EFFECT OF ANGLE OF INCIDENCE OF THE EARTHQUAKE ON TORSIONAL RESPONSE OF BASE ISOLATED STRUCTURE.

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Abstract - *In this paper effect of angle of incidence of the earthquake on torsional response of base isolated structure is studied. For the study building resting on fixed and base isolated structure is considered. Lead rubber bearing (LRB) and frictional pendulum system (FPS) base isolator considered in the study. Structure is subjected to bi-directional seismic excitation. The angle of incidence of earthquake is varied and corresponding torsional response in the base isolated structure for is observed and compared with base isolated structure. The result indicates that, base isolated structures reduces torsional rotation when compared to fixed base structure. It is also observed that torsional rotation is less between 60° to 100° earthquake incidence angle.*

Key Words: Angle of Incidence of the Earthquake, Lead Rubber Bearing (LRB), Friction Pendulum System (FPS), Torsion.

1. INTRODUCTION

An earthquake is a natural phenomenon which produces surface waves causing the vibration of the ground and structures on it. Building which is subjected to earthquake suffer severe damage, hence it is necessary to prevent the structure from harmful effects of the earthquake. Base isolation is a technique which prevents damage to the structures during earthquake by isolating the seismic energy [1]. Base isolators can be broadly classified as elastomeric bearing and sliding bearing. Elastomeric bearings are mainly classified in to three types as laminated/Low damping rubber bearing, lead rubber bearing, high damping natural rubber bearing. These isolators commonly have two thick steel end plates and alternate layers of rubber and steel shims. The steel shims prevent bulging of rubber providing high vertical stiffness. Laminated/Low damping rubber bearing exhibit low damping which arises resonance in severe earthquake. In high damping natural rubber bearing, increase in damping is achieved by adding extra fine carbon blocks, oils, resins to rubber. Lead rubber bearings contains one or more lead plugs in center to improve hysteretic damping [2]. . Sliding isolator works by the principle of pure friction. Among the various types of sliding isolators, Friction pendulum system [FPS] is most commonly used sliding isolator [3].

FPS has articulated element as slider, which slides over the spherical concave surface during earthquake. Due to curved geometry of FPS, slider comes back to its original position under action of gravitational force and minimizes residual displacement of the superstructure [4]. Researchers have shown that, the use of FPS as base isolator can reduce dynamic response of structures during earthquake in terms of roof displacement, roof acceleration, base shear as compared to fixed base structures [5-6].

During an earthquake, torsional mode of the building might activate and can cause severe damage to structure. Torsion usually occurs due to non-uniform distribution of mass, stiffness, strength in structures and torsional components of the ground movement etc. As per IS 1893 (Part 1): 2002, for the design of a structure, earthquake loads are considered only along the principal axes [7]. However, earthquake can also act on any other axis of structure which can lead to torsion in structure [8]. In the design of the structure, uni-directional seismic excitation is considered. However, during an earthquake, structure may be subjected to bi-directional excitations as well [9]. Thus, if a structure designed for uni-directional seismic excitation it might not respond well for a bi-directional seismic excitation [10]. So IN this study torsional response of fixed and base isolated structure is observed by varying angle of incidence of the earthquake.

2. METHODOLOGY

For the study twelve storey Reinforced cement concrete building is considered. Plan of the building considered for the study are given in Fig. 1. The height of each story is 3.5 m, the grade of concrete considered is M 40 for column and M 20 (as per IS 456: 2000) for beam and slab.

