"Seismic Analysis and Design of a Multistorey Steel Structure with Semi-rigid Connection"

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Abstract: *The objective of this study in steel structure framework are designed for vertical loads. Full strength of the beam section is never fully utilized due to the fact that support moment are always higher than the span moment and selection of a suitable section depends on support moment. By providing connection flexibility, the support moment can be reduced and span moment increased this means, transfer the support moment towards the mid-span of the beam hence leading to smaller section resulting in economy. This can be achieved by providing semi-rigid connections. Initial stiffness of the semi-rigid connection is to be found out first and Moment-Rotation relationship curve is developed for semi-rigid connection. Using available literature, Moment-Rotation relationship for Semi Rigid joints are reviewed for different loading and further work will be extended based on gap in research. By reading the available literature, the equation for finding the initial rotational stiffness of unstiffened top and seat angle with double web angle connection is reviewed. The equation is used for finding the initial rotational stiffness of unstiffened top and seat angle with double web angle connection considering vertical loading only. Further work shall be extended for horizontal loading.*

Keywords: **semi-rigid connection, moment-rotation relationship, unstiffened top and seat angle with double web angle connection, initial rotational stiffness.**

1. INTRODUCTION

1.1 General

Generally, steel structure frameworks are designed for vertical loads. And fixity in connections. Full strength of the beam section is never fully utilized due to the fact that support moments are always higher than the span moments and hence selection of a suitable section depends on support moments. By providing connection flexibility, the support moments can be reduced and span moment increased hence leading to smaller sections resulting in economy. This can be achieved by providing semi-rigid connections. Initial stiffness of the semi-rigid connection is to be found out first and Moment-Rotation relationship curve is developed for semi-rigid connection. This concept is to be extended for lateral loads and economy achieved is to be evaluated. Using available literature, Moment-Rotation relationship for Semi Rigid joints are found by developing Microsoft Excel Worksheets. Further analysis of the structure with Semi Rigid joints is to be carried out using STAAD Pro. Software.

1.2 Basic Definition of Semi-Rigid Connection

Moment required to cause unit rotation is called as "Rotational Stiffness." As we know, in pinned connection, at supports, moment is always zero so that stiffness of a pinned connection is also zero. Similarly, in rigid connection, at supports, angle of rotation is always zero so that stiffness of a rigid connection is infinity. But in semi-rigid connection, at supports, moment and angle of rotation will not be equal to zero. This means moment and angle of rotation both will be exist together with having some values.

a. Rigid connection

At support

Angle of rotation is zero. ($\theta=0$)

Stiffness of rigid connection is infinity.

b. Pinned connection

At support

Moment is zero. (M=0)

Stiffness of pinned connection is also zero.

c. Semi-Rigid Connection

At support

Moment and Angle of rotation is not equal to zero. **($M \neq 0$) & ($\theta \neq 0$)**

This means Moment and Angle of rotation both will be exist together.

1.3 Need to Research in Semi-Rigid Connection

Full strength of the beam section is never fully utilized due to the fact that support moments are always higher than the span moments and hence selection of a suitable section depends on support moments. By providing connection flexibility, the support moments can be reduced and span moment increased hence leading to smaller sections resulting in economy.

