（29） Effect of insertion of pile, concrete and steel strength in connection of steel box filled with concrete

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The purpose of this study is to develop design method for connection of steel box filled with concrete. The steel box is monolithically connected with steel beam, while a steel pile is inserted in the concrete. For different insertion length two types of failure mechanism were observed i.e. compression failure of concrete and flexural failure of steel then it was observed that peak load occurs after the concrete compression softening near the edges of the pile takes place. Then it was observed that by increasing concrete strength the ultimate load capacity of the connection increases nonlinearly. Then the effect of steel strength of pile on the connection strength was observed. After the analysis no change in the strength of connection was observed for a failure mechanism in which compression failure of concrete was dominant.

Key Words :*Steel Box Filled with Concrete Connection, Insertion of Pile, Concrete Strength, 3D FEM Analysis, and Ultimate Strength*

1. Introduction:

Steel concrete sandwich structure is a relatively new form of structural system. This form of structure has the potential to fully utilize respective strength of both steel and concrete with help of composite action such as confinement. It allows the prefabrication of large section in a factory, and enables rapid installation into main structure, dramatically reducing the fabrication cost and construction time. Steel faces act as permanent formwork during the construction and provide impermeable skins for the structure upon completion. So after considering these points we selected steel box filled with concrete for connection between two structural members such as beam and foundation pile in a bridge. It has advantage over steel structure because of cost factor and it is a better option as compared to reinforced concrete connection due to strength and construction time. Our purpose is to develop design method for connection by using a 3-D nonlinear finite element program CAMUI, which the authors' group has developed [1]. Therefore we can take part in the development of simple and economical hybrid structure with high mechanical properties. In order to develop the design method for connection, first step is to see the effect of insertion of pile, concrete and steel strength on the strength of connection. For that different specimens were prepared with different pile length, concrete and steel strength. Then these are analyzed by CAMUI. In this paper first details of analytical model and then analytical results for different cases will be shown. Analytical results comprises of load deflection curves and stress distribution along the inserted pile length. Load deflection curve is required to observe the change in strength of connection for five cases. Stress distribution along inserted pile length is required to find the reason of change in strength by changing the insertion length.

Japan Society of Civil Engineers (JSCE) established research subcommittee on Steel-Concrete Sandwich Structures in 1990. After intensive works in the subcommittee for one and half year to gather results of studies on sandwich structures as well as to conduct its large scale tests, the Subcommittee presented "proposed design code on steel concrete sandwich structures" in April 1992 which is based on limit state design method [2].

In the same year Ueda[3] proposed the shear strength equation for steel concrete sandwich structures. It was observed that shear resisting mechanism is sandwich structure with shear reinforcing steel plates located parallel or normal to member axis is truss like mechanism. Based on the observed truss mechanism prediction equations for shear capacities of sandwich structure as linear member are presented for both cases with or without shear reinforcing steel plates. Rahman[4] proposed the shear strength equation for full and open sandwich beams. This eliminated the limitation of existing shear design equation. Macro physical model, based on 2D nonlinear analysis FEM analysis was developed.

The research on connection between steel beam and foundation pile by using concrete filled steel box shell was started by Emoto [5]. The concrete filled steel box shell is a type of sandwich structure, however its failure mechanism is quite different from ordinary sandwich beams. The major finding was failure of this connection occurs, when compression softening of concrete is caused by bearing stress from the steel pile. And other Findings on shear connector effects were that the shear connector along the inserted length of pile enhanced the capacity of connection and shear connectors in steel shell box had almost negligible effect on the strength of connection. Emoto also conducted the experiment and compared the experimental and 3D-FEM analytical results for this type of connection[5].

2. Specimen Details for Analysis:

Economical and rational hybrid structures have been adopted recently. The connection of the hybrid rigid-frame bridge (**Fig. 1**) as shown in **Fig. 2** has been proposed due to construction conditions imposed to the bridge such as limited space. The rigid frame structure makes height of beam shorter, while the connection, which is a concrete filled shell steel box, makes the abutment size smaller. And, this connection improves the seismic resistance by penetration of steel pile to concrete filled steel shell box.

