

# Seismic Analysis and Design of Multistoried Industrial Steel Structure with Semi-Rigid Connection

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**Abstract** - Generally Structure framework are designed for gravity loading .In case of Rigid connection the full 100% strength of Beam section is never utilized due to the fact in Beam at the end the end support Moment are always having greater value than Midspan Moment .The end support moment value is decreased by providing semi-rigid connection i.e. Rotational spring at Rigid Joint only .In This Paper Firstly Initial Connection Stiffness(Rki) of Unstiffened Top & seat angle without double web angle connection(T&S) is workout using Microsoft excel sheet Further this concept is extended for lateral loading to obtained Economy in the structure. The Two Model of a G+2 Piperack Industrial Steel Structure with Rigid & Semi-Rigid Connection are Analyzed & Design with Equivalent Static Method Using STAAD Pro V8si Software. Finally The Result obtained from Both Model are Compared to study Various Parameter of Maximum shear force, Maximum bending Moment, Finally Steel Consumption in Both Model.

**Index Terms** - Semi-rigid Connection, Unstiffened top & seat angle without double web angle connection, Initial Connection Stiffness (Rki), Piperack Industrial Steel Structure.

## 1.INTRODUCTION

Generally, Industrial Steel Structure are designed for vertical Downward gravity loading .In Case of Rigid Connection the full 100% Strength of Beam section is never Utilized due to this fact in Beam at the end the end support moment are always having Greater value than Midspan moment Hence from design point of view Selection of a suitable Structural Steel Section depend upon end Support Moment Value. By Providing Rotational Spring at rigid joint only the end support moment value will be decreased and slightly increasing value in Midspan moment so by applying this concept to rigid joint after analysis we get smaller structural steel section finally leads to economical solution .So Firstly Initial Connection Stiffness (Rki)

of Top & seat angle without double web angle connection (T&S) is workout using Microsoft Excel sheets .Further for lateral loading this concept is applied in STAAD Pro V8si Software .[1]

## 2.LITRATURE REVIEW

- Kishi.N,et.al (2014) [5] Moment Rotation Relation of Top & Seat angle .The Derivation of Initial Connection Stiffness of Unstiffened top 7 seat angle without double web angle connection .Finally at the last Analytical Power provides good agreement result with Experimental Results
- Ashit K. Kikani, et.al (2015) [6] Comparative Study of. Piperack Structure with Modular Concept and Normal Stick-built Approach Using ASCE 7-02.This Paper States that Importance of Piperack Structure in Oil & gas Industries. Genarllly Comparative study of Piperack structure with Modular concept is done using a problem statement of 7 tiers Piperack in North America. Finally the Cost Comparison of Both Piperack Structure.
- Harsh Rana, et.al (2020) [9] High rise Long span Steel Structure with Semi-Rigid Connection Using Bracing System. This Paper Mainly Focus on Static & Dynamic Loading on high rise steel Structure of G+15 Storey Structure it is Analyzed Under Two Condition Partially Restrained of Semi-Rigid Connection which is derived by Fixity factor Value 0.7 & 0.75(as per (AISC). The Analysis is done in STAAD Pro software. Finally Result of lateral drift is compared in rigid & semi-Rigid Structure.
- Gaurav.S.Patil, et.al (2020) [10] Seismic Analysis and Design of Multistory Industrial Steel Structure with Semi-Rigid Connection .This Paper Describes the concept of Connection

Flexibility in Steel Frames. Initial Connection stiffness of top & seat angle with double web angle connection (TSDWA).The Result of Optimization shows 13.75 %less steel than rigid connection

III. OBJECTIVES

- Seismic Rigid Connection are classified into 7 types as per chapter 39 of INSDAG
- In this Paper Unstiffened top & seat angle without Double web angle connection(TS) is used to connection of Beam to column joint
- The effect of semi-rigidity is ensured in STAAD Pro V8i software by providing initial connection stiffness at the Beam to column connection. The mainly initial Connection Stiffness (Rki) of TS connection is workout & applied to Model 2 .Finally to Study Behaviour in Both Rigid & Semi-Rigid Structure.

