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Structural Analysis and Design of Beam-Column Joint Connectionsfor Steel Structure

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Abstract-The proposed building for this study is four-storeyed steel frame building in Mandalay area. The structure is composed of special moment resisting frame in seismic zone 4. The overall height of the building is 63ft and it is rectangular shape. The total length and width of the building are 58ft and 34ft respectively. All structural analysis and design of the superstructure of the building are carried out by using ETABS software (Extended Three Dimensional Analysis of Building Systems). The main aim of this study is to understand the connections of steel frame building. Required data for design specification of structural elements are considered according to AISC-LRFD (American Institute of Steel Construction-Load and Resistance Factor Design) 1993. Structural steel used in the building is A36 Grade 36 steel. Wide flanges W-sections are used for frame members.Connections are designed with bolted and welded connection. Bearing type connection with A325 high-strength bolts and fillet weld E_{70} electrodes with SMAW (Shielded Metal Arc Welding) process are considered.

Indexed Terms- steel frame building, rectangular shape, bolted and welded connection, Shielded Metal Arc Welding

I. INTRODUCTION

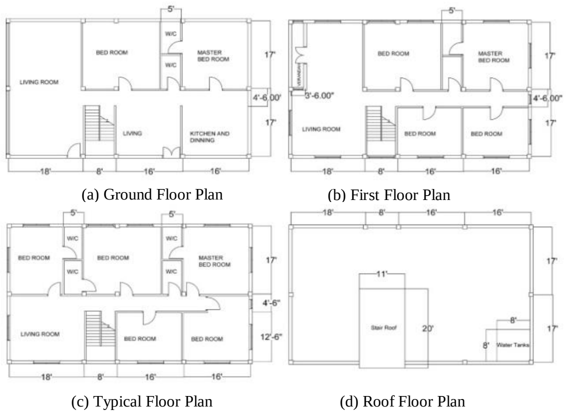
The most important aspect of structural steel work for buildings is the design of connections between individual frame components.Connections are usually classified according to the major load types to be carried, such as moment connections which carry primarily moment, shear connections such as framed, skewed and seated connections which carry primarily shear and axial force connections, such as splices and truss connections, hangers, etc. which carry primarily axial force. There are two ways to connect structural members using bolts or welds.

There are several types of bolts that can be used for connecting the members of steel structures. These are high-strength structural bolts manufactured under ASTM specifications A325, A490 and common bolts A307. The A325 and A490 bolts can be used for any building application. High-strength bolts range in diameter from 1/2 to 1.5 in. The most common diameters used in building construction are 3/4 to 7/8 in. Bolted connections are usually designed to resist shear only.

Welding is the process of joining materials (usually metals) by heating them suitable temperatures such that the materials coalesce into one material. There are many welding processes such as Shielded Metal Arc Welding (SMAW) and Submerged Arc Welding (SAW) processes that have special uses for particular metals and for various thicknesses. Welding is a process by which metallic parts are connected by heating their surfaces to a plastic or fluid state and allowing the parts to flow together and join (with or without the addition of other molten metal). Welded connections often are used because of their simplicity of design, fewer parts, less material, and decrease in shop handling and fabrication operations. So, in this study, Beam-Column joint connections for steel structure are designed with SMAW process.

II. MODELLING OF THE STRUCTURE

The proposed steel superstructure is designed as special moment resisting frame. The building is four-storeyed steel structure building. A-36 W-section steels are used for frame member. The plan view and 3D view of proposed building are shown in Figure 1 and Figure 2. The building is a rectangular regular shape with the length of 58ft and width of 34 ft. Total height of the building is 63 ft.



