ANALYSIS AND DESIGN OF MULTI-STOREY COMPOSITE BUILDING

Mr Nann Tin [1], Dr Tin Tin Win[2]

[1]Postgraduate Student, Department of Civil Engineering,
Mandalay Technological University, Myanmar
[2]Director, Myanma Science and Technological Research Department,
Ministry of Science and Technology
nantin.2008@gmail.com

ABSTRACT: Many types of multistory buildings are the symbols of modernized and developed nations. These buildings are the solution to the problem of living because of population growth. High-rise steel frame and concrete frame structures have been constructed in design of tall buildings in our country as a standard role. But, composite tall building is not situated up to now. Therefore, it is necessary to study special attention in designing the composite tall building.

This study deals with composite action in structural members of 5 stories composite building. It belongs to seismic zone 2A. The spans of the sample model are arranged from 10 feet to 30 feet. Analysis of building is carried out by using ETABS Software. In designing beam members, ETABS Software is also used, but CSICOL Software is introduced for column design. Only square sections are used in column design for the purpose of easy to construct the building. The structure is composed of special moment resisting frame by using steel and concrete materials. Seismic load follows the Uniform Building Code (UBC) procedure of equivalent static and dynamic analysis load assumptions and load combinations are also according to UBC provision. In dynamic analysis, response spectrum method is used. Wide flange W-sections are used for frame members associated with reinforced concrete. Floor slabs are designed as metal steel deck supporting concrete slab system. Joints are considered as rigid joints and connection is designed with bolts and weld. Necessary checking is carried out for the stability of the superstructure.

Keywords: composite action, column design, metal deck slab, connection design, dynamic analysis.

1. INTRODUCTION

All high-rise are composite buildings because a functional building cannot be built by using only steel or concrete. For example, concrete is invariably used for floor slabs in an otherwise all steel building. Similarly, in a critical sense, use of mild steel reinforcement transforms a concrete building into a composite building. Without being too pragmatic, we will settle for the definition of composite buildings as those with a blend of structural steel and reinforced concrete.

Composite members and some forms of composite systems have been used extensively somewhere around the world. The history of application of composite designs back to the last 30 years particularly for member designs. Formalized design standards and specifications for composite members have involved at slower pace compared to that of structural steel and reinforced concrete. This is because; the design standards for composite members have involved from either steel or concrete design methods.

The earliest composite construction consisted of structural steel beams and reinforced concrete slabs, with shear connectors in-between. The system called the composite floor system, first developed for bridge construction, was readily adopted to buildings. It phenomenal success inspired engineers to develop composite building system by combining structural steel reinforced concrete in a variety of vertical building systems.

2. **METHODOLOGY**

2.1. **Composite Action**

Composite action is developed when two load-carrying structural members such as a concrete floor system and the supporting steel beam are integrally connected and deflect as a single unit. The extent to which composite action is developed depends on the provisions made to insure a single linear strain from the top of the concrete slab to the bottom of the steel section.

When a system acts compositely *Fig.1.* no relative slip occurs between the slab and beam. Horizontal force (shears) are developed that act on the lower surface of the slab to compress and shorten it.


(a) (b)

Figure 1.Comparison of Deflected Beams with and without Composite Action (a) Deflected Non-composite Beam. (b) Deflected Composite Beam.

2.2. **Composite Elements**

To get an insight into different composite building schemes, it is instructive to study the various techniques of compositing both the horizontal and vertical elements. These are:

1. Composite slabs or steel concrete floor system.
2. Composite girders.
3. Composite column.
4. Composite diagonals.
5. Composite shear walls.

2.3. **Composite Slabs or Steel Concrete Floor System**

Composite floor system can consist of simply supported prismatic or haunched structural steel beams, trusses or slab girders linked via shear connectors to a concrete floor slab to form an effective T-beam flexural member. Formed metal deck supporting a concrete topping slab is an integral component in these floor systems used nearly exclusively in steel frame buildings.

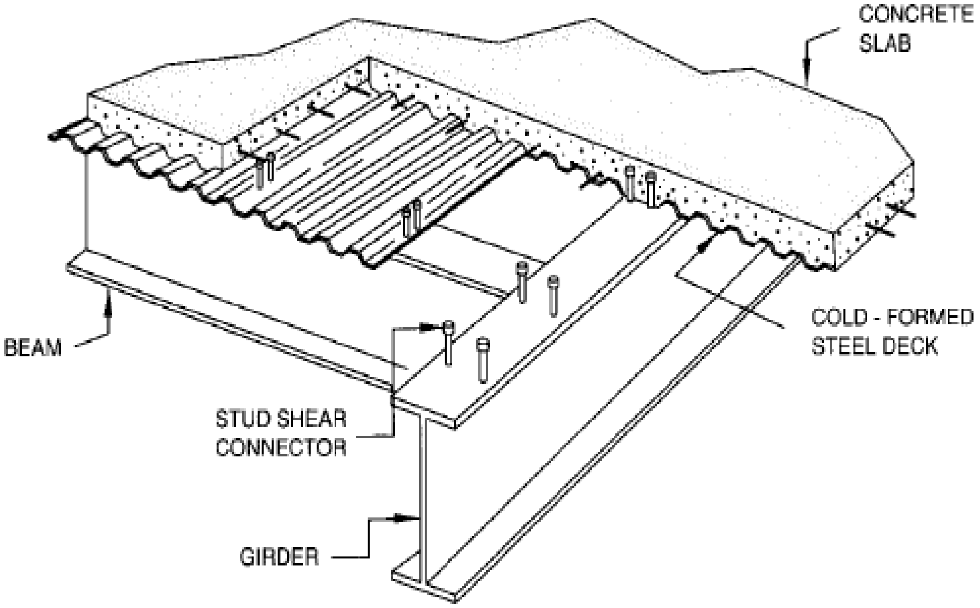


Figure 2. Beam and Girder with Shear Connectors for Composite Action with Concrete Slab

2.4. **Shear Connectors**

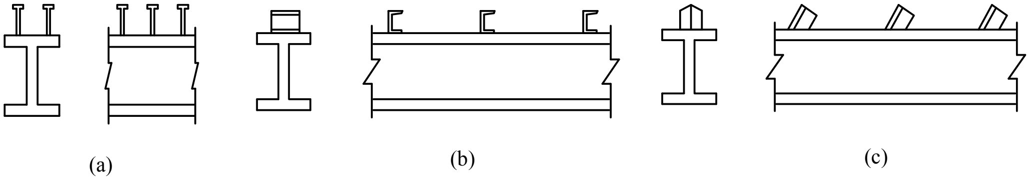


Figure 3. Types of Connector. (a) Stud Connectors (b) Channel Connectors (c) Angle Connectors

2.5. **Shear Connector Requirement for Composite Beam**

The number of shear connectors required for full composite action is determined by dividing the smaller value of V_h by the shear capacity of one connector. The number of connectors obtained represents the shear connectors required between the point of maximum positive moment and point of zero moment.

