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Research Article

Experimental and Finite Element Behavior of Concrete-Steel Frames under the Effect of Lateral and Vertical Loads

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Abstract

This research presents an experimental and finite element modeling investigation for the combined frames having reinforced concrete column connected to L-Shaped steel frame. Eight frames tested under constant vertical and variable lateral load up to failure. All frames had the same dimensions and classified into three groups. First group consist of two control frames (CC) and (SS) designed to carry the same lateral load. The second group includes testing of three combined frames (SC 1), (SC 0.5), and (SC 2) with different ratios of stiffness between steel beam and steel column (ksb/Ksc = 0.94, 0.5, 0.25) respectively. The third group includes testing of three combined frames (CS 1), (CS 0.5) and (CS 2) with the same dimensions in the second group, but changing lateral load direction. Frames SC1 and CS1 have the same cross section dimensions of steel beam, steel column and concrete column in control frames. Results indicates that lateral failure of the control concrete and steel frames were approximately equal but the horizontal displacement of concrete frame is about 31.74% compared to that of steel frame. Lateral failure load decreased by 34.7% for combined frame SC1, while horizontal displacement increased by 136% compared to concrete frame (CC) and decreased by 25% compared to steel frame (SS). Lateral failure load decreased by 37% for combined concrete - steel frame CS1, while horizontal displacement increased by 57% compared to concrete frame (CC) and decreased by 50% compared to steel frame (SS) since the concrete column absorbs most of lateral load and decreases horizontal displacement. The change in the relative stiffness between steel beam and steel column in frames does not influence lateral load capacity but affects the horizontal displacement. Three-dimensional finite element models created by using ANSYS program to simulate the behavior of the tested specimens. In addition, study of different parameters such as relative stiffness between steel beam and concrete column while change the relative stiffness between steel beam and steel column were investigated.

Keywords: *Concrete frames, Steel frames, Combined frames, Lateral Load.*

1. Introduction

Traditionally steel structures and concrete structures formed more or less two different worlds in structural engineering. Fortunately, this situation is changing rapidly. It is now recognized that each of the two materials have advantages and disadvantages and that often an optimal solution is found by combining both materials as shown in Fig. 1. This may be a combination of steel and concrete in an element as is the case in Composite steel-concrete construction or the combined use of concrete elements and steel elements in Mixed construction. There are not much research present combined structures but many researchers studied composite structures.

Ashraf E. Morshed (2015) presents RCS moment-resisting frame systems, consisting of Reinforced Concrete (RC) columns and Steel (S) beams, take advantage of the inherent stiffness and damping, low-cost of concrete, as well as the lightweight and construction efficiency of structural steel. Two structures without shear walls were considered to represent low-and medium rise RCS and RC structures to study. Theses consist of a typical steel beam and RC columns frame building three story RCS buildings designed according to the Egyptian Codes of Practice. The results shows that for even both structures have almost the base shear capacity, the RCS structures behave linearly till the maximum shear base capacity is reached , and soft story failure mechanism occurs.

Chin-Tung Cheng and Cheng-Chih Chen (2004) present the seismic behavior of steel beam to reinforced concrete column connections with or without the floor slab. Test results show that all specimens performed in a ductile manner with plastic hinges formed in the beam-ends near the column face.

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Fig. 1: Examples of Combined Structure in Kuwait

Under positive bending, it was found that the initial stiffness and ultimate strength of the composite beam had average increases of 67% and 27% respectively, compared with the steel beam without the slab. Under negative bending, similar ultimate strengths of specimens with and without the slab were obtained. This composite action disappeared after 3% drift of loading and then the lateral strength slowly deteriorated until fracture of the bottom flange occurred.

Pedro Silva and Sameh S. Badie (2008) presents computer analytically and graphically procedure that is used to establish the design optimization for portal frame under lateral load. Under lateral loads, frames design is highly dependent on the beam-column stiffness ratio, beam span to column height ratio, and the columns end supports. In this research, studying the frame with fixed end support and pinned support, the relative stiffness between beam and column were 0, 0.74 and ∞. The results show that for relative stiffness equal zero the frame deflection is fourth times higher than the deflection for relative stiffness equal ∞. This is because of relative stiffness equal zero the frame reverts to that of two cantilever columns.

2. Testing Program

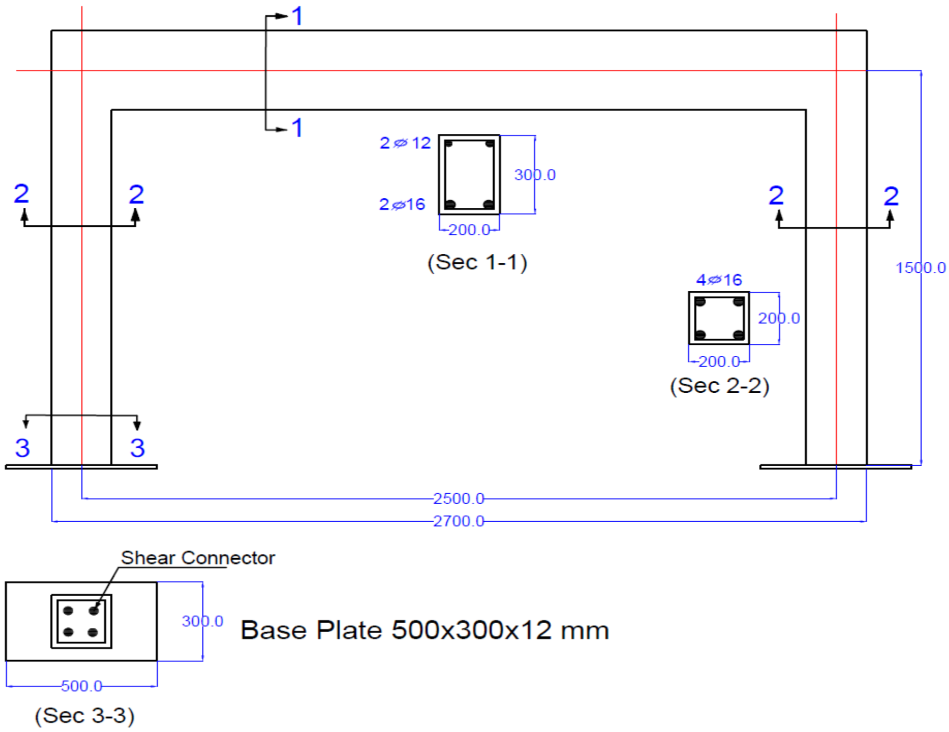
This section describes the experimental work performed through this study beginning with the used materials, specimen's details, measurement devices, test setup, and specimens grouping.