IV. PROBLEM DESCRIPTION

A. INDUSTRIAL STEEL STRUCTURE DESCRIPTION

- In this Study firstly G+2(3 tier) Piperack Industrial Steel structure with Rigid Connection are Analyzed & Design Using Equivalent Static Method in STAAD Pro V8i Software.
- Secondly same G+2(3 tier) Piperack Industrial Steel structure with Semi-Rigid Connection are Analyzed & Design Using Equivalent Static Method in STAAD Pro V8i Software.
- The Result Obtained from Rigid & Semi-Rigid Structure are Compared to study various Parameter such as Maximum Shear force ,Maximum Bending Moment .Finally Steel consumption in Both Rigid & Semi-Rigid structure

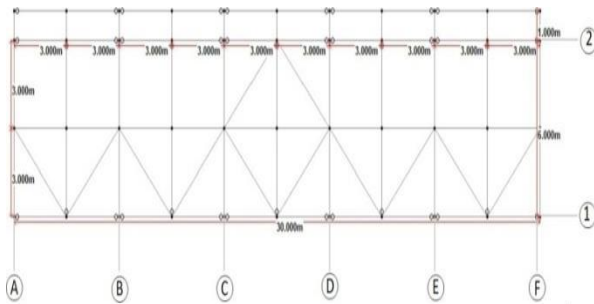


Fig.1 Plan Dimension of G+2 Piperack Structure

Table I Determination of Initial Connection Stiffness (Rki) of (TS)

S.N	Parameters	Values &Units
1	Young’s Modulus of steel Es	2*10 <sup>5</sup> N/MM <sup>2</sup>
2	Length of angle Provided (Le)	90MM
3	Length of top angle leg La top	90MM
4	Length of seat angle Leg La seat	150MM
5	Thickness of Top angle leg ta,top	8MM
6	Thickness of Seat angle leg, ta, seat	15MM
7	Distance Between bolt axis & Corner of top angle gt’	40MM
8	Nut Width Across Flat W	21MM
9	Depth of Beam d	300 MM
10	Second Moment of Inertia of top angle leg Connected to column face $I_{a, top}=Le*ta, top^3/12$	3840 MM <sup>4</sup>
11	The Distance between the centre line of top angle & washer $g_1=g_t’- W/2 - ta, top/2$	25.5 MM
12	The Distance between the centre line of top angle &centre line of seat angle leg $d1= d+ta, top/2+ta, seat/2$	311.5MM
13	First Equation $3*E*I_{atop}$	2 * 10 <sup>6</sup> N–MM <sup>2</sup>
14	Second Equation: $1+0.78 *(ta, top/g_1)^2$	1.0767
15	Final Initial connection stiffness (Rki) $=3*E*I_{a, top}/1+0.78 *(ta, top/g_1)^2 *(d1^2/g_1^3)$	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

Table II Problem 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 Z5 Direction	5 with 6 M (each)
5	Number of bays in Y3 Direction	3 with 6 M (each)
6	Total Height of Structure	7.6 M
7		1 <sup>st</sup> Tier Height is 3.6 M
8		2 <sup>nd</sup> & 3 <sup>rd</sup> 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	Load Combinations in Both Structure	As Per PIP STC01015
17	Design Code	As per IS 800:2007 LSD

