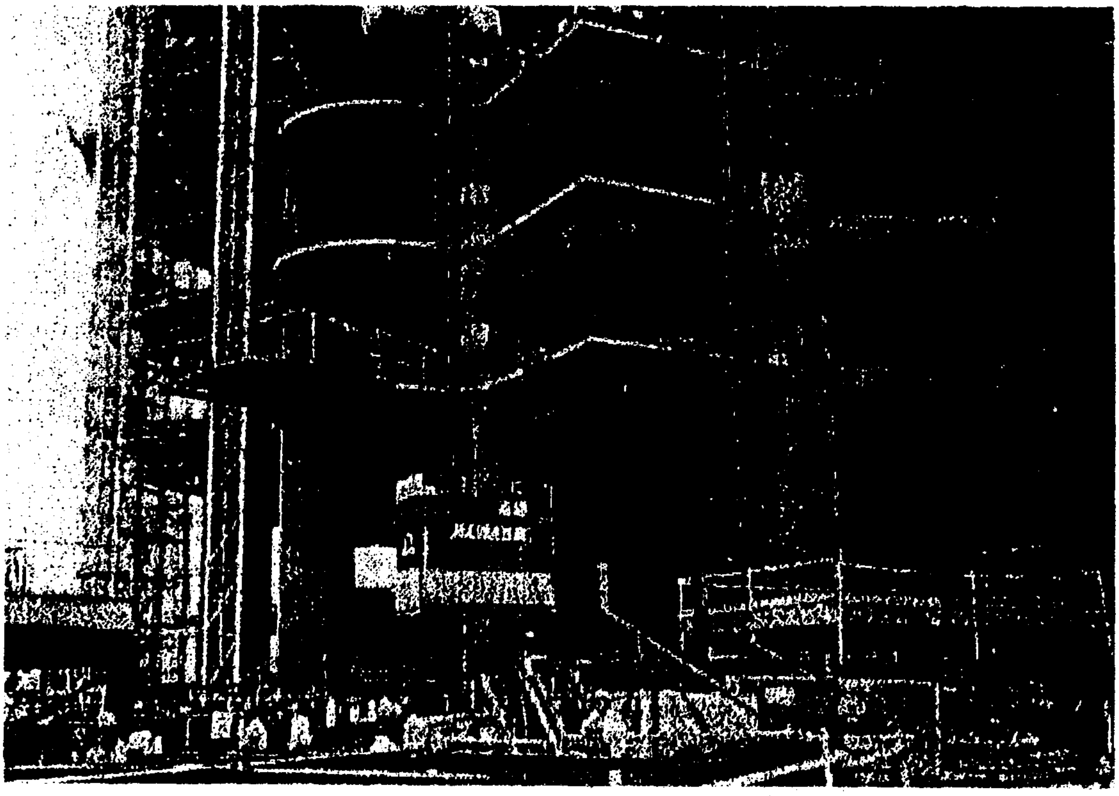
〈그림 1〉 KLCC Towers




〈그림 2〉 Site Plan




〈그림 3〉 Typical Floor Framing Plan

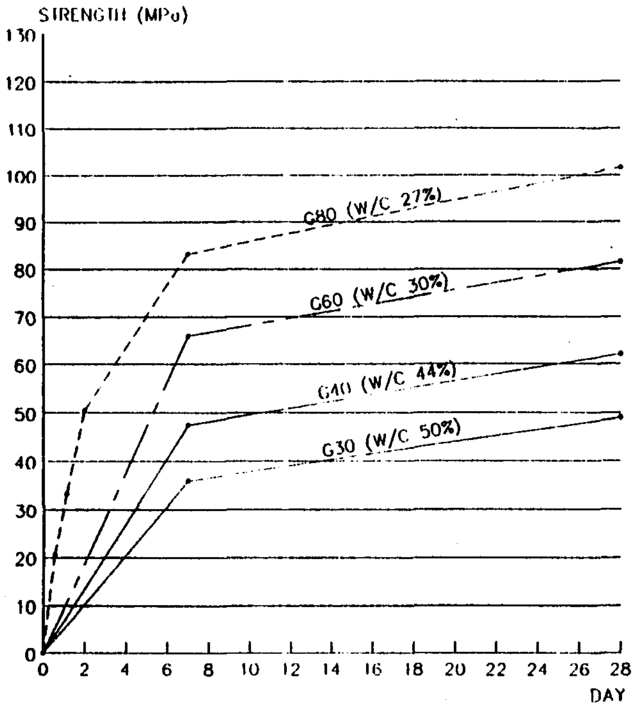


〈그림 4〉 Alternate Pointed Projection

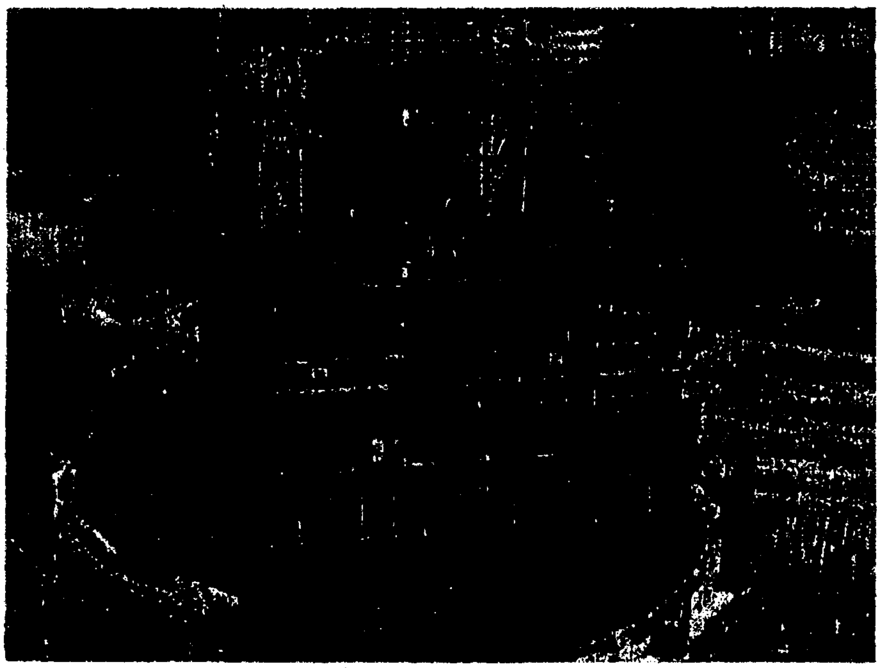
Table 1. Concrete Mix Designs

| Grade (MPa) (%) | W/C (%) | S/A (%) | Cement (kg) | Mascrete (kg) | Silica Fume | Water (kg) | C. Aggre-gate (kg) | F. Aggre-gate (kg) |
|---|---|---|---|---|---|---|---|---|
| 80 | 27 | 40 | 184 | 345 | 35 | 152 | 1040 | 694 |
| 60 | 30 | 44 | 500 | | | 150 | 1000 | 785 |
| 40 | 44 | 44 | 400 | | | 180 | 1000 | 775 |
| 30 | 50 | 45 | 360 | | | 180 | 1000 | 810 |