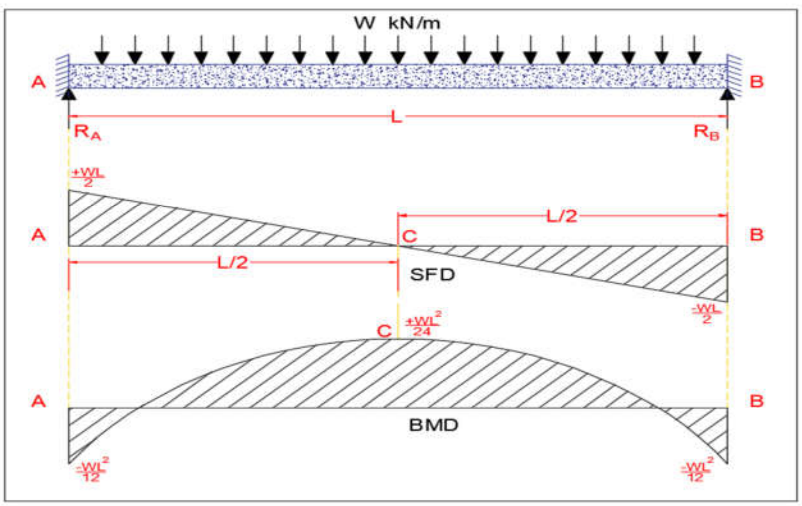

Figure 2.: Fixed Beam With Uniformly Distributed Load Over Entire Span

- In "Fig.1", we know that, the support moment is always greater than the mid-span moment.
- So we always select the section to resist the support moments. Hence, full strength of the beam section is never fully utilized.
- By providing connection flexibility means semi-rigid connection, support moment can be reduced and span moment can be increased. This means we can transfer the support moment towards the mid-span of the beam.
- Here, full strength of the beam can be utilized and this leads to economy.

1.4 Semi-rigid connections are basically categorized into 7 types:

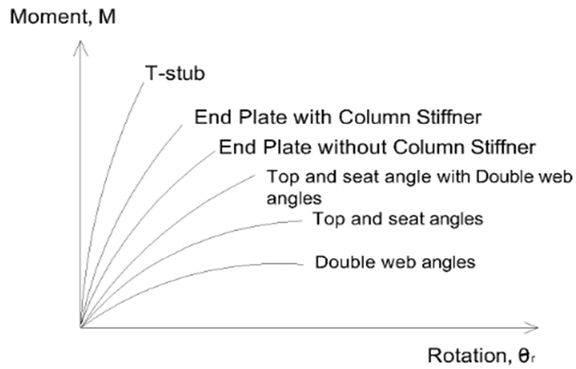

Figure 2. Semirigid Connections

2. METHODOLOGY

The Semi-rigid connections are basically categorized into seven types. A top-seat angle connection with double web angles (TSACW) is a popularly used type in steel structures because of its high flexural resistance as shown in fig.3. In AISC-ASD Specimens, this type of connection is considered as semi-grid connection, which can contribute substantially to the overall force distribution in the structure. In the dissertation work, Top and Seat Angle with double web angle type of semi-rigid connection will be used for the connection for beam and column joint. An effect of semi-rigidity shall be ensured in STAAD.Pro software by providing initial stiffness to the connection. Therefore, in order to design the steel structure with semi-rigid connection, initial rotational stiffness of the semi-rigid connection is to be determined. Semi-rigid connections are designed to provide a predictable degree of interaction between members, based on the Moment-Rotation characteristics of the joints. Therefore, Moment-Rotation relationship curve for semi-rigid connection is also to be developed.

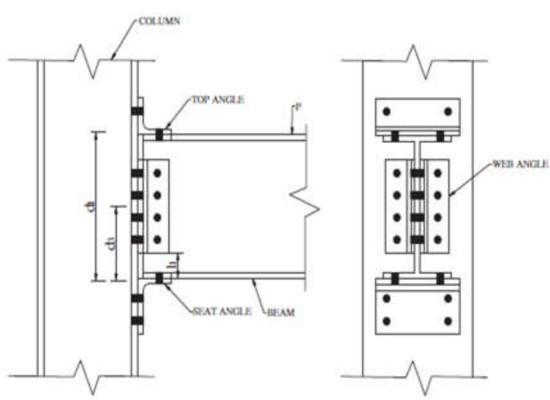

Figure 3. Top-seat angle with Double Web Angle Connection

2.1 Structural Modeling

A three tier piperack structure is to be considered. The structure is uncladded all over. The steel structure is having 5 bays in longitudnal direction. Intermediate secondary transverse beam is provided in between two main transverse beam for supporting future pipe and trys.

