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Design and Analysis of a Steel Structure (Warehouse) using Knee Elements

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Abstract: This research has been carried out to study the behavior of steel structures like warehouses provided with knee elements under seismic loading conditions and note the difference observed using knee elements over a standard structure. The Static Non-Linear pushover analysis is used during the research. The objective of this research analysis covers pushover analysis to determine pushover curve (a plot of force vs displacement curve) of the analyzed structure and to give its detailed comparison with and without the use of knee elements. An evaluation of differences in structural irregularities and their influence on seismic vulnerability of the building is conducted.

Index Terms –Knee Elements, Push Over Analysis, Seismic, Seismic Analysis, Steel Structure, Warehouse.

I. Introduction

With the changing times consideration of seismic loads is a must for the design of any structure. In general steel structures the floor to floor height provided is more as compared to standard designs and thus the seismic impact on such structures increases drastically. In this research knee elements are used to reduce the seismic impact on the structure. There is a huge amount of stress carried by the beam and column joints in such structures. These knee elements tend to undergo tension or compression depending on their positions and thus help the structure to resist more lateral forces that are generated due to wind or seismic force. These knee elements also help by reducing the lateral deflection occurring in the structure and thus help by imparting more stability and making the structure more reliable for use.

II. Need of the Project

The deflection in the higher levels of the steel structure due to horizontal sway of the column increases. This causes extreme stresses to be induced in the columns and the column ad beam joints, which may result into the failure of the structure. Thus the use of knee elements in the structure would help to brace the forces acting on the structure. The system created by the knee elements helps to resist the lateral moments created due to the wind or seismic loads.

III. Objectives

a) To compare the difference in the behavior of the structure under the imposed loads prior to and after the use of knee elements.

b) To compute the efficiency of the structure after the use of knee elements.

c) To optimize the effects of knee elements in a steel structure.

IV. Research Methodology

The entire research has been carried out using ETABS. For the research we designed a classical warehouse and it was then tested under the assumed loading conditions.

Dimensions of the designed structure:

The designed steel structure for the research was provided with an area of 400 sq.mts. The length along the 'Y' – direction was provided as 20 meters and along the 'X' – direction was provided as 18 meters. The designed warehouse has a typical floor height of 12 meters provided with a roof truss having a central rise of 2 meters.

Vertical columns are provided at a spacing of 5 meters along the 'X' as well as 'Y' direction. Along the 'Y' – direction 5 columns are provided and along the 'X' – direction 4 columns are provided at the given interval.

Section properties of the structural elements:

The material used throughout the structural design is steel having its strength of 345 MPa. The sectional properties of the various elements of the warehouse are as follows:

i) Columns – ISMB 600.
ii) Beams – ISA 150×150×12 mm.
iii) Top chord –ISLB 200.
iv) Purlin – Steel tube 120×60 mm.
v) Knee Elements – ISNB 50M

Load combination

The load combinations were assumed with reference to the values given in the code IS 1893 (Part 1). The loads taken into consideration for analysis of the structure were:

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- Dead Load – The dead load is considered same as the weight of the steel.
- Live Load – 0.63 KN
- Dead Load Surcharge – 0.9KN

Wind load is not mentioned as it is generally not considered for push over analysis. Dead load scale factor is considered as 1 and Live load scale factor (multiplier) is of 0.25. The earthquake loads along X and Y direction i.e. push x and push y are applied continuously during the analysis of the structure till the pre-specified deflection limits are reached.

Method of research adopted:

Further, the research study methodology extended to the study and understanding of non-linear time history analysis, non-linear static analysis under which we extensively covered certain main analysis such as push over analysis, response spectrum analysis, etc. Pushover is a static-nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behavior until an ultimate condition is reached. Further, we continued our research after finally going ahead with push over analysis by going in depth for understanding the push over demand curve. Under the static push over curve, we studied how the base shear vs displacement graph works with certain dummy projects and going through various projects, journals and research papers. Also going through other methods, we finally ended up electing the non-linear static push over curve. Also, one of the main advantages it had over the other analysis methods was that understanding and the execution of the push over analysis was very much simple and it gave good results as push over analysis is one of the easiest and the best method to follow under earthquake engineering.

Analysis of the Structure:

Phase 1: Analysis of the Structure without Knee Elements.

In the first stage, the structure as designed without knee elements was analyzed in push x and push y direction. The outputs of the analysis were noted and studied further for introduction of knee elements.

Phase 2: Analysis of the Structure with Knee Elements in the X direction.

In the second stage, the structure was provided with knee elements in the X direction for further analysis. Both the push X and push Y analysis was carried out. The outputs of this analysis were noted and a difference in the values was observed. Thus, it helped as it provided a positive influence towards our research.

Phase 3: Analysis of the Structure with Knee Elements in the Y direction.

In the third stage, the structure was provided with knee elements in the Y direction for further analysis. Similarly, both the push X and push Y analysis were carried out and the outputs were noted for further interpretation

Phase 4: Analysis of the Structure with Knee Elements in both the X and Y direction.

In this stage the structure was provided with knee elements in both the X and Y directions. Similarly, the outputs and the differences observed were noted.

V. RESULTS OBTAINED

The following results were obtained from the analysis performed on the structure for the following cases. During the analysis, for a measured displacement, the following values of base shear were observed in the structure.

