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SEISMIC ANALYSIS AND DESIGN OF MODULAR STEEL STRUCTURE WITH SEMI-RIGID CONNECTION

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Research Article

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ABSTRACT
In general, structural frames are designed to withstand loads caused by gravity. Because the moment at the beam ends (supports) is usually larger than at midspan, the entire strength of the beam section is seldom used in the case of rigid connections. Semi-rigid connections may be used to lower these end moments and make better use of the beam section. At the joints, they are represented as rotating springs. In this work, a Microsoft Excel spreadsheet is used to compute the initial connection stiffness (Rki) of an unstiffened top and seat angle connection without a double web angle (T&S). In order to investigate possible cost reductions, this idea is then expanded to buildings that are susceptible to lateral loads. The Equivalent Static Method in STAAD.Pro V8i software is used to analyze and build two models of a G+2 industrial Piperack steel structure, one with rigid connections and the other with semi-rigid connections. Maximum shear force, maximum bending moment, and total steel consumption are among the metrics used to compare the outcomes of the two models.

Keywords: Stiffness, industrial Piperack, and an unstiffened top and seat angle

INTRODUCTION

Because of its high strength-to-weight ratio, quick construction, and design flexibility, steel buildings serve as the foundation of industrial infrastructure. Industrial steel frameworks, like pipe racks, are among the many structural types that are usually made to support vertical gravity loads, such as the structure's self-weight, piping systems, equipment, and other utilities. Conventional design approaches presume that connections are either precisely pinned (simple) or completely stiff. Nevertheless, the behavior of beam-to-column connections in reality is not always reflected by this assumption. Full continuity is assumed in rigid beam-to-column connections, and the joint is made to withstand shear and moment stresses. However, since the moment at the beam ends (supports) is often significantly larger than at midspan, the entire strength of the beam section is seldom used. Overdesign at supports and underutilization at midspans are the results of this uneven distribution. Semi-rigid joint connections that permit some rotational movement may be used to solve this inefficiency. Support moments are decreased and midspan moments somewhat rise when joints like rotating springs are modeled, resulting in a more uniform moment distribution and a lower section required. In the end, this method produces a more cost-effective design. This research uses Microsoft Excel based on the Kishi-Chen analytical model to compute the initial connection stiffness (Rki) of a certain semi-rigid connection unstiffened top and seat angle without double web angle (T&S). The approach is then expanded to structures that are subjected to lateral loads, and STAAD.Pro V8i software modeling and analysis are used to assess the performance. The Equivalent Static Method is used to analyze two models of a G+2 Piperack steel structure, one with rigid connections and the other with semi-rigid connections. To evaluate factors like maximum bending moments, shear pressures, and total steel consumption, the outcomes from both models are compared.
Either the mid-span part (for fixed joints) or the support section (for pinned joints) is underused when we build the beam for maximal moments. Economy is not attained and the whole length of the beam cannot be fully used. The fundamental need for any structural design is economy combined with safety. In order to fully use the beam section for the maximum length of the beam, a different connecting mechanism is required. One is to use plates to create a beam with different parts along its length. However, creating such beams is challenging. Semi-rigid joints are a further method.

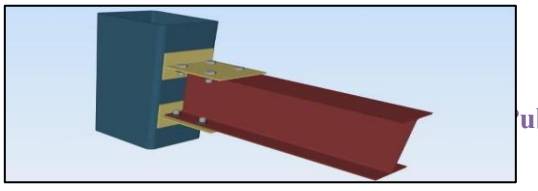


Fig 1: A typical fixed joint A Simple Definition of Semi-Rigid Connection

"Rotational stiffness" refers to the moment needed to rotate a unit. As is well known, a pinned connection's stiffness is zero since the moment at supports is always zero. Similarly, a rigid connection's stiffness is infinite because the angle of rotation at supports is always zero. However, the moment and angle of rotation in a semi-rigid connection will not equal zero at support. This implies that both the moment and the angle of rotation will exist concurrently and have certain values. Both vertical shear and certain moments may be transferred via a semi-rigid link. In theory, rigid connections convey 100% of the moment and permit no relative rotation at beam ends. It is expected that pinned connections provide little moment transmission and let the beam end to spin significantly freely. The majority of beam-to-column connections utilized in contemporary practice seem to exhibit intermediate stiffness, or semi-rigid behavior, according to experimental findings made by different researchers.

a. Stiff connection 1. The angle of rotation is zero at the support. ($\theta=0$)

2. The rigid connection's stiffness is infinite.

a. A pinned link

3. Moment is zero ($M=0$) at support.

4. The pin connection's stiffness is also zero.

c. Semi-rigid Attachment

5. The moment and rotational angle are not equal to zero at support. ($\theta \neq 0$) & ($M \neq 0$)

This implies that the moment and the rotational angle will coexist.Research on Semi-Rigid Connections Is Needed