A data related to structure as follow:

Total height of structure is 7.6 m	Total lenght of structure is 30 m
Width of structure is 6 m	A 1st tier height is 3.6 m , 2nd and 3rd tier height each 2.0m

2.2 Initial Rotation Stiffness (Rki) of Top-Seat angle with Double web angle.

To determine the initial elastic connection stiffness by use of angle section and beam section the Rki connection is modeled as follows:

Table 1. Input Parameter Of The Connections (Properties of angle used)

ISA	L_1	L_2	t_t/t_s	Unit
Using Top Angle ISA (L_t x L_t x t_t)	0.05	0.08	0.01	m
Using Seat Angle ISA (L_s x L_s x t_s)	0.05	0.08	0.01	m
Using Web Angle ISA (L_s x L_s x t_a)	0.065	0.065	0.01	m

Table 2. Properties Of Beam Section

Beam	*Wf* (m)	d (m)
ISMB 350	0.14	0.35
ISMB 300	0.14	0.35

From input Parameter Thus, the initial connection stiffness Rki has.Calculated by follwing imperical equation:

$$Rki = \left[\frac{3EIt}{1+\frac{0.78\,tt^2}{gct^2}} \frac{d1^2}{gct^3} + \frac{6EIa}{1+\frac{0.78\,ta^2}{gcc^2}} \frac{d3^2}{gcc^3} \right]$$

where,
Bending stiffness of top angle leg adjacent to the column flange (EIt)
Bending stiffness of web angles leg adjacent to column flange (EIa)
Distance between center of top angle leg to the center of diameter of bolt (gct)
Distance between center of web angle leg to the center of diameter of bolt (gcc)
Distance between the centers of legs of the top & seat angles (d1)
Distance between the center of depth of beam to the center of seat angle (d3)

2.3 Ultimate Moment Capacity (Mu)

The collapse mechanism of top-seat angle with Double web angle based on Drucker's yield criterion for the combined plastic bending moment M and shear force V, then they gave the following equation for calculating the ultimate moment Mu.

Mu= Mos + Mp + Vpt d2 + 2Vpa d4

The plastic moment capacity of seat angle (Mos)
The platic moment capacity of top angle (Mp)
The ultimate shear force acting on top angle (Vpt)
The ultimate shear force at upper edge of web angle (Vpu)

For top and seat-angle connection part:
Ultimate shear force acting on top angle (Vpt)

$$\left(\frac{\text{Vpt}}{\text{Vot}}\right)^4 + \frac{\text{gc2}}{\text{tt}}\left(\frac{\text{Vpt}}{\text{Vot}}\right) - 1 = 0 \quad \text{(a)}$$

$$\text{Vot} = \frac{fy\,\text{lt}\,tt}{2}$$

$$\text{gc2} = \text{gt} - \text{kt} - \frac{tt}{2} - \frac{w}{2}$$

The plastic shear force capacity of top angle (Vot)
Yield stress of top angle (fy)
Distance between the two plastic hinge (gc2)
Distance from the top angle heel to the toe of the fillet as (kt)

For web-angle connection part:
To calculate ultimate shear force acting at upper edge of web angle (Vpu)

$$\left(\frac{\text{Vpu}}{\text{Vo}a}\right)^4 + \frac{\text{g2}}{ta}\left(\frac{\text{Vpu}}{\text{Vo}a}\right) - 1 = 0 \quad \text{(b)}$$

$$\text{Voa} = \frac{fy\text{w}\,ta}{2}$$

$$\text{g2} = \text{g1} - \text{k} - \text{ta}$$

The ultimate shear force at upper edge of web angle (Vpu)
The ultimate shear force at the lower edge of web angle (Voa)
Thickness of web angle (ta)
The radius of the fillet of web angle (k)

Plastic Moment Capacity of Top and Seat angle:
Plastic moment capacity of top angle (Mp)

$$\text{Mp} = \frac{\text{Vpt}\,gc2}{2} \quad \text{(c)}$$

Plastic moment capacity of seat angle (Mos)

$$\text{Mos} = \frac{\text{fy ls}\,ts^2}{4} \quad \text{(d)}$$

$$\text{d2} = \text{d} + \text{tt} - \frac{ts}{2} - \text{kt} \quad \text{(e)}$$

$$\text{d4} = \frac{(2Vpu+Voa)}{3(Vpu+Voa)}\,\text{lp} + \text{l1} + \frac{ts}{2} \quad \text{(f)}$$