The total horizontal shear to be resisted between the point of maximum positive moment and point of zero moment and point of zero moment is the smaller of the two values as determined by

$$V_h = \frac{0.85 f_c' A_c}{2} \tag{2.1}$$

$$V_h = \frac{A_s F_y}{2} \tag{2.2}$$

Where, f_c' = specified compressive strength of concrete

A_c = actual area of effective concrete flange

A_s = area of steel beam

F_y = specified yield stress of steel beam

Note that the Equation (2.1) assumes that there is no longitudinal reinforcing steel in the compression zone of composite beam. If the compressive zone is designed with mild steel reinforcement, the formula for horizontal shear is to be modified as follows:

$$V_h = \frac{0.85 f_c' A_c}{2} + \frac{A_s' F_{yr}}{2} \tag{2.3}$$

Where, A_s' = area of the longitudinal compressive steel

F_{yr} = yield stress of the reinforcing steel

Shear connectors required in the region of negative bending moment and each point of zero moment. For concentrated loads, the numbers of shear connectors N_2 required between any concentrated load and the nearest point of zero moment is determined by AISC formula:

$$N_2 = \frac{N_1 \left[\frac{M_\beta}{M_{max}} - 1 \right]}{\beta - 1} \tag{2.4}$$

Where, M = moment at concentrated load point (less than the max: moment)

N_1= number of connectors required between point of maximum moment and point of zero moment

B = ratio of transformed section modulus to steel section modulus

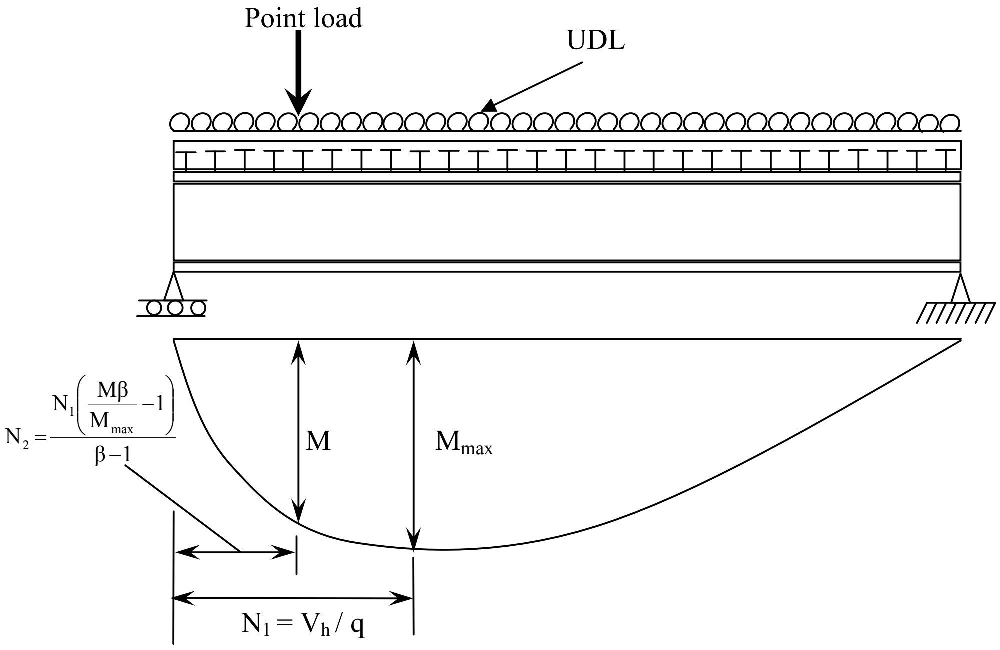


Figure 4. Shear Connector Requirements for Composite Beams Subjected to Concentrated Loads

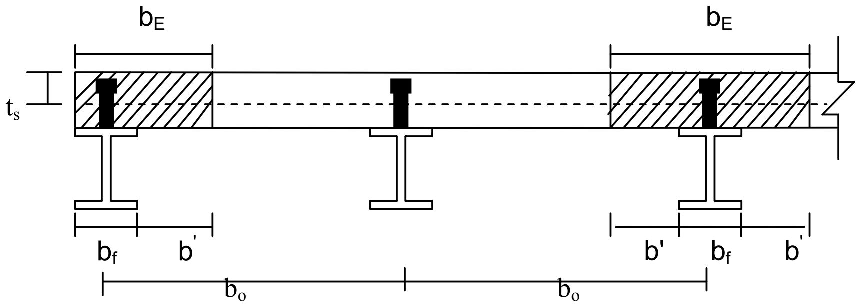


Figure 5. Effective width dimension

The American Concrete Institute (ACI) Code [16.15] has long used the following effective flange widths for T-sections:

1. For an interior girder,

   $b_E \leq {}^{L}/_{4}$

   $b_E \leq b_o$ (for equal beam spacing)

   $b_E \leq b_f + 16\ t_s$

2. For exterior girder,

   $b_E \leq b_f + {}^{L}/_{12}$

   $b_E \leq b_f + 16\ t_s$

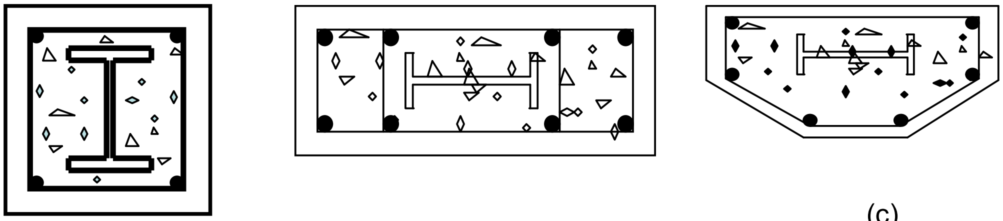
   $b_E \leq b_f + 0.5$ (clear distance to next beam)

2.6. **Composite Column**

The ACI code permits the use of any shape inside of a composite column, with a stipulation that the yield strength of steel cannot be greater than 50 ksi. For tied columns, the minimum reinforcement ratio is limited to 8 and 6 percent for wind and seismic designs respectively. The lateral spacing of longitudinal bars cannot exceed half the length of the shorter side of the section, 16 diameters of the longitudinal bars or 48 diameters of lateral ties. Two types of columns are used in composite building systems