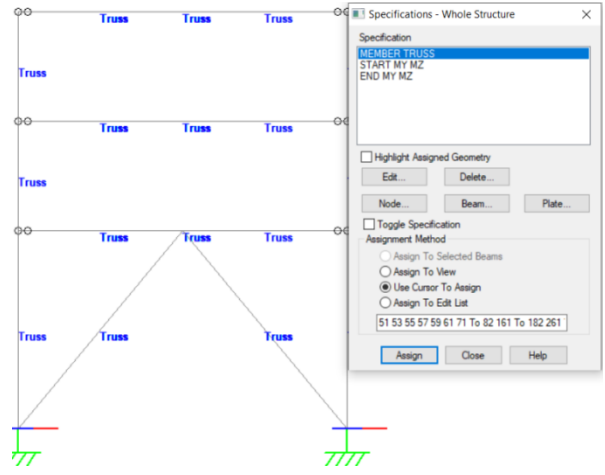


Fig.3 G+2 (3tier) Piperack Industrial steel Structure with rigid connection

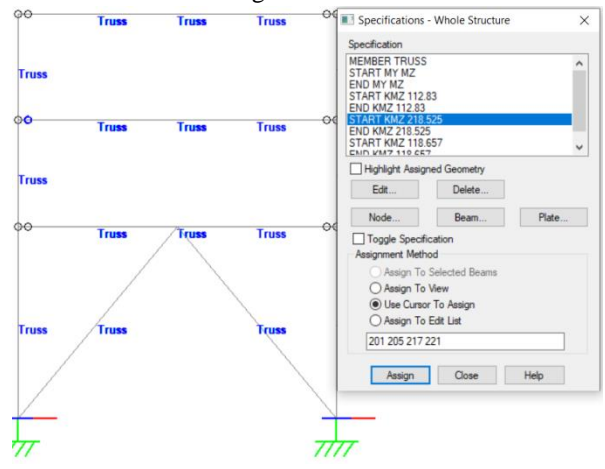


Fig 4. G+2 (3 tier) Piperack Industrial Steel structure with Semi-Rigid Connection

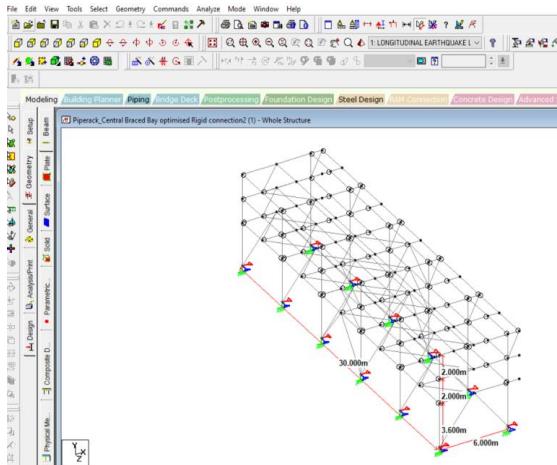


Fig.2 3D Modeling of G+2(3 tier)Piperack Rigid & Semi-Rigid Structure

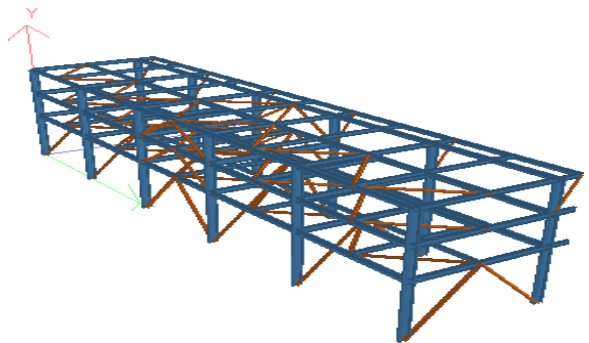


Fig .5 3D Rendered View of Model1 Rigid & Model2 Semi-Rigid Structure

- B. PRIMARY LOAD CASE AS PER ESM
- 1. Longitudinal Earthquake Load (EL)
- 2. Transverse Earthquake Load (ET)
- 3. Longitudinal Earthquake Load (Pipe Only) (ELP)
- 4. Transverse Earthquake Load (Pipe Only) (ET)
- 5. Dead Load (DL)

6. Cable Tray + Cable Load (CTC)
7. Pipe Empty Load (PE)
8. Pipe Content Load (PC)
9. Pipe Test Content Load (PT)
10. Longitudinal Pipe Friction Load (PFL)
11. Transverse Pipe Friction Load (PFT)
12. Longitudinal Pipe Anchor Load (PAL)
13. Transverse Pipe Anchor Load (PAT)
14. Pipe Contingency Load On Longitudinal Tie (PCL)
15. Live Load (LL)
16. Temperature Rise Load (TRL)
17. Longitudinal Wind Load (WL)
18. Transverse Wind Load (WT)

C. LOAD COMBINATION PREPARED AS PER PIPSTC01015STC

1. Limit State of Serviceability (Load List from 101 to 136)
2. Limit State of Collapse (Load List 201 to 237)
3. Local Design of Longitudinal Beam for Strength (Load List 301 to 320)
4. Local Design of Transverse Beam for Strength (Load list from 401 to 420).

