Experimental Study on The Seismic Performance of Knee Braced and Unbraced Frames

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Abstract - *Steel plays an important role in construction industry due to its high strength to weight ratio. A study regarding the seismic response of steel structures is necessary in the present scenario. The seismic response of knee braced steel frame and unbraced steel frame are studied experimentally using a Horizontal shake table. Knee bracings is found to be an effective bracing system to resist earthquakes. Two models were made for conducting the experiment, a normal unbraced frame and a knee braced frame. The Harmonic waves are used to create the desired frequencies in the horizontal shake table. Response of both the frames for each frequencies were obtained. Seismic response of knee braced frame and normal frame are compared with each other and results are obtained.*

Key Words: **seismic effect, knee bracings, steel frames, shake table, response spectra**

1.INTRODUCTION

Under extreme seismic excitations, the structures must have sufficient strength and ductility to prevent collapse.Our aim is to find out whether knee bracings is an effective solution for seismic resistance.

In K.K.Sanglel(2012)[1] the linear time history analysis is carried out on high rise steel building with different pattern of bracing system. His Aim of study was to compare the results of seismic analysis of high rise steel building with different pattern of bracing system and without bracing system. The result of the present study shows that bracing element will have very important effect on structural behavior under earthquake effect.

Anitha M, Divya K.K (2015) [2]studied the seismic effect of different types of steel bracings. A comparison of knee braced steel frame with other types of bracings had been done. The Performance of each frame is been studied using non-linear static analysis and non linear time history analysis. Various parameters such as displacement and stiffness were studied. In non linear static analysis performed, steel frames with double knee bracings showed very good behaviour during a seismic activity. The ultimate load for double knee bracings is very much higher compared to without bracings and with eccentric bracings.

Mina Naeemi and Majid Bozorg(2009)[3] investigates using non-linear and linear static analysis of several knee Braced Frames (KBF), the seismic behavior of this system is assessed for controlling the vulnerability of the main and the secondary elements. The knee elements prevent collapse of the structure under extreme seismic excitations by dissipating energy through flexural yielding.

Mahmoud Miri,Abdolreza Zare, Hossein Abbas zadeh (2009)[4]In their article, relation between seismic performance and structural parameters of the knee bracing system and chevron knee bracing system investigated and compared. They found that the performance of columns in ordinary knee braces system is better than chevron knee braces system. H.-L. Hsu & C.-Y. Lee (2012)[5] Their study focused on the experimental evaluation of the seismic performance of steel knee braced moment resisting frame with stiffened steel slit walls. It was found from the tests that the strength and stiffness of the proposed design were effectively enhanced.

2.PRINCIPLE

A detailed literature survey was conducted on different types of bracing systems. Their characteristics, performance advantages and disadvantages. From this study it has been concluded that knee bracings is an effective way of seismic resistance other than the conventional bracing systems. The knee bracing steel frame (KBF) is a new kind of energy dissipating frame, which combines excellent ductility and lateral stiffness. Since stiffness and ductility are generally two opposing properties, it is desirable to devise a structural system that combines these properties in the most effective manner without excessive increase in the cost. Since the knee element is properly fused, yielding occurs only to the knee element and no damage to major elements. Compared to other type of bracings it performs better during a seismic activity. These bracings limits inter-storey drifts, and knee element absorbs the earthquake energy, by providing cyclic deformations in shear or bending. The main advantage with respect to eccentric braced frames is that damage is concentrated in secondary element and it can easily replaced after destructive earthquakes. Considering these advantages knee braced frame have been choosen to compare with a normal frame.

3.MODEL SPECIFICATIONS

3.1 Conventional frame model

A three storeyed steel model was fabricated and the total dead load on the steel structure was 10 kg. The live load for each story was 2, 2, 1 kg in I, II, and III floor respectively. The overall external dimension of the model is 300 mm X 240 mm at the base and a floor height of 300mm each. The total height of the structure is 900 mm and the model is made of mild steel.

Table-1: conventional frame dimensions

Sl.No	Element	Dimension (mm)
1	Column – hollow section	30 x 30, thickness – 2.
2	Slab	300 x 240, thickness – 2.

