DYNAMIC ANALYSIS OF 2-D AND 3-D COLD FORMED STORAGE RACK STRUCTURES WITH RIGID AND SEMI RIGID CONNECTIONS

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ABSTRACT:

Rack systems are very similar to the framed steelworks traditionally used for civil and commercial buildings, but great differences in member geometry and in connection systems. In rack system, the beams are generally boxed cross-section, and columns are open thin walled perforated section to accept the tabs of beam end-connectors. In storage racks, hook-in end connectors are used to make beam to column connections. The semi-rigid nature of this connection is primarily due to distortion of the column walls, tearing of the column perforation, and distortion of the beam end connector. The structural behavior of storage racks for seismic loads depends on how the individual components like beam to column connections, column bases and members perform interactively with each other and therefore, it is important to have a proper way of predicting the structural behavior of storage racks systems under seismic load. The complete 2 -D and 3 -D finite element model of conventional pallet racking systems were prepared using the finite element program ANSYS. Free vibration modal analysis and spectrum analysis carried out on pallet racks with the 18 types of column sections developed along with semi -rigid connection . The principal aims were to find out fundamental time period, mode shape and response to the spectrum acceleration of conventional pallet racking systems, made up of cold form sections. Parameters selected for study are cross section of uprights, thickness of uprights, and stiffness of the connections.

KEY WORD : Dynamic analysis , pallet racks, cold formed steel, semi rigid joint

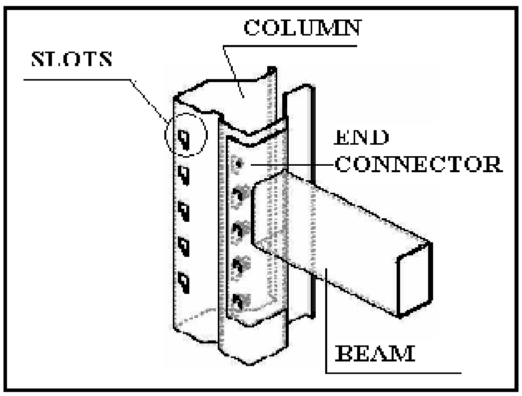
1. INTRODUCTION

One of the most significant uses of cold-formed members is for steel storage racking structures, such as pallet, drive in, and drive through racking systems. In typical pallet rack structure, generally, beams (stringers) have boxed cross sections, while columns (uprights) are open thin walled perforated to accept the tabs of beam end connectors, which join beams and columns together without bolts or welds. Therefore design of pallet racks is quite complex. The behavior of the perforated columns, that are generally thin walled members, is affected by different buckling modes (local, distortional and global) as well as by their mutual interactions. The response of beam to column is typically nonlinear. Moreover, bracing systems are generally placed only in the cross aisle direction. The need for organizing pallet racks in such a way that the product is efficiently stored and sufficiently accessible hampers the presence of bracings in the down aisle direction. Lateral stability is, hence, provided by the sole degree of continuity associated with beam to column connections as well as by base plate connections. The analysis and design of thin walled cold formed steel pallet racking frames structure with perforated open upright section and semi rigid connections presents several challenges to the structural engineers. Presently, for the design of these frames no specific code of practice exists. Although in the United States and some other countries the specification published by the Rack Manufacturer's Institute (RMI) serves as a guideline. Therefore analysis and design of pallet racks is quite complex under seismic load. Defining behavior of frames under dynamic loads exactly takes an important place in earthquake engineering. In engineering design, to the real behavior of a structure is provided by determining geometrical, damping mass and connection model well. In design purposes; structures are designed as having such flexible connections in which connection flexibility becomes important, are called "semi-rigid frames". Semi-rigid frames are frames for which the beam-to-column connections are neither pinned nor rigid. In reality all frames are semi-rigid, because there is not a frame which has truly pinned and perfectly rigid connections. In the current design codes no analysis or design guidance is given for semi-rigid frames. The traditional approaches to the design of frames are concisely described as continuous framing with rigid connections and /or simple framing with pinned connections. However, the connection behavior significantly affects the displacements and internal force distribution of framed structures.

In the current practice of stability analysis of steel-framed building structures, the actual behavior of connections is generally simplified to the two idealized extremes of either fully-rigid behavior or ideally-pinned behavior. Although the adoption of such idealized connection behavior simplifies the stability analysis, it by no means represents the actual behavior of the structure. Therefore, the predicted response of the idealized structure may be quite unrealistic compared to that of the actual structure. This is because most connections used in current practice actually exhibit semi-rigid deformation behavior that can contribute substantially to the stability of the structure as well as to the distribution of member force. Neglecting realistic connection behavior may lead to unrealistic predictions of the response and strength of structures, and therefore, to approximations in design.