D. Design Parameter as per IS 800:2007 LSD

1. Design parameter for Serviceability
2. Design Parameter for Collapse
3. Design Parameter for Local Longitudinal Beam
4. Design Parameter for Local Transverse Beam

V.METHODOLOGY

A. GENERAL

Behaviour of Structure with Rigid & Semi-rigid G+2 (3 tier) Piperack Industrial Steel Structure subjected to Earthquake loading & Wind Loading is complicated Phenomenon. There are several Numbers of factors affecting the behavior of the Both Rigid & Semi-Rigid Structure out of Which Maximum Shear Force & Maximum Bending Moment. Finally Steel Consumptions in Both Rigid & Semi-Rigid Structure. The 3D Analysis is carried in Both Models. The Equivalent Static Method (ESM) is carried in Both Models Using Software STAAD Pro V8i. The Result Obtained from Analysis are Discussed in this Paper.

C. METHOD OF ANALYSIS

Equivalent Static Method is carried in Both Model Rigid Structure and Semi-Rigid Structure. The Results are presented in form of Tables. The Results Obtained are Compared with respect to following Parameter like Maximum Shear force & Bending Moment in Both Structure. Finally After Optimization of Both Structure Steel Consumption in Rigid & Semi-Rigid Structure

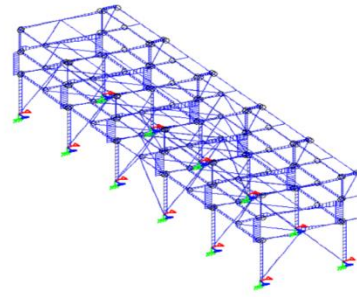


Fig.6 Maximum Shear force Diagram of Rigid Structure

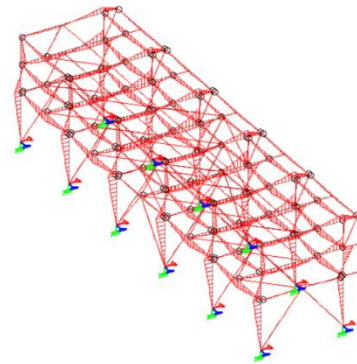


Fig.7 Maximum Bending Moment Diagram of Rigid Structure

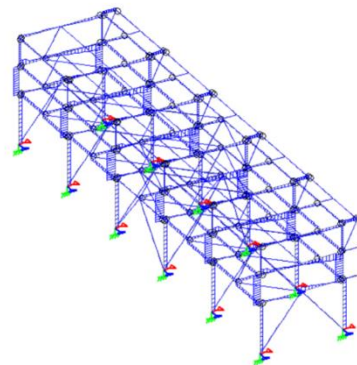


Fig.8 Maximum Shear force Diagram of Semi-Rigid Structure

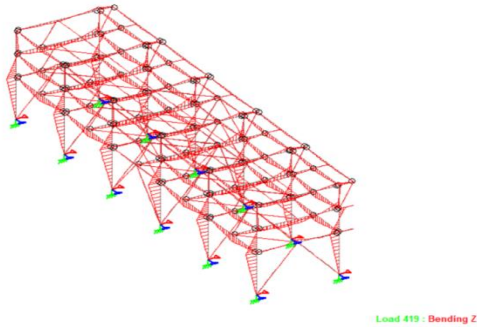


Fig.9 Maximum Bending Moment of Semi-Rigid Structure

Table III 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	38.166	-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 IV 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	16.622	-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	86.168
Min Mz	147	301 1.4 DL +	128	-102.904	21.906	0.348	-0.002	1.044	-68.279

