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Effect of Building Height on Torsional Rotation of Base Isolated Structures

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Abstract*: *The effect of height variation of a base isolated building on torsional response has been studied in the paper Also response of lead rubber and friction pendulum base isolator on torsional rotation has been compared. For the study, building rests on friction pendulum system (FPS) and lead rubber bearing (LRB) has been considered. The height of the building is varied successively and subjected to bi-directional seismic excitation. The torsional response of isolated structure is studied for each increment in the storey height for both LRB and FPS isolators and compared with fixed base structure. The result indicates that, base isolated structures reduces torsional rotation. It is also found that torsional rotation for buildings of ten to fifteen stores have significant reduction compared to other models considered in present study. Beyond this, the effectiveness reduces. It is also observed that FPS base isolator has effectively reduced torsional rotation when compared to LRB.

***Keywords*: Angle of incidence, base isolation, storey increment, torsional response.**

I. 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.

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 [2]. 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 [3]. 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 [4-5].

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 [6]. However, earthquake can also act on any other axis of structure which can lead to torsion in structure [7]. 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 [8]. Thus, if a structure designed for uni-directional seismic excitation it might not respond well for a bi-directional seismic excitation [9]. Various researches have carried out in order to study the effect of torsional rotation in structure on base isolation and it is observed that base isolation is effective in reducing dynamic response of fixed base structures even in torsionally coupled structures [10-11]. However, limited studies are carried out in the effect of torsional rotation on LRB and FPS base isolated structure in tall buildings. So in this study, the effect of torsional rotation of LRB and FPS base isolated structure on tall buildings is carried out by varying storey numbers.

II. METHODOLOGY

Details 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. The unit weight of RCC is 25 kN/m^3. Beams and column are of dimensions 250 mm × 450 mm and 850 mm × 850 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 [12-13]. A 3 D model of the building is developed in ETABS. Beam and column elements are modelled as frame elements and slab as shell elements are modelled as frame elements and slab as shell A 3 D model of the building is developed in ETABS. Beam and column elements are modelled as frame elements and slab as shell 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.

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Rigid diaphragm property has been assigned to all the floors. LRB and FPS are modelled as link/support element in the software. Various parameter of base isolators like vertical stiffness, effective horizontal stiffness, slow and fast coefficient of friction, rate parameter are calculated based on the methods given in [14-16]. Table 1 and 2 lists typical FPS and LRB isolator property values for thirty story building.

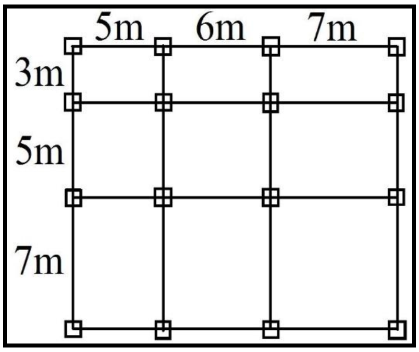

Fig. 1. Plan of the building

Table- I: FPS Isolator properties

Vertical stiffness	2435704 kN/m
Effective horizontal stiffness (Linear)	4538 kN/m
Effective horizontal stiffness (Non-Linear)	11217 kN/m
Frictional coefficient (Slow)	0.06
Frictional coefficient (Fast)	0.12
Rate parameter	0.05 mm/sec
Isolator radius	3.322 m

Table- II: LRB Isolator properties

Effective horizontal stiffness	1942 kN/m
Vertical stiffness	812322 kN/m
Yield force	175 kN
Post yield stiffness ratio	0.1
Effective damping	0.1

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 3.

