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COMPARISION OF EFFECT OF DIFFEERENT STEEL BRACINGS ON RESPONSE OF STEEL STRUCTURE

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Abstract - *Civil engineering structures are prone to natural disaster like floods, earthquake, and strong winds. There are numerous anti-earthquake technique adopted during structural design. Incorporating the steel bracings to the structure is one of the effective structural controlling technique during earthquake. These bracings effectively dissipate the energy triggered by seismic waves. Bracings add strength and stiffness to a bare frame and helps reduce the dynamic response. This paper presents a comparative study on dynamic performance of braced and bare frame steel structure. For the study a six story unsymmetrical steel structure has been analyzed in ETABS using linear time history approach. Seismic performance is observed by considering bi-directional seismic excitations of Chi-Chi and Kobe as near fault and El-Centro as far field earthquake. Dynamic parameters like story drift, story displacement, base shear, torsion are compared between steel braced and bare frame structure. It is concluded from the study that, dynamic response the structure is greatly reduced in steel braced structure. Dynamic response of the structure is even affected by nature of earthquake excitation (i.e far field or near fault) and angle of incidence of the earthquake.*

Key Words: *Steel Bracing, Torsion, Angle of Incidence of the Earthquake.*

1. INTRODUCTION

Amongst all natural calamities, earthquake is unpredictable, and quite devastative in nature. Earthquake can cause severe damage to structures which often results into loss of life and property [1]. Eurasian and Austrian plate in Himalayan regions represents active boundary fault of India. India had witnessed some strong magnitudional earthquakes of order 7.5 to 8.5 in north-east part [2]. Indian standard (IS 1893-Part1:2002-Criteria for earthquake resistant design of structures) is suggested for earthquake resistant design of structure. IS 1893, describes three major analysis methods as “Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA) and Time History Analysis (THA)” [3]. Regular buildings are analyzed by ESA and irregular buildings are analyzed by RSA and ESA methods. Plan irregularity refers to asymmetric distribution of strength, stiffness, mass, geometric and diaphragm discontinuity [4]. Due to less resistance and large stresses and force development in irregular structure, these are more susceptible to sever damage [5]. Earthquake ground motions are generally classified into near and far field earthquake excitations. Classification of these excitations are based on forward-directivity, representing the propagation of rupture direction and fling step which constitute ground displacement [6]. Due to the phenomenon of forward directivity in near-fault earthquakes, the component perpendicular on fault has pulses with longer periods and wider range [7]. When Seismic isolated structure is impacted by near-fault ground motion, two aspects of motion has to be considered. First, the ground motion normal to the fault trace is richer in long-period spectral components than that parallel to the fault [8]. The fault normal and fault parallel motions are more or less uncorrelated, and higher spectral acceleration is expedited by parallel fault component at shorter period than the fault normal motion. This behaviour is, in fact, problem for structure. The second aspect of near-fault ground motion that strongly impacts seismic isolation systems is the presence of long-duration pulses. The ground motions may have one or more displacement pulses, with peak velocities of the order of 0.5m/sec and durations in the range of 1-3 sec [9]. These pulses will have a large impact on a structure with a period in this range and can lead to a structural displacement. In this paper, structure is analyzed by considering three earthquake, out of which two are near-fault and other far-field excitations [10].

Earthquake measuring stations, record the ground motions in three orthogonal directions, two of them in the horizontal direction and third in a vertical direction. In the design of buildings, earthquake loads are considered only along principal axes of buildings. However, an earthquake can also act along any axes of the building, other than principal axes. The critical angle of incidence of an earthquake on structure causing a maximum response, may not always occur along principal axes of the building [11]. Critical incidence angle for every earthquake is unique according to its excitations conditions. There is no particular angle of incidence of earthquake for a structure causing the maximum response in all structural elements. Each member gets its maximum responses by the specific angle of incidence of an earthquake. As per IS code IS 1893-Part1:2002, only uni-directional seismic excitations are reflected in seismic design. However, during an earthquake, the structure may be subjected to bi-directional excitations as well. Thus, if a structure designed for uni-directional seismic excitation it might not respond well to bi-directional seismic excitations especially in irregular structure [12].