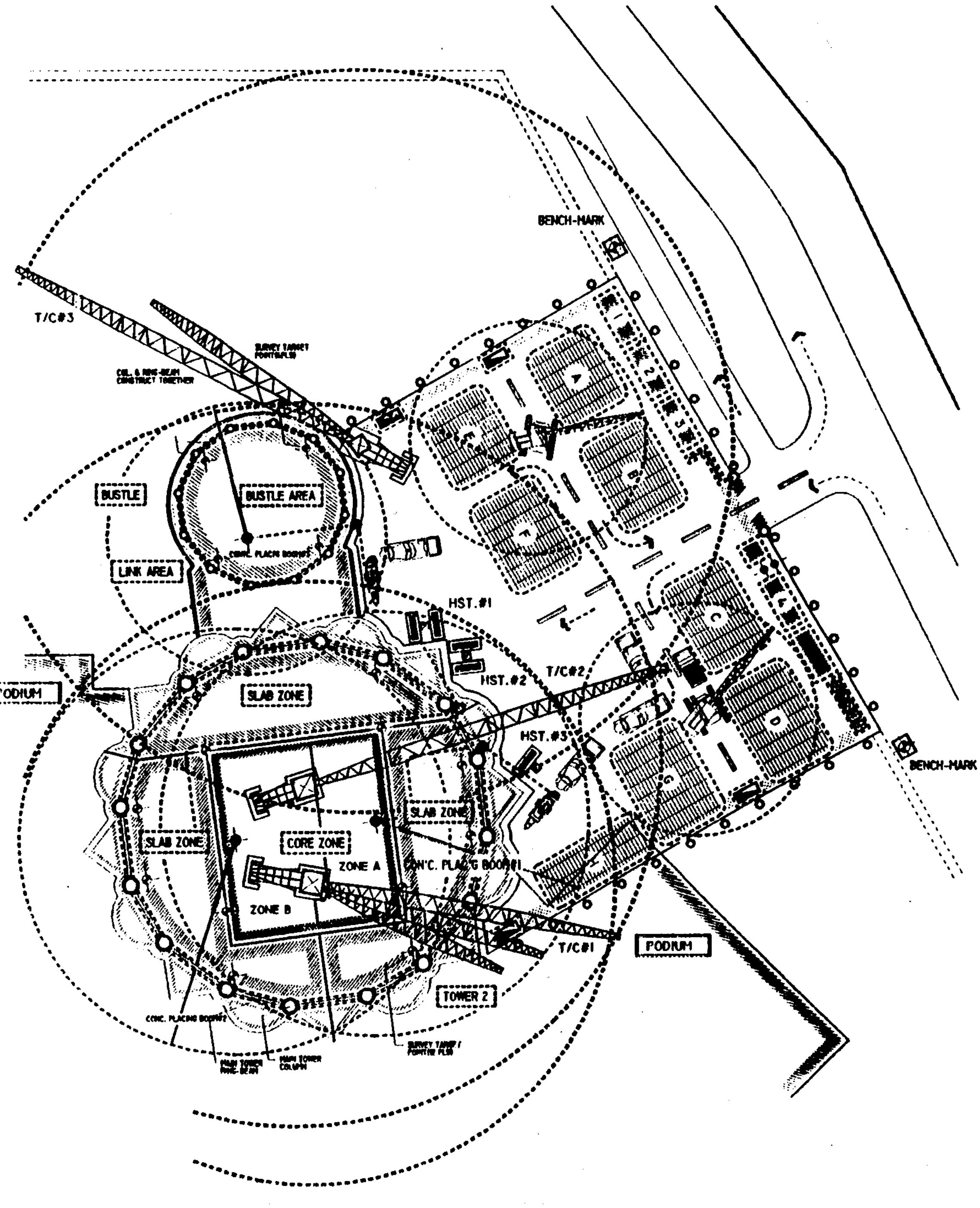
| Grade (MPa) (%) | Admixture | | Slump | Strength(Cube) MPa | | | | |
|---|---|---|---|---|---|---|---|---|
| | P300N | R1000 | (mm) | 12HR | 24HR | 48HR | 7DAY | 28DAY |
| 80 | 0.80 | 8.50 | 200+40, −20 | 21.3 | 33.4 | 50.4 | 83.2 | 101.9 |
| 60 | 1.00 | 5.50 | 200+40, −20 | | | | 66.0 | 81.4 |
| 40 | 1.20 | 0.80 | 200±25 | | | | 47.5 | 62.1 |
| 30 | 0.90 | 0.54 | 175±25 | | | | 36.0 | 49.0 |



