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Comparison of Two Similar Buildings with and without Base Isolation

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Abstract*— Reinforced concrete is a major construction material for civil infrastructure in current society. Construction design has always preceded the development of structural design methodology. Dramatic collapse of buildings has been observed after each disastrous earthquake, resulting in loss of life. To prevent such a loss Base-isolation is used which enables a building to survive potentially devastating seismic impact by providing flexibility into the connection between the building and the foundation. The mechanism of the base isolator increases the natural period of the overall structure, and decreases its acceleration response to earthquake/seismic motion. A reinforced concrete building with lead rubber bearing is used. The study analysis performed to check for the adequacy of the base isolation against earthquake damage when compared to the conventional earthquake resistant design. A building was analyzed using the equivalent lateral force method and response spectrum analysis as fixed base (FB) and as isolated base (IB) with lead rubber bearing. The analysis represents a case study for reinforced concrete to show the ultimate capacity of the selected bearing system, and to make a comparison for the difference between the isolated base and the fixed base buildings. Results show that the presence of the lead rubber bearing reduces significantly the displacement, moment and shear generated for the same mode and hence the reinforcement required is also lesser when compared to the traditional fixed based structure.

Keywords—**Base-isolation, Lead rubber bearings, ETABS, Performance evaluation and Earthquake resistant design**

I. INTRODUCTION

Base isolation (BI) is a mechanism that provides earthquake resistance to the new structure. The BI system decouple the building from the horizontal ground motion induced by earthquake, and offer a very stiff vertical components to the base level of the superstructure in connection to substructure (foundation). It shifts the fundamental lateral period, dissipates the energy in damping, and reduces the amount of the lateral forces that transferred to the inter-story drift, and the floor acceleration. The structural bearing criteria include vertical and horizontal loads, lateral motion, and lateral rotation that transferred from the superstructure into the bearing and from the bearing to the substructure. Bearing allows for stress-free support of the structure in terms of (1) they can rotate in all directions, (2) they deform in all directions, (3) they take horizontal forces (wind, earthquake). In this study lead rubber bearings are used as the base isolation system [8].

II. PROBLEM DESCRIPTION

The building is an existing hospital situated in Agartala. It is a 7 storey RC beam-column framed structure with brick infill walls and four shear walls. It is located in Seismic Zone V. The basic wind speed is 55m/s as per IS 875 Part 3. Materials used are M30 grade concrete and Fe 415 grade steel. ETABS version 13 was used for analysis purposes. A typical floor plan is shown figure 1 with a perspective view of the building in figure 2.

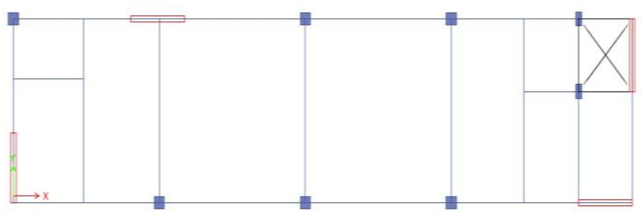

Fig. 1 A typical floor plan

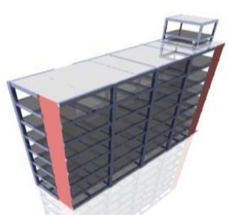

Fig. 2 Perspective view of the building

Earthquake loads are calculated as per IS 1893-2002. The zone factor is 0.35. Since this is an institutional building an importance factor of 1.5 is assigned with response reduction factor of 5. Type of soil at site is soft.

Height of building, h	= 29.15 m
Width of building in x direction, dx	= 30.58 m
Width of building in y direction, dy	= 7.825 m
Seismic weight of building	= 31323 kN
Fundamental natural time period (with infill)	
X direction	= 0.47 s
Y direction	= 0.94 s
$(S_a/g)_x$	= 2.50
$(S_a/g)_y$	= 1.78
Acceleration coefficient	
X direction	= 0.135
Y direction	= 0.096
Base shear	
X direction	= 4228.65 kN
Y direction	= 3011.89 kN

III. DESIGN OF THE ISOLATION SYSTEM

The bearing system is to be designed as per Uniform Building Code, 1997, appropriate site and geological conditions were assumed and constants were calculated as given in table 1. The units are in kN and mm. The performance summary of the isolator is given in table 2 for the Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE). Table 3. gives the modelling parameters for the ETABS program.