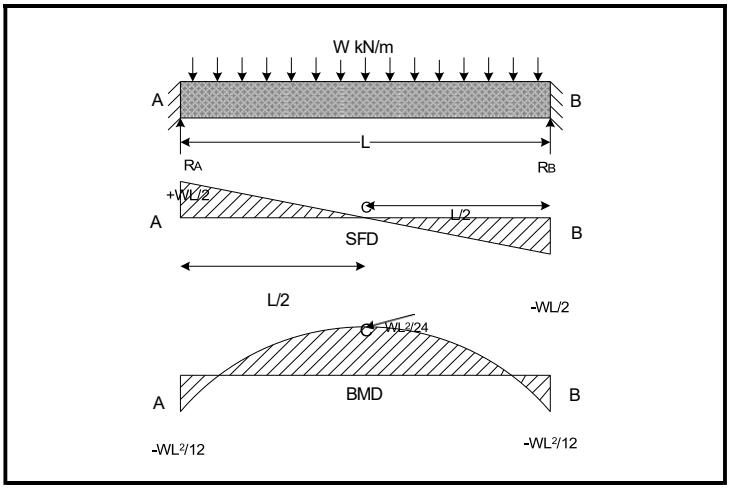


Figure 2: Fixed Beam with Evenly Spread Load Across the Whole Span

From above fig,

1. We are aware that the mid-span moment is always smaller than the support moment.
2. As a result, we consistently choose the portion to withstand the support moments. As a result, the beam section's full strength is never completely used.
3. Support moment may be decreased and span moment can be enhanced by offering semi-rigid connection flexibility. This implies that we may move the support moment to the beam's mid-span.
4. In this case, the beam's full power may be used, which results in economy.

Connection Flexibility in Steel Frames

Let's look at the two-story steel frame structure seen in Fig. to demonstrate the flexibility of connections in steel frames. The beam BC is linked to the supporting columns by connections that may be made in a number of ways. The beam BC will spin via a greater clockwise angle than the column BA as a result of this connection

distortion. According to Fig. 1.3 (b), the beam BC would have rotated along the line BR1 if the beam column joint had been completely stiff. Rather, the beam has been rotated to the location along BR2. This indicates that the relative angle of rotation, or additional angle θr, has been turned by the beam in relation to the column. Therefore, the relationship between applied moment M at the joint and relative rotation θr is crucial if we want to take connection flexibility into account in analysis.

Semi-Rigid Connections and Initial Stiffness (Rki)

A connection that may transfer partial moment and vertical shear between parts is called semi-rigid. The rotational stiffness (Rki), or the moment needed to generate a unit rotation at the joint, is the primary factor that determines how a semi-rigid joint behaves. For analytic tools to simulate such relationships, Rki must be accurately estimated.

The Rki value for the unstiffened top and seat angle without double web angle connection—a typical semi-rigid joint type in industrial structures—is calculated in the current research. The Kishi-Chen Power Model, which offers an analytical framework for estimating moment-rotation properties, serves as the foundation for this computation. Rigid joints in STAAD are then subjected to computed stiffness.Pro to assess structural performance and model semi-rigid behavior.

Semi-rigid connections have the ability to transmit moment and vertical shear force. The concept of rotational stiffness (Rki) must be understood in order to grasp the fundamentals of semi-rigid connections.It is the moment needed to generate rotation of a unit. Finally, the behavior of semi-rigid connections may be studied by the experimental, numerical, and analytical examination of the moment rotational curve. The choice of semi-rigid connection type is often dependent on connection stiffness. However, in this study, only the initial connection stiffness (Rki) of the unstiffened top and seat angle without double web angle semi-rigid connection is calculated using the Kishi-Chen Analytical Power Model, which is created using a Microsoft Excel sheet.

Research Gap

There is little study on the use of semi-rigid connections in multi-tier industrial structures, such as pipe racks, under combined vertical and lateral loads, despite the rising interest in semi-rigid connection modeling. Moreover, the majority of research is on building-type frames rather than non-building structures, which exhibit distinct behavior because of their load arrangements and shape.

Furthermore, the practical effects of semi-rigid joints vs stiff joints in real-world design processes utilizing commercial tools such as STAAD Pro are seldom compared in previous research. Additionally, there aren't many easily accessible methods (like spreadsheets) for determining the stiffness of certain connection types according to Indian regulations.

Necessity of the Study

1. This research is required to close the gap between theoretical knowledge and real-world application of semi-rigid connections in industrial steel structures. Additionally, it offers a methodical approach to:
2. Optimize joint behavior to cut down on steel usage Use semi-rigid modeling to increase design efficiency.
3. Offer an Excel sheet as a design tool for determining initial stiffness.
4. Provide structural engineers with an affordable and secure substitute for conventional rigid connection design.

bjectives of the study

1. To recognize and categorize semi-rigid connections according to INSDAG (Indian Steel Development and Growth Institute) norms, Chapter 39, based on stiffness and type.
2. To use analytical techniques to determine the initial connection stiffness (Rki) of the unstiffened top and seat angle without double web angle type of semi-rigid connection.
3. To replicate the impact of semi-rigid behavior in STAAD.Pro V8i by giving beam-column joints in a G+2 Piperack construction rotational spring stiffness.