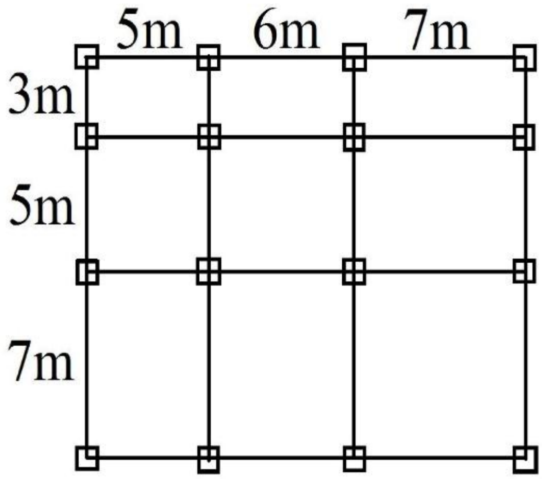

Fig -1: Plan of the Building

The unit weight of RCC is 25 kN/m^3. Beams and column are of dimensions 250 mm × 450 mm and 400 mm × 400 mm respectively. Thickness of slab is 150 mm. Live load on all floors is 3 kN/m^2 and on roof is 1.5 kN/m^2. Dead load on floors is 2 kN/m^2 and on the roof is 1 kN/m^2 [11]. A 3 D model of the building is developed in ETABS. Beam and column elements are modelled as frame elements and slab as shell element. Rigid diaphragm property has been assigned to all the floors. LRB and isolators are modelled as link/support element in the software. Various parameter of isolators like vertical stiffness, effective horizontal stiffness, slow and fast coefficient of friction, rate parameter are calculated based on the methods given in [12-13].

Table -1: Details of the Earthquake Records

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

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. Out of three earthquake records considered (Fig.2, 3 and 4), Chi-Chi and Kobe are far field earthquakes and El-Centro is near fault earthquake. Details of earthquake records are given in Table 1.