Because connection is symmetric along the pile so in order to reduce the analysis time half of the connection is modeled.

(1) Analytical model:

Analytical model is prepared by using a commercially available software. The connection is symmetrical in Z-axis so In order to reduce the mesh size one half of the connection is modeled. This software generates the text file. Then this text file is changed into the format, which is readable by CAMUI. In order to develop the design method as a first step two parameters were selected for analysis. These two parameters are pile insertion length, concrete and steel strength, In one analysis one parameter is variable and the rest of the parameters are kept constant.

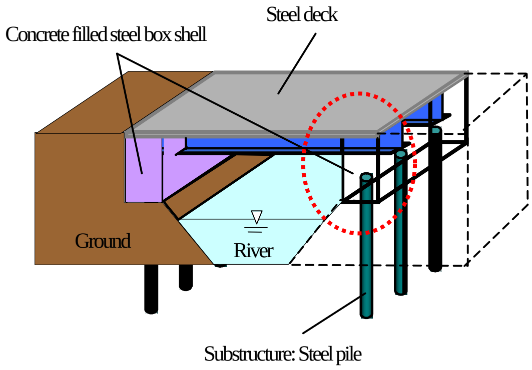

Fig.1 Hybrid rigid frame bridge

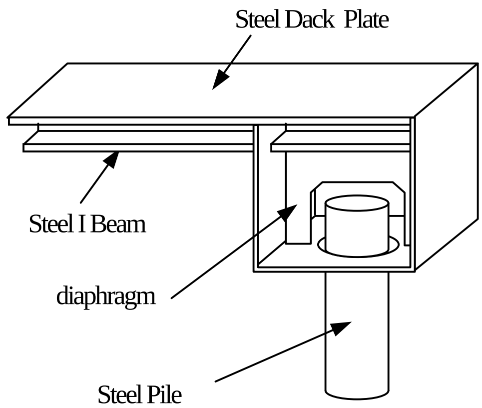

Fig.2 Connection of hybrid structure

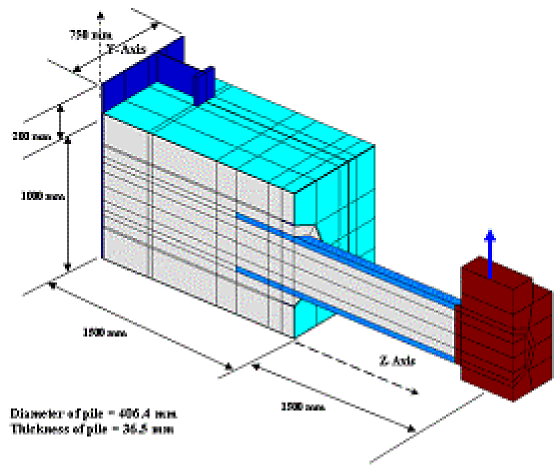

Fig.3 Analitical model

(2) Pile Insertion length:

First step is to see the effect of insertion of pile on the strength of connection. For this five analytical models were prepared. The insertion length for five cases is 450 mm, 604.5 mm, 684.5mm, 684.5mm, 854.5mm and 1110 mm respectively. Rests of all other parameters are kept constant. This is shown in **Table 1**.