(a) (b)

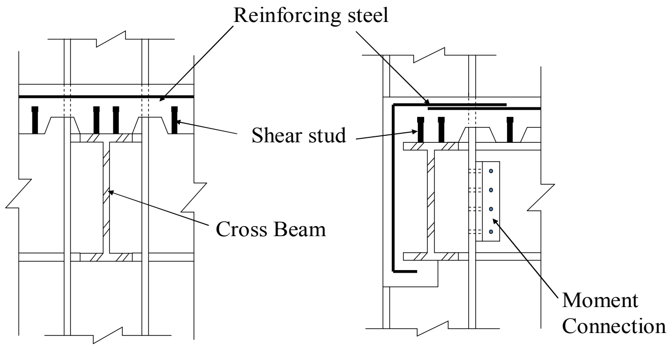
Figure 6. Types of Composite Column (a) Encased Column (b) Concrete Filled Tubular Column



(a) (b) (c)

Figure 7. Shapes of Composite Column (a) Square Column (b) Deep Reinforced Column (c) Modified Shape for Exterior Column

2.7. **Connection for Composite Steel Frame**



Interior Moment Connection . Exterior Moment Connection

Figure 8. Composite Slab Connection Moment-connected Steel Frame

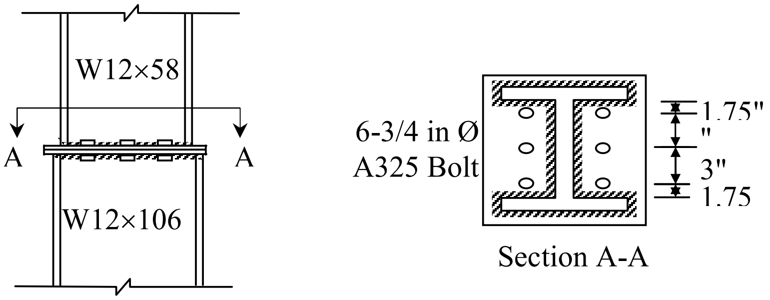


Figure 9. Column Splice

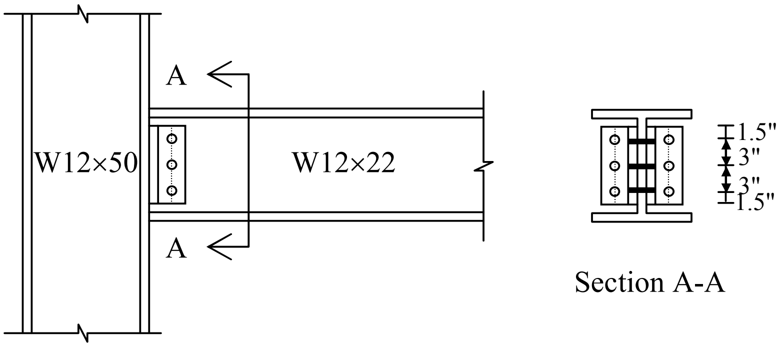


Figure 10. Beam to Column Flange Connection

2.8. **Profile of Structures**

Proposed model is located in Yangon area. The profiles of this structural model are listed as follow:

Types of Buildings = 6-storey composite building
Types of Occupancy = Residential
Size of Buildings = Maximum length (59 ft)
Maximum width (40 ft)
Shape of Buildings = Rectangular shape
Height of Buildings = Under Ground Basement (5 ft)
Typical storey height (10 ft)
Bottom storey height (12 ft)
Overall height (65 ft)