2.1. Materials Used

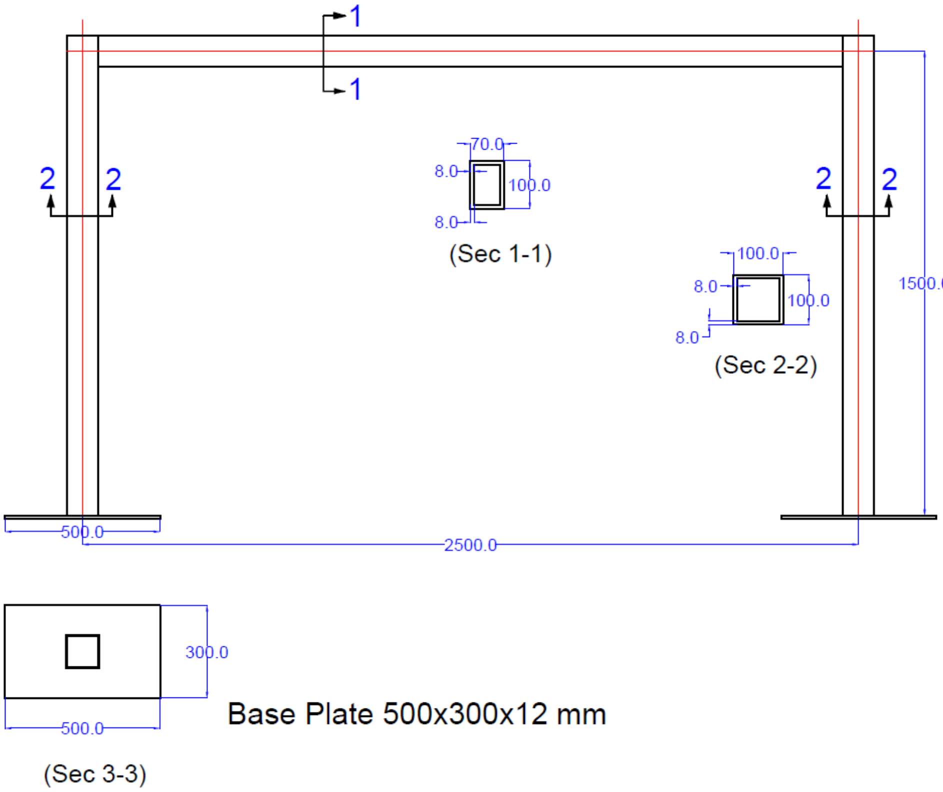
All specimens are made from one concrete mix of compressive strength, *Fcu*= 25 MPa, and according to the EN the equivalent compressive cylinder strength, Fc´= 20 MPa. The specimen's main reinforcement (longitudinal) is high grade deformed steel bars with 360 MPa nominal yield stress while the lateral reinforcement (stirrups) is mild smooth bars with 240 MPa nominal yield stress. The steel sections used had 240 MPa yield stress, ultimate stress 370 MPa passion's ratio 0.3.

2.2. Specimens Details

The frames had a rectangular cross section for concrete column with a 200 mm width, 200 mm thickness, box section for steel columns (compact section) to avoid local torsional buckling and a span of 2500 mm, the height of frames was 1500 mm. The base plate is 500 x 300 x 12 mm. All frames tested under constant vertical load and variable lateral load up to failure. First group consist of concrete frame F1 (CC) and steel frame F2 (SS) as shown in Fig. 2. The second group includes testing of three concrete and steel frames F3 (SC 1), F4 (SC 0.5), and F5 (SC 2) to study the influence of relative stiffness ratio of beam–column (Ksb/Ksc = 0.94, 0.5, 0.25) on the behaviors of the frame structures as shown in Fig. 3. The parameters remain the same, just changing the inertia of steel column to achieve the purposes of changing the relative stiffness ratio of the beam–column. The third group includes testing of three frames F6 (CS 1), F7 (CS 0.5) and F8 (CS 2) with the same dimension in second group, but changing lateral load direction.