To prevent the structural failure and to enhance the performance of building during earthquake, seismic forces on structural elements need to be minimized [13]. Earthquake force in structural members are counteracted by incorporating the bracings to the structure. [14]. Addition of bracings prolongs the formation of plastic hinges during the earthquake by providing the additional strength and stiffness to bare frame.

In this paper, linear time history approach is used in ETABS to analyze the six storey building with plan irregularity. A comparative study of dynamic performance of three different steel braced structures is presented, namely Diagonal bracing, Diamond bracing, and X bracing. Performance of bare and braced steel structure is studied by considering bi-directional seismic excitations of near fault and far field earthquake.

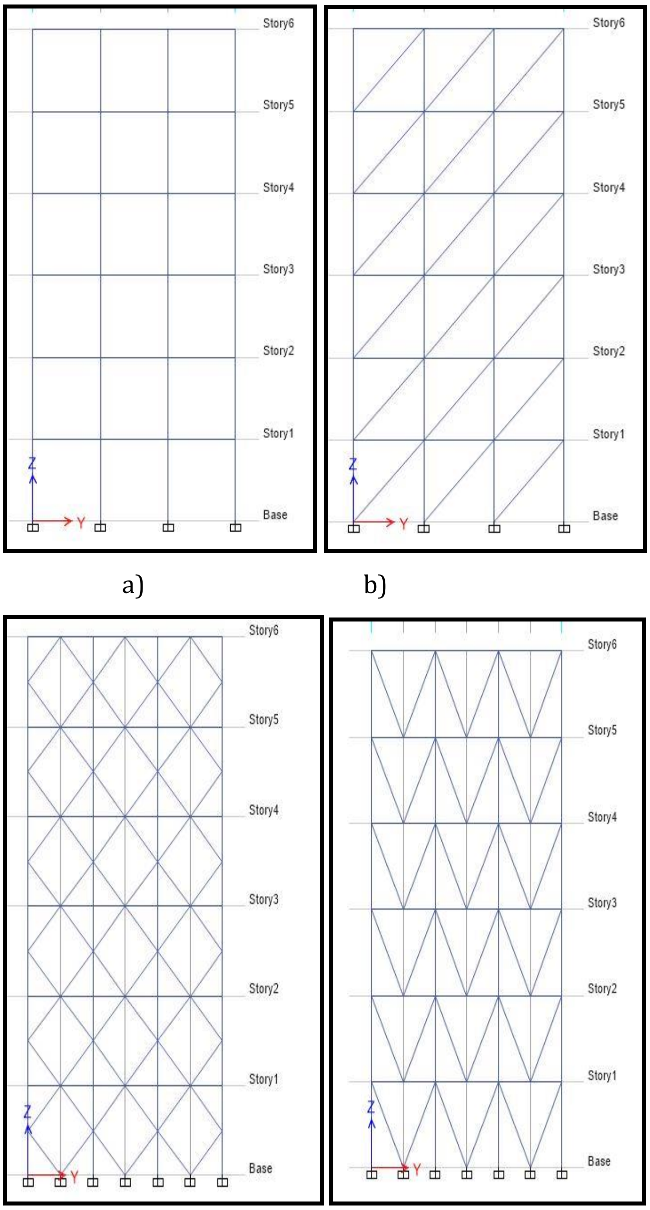
2. RESEARCH SIGNIFICANCE

Generally the research is carried out focusing on investigating the response of structure with and without bracings and factors affecting it. Most of the research is carried out in investigating dynamic response of the structure by considering the earthquake excitations only along principal axes. This research concentrates on investigation of performance of three different steel braced structure subjected to near fault and far field excitations by varying angle of incidence of earthquake. Discrepancy in structural behaviour for varying the angle of incidence of the earthquake provides a good indication about advantages and limitations different bracings to control response of structure. The study also recommends structural engineer to have efficient design by analyzing the existing structure for different steel bracings under different angle of incidence of earthquake.

3. SYSTEM DISCRIPTION

Six storey virtual commercial steel building is considered for the study. Figure 1 show top view of building having plan irregularity. Figure 2a, 2b, 2c and 2d represents front elevation of bare structure, diagonal, diamond, V braced steel structure respectively. The building is considered to be located in Mangalore region, which is southern part of Karnataka. Zone factor and response reduction factor for the building is 0.16 and 5 respectively. The dynamic parameter of structure mass, stiffness are presented in table 1.