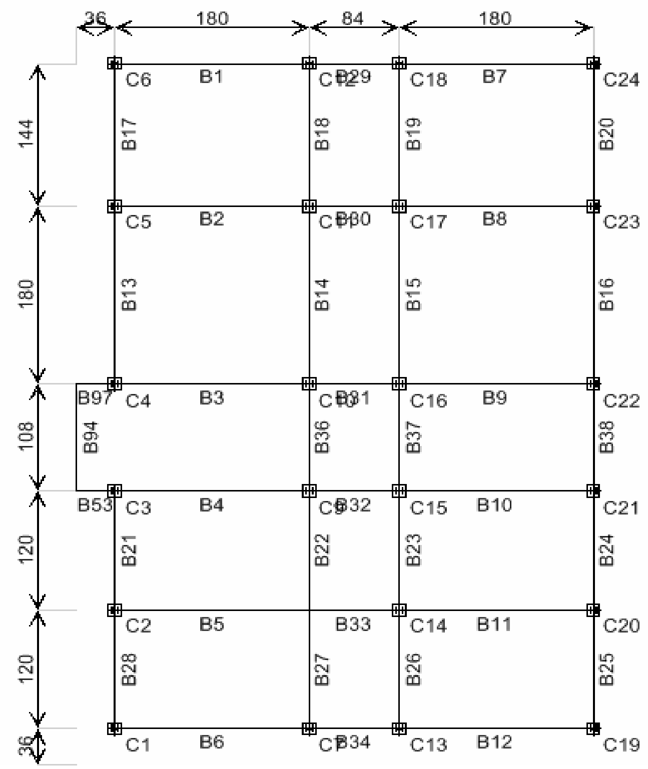


Figure 11. Ground Floor Plan of Proposed Building

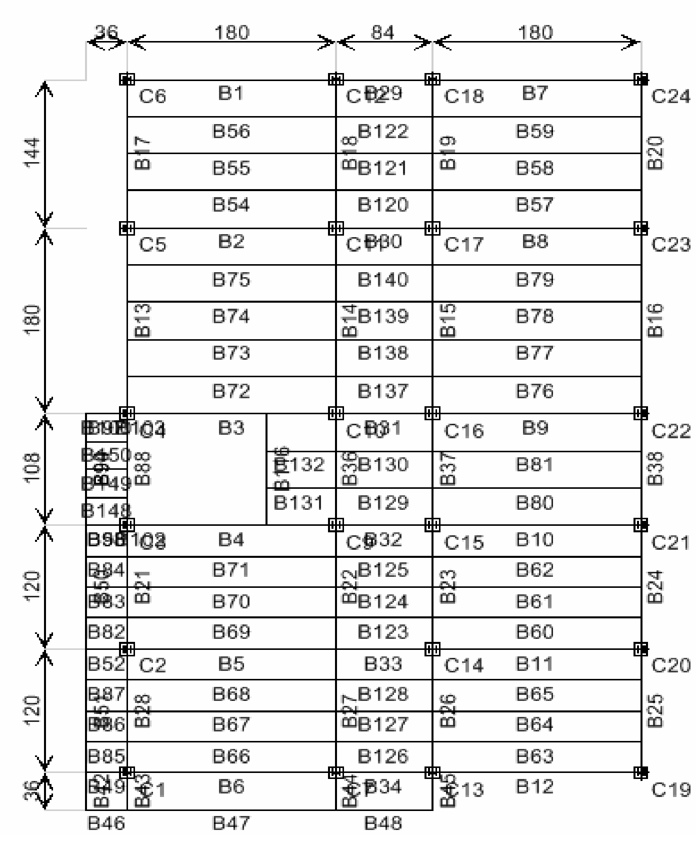


Figure 12. Typical Floor Plan (Storey-1 to Storey-5) of Proposed Building

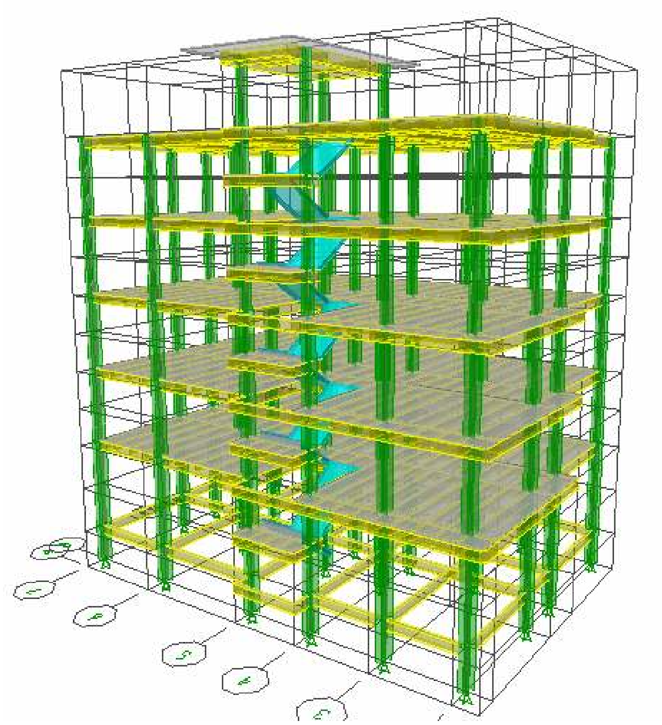


Figure 13. Three Dimensional View of Proposed Building

2.9. **AISC Design Specifications for Composite Beam**

Including provisions for solid slab, there are three categories of composite beams in the AISC specifications each width a differing effective concrete area.

2.9.1. Solid Slab

The total slab deck is effective in compression unless the neutral axis is above the top of steel beam. In high-rise floor systems with relatively thin slab the neutral axis of steel beams is invariably below the slab, rendering the total slab depth effective in compression.

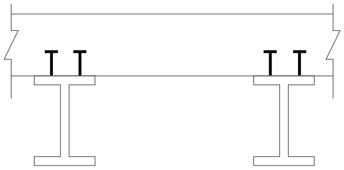


Figure 14. Solid Slab Beam

2.9.2. Deck Perpendicular to Beam

1. Concrete below the top of steel decking shall be neglected in computations of section properties and in calculating the number of

shear studs, but the concrete below the top flange of deck may be included for calculating the effective width.

2. The maximum spacing of shear connectors shall not exceed 32 in. along the beam length.
3. The steel deck shall be anchored to the beam either by welding or by other means at a spacing not exceeding 16 in.
4. A reduction factor as given by the AISC formula I5-1 be used for reducing the allowable horizontal shear capacity of stud connectors.

$$\left(\frac{0.85}{\sqrt{N_r}}\right)\left(\frac{w_r}{h_r}\right)\left(\frac{H_s}{h_r}-1\right)\leq 1.0 \qquad (4.1)$$

Where, w_r = average width of concrete

N_r = number of studs in one rib

H_r = normal rib height

H_s = length of stud connector

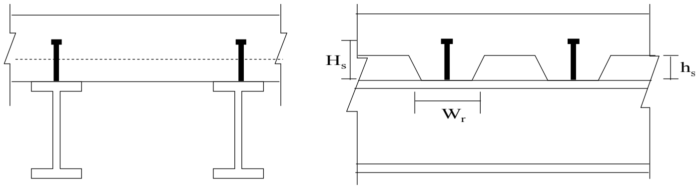


Figure 15. Composite Beam with Deck Perpendicular to Beam

2.9.3. Deck Rib Parallel to Beam

1. The concrete below the top of the decking can be included in the calculations of section properties and must be included when calculating the number of shear studs.
2. If steel deck ribs occur on supporting beam flanges, it is permissible to cut high-hat to form a concrete haunch.
3. When normal rib height is 1 ½ in. or greater, minimum average width of deck flute should not be less than 2 in. for the first stud in the transverse row plus four stud diameters for each additional stud. This gives minimum average widths of 2 in. for one stud, 2 in. plus 4 times of diameter of stud for two studs, 2 in. plus 8 times for three studs, etc.
4. A reduction factor as given by AISC formula I5-2.

$$0.6\left(\frac{w_r}{h_r}\right)\left(\frac{H_s}{h_r}-1\right)\leq 1.0 \qquad (4.2)$$

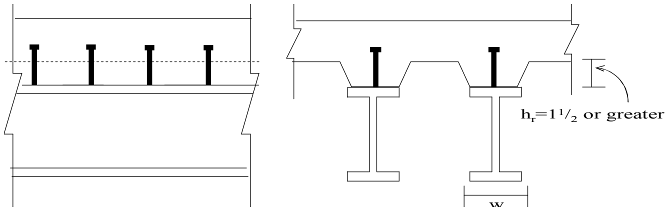


Figure 16. Composite Beam with Deck Rib Parallel to Beam

2.10. **Design of Composite Steel Deck Slabs**

Composite steel deck slabs generally consist of light gage, corrugated or ribbed, or cellular metal deck forms which interact with a structural concrete topping as a composite unit to floor loads. The slabs are generally used as one-way slabs with the steel metal deck acting as reinforcement in the span direction. The composite steel deck slab is used quite extensively in steel framed buildings and is usually required to perform the following functions:

