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Seismic Analysis and Design of a 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.*

Key Words: **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]

1.1 Background Problem of Connection

In the Traditional design of steel structures, the real Performance of Beam to Column Connection is simplified into Two Categories. The One category is Fully Rigid, and other category is Perfect simple connection. In ideal Structures however both categories are not genuine as majority of beam to column joints demonstrate Semi-rigid joint performance of third category is so called as partially restrained connection or semi-rigid connection. The Significant role of beam to column connections in steel structure under extreme loading is well estabilished.Widespread damage of steel moment frame during 1994 Northridge earthquake led researcher to develop alternative Connection Design to the Perspective Pre-Northridge earthquake moment connection. The Semi-Rigid Design Methodology aims to address a reliable Optimization by including real beam to column connection behavior in the design procedure. The Previous studies on the response of semi-rigid frame & beam to column connection confirms adequate benefits by using this system including satisfactory of overall performance Lowering Fabrication costs compared to Fully- rigid frames. The Purpose of Semi-rigid connection not only increase system flexibility to attract less seismic demand , but also to allow more energy dissipation by damaging specified non –critical structural component.

1.2 Semi-Rigid Connection

Semi-rigid connection can transfer vertical shear force and also have capacity to transfer some moment. For the Basics understanding of semi-rigid connection it is necessary to understood the term Rotational stiffness (Rki) .it is the Moment required to Produce unit rotation .Finally From the Experimental, Numerical & Analytical study of Moment Rotational curve it is helpful to study behavior of semi-rigid connection. Generally based upon Connection Stiffness the selection of type of semi-rigid connection. But in this Present work only Initial connection stiffness (Rki) of unstiffened top & seat angle without double web angle semi-rigid connection is worked out taken from Analytical Power Model of Kishi-Chen it is formulated Using Microsoft excel sheet. [5]

$$Rki = \frac{3 \cdot (EI)}{\left(1 + \frac{0.78 \cdot (t_t)^2}{(g_1)^2}\right)} \cdot \frac{(d_1)^2}{(g_1)^3} \theta_r$$

Where EI=Bending Stiffness of Leg Adjacent to Column face

$$g_1 = g_t' - D/2 - t_t/2$$

gt=Gauge distance from top angle heel to centre of fasteners hole in leg adjacent to column face

g1=distance between the centre line of top angle leg and edge of washer used in top angle

D=db, case using rivet as fasteners

=W, the case using bolts as fasteners

Db=fasteners diameter

W=nut Width across flats

$$d_1 = (d + t_t/2 + t_s/2)$$

t_t=Thickness of top angle

ts=Thickness of seat angle

d=total depth of the Beam section

ϴr= relative rotation.

1.3 Piperack Industrial Steel Structure

Piperack it is Industrial Steel structure whose Basics geometry is like steel portal frame having Multi-tiers which are provided to support piping assembly, cable trays, and (with) fin-fan coolers without coolers.Piperack is main artery of Process unit .It connects all equipments with lines that cannot run through adjacent areas .Piperack structure are used in Petrochemical, chemical, power plant that are designed to support pipes,. Instrumental, cable trays. Design criteria of non-building structures are provided in industry reference guidelines.[6]