Table 1 Specimen detail for observing the effect of pile insertion length

Variable parameter		f'c (MPa)
Analytical Specimen	Insertion length (mm)	
1	450.0	24.0
2	604.5	
3	684.5	
4	854.5	
5	1110.0	

Table 2: Specimens detail for observing the effect of compressive strength of concrete

Variable parameter		Insertion length (mm)	Steel Strength (MPa)
Analytical Specimen	Concrete Strength f'c (MPa)		
1	15.3	450	347
2	24.0		
3	30.6		
4	40.8		
5	51.0		
6	61.2		

Table 3 Specimens detail for observing the effect of pile yield Strength

Variable parameter		Insertion length (mm)	Concrete Strength (MPa)
Analytical Specimen	Yield strength of pile (MPa)		
1	300	450	24.0
2	347		
3	400		

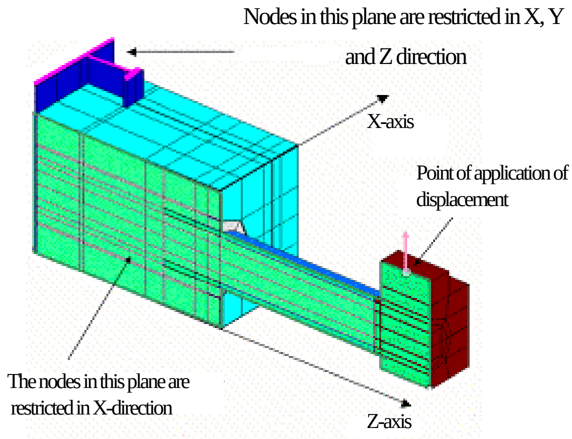

Fig.4 Boundary conditions of the connection

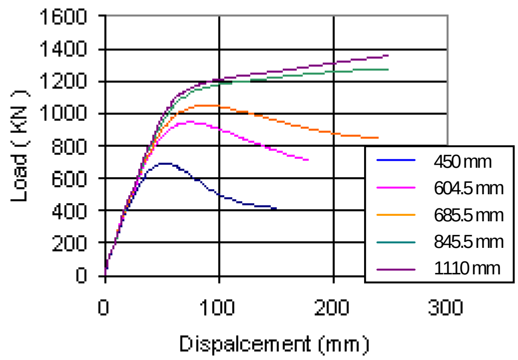

Fig.5 The Load displacement relationship for different insertion length

(3) Concrete strength:

Second step is to observe the effect of concrete strength on the strength of connection. For this six analytical models were prepared. The concrete strength for the cases is 15.3 MPa, 24 MPa, 30.6 MPa, 40.8 MPa,51 MPa and 61.2 MPa respectively . This is shown in **Table 2**.

(4) Steel strength:

Then steel strength of pile is changed to observe its effect on the strength of connection. For this three analytical models were prepared. The steel strength for those three cases is 300MPa, 347MPa and 400MPa respectively . This is shown in **Table 3**.

(5) Bond link elements:

After changing the format of text file then bond link elements were added. Two types of bond link element were used. One is the friction bond link element and other is elastic bond element for shear connector of pile.

(6) Boundary conditions:

After adding bond link element then boundary conditions for the connection is introduced, which is shown in **Fig. 4**. The node at which displacement is applied is restricted in the direction of the displacement.

(7) Loading condition:

Loading condition can be applied in two ways either applying the load or displacement. In this study displacement is applied with an increment of 0.2cm. Point of application of displacement is shown in **Fig. 4**.

3. Results

(1) Effect of insertion of pile:

In order to see the effect of insertion length of pile on the strength of connection, five cases with 450 mm, 604.5 mm, 685.5 mm, 854.5