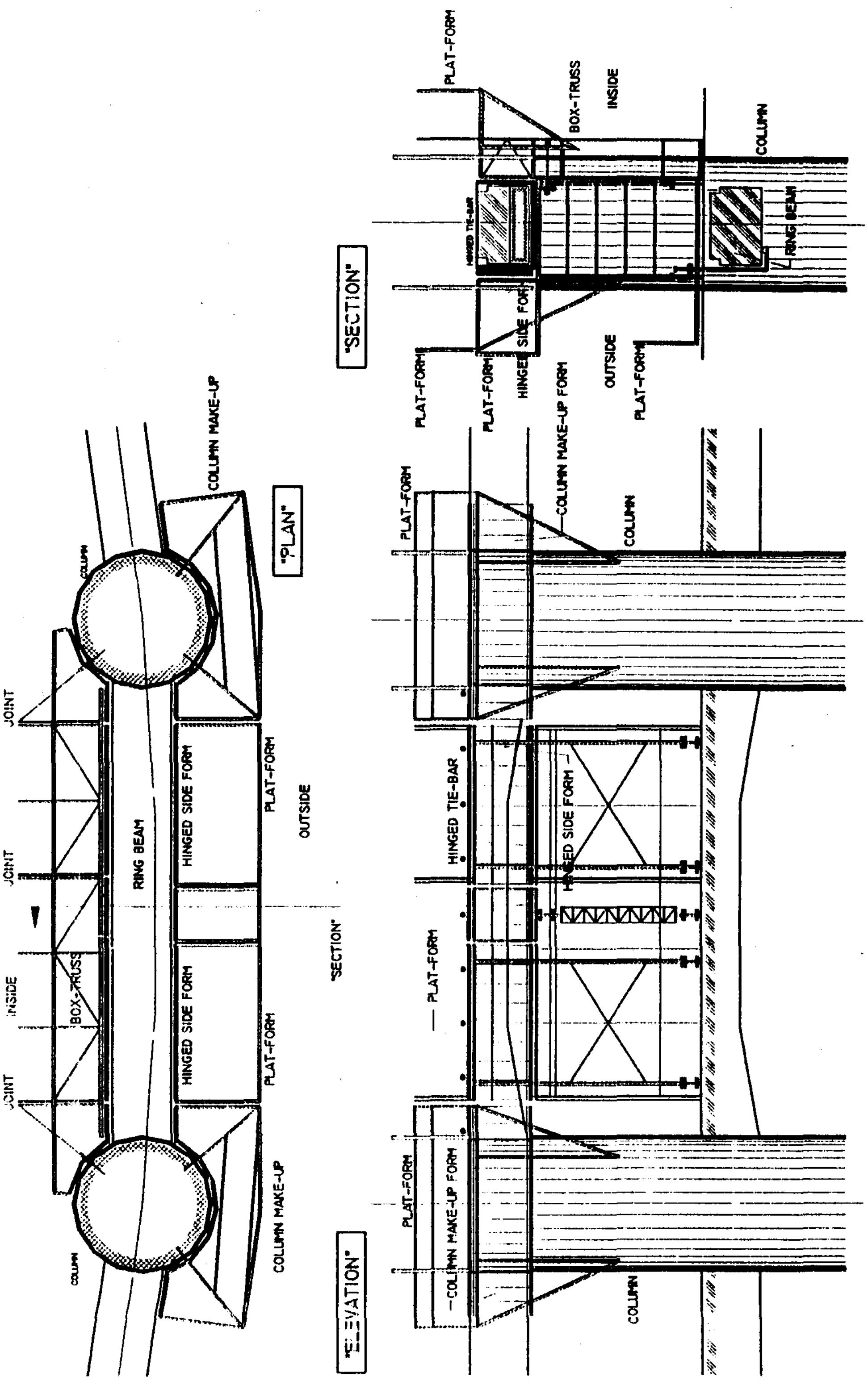

〈그림 5〉 Concrete cube strength test



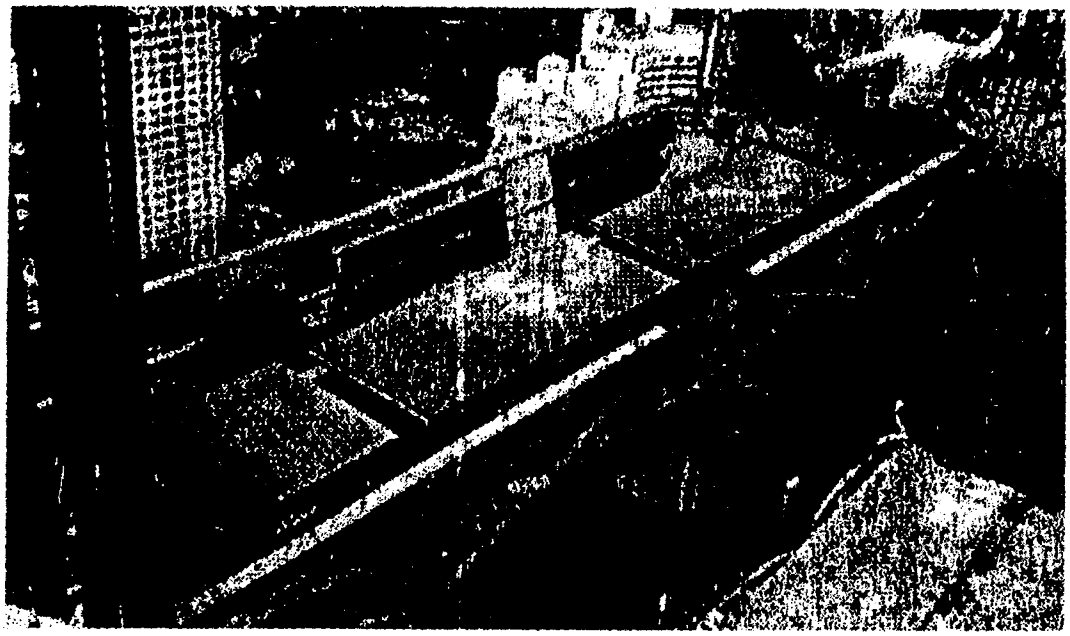
〈그림 6〉 Self-Climbing Form(with Placing Boom)