2. CONNECTION IN STORAGE RACK

In storage racks, hook-in end connectors are used to make beam to column connections. The performance of a racking system depends upon the efficiency of the beam end connectors. The beam end connectors provide support to the beams and in un-braced racks is the only source of stiffness required for down-aisle stability. For practical reasons pallet racks are not braced in the down-aisle direction. Therefore, the resulting side sway is governed by the efficiency of the beam end connector, in particular its rotational stiffness, as well as by the behavior of the floor-upright connection. The degree of side sway determines the strength and stability of the structure. Beam-to-column connections have a significant role in the design of pallet rack structures. Methods for connecting cold-formed members are often quite different from those of hot-rolled members. Where welding and bolting are common for hot-rolled members, such connection types as screws, clinching and riveting may be used for cold-formed members. Also even for bolted connections, the structural behaviour of cold-formed connections is often quite different from hot-rolled members due to the thin sheets and higher strength steels used.



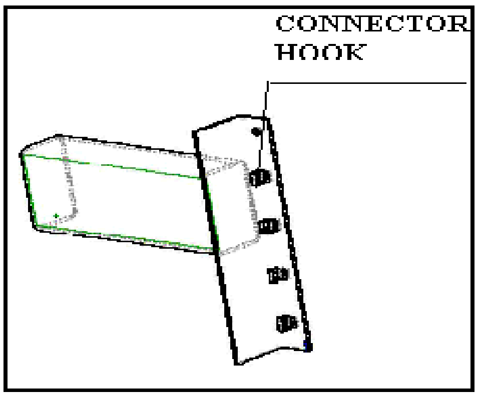


Figure 1 Typical Connection Details Assembly Of Beam-Column Connector

This paper deals with the modal and spectrum analysis of a cold-formed steel storage rack structure, with rigid and semi rigid connections, under gravity and seismic load. Spectrum analysis is performed as per the spectrum given in IS 1893-2000.

3. COLUMN SECTION USED IN THE STUDY

In this paper open and torsionally strengthened sections were used. Original open sections were strengthened by providing channel and hat stiffeners to avoid the local buckling of uprights. These sections are medium weight (MW) column section having three thicknesses 1.6 mm, 1.8 mm and 2.0 mm each with hat and channel stiffener and HW (Heavy Weight) column section having three thicknesses 2.0 mm, 2.25 mm and 2.5 mm each with hat and channel stiffener. Their cross sectional geometry is given in figure 2 to figure 4. Purpose of choosing three different thicknesses is to know the change in behavior when the sections are made locally stable by having higher thickness.

3.1 Calculation of Sectional Properties of the Columns Used in the Study

For the above sections, sectional properties are calculated based on weighted average section. A weighted average section is a section that uses an average thickness in the web portion to account for the absence of the material due to the holes along the length of the section and additional thickness for the additional material of channel and hat stiffener. Excel program is developed to calculate the sectional properties of sections used in this study.