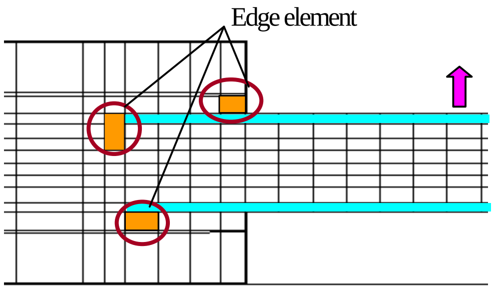

Fig.6 Location of Edge elements

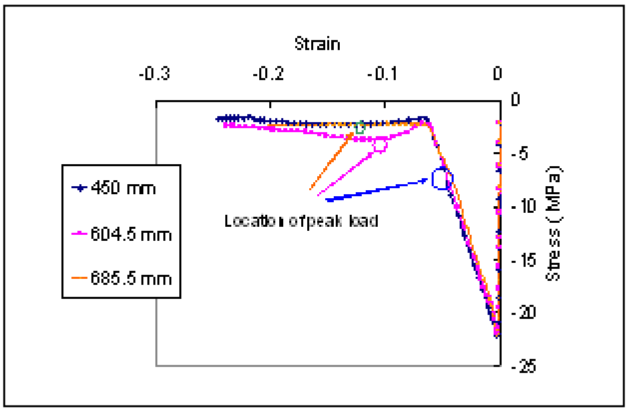

Fig.7 Location of peak load in Stress strain graph

and 1110 mm insertion lengths were analyzed.. After analyzing the specimens the load displacement curves are shown in the following **Fig. 5**.

a) Failure mechanism:

After analysis two types of failure mechanism were observed;

- Failure mechanism controlled by concrete crushing.
- Failure mechanism controlled by yielding of steel.

For first three cases the concrete crushing controls the failure mechanism and for the last two cases the failure mechanism is controlled by the yielding of the steel pile.

b) Occurrence of peak load:

Peak load occurs after the softening of the edge elements and these edge elements are shown in **Fig. 6** Softening of the edge element can be seen in the **Fig. 7**.

From load deflection curve it was also observed that strength of the connection increases with the increase of the insertion length. This increase in strength is due to increase in resistive moment and resistive moment increases due to larger liver arm. For that the stress distribution along the pile length is observed and it was found that as the pile insertion length increases the liver arm increases. Due to this the resistive moment increases and finally the peak load increases. Stress distribution along the pile for different pile insertion length is shown in **Figures 8 and 9**.

(2) Effect of concrete strength:

In order to see the effect of concrete strength on the strength of connection six cases with different concrete strength were analyzed. The compressive strength of concrete for six cases was 15 MPa, 24 MPa, 30.6 MPa, 40.8 MPa, 51 MPa and 61.2 MPa respectively. After the analysis it was observed that strength of the connection increases with the increase of concrete strength. It was also observed that by increasing the concrete strength the failure mechanism changes from concrete crushing to steel yielding dominant case. This can be observed by the following **Fig. 10**.