Mass and stiffness of each storey are obtained from analytical approach and these values are verified by mathematically by considering the structural specifications and material properties. Tributary weight of the slab is generally considered as mass. Stiffness is calculated through Euler's formula (12 EI/L^3). Damping ratio is assumed as an average for design and analysis of concrete structures. 2% damping ratio is considered for steel structure. Table 1 shows the dynamic parameter which includes the mass and stiffness values of individual story for bare and braced frame structure. Higher mass of the structure is observed in braced structure compared to bare frame. To compare the dynamic response of the different braced structure with bare frame, stiffness parameter of the different braced structure are made almost constant by varying the sectional properties of bracings. Then effectiveness of different bracings are compared with bars frame structure.



a) b)

c) d)

Figure 2a: Elevation of bare frame, 2b: Elevation of diagonal frame, 2c: Elevation of diamond frame, 2d: Elevation of V frame

TABLE 1: DYNAMIC PARAMETER OF THE STRUCTURE

STOREY	BARE		DIAGONAL		DIAMOND		V	
	Mass (kg)	*Stiffness (N/m)*	*Mass (kg)*	*Stiffness (N/m)*	*Mass (kg)*	*Stiffness (N/m)*	*Mass (kg)*	*Stiffness (N/m)*
Story6	2464.8	13717.77	2507.43	132319.8	2649.99	134677.3	2532.16	132138.85
Story5	2547.8	22472.15	2632.93	194455.2	2618.05	194495.0	2582.39	195476.15
Story4	2547.8	28007.28	2632.93	219965.3	2718.05	219828.3	2682.39	218606.68
Story3	2647.8	33994.37	2732.93	239985.3	2818.05	239201.0	2782.39	239547.35
Story2	2747.8	46665.58	2832.93	274968.1	2918.05	274276.8	2882.39	274478.03
Story1	2847.8	112128.1	3254.98	478380.2	3680.57	477241.0	3502.31	477504.96

4. MODELLING TECHNIQUE

Unsymmetrical building is considered in the study to accomplish the torsional irregularity. Due to asymmetry, centre of mass and stiffness of the structure are not lying at the same point, leading to eccentricity in the structure. Height of each storey is 3.5m. Beam and columns are assemble of steel sections and slabs are reinforced concrete section (RCC). Unit weight of concrete is 25 KN/m^2. Slab thickness is 120 mm and grade of concrete is M20. ISHB 255252 I section is defined for beam and column. Live load on all floors is 3 kN/m^2 and on roof is 1.5 kN/m^2. A 3 D model of the building is developed in ETABS. Beam and column are modelled as frame elements and slab as shell elements. Frame element is modelled as straight line connecting two points. Under the application of load, frame element is subjected to biaxial bending, torsion, axial deformation and biaxial shear deformation. Each frame element has its own local coordinate system for defining section properties and loads and for interpreting output. The frame element will have all six degree of freedom at both of its connected joints. Each frame element will have three global co-ordinate system represented as X, Y and Z and local co-ordinate system denoted as U_1, U_2 and U_3. Figure 2e represents the frame element and its axes.

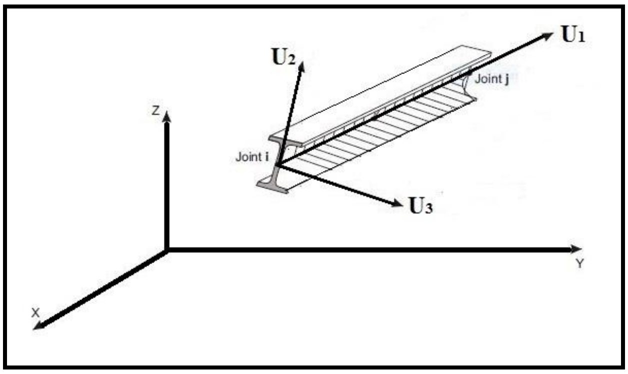


Figure 2e: Frame element and its axes.