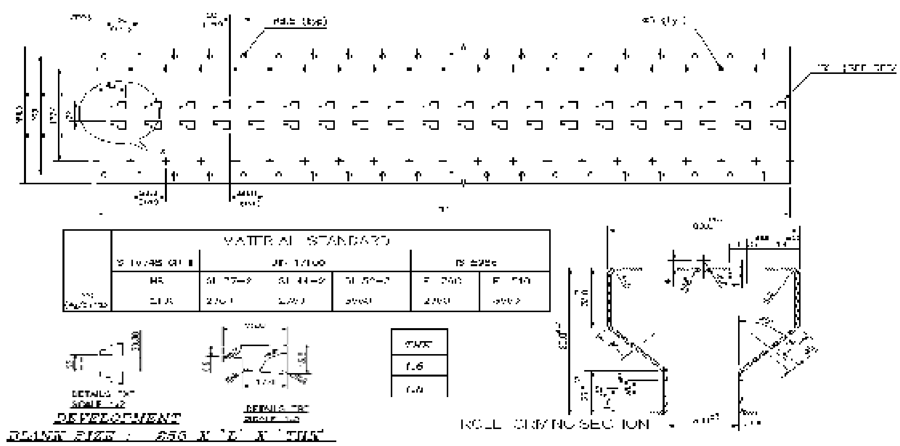


Figure 2 Medium Weight Sections 1.6, 1.8 and 2.0 mm

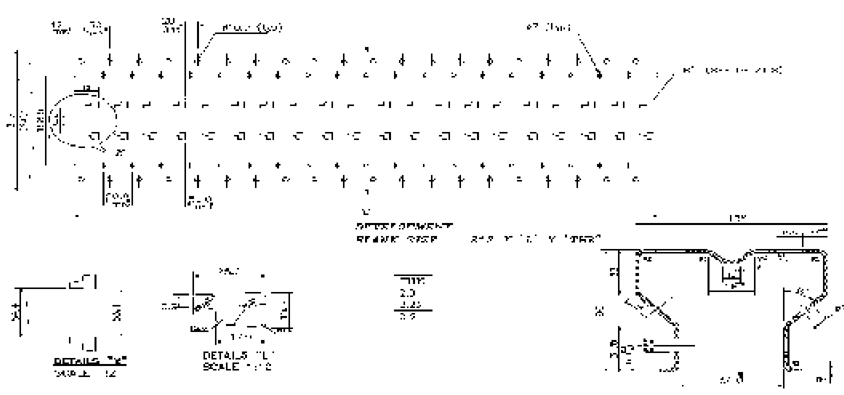


Figure 3 Heavy weight sections 2.0, 2.25 and 2.5 mm.

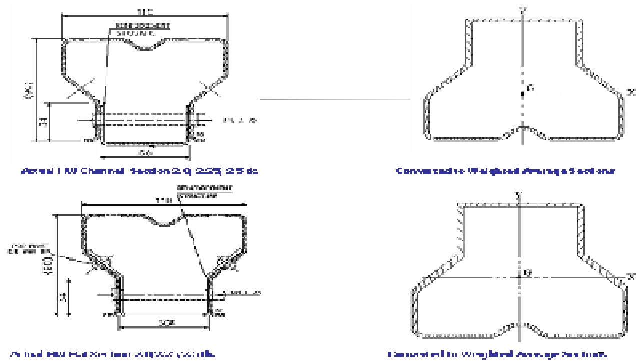


Figure 4 Tortionally strengthened MW and HW section with channel and hat stiffeners

4. STRUCTURAL DETAILS OF RACK STRUCTURES USED FOR ANALYSIS

Structural details of the rack structures are as fallows.

Upright section used (Cold Formed Section)	Heavy Weight Hat Section	2.5 mm, 2.25 mm, 2.0 mm thick.
	Heavy Weight Channel Section	2.5mm, 2.25mm, 2.0mm thick.
	Medium Weight Hat Section	2.0mm, 1.8 mm, 1.6mm thick.
	Medium Weight Channel Section	2.0mm, 1.8 mm, 1.6 mm thick.
Stringer Beam section	Rectangular hollow section	100 x 50 x 3 mm
Cross Beam section	Rectangular hollow section	100 x 50 x 3 mm
Side bracing section	Channel section	100 x 40 x 3 mm
Coupling bar	Rectangular Hollow section	100 x 50 x 3 mm
Height of first shelve from floor		150 mm from floor
Height between each shelve		900 mm C/C of shelve
Width of bay		2.4 m
Depth of Rack shelve		1.0 m
Product load		3 KN/m
Live load		0.5 KN/m
Yield stress of steel		250 N/mm^2
Maxi. Storey height		10.85 m
Distance between two rows		150 mm

5. FINITE ELEMENT MODELLING

5.1 2-D plane frame

The model generation and analysis of frame in Ansys with proper element for column with perforation, channel and hat stiffeners and also with spacers and bracings become quite complicated and time consuming, so in order to overcome this problem another program was developed with the help of APDL (Ansys parametric design language) to run the same in Ansys and get the results of the desired analysis. The uprights of the frame are modeled using shell 63 elements. The spacers used as stiffeners and bracing are modeled using solid 45 elements. Following a series of convergence studies, a mesh size of 5 mm x 5 mm is used for shell element. Properties of the finite elements used in the analysis in brief are given in table 1. Typical finite element model shown in figure no 5. The finite element assumptions were as follows.

- The connection between the braces and columns were considered to be continuous.
- At loading end of the upright all three rotations and displacement allowed and at the bottom base is assumed fixed.
- For the all the frame distance between solid spacers are kept 600mm.