TABLE I
DESIGN PARAMETERS FOR THE BASE ISOLATION SYSTEM

Parameter	Value	Code reference
Seismic Zone Factor, Z	0.4	Table 16-I
Soil Profile Type	SD	Table 16-J
Seismic Coefficient, C_A	0.440	Table 16-Q
Seismic Coefficient, C_V	0.640	Table 16-R
Near-Source Factor N_a	1.000	Table 16-S
Near-Source Factor N_v	1.000	Table 16-T
MCE Shaking Intensity $M_M Z N_a$	0.500	
MCE Shaking Intensity $M_M Z N_v$	0.500	
Seismic Source Type	B	Table 16-U
Distance to Known Source	15.0 km	
MCE Response Coefficient, M_M	1.25	Table A-16-D
Lateral Force Coefficient, R_I	2.0	Table A-16-E
Fixed Base Lateral Force Coefficient, R	8.5	Table 16-N
Importance Factor, I	1.0	Table 16-K
Seismic Coefficient, C_{AM}	0.550	Table A-16-F
Seismic Coefficient, C_{VM}	0.800	Table A-16-G
Eccentricity, e	1.53	
Shortest Building Dimension, b	7.53	
Longest Building Dimension, d	30.53 m	
Dimension to Extreme Isolator, y	15.3 m	
$D_{TD}/D_D = D_{TM}/D_M$	1.283	

TABLE II
THE PERFORMANCE SUMMARY OF THE ISOLATION SYSTEM AT DBE AND MCE

Criteria	**LRB**	**DBE**	**MCE**
Gravity Strain F.S.	11.97		
Gravity Buckling F.S	5.74		
DBE Strain F.S	2.66		
DBE Buckling F.S	2.20		
MCE Strain F.S	1.71		
MCE Buckling F.S	1.32		
Reduced Area / Gross Area	29.0%		
Maximum Shear Strain	146%		
Effective Period T_D , T_M		3.10	3.29
Displacement D_D , D_M		320.6	454.6
Total Displacements D_{TD} D_{TM}		411.2	583.2
Force Coefficient V_b / W		0.134	0.169
Force Coefficient V_s / W		0.067	
1.5 x Yield Force / W		0.076	
Wind Force / W		0.031	
Fixed Base V at T_D		0.048	
Design Base Shear Coefficient		0.076	
Damping β_{eff}		22.29%	18.10%
Damping Coefficients B_D B_M		1.54	1.44

TABLE III
MODELLING VALUES TO BE ENTERED IN THE ETABS SOFTWARE AS A LINK ELEMENT

ETABS Link Properties	LRB
First Data Line:	
ID	1
ITYPE	Rubber Isolator
KE2	0.97
KE3	0.97
DE2	0.131
DE3	0.131
Second Data Line:	
K1	1340.0
K2	6.25
K3	6.25
FY2/K11/CFF2	148.18
FY3/K22/CFF3	148.18
RK2/K33/CFS2	0.11
RK3/CFS3	0.11

IV. PERFORMANCE EVALUATION

Performance of the FB and IB buildings was compared and are tabulated in tables 4 to 6. The inter-story drifts ratios are within limits of 0.007 as specified is Cl.1659.8.1 of Uniform Building Code - 1997. The Isolator Displacement is within limits of 400 mm for which it is designed. There is reduction in base shear and is tabulated in table 7. Tables 8 to 10 show the difference in the reinforcement between the FB and IB buildings.

TABLE IV
COMPARISON OF STORY DRIFTS FOR THE FB AND IB STRUCTURE

Direction X	**Load case: DL+LL+EQX**		**Percentage Change**
Story	**Fixed Base**	**Isolated Base**	
TF	0.00453	0.00277	38.83
6F	0.00464	0.00284	38.81
5F	0.00514	0.00320	37.71
4F	0.00518	0.00324	37.43
3F	0.00522	0.00348	33.22
2F	0.00483	0.00330	31.69
1F	0.00390	0.00614	-57.46
GF	0.00197	0.01990	-907.39
Isolator		0.06911	
Direction Y	**Load case: DL+LL+EQY**		**Percentage Change**
Story	**Fixed Base**	**Isolated Base**	
TF	0.004394	0.004079	7.17
6F	0.004407	0.004095	7.08
5F	0.004403	0.004212	4.34
4F	0.004358	0.00418	4.08
3F	0.004195	0.004205	-0.24
2F	0.003696	0.0036	2.60
1F	0.002725	0.004256	-56.18
GF	0.001298	0.021379	-1547.07
Isolator		0.001617	