Rigid diaphragm property has been assigned to all the floors. Diagonal, diamond and V bracings are modelled as truss elements, which can carry only axial tension and compression. Area of cross section of bracings are varied to attain comparable stiffness. All the structures are subjected to bi-directional seismic excitations. Dynamic response of the structures is observed by varying angle of incidence of earthquake from 0^{o} to 90^{o} for every 10o increment.

5. EARTHQUAKE EXCITATIONS

Magnitude, Peak ground acceleration of the earthquakes considered for the study are shown in the TABLE 2. Linear time history analysis is carried out for the study by considering three different earthquake records. As per guidelines of ASCE7-05 16.1.3 minimum three different previously recorded earthquake data should be considered for the design in dynamic analysis. To study the difference in dynamic response of the structure, response of the building is investigated under far field and near field earthquake excitations.

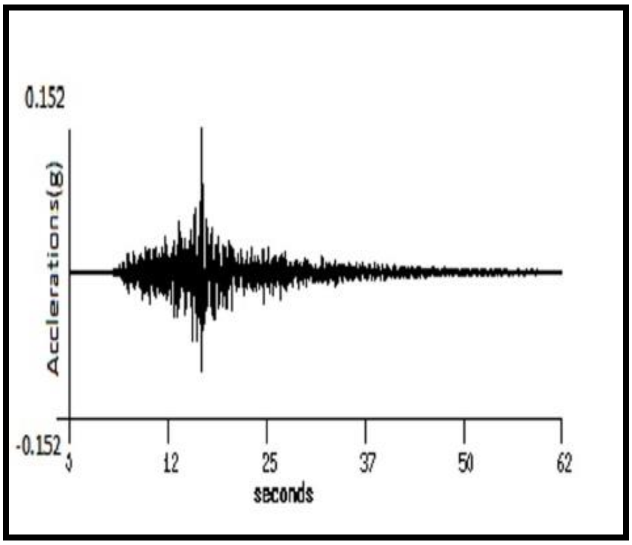


Figure-3: Accelerograms of Chi-Chi Earthquake

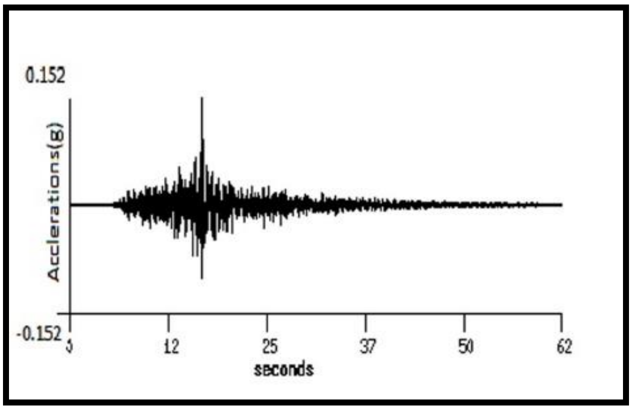


Figure-4: Accelerograms of Chi-Chi Earthquake

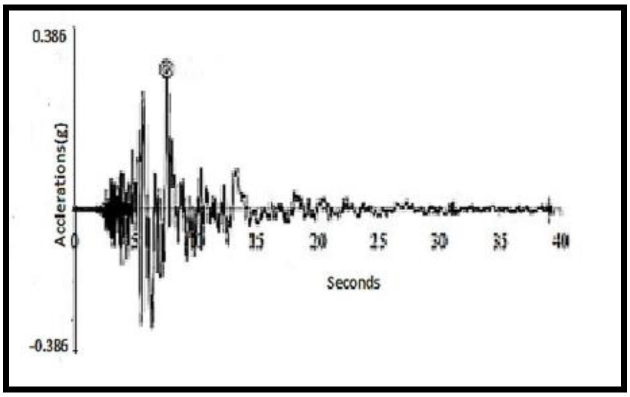


Figure-5: Accelerograms of Chi-Chi Earthquake

TABLE 2: EARTHQUAKE EXCITATIONS DETAILS

Earth quake	**Recording station**	**Magnitude**	**Peak ground acceleration (PGA) in g**
Chi-Chi	Hualian, Taiwan	7.3	0.152
Kobe	Kobe university,	6.9	0.284
El-Centro	El Centro Array #5	6.53	0.386

Response of the different steel braced structure is studied for every 10o increment in earthquake incidence angle from 0o to 90o. Out of three earthquake records considered (Fig.3, 4 and 5), Chi-Chi and Kobe are far field earthquakes and El-Centro is near fault earthquake. Real earthquake ground motions are obtained from peer strong ground motion database. Both 0o and 90o earthquake components are incorporated.