1.3 Need to do Research in Semi-Rigid Connection

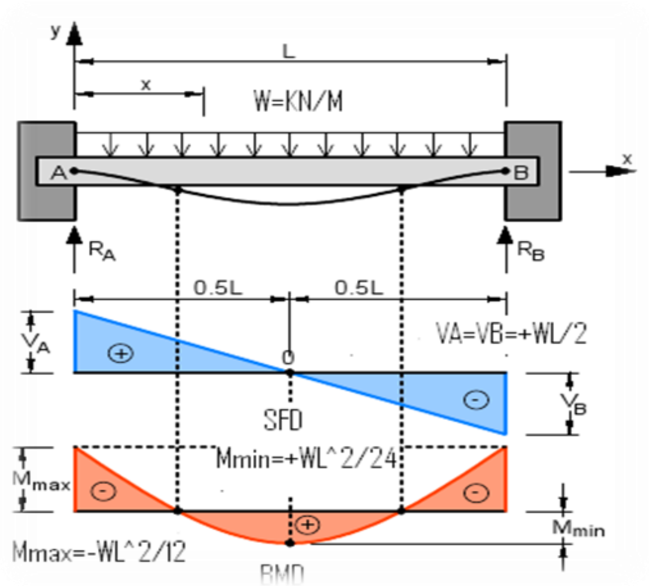

Fig 1. Fixed Beam with Uniformly Distributed Load over entire span

- As we Know that in case of Rigid Beam the end support moment are always having greater value than Midspan Moment
- So we always selected the section to resist the end support Moment, Full 100% strength of Beam section is Never utilized generally in rigid connection

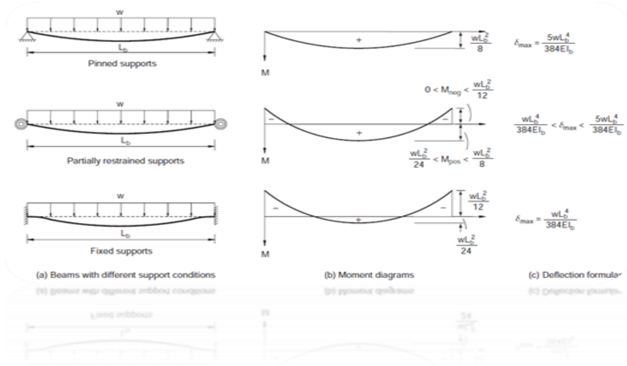

Fig 2. Effect of Partially Restrained support[15]

- In semi-rigid Connection by Providing Rotational spring at rigid joint only as Partially Restrained support as shown in fig 2
- The Above moment Diagram are obtained from principal of superposition .Finally applying Rotational spring at rigid joint only then The end support moment as well as beam deflection are reduced but slightly moment in Midspan increases .This Means that we transfer end support moment o Midspan moment .
- Here, full strength of beam can be utilized and this leads to economy

1.4 Objective

- Semi-rigid connections are basically categorized into seven types. (Referring Indian Institute for steel development and growth –Chapter no .39.
- In this Paper, Unstiffened top & seat angle without double web angle type of semi-rigid connection will be used for the connection for beam to column joint.
- An effect of semi-rigidity shall be ensured in STAAD Pro V8i Software by Providing Initial connection stiffness to Rigid Joint only to the G+2 Piperack Industrial Steel

Structure for Comparative study of Rigid & Semi-rigid Structure .

2. RELATED WORK

2.1 Industrial Steel Structure Description

- In this Study Firstly G+2(3tier) Piperack Industrial steel structure with rigid connection are analyzed & design using equivalent static Method in STAAD Pro V8i software
- Secondly Same G+2(3tier) Piperack Industrial steel structure But with Semi-Rigid Connection at Rigid Joint 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 Comparisons of Steel Consumption in Both Rigid & Semi-Rigid structure

Table 2.1 Determination of Rki of Unstiffened Top & Seat angle

S.N	Parameters	Values &Units
1	Young's Modulus of steel Es	$2*10^5$ N/MM^2
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 Ia, top=Le*ta,top^3/12	3840 MM^4
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*Iatop	$2*10^6$ 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

