

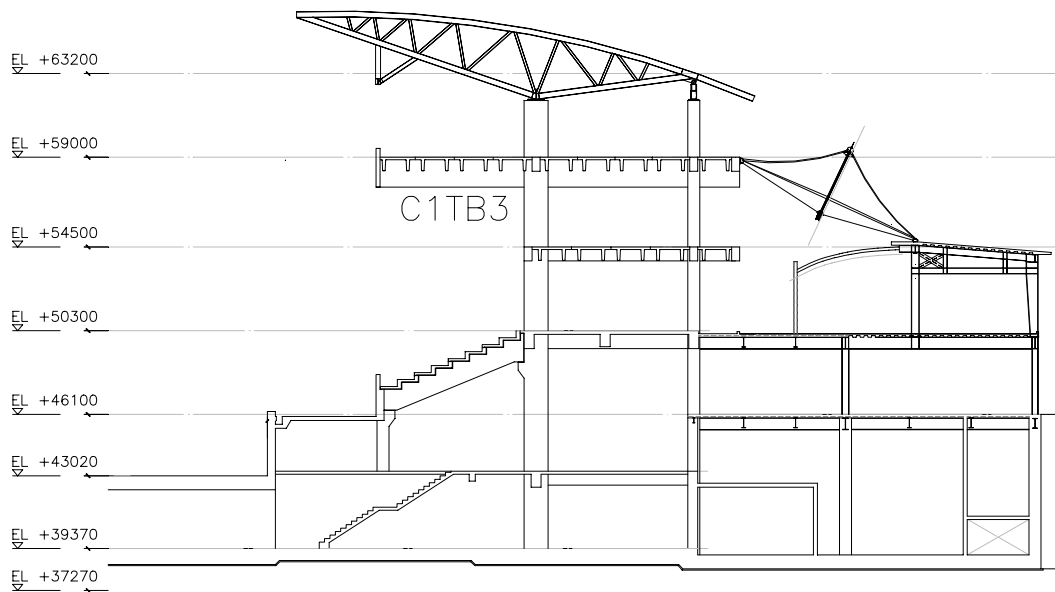
# THE DESIGN OF LONG CANTILEVER BEAM USING POST-TENSIONED TENDONS IN KUMJUNG STADIUM

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## 1 INTRODUCTION

The 2002 Asian Olympic Stadium (mainly intended for cycle racing) that will open in Pusan, Korea, is a structure with one story below and four above the ground. It has a seating capacity of about 20,000 spectators. The structure has seats for general spectators from the 1st floor to 3rd floor. The VIP seating is on the fourth floor. At first, this stadium was designed as a structure with one story below and two above the ground. After this game (Asian Olympic Game), there will be a change in the bicycle race track. This is designed as a reinforced concrete and steel system from one story below to two above the ground. A precast/prestressed concrete system from the column of the 2nd story above of it was built because of design modifications. Fig. 1 shows a typical section through the structure.



**Fig 1** A typical section through the structure

## 2 SELECTION OF SYSTEM

The key point of this project under design modification was construction in a short amount of time. Additionally, table 1 makes a comparison between reinforced concrete, steel and precast/prestressed concrete systems taking into consideration the cost of construction and serviceability by vibration and displacement. As a result of comparing each system, reinforced concrete and precast/prestressed concrete have a cost advantage in construction, while steel and precast/prestressed concrete can be built in a short time. Especially the serviceability of 8m cantilever beam was a careful consideration. In

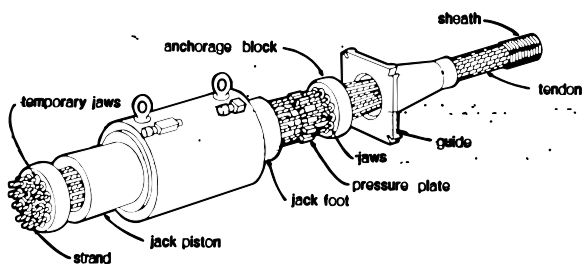
cases using post-tensioning in such aspects, a prestressed one had advantage in serviceability. Therefore, it was designed as prestressed one that is the best in regards to time and cost of construction and serviceability