The real previously recorded earthquake data are obtained from PEER ground motion data base. These earthquake accelerograms files are imported to the software and ground accelerations are multiplied by suitable scale factor to complement the current soil condition. Time history analysis is carried out on the structure by assigning the earthquake load as linear model. 0^{o} component is assigned along X-axis and 90^{o} component along Y-axis of the structure. Figure 6 represents the variation of the angle of incidence of the earthquake. During the variation of the earthquake incidence angle, it is varied such that, horizontal and vertical components of the earthquake remain perpendicular to each other. Details of earthquake records are given in Table 2.

6. RESULTS AND DISCUSSION

This section presents results and discussion of dynamic performance of the structure. The response of the structure is investigated under different bracings with bare frame structure. The results of the parameter like structure displacement, story drift, and torsional rotation are compared for the braced structure with response of the bare frame structureunder near and far field earthquake excitations.

A. Story Drift and Displacement

Story drift is the displacement of one storey with respect to other. Graph 7 represents storey drift comparison of bare frame structure and braced structure for near fault and far field earthquake. Difference in their performance is observed for the top most story where the stiffness of the storey is very less. The story drift of the braced structure has greatly reduced than the bare frame structure, for both near fault and far field earthquakes. Diagonal bracing is most effective in reducing the story drift compared to other bracings for all the earthquakes. Diamond and V bracings were quite not effective in reducing responses for El-Centro earthquake, which is far-field earthquake. Storey displacement is the movement of a storey with respect to base of a structure.

Graph 8 represents storey displacement comparison of bare frame structure and braced structure for near fault and far field earthquake. All bracings were effective in reducing the story displacement. V bracing has shown the least story displacement (40 mm) for Chi-Chi earthquake, followed by diagonal and diamond bracing. Maximum reduction in the story displacement was observed in V bracings for both near and far field earthquake.