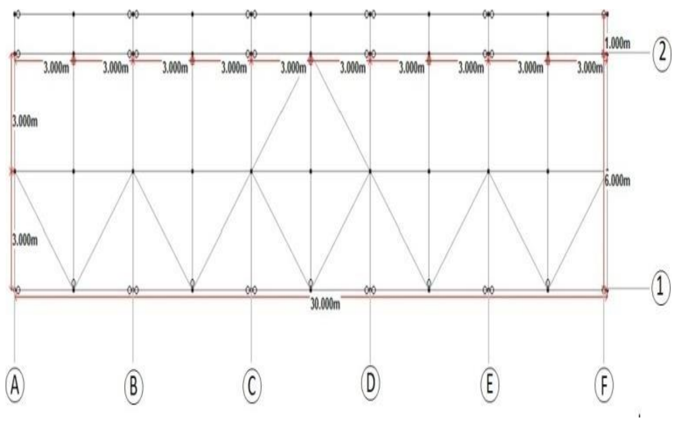

Fig 3 Plan Dimension of G+2 (3 tier) Piperack Industrial Steel structure

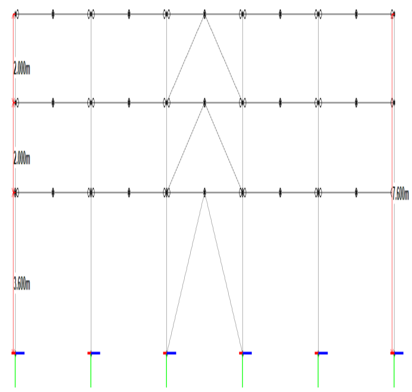

Fig 4 Side Elevation of G+2(3 tier) Piperack Structure

Table 2.2 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 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
7		1st Tier Height is 3.6 M
8		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	Load Combinations in Both Structure	As Per PIP STC01015
17	Design Code	As per IS 800:2007 LSD