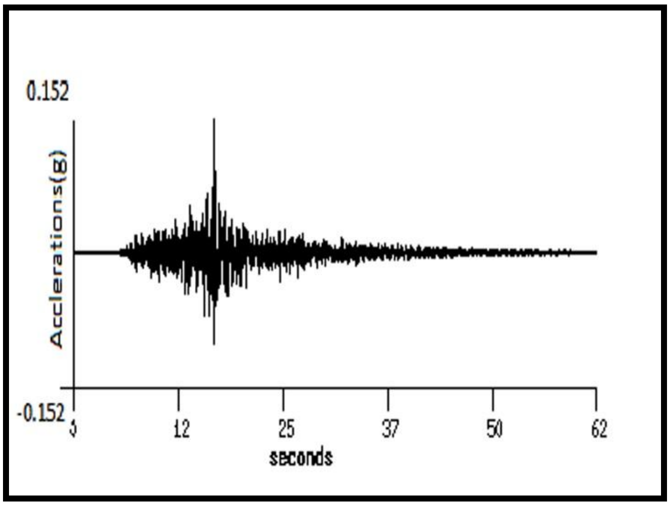

Fig -2: Accelerograms of Chi-Chi Earthquake

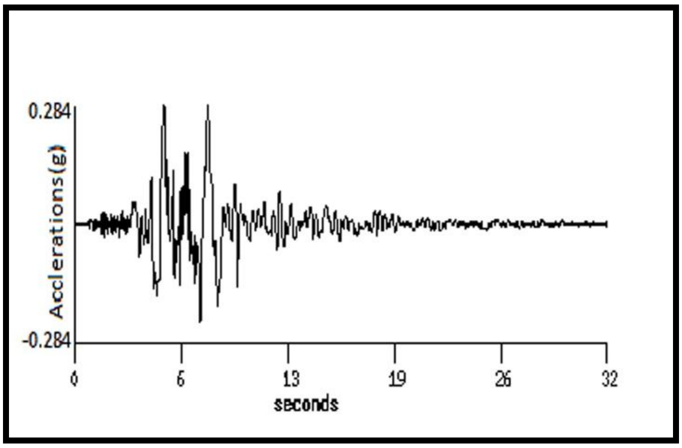

Fig -3: Accelerograms of Kobe Earthquake

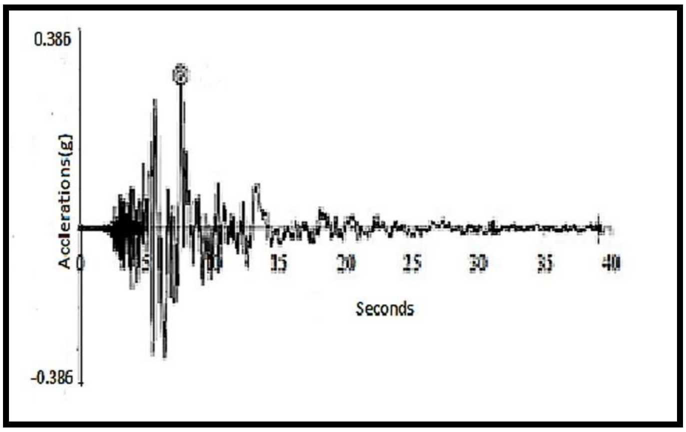

Fig -4: Accelerograms of El-Centro Earthquake

For the study bi-directional seismic excitations have been considered by varying the angle of incidence of earthquake from 0^o to 180^o at an interval of 10^o. This incidence angle variation considered in order to capture effect of torsion on structures. The torsional rotations are obtained by the rotation of diaphragms along vertical axis in terms of radians.

3. RESULTS AND DISCUSSION

The results obtained after carrying out linear time history analysis are discussed here. Chart 5, 6, and 7 represents torsional response of twelve storey fixed and base isolated structures for different angle of incidence of earthquake subjected to Chi-Chi, Kobe and El-Centro earthquake respectively. It is observed that, as angle of incidence of earthquake increases from 0^o, torsional rotation in structure also increases and reaches to least value in between 60^o and 100^o. Again torsional rotation increases as incidence angle of earthquake approaches towards 180^o. It also observed that, both lead rubber bearing and friction pendulum system has effectively reduced torsional rotation for all angle of incidence of earthquake. In all three earthquakes, reduction in torsional rotation by lead rubber bearing is more effective than friction pendulum system.

Table -1: Details of the torsional rotation of different angle of incidence of Chi-Chi earthquake

ANGLE OF INCIDENCE OF EARTHQUAKE	TORSIONAL ROTATION IN FIXED BASE STRUCTURE	TORSIONAL ROTATION IN LRB BASE ISOLATED STRUCTURE	TORSIONAL ROTATION IN LRB BASE ISOLATED STRUCTURE	% REDUCTION IN TORSIONAL ROTATION BY LRB	% REDUCTION IN TORSIONAL ROTATION BY FPS
0	0.001392	0.000133	0.000326	90.45	76.58
10	0.001348	0.000124	0.000261	90.80	80.64
20	0.001264	0.000111	0.000248	91.22	80.38
30	0.001141	9.50E-05	0.000231	91.67	79.75
40	0.000984	7.60E-05	2.11E-04	92.28	78.56
50	0.000796	5.50E-05	1.88E-04	93.09	76.38
60	0.000595	3.20E-05	1.62E-04	94.62	72.77
70	0.000397	8.00E-06	1.38E-04	97.98	65.24
80	0.000245	2.00E-06	1.21E-04	99.18	50.61
90	0.000263	4.00E-06	1.47E-04	98.48	44.11
100	0.000368	4.20E-05	1.67E-04	88.59	54.62
110	0.000597	6.20E-05	1.98E-04	89.61	66.83
120	0.000807	0.000101	0.000221	87.48	72.61
130	0.000993	0.000116	0.000239	88.32	75.93
140	0.001149	0.000127	0.000254	88.95	77.89
150	0.001237	0.000135	0.000275	89.09	77.77
160	0.001352	0.000138	0.000311	89.79	77.00
170	0.001393	0.000137	0.000334	90.17	76.02
180	0.001392	0.000133	0.000326	90.45	76.58

Table -2: Details of the torsional rotation of different angle of incidence of Kobe earthquake