(a)Concrete frame



(b) Steel frame

Fig. 2: Details of Control Frames in the First Group

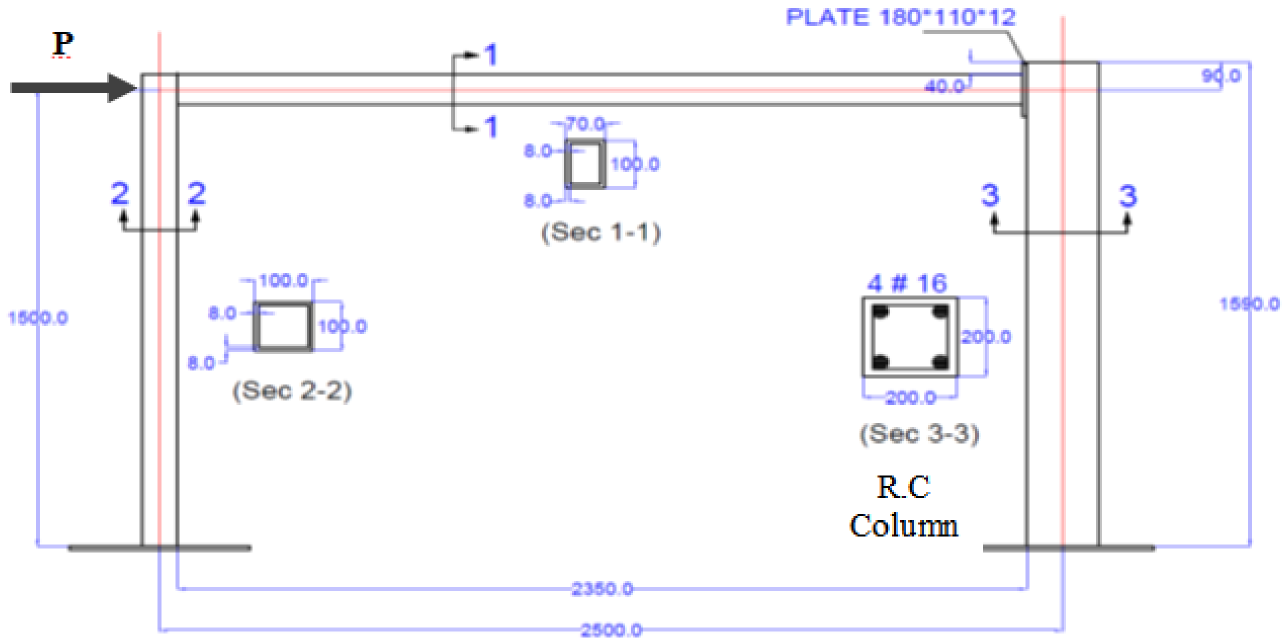
2.3. Test Setup and Instrumentation

The specimens were tested using the facilities and resources of the reinforced concrete laboratory of the Faculty of Engineering, El-Mataria, Helwan University. All specimens were statically tested using rigid steel frame such that the centerline of the specimen was oriented perpendicular to the centerline of the steel frame. The specimen was supported over two steel footings of height 120 mm each footing (fixed support).

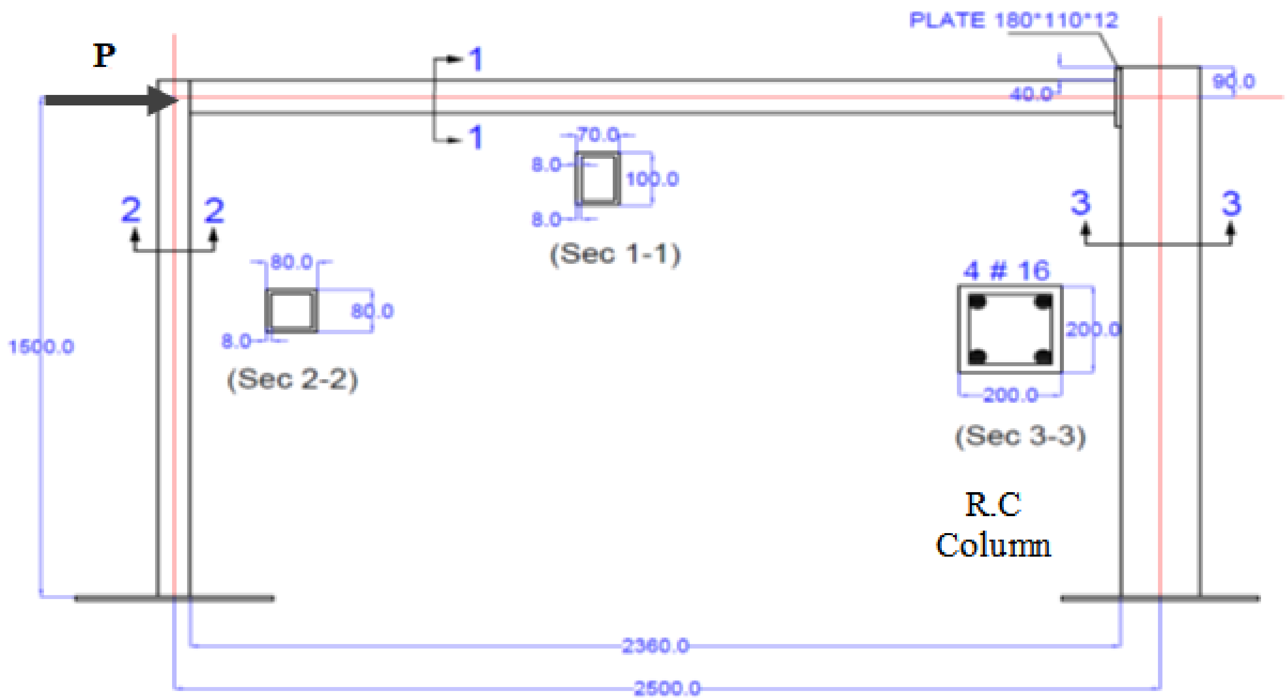
Two steel footing are tied to the rigid steel I-beam using very rigid angles. These angles were mainly to prevent the movement of the footing during the test. The load was manually and monotonically increased up to failure using a hydraulic jack of 1000 kN capacity. Fig.4a and Fig.4b shows the setup

2.4. Measurements

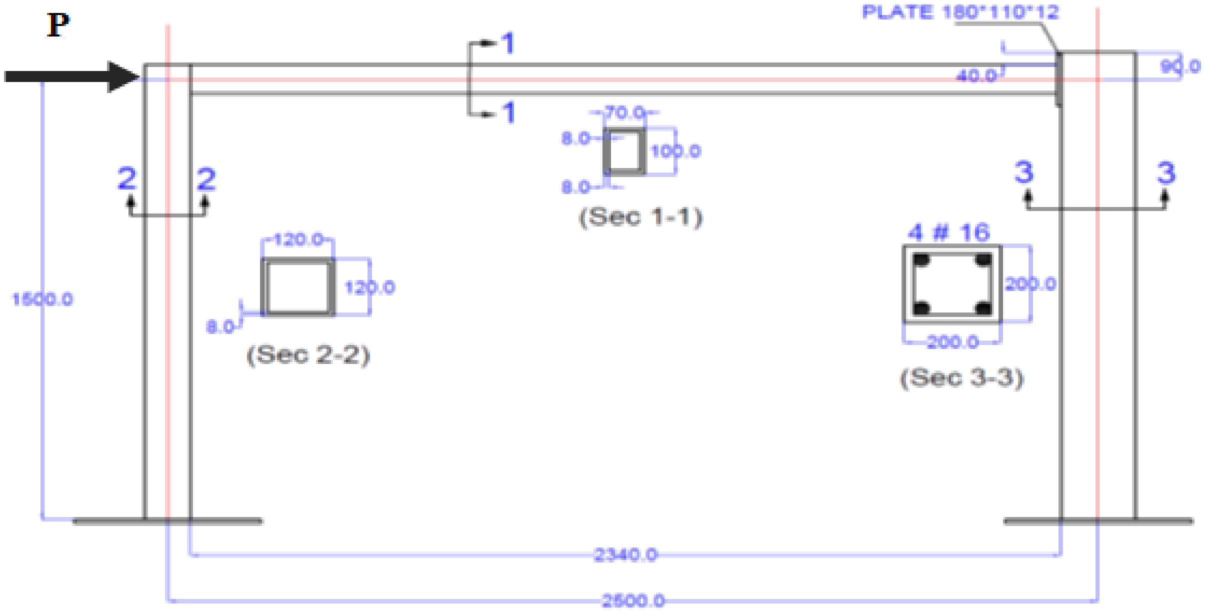
Two linear voltages Displacement Transducer (LVDT'S) were used to measure the various types of deformations on frame. The LVTD (1) was attached the lower mid-span part of the frame beam to measure the vertical displacement. The LVTD (2) was attached the upper part of the frame column to measure the horizontal displacement. Electrical strain gauges were used to measure strain in steel reinforcement bars, and steel section. The electrical strain gauges were of type PL-60-11-1L. The locations of the strain gauge are shown in Fig.5a and Fig.5b.



