Application of High Performance Concrete on a 85-story High Rise Building in Taiwan

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ABSTRACT

High Performance Concrete (HPC) has become a potential research topic of construction automation due to its cost effectiveness, laborer reduction, productivity improvement and high quality of concrete pouring on construction fields. HPC not only has the characteristics of traditional high strength concrete, but also high flowability, workability , durability, as well as high resistance to segregation. HPC can be placed in heavily reinforced formwork without applying vibrators and save substantial amount of labor requirement. A 85-story high rise building is currently being built in the Kaohsiung city in south Taiwan. To reduce the steel amount required for column boxes as well as ease the placing and vibrating concrete into these steel column boxes, 16,000 m^3 of high performance concrete with compressive strength of 560 kg/cm^2 and slump of 25 cm. are designed to be filled in these steel column boxes. The high performance concrete demonstrates excellent workability, flowability, and required compressive strength. The steel column boxes are filled with HPC by a upward filling process without vibrators. The use of HPC in the 85-story high rise building not only solve the filling difficulty and produce a high quality concrete, but also save substantial material cost and labor requirement. This paper presents experience of HPC and its application to a 85-story high rise building. The successfully utilization of HPC in Taiwan encourages more research and utilization of HPC in the future.

1. Introduction

The main objectives of construction automation are to improve productivity, quality, safety and reduce labor requirement on the.construction site. High Performance Concrete (HPC) has become a potential research topic of construction automation due to its cost effectiveness, laborer reduction, productivity improvement and high quality of concrete pouring on construction site. HPC not only has the characteristics of traditional high strength concrete, but also high flowability, workability , durability, as well as high resistance to segregation [3,4,6]. HPC can be placed in heavily reinforced formwork without applying vibrators and save substantial amount of labor requirement. Past experience of construction automation had developed articulated boom and automated vibrator for pouring concrete to reduce intensive labor requirement and increase productivity on construction site. However, the improvement of concrete material itself, HPC, has more direct impacts and influences on the objectives of construction automation.

High performance concrete has been developed and utilized in many construction projects during the last decade. The U.S.A., France and many European countries have began a lot of research and implementation of high performance concrete [1,2,5,7,9]. Japanese construction companies have also developed various types of high performance concrete such as NEURO-CRETE and BIO-CRETE [8]. In Taiwan, the first time that high performance concrete been developed and utilized was in the Far East Trade Center project which contains 5 stories below ground and 43 stories above ground and was completed in 1994. The HPC used for the Far East Trade Center was designed as f'c=420 kg/cm^2 and with a slump of 25 cm. The Far East Trade Center is located in the Taipei city not far from the National Taiwan University. High performance concrete was pump into the steel column through a reserved nipple hole on the steel column box. The success of utilizing HPC in the Far East Trade Center encouraged more practical implementations of HPC for high rise building in Taiwan.

2. T&C Tower Project

The T&C tower building is the second project that HPC was utilized and implemented in Taiwan. The T&C tower is located in the Kaohsiung city in south Taiwan with 5 stories below ground and 85 stories above ground. The total height of this high rise building is 347.6m above ground. It will become the highest building in Taiwan when it is completed in 1997. The T&C tower project is designed by the T.Y.Lin Consultant Company and the general contractor is Han-Luh Construction Company. The high performance concrete utilized in this project is developed by the Han-Luh Construction Company incorporated with the Hsin-Nan Cement Company. The basic design of the T&C tower adapted a 100-year regression period of ground surface acceleration for 0.21g and a 50-year regression period of wind velocity for 40.7 m/sec.

The T&C tower is designed as a eccentric supported steel structure (figure 1). The total steel amount required for this project is about 44,000 tons. To increase the stiffness of the steel structure and reduce the amount of steel needed for this project, all the hollow steel boxes below the 60th floor are designed to be filled with high performance concrete. The major steel frame structure of the T&C tower consists of ten core wall blocks which contain forty steel column boxes with filled-in concrete to support the heavy load of the whole building (figure 2). A lot of steel plate stiffeners are designed in these steel column boxes to resist lateral wind load and thus results in the difficulty of filling, vibrating, and compacting concrete in these steel column boxes (figure 3). To reduce the heavy weight of concrete itself as well as ease the placing and vibrating concrete into these steel column boxes, 16,000 m^3 of high performance concrete are designed to be filled in these steel column boxes.