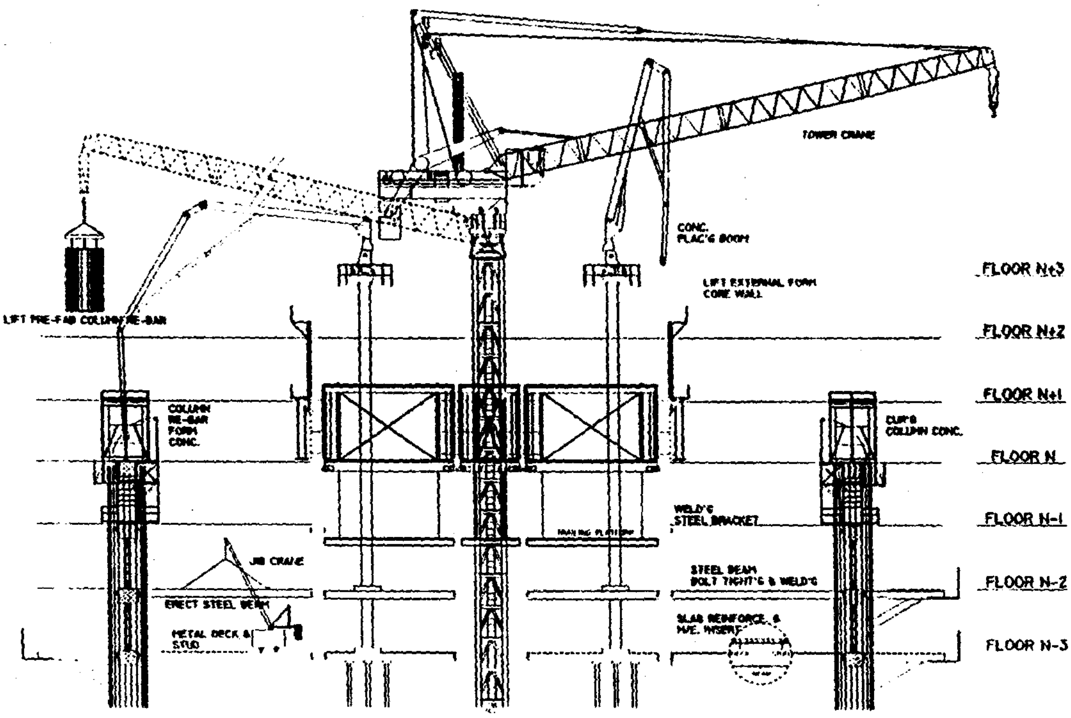

〈그림 7〉 Tower Crane



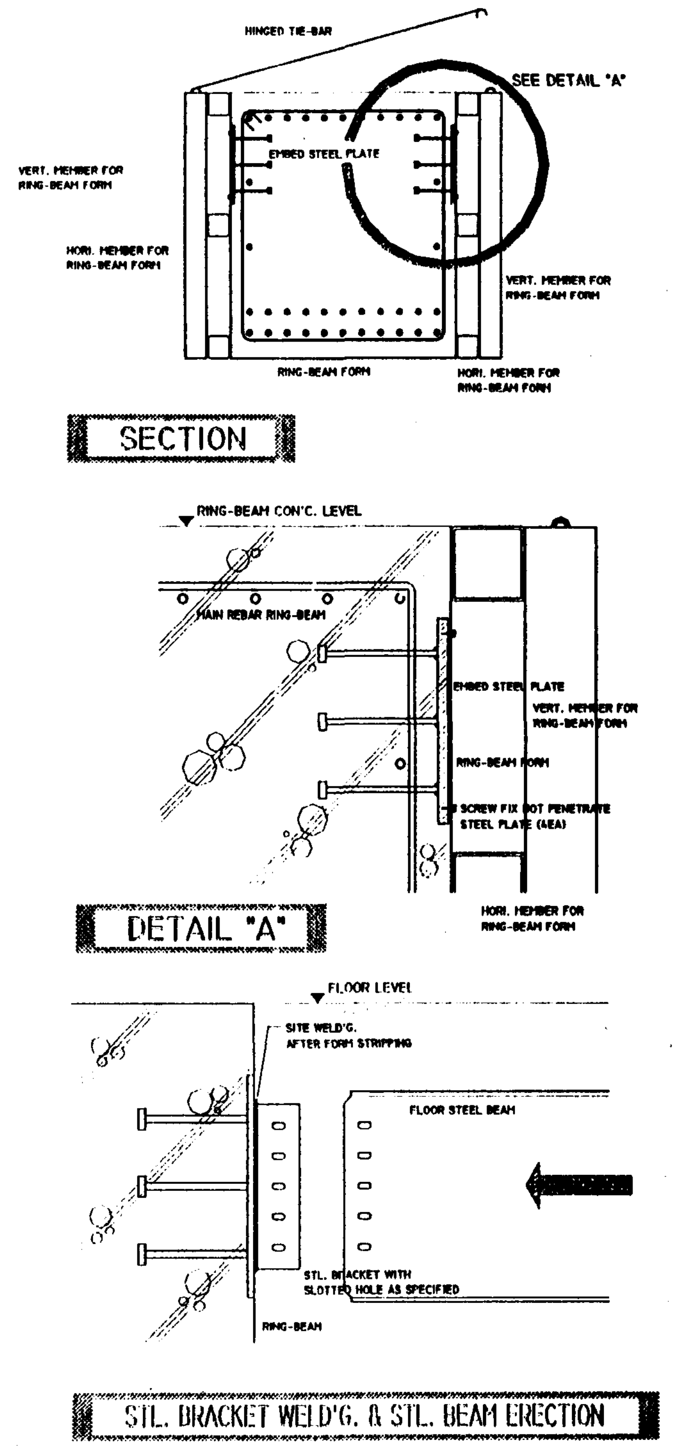

〈그림 8〉 Column Jump Form



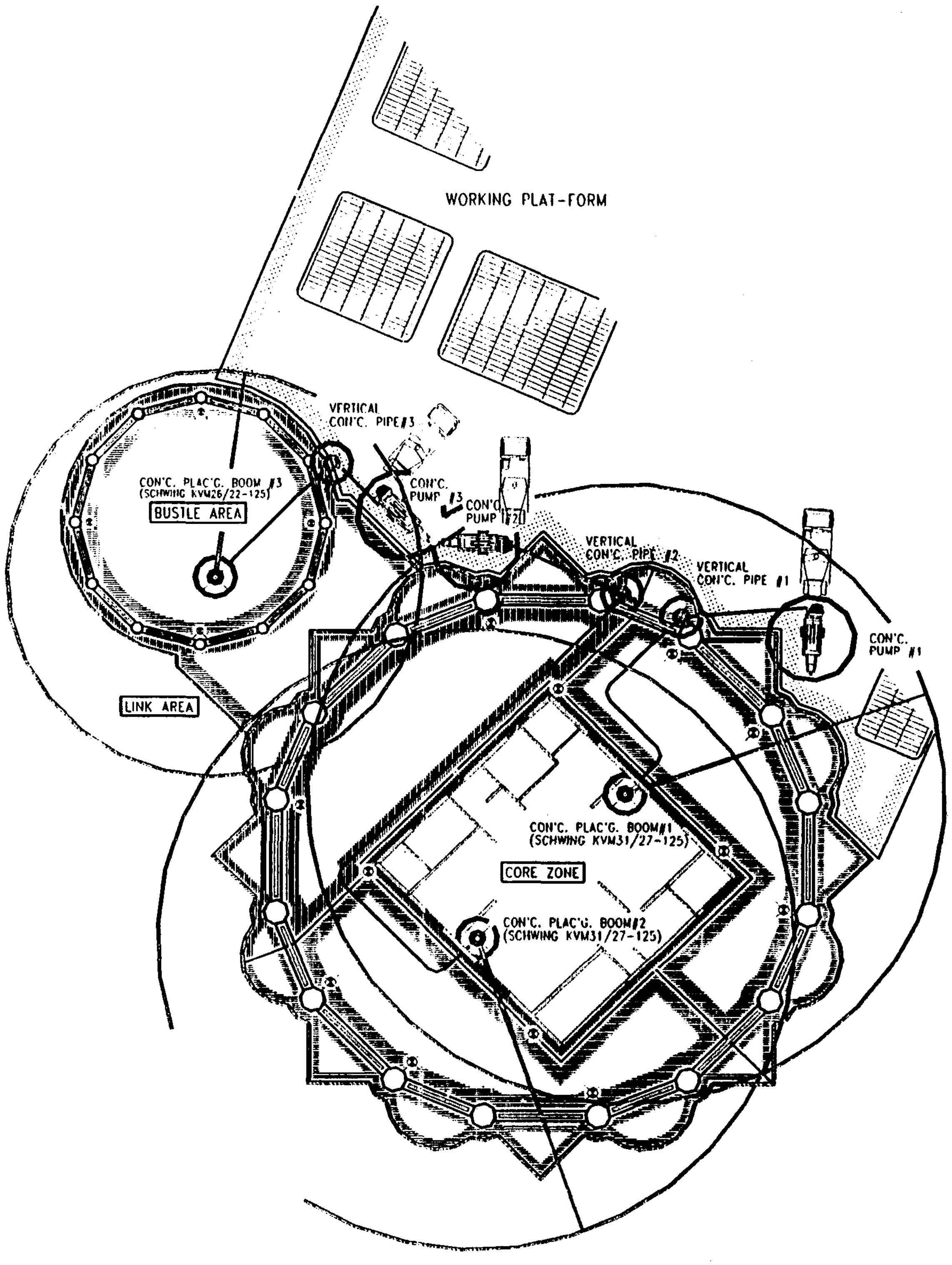
〈그림 9〉 Ring Beam Jump Form