4. To evaluate rigid and semi-rigid models according to three important factors: steel consumption, shear forces, and bending moments.
5. To assess semi-rigid connection modeling's structural and economic viability in industrial steel constructions.

PROBLEM STATEMENT

1. Rigidity analysis and design of a steel pipe rack structure. The analysis and design of a steel pipe rack structure for several connection rigidities—rigid, semi-rigid, and pinned—is the aim of this work. The goal of the study is to ascertain the structure's maximum horizontal displacement and total material amount for each stiffness condition.
2. In order to determine the ideal rigidity scenario that guarantees the least amount of material consumption while meeting strength and serviceability requirements, the research will examine the pipe rack's performance for each of the three connection circumstances.

METHODOLOGY

A steel pipe rack structure with various connection rigidities (rigid, semi-rigid, and pinned) is analyzed and designed using Chapter 39 of the INSDAG Design Manual, which provides guidance on the evaluation of initial rotational stiffness and the creation of moment–rotation relationship curves for semi-rigid connections.
The analysis and design were conducted using the following methodology:
1. Pipe Rack Configuration Selection
Describe the pipe rack's function, working conditions, and design (number of bays, tiers, and span lengths).
Determine the kind of pipes that are supported (instrument, utility, or process lines).
2. Choosing the Structure's Geometry
Based on the plumbing needs and process plan, calculate the overall height, bay spacing, and tier elevations.

For lateral stability, choose the bracing configuration and column orientation.
3. Dead Load Calculation
Incorporate the self-weight of gratings, pipe supports, structural pieces, and other permanent parts.
When relevant, take into account the self-weight of pipes and insulation.
4. Calculating Operating and Live Loads
In accordance with IS 875 (Part 2), include pipe contents (operation and test circumstances), valves, fittings, and maintenance loads.
5. Additional Forces and Pipe Loads
Calculate thermal expansion, sporadic, and sustained loads using data from the pipe arrangement.
Incorporate guide loads, wind loads transferred from pipes, and frictional forces at supports.
6. Wind and Seismic Load Calculation
Assess seismic loads in accordance with IS 1893 (Part 1) and wind loads in accordance with IS 875 (Part 3).
For both longitudinal and transverse frames, take directional effects into account.
7. Combinations of loads
Consider operational, testing, and severe events when generating load combinations in accordance with IS 800:2007 and project-specific design requirements.
8. STAAD Modeling and Analysis.Pro V8i
Use beam elements with suitable boundary conditions to model the pipe rack structure.
Assign various connection stiffness values (rigid, semi-rigid, pinned) according to the INSDAG requirements' moment-rotation characteristics.
Analyze member forces, moments, and deflections under every possible combination of loads.
9. Members and Connections Design
Create bracings, beams, and columns in accordance with IS 800:2007 (Limit State Method).
Based on the study findings, design beam-to-column and column-base connections for the chosen stiffness condition.
Piperack Industrial Steel Structure
Piperack is an industrial steel structure with multi-tiers that hold cable trays, pipe assemblies, and (with) fin-fan coolers without coolers. Its basic shape is similar to that of a steel portal frame. The Process unit's major artery

is Piperack. All equipment is connected via wires that are unable to pass through nearby areas. Piperack structures are used in chemical, petrochemical, and power plants to support cable trays, pipes, and instruments. Industry reference standards give design requirements for non-building structures. Steel for Industry

Structure Description

In this study, G+2 (3tier) Piperack industrial steel structures with stiff connections are first analyzed and designed using STAAD Pro V8i software's equivalent static method.

Second, the same G+2 (3tier) Piperack industrial steel structure with a semi-rigid connection at a rigid joint is analyzed and designed using an equivalent static method in STAAD Pro V8i software. The results obtained from the rigid and semi-rigid structures are compared to study various parameters like maximum bending moment and maximum shear force. Lastly, Steel Consumption Comparisons for Rigid and Semi-Rigid Structures

Table 1: Determination of Rki of Unstiffened Top & Seat angle

Sr. No.	Parameters	Values &Units
1	Young's Modulus of steel Es	2X10^5 N/mm
2	Length of angle Provided (Le)	90 mm
3	Length of top angle leg La top	90 mm
4	Length of seat angle Leg La seat	150 mm
5	Thickness of Top angle leg Ta, top	8 mm
6	Thickness of Seat angle leg ,ta, seat	15 mm
7	Distance Between bolt axis & corner of top angle gt'	40 mm
8	Nut Width Across Flat W	21 mm
9	Depth of Beam d	300 mm
10	Second Moment of Inertia of top angle leg Connected to column face Ia, top=Le*ta, top^3 /12	3840 mm^4
11	The Distance between the centre line of top angle & washer $g_1 = g_r' - W/2 - ta, top/2$	25.5 mm
12	The Distance between the center line of top angle & center line of seat angle leg d1= d + ta, top/2 + ta, seat/2	311.5 mm
13	First Equation 3*E*Iatop	2X10^6 N-mm^2
14	Second Equation: 1+0.78 *(ta, top/ $g_1)^2$	1.0767
15	Final Initial connection stiffness (Rki) =3*E*Ia,top/1+0.78 *(ta,top/$g_1)^2$ *($d1^2$/ g_1^3)	12521457 N_mm/Rad
16	Required Initial Connection Stiffness (Rki)	12521.4579 kN-m/Rad

