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Comparison of Direct Displacement-based Design with Force-based Design for Lead Rubber Bearing base-isolated buildings.

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Abstract - Force-based design (FBD) is the conventional method; it mainly focuses on seismic force on the structure through which the building will be designed. It has limitations such as assumed member stiffness and reduction factors through which time period and seismic forces on the structure are determined and structure will be designed. The performance level is directly related to displacement but not to strength. To overcome these limitations Direct displacement-based design (DDBD) came as an efficient alternative. In DDBD initially, the target displacement is defined through which the stiffness of members and seismic forces acting on the building will be determined. In this paper, the performance of G+3 and G+5 lead rubber bearing base-isolated building is evaluated using FBD and DDBD method, and a comparison is made. The building is designed according to Indian standards with IS 1893 (part 1) 2016 for seismic design and IS 456 (2000) for all RC frame members. Non-linear pushover analysis is carried out using SAP2000 for finding out a structural performance like base shear and inter-story drift ratio (IDR%.) This paper concludes that the DDBD method is more reliable and effective compared to the FBD method for LRB base-isolated buildings.

Keywords - Performance level; Direct displacement-based design; Base- Isolation (BI); Non-linear pushover analysis; Base shear; Inter-storey drift ratio.

INTRODUCTION

The conventional Force-based design (FBD) method uses assumed initial stiffness of members to determine the time period of the building and seismic forces are distributed to members in proportion to assumed stiffness and height. Ductility demand, Force reduction factors are also assumed in Force-based design method. So, with an increase in the necessity of a more reliable design method for seismic design, the Direct displacement-based design method came as an efficient alternative method. DDBD method is developed from performance-based design philosophy and displacement-based design by Priestley et al., this method provides a more effective implementation of the displacement-based design.

In this DDBD method, Displacement spectra are used instead of acceleration spectra, and the displacement profile of the building is determined through which viscous damping, time period, and stiffness of structure are determined, and then base shear is found out and is distributed to each floor level in proportion to floor mass and floor displacement. In this method, initially, inelastic displacement profile is found out for MDOF frame structure then an equivalent SDOF system is established through which the stiffness and lateral seismic force in design-level can be determined.

Up to now, much researches have been done suggesting DDBD. DDBD methods are developed for Frame buildings Structural wall buildings, Dual wall-frame Buildings, masonry buildings, timber structures, Bridges, and structures with isolation by Priestley and co-workers. In the DDBD method, elastic properties such as initial stiffness, time period, and strength of the structure are determined unlike FBD, where it assumes those parameters. Comparative performance evaluation is made using non-linear analysis on low and medium-rise fixed-base buildings using FBD and DDBD method and evaluation is done for structural performances like base shear, maximum displacement, and inter-storey drift ratio (IDR%) and concluded that DDBD is more effective than FBD method (Sharma et al., 2020.) DDBD method is also implemented for buildings with different isolation systems considering different idealized force-displacement cyclic behaviour which describes the response behaviour of different isolator systems such as i) Lead rubber bearings (LRB,) ii) High damping rubber bearing (HDRB,) iii) Friction pendulum systems (FPS,) iv) Combinations of lubricated flat sliding bearings (FSB) with different recentering and/or dissipating auxiliary devices. The design procedure is proposed with different isolators and results are validated using non-linear time history analysis on different configurations of base-isolated buildings (Cardone et al., 2010.)

In this paper, Lead rubber bearings are used for base isolators and properties of lead rubber bearings are determined using both the DDBD method proposed by Cardone (Cardone et al., 2010) and UBC – 97. Two different base isolators are used and designed G+3 and G+5 base-isolated buildings using FBD and DDBD methods and Nonlinear pushover analysis is carried out and parameters such as base shear and inter-storey drift ratio (IDR%) are determined and compared.

DDBD PROCEDURE OF LEAD RUBBER BEARING BASE-ISOLATED BUILDINGS

The aim of DDBD is to get structure to respond to excitation or earthquake according to target displacement profile

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consistent with the reference response spectrum. Fig 1 shows the fundamental steps involved in procedure of DDBD for base isolated buildings. Fig 1a shows the target displacement profile defined for the base isolated frame buildings compacted with design of the structure. In this method non-linear MDOF is converted into linear SDOF system as shown in Fig 1a, from which the equivalent stiffness K_{eq} and equivalent viscous damping ξ_{eq} will be found out at peak displacement response of the building in Fig 1b. Equivalent viscous damping is the combination of superstructure and damping of isolation system. A displacement spectrum is used to find out equivalent time period T_{eq} corresponding to design displacement Δ_d in Fig 1c. Finally base shear is calculated by the product of equivalent stiffness and design displacement and distributed to the MDOF structure as shown in Fig 1d.