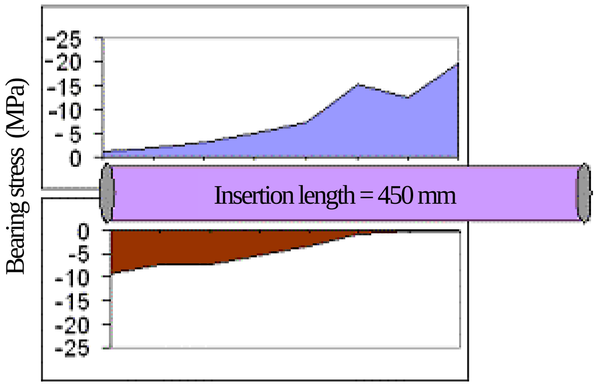

Fig.8 Stress distribution along the 450 mm insertion length of pile

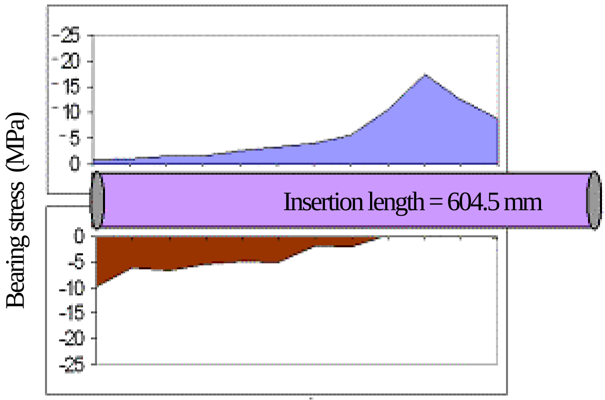

Fig.9 Stress distribution along the 604.5 mm insertion length of pile

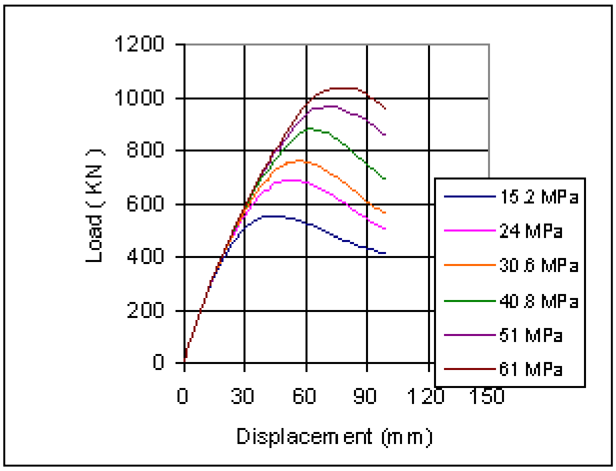

Fig.10 Load - displacement relationship for different concrete strength

Then it was observed that the variation of peak load is not linear with respect to concrete strength. This nonlinear behavior of peak load is due to tensile strain produced in other direction. Due to these tensile strains compressive strength of the concrete reduces as displacement increases and thus variation of peak load becomes non linear as shown in **Fig. 11**.

(3) Effect of steel strength

a) Concrete crushing dominant case

Three cases with different steel strength of pile were analyzed. The pile steel strength for these cases was 300 MPa, 347 MPa and 400 MPa respectively. After the analysis it was observed that by changing the steel strength has no effect on the strength of connection until the yielding of steel does not take place. This can be observed from **Fig. 12**.

b) Yielding of Steel dominant case:

If the yielding of steel takes place then peak load is different. In order to prove this statement the specimen with 206.4 mm diameter was analyzed with different yield strength of pile. Smaller diameter is used to allow the yielding of steel pile. After analysis it was observed that peak load changes with the change in yield strength. This statement is only valid when the failure mechanism occurs due to yielding of steel. This is shown in the following **Fig. 13**.

4. Conclusions:

Two types of failure mechanisms were observed. In the first type of failure mechanism concrete crushing is dominant. The 2nd type of failure mechanism occurs after the yielding of steel. Peak load occurs after softening of the concrete near edge of the steel pile.

It was also observed that by increasing the insertion length of pile the peak load increases. This increase in peak load is due to increase of resistive moment. Resistive moment increases as lever arm increases.

Ultimate strength of the connection increase as the concrete strength increases. This increase of peak load is not linear. This non-linearity is because of increase of the tensile strain in concrete in the direction other than the compressive stress direction with the increase of concrete strength.

There is no effect of steel strength on the ultimate strength of the connection provided that concrete crushing controls failure mechanism of the connection before the steel yielding. If yielding of steel controls the failure mechanism then ultimate load of the connection increases with the increase of the steel strength until the failure mechanism changes from yielding of steel to concrete crushing dominant case.

