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Concrete Filled Steel Tube Column And Wide Beam Connection: Proposed Structures and Experiment

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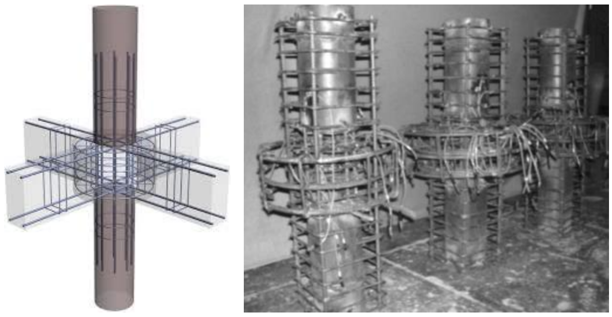
Abstract*: Structural solutions utilizing concrete filled steel tube (CFST) column and reinforced concrete (RC) wide beams are used effectively in high-rise buildings, especially for large span. Currently, there have not been many theoretical and experimental researches on CFST column - RC wide beam connection to ensure the effectiveness of this structure type. Moreover, there have not been any experimental researches on the connection of CFST column – Prestressed concrete (PC) wide beam, as well as on assessing the effect of prestressed cables and shear head shape on the shear strength of the connection. This paper proposes connection structures; conducts experimental program, analyzes and compares different types of connections between CFST column and RC, PC wide beam using large size specimens to evaluate the actual behavior of proposed connections. Experimental results give a better view of the effect of shear-head shape as well as the prestressed force on the shear strength of the wide beam at the connections.

***Keywords*: Concrete filled steel tube, Reinforced concrete, Prestress concrete, Wide beam, Column**

I. INTRODUCTION

Concrete filled steel tube (CFST) structure has been increasingly used in construction field due to outstanding efficiencies compared to reinforced concrete structures such as high strength, ductility of large structures, fast construction, less costly and time consuming for formwork. For high-rise buildings with large span, reinforced concrete (RC) or prestressed concrete (PC) wide beams are the effective solutions that have such more advantages in comparison with conventional RC beams as increasing horizontal stiffness, reducing calculated length of floor structure and limiting the story height.

There are currently very few researches on connecting CFST column and wide beams. Some CFST column - RC beam connection solutions were proposed by Nie, J., Bai, Y. and Cai, A. C. S. (2008) [1], [2], Chen, Q. J. et al (2015) [3], Yu, H. Y. (2013) [4] as shown in Fig. 1. These connections ensure the strength but are still relatively complex in term of construction. There have been very few theoretical and experimental researches on connection structures for CFST column and prestressed concrete wide beam as well as no experimental works to assess the impact of post-tensioning cables on the connections. At the same time, there are no researches on comparing the effects of shear-head shape, which is the most important factor to ensure effective connection.



(a) (b)

Fig. 1. The CFST column – RC beam connection proposed on [3] (a) and [2] (b)

Therefore, this paper proposes improved different types of connections, specifically: (1) The connection of CFST column – RC wide beam using steel plate shear-head (Specimen 1, S1); (2) The connection of CFST column – RC wide beam using H-shaped steel shear-head (Specimen 2, S2); (3) The connection of CFST column – PC wide beam using H-shaped steel shear-head (Specimen 3, S3). The paper also performs large size tests to evaluate the actual behaviors of the proposed connections. In particular, the comparison of experimental results clarifies the effect of the shear-head shape on the working of the connections (comparing S1 and S2) and the effect of prestressed force on the shear strength of the wide beam at the connections (comparing S2 and S3).

II. DETAILS OF PROPOSED CONNECTIONS

A. The connection of CFST column – RC wide beam using steel plate shear-head (Specimen 1, S1)

This connection consists of steel plate welded on the

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outside surface of the column. The continuity of CFST column through the connection zone assures the axial bearing capacity of the column, eliminating the use of ring-beam to facilitate easy construction.Due to the continuous steel pipe through the connection area, part of the longitudinal reinforcing bars of the beam passes through the steel pipe, the rest is anchored to the steel pipe in order to create space for easy concrete pouring. Thus, it is necessary to create available holes in the column surface to arrange longitudinal bars as shown in Fig. 2.