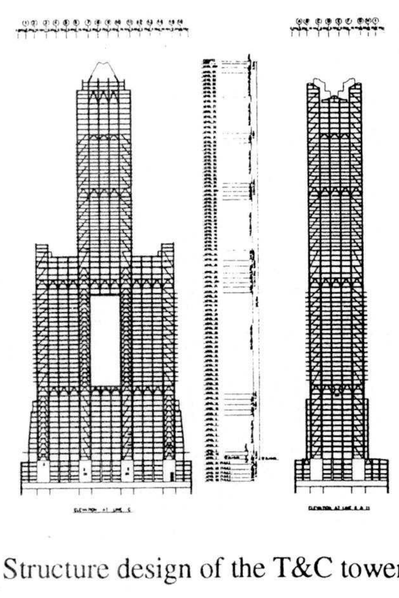

Figure 1 Structure design of the T&C tower

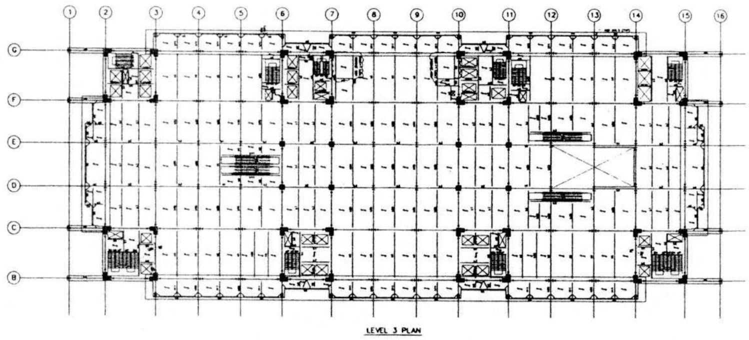

Figure 2 Steel column boxes layout of the T&C tower

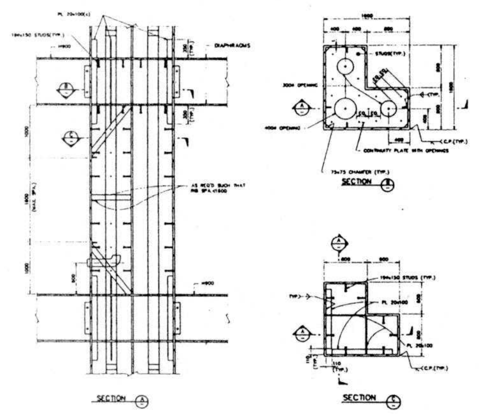

Figure 3 Detail design of the steel column box

3. Design specification and Quality Assurance

The design specifications for the high performance concrete in the T&C tower include:

1. compressive strength f'c=560 kg/cm^2 (56 days of age)
2. slump = 25 $\pm$ 2 cm. during 45 minutes after mixing.
3. water reduce agent, super plasticizer and pozzolanic material are allowed to reduce water amount and increase compressive strength.
4. the air bubble content measured under the lateral steel plate stiffener in the steel column box cannot be greater than 5% of the area of the lateral steel plate stiffener.

The materials and mix proportions are outlined in Table 1.

Table 1 Mix proportion for HPC

Material	Cement	Coarse Aggregate	Sand	Water	Fly ash	Super Plasticizer	Slag
Mix proportion kg / m^3	358	942	801	154	141	11	19

The T&C tower is the first project that HPC with f'c=560 kg/cm^2 been utilized in Taiwan. Since the HPC is filled in the steel column boxes, it is difficult to observe the appearance of concrete and evaluate the quality of HPC. The quality control and assurance of HPC become significant and essential for this project. To control the quality assurance of HPC in the T&C tower project, several requirements are specified in the contract:

1. The contractor should schedule a 6-month period for tests and experiments of HPC. These tests should include trial mix, field test, slump lost test, shrinkage test, and other concrete property tests. All the results related to the stability of HPC, such as moisture content, humidity and temperature must be recorded into a database for reference of field operations.
2. The contractor must perform a full-scale mock up test to evaluate the workability of HPC as well as the coordination between field workers and pumping equipment.
3. The contractor must provide emergency plans to cope with any incidents that might occur during field operation. The possible incidents may include equipment breakdown, interruption of concrete delivery, failure of concrete to meet the design specifications and other quality control issues. Procedures to deal with incidents and follow-up actions should be provided in these emergency plans.