Generally Initial Connection Stiffness obtained is in Kn-M/Rad but in STAAD Pro V8si Software We have enter in kN-m/Degree. So Above Value is converted into 218.535kN-m/Degree so this Value is applied at Rigid Joint in Model 2

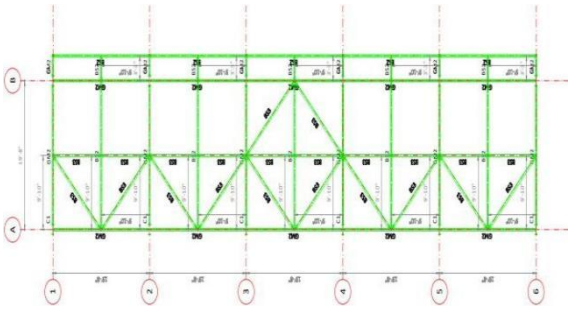


Fig 3 Plan Dimension of G+2 (3 tier) Piperack Industrial

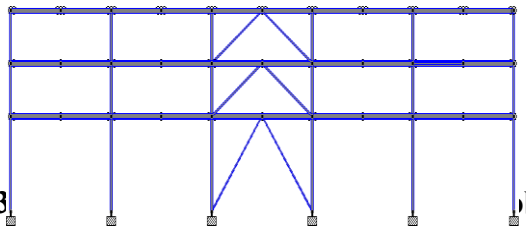


Fig 4 Side Elevation of G+2(3 oblem Statistics

S.N	Parameters	Values
1	Type of Building	Industrial
2	Location of Building	Mumbai (Maharashtra)
3	Number of Bay in X Direction	1 with 6 M (each)
4	Number of bays in Z Direction	5 with 6 M (each)
5	Number of bays in Y Direction	3 with 6 M (each)
6	Total Height of Structure	7.6 M 1st Tier Height is 3.6 M 2nd & 3rd Tier Height is 2 M (each)
9	Yield Strength of Steel	250 Mpa
10	Ultimate strength of Steel	420 MPa
11	Primary Load Case of Structure	As per ASCE7- 05
12	Primary Load Case of Pipe	As per PIP STC01015
13	Primary load Case of Cable Tray	As per PIP STC01015
14	Wind Load	As Per ASCE7-05
15	Seismic Load	As per ASCE7-05
16	Design Code	As per IS 800:2007 LSD