5.2 3-D Frame of Conventional Pallet Rack Structure

The uprights, stringer beam, bracing and coupling bar of the frame are modeled using beam 4 elements. Combin39 element used to represent the semi rigid nature of the connection. Properties of the combin 39 are taken from the experimental study conducted by Mr. R.S Talicoti on storage rack structure [Talicotti R.S. Performance of Thin Walled Cold-Formed Steel Frames with Perforated Upright Sections and Semi-Rigid Joints. PhD Thesis, Indian institute of technology, Mumbai 2006, Under the supervision of Dr. K.M Bajoria]. Properties of the finite elements used in the analysis in brief are given in table 1.

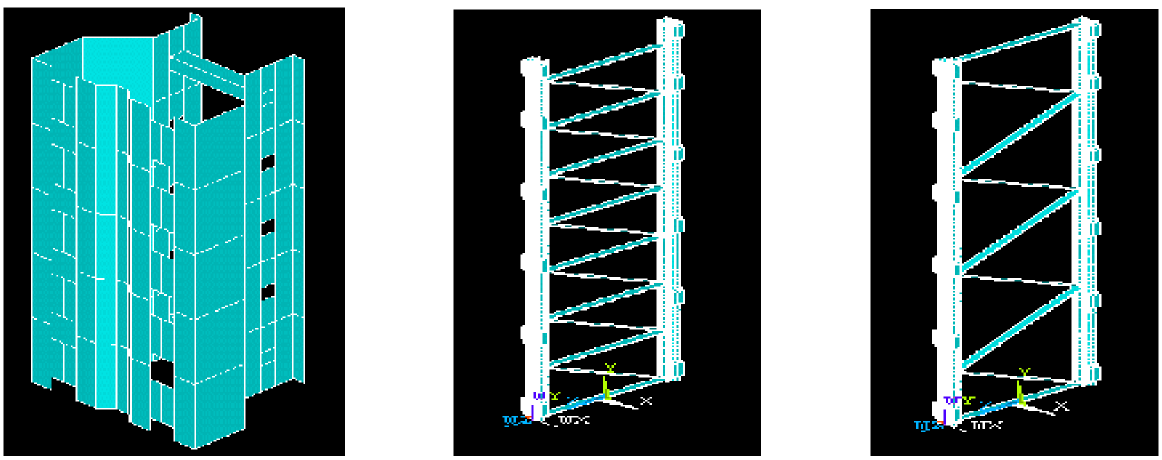


Figure 5:-a) Typical Finite element model b) Frame with horizontal and inclined bracing c) Frame with inclined bracing only

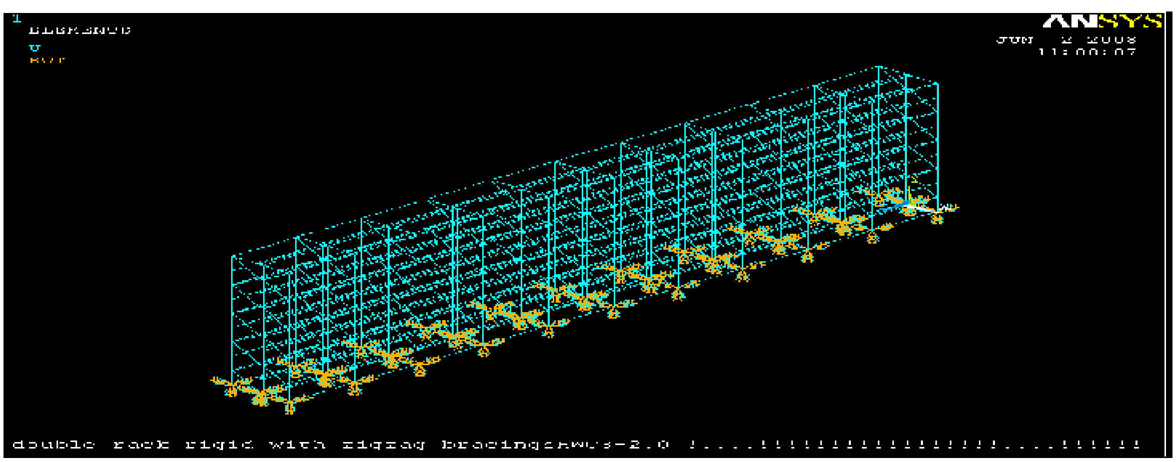


Figure 6 Finite Element Model for Double Rack structure with Single Bracings (Rigid Connection)