4. Field control of HPC

The trial mixing of HPC for the T&C tower project began in July 1993. After the two-story mock-up test have been successfully conducted and demonstrated the excellent quality and workability of HPC, the field operation of filling HPC on the T&C tower project began in July 1994. Currently the T&C tower project is still underway and the utilization of HPC works out very well. To insure the quality of HPC in the filling process, field records and control are important. The control process includes two parts. One is for the delivery of the HPC, another is for the pumping operation. When the transportation truck leaves the pre-mix plant, the transportation time for delivering HPC is recorded. Once the truck arrived the field, slump test and slump flow measurement are conducted, and the temperature of HPC is also recorded as well. If the specification requirements are not fulfilled, the HPC in this truck will be returned. Table 2 shows some field control data for the delivery of HPC.

Table 2 Field control for the delivery of HPC

Truck #	Plate #	Time Leave	Time Arrive	Transp. Time	Slump	Slump Flow	Temperature	Remark
1	550	8:57	9:20	23	26.5	60	31	
2	357	9:10	9:31	21	26.5	64	31	
3	385	9:11	9:37	26	27	63	30	
4	155	9:27	9:45	18	27	65	30	
5	356	9:31	9:50	19	26.5	68	31	
6	250	9:35						Returned
7	746	9:43	10:07	24	27	65	31	
8	328	10:08	10:33	25	27	64	31	
9	507	10:13						Returned
10	238	10:22	10:53	31	26.5	65	31	
11	508	10:28	11:03	35	26	64	31	
12	885	10:45	11:21	36	27	64	31	
13	545	10:50						Returned
14	251	11:07	11:40	33	28	67	31	
15	219	11:30	11:50	20	27	65	31.5	
16	216	11:43	12:15	32	27	66	31	

The control criteria include a slump with 25 ± 2 cm, a slump flow between 65 ± 5 cm, and the temperature of HPC must be within 31 ± 1°C. The transportation time is about 30 minutes so that the slump flow lost is small enough and can be neglected. The average amount of HPC delivered in a truck is about 8 m^3.

When the field quality test of HPC passes the specification requirements, pumping operation can be conducted. In this part, the volume of HPC, the duration for pumping, and the pumping numbers are all recorded. This data provides essential information for controlling the pumping velocity and volume of HPC. The pumping velocity is about 0.5~1 m^3 /min. and the average is about 0.8 m^3 /min. (Table 3)

Table 3 Field control for the pumping of HPC

Column #	Volume / Cum.	Truck # - Volume	Time Start	Time End	Pump Time	Total Pump #	Pump Velocity
1-14-G	17 / 17	1 - 8m^3 2 - 8 3 - 1	9:45	10:04	18' 59"	179	0.9 m^3/min.
2-14-F	11 / 28	4 - 8 5 - 3	10:23	10:45	21' 03"	187	0.5
3-15-F	13 / 41	5 - 5 7 - 8	10:48	11:05	16' 19"	184	0.8
4-14-C	11 / 52	10 - 8 11 - 3	11:39	11:58	14' 25"	186	0.8
5-15-C	13 / 65	11 - 5 12 - 8	12:00	12:16	15' 34"	185	0.8
6-10-G	15 / 80	14 - 8 15 - 7	12:28	12:44	14' 34"	179	1
7-11-G	13 / 93	15 - 1 16 - 8 17 - 4	12:50	13:06	15' 58"	170	0.8
8-10-F	18 / 111	17 - 4 18 - 8 19 - 6	13:12	13:29	16' 58"	200	1

5. Implementation evaluation of HPC

The utilization of high performance concrete in the T&C tower project has several beneficial impacts:

1. The fundamental period of this structure is decreased from 5.85 sec. to 5.08 sec., and thus the maximum displacement of the top floor is decreased from 1.30 m to 0.95 m. (Table 4).

2. If high performance concrete is not adapted in this project, the steel amount required for the steel boxes will increase about 8000 tons which is about 66% of the steel boxes (Table 5). Compared to the total amount of this project, there is about 18% reduction of steel amount for utilizing HPC.