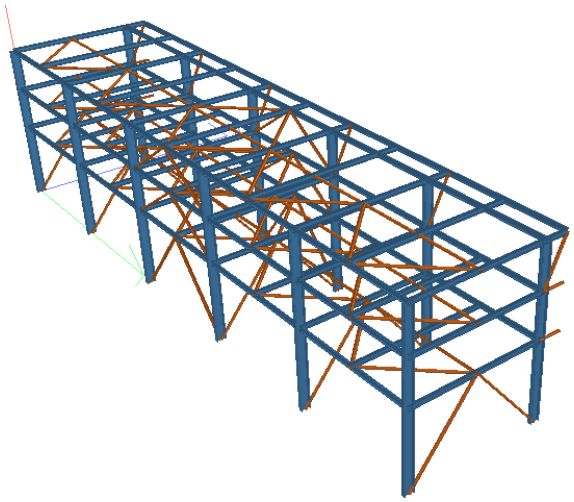


Fig 5 3D Modelling of G+2 (3tier) Piperack Rigid & Semi-Rigid Structure

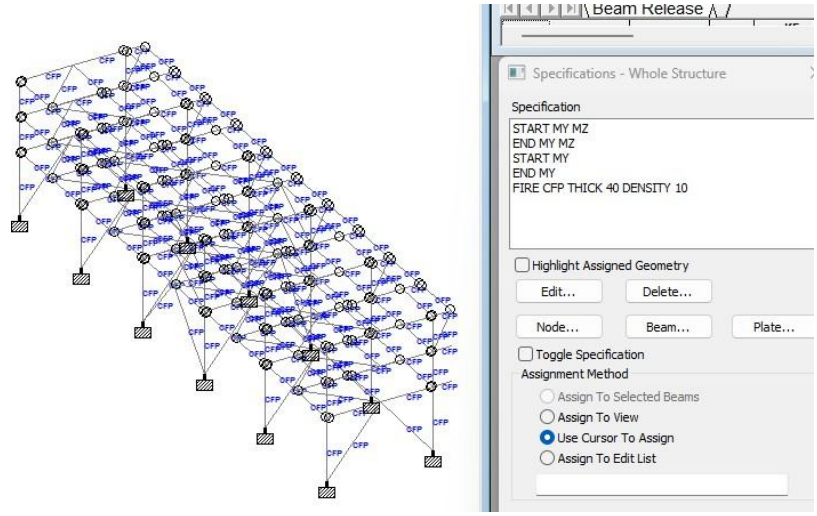


Fig. 6 G+2 Piperack with Rigid Connection

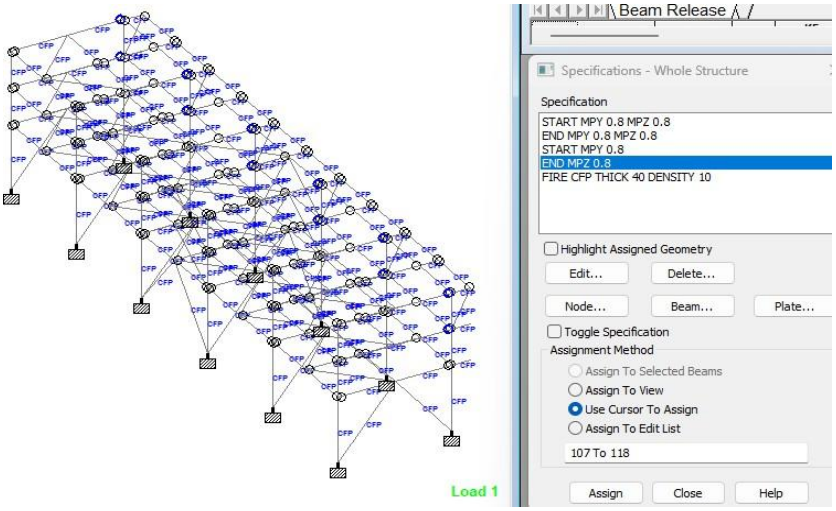


Fig. 7 G+2(3-tier) Piperack with Semi-Rigid Connection

RESULT AND DISCUSSION

Moment-Rotation Characteristics of Structural Steel Connections

the several kinds of structural steel connections that are often used in real-world applications. The many kinds of connections may be categorized as flexible or stiff connections based on their flexibility (or, conversely, their stiffness). These connections are better categorized as rigid (where the rigid elastic assumption is valid), semi-rigid (where connection flexibility is to be taken into consideration), and pinned (where no moment is assumed to be transferred across the joint) for ease of design. The intricacy of the connections shown makes it clear that using mathematical formulas to determine the stiffness of these linkages is almost impossible. As a result, tests are mostly used to identify connection properties. Analytical formulas in the form of empirical equations are recommended for design based on these investigations. Numerous findings from studies of semi-rigid connections are entered into a data bank of M-r curves to get the empirical equations. The proper M-r curves for design are then created using curve-fitting techniques using experimental data.

Primary Load Cases as Per ESM

Longitudinal Earthquake Load (EL)
Transverse Earthquake Load (ET)
Longitudinal Earthquake Load (Pipe Only) (ELP)
Transverse Earthquake Load (Pipe Only) (ET)
Dead Load (DL)
Cable Tray + Cable Load (CTC)
Pipe Empty Load (PE)
Pipe Content Load (PC)
Pipe Test Content Load (PT)
Longitudinal Pipe Friction Load (PFL)
Transverse Pipe Friction Load (PFT)
Longitudinal Pipe Anchor Load (PAL)
Transverse Pipe Anchor Load (PAT)
Pipe Contingency Load On Longitudinal Tie (PCL)
Live Load (LL)
Temperature Rise Load (TRL)
Longitudinal Wind Load (WL)
Transverse Wind Load (WT)

Load Combination are Prepared as per PIPSTC01015

Limit State of Serviceability (Load List from 101 to 136)
Limit State of Collapse (Load List 201 to237)
Local Design of Longitudinal Beam for Strength (Load List 301 to 320)
Local Design of Transverse Beam for Strength (Load list from 401 to 420).

Result & Discussion

Structure Behavior with Rigid and Semi-rigid G+2 (3 tier) Piperack Industrial Steel Structures are intricate phenomena that are exposed to wind and seismic loads. The behavior of both rigid and semi-rigid structures is influenced by a number of parameters, including maximum shear force and maximum bending moment. Lastly, the consumption of steel in both rigid and semi-rigid structures. Both models are used for the 3D analysis. STAAD Pro V8i software is used to implement the Equivalent Static Method (ESM) in both models. This paper discusses the results of the analysis. Both Model Rigid Structure and Semi-Rigid Structure use the Equivalent Static Method. Tables are used to display the results. The following parameters, such as maximum shear force and bending moment in both structures, are used to compare the obtained results. Ultimately, Following Both Structure Optimization Steel Use in Semi-Rigid and Rigid Structures