**Table 1** The comparison of reinforced concrete, steel and precast concrete

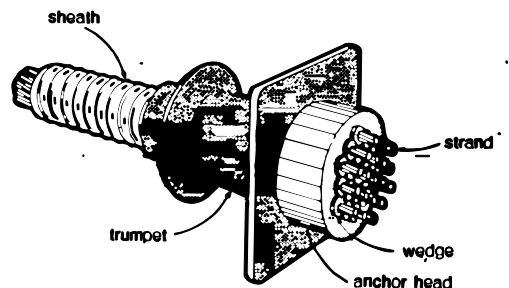
	RC	Steel	PC
<b>Construction</b>	<ul style="list-style-type: none"> <li>•Need long time for construction because it is a site process</li> <li>•Difficulty of using a concrete form due to high place</li> <li>•Quality of construction isn't uniform</li> <li>•Need temporary supports</li> </ul>	<ul style="list-style-type: none"> <li>• Shorter construction time because it is a prefabricated process</li> <li>•Need fire-resisting cover</li> <li>•No need for temporary supports and form</li> </ul>	<ul style="list-style-type: none"> <li>• Shorter construction time because it is a prefabricated process</li> <li>•No need for fire-resisting cover</li> <li>•Can provide PC members of good quality at Korea plant</li> <li>•Superior to durability due to use of high strength concrete</li> </ul>
<b>Cost</b>	•Low-priced structure system	•High-priced structure system	•Middle-priced structure system dependent on the number of time used
<b>Serviceability</b>	•Advantageous in serviceability by vibration and displacement	•Disadvantageous in serviceability by vibration and displacement	•Most Advantageous in serviceability by vibration and displacement by post-tension
<b>Assessment</b>	•Proper	•Proper	•Best

### 3 EQUIPMENT USED IN POST-TENSIONING

Different from pre-tension system, post-tension system needs jacking equipment and anchorage components. Fig. 2 is a jacking piston and tool that needs tensioning. Fig 3 is an anchorage detail used in a multi-strand system. In addition, strand, sheath pipe and grouting are a Korea components



**Fig. 2** Jacking and anchorage components



**Fig. 3** Anchorage detail

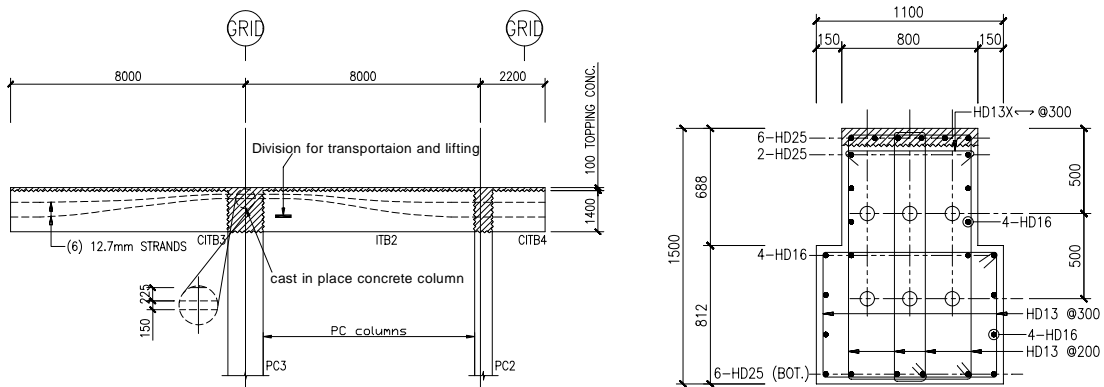
### 4 DESIGN OF LONG CANTILEVER BEAM

The aspect that was the most difficult in the design of this structure was the 8m long cantilever beam. The reason of using Post-tension for its design was described above. This section will explain about the load of each step, prestress loss and the method of design separately.

#### 4.1 Design load

It was taken account of the stability of building about the load of every step under construction as well as dead load and live load of the fourth floor. Especially, if it is produced as a monolithic member in a horizontal direction because the section is 800mm wide and 1500mm deep, there is a problem in lifting it. For that reason, it was divided in the top of columns (see Fig. 4). The construction sequence

taken into account is as follows.



**Fig.4** Elevation and section of long cantilever beam

The construction's sequence that took into account is as follows.