Frame SC1



Frame SC 0.5



Frame SC 2

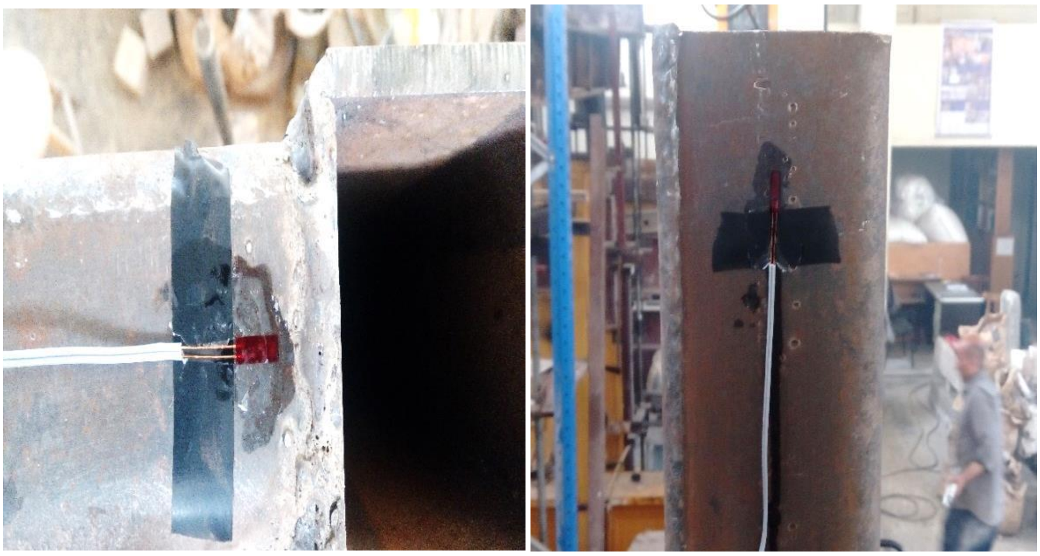
Fig. 3: Details of the Tested Frames in Second Group

4-a) Concrete Frame

4-a) Concrete-Steel Frame

Fig.4: Test Setup and Loading System

5-a) Steel Bars



5-b) Steel Sections

Fig 5: Electrical Strain Gauges Locations

3. Test Results and Discussions

This section describes the experimental test results and discussion concerning ultimate loads, load-displacement relationship, and failure patterns.

3.1 Crack pattern and Failure Modes

Frame CC tested as a control concrete specimen. The failure lateral load of the specimen was 48.9 kN and the corresponding horizontal displacement measured by LVDT was 30.22 mm. The frame failed in a tension failure mode. The tension cracks first appeared at the mid span at vertical load 30 kN and lateral load 11.0 kN. Second crack at far joint were observed at lateral Load 38.8 kN. While the lateral load increases, cracks at both mid span and joint increases in width and extended towards the compression zone. The frame failed due to yielding of steel bars followed by crushing of concrete at tension side. Cracking continued to increase up to failure load of the test frame. Cracks propagation and failure modes of the frame shown in Fig.6 .For Frame SS tested as a control steel specimen. The failure lateral load of the specimen was 49.5 kN and the corresponding horizontal displacement measured by LVDT was 95.2 mm. The frame failed in a tension failure mode. The observed deflection appeared at the mid span of steel beam at vertical load 31.1 kN and lateral load 15.7 kN. The frame failed due to an excessive lateral drift at constant load, followed by splitting the column from base plate.

Failure mode of the frame shown in Fig. 7. For frame SC1, The failure lateral load of the specimen was 32.3 kN and the corresponding horizontal displacement measured by LVDT was 67.52 mm. The tension cracks first appeared at the top of concrete column at vertical load 30 kN and lateral load 14.5 kN. Second crack appeared at base of concrete column at lateral load 15.0 kN. The frame failed by splitting at the base of the concrete column in tension direction. Cracking continued to increase up to failure load of the test frame. Cracks propagation and failure modes of the frame shown in Fig. 8. For Frame SC 2 the failure lateral load of the specimen was 32.0 kN and the corresponding horizontal displacement was 53.52 mm. The tension cracks first appeared at the base of concrete column at vertical load 30 kN and lateral load 16.5 kN. Second crack appeared at base of concrete column at lateral load 22.8 kN. The frame failed by splitting of the far base of the concrete column in tension direction. Cracking continued to increase up to failure load of the test frame. Cracks propagation and failure modes of the frame shown in Fig. 9. For Frame SC 0.5 the failure lateral load of the specimen was 32.2 kN and the corresponding horizontal displacement was 89.47 mm. The tension cracks first appeared at the base of concrete column at vertical load 30 kN and lateral load 17.0 kN and separation of steel plate from the concrete at the connection between steel beam and concrete column. Second crack appeared at base of concrete column at lateral load 16 kN. The frame failed by splitting at the far base of the concrete column in tension direction. Cracking continued to increase up to failure load of the test frame. Cracks propagation and failure modes of the frame shown in Fig. 10. For Frame CS1 the failure lateral load of the specimen was 31.1 kN and the corresponding horizontal displacement was 47.39 mm The tension cracks first appeared at the base of concrete column at vertical load 30 kN and lateral load 20.61 kN. The frame failed by splitting of the base of the concrete column. Cracking continued to increase up to failure load of the test frame. Cracks propagation and failure modes of the frame shown in Fig. 11. For Frame CS2 the failure lateral load of the specimen was 31.8 kN and the corresponding horizontal displacement was 35.5 mm. The tension cracks first appeared at the base of concrete column and splitting of the base of the concrete column at vertical load 30 kN and lateral load 23.3 kN. The frame failed by splitting of the base of the concrete column. Cracking continued to increase up to failure load of the test frame. Cracks propagation and failure modes of the frame shown in Fig. 12. For Frame CS0.5 the failure lateral load of the specimen was 28.30 kN and the corresponding horizontal displacement was 60.95 mm. The tension cracks first appeared at the base of concrete column at vertical load 30 kN and lateral load 23.9 kN. The frame failed by splitting of the base of the concrete column. Cracking continued to increase up to failure load of the test frame. Cracks propagation and failure modes of the frame shown in Fig. 13.