ANGLE OF INCIDENCE OF EARTHQUAKE	TORSIONAL ROTATION IN FIXED BASE STRUCTURE	TORSIONAL ROTATION IN LRB BASE ISOLATED STRUCTURE	TORSIONAL ROTATION IN LRB BASE ISOLATED STRUCTURE	% REDUCTION IN TORSIONAL ROTATION BY LRB	% REDUCTION IN TORSIONAL ROTATION BY FPS
0	0.001801	0.000221	0.000335	87.73	81.40
10	0.001757	0.000205	0.000314	88.33	82.13
20	0.001639	0.000182	0.000284	88.90	82.67
30	0.001512	0.000154	0.000245	89.81	83.80
40	0.001318	0.000122	0.000199	90.74	84.90
50	0.001085	8.50E-05	0.000147	92.17	86.45
60	0.000818	4.60E-05	9.50E-05	94.38	88.39
70	0.000426	6.00E-06	3.90E-05	98.59	90.85
80	0.000367	3.50E-05	6.50E-05	90.46	82.29
90	0.000347	7.40E-05	9.90E-05	78.67	71.47
100	0.000353	0.000111	0.000149	68.56	57.79
110	0.000539	0.000145	0.000202	73.10	62.52
120	0.001003	0.000175	0.000248	82.55	75.27
130	0.001236	0.000199	0.000286	83.90	76.86
140	0.001506	0.000217	0.000316	85.59	79.02
150	0.001607	0.000228	0.000336	85.81	79.09
160	0.001825	0.000233	0.000346	86.49	79.94
170	0.001796	0.000229	0.000348	87.25	80.62
180	0.001803	0.000221	0.000335	87.74	81.42

Table -3: Details of the torsional rotation of different angle of incidence of El-centro earthquake

ANGLE OF INCIDENCE OF EARTHQUAKE	TORSIONAL ROTATION IN FIXED BASE STRUCTURE	TORSIONAL ROTATION IN LRB BASE ISOLATED STRUCTURE	TORSIONAL ROTATION IN LRB BASE ISOLATED STRUCTURE	% REDUCTION IN TORSIONAL ROTATION BY LRB	% REDUCTION IN TORSIONAL ROTATION BY FPS
0	0.000662	0.000197	0.000251	70.24	62.08
10	0.000617	0.000182	0.000224	70.50	63.70
20	0.000552	0.000162	0.000195	70.65	64.67
30	0.000471	0.000137	0.000177	70.91	62.42
40	0.000375	0.000108	0.000139	71.20	62.93
50	0.000275	7.50E-05	0.000116	72.73	57.82
60	0.000174	4.10E-05	7.80E-05	76.44	55.17
70	0.000105	5.00E-06	3.30E-05	95.24	68.57
80	0.000107	3.20E-05	5.80E-05	70.09	45.79
90	0.000208	6.70E-05	8.60E-05	67.79	58.65
100	0.000318	0.0001	0.000122	68.55	61.64
110	0.000421	0.00013	0.000164	69.12	61.05
120	0.000496	0.000156	0.000201	68.55	59.48
130	0.000584	0.000178	0.000212	69.52	63.70
140	0.000643	0.000194	0.000226	69.83	64.85
150	0.000677	0.000204	0.000233	69.87	65.58
160	0.000693	0.000208	0.000237	69.99	65.80
170	0.000688	0.000206	0.000239	70.06	65.26
180	0.000662	0.000197	0.000241	70.24	63.60

Table 2, 3 and 4 represents torsional response of fixed and base isolated structure for Chi-Chi, Kobe and Elcentro earthquakes. From above tables it is clear that both base isolated structures has effectively reduced torsional rotation in structure compared to fixed base structure for all angle of incidence of earthquakes. Maximum percentage reduction in torsion by LRB and FPS isolators are 99.18%, 80.64% in Chi-Chi and 95.24%, 68.57% for Kobe and 95.24%, 68.57% in Elcentro earthquakes respectively. It is also observed that, in all three earthquakes maximum torsional rotation in fixed base structure observed at incidence angle other than orthogonal direction (0° and 90°). The maximum torsional rotation for Chi-Chi, Kobe and El-centro earthquake is at incidence angle of 170°, 160° and 160° respectively.