- Installation of PC column in 3rd floor.
- Installation of PC beam(including 8m long cantilever beam) over PC column.
- Concrete pouring in connection between column and beam in the field.
- Post-tensioning.
- Grouting in the sheath pipe.
- Installation of DTS(Double Tee Slab).
- Topping concrete pouring.

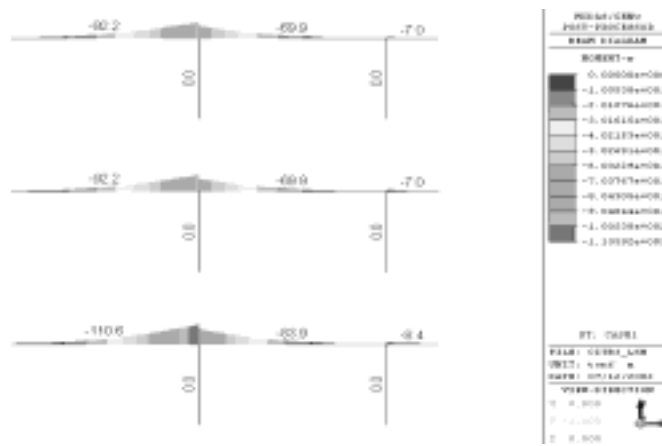
The construction sequence is divided in Self-load step, Superimposed-load step and Live-load step. The load condition and values of every step are described as Table2

**Table 2** Load condition and value at every step

Construction sequence	Load condition	Load value (tonf/m)
Self load	A condition that install PC cantilever beam	3.30
Superimposed load	A condition that construct of topping concrete after the installation of DTS	5.64
Live load	A condition of final live load	4.00

**4.2 Stress of member in every construction step**

The tool of analysis is MIDAS GEN. Fig. 5 shows the bending moment diagram of C1TB3 that is the longest member.



**Fig.5** Bending moment diagram of C1TB3

### 4.3 Design of cantilever beam post-tensioned

#### 4.3.1 Prestress Loss

Anchorage loss, friction, relaxation and shortening in member post-tensioned was considered. The equation is

$$\Delta f_{pT} = \Delta f_{pA} + \Delta f_{pF} + \Delta f_{pR} + \Delta f_{pS} \quad (1)$$

- A: Anchorage seating loss
- B: Friction
- R: Relaxation of tendon
- S: Shortening of concrete

The prestress loss by seating of the wedges can be written in the same form as Eq. 2. Through this, we can get the length of tendon affected by anchorage and force variation after anchor set. The equation is

$$\Delta P = 2Pl_{set} \quad (2)$$

$P$  : friction loss

$l_{set}$  : length of tendon affected by anchorage

The curvature coefficient and wobble coefficient in this design is as follows.

$$\mu = 0.2$$

$$k = 0.002$$

In addition, the prestress loss by relaxation and shortening (elastic, creep, shrinkage) is suggested in 15% of jacking force.

#### 4.3.2 Service-Load Design

The stress of CITB3 is described above. The design method took into account curvature coefficient, wobble coefficient and affection of seating of the wedges as described in Fig. 6. During post-tensioning it was permitted to stress the tendon to a maximum of about 80% of the specified tensile strength of the tendon.

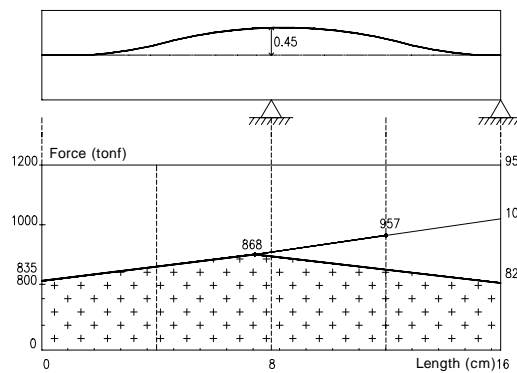


Fig. 6 Fiction loss diagram

Table 3 Frictional loss calculation

e(m)		0.45	0
$e \sum \mu\alpha + kx$		0.827	0.86
Stress at Transfer	P/A (tonf/cm <sup>2</sup> )	69.62	79.81
	ft (tonf/cm <sup>2</sup> )	125.32	0
	fb (tonf/cm <sup>2</sup> )	-125.32	0
Effective Stress after losses	P/A(tonf/cm <sup>2</sup> )	59.18	67
	ft (tonf/cm <sup>2</sup> )	106.52	0
	fb (tonf/cm <sup>2</sup> )	-106.52	0
Service-load final stress	ft (tonf/cm <sup>2</sup> )	-12.4 ( O.K)	56.7( O.K)
	fb (tonf/cm <sup>2</sup> )	130.8 ( O.K)	64.7( O.K)

