# Research on a New CFT column-CFT beam Frame Structure

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**Abstract:** Concrete filled steel tube (CFT) structure, which has many merits, is popularly used in practical structures nowadays. Before the development of self-compacting concrete (SCC), all CFT systems were limited to CFT column-steel beam systems, since it is hard to make CFT beam using conventional concrete. In this research program, SCC is introduced to a new CFT column-CFT beam system. Cost estimation and comparison, which based on a building frame design, was performed between the new CFT structure and steel structure. An experimental investigation into the seismic behavior of CFT column-CFT beam joints was conducted. It was found that the new CFT column-CFT beam structure is a cost-effective structure and able to achieve high-seismic behavior. The paper also describes a concrete construction method for this new CFT system.

**Keywords:** CFT column-CFT beam joint, cost estimation, seismic behavior, construction method

## 1. Introduction

A concrete filled steel tube (CFT) structure has the merits of the high tensile strength and ductility of steel in addition to the high compressive strength and stiffness of concrete. Although many researches have been done on CFT column systems during the past several decades, almost all of them were limited to CFT column-steel beam systems. No information on CFT column-CFT beam systems is available until now.

Conventional concrete can be introduced to CFT column, however, it impossible to be introduced to CFT beam due to need of vibrating compaction work. Self-compacting concrete (SCC) can be compacted into every corner of a formwork purely by means of its own weight without need of vibrating compaction [1]. The character of SCC makes it possible to be applied to CFT beam.

The main objective of this research is to develop a high-performance, more cost-effective, and less labor-intensive new CFT frame structure. This paper first describes the cost estimation and comparison result of the new CFT system and steel structure, then introduces the experimental work on seismic behavior of the new CFT column-CFT beam connection, finally discusses the construction method for the new CFT system.

## 2. Cost estimation

### 2.1 Building frame design

In order to look for the cost performance of the new CFT column-CFT beam system, building frame design was performed.

Theme structures treated in this research are 9, 18 and 40-story unbraced building frames of office building made of CFT column-CFT beam frame system and conventional steel frame system. Hollow steel tube is used for column and H-shaped steel is used for beam in the steel system.

The design was based on Japanese steel structure design code [2] and CFT guideline [3].

The design complied with the concept of weak beam and strong column, which means plastic hinges only formed in beams, all columns remained elastic until the mechanism state was reached. All the joints were assumed to be rigid joints. Story drift angle was kept within 1/200 under the design load. The material properties are as following: yield strength of steel is 245MPa; compressive strength of concrete is 80MPa. Column and beam members list of the 9-story building for steel structure and CFT structure are shown in Table1 and Table2 respectively. Story drift angles for steel structure and CFT structure under seismic load are shown in Table3. Almost same drift angles were obtained from steel structure and CFT structure.

Table1 Column Members List of Steel and CFT structure

| Story | Steel structure Dimension (mm) | $M_u$ (kN·m) | $A_s$ (cm²) | CFT structure Dimension (mm) | $M_u$ (kN·m) | $A_s$ (cm²) |
|---|---|---|---|---|---|---|
| 8,9 | 300×300×9 | 244 | 105 | 250×250×6 | 230 | 59 |
| 6,7 | 300×300×19 | 381 | 232 | 300×300×12 | 480 | 138 |
| 4,5 | 400×400×19 | 741 | 290 | 350×350×16 | 850 | 213 |
| 2,3 | 450×450×25 | 1138 | 425 | 450×450×16 | 1410 | 278 |
| 1 | 550×550×25 | 1820 | 525 | 550×550×16 | 2114 | 342 |

Table2 Beam Members List of Steel and CFT Structure

| Story | Steel structure Dimension (mm) | $M_u$ (kN·m) | $A_s$ (cm²) | CFT structure Dimension (mm) | $M_u$ (kN·m) | $A_s$ (cm²) |
|---|---|---|---|---|---|---|
| 9-7 ($G_1$,$G_2$) | 390×300×10 | 457 | 133 | 400×200×6 | 335 | 70 |
| 6-5 ($G_1$,$G_2$) | 582×300×12 | 790 | 169 | 450×150×12 | 574 | 138 |
| 4-1 ($G_1$,$G_2$) | 692×300×13 | 1141 | 208 | 600×200×9 | 899 | 140 |
| 9-7 ($G_3$) | 600×200×11 | 592 | 132 | 400×200×6 | 336 | 70 |
| 6-5 ($G_3$) | 692×300×13 | 1141 | 208 | 600×200×9 | 899 | 141 |
| 4-3 ($G_3$) | 792×300×14 | 1472 | 240 | 600×200×12 | 1123 | 186 |
| 2-1 ($G_3$) | 900×300×13 | 2110 | 306 | 650×300×12 | 1563 | 222 |