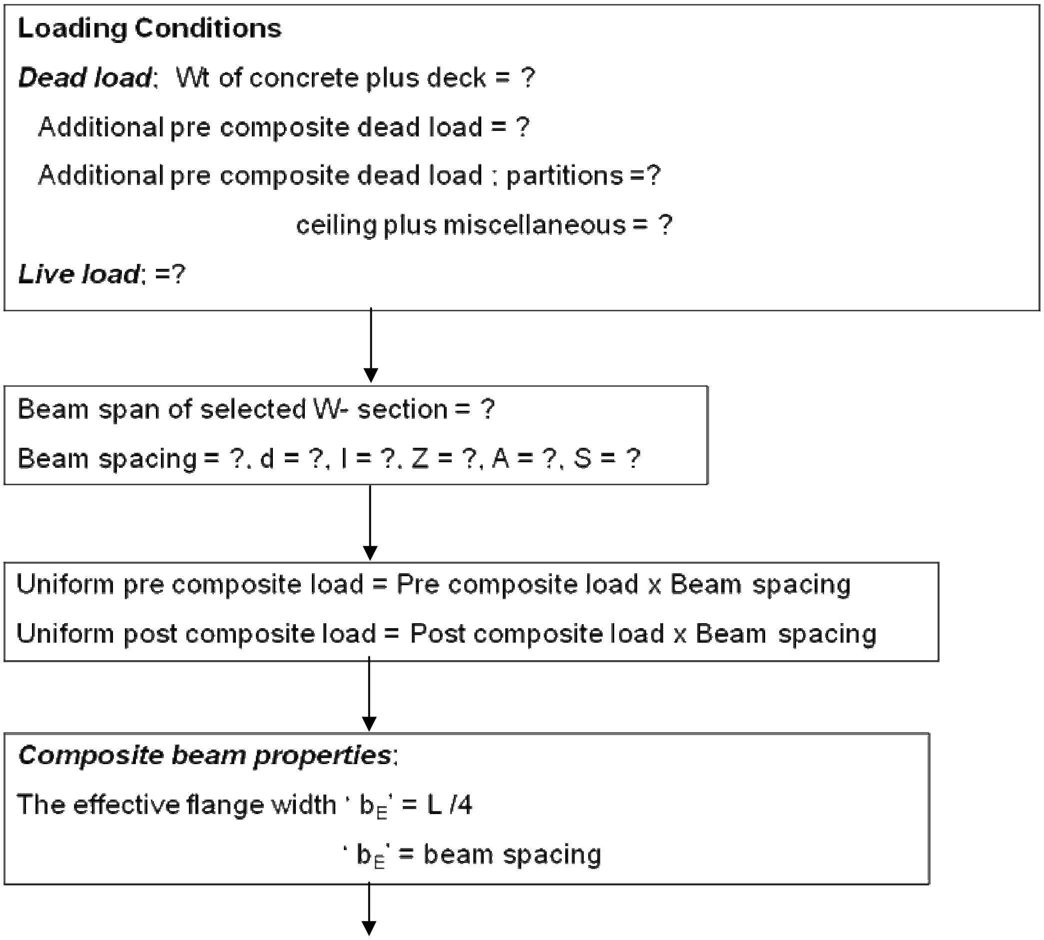
1. To act as a construction platform at derrick floors in high-rise buildings.
2. To act as formwork for concrete usually without any shoring between steel beams. The imposed loads are wet weight of concrete and construction loads for placement of concrete.
3. To act as a composite slab for all superimposed loads.
4. To act as a diaphragm in distributing shear forces due to wind and earthquake to various resistive elements and to absorb the stabilizing P-Δ forces of unbraced columns.

The following criteria are considered in the design of composite slab.

1. Stress shall not exceed 0.6 times the yield strength or 36 kip per square inch under the combined loads of wet concrete plus deck.
2. Calculated deflection shall be based on the load of the concrete and the load of deck and shall be limited to L/180 or ¾ inch, whichever is smaller.
3. Under the combined stresses caused by the superimposed live load and the tensile stresses in the deck, the tensile stress of the deck shall not exceed 0.6 F_y or 36 kip per inch.
4. The compressive strength in the concrete shall not exceed 0.45 $f_c^{'}$.
5. Deflection of the composite slab shall not exceed L/360 under the superimposed dead and live load.
6. Steel deck yield strength must be at least 33 ksi and it must be permanent for the life of the structure.
7. The concrete strength must be at least 3000 psi in accordance with ACI 318.

8. The minimum diameter of shear connector is ½ in. and maximum diameter is ¾ in.
9. The minimum center-to-center spacing of studs is six times of stud diameter and maximum spacing of studs is 32 in.
10. After installation, the studs should extend a minimum of 1 ½ in above the steel deck.
11. The upset head thickness of the stud is usually $^{3}/_{8}$ in. or ½ in. and its diameter is ½ in. larger than the stud diameter.
12. Rib average width of the deck shall not be less than 2 in.. If the deck profile is such that the width at the top of the steel deck is less than 2 in., this minimum clear width shall be used in the calculation.
13. The section properties do not change a great deal from deck running perpendicular or parallel to the beam, but the change in the number of studs can be significant.
14. The depth of deck shall not be less than 3 in.

2.11. Design Procedure for Composite Slabs



Loading Conditions

Dead load; Wt of concrete plus deck = ?

Additional pre composite dead load = ?

Additional pre composite dead load ; partitions =?

ceiling plus miscellaneous = ?

Live load; =?

Beam span of selected W- section = ?

Beam spacing = ?, d = ?, I = ?, Z = ?, A = ?, S = ?

Uniform pre composite load = Pre composite load x Beam spacing

Uniform post composite load = Post composite load x Beam spacing

Composite beam properties;

The effective flange width ' b_E' = L /4

' b_E' = beam spacing

Transformed section of slab: $bE/n = ?$. $I_x = I_o + A\,y^2$. $\bar{y} = \Sigma Ay / \Sigma A$. $I_{tr} = I_x - A\,\bar{y}^2$

To find y_t and y_b

$S_t = I_{tr} / y_t$, $S_{tr} = I_{tr} / y_b$

Check the stress at the top of concrete slab

$M_D = w_D L^2/8$; $M_L = w_L L^2/8$

Check the allowable stress for two condition

$f_b = M_D / S_s + M_L / S_{tr} < 0.9 f_y$

$f_b = (M_D + M_L) / S_{tr} < 0.6 f_y$

Horizontal shear ' $V_{nh} = C_{max} = 0.85 f_c' b_E t_s$

$V_{nh} = T_{max} = A_s F_y$

smaller control

The required section modulus $= (M_D + M_L)/0.6 F_y$

$$V_h' = V_{nh}\left(\frac{S_{eff} - S_s}{S_{tr} - S_s}\right)^{1/2};\ \frac{V_h'}{V_{nh}} = \% > 25\% \Rightarrow \text{Use } \frac{3}{4} \text{ in stud}$$