(a) Ground Floor Plan (b) First Floor Plan

(c) Typical Floor Plan (d) Roof Floor Plan

Figure 1. Plan View of Proposed Building

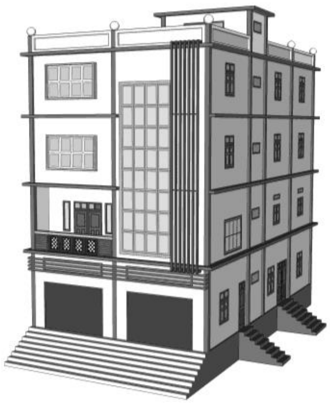


Figure 2. 3-D View of Proposed Building

Wide flange W-sections are used for frame members. Loads acting on a structure or structural elements are considered dead loads, super dead load, live loads, wind load and earthquake load. Dead load is considered as the own weight of structure member. Super dead load is considered according to materials such as 9" and 4.5" thick brick walls, topping weight and ceiling weight. For live load, 20 psf for roof floor, 40 psf for residential room and 100 psf for corridors and stairs are considered for analyzing. For wind load, exposure type B and basic wind speed 80 mph are considered for analyzing. For earthquake load, seismic zone 4 is considered. The structure is analyzed with ETABS software. According to UBC-97, necessary checking such as storey drift, sliding, overturning, torsional irregularity and P-Δ effects are carried out for the stability of the structure.

III. DESIGN SECTIONS OF PROPOSED BUILDING

After analyzing, design results for superstructure are obtained in the following tables and figures. Columns are classified as column type C1 and C2. Wide flange W sections are used for compression and bending or flexural members.

A typical column section for the building is shown in Table 1. Column layout plan is shown in Figure 3. Beams are classified as type B1 to B4. Steel beam sections for the structure are shown in Table 2 and beam layout plans are shown in Figure 4 to 7.

Table.1 Typical Column Sections for the Building

Column Type	GF to 1F	2F to RF	RF to SRF
C1	W 12× 65	W 12 × 45	W 12 × 45
C2	W 12×65	W 12 × 45	-