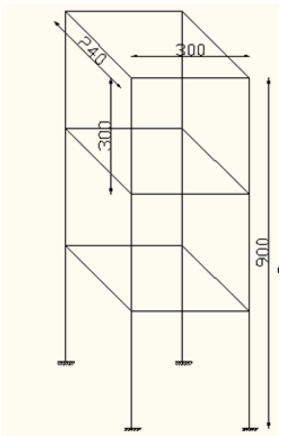

Fig-1: Conventional frame model

3.2 Knee Braced Frame Model

A three storeyed steel model was fabricated with same dimensions of conventional model and the total dead load on the steel structure was 14 kg. The live load for each story was 2, 2, 1 kg in I, II, and III floor respectively.

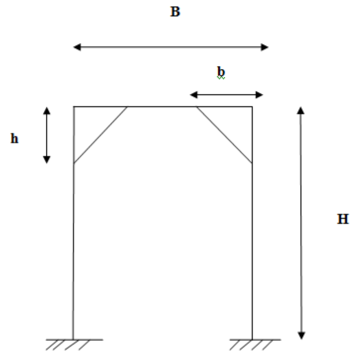

Fig-2: Knee braced model dimensions

For obtaining the spacing use the relation;

h/H = b/B [8] (1)

where H is the storey height and B is the width of the storey, h and b are the vertical and horizontal spacings of the knee element

For wider face(300 X 300 mm), h= 67.5 mm and b= 67.5 mm

For smaller face (300 X 240 mm),h= 67.5 mm and b= 52.5 mm

30mm x 30mm x 2 mm rectangular hollow section is used as the knee member in knee braced frame.

4. EXPERIMENTAL SETUP

The experiment was carried out by using MT horizontal shake table. The frequency can be varied from 0.25Hz to 25Hz and there are 4 channels for data acquisition. The harmonic vibration simulating seismic shake table of size 400mm x 400mm was used to generate horizontal load for the evaluation of the performance of isolators. The earthquake stimulator can achieve an usable peak to peak stroke of amplitude 10mm. Transducers (LVDT) were installed on each floor to measure the displacement during the experiment. The velocity & acceleration reading were taken from vibration analyzer. Both the models were tested for frequencies ranging from 1Hz to 10 Hz. Displacement, velocity, acceleration for each frequencies for each floors are obtained for both models

5.RESULTS AND DISCUSSIONS

The output results obtained from shake table are tabulated and Response spectra graphs are drawn for interpretation of results.

5.1 Relative Displacement spectra

Relative displacement of each floors with the ground floor has been find out from the obtained displacements of each floors.

Table-2: conventional frame relative displacement of each floors

Frequency	time period	Relative displacem ent FF	Relative displacem ent SF	Relative displacem ent TF
Hz	Sec	mm	mm	mm
2	0.50	0.58	0.81	0.54
3	0.33	0.21	0.64	1.30
4	0.25	0.72	1.53	2.66
5	0.20	2.99	7.53	11.89
6	0.17	1.07	0.41	1.81
7	0.14	0.81	0.24	1.28
8	0.13	0.41	0.17	0.32
9	0.11	0.26	0.27	0.17
10	0.10	0.18	0.26	0.10