Fig. 2. The connection of CFST column – RC wide beam using steel plate shear-head

Based on above description, the experimental specimen includes: (1) RC wide beam with cross section of b×h= 1050×350(mm), full length of L = 3.1m; (2) CFST column is made of 300×300(mm) square steel pipe with wall thickness of 10mm; (3) 250×350×15(mm) steel plate shear-head: the plate goes through the column by holes on the column surface and welded at outer surface of the column, the strength of the steel plate f_y = 231Mpa; (4) The reinforcement bars consist of top layer of 11ϕ14, bottom layer of 11Ø12, (5) Stirrups of ϕ10a50 within the length of shear-head and ϕ10a150 for the rest as shown in Fig. 3.

In addition, a 340×340×20(mm) square plate is welded to the foot of the column while the head of the column is empty to pour concrete. The yield strength of the longitudinal bar and the stirrup is f_y= 350MPa. The concrete that use for wide beam and column have compressive strength f'_c = 17MPa at the testing date.

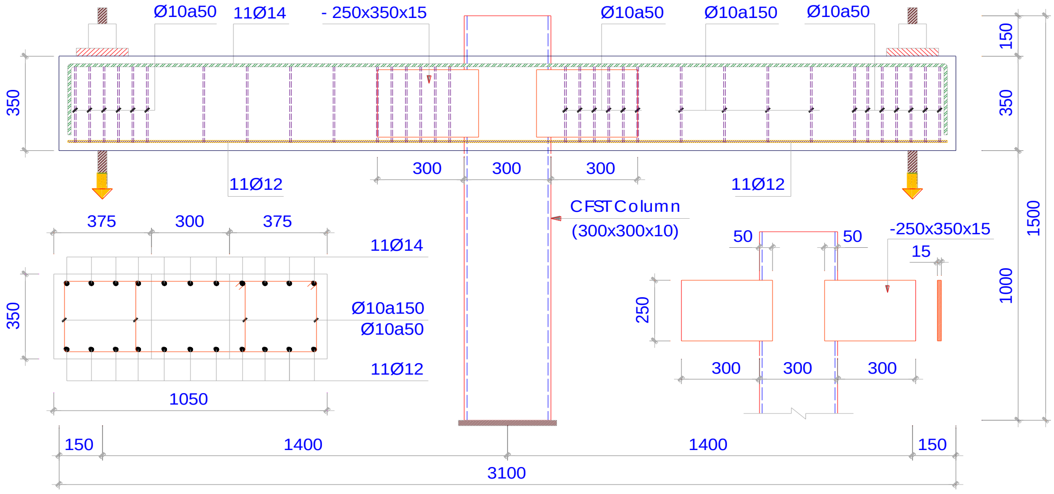

Fig. 3. Structural details of Specimen 1 (S1)

B. The connection of CFST column – RC wide beam using H-shaped steel shear-head (Specimen 2, S2)

H or I shaped steel shear-head works as a shear key to ensure continuity between beam and CFST column. The web of H or I steel is inserted inside the column and welded on the column surface to ensure the reliability of the connection, and this part is considered as a key factor to ensure the simultaneous work of the concrete core and wall of steel tube when subjected to bending as well as compression. The reinforcement of wide beam is through the column at holes in the column surface to improve continuity and the flexural strength of beam as shown in Fig. 4.

Specimen 2 includes: (1) RC wide beam with cross section of b×h = 600×350 (mm); (2) CFST column is made of 300× 300×10 (mm); (3) H-shaped steel shear-head with the section of H200 and the length of l_v = 250mm, shear-head is welded to the outer surface of the steel tube; (4) longitudinal reinforcing bars and the stirrups are summarized in Table- I.