Case 1: For structure without Knee Elements

During the analysis in this case the standard structure designed, without the provision of knee elements was tested and the values for displacement and base shear were obtained. This was further used in the research as a standard for all comparisons made.

Push Over 'X' Analysis

Step	Monitored Displ mm	Base Force kN
0	0	0
1	-60	116.0636
2	-120	232.1272
3	-180	348.1908
4	-240	464.2544
5	-281.459	544.4531
6	-381.278	708.879
7	-441.278	801.1161
8	-484.32	865.8596
9	-549.193	921.192
10	-600	962.3409

Push Over 'Y' Analysis

Step	Monitored Displ mm	Base Force kN
0	0	0
1	-0.053	514.8925
2	-0.4	624.5789
3	-0.484	639.3894
4	-18.039	1610.399
5	-18.986	1439.294
6	-19.353	1503.996
7	-19.645	1532.245
8	-20.108	1558.404
9	-20.786	1413.398
10	-20.788	1412.695
11	-20.792	1413.684
12	-21.269	1456.774
13	-22.159	1309.602
14	-22.163	1309.442
15	-22.166	1308.518
16	-22.175	1310.468
17	-23.668	1437.697
18	-24.006	1446.076
19	-24.997	1180.414
20	-24.998	1176.217

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Case 2: For structure with Knee Elements in X direction

The knee elements were then introduced in the X direction and thus the following results were obtained when the structure was analyzed in the push x and push y analysis.

Push Over 'X' Analysis

Step	Monitored Displ	Base Force
	mm	kN
0	0	0
1	-60	123.4554
2	-120	246.9108
3	-180	370.3662
4	-240	493.8216
5	-269.52	554.5614
6	-369.004	729.0147
7	-429.004	827.694
8	-496.261	937.5997
9	-505.702	952.4927
10	-577.707	1024.456
11	-600	1046.5205

Push Over 'Y' Analysis

Step	Monitored Displ	Base Force
	mm	kN
0	0	0
1	-0.048	512.6972
2	-0.379	623.6884
3	-0.461	640.2769
4	-16.895	1609.277
5	-17.789	1439.488
6	-18.112	1499.891
7	-18.391	1528.522
8	-18.84	1555.522
9	-19.477	1409.876
10	-19.948	1455.238
11	-20.79	1307.696
12	-22.196	1434.687
13	-22.518	1443.178
14	-23.437	1180.813

Case 3: For structure with Knee Elements in Y direction:

In this case the knee elements were then provided in the Y direction only for further analysis and the below mentioned results were obtained.

Push Over 'X' Analysis

Step	Monitored Displ	Base Force
	mm	kN
0	0	0
1	-60	115.6483
2	-120	231.2966
3	-180	346.9449
4	-240	462.5932
5	-283.765	546.9499
6	-383.784	711.3415
7	-443.784	803.4151
8	-483.835	863.4639
9	-547.535	917.679
10	-600	960.0144

Push Over 'Y' Analysis

Step	Monitored Displ	Base Force
	mm	kN
0	0	0
1	-2.361	5809.918
2	-26.474	62731.79
3	-45.78	72942.18
4	-45.815	73000.47
5	-45.821	72872.82
6	-47.087	73553.44
7	-53.986	84586.22

Case 4: For structure with knee elements in both directions:

After studying the above cases the knee elements were then provided in both the directions i.e. X and Y direction for the final stage of analysis. The below mentioned results were thus obtained.

Push Over 'X' Analysis

Step	Monitored Displ	Base Force
	mm	kN
0	0	0
1	-60	122.8879
2	-120	245.7758
3	-180	368.6637
4	-240	491.5517
5	-272.772	558.672
6	-372.842	733.7423
7	-432.842	832.2272
8	-495.543	934.4652
9	-505.269	949.7784
10	-577.024	1021.2562
11	-600	1043.9174

Push Over 'Y' Analysis

Step	Monitored Displ	Base Force
	mm	kN
0	0	0
1	-1.883	5918.286
2	-20.989	63755.8
3	-32.292	70901.63
4	-34.047	74807.29
5	-34.053	74642.86
6	-34.088	74749.36
7	-39.504	86793.99

After studying the results obtained the following observations were made

Use of Knee Elements	Base Shear	Displacement	Base Shear	Displacement
	Push X Analysis		Push Y Analysis	
Without	962.34	-600	1176.217	-24.98
In X Direction	1056	-600	1180.813	-23.437
In Y Direction	960	-600	62731.79	-26.474
In Both Direction	1053.91	-600	67335.2	-27

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Thus we observe that by the use of Knee Elements in any specific direction the capacity of the structure to sustain a value of base shear and yield a specific displacement increases. After provisions of knee elements, for a specific displacement there was a higher value of base shear observed.

VI. CONCLUSION

We can conclude that there is a notable improvement in the capacity of the structure to sustain the base shear induced in it. We also observe that for the base shear induced the displacement observed in the structure is reduced considerably. Thus, an overall reduction in the inter-storey displacement, with increased moment carried capacity of the structure proves to make it more reliable. By providing Knee Elements in a single direction there is an increase in the base shear carrying capacity in that specific direction, thus during our final analysis Knee Elements were provided in both the directions in the structure i.e. the X and Y direction as the nature of a earthquake cannot be predicted. An overall positive result proving the effectiveness of Knee Elements was observed from the research study carried out.

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