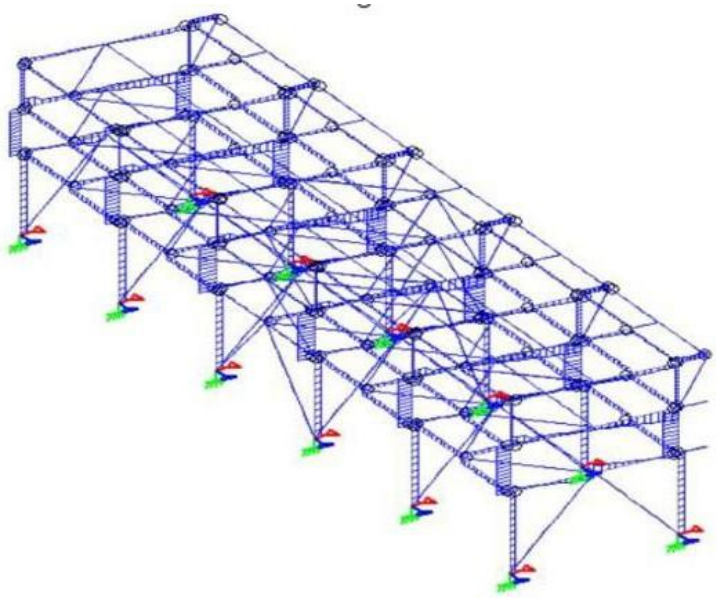


Fig 8. Maximum Shear Force Diagram for Rigid Structure

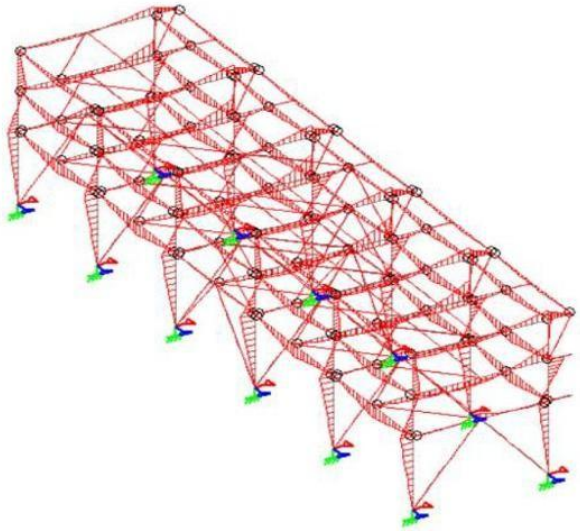


Fig 9. Maximum Bending Moment Diagram for Rigid Structure

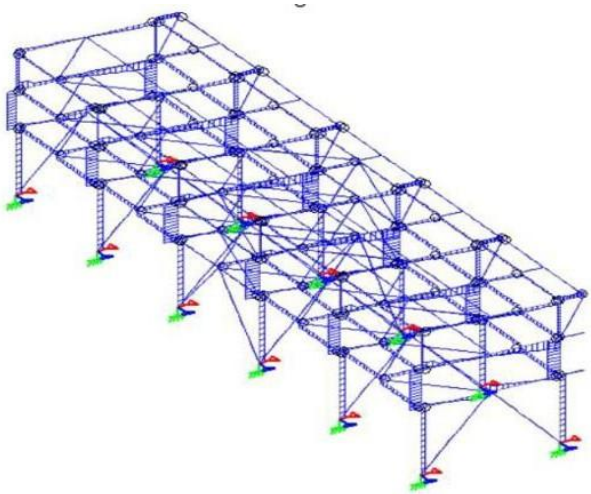


Fig. 10. Maximum Shear Force Diagram for Semi-Rigid Structure

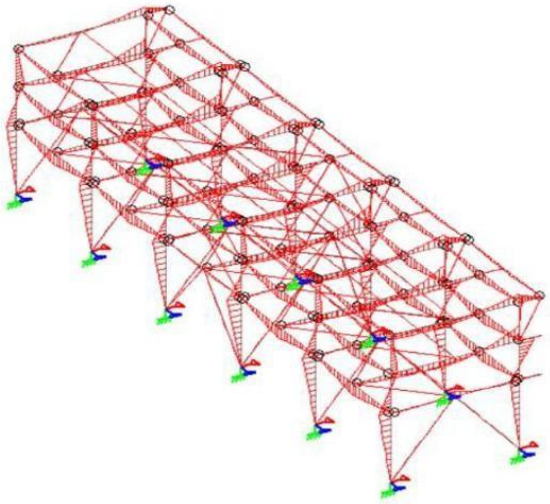


Fig 11. Maximum Bending Moment for Semi-Rigid Structure

Table 3: Maximum Shear Force & Bending Moment in Rigid Structure

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	77	313 1.2 DL +	7	**367.124**	0.000	0.642	0.000	0.000	0.000
Min Fx	71	317 1.2 DL +	116	**-321.426**	-0.000	-0.642	-0.000	-0.000	-0.000
Max Fy	18	415 1.2 DL +	115	146.348	**73.885**	-0.201	-0.008	0.299	53.519
Min Fy	210	403 1.4 DL +	215	36.166	**-68.291**	6.372	-0.001	0.220	95.094
Max Fz	213	318 1.2 DL +	219	-3.425	46.209	**72.228**	-0.001	-0.715	37.974
Min Fz	209	317 1.2 DL +	213	-30.970	38.568	**-72.256**	-0.001	0.717	14.972
Max Mx	14	310 1.2 DL +	103	106.463	-7.560	1.255	**0.693**	-0.361	-17.599
Min Mx	24	309 1.2 DL +	133	116.695	20.659	-0.157	**-0.687**	-0.375	8.049
Max My	213	317 1.2 DL +	220	-8.963	-6.797	47.162	-0.001	**27.999**	-29.442