Fig 6: Failure Mode of Frame CC

Fig 7: Failure Mode of Frame SS

Fig 8: Failure Mode of Frame SC1

Fig 9: Failure Mode of Frame SC2

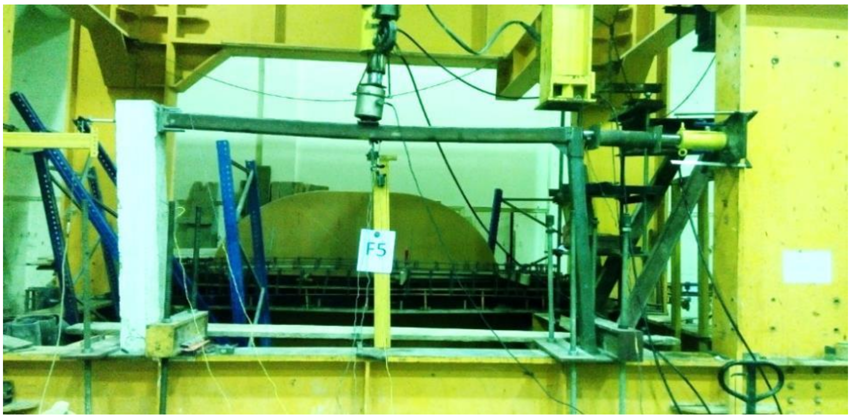


Fig 10: Failure Mode of Frame SC0.5

Fig 11: Failure Mode of Frame CS1

Fig 12: Failure Mode of Frame CS 2

Fig 13: Failure Mode of Frame CS 0.5

3.2 Load-Deflection Relationship

Table (1) shows the experimental results of the tested frames.

Table 1: Experimental results

Specimen Name	Experimental Failure lateral load Hu (kN)x10	Horizontal displacement Δh (mm)
CC	4.89	30.22
SS	4.95	95.2
SC 0.5	3.21	89.47
SC 1	3.23	71.50
SC 2	3.206	53.52
CS 0.5	2.826	60.95
CS 1	3.11	47.39
CS 2	3.18	35.5

From Fig. 14, it could be seen that the lateral failure load of whole concrete and whole steel frames approximately equal but the horizontal displacement of concrete frame less than 68.2% relative to the which of whole steel frame. Lateral failure load decreased by 34.7% for combined concrete and steel frame SC1, while horizontal displacement increased by 136% compared to that of whole concrete frame and decreased by 25% compared to that of whole steel frame. Using combined steel and concrete in frame structure does not significantly improve lateral load capacity when columns have the same capacity and different stiffness resulting in decreasing lateral load this is due to the action of concrete column acts as a cantilever action.

From Fig. 15 it could be seen that lateral failure load decreased by 37% for combined concrete and steel frame CS1, while horizontal displacement increased by 57% compared to whole concrete frame and decreased by 50% compared to whole steel frame this due to the concrete column absorbs most of lateral load and decreases horizontal displacement.

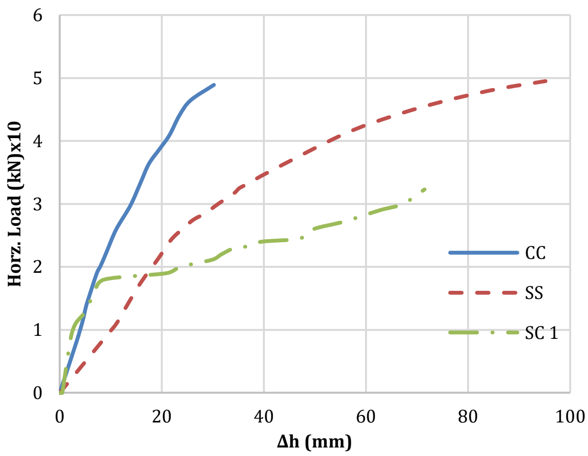


Fig 14: Effect of Used Combined Concrete - Steel Frame (SC 1) on Load-Displacement compared to Steel and Concrete Frames

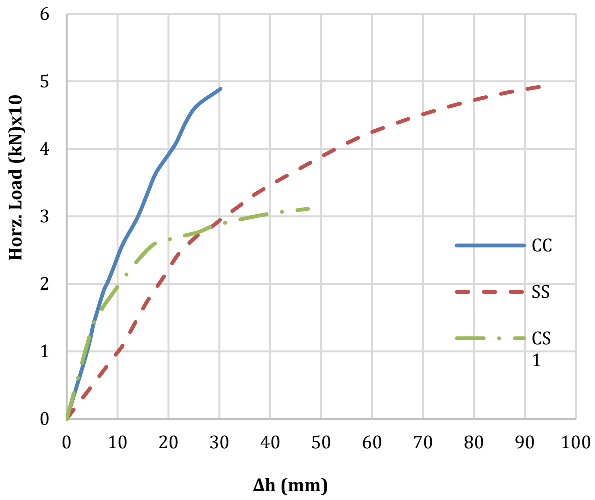


Fig 15: Effect of Used Combined Concrete - Steel Frame (CS 1) on Load-Displacement compared to Steel and Concrete Frames

From Fig. 16 it could be seen that the lateral failure load approximately same for the three frames, while horizontal displacement decreased by decreasing the relative stiffness between steel beam and steel column (increase inertia of steel column 0.5, 1.0 and 2.0). Therefore, decrease relative stiffness between steel beam and steel column in frame structure does not improve lateral load due to the concrete column behavior is a cantilever action, but decrease the frame horizontal displacement due to stiff steel column. Therefore, a parametric study required to explain the effect of changing the dimensions of the concrete column.