Reduction factor for deck perpendicular to beam; $= \left(\frac{0.85}{\sqrt{N_r}}\right)\left(\frac{w_r}{h_r}\right)\left(\frac{H_s}{h_r} - 1\right) > 1 \Rightarrow \text{use } 1$

The number of shear connectors required for each half span; 'N' $= V_h' / Q_n$

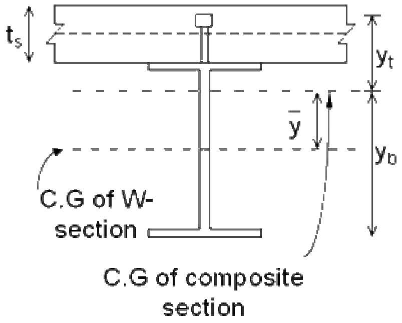
Check the calculated deflection for unshored conditions;

Deflection under pre composite load $= \left(\frac{5wL^4}{384EI_s}\right) < L/180$

Deflection under post composite load $= \left(\frac{5wL^4}{384EI_{eff}}\right) < L/360$

Check the strength of the steel section; $M_D = w L^2/8$; $\phi_b M_p = \phi_b Z_x F_y$

$M_D < \phi_b M_p$ **ok**



2.12. **Overview of CSICOL Software**

This Software can design the column cross-sections for special axial loads and moments directly or can compute the magnified moments caused by slenderness effects. In this software, an unlimited number of load combinations can be defined both for sway and non-sway conditions. Sway and non-sway conditions check may also be performed as specified in the selected design code. In addition, CSICOL is capable of determining the Effective Length Factor on the basic of a column's framing and end conditions. An auto cross-section design tool helps in automatically selecting the column size and reinforcement for specified actions using user-defined rules.

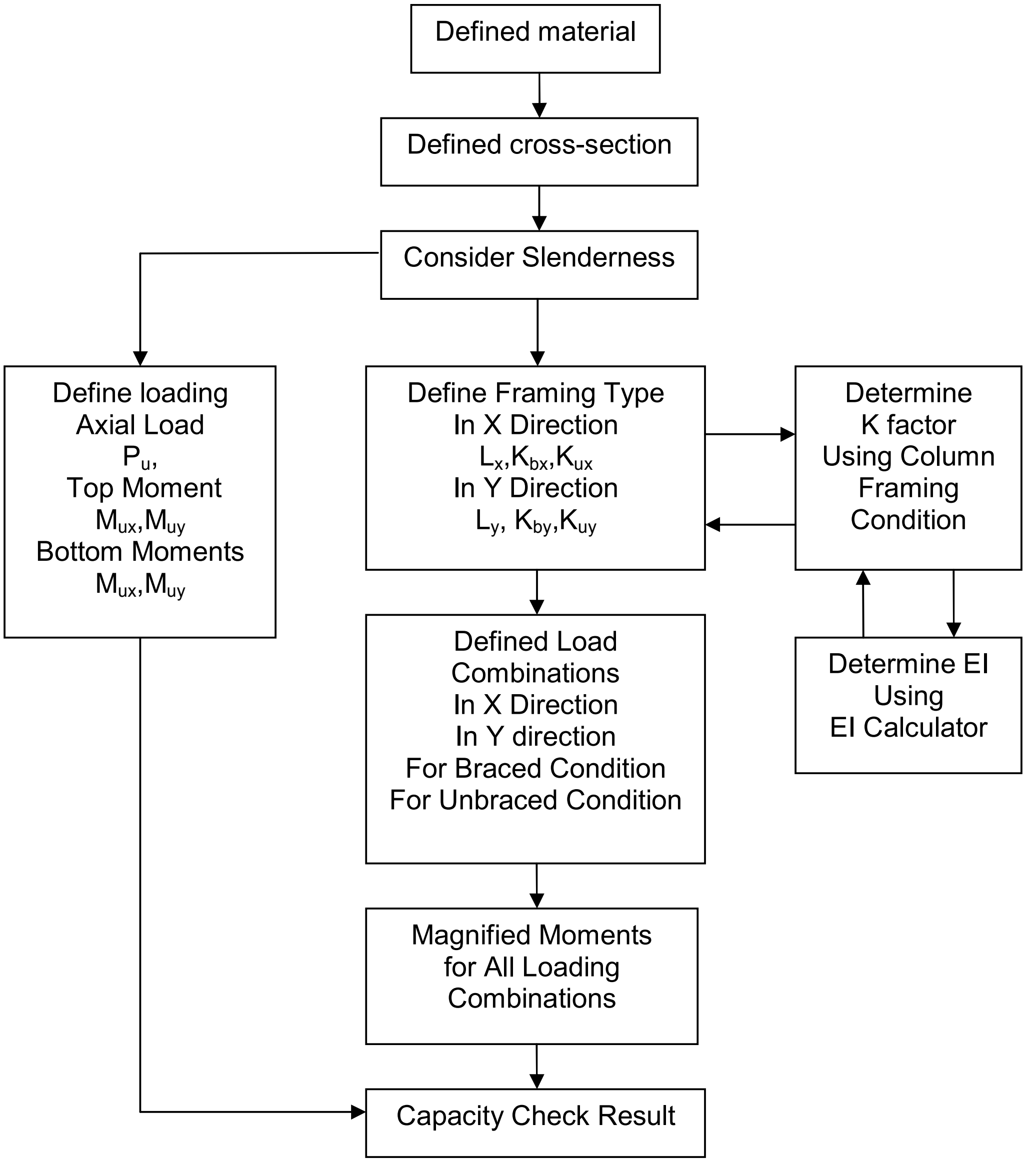


Figure 17. Overview of CSICOL Design and Analysis Process

Table 1. CompareTypical Section for Steel Columns and Composite Columns

Height of column	Range of steel column sections	Range of composite column sections
0 level to 22 ft	W 12 × 152	(12″ × 12″) to (18″ × 18″) with $W_{6\times 9}$ to $W_{8\times 67}$
22 ft to 42 ft	W 12 × 106	(10″ × 10″) to (12″ × 12″) with $W_{6\times 20}$ to $W_{8\times 67}$
42 ft to 70 ft	W 12 × 58	(10″ × 10″) with $W_{6\times 20}$ to $W_{8\times 67}$