After prestress loss, stress in service-load condition is usually limited to values shown in Table 3 in accordance with "Concrete Design Code(Korea, 1999)"

Table 4 Allowable stress in compression and tension

Extreme fiber stress in compression	$0.4 f'_c$
Extreme fiber stress in tension	$1.6\sqrt{f'_c}$

As a result of considering bending stress in every construction step, it is acceptable.

#### 4.3.3 Ultimate-Strength Design

In the design of all prestressed concrete members it is necessary to consider the different stages in

the life of a member. Additionally, there is a need to check a member by the ultimate strength design. The value of the stress  $f_{ps}$  of the prestressing steel can be determined by strain compatibility through the various loading stages up to the limit state at failure. The empirical expression for bonded members is

$$f_{ps} = f_{pu} \left[ 1 - \frac{\gamma_p}{\beta_1} \left\{ \rho_p \frac{f_{pu}}{f'_c} + \frac{d}{dp} (\omega - \omega') \right\} \right] \quad (3)$$

The cantilever beam is made of concrete with a compression strength of  $400\text{kg/cm}^2$  and 6-D25 bars with a yield strength of  $4000\text{kg/cm}^2$ . The design moment capacity by ultimate-strength design is the same as in Table 4.

**Table 5** Design moment capacity

$M_u$	801.66 t m
$F_{ps}$	12,072 $\text{kg/cm}^2$
$\Phi M_n$	1215.62 t m

#### 4.4 Vibration and displacement

VIP seats resisted by cantilever beam must be considered in serviceability; vibration and displacement. The codes are those used in the PCI Design Handbook(4th Edition). The values of Table 5 and Table 6 are about vibration and displacement. The natural frequency of member is a value of eigenvalue analysis by MIDAS GEN.

**Table 6** The vibrations of member

Natural Frequency of Member	Required Natural Frequency				Remarks
	Minimum Required Natural Frequency	Forcing Frequency	Acceleration Limit % Gravity	Dynamic Load Factor	
5.46Hz	1.67Hz	1.5Hz	5.0%	0.25	1st frequency
	3.33Hz	3Hz	5.0%	0.25	
	3.07Hz	3Hz	5.0%	0.05	2nd frequency
	5.12Hz	5Hz	5.0%	0.05	

As a result of checking vibration as above, this is acceptable because the natural frequency of member (5.46Hz) is higher than minimum required natural frequency (5.12Hz).

**Table 7** The displacements of member

	Release (cm)	Multiplier	Erection (cm)	Multiplier	Final (cm)
Prestress	0.810 ↑	1.8	1.458 ↑	2.2	1.782 ↑
$w_d$	0.280 ↓	1.85	0.518 ↑	2.4	0.672 ↓
	0.530 ↑		0.940 ↑		1.110 ↑
$w_{sd}$			0.460 ↓	3.0	1.380 ↓
			0.480 ↑		0.270 ↓
$w_l$					0.500 ↓
					0.770 ↓

As a result of checking displacement as above, the final displacement of the cantilever beam is 0.77cm. The allowable displacement of structure resisting dynamic load is  $L/300 (=2.67\text{cm})$ . This is acceptable.

## 5 CONCLUSION

The key point of design in this structure is the 8m long cantilever beam. Key considerations are time and cost of construction and serviceability. The condition of construction now is after DTS and topping concrete installation. There is a need to check additional stress by live load and serviceability by vibration continuously.

Consequently, a cantilever beam is designed with an effective section that could control vibration and displacement by post-tensioning. The Fig. 7 shows constructed cantilever beam.



**Fig. 7** Long Cantilever beam constructed

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