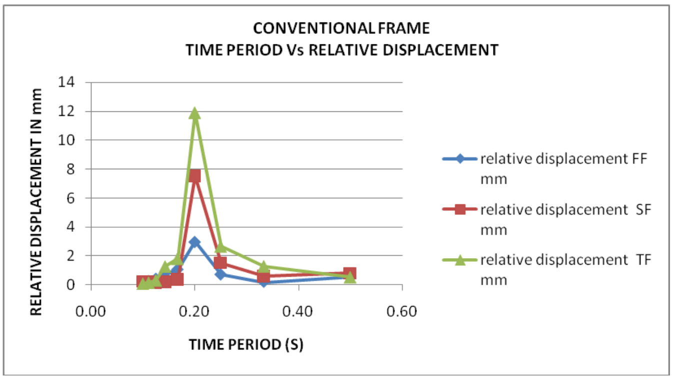

Chart-1: graph between time period and relative displacement

Table- 3:knee braced frame relative displacement

Frequency	time perio d	Relative displacem ent FF	Relative displacemen t SF	Relative displacemen t TF
Hz	Sec	mm	mm	mm
2	0.50	0.18	0.20	0.73
3	0.33	0.34	0.36	0.54
4	0.25	0.38	0.51	0.89
5	0.20	0.51	0.79	1.16
6	0.17	0.46	0.96	1.22
7	0.14	0.59	1.16	1.66
8	0.13	0.82	1.73	2.56
9	0.11	1.13	2.03	2.66
10	0.10	1.09	1.18	2.57

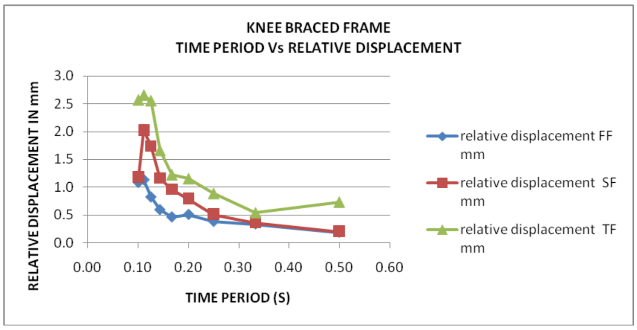

Chart-2: graph between time period and relative displacement

For conventional frame the maximum relative displacement obtained was 11.89 mm at 5 Hz frequency in the third floor, whereas for knee braced frame the relative displacement at 5Hz in third floor is 1.16 mm. also the maximum relative displacement in knee braced frame for all the frequencies was 2.57 mm which was reduced to great extent compared to conventional frame.

5.2 Velocity spectra

Velocity obtained for each floors in both frames are compared with each other and results are tabulated.

Table 4:conventional frame velocity of each floors

Freque ncy	time perio d	velocity GF	velocity FF	velocity SF	velocity TF
Hz	Sec	mm/s	mm/s	mm/s	mm/s
1	1.00	61.023	33.283	21.626	36.568
2	0.50	49.301	42.386	39.584	42.883
3	0.33	55.038	58.82	66.447	78.295
4	0.25	62.5	79.79	99.078	125.903
5	0.20	59.346	147.78	281.7	410.401
6	0.17	50.724	12.103	65.694	116.055
7	0.14	42.89	8.829	53.166	96.59
8	0.13	33.652	13.717	25.557	49.359
9	0.11	24.558	10.58	9.924	33.519
10	0.10	21.137	67.318	5.691	14.832

GF- ground floor FF –first floor SF-second floor TF-third floor

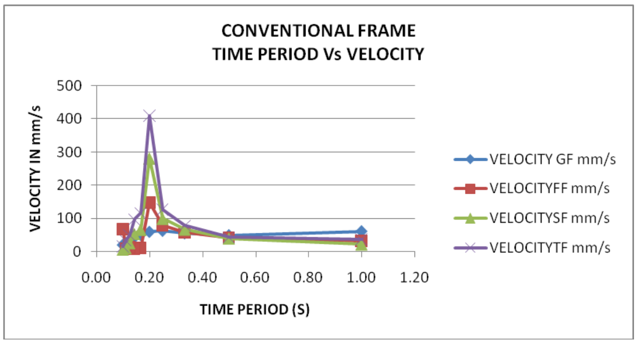

Chart-3: graph between time period and velocity

Table-5 :knee braced frame velocity of each floors

Frequency	time period	velocity GF	velocity FF	velocity SF	velocity TF
Hz	Sec	mm/s	mm/s	mm/s	mm/s
1	1.00	81.246	57.658	63.65	73.142
2	0.50	39.82	42.017	40.98	48.582
3	0.33	49.037	55.311	55.726	59.004
4	0.25	54.425	63.515	66.489	74.589
5	0.20	55.61	70.703	79.184	90.066
6	0.17	51.422	67.79	85.381	94.84
7	0.14	44.162	68.767	92.095	113.137
8	0.13	39.34	78.122	120.992	159.81
9	0.11	24.085	83.215	129.741	162.656
10	0.10	17.89	66.789	88.677	143.87