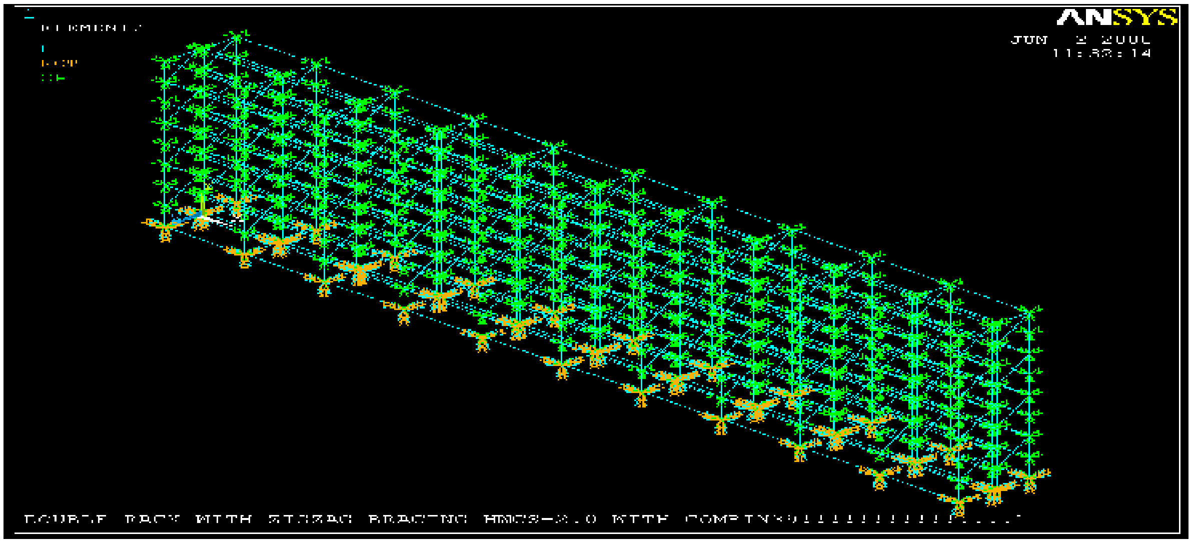


Figure 7 Finite Element Model for Double Rack structure with Zig-Zag Bracings (Semi-Rigid connection)

Table 1: Properties of the finite elements used in the analysis

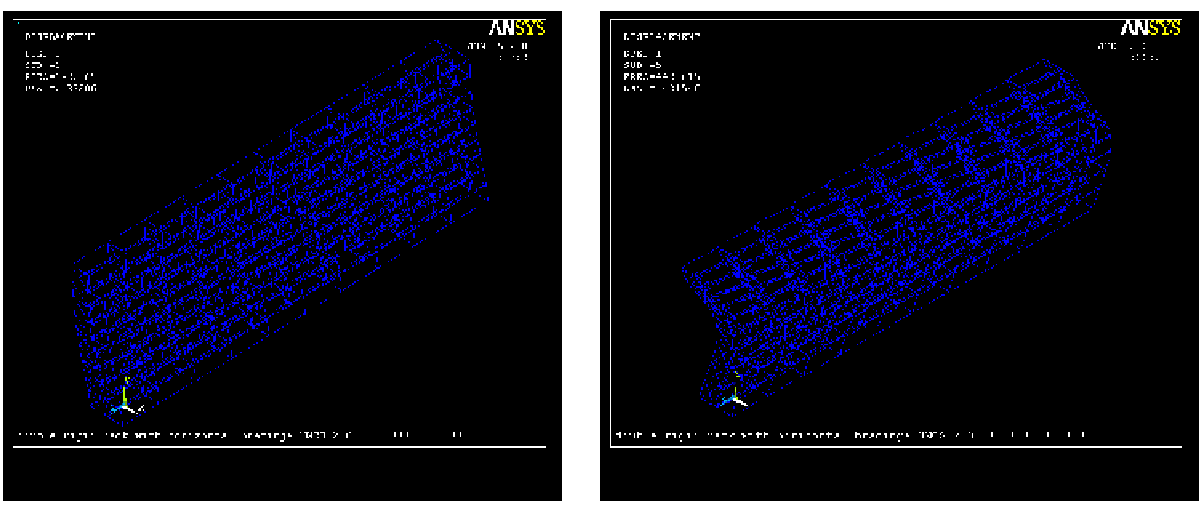
Element name	SHELL 63	SOLID 45	Beam-4.	Combin 39
Position of element	Upright in 2-D frame	Spacers and Bracings in 2-D Frame	Upright, Stringer Beam, Coupling Bar and Bracing in 3-D frame	Semi rigid connection in 3-D frame
Description of element	Plastic shell element	3-D Structural solid element	3-D Elastic Beam	Nonlinear Spring 3-D space
Number of nodes	4	8	2	2
Degrees of freedom	x, y, and z translation and rotational displacement	x, y, and z translation displacement	x, y, and z translation and rotational displacement	UX,UY, UZ, ROTX,ROTY,ROTZ, PRES, or TEMP