TABLE V
COMPARISON OF STORY DISPLACEMENTS FOR THE FB AND IB STRUCTURE FOR LOAD CASE DL+SLL+EQX

Story	**Fixed Base**	**Isolated Base**	**Difference**
TF	123.5	287.4	163.9
6F	108.2	278.3	170.1
5F	91.5	268.8	177.3
4F	74.4	258.9	184.5
3F	56.5	248.3	191.8
2F	37.7	236.7	199
1F	20.3	225.1	204.8
GF	7.6	214.5	206.9
BASE	0	207.3	207.3
ISOLATOR	0	0	0

TABLE VI
COMPARISON OF STORY DISPLACEMENTS FOR THE FB AND IB STRUCTURE FOR LOAD CASE DL+SLL+EQY

Story	**Fixed Base**	**Isolated Base**	**Difference**
TF	103.9	320.4	216.5
6F	88.2	305.9	217.7
5F	72.4	291.1	218.7
4F	57.2	276.8	219.6
3F	42.1	262.4	220.3
2F	27	247.9	220.9
1F	13.7	235	221.3
GF	4.9	224.8	219.9
BASE	0	218.2	218.2
ISOLATOR	0	0	0

TABLE VII
COMPARISON OF BASE SHEAR THE FB AND IB STRUCTURE

Direction	**Fixed Base**	**Isolated Base**	**Percentage Reduction**
X	4228 kN	2380 kN	43%
Y	3011 kN	2380 kN	21%

TABLE VIII
COMPARISON OF QUANTITY OF REINFORCEMENTS REQUIRED IN SHEAR WALLS

Wall 1	**Percentage Difference**		
STORY	Boundary Element	Vertical Reinforcement	Horizontal Reinforcement
GF	36.01	92.48	0.00
1F	49.29	74.77	0.00
2F to TF	0.00	0.00	0.00
Wall 2	Boundary Element	Vertical Reinforcement	Horizontal Reinforcement
GF	28.46	53.18	0.00
1F	67.58	51.30	0.00
2F	68.77	71.84	0.00
3F	58.42	0.00	0.00
4F to TF	0.00	0.00	0.00
Wall 3	Boundary Element	Vertical Reinforcement	Horizontal Reinforcement
GF	36.07	92.48	0.00
1F	37.31	74.77	0.00
2F to TF	0.00	0.00	0.00
Wall 4	Boundary Element	Vertical Reinforcement	Horizontal Reinforcement
GF	26.81	53.18	0.00
1F	23.84	55.22	0.00
2F	27.59	44.66	0.00
3F	40.88	0.00	0.00
4F to TF	0.00	0.00	0.00

TABLE IX
COMPARISON OF QUANTITY OF REINFORCEMENTS REQUIRED IN BEAMS

Story	Fixed Base (m^3)	Isolated Base (m^3)	Percentage Difference
GF	0.72	1.06	-47.37
1F	1.15	0.91	20.55
2F	1.33	1.02	23.22
3F	1.30	0.97	25.45
4F	1.27	0.94	25.74
5F	1.19	0.92	22.52
6F	1.05	0.81	22.36
TF	0.93	0.80	13.29
Sum	8.93	7.44	16.64

TABLE X
COMPARISON OF QUANTITY OF REINFORCEMENTS REQUIRED IN COLUMNS

Story	Fixed Base (m^3)	Isolated Base (m^3)	Percentage Difference
GF	0.70	1.01	-44.71
1F	0.44	0.26	41.27
2F	0.46	0.20	57.42
3F	0.37	0.18	50.78
4F	0.31	0.15	52.00
5F	0.24	0.13	42.99
6F	0.25	0.15	41.50
TF	0.08	0.05	40.21
Sum	2.84	2.13	25.00

V. REINFORCEMENT QUANTITY

The FB building was compared with its IB counterpart. The sections used for the comparison are identical. So, difference is shown in the quantity of reinforcement provided for the two cases of FB building and IB.

TABLE XI
COMPARISON OF QUANTITY OF REINFORCEMENTS

Reinforcement m^3		Fixed Base	Isolated Base	Percentage reduction
1	Beams	8.93	7.45	16.57
2	Columns	2.84	2.13	25.00
3	Shear wall	1.63	1.03	36.35
	Sum	13.40	10.61	20.76

VI. CONCLUSIONS

Analytically it has been show that lead rubber bearings can bring about 20% savings in the reinforcement used. Since the building does not undergo any deformation but only gets displaced, the hospital is still serviceable after the occurrence of the design earthquake. A further study can be made where a comparison of a building with shear wall with a building equipped with base isolators is done in order to estimate the reduction in concrete quantity.

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