Fig. 4. The connection of CFST column – RC wide beam using H-shaped steel shear-head

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Table-I: The reinforcement bar and concrete used for Specimen 2 (S2)

Specimen	Longitudinal bar		Stirrup bar		Tendon		Concrete
	ϕ(mm)	f_y(MPa)	ϕ(mm)	f_{yw}(MPa)	ϕ(mm)	f_y(MPa)	f'_c(MPa)
S2	Top layer: 7Ø22 + 2Ø20 Bottom layer: 7Ø12	454 454	ϕ8a150	300	-	-	29.7

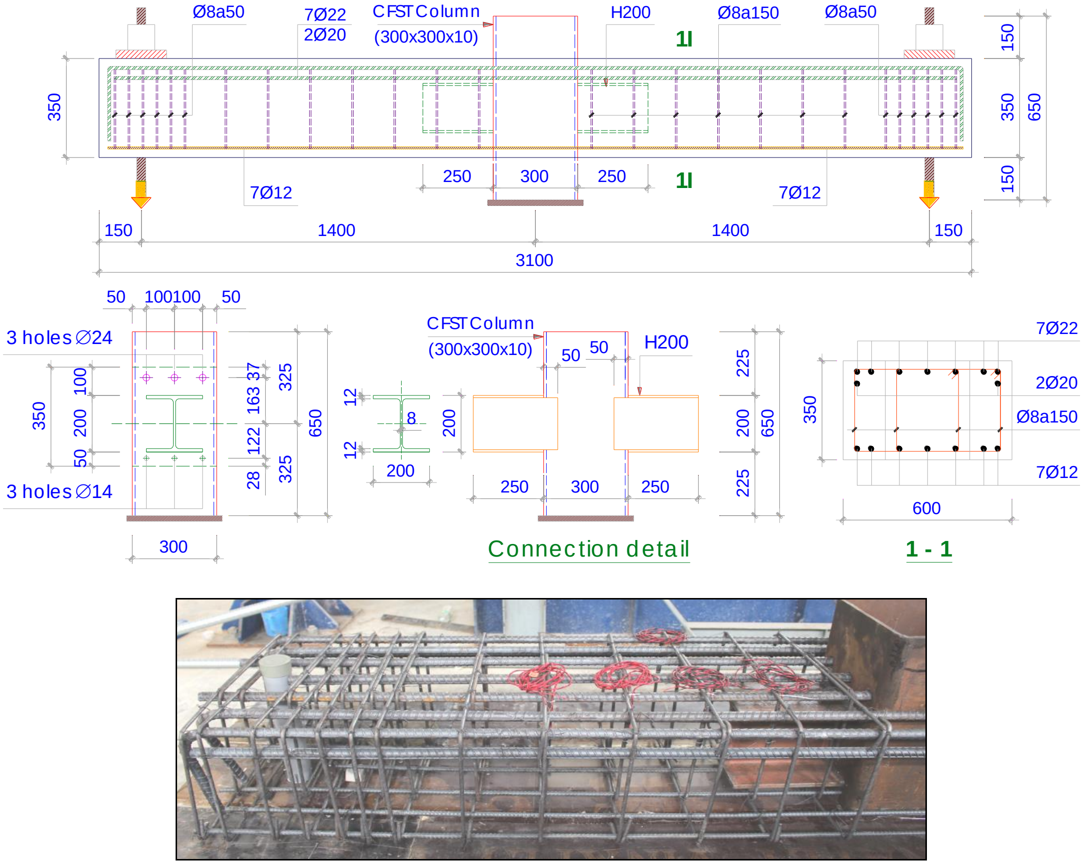

Fig. 5. Structural details of

Specimen 2 (S2)

C. The connection of CFST column – PC wide beam using H-shaped steel shear-head (Specimen 3, S3)

The details of Specimen 3 are similar to Specimen 2, except the prestressed cables arrangement as shown in Fig. 6. Due to the beam width is larger than the column one, the prestressed cable can be arranged on the two sides of the CFST column. Prestressed cables are calculated according to ASTM A416M-06 [5] including 4 No13 (ϕ= 12.7mm, A_s = 97.8mm^2, Grade 1860) arranged in 2 ducts with diameter of 40mm. Yield strength measured at 1% extension under load f_{py} (MPa) and limit strength f_u(MPa) are presented in Table II.