Table .2 Steel Beams Sections for the Building

Beam Type	For First Floor to SRF
B1	W 6×9
B2	W 8×28
B3	W 10×30
B4	W 10×45

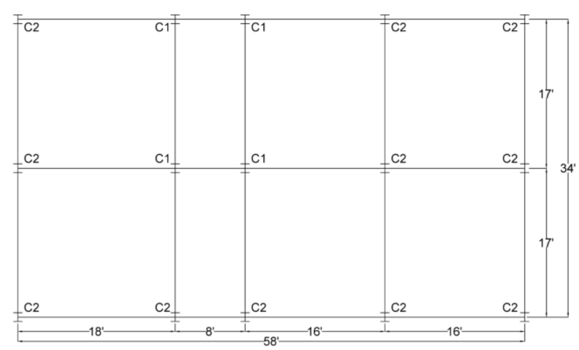


Figure 3.Typical Column Layout Plan

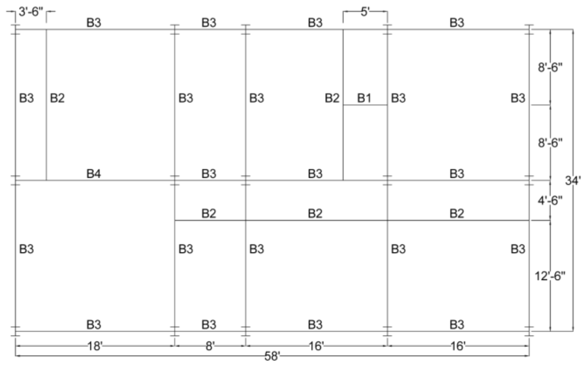


Figure 4.First Floor Beam Plan

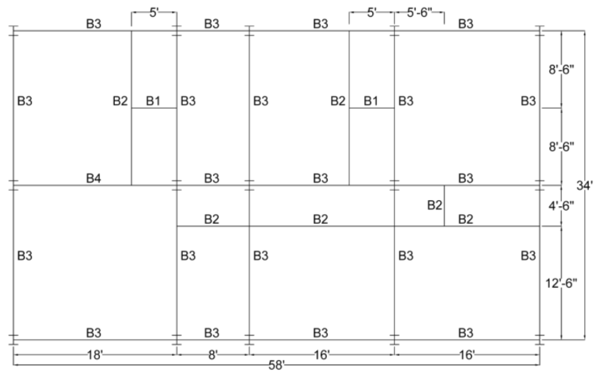


Figure 5.Second Floor and Third Floor Beam Plan

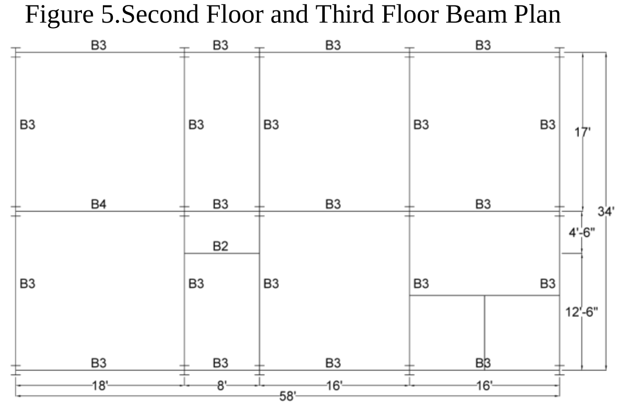


Figure 6.Roof Floor Beam Plan

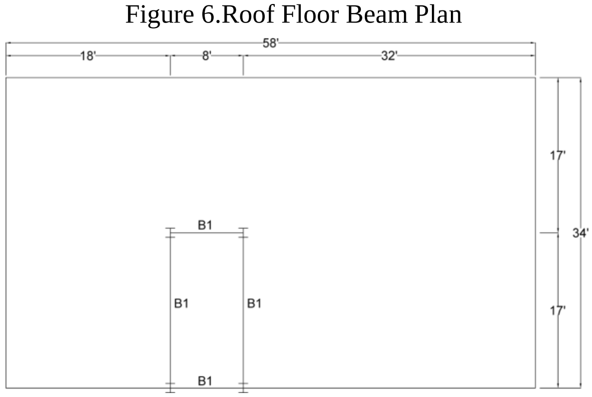


Figure 7.Stair Roof Beam Plan

IV. DESIGN OF BEAM TO COLUMN CONNECTION

The design strength and the total length of weld design for LRFD method is,

$$\phi R_{nw} = \phi(0.707a)(0.6F_{EXX})$$

$$L_w = 4b_f + 2d - 2t_w$$

where,

ϕR_{nw} = design strength per unit length of fillet weld (k/in)

F_{EXX} = tensile strength of electrode material (ksi) (70 ksi is used for calculation of weld strength based on base metal specification A 36 steel)

a = size of weld (in) depends on the thickness of base metal

L_w = total length of fillet weld

The design tension and shear strength of bolt design for LRFD method is,

$$\phi R_{nt} = \phi(0.75A_b)F_u^b$$

where,

ϕR_{nt} = design tension strength of one bolt

A_b = gross cross-sectional area of one bolt

F_u^b = tension strength of bolt

When threads are included in shear plane, the design shear strength is

$$\phi R_n = \phi(0.45F_u^b)mA_b$$

where,

ϕ =0.65

ϕR_n = design shear strength of one bolt

F_u^b = tension strength of the bolt material

m = the number of shear planes

A_b = gross cross-sectional area across the unthreaded shank of the bolt

For usual conditions (standard holes or short-slotted holes, end distance not less than 1.5d, bolt spacing center-to-center not less than 3d, and with two or more bolts in the line of force), the design strength ϕR_n based on the design bearing strength at bolt holes is

$$\phi R_n = \phi(2.4dtF_u)$$

where,

ϕ = 0.75

d = nominal diameter of bolt (not at threads)
t = thickness of connected part
F_u = tensile strength of steel comprising connected part

The usual spacing of bolts in the direction of the transmitted forces must be at least 3 diameters. The minimum end distances must be at least 1.5 diameters. The maximum distance from the center of a bolt to the nearest edge is 12t.

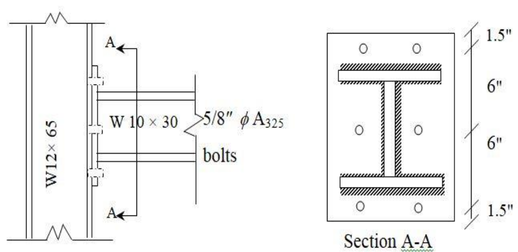
A. Design of Beam to Column Flange Connection

Design of beam to column connection consists of beam to column flange connection and beam to column web connection. Bearing type connection with A325-N bolts is used. E 70 electrodes are used with SMAW process. Beam to column flange connections are classified into three types as corner joints, exterior joints and interior joints.