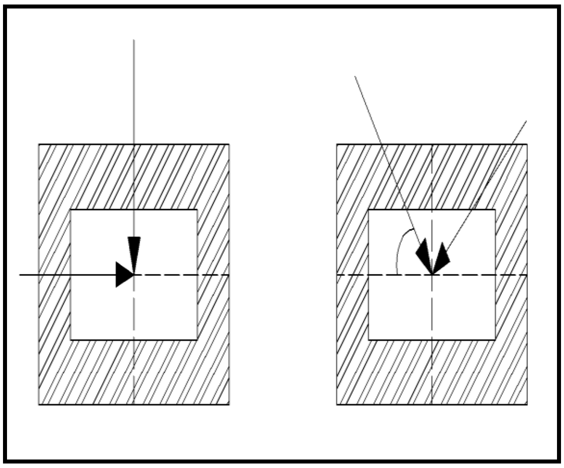


Figure-6: Variation of angle of incidence of the earthquake

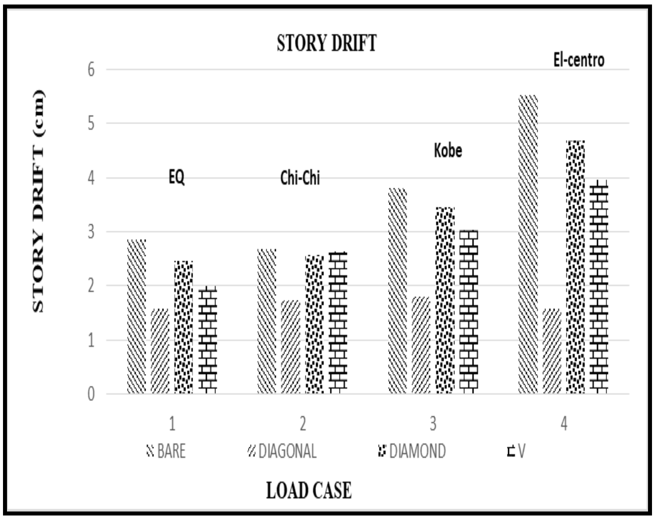


Figure-7: Story drift of the structure

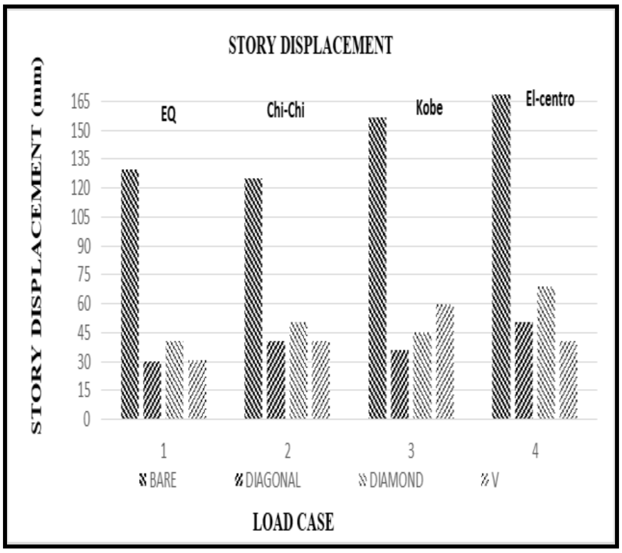


Figure-8: Story displacement of the structure

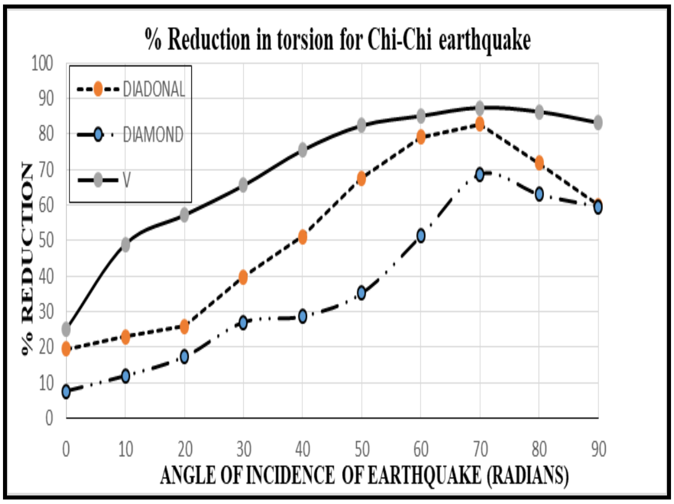


Figure-9: % Reduction in torsion rotation for Chi-Chi earthquake

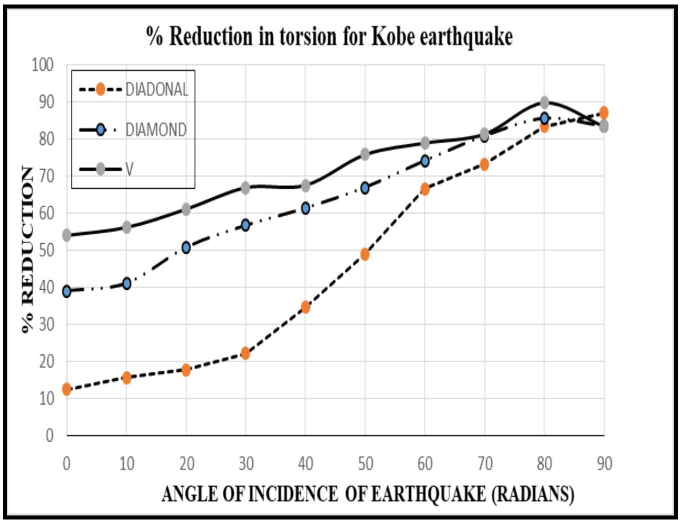


Figure-10: % Reduction in torsion rotation for Kobe earthquake

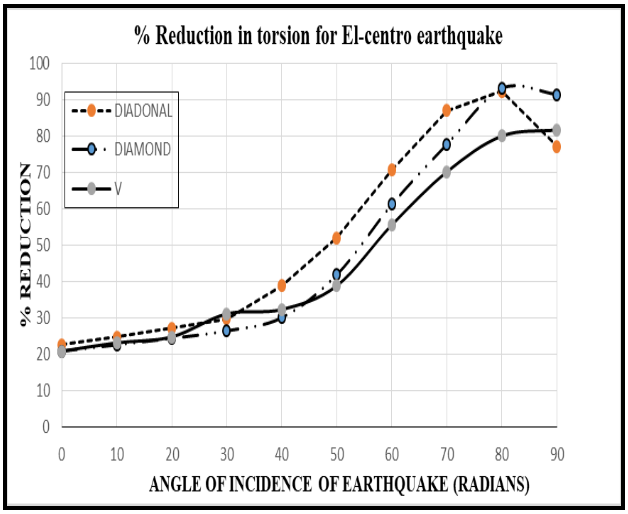


Figure-11: % Reduction in torsion rotation for El-Centro earthquake

B. Torsional Rotation

The torsional response of the structure is obtained to every 10° increment in earthquake incidence angle from 0° to 90°. Torsional rotation is obtained in terms of diaphragm rotation, which is applied to all floors of the structure. Bracings have effectively reduced the torsional rotation in structure when compared to bare frame structure, for all angles of bi-directional seismic excitations. Torsional rotation in the structure increased as earthquake incidence angle varied from 0° to 90°. Maximum torsional rotation in the structure was observed for Kobe earthquake, which is near fault earthquake. Graph 9, 10 and 11 represents the percentage reduction in torsional rotation of braced structure Chi-Chi, Kobe, El-Centro earthquakes respectively. Maximum percentage reduction in torsional rotation was observed by V bracing for the Chi-Chi and Kobe earthquake. But for El-Centro, torsional reduction was observed by the diagonal bracing. Table 3, 4 and 5 represents the torsional rotation for every earthquake incidence angle for bare and braced structure. For the Chi-Chi earthquake, torsional rotation for the structure increased drastically from 0° to 90°. Whereas, for Kobe earthquake, torsional rotation reduces to minimum and reaches to maximum value as angle approaches towards the 90°. In El-Centro earthquake, variation of the rotation is from higher to lower value. For the Chi-Chi earthquake, maximum % reduction in the torsion was 87.38 % for 70° incidence angle by V bracing. Similarly, maximum % reduction in the torsion was 89.79 %, 93.21 % for Kobe and El-Centro earthquake at 80° incidence angle by V and diamond bracing respectively. Overall reduction in torsional rotation for every angle of incidence of earthquake by all three bracings are quite lacking for far field earthquake.