Table-II: Properties of Reinforcement bar, Tendons and Concrete used for specimen 3 (S3)

Specimen	Longitudinal bars		Stirrups		Tendon			Concrete
	ϕ(mm)	f_y(MPa)	ϕ(mm)	f_{yw}(MPa)	ϕ(mm)	f_{ys}(MPa)	f_u(MPa)	f'_c(MPa)
S3	Top layer: 7Ø20 + 2Ø22 Botom layer: 7Ø12	454	ϕ8a150	300	4.No13	1670	1860	29,7

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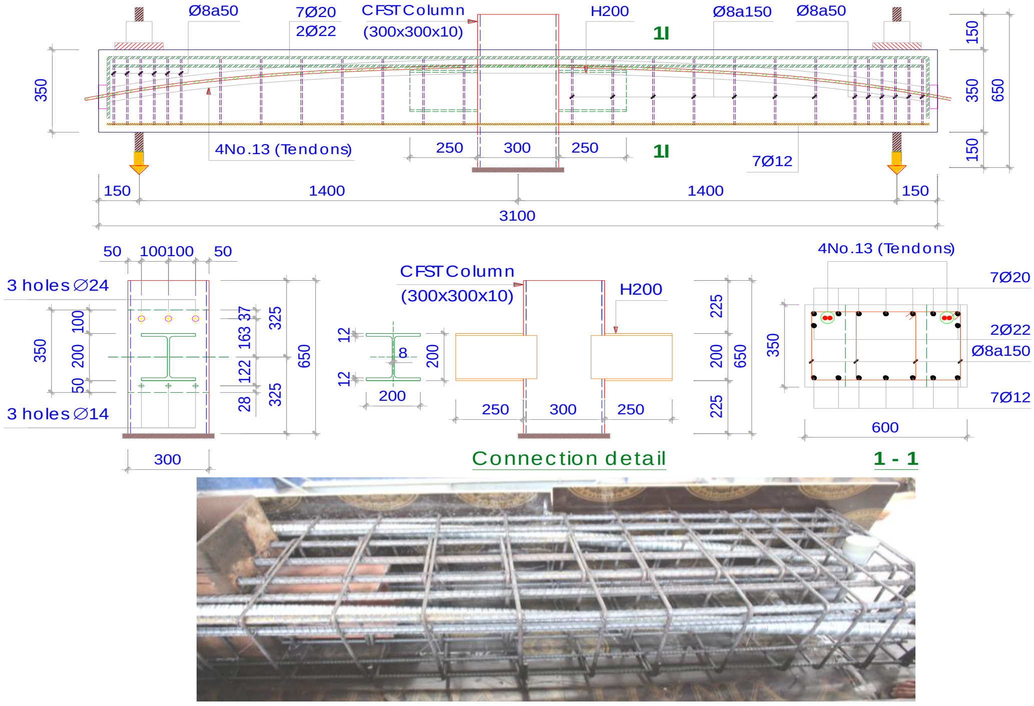

Fig. 6. Structural details of Specimen 3 (S3)

III. EXPERIMENTAL SET UP AND RESULTS

A. Experiment set up and results for Specimen 1 (S1)

The middle column of Specimen 1 is fixed and loads are applied at the two ends of the beam at each load level P=10kN (Fig. 7). Up to P = 40kN, cracks perpendicular to beam axis appear and the cracks width is small at the column surface. Continue to increase load, only the vertical crack can be observed, they are evenly distributed from the column surface to the outside, then these cracks extend to the bottom of the beam. Cracks mainly develop in areas near the column face and the free end of shear-head and the cracks are negligible in other areas. At load level P = 128kN, while the load does not increase, beam deformation increases rapidly and crack width increases. The failure section is near the free end of the steel plate and at the surface of the column.

Fig. 7. Experiment set up for Specimen 1

B. Experiment set up and results for Specimen 2 (S2)

The arrangement of experiment is shown in Fig. 9. The specimen is placed on a load frame system consisting of two high-strength steel anchor bars of 36mm in diameter. The bars are anchored to the beam on top points and to the rigid testing floor on bottom points as in Fig. 8. The system is loaded by hydraulic jacks with a lifting capacity of 2500kN. Test load is recorded by load cell force sensor.