Calculation of Beam to Column flange connection for corner joint is expressed as follow;

F_y= 36 ksi,F_u = 58 ksi, F_u^b = 120 ksi,F_{EXX}= 70 ksi

The sectional properties of W 10×30 beam are expressed as follow and are taken from steel manual.
b_f = 5.81 in, d = 10.47 in, t_f = 0.51 in, t_w = 0.3 in, k = 0.937 in,
$A_f = b_f \times t_f = 5.81 \times 0.51 = 2.963$ in^2



Corner Joint

(a) Calculation of bolted connection

From analysis data,
M_u = 744.138 kips-in
V_u = 21.89 kips

The sectional properties of W 12×65 column are expressed as follow and are taken from steel manual.
b_f =12 in,d = 12.12 in, t_f = 0.605 in, t_w=0.39 in, k = 1.312 in

$$T_u= \frac{M_u}{d - t_{fb}} = \frac{744.138}{10.47 - 0.51} = 74.713 \text{ kips}$$

Try 3/4" ϕ bolt.

$$A_b = \frac{\pi}{4} \times \left(\frac{3}{4}\right)^2 = 0.442 \text{ in}^2$$

$$\phi R_{nt} = \phi(0.75 A_b) F_u^b$$
$$= 0.75 \times (0.75 \times 0.442) \times 120$$
$$= 29.84 \text{ kips/bolt}$$

Required number of bolt = $\frac{T_u}{\phi R_{nt}}$ =u = 2.5

Try 6 Nos (for both directions)

Shear stress, $f_{uv}= \frac{V_u}{nA_b} = \frac{21.01}{6 \times 0.442} = 7.92$ ksi

Check combined shear and tension
For A 325-N
Allowable tensile stress $F_{ut}^{'}$ = 85 – 1.8f_{uv} ≤ 68 ksi
= 85 – 1.8×7.92
= 70.74 ksi > 68 ksi
Therefore, smaller control.

Tensile stress, $f_{ut}= \frac{T_u}{A} = \frac{74.713}{3 \times 0.442}$
f_{ut} =56.34 ksi < Allowable = 68 ksi
Therefore, it is satisfied.

Use c/c spacing = 6 in > 3d
=3×0.75 = 2.25 in

Use end distance = 1.5 in > 1.5d
= 1.5×0.75
= 1.125 in

(b) Calculation of welded connection

Weld thickness,

Required, $\phi R_{nw} = \frac{T_u}{2b_f - t_w}$
$= \frac{74.713}{2 \times 5.81 - 0.3}$
= 6.6 kip/in

Design strength,
ϕR_n = ϕ (0.707 a) (0.6 F_{EXX})
6.6 = 0.75(0.707a) (0.6×70)
a = 0.2963 in

Use 1/2 in weld thickness.
The required length L_w of fillet weld,

$$L_w = \frac{T}{\phi R_{nw}} = \frac{74.713}{6.6} = 11.3 \text{ in}$$

Total design strength =6.6×11.3
= 74.713 kips > 21.01 kips

Determination of plate thickness,

$$S = k + \text{weld thickness} = 0.9375 + 1/2 = 1.437 \text{ in}$$

$$b' = s - \frac{d_b}{4} - \text{weld thickness} = 1.437 - \frac{3/4}{4} - \frac{1}{2} = 0.749 \text{ in}$$