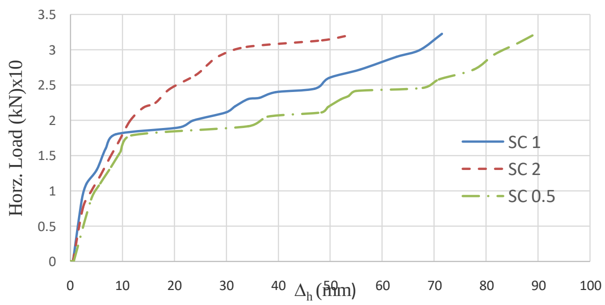


Fig 16: Effect of Change the Relative Stiffness between Steel Beam and Steel Column on Load-Displacement

From Fig. 17 it could be seen that a small increase in lateral failure load resulted from decreasing the relative stiffness and change loading directions, while horizontal displacement decreased by decreasing the relative stiffness between steel beam and steel column (increased inertia of steel column 0.5, 1.0 and 2.0). So increase the relative stiffness between steel beam and steel column in frame structure decrease lateral load capacity and increase the frame horizontal displacement.

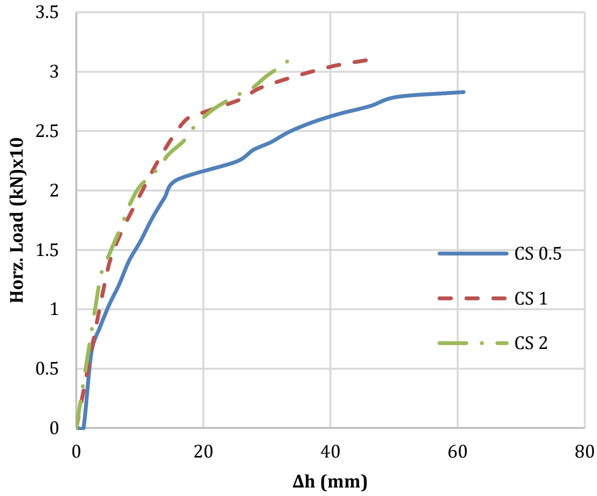


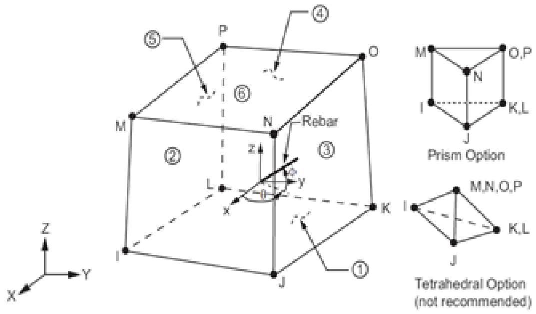
Fig 17: Effect of Change the Lateral Load Direction on Load-Displacement

Accordingly, the stiffness of concrete column significantly control the lateral failure load and horizontal displacement in combined frames. Therefore, finite element analysis included the study of change relative stiffness between steel beam and concrete column with change the relative stiffness between steel beam and steel column.

4. Finite elements Analysis

This part describes the proposed finite element modeling using software program ANSYS (version 15.0). All necessary steps are taken to creating the analytical models capable of simulating the behavior of frames consist of reinforced concrete parts and steel parts under lateral and vertical loads. To verify the model, the analytical results were correlated to the experimental results.

An eight-node solid element, solid65, was used to model the concrete as solid element Fig.18, which has eight nodes with three degrees of freedom at each node, translations in x, y, and z directions. A three dimensional element link180 was used to model the steel reinforcement, the element has two nodes, each node has three translations degrees of freedom, in x, y, and z directions as shown in Fig. 19. SOLID185 is used for the 3-D modeling of solid structures. Eight nodes having three degrees of freedom at each node define the element: translations in the nodal x, y, and z directions as shown in Fig. 20. Meshing allow to establish such factors as element shape, mid side node placement, and element size to be used in meshing the model which affect on the accuracy of the model analysis. Many area element can be both triangular and quadrilateral shaped within the same meshed area as shown in Fig. 21.



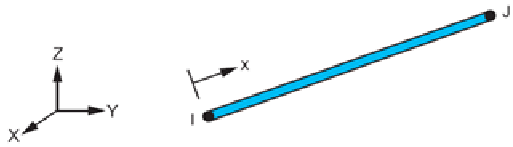


Fig. 18: Solid65 Element for Concrete Model **Fig. 19:** LINK180 Geometry ANSYS 15

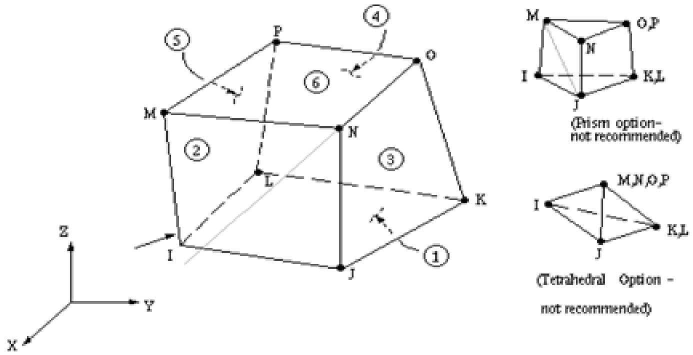


Fig. 20: SOLID185 for Steel Section and Steel Plates Element

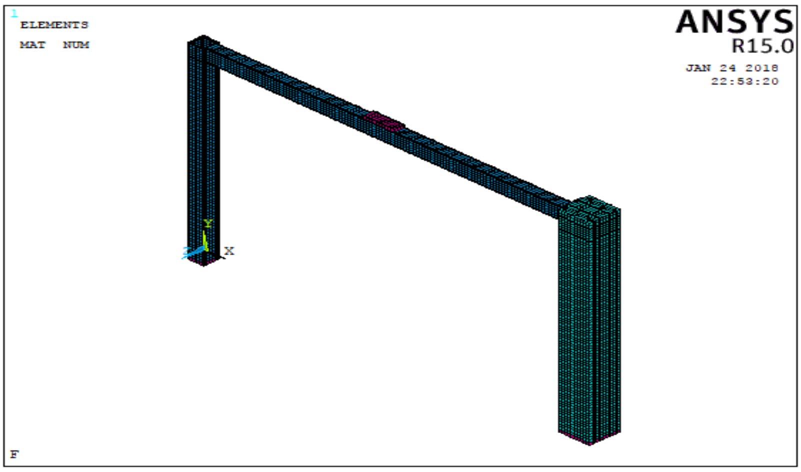


Fig. 21: Shape of Finite Element Model for Frame SC 1

4.1. Correlation between the Analytical and Experimental Results.

The numerical results are presented in terms of the load carrying capacity, horizontal displacement. Test the experimental results previously presented are compared with those calculated from the finite element program and represented in Table 2.