Table- III: Details of the earthquake records

Earthquake	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

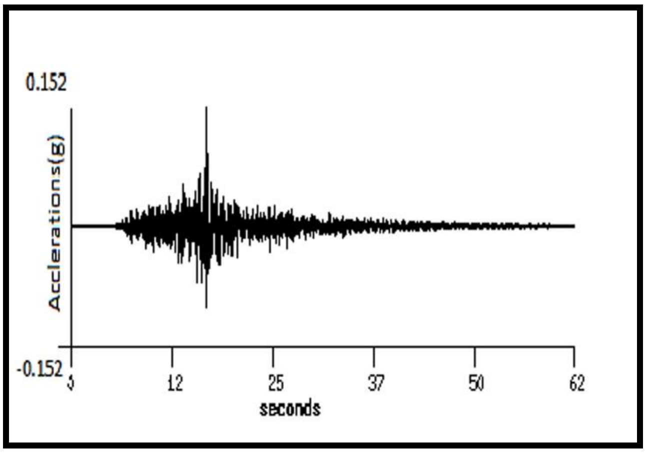

Fig. 2: Accelerograms of Chi-Chi Earthquake

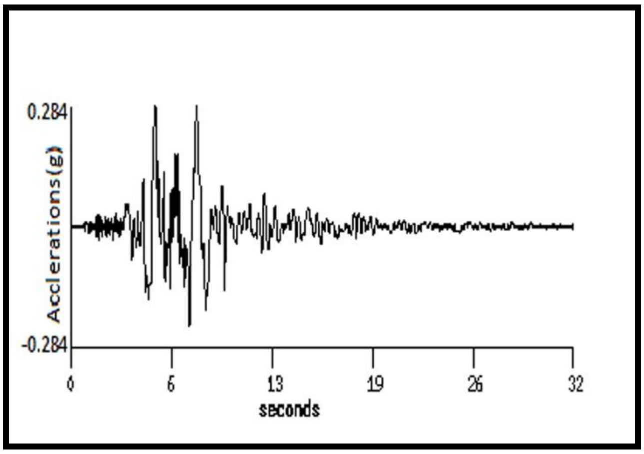

Fig. 3: Accelerograms of Kobe Earthquake

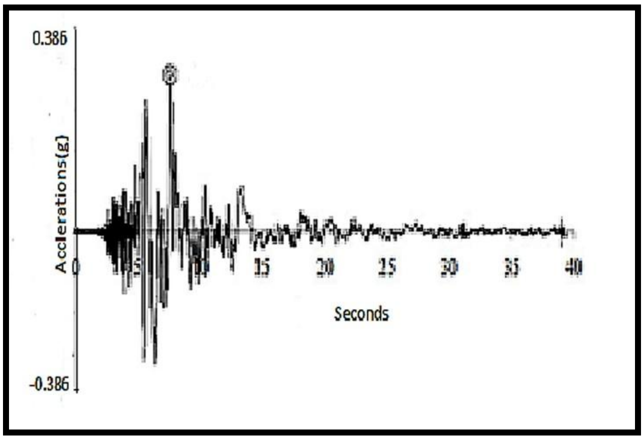

Fig. 4: Accelerograms of El-Centro Earthquake

III. RESULTS AND DISCUSSIONS

The results obtained after carrying out linear time history analysis are discussed here. Table’s no.4, 5 and 6 represent the percentage reduction in torsional rotation when fixed base structure is compared with base isolated structure for all buildings for various earthquake records. Since, the torsional response of buildings up to five storey heights is considerably less, the response for these structures have not been accounted for. It can be seen that, torsional rotation in structure increases with increase in storeys.

It is also seen that, LRB and FPS base isolator has effectively reduced the torsional rotation in all structures for all three earthquakes. For all the three earthquakes, both LRB and FPS isolator reduces torsional rotation, and this reduction is more for buildings of ten to fifteen storeys. This could be due to the phase lag which happens between earthquake and frequency of isolated structure. The maximum reduction in torsional rotation by FPS isolator is 83.20% for twelve story building for Chi-Chi earthquake. It is 81.42% for twelve story building in Kobe and 72.34% for eleven story building in El-Centro earthquake respectively. Similarly, the maximum reduction in torsional rotation by LRB isolator is 92.31% for twelve story building for Chi-Chi earthquake. It is 90.83% for eleven story building in Kobe and 73% for eleven story building in El-Centro earthquake respectively.

Table- IV: Torsional response of fixed and base isolated structures for Chi-Chi earthquake