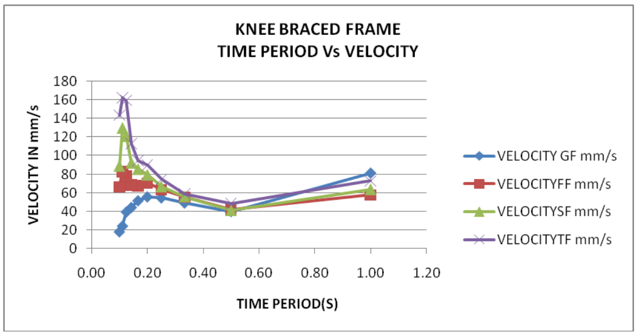

Chart-4: graph between time period and velocity

The maximum velocity for conventional frame was 410.401 mm/s at 5 Hz frequency in third floor, whereas the corresponding velocity in knee braced frame is 90.006 mm/s. for knee braced frame the maximum velocity was at 9 Hz which equals to 162.656 mm/s in third floor.

5.3 Acceleration spectra

Acceleration of each floors during the seismic movements for both frames are tabulated and compared

Table-6 :conventional frame acceleration of each floors

Frequency	time period	acceleration GF	acceleration FF	acceleration SF	acceleration TF
Hz	Sec	m/s²	m/s²	m/s²	m/s²
1	1.00	0.035	0.019	0.012	0.021
2	0.50	0.06	0.052	0.048	0.052
3	0.33	0.1	0.107	0.121	0.143
4	0.25	0.152	0.194	0.241	0.307
5	0.20	0.179	0.445	0.848	1.236
6	0.17	0.187	0.045	0.242	0.428
7	0.14	0.184	0.038	0.228	0.415
8	0.13	0.166	0.068	0.126	0.244
9	0.11	0.136	0.059	0.055	0.186
10	0.10	0.131	0.062	0.035	0.092

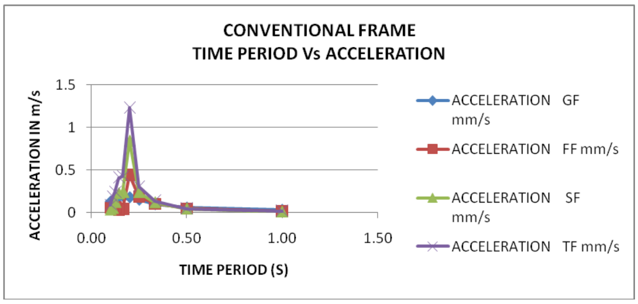

Chart-5: graph between time period and acceleration

Table-7 : knee braced frame acceleration for each floors

Frequency	time period	acceleration GF	acceleration FF	acceleration SF	acceleration TF
Hz	Sec	m/s²	m/s²	m/s²	m/s²
1	1.00	0.047	0.033	0.037	0.042
2	0.50	0.048	0.051	0.05	0.059
3	0.33	0.09	0.101	0.102	0.108
4	0.25	0.133	0.155	0.162	0.179
5	0.20	0.169	0.215	0.241	0.214
6	0.17	0.186	0.245	0.309	0.343
7	0.14	0.187	0.291	0.389	0.478

8	0.13	0.189	0.375	0.581	0.768
9	0.11	0.128	0.443	0.69	0.865
10	0.10	0.104	0.257	0.439	0.712

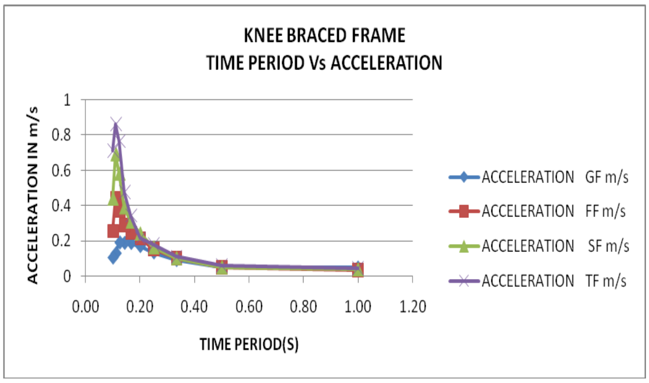

Chart-6: graph between time period and acceleration

For conventional frame the maximum acceleration obtained was 1.236 m/s² and for knee braced frame maximum acceleration was 0.865 m/s².