7. CONCLUSIONS

Following are the conclusions drawn from dynamic analysis various steel braced structure under the influence of the far field and near fault earthquakes:

- All the bracings has effectively reduced the story drift. Under the influence of near fault earthquake excitation, story drift in braced structure varied from 15 mm to 30 mm. whereas for far-field earthquake story drift varied from 15 mm to 45 mm.
- Story displacement is effectively reduced by all the bracings. Under the influence of near fault earthquake excitation, story displacement in braced structure varied from 30 mm to 60 mm. whereas for far-field earthquake story drift varied from 30 mm to 70 mm.
- Torsional rotation in structure is greatly reduced by bracings for all earthquake incidence angle. For Chi-Chi earthquake, maximum reduction in torsion was 87% by V bracings. Similarly, For Kobe and El-Centro earthquakes, maximum reduction in torsion was 89% and 93% by V and diamond bracings respectively.

In the light of the above conclusions, it is clear that, bracings are effective in reducing the dynamic response of structure for both near and far field earth quake. Different bracings are effective in reducing the dynamic response of structure for different earthquake. One particular bracing capable of diminishing the response for particular seismic excitations, may not respond well for other earthquakes. Likewise, one distinct bracing in a structure may not counter act well in reducing the response for different angle of incidence of the earthquake. It is recommended that the designer must analyze the braced structure under near and far field earthquakes to efficiently control its dynamic response. As different bracings respond to various earthquake excitations differently, their effects should be considered. In some cases, a combination of bracings may be installed to overcome the deficiency of one bracings with the other one.

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