No. of Stories in the structure	**Angle of incidence of the earthquake causing maximum torsional rotation for fixed structure**	**Maximum torsional rotation (Radians) for fixed base structure**	**Torsional rotation (Radians) in base isolated structure corresponding to maximum rotation in fixed structure**		**% Reduction in torsional rotation**	
			LRB	**FPS**	**LRB**	**FPS**
30	160	0.001776	0.000904	0.000918	**49.099**	**48.311**
29	160	0.001686	0.000835	0.000851	**50.474**	**49.526**
28	170	0.001456	0.000708	0.000718	**51.374**	**50.687**
27	170	0.001296	0.000618	0.000625	**52.315**	**51.775**
26	170	0.001255	0.000559	0.000599	**55.458**	**52.271**
25	170	0.001218	0.000524	0.000554	**56.979**	**54.516**
24	170	0.001152	0.000487	0.000514	**57.726**	**55.382**
23	160	0.001166	0.000469	0.000509	**59.777**	**56.346**
22	170	0.001058	0.000418	0.000447	**60.491**	**57.750**
21	170	0.001017	0.000379	0.000426	**62.734**	**58.112**
20	170	0.000995	0.000361	0.000403	**63.719**	**59.497**
19	170	0.000982	0.000352	0.000392	**64.155**	**60.081**
18	170	0.000868	0.000302	0.000332	**65.207**	**61.751**
17	170	0.000895	0.000286	0.000291	**68.045**	**67.486**
16	170	0.000865	0.000258	0.000273	**70.173**	**68.439**
15	170	0.000862	0.000219	0.000193	**74.594**	**77.610**
14	170	0.000763	0.000187	0.000145	**75.491**	**80.996**
13	180	0.000706	0.000126	0.000128	**82.153**	**81.870**
12	170	0.001393	0.000107	0.000234	**92.319**	**83.202**
11	170	0.001237	0.000104	0.000265	**91.593**	**78.577**
10	170	0.000943	0.000106	0.000229	**88.759**	**75.716**
9	170	0.000636	0.000138	0.000212	**78.302**	**66.667**
8	160	0.000317	0.000113	0.000123	**64.353**	**61.199**
7	160	0.000394	0.000164	0.000155	**58.376**	**60.660**
6	170	0.000269	0.000143	0.000124	**46.84**	**53.903**

Table- V: Torsional response of fixed and base isolated structures for Kobe earthquake

No. of Stories in the structure	Angle of incidence of the earthquake causing maximum torsional rotation for fixed structure	Maximum torsional rotation (Radians) for fixed base structure	Torsional rotation (Radians) in base isolated structure corresponding to maximum rotation in fixed structure		% Reduction in torsional rotation	
			LRB	FPS	LRB	FPS
30	170	0.002765	0.001412	0.001456	**48.933**	**47.342**
29	170	0.002715	0.001373	0.001403	**49.429**	**48.324**
28	170	0.002696	0.001323	0.001353	**50.927**	**49.815**
27	170	0.002636	0.001273	0.001311	**51.707**	**50.266**
26	170	0.002611	0.001225	0.001255	**53.083**	**51.934**
25	160	0.002594	0.001155	0.001195	**55.474**	**53.932**
24	170	0.002556	0.001076	0.001154	**57.903**	**54.851**
23	170	0.002437	0.001014	0.001094	**58.391**	**55.109**
22	160	0.002332	0.000935	0.001024	**59.906**	**56.089**
21	170	0.002252	0.000886	0.000965	**60.657**	**57.149**
20	170	0.001904	0.000734	0.000797	**61.45**	**58.141**
19	170	0.002195	0.000797	0.000917	**63.69**	**58.223**
18	170	0.001901	0.000671	0.000778	**64.703**	**59.074**
17	160	0.001711	0.000589	0.000649	**65.576**	**62.069**
16	170	0.001593	0.000523	0.000569	**67.169**	**64.281**
15	170	0.001346	0.000368	0.000422	**72.66**	**68.648**
14	170	0.001168	0.000347	0.000307	**73.716**	**69.264**
13	170	0.001555	0.000309	0.000386	**80.129**	**75.177**
12	180	0.001803	0.000151	0.000335	**91.625**	**81.420**
11	170	0.001549	0.000142	0.000361	**90.833**	**76.695**
10	170	0.001038	0.000122	0.000272	**88.247**	**73.796**
9	150	0.000703	0.000175	0.000248	**75.107**	**64.723**
8	170	0.000686	0.000252	0.000275	**63.265**	**59.913**
7	160	0.000407	0.000175	0.000175	**57.002**	**57.002**
6	170	0.000305	0.000167	0.000149	**45.246**	**51.148**

Table- VI: Torsional response of fixed and base isolated structures for Elcentro earthquake