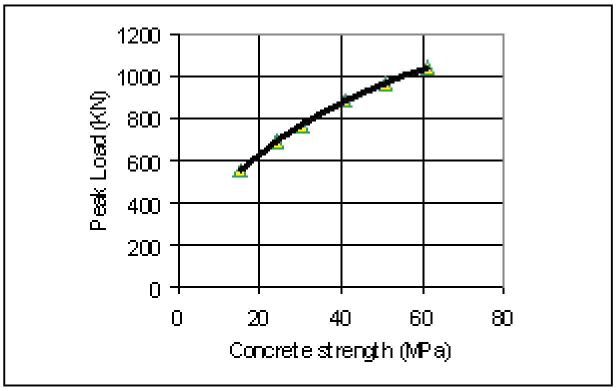

Fig. 11 Relationship between peak load and concrete strength

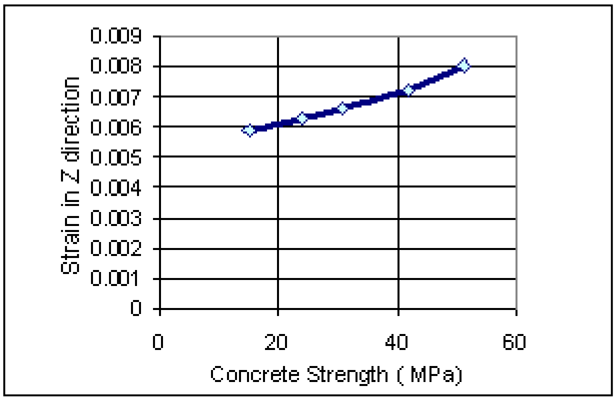

Fig. 12 Relationship of strain and concrete strength.

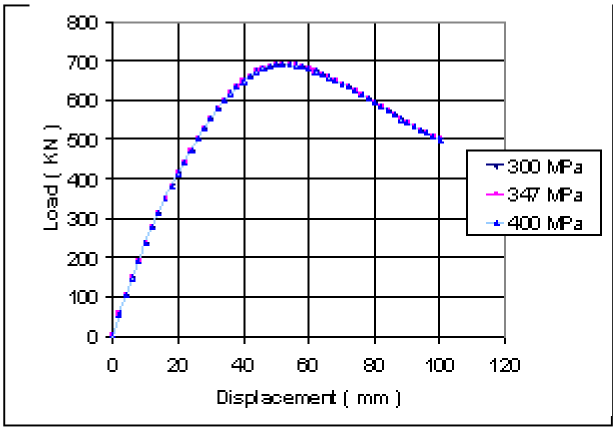

Fig. 13 Load - displacement relationship for different steel strength when no yielding of steel takes place

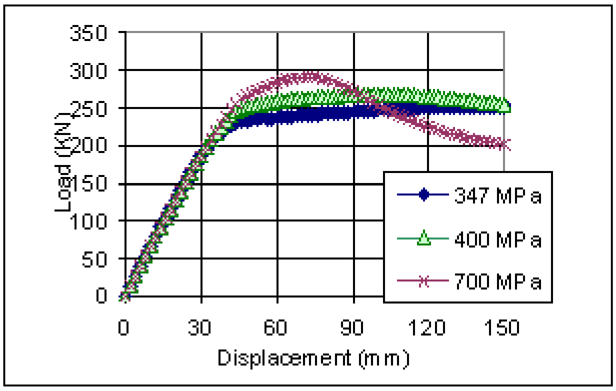

Fig. 14. Load - displacement relationship for different steel strength when yielding of steel takes place

5. Future work:

Effect of box size, diameter of pile and moment to shear retio in pile on the strength of connection will be observed in future. After that a simple model for the prediction of peak load will be determined on the basis of this parametric study.

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コンクリート充填鋼殻接合部における杭貫入深さ，コンクリートおよび鋼材強度の影響

ムハマド・オン・バシール，古内　仁，上田　多門

この研究の目的は，コンクリート充填鋼殻接合部の設計法を開発することである．この接合部は，鋼構造の接合部と比べて経済性で利点を有し，鉄筋コンクリート構造の接合部に比べて耐力や施工性で利点を有している．本研究では，接合部の強度に与えると考えられる杭の貫入深さ，鋼殻に充填されるコンクリートの圧縮強度，鋼殻の降伏強度の影響を調べた．これらを変数として，３次元有限要素プログラムCAMUIを用いて解析を行った結果，コンクリートの圧縮破壊と鋼材の曲げ破壊の２つの破壊形式が観測された．コンクリートの圧縮破壊においては，杭の抵抗モーメントのアーム長の大きさと，杭縁端を受けている付近のコンクリートの支圧強度が，接合部の耐力に影響を与えることが明らかとなった．また，この破壊形式では，鋼殻の降伏強度が変化しても，接合部の強度にはそれほど大きい影響を与えないことが明らかとなった．