Table 2: Comparison Experimental and Finite Element Predicted Results

Frame ID	Experimental Work		Finite Element Models		F.E/ Exp	
	Failure load (kN)x10	Horizontal Deflection (mm)	Failure load (kN)x10	Horizontal Deflection (mm)	Load	Horizontal Deflection
CC	4.89	30.22	5.01	28.16	1.02	0.932
SS	4.95	95.2	4.80	93.16	0.97	0.979
SC 1	3.23	71.5	3.45	58.18	1.11	0.814
SC 2	3.206	53.52	3.32	33	1.035	0.617
SC 0.5	3.215	89.47	3.32	69	1.033	0.771

Frame ID	Experimental Work		Finite Element Models		F.E/ Exp	
	Failure load (kN)x10	Horizontal Deflection (mm)	Failure load (kN)x10	Horizontal Deflection (mm)	Load	Horizontal Deflection
CS 1	3.11	47.39	3.32	38.25	1.067	0.807
CS 2	3.18	35.5	3.32	25.6	1.044	0.721
CS 0.5	2.826	60.95	3.32	43.81	1.175	0.719

Table 2: Comparison Experimental and Finite Element Predicted Results

Frame ID	Experimental Work		Finite Element Models		F.E/ Exp	
	Failure load (kN)x10	Horizontal Deflection (mm)	Failure load (kN)x10	Horizontal Deflection (mm)	Load	Horizontal Deflection
CC	4.89	30.22	5.01	28.16	1.02	0.932
SS	4.95	95.2	4.80	93.16	0.97	0.979
SC 1	3.23	71.5	3.45	58.18	1.11	0.814
SC 2	3.206	53.52	3.32	33	1.035	0.617
SC 0.5	3.215	89.47	3.32	69	1.033	0.771
CS 1	3.11	47.39	3.32	38.25	1.067	0.807
CS 2	3.18	35.5	3.32	25.6	1.044	0.721
CS 0.5	2.826	60.95	3.32	43.81	1.175	0.719

Table 3: Finite Element Models Details

Specimen Name	Beam X-section (mm)	Column X-section (mm)		As of Concrete Beam (mm^2)	As of Concrete Column (mm^2)	Stirrups
		Right	Left		Left column	
CC	140x140	140x140	140x140	534	571.4	Φ8/140 mm
SS	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	Steel Tube 100 x 100 x 8	----	----	----
SC	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	140x140	534	571.4	Φ8/140 mm

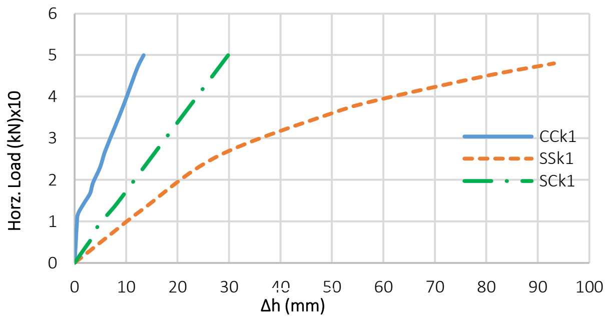


Fig. 22: Effect Stiffness of Combined Concrete - Steel Frame (SCk1) on Load-Displacement compared to Steel and Concrete Frames

4.2. Effect of Equal Stiffness in Concrete, Steel Frame and Combined Frame

A new finite element models are introduced. Concrete, Steel, and combined frames are modeled with the same stiffness and same capacity of beams and columns in Table 3 to study the effect of stiffness on the behavior of combined frames.

4.2.1 Load – Horizontal Displacement Relationship

From Fig. 22, it can be seen that the lateral failure of concrete, steel and combined frames were approximately equal because they have the same initial stiffness and same capacity but the horizontal displacement of concrete frame less than 85.6% compared to the horizontal displacement of steel frame.

While horizontal displacement of combined frame increased by 123% compared to concrete frame and decreased by 68% compared to steel frame.

4.3 Effect of Change the Relative Stiffness between Steel Beam and Steel Column, Concrete Column

New finite element models are introduced in Table 4 to study effect of different relative stiffness between steel beam and both of steel and concrete column in the behavior of combined frames. Relative stiffness between steel beam and concrete column Ksb/Kcc= 2.17, 1, 0.57, 0.33, 0.25, 0.136, 0.027 and 0.00108

Where, Ksb = Stiffness of steel beam
Kcc = Stiffness of concrete column
Ksc = Stiffness of steel column