Min My	209	318 1.2 DL +	214	-36.290	-2.013	-47.197	-0.001	**-28.100**	-29.391
Max Mz	210	419 1.2 DL +	215	43.398	-68.145	5.458	-0.001	0.188	**110.245**
Min Mz	18	415 1.2 DL +	215	144.995	73.885	-0.201	-0.008	-0.102	**-94.251**

Table 4: Maximum Shear force & Bending Moment in Semi-rigid structure]

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	77	313 1.2 DL +	7	**373.957**	0.000	0.642	0.000	0.000	0.000
Min Fx	71	317 1.2 DL +	116	**-327.845**	-0.000	-0.642	-0.000	-0.000	-0.000
Max Fy	18	415 1.2 DL +	115	129.420	**67.627**	-0.197	-0.006	0.290	73.592
Min Fy	210	403 1.4 DL +	215	38.430	**-63.164**	6.468	-0.000	0.184	69.850
Max Fz	213	318 1.2 DL +	219	-0.374	45.315	**72.239**	-0.001	-0.389	26.753
Min Fz	209	317 1.2 DL +	213	-28.219	40.274	**-72.311**	-0.000	0.391	11.603
Max Mx	14	310 1.2 DL +	103	105.403	-8.671	1.249	**0.618**	-0.359	-18.074
Min Mx	24	309 1.2 DL +	133	112.120	18.622	-0.140	**-0.612**	-0.395	15.278
Max My	213	317 1.2 DL +	220	-7.817	-5.545	47.187	-0.000	**27.746**	-38.181
Min My	209	318 1.2 DL +	214	-34.063	-1.516	-47.271	-0.000	**-27.996**	-38.161
Max Mz	17	419 1.2 DL +	113	91.102	58.624	-0.382	0.047	0.414	**86.186**
Min Mz	147	301 1.4 DL +	128	-102.904	21.906	0.348	-0.002	1.044	**-68.279**