3. The total amount of HPC for this project is about 16,000 m^3. Although the unit price of HPC is about double the cost of traditional concrete (4200NT/m^3 vs. 1800NT/m^3), the total cost of HPC is still far below the cost of steel (35,000 NT/ton) if HPC is not adapted (Table 6). Just for the benefit of material saving, the utilization of HPC has significant economic benefit for this project.

Table 4 Fundamental period and maximum displacement of top floor

	Fundamental period *	Max displacement of top floor **
f'c=560 kg/cm^2 filled in steel column boxes	5.08 sec.	0.95 m, h / 365
f'c=210 kg/cm^2 filled in steel column boxes	5.32 sec.	1.06 m, h / 328
Steel column boxes without filled in concrete	5.85 sec.	1.30 m, h / 268

* The fundamental period is for the first mode of the short span
** 50-year regression period of wind velocity for 40.7m/sec.

Table 5 Design comparison for steel column box

	Size of steel column box *	Steel amount required for column box**
f'c=560 kg/cm^2 filled in steel column boxes	Box L- 1600 x 1650 x 50	1.00
f'c=210 kg/cm^2 filled in steel column boxes	Box L- 1600 x 1650 x 75	1.48
Steel column boxes without filled in concrete	Box L- 1600 x 1650 x 85	1.66

* Steel type: A572 GR50
** AISC LRFD specification, axial force 14500t, bending moment 290 t-m

Table 6 Economic comparison for utilizing HPC

	Steel amount compared with utilizing HPC	Cost of steel (35,000NT*/ton)	Cost of concrete	Total cost
f'c=560 kg/cm^2 filled in steel column boxes	--------	--------	4,200 NT/m^3 16,000 x 4200 = 67,200,000	67,200,000
f'c=210 kg/cm^2 filled in steel column boxes	5800 tons more	5800 x 35,000 = 203,000,000	1,800 NT/m^3 16,000 x 1800 =28,800,000	231,800,000
Steel column boxes without filled in concrete	8000 tons more	8000 x 35,000 = 280,000,000	--------	280,000,000

* 1 U.S.$ is equal to about 27 NT dollars.

4. The utilization of HPC in this project has resolved the difficulty for vibrating and filling concrete into the steel column boxes. The concrete was pumped into the steel column boxes through a reserved nipple hole by a upward filling process (Figure 4). The filling height of HPC in the steel column box can be observed by a series of tiny checking holes on the steel column (Figure 5). If traditional concrete has been used instead of HPC, the stiffener plates in the steel column boxes will cause the vibrating and filling tasks very difficult to perform, and outside vibrating on the steel boxes cannot do much help either.

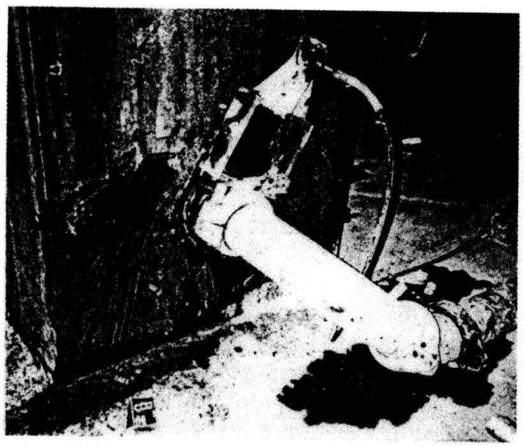

Figure 4 Upward filling of HPC

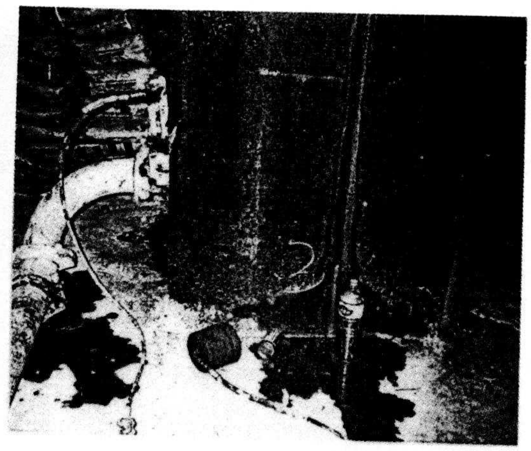

Figure 5 Checking holes on column

5. The manpower needed for filling HPC into the steel column boxes has been decreased to about 1/2 compared to traditional concrete. The laborers for spreading, leveling, and vibrating concrete are all eliminated. The major tasks during the filling process are setting up pumping pipes (Figure 6) and clearing those spilled concrete when pumping pipes are removed (Figure 7).