No. of Stories in the structure	Angle of incidence of the earthquake causing maximum torsional rotation for fixed structure	Maximum torsional rotation (Radians) for fixed base structure	Torsional rotation (Radians) in base isolated structure corresponding to maximum rotation in fixed structure		% Reduction in torsional rotation	
			LRB	FPS	LRB	FPS
30	170	0.003511	0.002278	0.002287	**35.118**	**34.862**
29	160	0.003512	0.002214	0.002254	**36.959**	**35.820**
28	170	0.003115	0.001954	0.001984	**37.271**	**36.308**
27	170	0.002919	0.001784	0.001815	**38.883**	**37.821**
26	170	0.002765	0.001664	0.001694	**39.819**	**38.734**
25	170	0.002682	0.001592	0.001622	**40.641**	**39.523**
24	170	0.002498	0.001459	0.001477	**41.593**	**40.873**
23	170	0.002355	0.001382	0.001422	**41.316**	**39.618**
22	170	0.002209	0.001276	0.001316	**42.236**	**40.426**
21	170	0.002034	0.001143	0.001196	**43.805**	**41.200**
20	170	0.001788	0.000974	0.001016	**45.526**	**43.177**
19	170	0.001567	0.000815	0.000855	**47.99**	**45.437**
18	170	0.001506	0.000749	0.000785	**50.226**	**47.875**
17	170	0.001336	0.000652	0.000692	**51.198**	**48.204**
16	160	0.001121	0.000537	0.000564	**52.096**	**49.688**
15	160	0.001073	0.000483	0.000526	**54.986**	**50.979**
14	170	0.000882	0.000354	0.000401	**59.864**	**54.535**
13	170	0.000747	0.000289	0.000321	**61.312**	**57.028**
12	160	0.000693	0.000208	0.000221	**69.986**	**68.110**
11	170	0.000799	0.000215	0.000221	**73.091**	**72.340**
10	170	0.000975	0.000264	0.000357	**72.923**	**63.358**
9	170	0.000864	0.000294	0.000338	**65.972**	**60.880**
8	160	0.000699	0.000279	0.000309	**60.086**	**55.794**
7	160	0.000443	0.000215	0.000221	**51.467**	**50.113**
6	170	0.000294	0.000154	0.000153	**47.619**	**47.959**