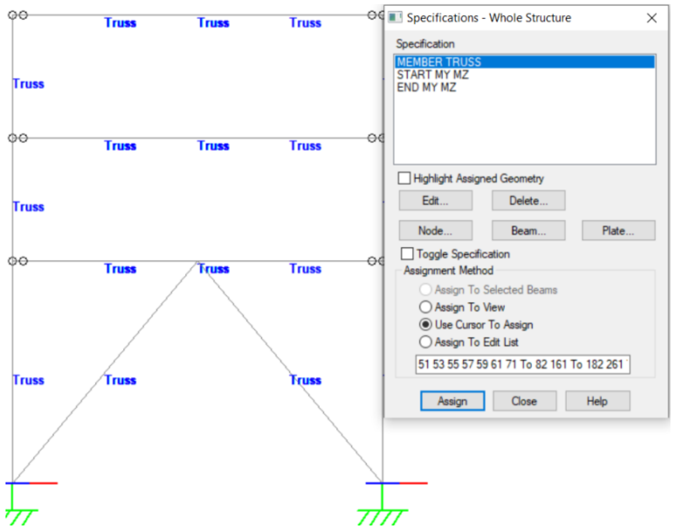

Fig.6 G+2 Piperack with Rigid Connection

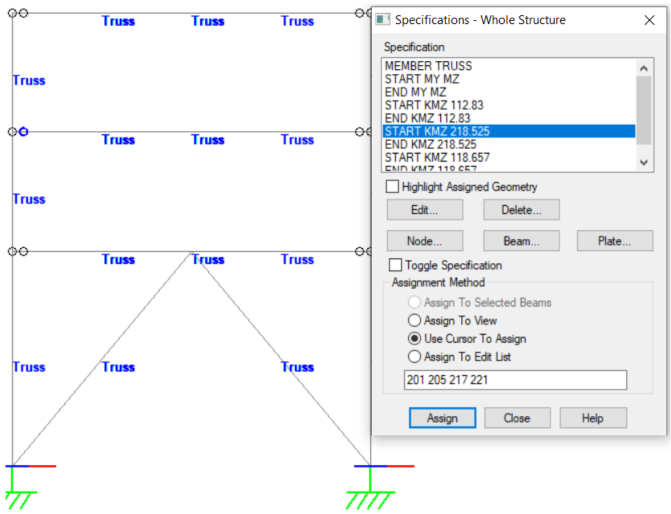

Fig.7 G+2(3-tier) Piperack with Semi-Rigid Connection

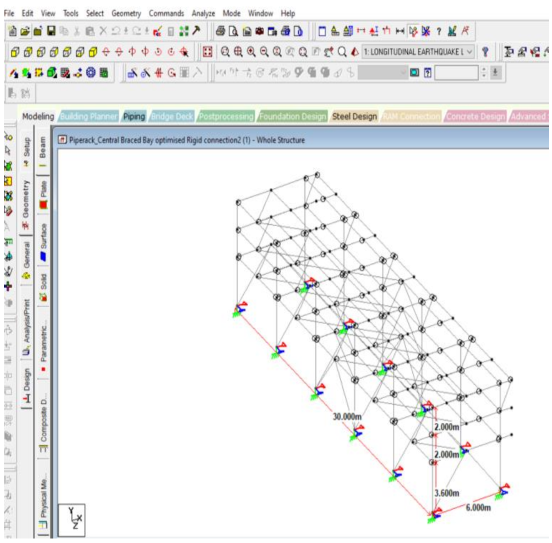

Fig .5 3D Modeling of G+2(3tier)Piperack Rigid & Semi-Rigid Structure

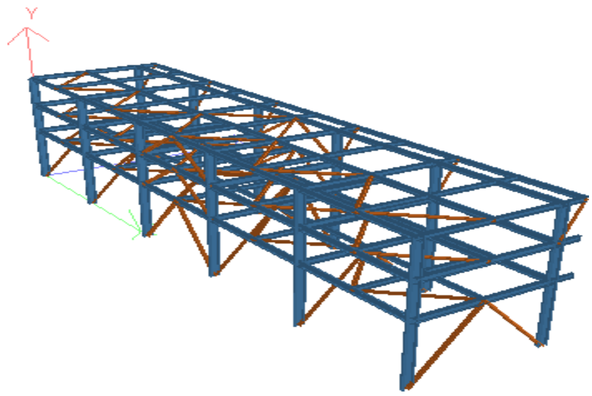

Fig.8 3D Rendered View of Both Model1 Rigid & Model 2 Semi-Rigid Structure

2.2 Primary Load Cases 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)

2.3 Load Combination are Prepared as per PIPSTC01015

1. Limit State of Serviceability (Load List from 101 to 136)

2. Limit State of Collapse (Load List 201 to237)

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).

2.4 Design Parameter as per IS 800:2007

1. Design parameter for Serviceability

2. Design Parameter for Collapse

3. Design Parameter for Local Longitudinal Beam

4. Design Parameter for Local Transverse Beam

3. METHODOLOGY

3.1 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.