Table 2.Forces and Sizes of Composite Column are calculated by CSICOL Software

Location	Axial load (P_u) kip	M_x(Bot) kip-ft	M_y(Bot) kip-ft	M_x(Top) kip-ft	M_y(Top) kip-ft	Column Sizes
Gr-floor (C1)	-227.65	-67.58	-12.05	14.37	-12.68	$W_{6\,x25}$ 4# 8 (14″ x 14″)
2nd floor (C1)	-153.1	-20.4	-24.4	21.2	-15.9	W_{6x16} 4# 8 (12″ x 12″)
4rd floor (C1)	-63.8	-14.43	-16.18	13.65	-15.93	W_{6x16} 4# 8 (10″ x 10″)
Gr-floor (C3)	-614.9	-90.53	-46.73	13.37	-31.2	W_{6x25} 4# 8 (18″ x 18″)
2nd floor (C3)	-343.88	-29.63	-86.68	16.84	-23.11	W_{6x25} 4# 8 (16″ x 16″)
4rd floor (C3)	-182.16	-17.514	-47.88	12.96	1.23	W_{6x25} 4# 6 (12″ x 12″)
Gr-floor (C7)	-251.57	-61.84	16.03	-21.9	-0.32	W_{8x28} 4# 6 (14″ x 14″)
2nd floor (C7)	-176.04	-33.98	11.13	30.96	-11.99	W_{6x25} 4# 6 (12″ x 12″)
4rd floor (C7)	-77.62	-22.68	12.33	21.35	-10.97	W_{6x20} 4# 6 (10″ x 10″)
Gr-floor (C9)	-358.32	-71.22	32.48	-7.48	18.42	W_{6x25} 4# 8 (16″ x 16″)
2nd floor (C9)	-266.43	17.39	110.75	-12.51	-87.75	W_{6x25} 4# 7 (16″ x 16″)
4rd floor (C9)	-121.66	8.608	63.05	-7.9	-62.14	W_{6x25} 4# 6 (12″ x 12″)
Gr-floor (C11)	-261.31	54.14	31.83	33.57	-26.27	W_{6x25} 4# 7 (14″ x 14″)
2nd floor (C11)	-193.69	45.13	23.78	39.13	15.11	W_{6x25} 4# 6 (12″ x 12″)
4rd floor (C11)	-90.36	26.2	16.26	-24.05	-12.46	W_{6x25} 4# 6 (10″ x 10″)
Gr-floor (C14)	-228.27	-70.85	12.74	-7.31	5.35	W_{8x28} 4# 6 (14″ x 14″)

2nd floor (C14)	-166.13	-41.95	-10.73	36.76	4.67	W_{6x25} 4# 5 (12″ x 12″)
4th floor (C14)	-78.87	-21.98	-3.66	19.75	3.02	W_{6x20} 4# 5 (10″ x 10″)
Gr-floor (C16)	-300.03	66.112	-4.16	13.41	3.81	W_{6x25} 4# 6 (14″ x 14″)
2nd floor (C16)	-174.13	-50.02	-26.09	43.11	17.82	W_{6x15} 4# 7 (12″ x 12″)
4th floor (C16)	-79.65	-27.63	-18.79	25.31	16.15	W_{6x9} 4# 6 (10″ x 10″)
Gr-floor (C18)	-171.78	52.83	-23.29	-32.68	19.61	W_{6x15} 4# 7 (12″ x 12″)
2nd floor (C18)	-129.74	29.1	-18.82	-27.51	17.73	W_{6x9} 4# 7 (10″ x 10″)
4th floor (C18)	-52.63	19.39	-14.77	-18.25	16.16	W_{6x9} 4# 5 (10″ x 10″)
Gr-floor (C24)	-146.67	-54.78	2.01	-32.58	-14.76	W_{6x15} 4# 5 (12″ x 12″)
2nd floor (C24)	-110.4	30.47	18.55	-28.49	-11.25	W_{6x9} 4# 6 (10″ x 10″)
4th floor (C24)	-44.13	20	13.92	-19.24	-10.62	W_{6x9} 4# 5 (10″ x 10″)

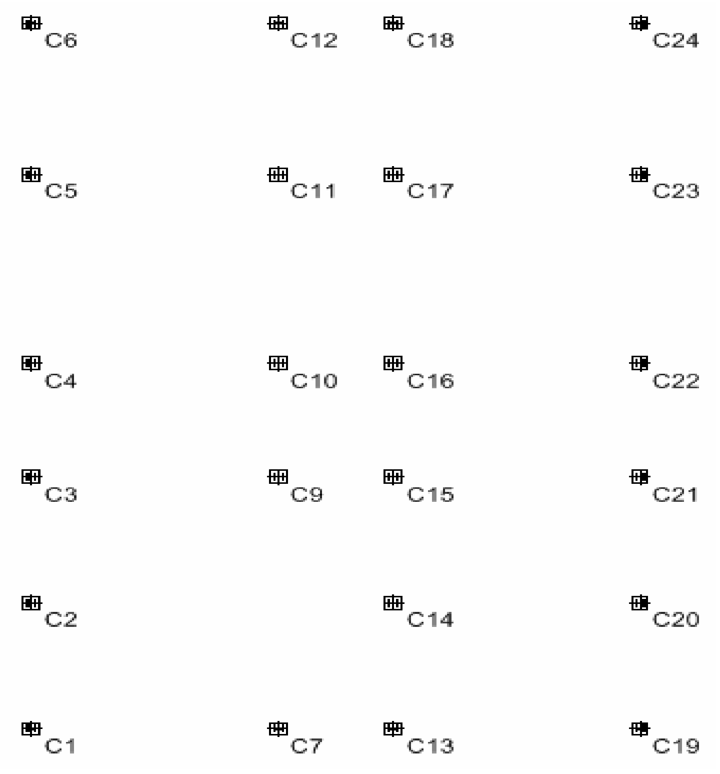
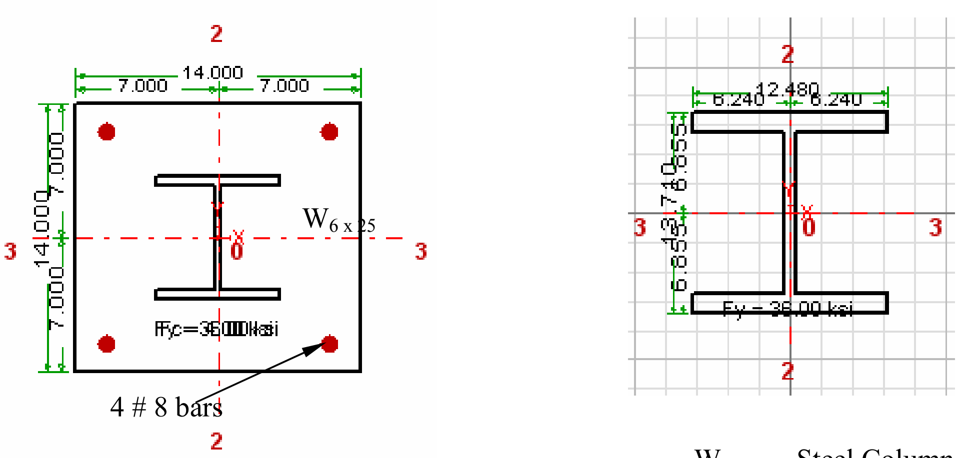