5.4 Storey Drift

Storey drift of the structure is calculated from the equation

Storey drift= relative displacement /storey height (2)

Table-8: conventional frame storey drift

Frequency	time period	Storey drift FF	Storey drift SF	Storey drift TF
Hz	Sec	-	-	-
1	1.00	0.01635	0.02358	0.01441
2	0.50	0.00193	0.00271	0.00179
3	0.33	0.00070	0.00212	0.00433
4	0.25	0.00241	0.00511	0.00885
5	0.20	0.00998	0.02510	0.03962
6	0.17	0.00356	0.00138	0.00603
7	0.14	0.00270	0.00081	0.00425
8	0.13	0.00137	0.00056	0.00108
9	0.11	0.00086	0.00090	0.00055
10	0.10	0.00061	0.00085	0.00035

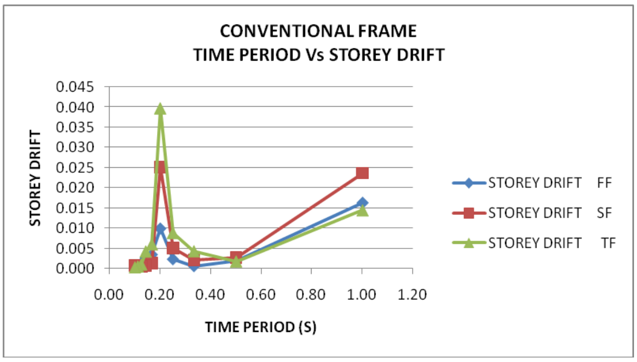

Chart-7: graph between time period and storey drift

Table-9: knee braced frame storey drift

Frequency	time period	Storey drift FF	Storey drift SF	Storey drift TF
Hz	Sec	-	-	-
1	1.00	0.013903	0.010370	0.004777
2	0.50	0.000613	0.000657	0.002447
3	0.33	0.001117	0.001193	0.001803
4	0.25	0.001270	0.001687	0.002957
5	0.20	0.001687	0.002633	0.003850
6	0.17	0.001537	0.003187	0.004077
7	0.14	0.001977	0.003853	0.005543
8	0.13	0.002743	0.005777	0.008520
9	0.11	0.003780	0.006753	0.008857
10	0.10	0.003620	0.003923	0.008567

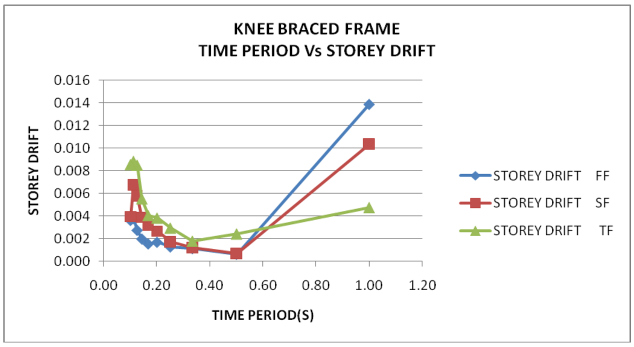

Chart-8: graph between time period and storey drift

Maximum storey drift for conventional frame was 0.03962 at 5Hz and the maximum storey drift for knee braced frame was 0.013903 at 1 Hz in the first floor.