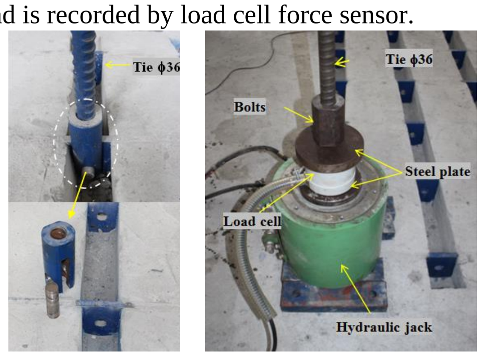

Fig. 8. Design and test for anchor on rigid testing floor

Fig. 9. Experiment set up for Specimen 2

At load level P = 200kN, small cracks appear on the top of the beam near the column edge. Continue to increase the load, the cracks spread from the surface to the beam sides and it can be observed inclined cracks on both sides of the beam. The cracks tend to be inclined to the bottom flange of the shear-head with the inclination angle of about $\theta_{cr} = 45^0 - 50^0$. At the load level $P_u = 628$kN, large cracks occur at the edge of the column (w_{cr} = 2mm), cracks spread rapidly to the free end of the shear-head, the beam move quickly and does not receive additional load, concrete compression area at the beam bottom surface near the column surface is crushed and the wide beams is failure.

C. Experimental set up and results for Specimen 3 (S3)

Specimen 3 was arranged on a load frame system as shown in Fig. 10. The test load is carried out by a hydraulic jack with a lifting capacity of 2500kN placed at the foot of the column. The pressure sensor determines the force of the jack, the LVDT measures the column displacement.

Fig. 10. Experiment set up for Specimen 3

The cables are prestressed before the experiment. An initial tension of $0.7f_{pu}$ = 1300Mpa, which corresponds to the tension in a cable of 128.3kN, is selected. Then, the cables outside the anchor head are cut off and grouting concrete into the ducts is carried out. Perform additional load on the column, cracks begin to appear at the load level P = 300 kN at the edge of the column. Further increasing the load, the behavior of S3 is similar to that of S2, but the width and length of the crack develops very slowly. At P = 840kN, the load increases slowly but the vertical displacement increases very quickly, perpendicular cracks at the edge of the column grow faster than the incline cracks, the crack width measured at $w_{cr, max}$ = 1.3mm. The failure mode of beam is bending.

IV. DISCUSSION OF THE EXPERIMENT RESULTS

A. Effect of shear-head shape by comparing S1 and S2

From the results of the experiments for the two types of proposed connections (S1 and S2), the behavior differences of wide beams can be observed and discussed as follows:

For connection using steel plate for shear-head (S1), only vertical cracks appear in the beams, there is no inclined crack. At the damage position at the top of the steel plate, vertical cracks widen and split the beam. Thus, the steel plate does not play the role as a fulcrum for concrete strut to transfer the load from the slab into the column.

a) Crack patterns of Specimen 1

b) Crack patterns of Specimen 2

c) Crack patterns of Specimen 3

Fig. 11. Crack patterns on the experiment specimens

At the position of RC column-RC beam, the load on the beam transferred to the column can be illustrated as the working of the strut and tie system as Fig. 12.

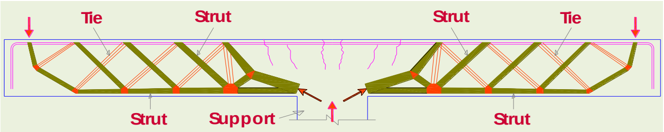

Fig. 12. Illustration of load transferring mechanism from beam to column

Through the mechanism of transferring force, it can be seen that the load on the slab is transferred through space strut and tie system and transmitted to the support at column. Therefore, for the connection details, it is necessary to create support for the transmitting load. Using H or I-shaped steel as in Specimen 2 has advantage that the extended lower flange provides a support for the concrete struts, ensuring the compression transmission mechanism of the struts clearly. Thus, for the connection of CFST column – RC wide beams, using H-shaped steel shear-head as in Specimen 2 is more reasonable than steel plate in Specimen 1.

B. Effect of prestressed forces by comparing S2 and S3

Compared to normal reinforced concrete wide beams, the presence of cables significantly increases the strength of the beams (33.7% increase compared to non-stressed wide beams using the same connection) as in Fig. 13.