3.2 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

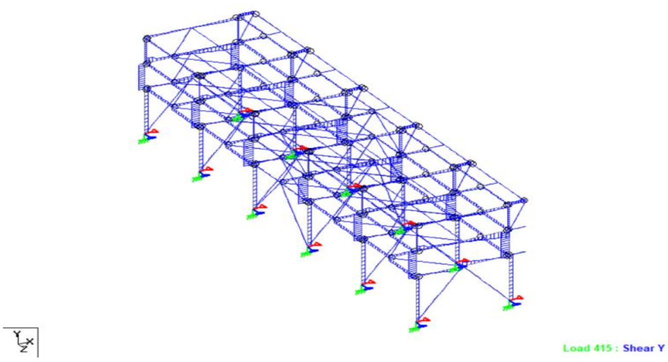

Fig 9. Maximum Shear Force Diagram for Rigid Structure

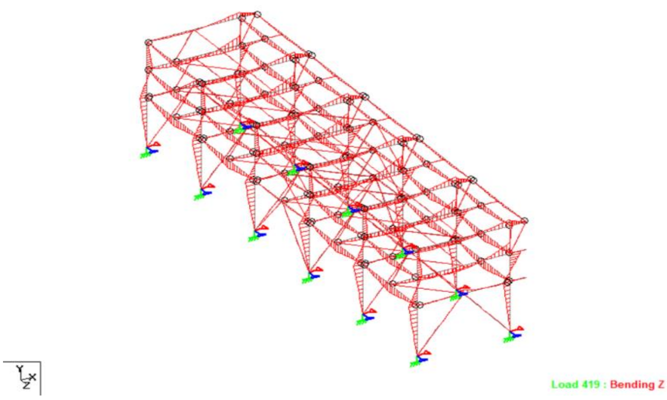

Fig 10. Maximum Bending Moment Diagram for Rigid Structure

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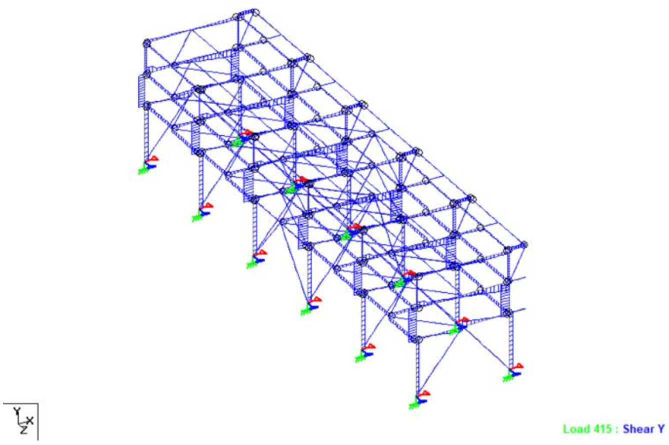

Fig.11 Maximum Shear Force Diagram for Semi-Rigid Structure

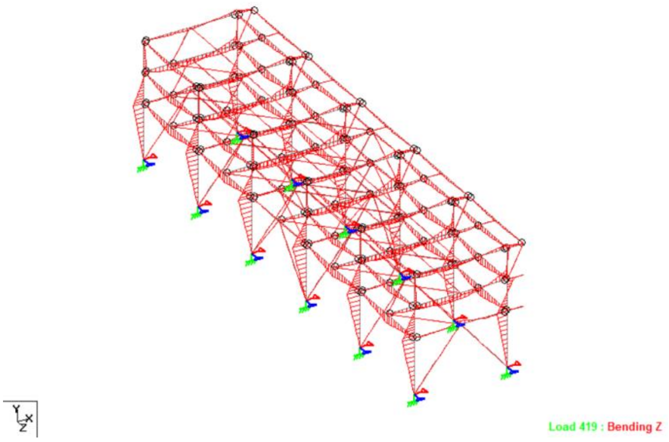

Fig 12. Maximum Bending Moment for Semi-Rigid Structure

Table 3.1 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 3.2 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

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

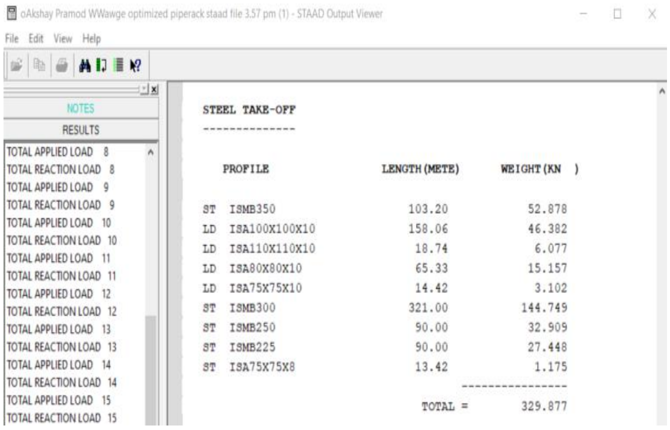

Fig.13 Steel Take off for Rigid Structure

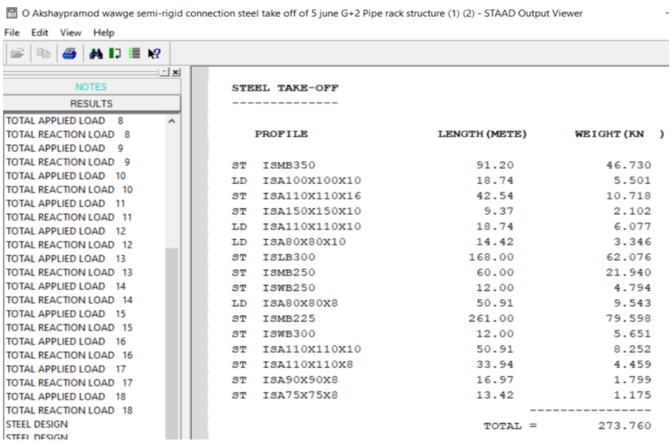

Fig.14 Steel Take off for Semi-Rigid Structure

Table 3.3 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 (Tonne)	Steel Used (Tonne)	
33.1068	27.4748	18.5931%

4. RESULT ANALYSIS

- Table 3.1 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 3.2 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 3.3 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.

5. 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 Experience 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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