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

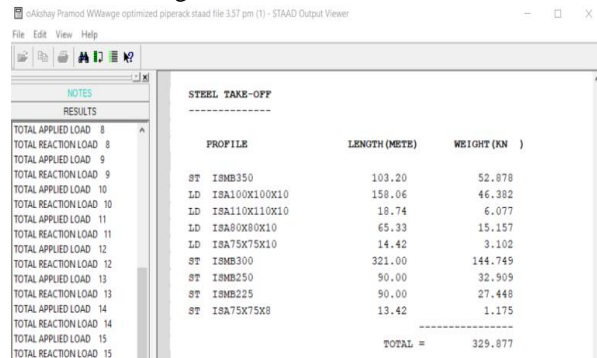


Fig. 10 Steel take off for Rigid Structure

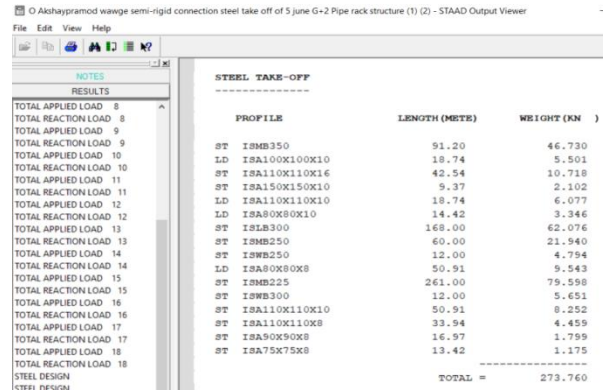


Fig .11 Steel take off for Semi-Rigid Structure

Table V Comparison of steel in Both Rigid & Semi-Rigid Structure

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

Rigid Structure

VI. RESULT ANALYSIS

- Table III Shows the Maximum Shear force & Bending Moment in Rigid Structure generally The Governing Load combination Number for Shear force is LC No 415 for which Maximum Shear force i.e. Fy of 73.885 kN. But The Governing Load Combination Number for Bending Moment is LC No 419 for which Maximum Bending Moment i.e. Mz is 110.245 kN-m
- Table IV Shows the Maximum Shear force & Bending Moment in Semi-Rigid Structure Generally the Governing Load combination Number for Shear force is LC No 415 for which Maximum Shear force i.e. Fy is equal to 67.627 kN. But The Governing Load Combination Number for Bending Moment is LC No 419 for which Maximum Bending Moment i.e. Mz is equal to 86.168 kN-m.
- Table V Shows the Maximum Steel Consumption in Both Rigid & Semi-Rigid Structure After the Optimization of Both Models in STAAD Pro V8i. Finally after Optimizing Both Structure it is proved that by Providing Connection Stiffness at Rigid Joint then we get less end support Moment for that less Depth of Structural Steel section is

required. So as per our condition 18.5931% less steel is required than Rigid Structure.

## VI. CONCLUSIONS

In this paper, the Concept of Semi-Rigid Connection is used Generally Top & Seat angle without Double web angle type of Semi-Rigid Connection is used. Finally Initial Connection Stiffness (Rki) of such type Connection is Workout & applied to only Rigid Joints to Problem Statement. Following observations are made from work conducted in this paper

- Two types of Structures is Modeled in STAAD Pro V8i Software namely Rigid Structure (Model-1) and Semi-Rigid Structure (Model-2).
- Unstiffened Top & Seat angle without Double web angle (T&S) type of semi-rigid connection is used for Beam to column joint connection. But this type of Connection is applied as a connection Flexibility (Rotational Spring) to Rigid Joints only.
- Initial Connection Stiffness (Rki) of T&S is formulated manually & Workout Using Microsoft Excel Worksheet and it is applied to Rigid Joint in Model 2.
- Maximum Shear force & Bending Moment is Reduced in Semi-Rigid Structure by Providing Connection Stiffness. So, for less Shear force & Bending Moment is experienced by the Semi-Rigid structure
- Percentage of Saving of the Structural Steel is estimated by Considering Semi-rigid Structure (Model-2). Overall saving of the Structural Steel is estimated as 18.5931%
- Economy of Industrial Steel Structure is achieved by saving Structural steel Material.

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