Table3 Story Drift Angles of Steel and CFT Structure

| Story | CFT X | CFT Y | S X | S Y | CFT/S X | CFT/S Y |
|---|---|---|---|---|---|---|
| 9 | 1/292 | 1/292 | 1/287 | 1/293 | 0.98 | 1.0 |
| 8 | 1/276 | 1/278 | 1/269 | 1/277 | 0.97 | 0.99 |
| 7 | 1/276 | 1/287 | 1/266 | 1/280 | 0.96 | 0.98 |
| 6 | 1/275 | 1/285 | 1/260 | 1/276 | 0.95 | 0.97 |
| 5 | 1/284 | 1/290 | 1/267 | 1/281 | 0.94 | 0.97 |
| 4 | 1/292 | 1/298 | 1/276 | 1/292 | 0.95 | 0.98 |
| 3 | 1/313 | 1/342 | 1/319 | 1/333 | 1.02 | 0.97 |
| 2 | 1/340 | 1/363 | 1/332 | 1/348 | 0.98 | 0.96 |
| 1 | 1/462 | 1/439 | 1/419 | 1/456 | 0.91 | 1.04 |

### 2.2 Cost performance investigation

The cost estimation was based on Japanese price. Unit cost of steel is 635$ per ton including cost of material, transportation and fabrication. Unit cost of concrete is 244$ per cubic meters including cost of material, transportation and construction.

The comparison results of consumed steel material and weight of both CFT frame structure and steel frame structure are shown in Fig.1, Fig.2 respectively. Fig.3 shows cost comparison result of the two kinds of building frame. The result shows that CFT structure exhibits cost merits compared with pure steel structure.

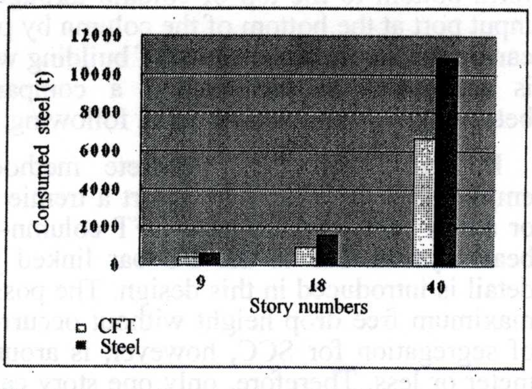


Fig.1 Comparison of Consumed Steel Material

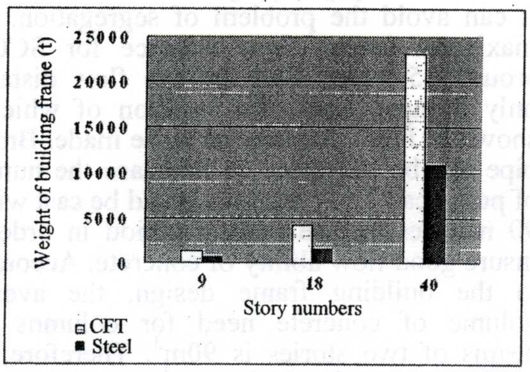


Fig.2 Comparison of Frame Weight

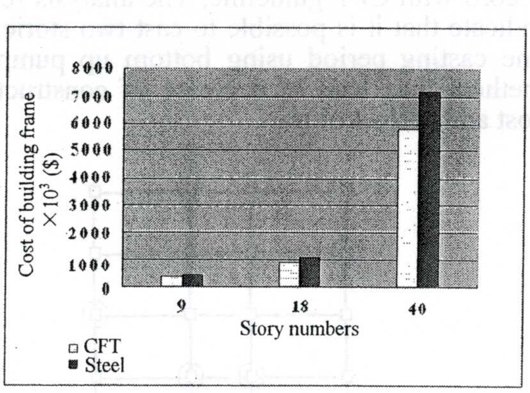


Fig.3 Comparison of Frame Cost

## 3. Seismic behaviour of CFT column-CFT beam structure

### 3.1 Joint detail and test procedure

Three specimens including two CFT specimens and one steel specimen were tested in the experimental work. Outer diaphragm joint detail and PC bar joint detail were employed in two CFT specimens respectively. Through-type diaphragm joint detail was employed in steel specimen. The joint details are shown in Fig.4.Dimensions of the connection specimens were chosen basing on a real 10-story steel prototype building. 56% scale joint specimens were employed. Column dimension of specimen is 250×250×6 for CFT, and 250×250×12 for steel. Beam dimension of specimen is 250×150×9 for CFT, and 294×200×8 for steel. Yield strength of steel is 245MPa; compressive strength of concrete is 80MPa. A typical test setup is shown in Fig.5. 1000 KN axial load was applied to the columns firstly. This value was remained constant during the whole period of test. Equal and opposite vertical loads were then cyclically applied to the end of beam.