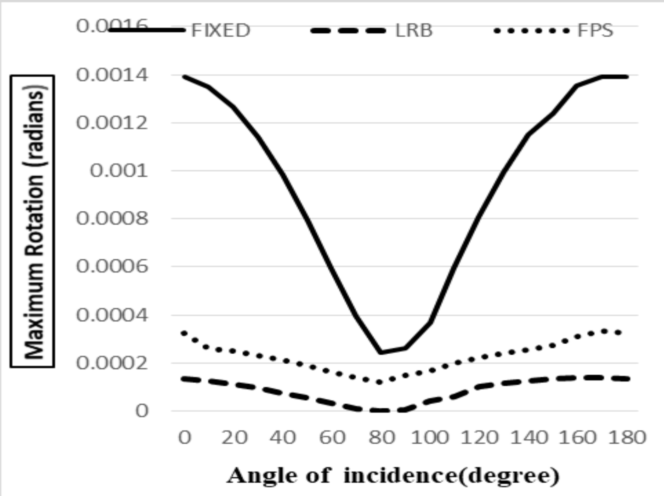

Chart -1: Torsional rotation v/s angle of incidence of earthquake for Chi-Chi earthquake

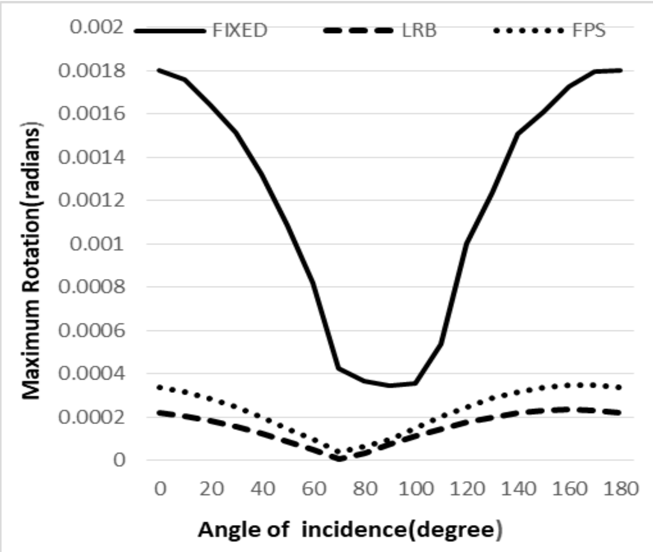

Chart -2: Torsional rotation v/s angle of incidence of earthquake for Kobe earthquake

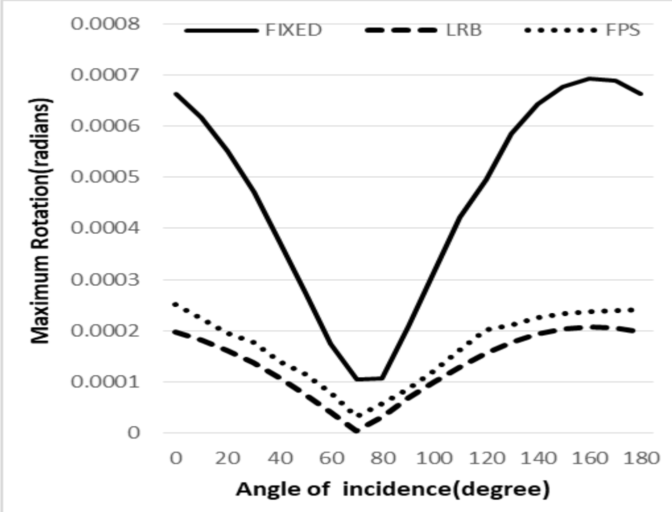

Chart -3: Torsional rotation v/s angle of incidence of earthquake for El-centro earthquake

4. CONCLUSION

Effect of angle of incidence of the earthquake on torsional response of fixed and base isolated structure is studied. Structure is subjected to three previously recorded earthquake data and angle of incidence of earthquake is varied from 0° to 180° by 10° increments. Torsional rotation in fixed and base isolated structure is observed for every 10° increment. Both isolators has effectively reduced the torsional rotation in the structure for every earthquake incidence angle. LRB is more effective compared to FPS. It is found that maximum torsional rotation in structure was not along earthquake of orthogonal direction. If building is designed by considering earthquake along orthogonal direction, it might not respond well if earthquake incidence is in other direction.

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