6. RESULTS

In the above articles, the factors that affect the time period and base shear of rack structure were highlighted and to account for the same, different parameters, their combinations and structural details were decided. Few results obtained from the analysis, with different combinations, are presented in this paper. The few results are presented in tabular form in table 2and table 3. At the end of result first two mode shapes of the 3-D frames are shown in figure no 8.

Table 1 Results for single Rack structure with Single Bracings, with 10 bays.

No of Storey	Type of Frame	Type of Connection	Base Shear (KN)	Fundamental Period(sec)	D_{max} (m)
9	Single rack-single bracing-HWCS-2.0	rigid	107.52	1.383	0.00380
		semi-rigid	27.054	6.653	0.00479
10	Single rack-single bracing-HWCS-2.0	rigid	82.198	1.565	0.01432
		semi-rigid	49.746	8.311	0.00456
11	Single rack-single bracing-HWCS-2.0	rigid	103.43	1.747	0.00338
		semi-rigid	35.457	10.154	0.00436
12	Single rack-single bracing-HWCS-2.0	rigid	83.157	1.930	0.01299
		semi-rigid	25.945	12.181	0.00419
9	Single rack-single bracing-HWCS-2.25	rigid	112.48	1.372	0.00380
		semi-rigid	28.752	6.458	0.00479
10	Single rack-single bracing-HWCS-2.25	rigid	85.733	1.554	0.00358
		semi-rigid	52.873	8.068	0.00455
11	Single rack-single bracing-HWCS-2.25	rigid	107.68	1.736	0.00339
		semi-rigid	37.679	9.856	0.00436
12	Single rack-single bracing-HWCS-2.25	rigid	86.551	1.917	0.00323
		semi-rigid	27.566	11.824	0.00418
9	Single rack-single bracing-HWCS-2.5	rigid	117.24	1.363	0.00381
		semi-rigid	30.419	6.283	0.00478
10	Single rack-single bracing-HWCS-2.5	rigid	89.148	1.544	0.00359
		semi-rigid	55.942	7.849	0.00453
11	Single rack-single bracing-HWCS-2.5	rigid	111.66	1.725	0.00339
		semi-rigid	39.86	9.589	0.00436
12	Single rack-single bracing-HWCS-2.5	rigid	90.467	1.906	0.00323
		semi-rigid	29.156	11.502	0.00418



a) Sway in down-aisle direction b) Second **sway** in down aisle direction

Figure 8 First two mode shapes of the 3-D frames

7. CONCLUSION

In this study, Flexible connections were located at the intersection of beam & column, were modeled using a rotational springs, at the joint. The dynamic properties of the model so developed in ANSYS were investigated with reference to modal attributes. Also the seismic analysis was performed by "Response Spectra" method as available in ANSYS for both rigid as well as semi rigid model of rack structure, & corresponding results were compared. The study compares these two models in lights on natural dynamic properties & base shear obtained after spectrum analysis. This study gives important information about the differences which can be occurred by modeling flexible connection as a rigid connection.The study indicates that connection models have influences on the dynamic characteristics of the structure. Introduction of semi-rigid connection causes increase in natural period of the structure, but the displacements were found to be increased. Also the semi-rigid modeling of rack structure has reduced the base shear for the structure. Some of the important observations are as follows

- Modeling the rack structure as Semi-Rigid makes the structure more flexible causing increase in natural time Period of the structure.
- Secondly introducing the semi rigidity has caused reduction in the overall Base Shear for the structure.
- The max displacement for the structure has increased when rack modeled as semi-rigid.
- Since the introduction of semi-rigidity in analysis of storage racks reduces the natural period of the structure, therefore in spectrum analysis the values of spectrum acceleration to be considered are on lower side. The structure thus attracts lower values of base shear.

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