5.5 Shear Force

Shear force for each frequency is calculated from the equation

$F= m\ddot{x}+c\dot{x}+kx$ (3)

x is the acceleration, x' is the velocity, x is the relative displacement of corresponding frequencies

Table-10: conventional frame shear force

Frequency	Time Period	Shear FF	Shear SF	Shear TF
Hz	sec	N	N	N
1	1.00	13325.76	14874.99	7971.019
2	0.50	2462.954	2478.39	1643.081
3	0.33	1902.928	2674.415	3538.674
4	0.25	3704.587	5178.569	6658.804
5	0.20	11097.62	21205.55	27210.79
6	0.17	3018.241	2210.269	5057.218
7	0.14	2276.734	1602.655	3822.601
8	0.13	1374.757	875.6774	1397.06
9	0.11	905.1066	756.0273	856.0399
10	0.10	2024.993	639.2388	431.8827

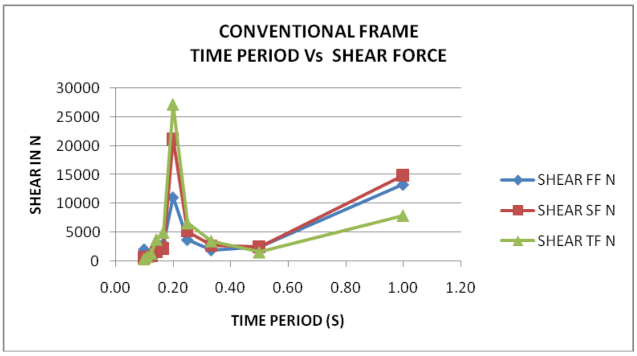

Chart-9: graph between time period and shear force

Table-11:knee braced frame shear force

Frequency	Time Period	Shear FF	Shear SF	Shear TF
Hz	Sec	N	N	N
1	1.00	12009.87	7659.401	3676.64
2	0.50	1443.188	1248.568	2073.097
3	0.33	2139.09	1883.441	1923.576
4	0.25	2448.953	2410.17	2778.726
5	0.20	2937.924	3255.119	3497.928
6	0.17	2757.068	3724.934	3699.825
7	0.14	3119.92	4275.382	4763.406
8	0.13	3928.94	6057.643	7084.215
9	0.11	4846.147	6841.232	7308.208
10	0.10	4334.594	4250.416	6835.686

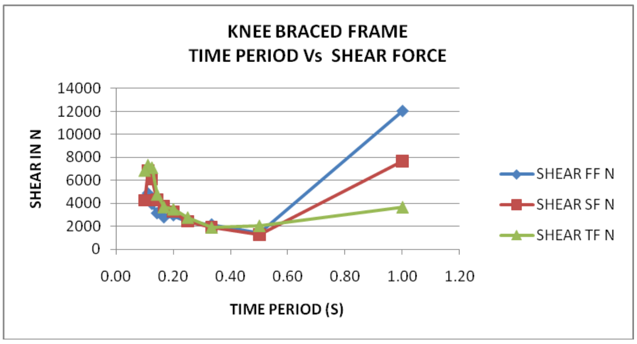

Chart-10: graph between time period and shear force

Maximum shear force in the normal frame obtained was 27210.7 N and the corresponding shear force in the knee braced frame was 3497.928 N.

6. CONCLUSIONS

After conducting the experiments and comparing the results it is clear that the seismic performance of knee braced frame is much better than normal unbraced frame. Major aspects used for the comparison of both frames was relative displacement, velocity, acceleration, storey drift, and shear force.

1.Maximum Relative displacement of the knee braced frame has been reduced by 90.24% compared to normal unbraced frame at a resonance frequency of 5 Hz.

2.There was also a reduction in velocity of the movement of knee braced frame by 78.06 % compared to unbraced frame

3.Acceleration has also been reduced by a considerable extent and shown a decrease by30 %

4.Storey drift is another major area of concern during the earthquakes, here by the use of knee bracings storey drift of the structure can be reduced upto64%.

5.Shear force in the knee brac frame compared with the normal unbraced frame made a decrease of 87%.

All these statistics indicate that knee bracings is an effective solution to resist seismic forces during earthquakes. We can provide knee bracings in underground car parking, soft stories etc where more damages during earthquakes are occurring.

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