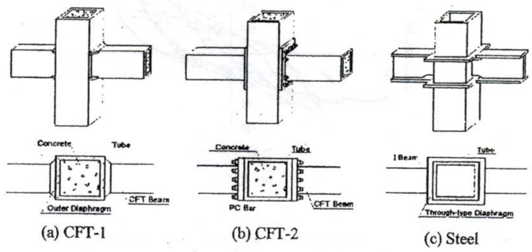


Fig4. Joint Details

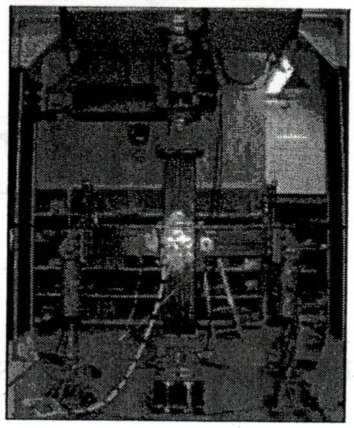

Fig5. Typical Test Setup

### 3.2 Test results and discussion

Load-drift angle responses were used to compare the performance of each specimen. The drift angle of the specimen was calculated as the ratio of the total relative vertical displacement between the two ends of the beam to the distance between the two ends. Fig6 shows the load-drift angle relationship of each specimen. Failures of all CFT joint specimens were due to fracture of the weld that attached the beam flange to tube or PC bar flange. CFT-1 was not able to develop plastic capacity of beam due to precocious weld fracture. Specimen CFT-2 was not able to develop full plastic capacities of the beam due to the brittle weld fracture. The substantial deformation capacity expected was obtained in Specimen CFT-2. No failure occurred in steel specimen until end of test. The hysteresis loops of CFT specimens were plumper than that of steel specimen, which indicated a higher energy dissipation capability of CFT structure.

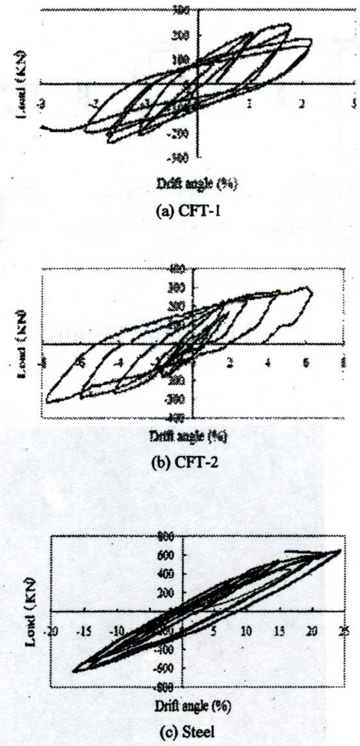


Fig6. Load-drift Angle of Each Specimen

## 4. Construction method for new CFT structure

High-dropping of concrete method and bottom-up pumping method are popularly employed in CFT column systems nowadays. In high-dropping concrete method, concrete is poured from top to the bottom of the column, a tremie tube or sunny hose is inserted inside the column tube in order to avoid the occurrence of segregation due to the high free drop height. In bottom up pumping method, concrete is poured form bottom to the top of column through the input port at the bottom of the column by pump car. Based on the dimensions of building which is introduced in this paper, a comparison between two methods is done as following.

If high-dropping of concrete method is employed, it is difficult to insert a tremie tube or sunny hose into the new CFT column-CFT beam system due to the PC bar linked joint detail is introduced in this design. The possible maximum free drop height without occurrence of segregation for SCC, however, is around 5 meter or less. Therefore, only one story can be cast in one casting period.

If bottom-up pumping method is employed, it can avoid the problem of segregation. The maximum lateral flow distance for SCC is around 15 meter. Base on the flow distance, only 8 input ports, the location of which is shown in Fig.7, are needed to be made. Branch pipe can be employed to decrease the number of pump car. The concrete should be cast within 90 minutes in one casting period in order to insure good flow ability of concrete. According to the building frame design, the average volume of concrete need for columns and beams of two stories is $90m^3$. Therefore, the casting speed should be $1m^3$/min. When this value is distributed to 8 columns input ports, the casting speed is within 1m/min which in accord with CFT guideline. The analysis result indicate that it is possible to cast two stories in one casting period using bottom up pumping method, thus lead to decrease of construction cost and project time.

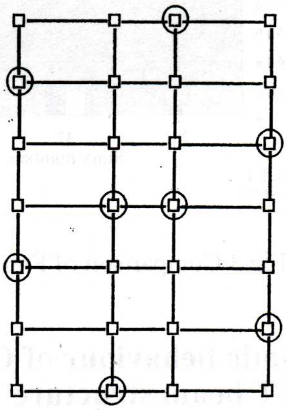

Fig.7 Location of Input Ports on Framing Floor Plan

## 5. Conclusions

1).The new CFT structure is a cost-effective structure compared with pure steel structure.

2).CFT column-CFT beam frame can be made using self-compacting concrete.

3).Sufficient deformation capacity was obtained in PC bar jointed CFT column-CFT beam specimens. Insufficient thickness of PC bar flange led to a little larger deformation of PC bar flange; increase of the thickness of PC bar flange is inferred able to strengthen the connection.

4).In the bottom up pumping method, concrete can be cast through input ports which are only made on several columns and several stories are supposed able to be cast together in one casting period, thus lead to less construction cost and project time.

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