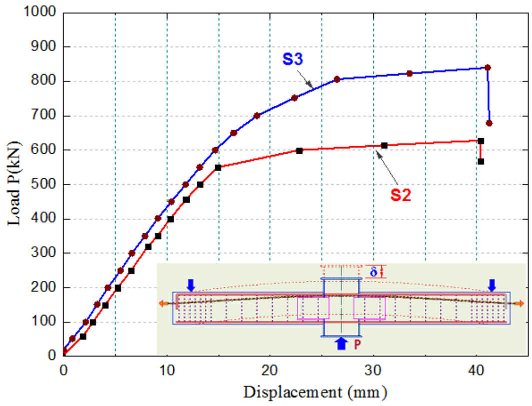

Fig. 13. Load versus vertical column displacement chart for the specimen S2, S3

The increase in shear strength can be explained as follows: under the influence of shear force, inclined cracks appear in the beam. Accordingly, at the position of the inclined cracks, the force components appear to resist the shear force. The basic components of RC beams contribute to shear resistance such as: Aggregate interlock (V_{agg}); Concrete compressive zone (V_{ch}); Dowel action (V_{dow}); Transverse reinforcement ($V_{sw,i}$); the work of shear - key, V_v [6]. For prestressed concrete beams, besides shear resistance components as in RC, there is the contribution of prestressed force to shear resistance, which is: The effect of pre-compression force in concrete increases the compression strengthen V_{ch}; the inclined cable arrangement causes the force in the vertical direction opposite to the external load. This contribution occurs when the cable trajectory cuts through the inclined cracks of the beam as illustrated in Fig. 14. Besides, the width of the crack and the speed of crack growth are slow and much smaller. This shows the suitability of using pre-stressed wide beam structure in large span buildings.

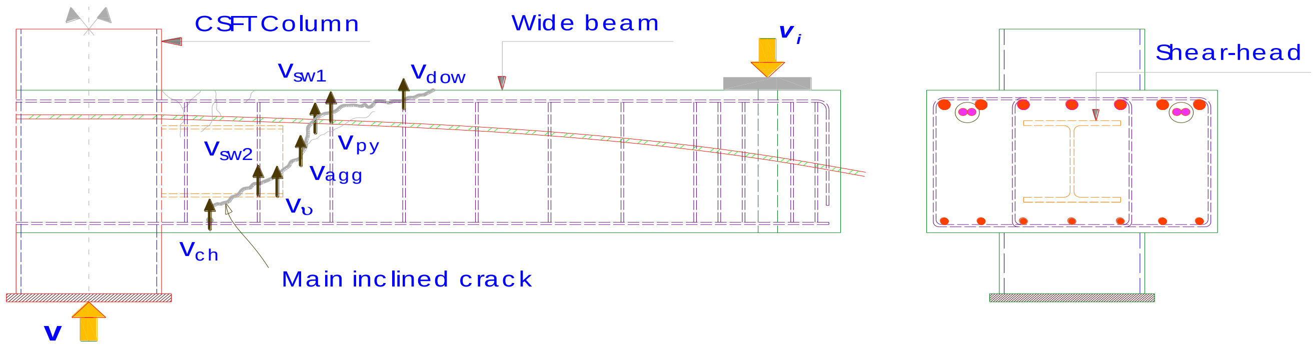

Fig. 14. The mechanism of forces transfer on inclined cracks of wide beam

V. CONCLUSION

The structural system using CFST column – reinforced or prestressed concrete wide beams in a high-rise building is an effective and potential solution because of the economic-technical effects. The paper proposes and then conducts experimental research on different connection types of CFST column and RC, PC wide beams. The paper results show that H-shaped shear-head is working more effective and reasonable than steel plate shear-head as extended bottom flange create a fulcrum for the concrete struts, ensuring the mechanism of transferring compressive force from beam to column. The experimental results also show that the prestressed force in the cable significantly increases the shear resistance of the beam, reduces the width and speed of crack development. This shows the suitability of using pre-stressed wide beam structure in large span buildings.

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