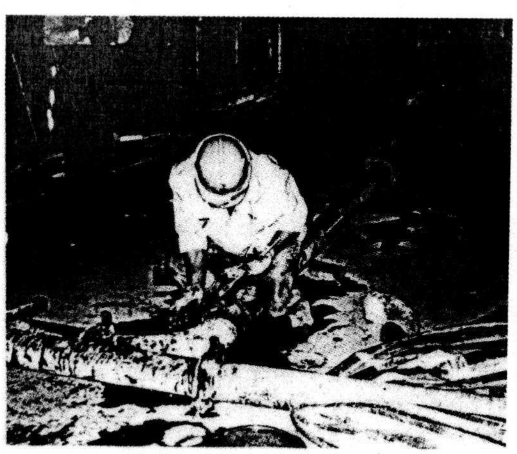

Figure 6 Set up pumping pipe

Figure 7 Clear up spilled concrete

6. The full-scale mock-up test has demonstrated the high quality of the HPC in this project. The compressive strength fulfilled the specification requirement. The 25 + 2 cm slump results in excellent workability and flowability. The significantly improved quality control ensure the high quality of HPC being filled in this project.

7. The construction schedule is not effected by utilizing HPC. Since the critical path of this project is depended on the erecting schedule of steel structure, the filling of HPC into the steel column boxes does not have schedule impact on the whole project.

6. Conclusion

Construction automation is a necessary and inevitable approach for developed countries which suffering from declining productivity, increasing labor cost and shortage of labor supply. Construction automation may also lead the industry to proceed a safer working environment, improved quality of construction work, as well as an advanced constructability design for the construction itself. While most of the past experience of construction automation focus on construction equipment, technique, computer interface and applications, the development and implementation of high performance concrete has created a new area for construction automation.

The high performance concrete utilized in the T&C tower project have demonstrated excellent workability, flowability, and required compressive strength. The use of HPC in the 85-story high rise building not only solve the filling difficulty and produce a high quality concrete, but also save substantial material cost and labor requirement. The success of the development and implementation of HPC in Taiwan encourages more research and utilization of HPC in the future. The new age of concrete construction material --- HPC will undoubted change the concrete filling process and bring a new aspect for future construction automation.

References

[1] de Larrard, F., "A survey of Recent Researches Performed in the French 'LPC' Network on High Performance Concrete', Proc. of the 3rd. Int. Symposium on Utilization of High-Strength Concrete, Lillehammer, Norway, pp. 57-63, June 1993.

[2] MacGregor, G., "Canadian Network of Centers of Excellence on High-Performance Concrete", Concrete International, ACI, Vol. 15, No. 2, pp. 60-61, 1993.

[3] Miura, N., et. al., "Fundamental Study on Rapid Flowing Concrete", Proceedings of the Japan Concrete Institute, Vol. 13, No. 1, 1991, pp. 185-190. (In Japanese)

[4] Okamura, H. and Ozawa, K., "Self-Compactable Concrete for Bridge Construction", Proceedings of the International Workshop on Civil Infrastructure Systems, Taipei, Taiwan, 1994, pp. 24-40.

[5] Ozawa, K., Maekawa, K., and Okamura, H., "Development of the High Performance Concrete", Proceedings of the Japan Concrete Institute, Vol. 11, No. 1, 1989, pp. 699-704.(In Japanese)

[6] Sakamoto, J., et. al., "Application of Super-Workable Concrete to Actual Construction", *Concrete 2000*, E & FN Spon, 1993, pp. 891-902.

[7] Stephan, D.E., "High performance Concrete", Proceedings of the International Workshop on HPC, Bangkok, Thailand, Nov. 1994.

[8] Shindoh, T., et. al., "Development of Super Workable Concrete BIOCRETE-21", Taisei Technical Research Report, Vol. 24, 1991, pp. 357-368. (In Japanese)

[9] Tanaka, S., et. al., "The Application of Super Workable Concrete and Polymer Impregnated Concrete Form to PC Cable-stayed Bridge", Proceedings of FIP Symposium'92, 1992, pp. 729-735.

[10] AISC-LRFD, Load and Resistance Factor Design Specification for Structural Steel Buildings, American Institute of Steel Construction, 1993.