5.3 Optimization with Steel Take off for Both Rigid & Semi-Rigid Structure

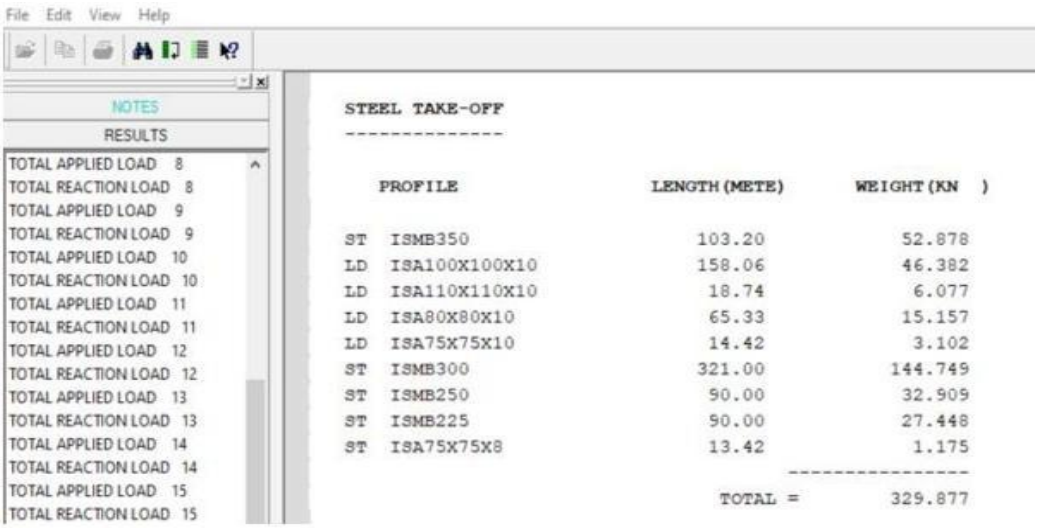


Fig. 12 Steel Take off for Rigid Structure

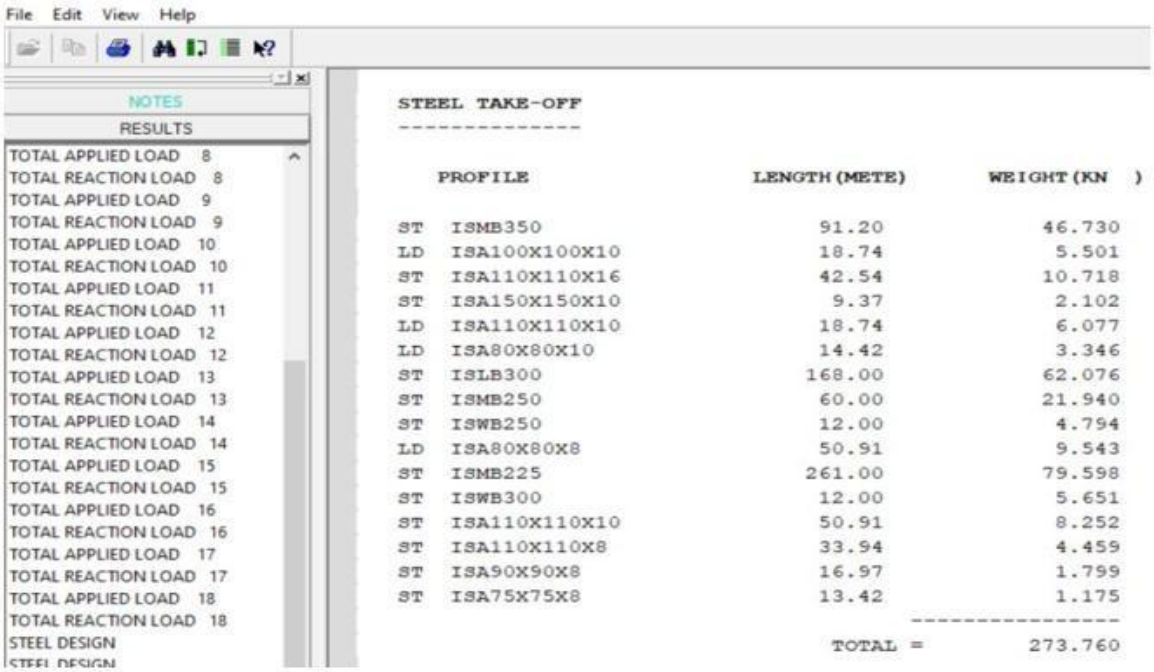


Fig. 13 Steel Take off for Semi-Rigid Structure

Following observations are made from work:

Table 5: Comparison of Steel Consumptions in both Rigid & Semi-Rigid Structure

Steel Consumptions		
Rigid Connections	Semi-Rigid Connections	% Decrease of steel w.r.to Rigid Connection
Steel Used (Ton.)	Steel Used (Ton.)	
33.1068	27.4748	18.5931%

Result Analysis

1. The maximum shear force and bending moment in a rigid structure are shown in Table 3.1. The

governing load combination number for shear force is LC No. 415, which has a maximum shear force, or Fy, of 73.885 kN. However, LC No. 419 is the governing load combination number for bending moment, and its maximum bending moment, or Mz, is 110.245 kN-m.
2. The maximum shear force and bending moment in a semi-rigid structure are presented in Table 3.2. The maximum shear force, or Fy, is typically 67.627 kN, and the governing load combination number for shear force is LC No. 415. However, LC No. 419 is the governing load combination number for bending moment, and its maximum bending moment, or Mz, is 86.168 kN-m.
3. Following the optimization of both models in STAAD Pro V8i, Table 3.3 displays the maximum steel consumption in both rigid and semi-rigid structures. After the structure has been optimized, it has been shown that by providing connection stiffness at the rigid joint, we may reduce the end support moment and, therefore, the depth of the structural steel section. Therefore, compared to a rigid structure, 18.5931% less steel is needed.

CONCLUSIONS

1. The idea of a semi-rigid connection is often applied with a top and seat angle without a double web angle. Lastly, the Initial Connection Stiffness (Rki) of this kind of connection is only applied to rigid joints in the problem statement. The STAAD Pro V8i software models two different kinds of structures: semi-rigid structures (Model-2) and rigid structures (Model-1).
2. The beam to column joint connection is made using the unstiffened Top & Seat angle without Double web angle (T&S) kind of semi-rigid connection. However, this kind of connection is only used with rigid joints to provide flexibility (rotational spring).
3. The Initial Connection Stiffness (Rki) of T&S is applied to the rigid joint in Model 2 after being manually calculated and worked out using a Microsoft Excel spreadsheet.

4. In a semi-rigid structure, connection stiffness reduces the maximum shear force and bending moment. Therefore, the semi-rigid structure experiences reduced shear force and bending moment.
5. The semi-rigid structure (Model-2) is taken into consideration when estimating the percentage of structural steel saved. The predicted overall structural steel savings is 18.5931%.

Saving structural steel material leads to an economical industrial steel structure.

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