F_y = 36 ksi , A 325 $\Rightarrow$ C_a = 1.36

$$C_b = \sqrt{\frac{b_f}{b_s}} = \sqrt{\frac{5.81}{8}} = 0.85$$

$$\alpha_m = C_a C_b \left(\frac{A_f}{A_w}\right)^{\frac{1}{3}} \left(\frac{b'}{db}\right)^{\frac{1}{4}}$$

$$\alpha_m = 1.36 \times 0.85 \times \left[\frac{2.963}{(5.81 - 2\times 0.51)\times 0.3}\right]^{\frac{1}{3}} \left[\frac{0.749}{0.75}\right]^{\frac{1}{4}} = 1.47$$

$$M_e = \frac{\alpha_m T_u b'}{4} = \frac{1.47 \times 74.713 \times 0.749}{4} = 20.56 \text{ kip-in}$$

$$t_p = \sqrt{\frac{4.44 M_e}{w f_y (1+\alpha\delta)}} = \sqrt{\frac{4.44 \times 20.56}{8 \times 36}} = 0.56 \text{ in}$$

Use 0.75 in.

$$P_{bf} = F_{yc} t_{wc} (t_{fb} + 6k + 2t_p + 2a)$$
= 36×0.39 (0.51 + 6×1.312 + 2×0.75 +2×0.5)
= 152.78kips >Compressive force,C= 69.84kips

Therefore, stiffener is not required.

Design results for beam and column flange connection are shown in Table 3.

Table 3. Design Result for Beam to Column Flange Connection

Joint type		Corner joints			Exterior joints		Interior joints	
Size	Beam	W10x30	W10x30	W10x30	W10x30	W10x30	W10x30	W10x30
	Column	W12x45	W12x45	W12x45	W12x45	W12x45	W12x45	W12x45
Storey level		3F, RF	3F, RF	3F, RF	3F, RF	3F, RF	3F, RF	3F, RF
Moment (kips-in)		800.011	800.011	800.011	800.011	800.011	800.011	800.011
Shear (kips)		28.98	28.98	28.98	28.98	28.98	28.98	28.98
Number of bolts		8	8	8	8	8	8	8
Size of fillet weld		1/2	1/2	1/2	1/2	1/2	1/2	1/2
Length of weld (in)		11.3	11.3	11.3	11.3	11.3	11.3	11.3
Plate thick - ness (in)		0.75	0.75	0.75	0.75	0.75	0.75	0.75

B. Design of Beam to Column Web Connection

Beam to column web connections are classified into three types as corner joints, exterior joints, and interior joints.

Design results for beam and column web connections are shown in Table 4.

Table 4. Design Result for Beam to Column Web Connection

Joint type		Corner joints			Exterior joints		Interior joints	
Size	Beam	W10x45	W10x45	W10x45	W10x45	W10x45	W10x45	W10x45
	Column	W12x45	W12x45	W12x45	W12x45	W12x45	W12x45	W12x45
Storey level		3F, RF	3F, RF	3F, RF	3F, RF	3F, RF	3F, RF	3F, RF
Moment (kips-in)		168.88	168.88	168.88	168.88	168.88	168.88	168.88
Shear (kips)		8.31	8.31	8.31	8.31	8.31	8.31	8.31
Number of bolts		8	8	8	8	8	8	8
Size of fillet weld		1/2	1/2	1/2	1/2	1/2	1/2	1/2
Length of weld (in)		15.7	15.7	15.7	15.7	15.7	15.7	15.7
Plate thickness (in)		1	1	1	1	1	1	1

V. CONCLUSION

In this study, a four-storeyed steel frame building with rectangular shape in plan is proposed. The location of building is considered in severe earthquake zone. The structural frame is designed as special moment resisting frame.The design concepts and load combinations are considered in accordance with load and resistance factor design AISC-LRFD 1993. The superstructure is analyzed by ETABS software. For earthquake and wind forces, loading data are referenced from UBC 1997. A36 Grade-36 structural steels are used. Wide flange W-sections is used for frame members.

Steel columns are classified as type C1 and C2. Column sections are changed between first floor and second floor from W12x65 to W12x45. Steel beams are classified as type B1=W6x9, B2=W8x28, B3=W10x30 and B4=W12x45. Connections used in the building are bolted and welded connections. Bearing type connection with A 325 high-strength bolts and fillet weld with E70 electrodes are used in this study. For beam to column connection, 3/4" and 5/8" diameter bolts are used. The design result of the base plate thickness is 14"×14"×3/4".

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