2.4 Reference Plastic Rotation

$\theta o = Mu/R_{ki}$

2.5 Formulation of Moment-Rotation (M-θr) Relationship Curve

$M = [R_{ki} * \theta r]/[\{1+(\theta r/\theta o)^n\}^{1/n}]$

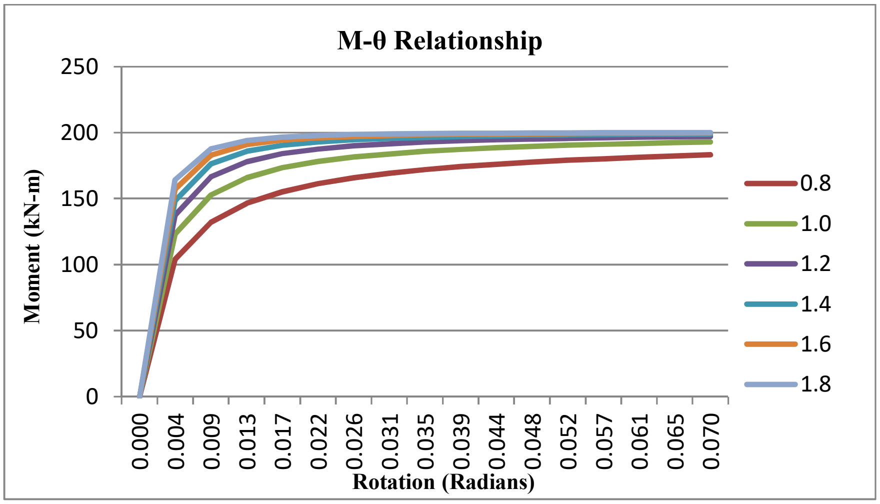

Figure 4. Moment-Rotation (M-θr) Relationship Curve

3. RESULTS

3.1 Geometry

The fig.5 shows the three-tier rigid frame. The yield strenght of all members 250 Mpa and modulus of elasticity of steel 200 Gpa. the vertical and horizontal loads apply on structure. The initial stiffness is calculated for end connection by stiffness equation. The rotational stiffness value are provide to end connection, then connection are converted of rigid to semirigid connection. Geometry of the Steel Structure is as follows:

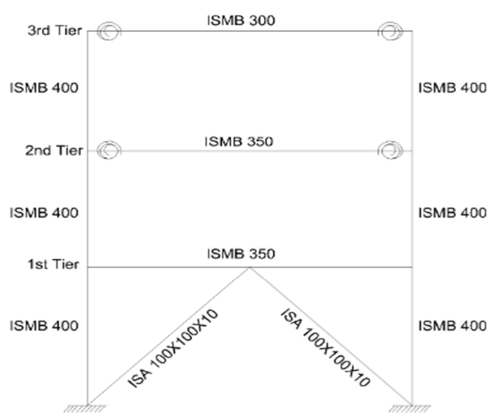

Figure 5. Space Frame Of Three-tier Rigid Frame

Table 3. Consideration For Space Frame Of Three-tier Rigid Frame

Floor	Y-Direction	X-Direction	Z-Direction
1st Tier	3.6 m	6 m	30 m
2nd Tier	2 m	6 m	30 m
3rd Tier	2 m	6 m	30 m

3.2 Comparison of Steel Consumption

Overall, the Optimization of the structure. and then comparison between rigid and semirigid structure we have to seen a Semi Rigid connection requires 13.75 % less steel as compare to rigid connection for the selected Steel Structure. These figures do not take into account the steel used for connection.

Table 4. Comparison of Steel Consumption In Steel Structure

Steel Consumption		
Rigid Connections	Semi-Rigid Connections	% Decrease steel w.r.t. Rigid Connection
Steel Used (tonne)	Steel used (tonne)	
35.017	30.204	13.75

4. CONCLUSION

On the basis of the literature review in steel structure of semi-rigid connection, the following conclusion are as below.

1. The initial connection stiffness are find out for top and seat angle with double web angle for providing connection partial flexibility.
2. From the above discussions, the most of the research work is clear. The parameters written above will be checked for structure. The focus will be to get an overall economy, which, in these days of high priced steel, fully justifies the additional engineering cost.
3. The research work done by considering end connection is partial flexibility (semi-rigid connection) . This means, transfer the support moment towards the mid-span of the beam. This leads to smaller section and resulting in economy.

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