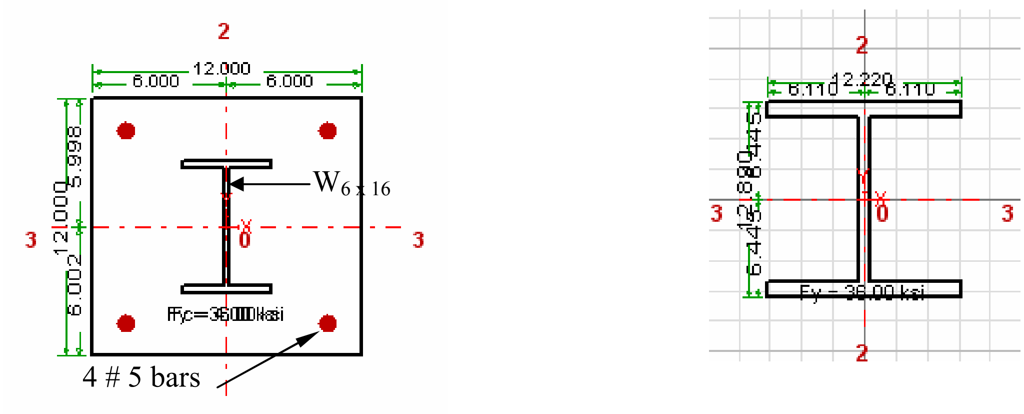
Figure 18. Column Layout Plan



14" x 14" with $W_{6 \times 25}$ Composite Column

$W_{12 \times 152}$ Steel Column

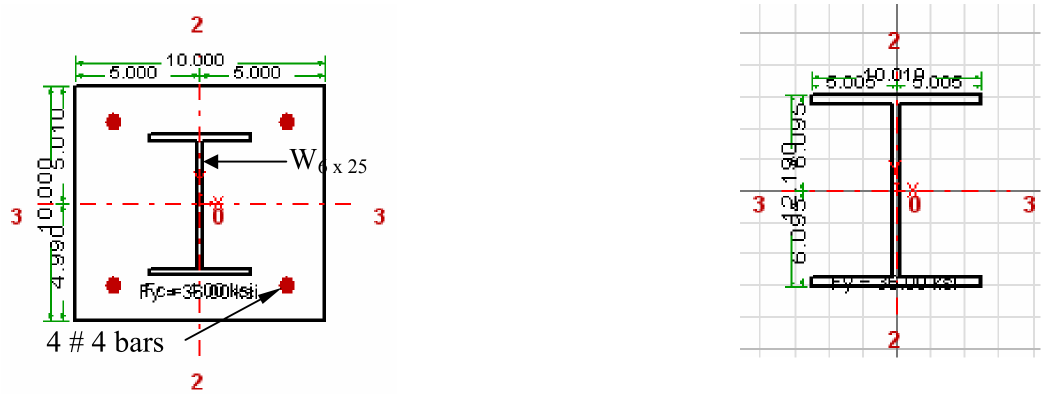
Figure 19. Compared Design Sections of Composite Column and steel column (Ground Floor C_1)



12" x 12" with $W_{6 \times 16}$ Composite Column

$W_{12 \times 106}$ Steel Column

Figure 19. Compared Design Sections of Composite Column and steel column (Second Floor C_1)



10" x 10" with $W_{6 \times 25}$ Composite Column

$W_{12 \times 58}$ Steel Column

Figure 19. Compared Design Sections of Composite Column and steel column (Fourth Floor C_1)

3. **DISCUSSION AND CONCLUSION**

In this study, five storeys steel frame building with rectangular shape in plan was selected. The structure was located in zone 2A and 70 feet above ground level. It was composed of Ordinary Moment Resisting Frame System.The superstructure is a steel frame building with composite floor system using metal sheeting. Columns are designed as composite column. In this, W-shaped rolled steel and reinforcing steel are mixed with concrete.

The design concepts and design load combinations are in accordance with Load and Resistance Factor Design AISC-LRFD. The superstructure is analyzed and designed with ETABS Software. CSICOL Software is used in design of Composite column. Design of floor slabs and connections are manually calculated. Connections used in the building were bolted and welded connection.

Design provision for seismic and wind forces are based on (UBC 97). All floor slabs are designed as metal steel deck supporting concrete slab systems. Dealing with (UBC 97), story-drift, overturning and sliding are checked in the design calculation. Structural steel used in the building is A 36 steel. Although story drift is satisfactory, it is close to limit. Therefore, frame with diagonal braced, core braced, shear wall or core wall structure should be used because of lateral stability.

Connections used in the building were bolted and welded connections. In this study, bolted connection was mainly used for joint design and welded connection was considered for erection process. Bearing type connection with 1/4, 3/4, 1 in. diameters A325 high- strength bolts were considered in this study. Column splice and base plate design were also presented.

4. **REFFERENCES**

[1] Williams, A.: *Seismic Design of Buildings and Bridges for Civil and structural Engineers*, (2003).

[2] Lindeburg, M.R.: *A Professional's Introduction of Earthquake Forces and Design Details. In Seismic Design of Building Structures.* 8th Edition, Professional Publication, Inc., (2001).

[3] Taranth, B.S.: *Steel, Concrete and Composite Design of Tall Building,* 2nd Edition, Mc Graw Hill Co. Inc., (1997).

[4] Iyengar, S.: *Composite or Mixed Steel-concrete Construction for Buildings,* (1997).

[5] Gaylord Jr, E.H., Gaylord, C.N. and Stallmeyer, J.E.: *Design of Steel Structures*, 3rd Edition, Mc Graw Hill Co. Inc., (1992).

[6] Johnson, J.E. and Salmon, C.G.: *Steel Structures (Design and Behavior)*, 3rd Edition, (1986).

[7] Yam, L.C.: *Head of Structural Design Division Building Research Station Garston,* United Kingdom, (1981).

[8] Lyengar, H.S.: *Composite or Mixed steel-concrete construction for Buildings*, the Structural Specification Liaison Committee, (1977).