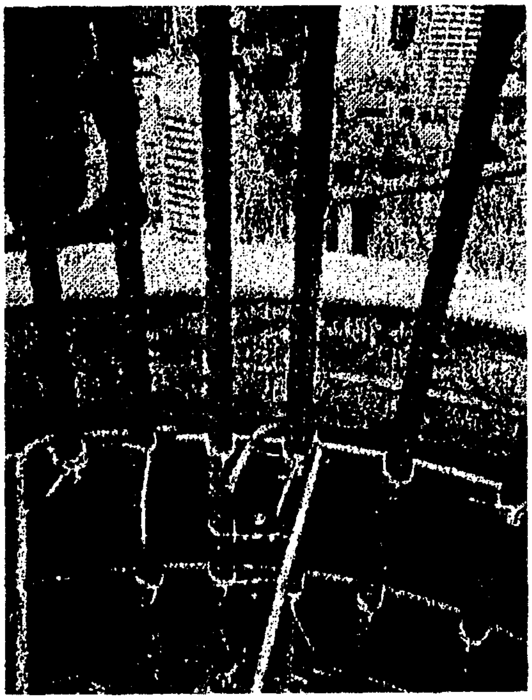

〈그림 10〉 Construction Activity




〈그림 11〉 Embed. Steel Plate & Steel Beam Connection



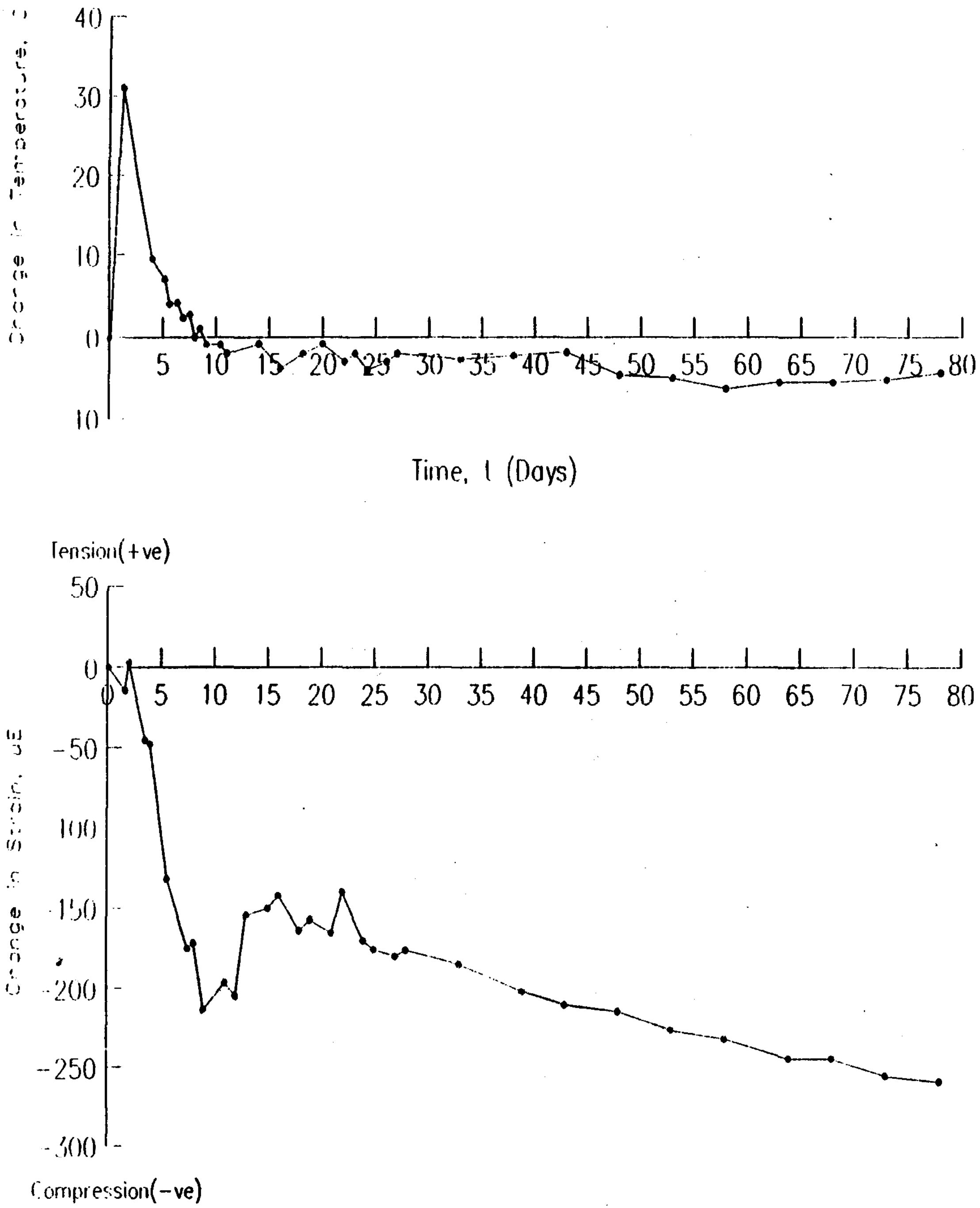