Table 4: Finite Element Models Details

ksb/Ksc	ksb/kcc	Beam X-section (mm)	Column X-section (mm)		As of Concrete Column (mm^2)	Stirrups
			Right	Left		
0.94	2.17	Steel Tube 100 x 70 x 8	Steel Tube 80 x 80 x 8	100 x 100	400	Φ8/140 mm
	1	Steel Tube 100 x 70 x 8	Steel Tube 80 x 80 x 8	120x120	400	Φ8/140 mm
	0.57	Steel Tube 100 x 70 x 8	Steel Tube 80 x 80 x 8	140x140	400	Φ8/140 mm
	0.33	Steel Tube 100 x 70 x 8	Steel Tube 80 x 80 x 8	160x160	400	Φ8/140 mm
	0.25	Steel Tube 100 x 70 x 8	Steel Tube 80 x 80 x 8	170x170	400	Φ8/140 mm
	0.136	Steel Tube 100 x 70 x 8	Steel Tube 80 x 80 x 8	200x200	400	Φ8/140 mm
	0.027	Steel Tube 100 x 70 x 8	Steel Tube 80 x 80 x 8	300x300	400	Φ8/140 mm
	$1.08x10^{-3}$	Steel Tube 100 x 70 x 8	Steel Tube 80 x 80 x 8	200 x 1000	*1130*	Φ8/140 mm
0.5	2.17	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	100 x 100	400	Φ8/140 mm
	1	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	120x120	400	Φ8/140 mm
	0.57	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	140x140	400	Φ8/140 mm
	0.33	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	160x160	400	Φ8/140 mm
	0.25	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	170x170	400	Φ8/140 mm
	0.136	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	200x200	400	Φ8/140 mm
	0.027	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	300x300	400	Φ8/140 mm
	$1.08x10^{-3}$	Steel Tube 100 x 70 x 8	Steel Tube 100 x 100 x 8	200 x 1000	*1130*	Φ8/140 mm
0.25	2.17	Steel Tube 100 x 70 x 8	Steel Tube 120 x 120 x 8	100 x 100	400	Φ8/140 mm
	1	Steel Tube 100 x 70 x 8	Steel Tube 120 x 120 x 8	120x120	400	Φ8/140 mm
	0.57	Steel Tube 100 x 70 x 8	Steel Tube 120 x 120 x 8	140x140	400	Φ8/140 mm
	0.33	Steel Tube 100 x 70 x 8	Steel Tube 120 x 120 x 8	160x160	400	Φ8/140 mm
	0.25	Steel Tube 100 x 70 x 8	Steel Tube 120 x 120 x 8	170x170	400	Φ8/140 mm
	0.136	Steel Tube 100 x 70 x 8	Steel Tube 120 x 120 x 8	200x200	400	Φ8/140 mm
	0.027	Steel Tube 100 x 70 x 8	Steel Tube 120 x 120 x 8	300x300	400	Φ8/140 mm
	$1.08x10^{-3}$	Steel Tube 100 x 70 x 8	Steel Tube 120 x 120 x 8	200 x 1000	*1130*	Φ8/140 mm

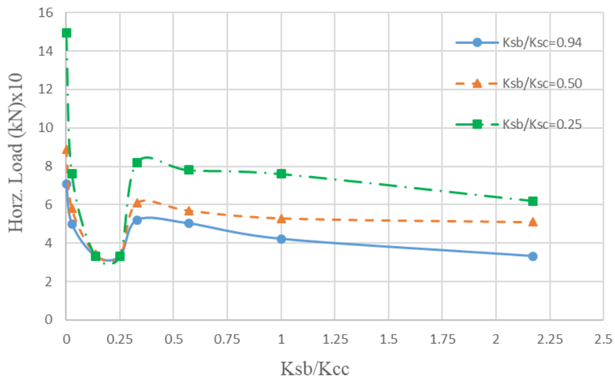


Fig. 23: Effect of Change the Relative Stiffness Ksb/kcc at Different Ksb/Ksc on Horizontal Load

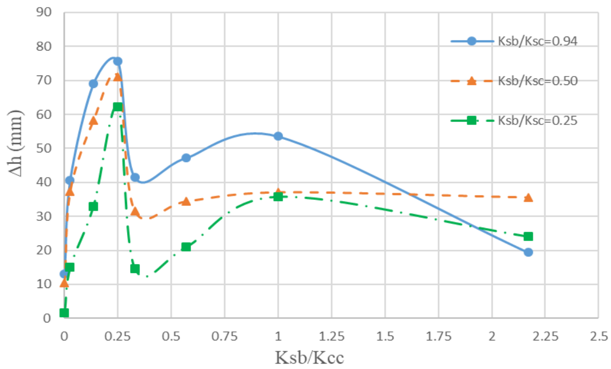


Fig. 24: Effect of Change the Relative Stiffness Ksb/kcc at Different

Fig. 23 and Fig. 24 show the effect of change of the relative Stiffness Ksb/kcc (2.17, 1, 0.57, 0.33, 0.25, 0.136, 0.027 and 0.00108) at different Ksb/Ksc (0.94, 0.5and 0.25) on horizontal Load and horizontal displacement of combined concrete-steel frames. Three curves have same behavior but the increase in relative stiffness between steel beam and steel column Ksb/Ksc lead to decrease the failure horizontal load and increase the horizontal displacement.

Conclusions

Conclusions based on to Experimental Results

- The lateral failure of concrete and steel frame that have the same capacity approximately equal but the horizontal displacement of concrete frame is about 31.74% compared to the horizontal displacement of steel frame.
- Failure load decreased by 34.7% for the combined frame SC 1 compared to steel, concrete frames, while horizontal displacement increased by 136% compared to concrete frame, decrease, and 25% compared to steel frame. Using combined frame when columns have the same capacity and different stiffness which in whole concrete and whole steel frames does not significantly improve lateral load capacity this is due to the action of concrete column acts as a cantilever action.
- Failure load decreased by 37% for the combined frame CS 1 compared to steel, concrete frames, while horizontal displacement increased by 57% compared to whole concrete frame and decreased by 50% compared to whole steel frame.
- Increase the relative stiffness between steel beam and steel column in frame structure does not improve lateral load capacity but increase the frame horizontal displacement.
- Lateral displacement decreases with decreasing the relative stiffness between steel beam and steel column, until in case of reversing load direction.

Conclusions According to Analytical Analysis

- The lateral failure load of concrete, steel and combined concrete-steel frames that have the same stiffness and same capacity approximately equal. However, the horizontal displacement of concrete frame is about 14.4% of the horizontal displacement of steel frame. While horizontal displacement of combined concrete-steel frame increased by 123% compared to concrete frame and decreased by 68% compared to steel frame.
- Decreasing relative stiffness between steel beam and concrete column (Ksb/Kcc), from 2.17 to 0.33, the failure load increases.
- The lateral displacement increases with decrease the relative stiffness (Ksb/Kcc) from 2.17 to 1.0 due to presence stiff beam, which developed to that propped cantilever concrete column.
- For (Ksb/Kcc) from 1.0 to 0.33, the lateral displacement decreases, due to the effect of increase column stiffness.
- For relative stiffness (Ksb/Kcc) ≤ 0.25, the concrete column behaves to a cantilever column, so the failure load at (Ksb/Kcc) equal 0.25 decreases while lateral displacement increases.
- At relative stiffness (Ksb/Kcc) values < 0.25, the failure load begin to increase, while lateral displacement decrease. This is due to the increase the concrete column stiffness.
- The increase in relative stiffness (Ksb/Ksc) leads to decrease in lateral failure load and increase the lateral displacement.

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