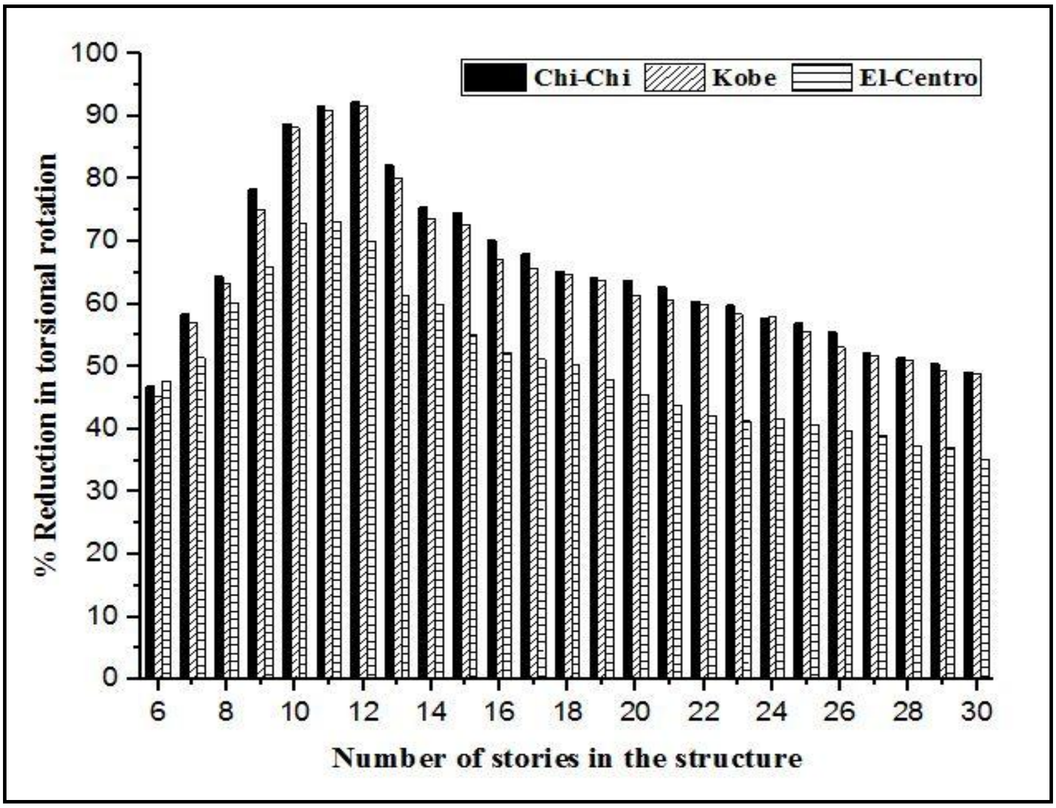

Fig. 5: Reduction in torsional rotation of LRB base isolated structures

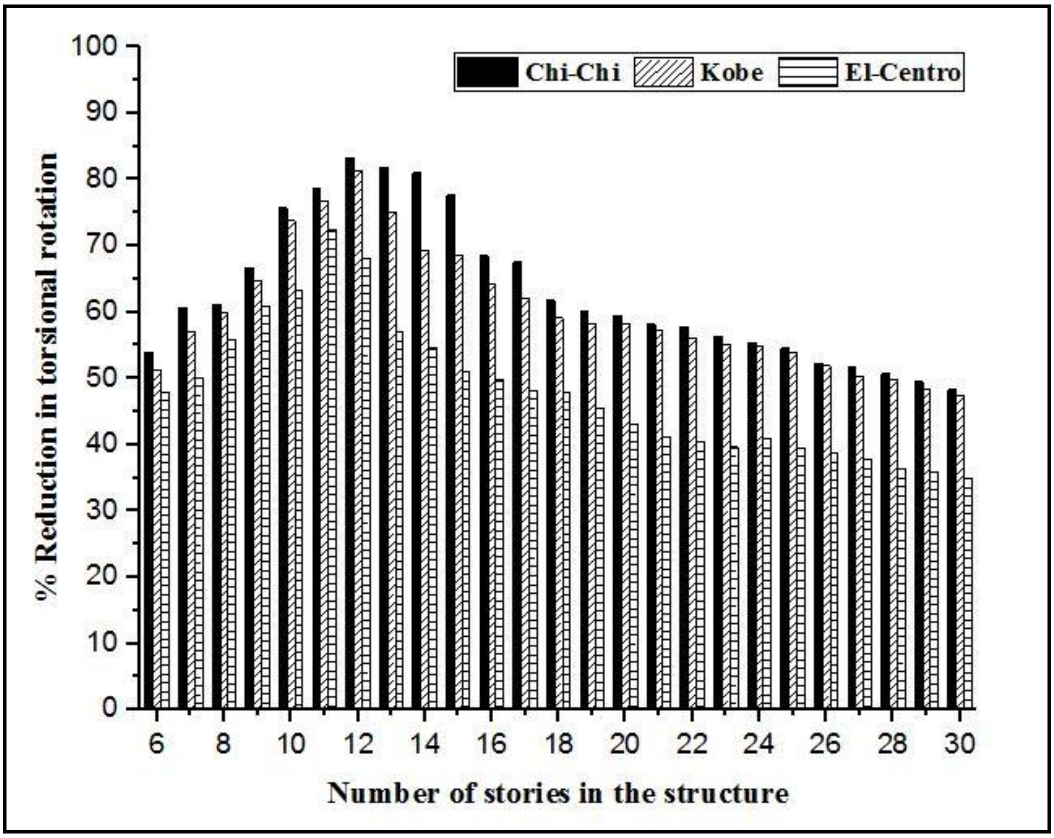

Fig. 6: Reduction in torsional rotation of FPS base isolated structures

It is observed that, lead rubber isolator is more effective in reducing the torsional rotation as compared friction pendulum system in all three earthquakes. Reductions in torsional response for various earthquakes can be seen in Fig. 5 and 6. It can be seen that, for El-Centro earthquake, which is a near fault earthquake with peak ground acceleration (PGA) of 0.386g, reduction in torsional rotation by LRB and FPS isolator is least. For Chi-Chi and Kobe earthquakes which is a far field earthquakes with PGA of 0.152g and 0.284g respectively, reduction in torsional rotation by both LRB and FPS isolator is less for Kobe with higher PGA then Chi-Chi earthquake.

IV. CONCLUSION

Effect of building height on torsional rotation of base isolated structures is studied. Effectiveness of LRB and FPS base isolator in reducing torsional rotation is studied by considering buildings of different heights, subjected to bi-directional seismic excitations. For the study, two far field and one near fault earthquakes were considered. Based on the study it can be concluded that, both LRB and FPS base isolator can successfully reduce overall torsional rotation in tall structures. LRB isolator is effective in reducing torsional rotation for all earthquakes as compared to FPS isolators. FPS reduces torsional rotation up to 83% for buildings of twelve storey. Likewise LRB reduces torsional rotation up to 92% for buildings of twelve storey. Also, FPS isolated structure was found to be quite effective in reducing torsional rotation in far field earthquake and are found to be less effective in near fault earthquakes. The effectiveness of both LRB and FPS base isolator in reducing torsional rotation was found to reduce with increase in PGA of earthquakes.

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