〈그림 12〉 Concrete Placing System



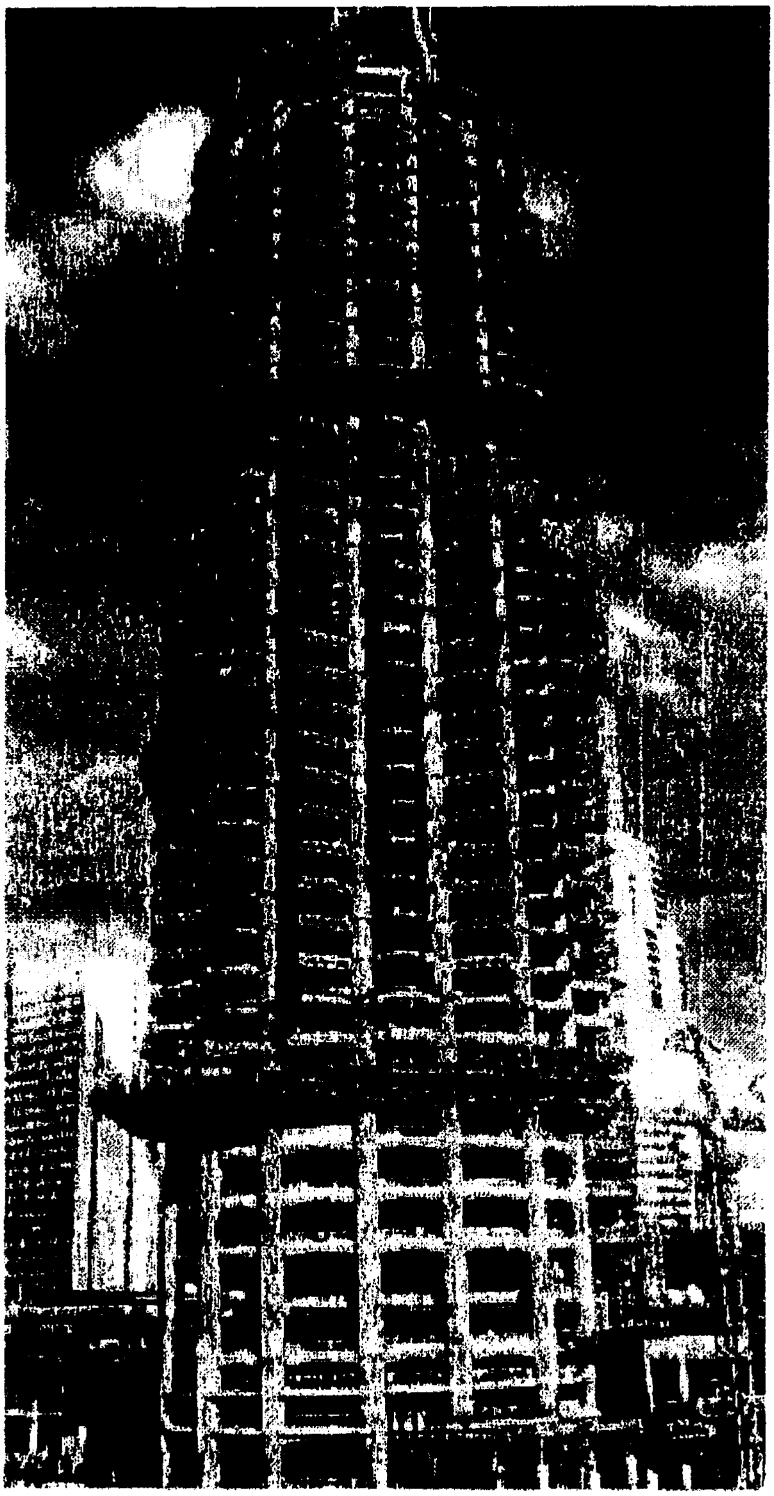
〈그림 13 a〉 Strain Gage at Tower Column before Connection of Cables.

〈그림 13 b〉 Strain Gage installed between Rebars at Corewal.

〈그림 13〉 Strain Gages at Tower Column & Corewall.




〈그림 14〉 Plot of Change of Temperature, C and Change in Strain uE Against Time for Tower Column@ Street level.



〈그림 15〉 Tower under Construction