The design displacement of the equivalent SDOF system Δ_d is computed using displacement profile from following equation (Priestley, 2003):

$$\Delta_d = \frac{\sum_{i=0}^{n}(m_i \cdot \Delta_i^2)}{\sum_{i=0}^{n}(m_i \cdot \Delta_i)}, \qquad (1)$$

The equivalent time period of the building is found out using Fig 1c and used to calculate equivalent stiffness. The equivalent stiffness of the SDOF system (K_{eq}) is calculated using below formula:

$$K_{eq} = 4\pi^2 \cdot m_e / T_{eq}^2, \qquad (2)$$

The effective mass of converted SDOF system (m_e) is calculated from derived displacement profile using below equation (Priestley, 2003):

$$m_e = \frac{\sum_{i=0}^{n}(m_i \cdot \Delta_i)}{\Delta_d}, \qquad (3)$$

Finally, the design base shear is computed using the product of equivalent stiffness and design displacement and distributed to each floor level in proportion to masses and displacements (see Fig 1d) as given below:

$$V_b = K_{eq} \cdot \Delta_d \qquad (4)$$

$$F_i = V_b \cdot \frac{m_i \cdot \Delta_i}{\sum_{i=0}^{n}(m_i \cdot \Delta_i)}. \qquad (5)$$

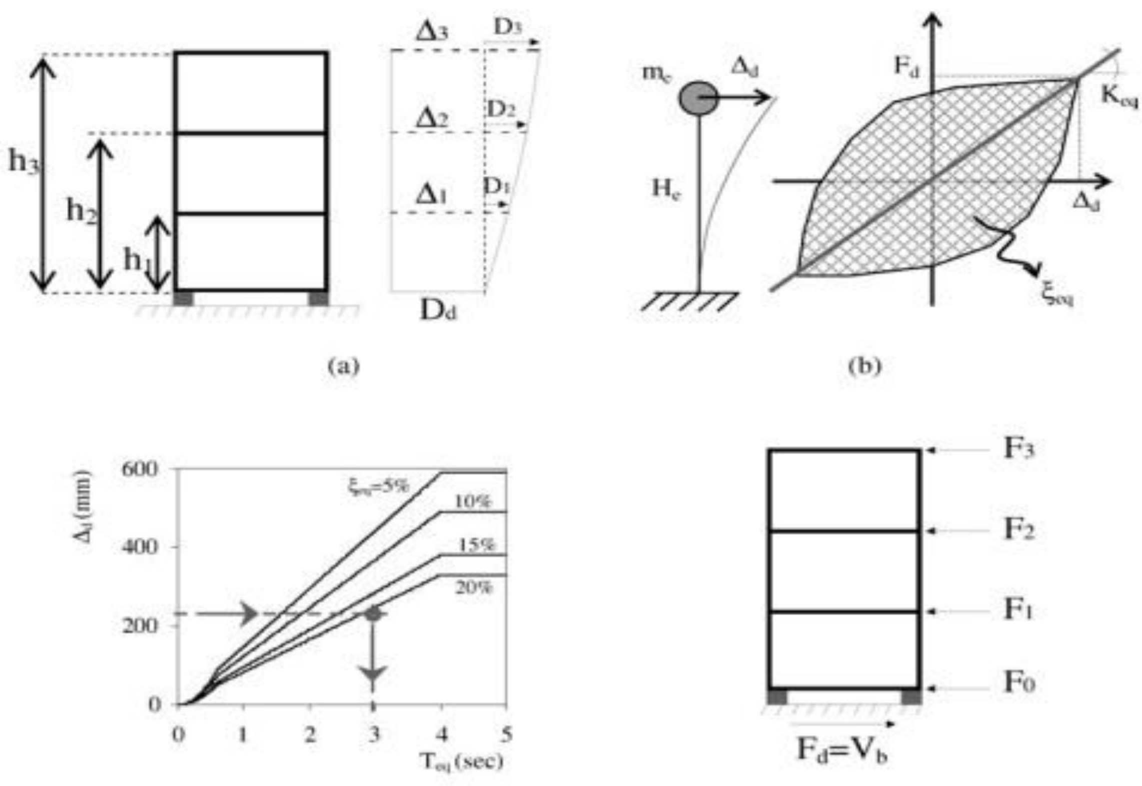

Fig. 1 Fundamental steps of DDBD for base isolated buildings (Cardone et al., 2010.)

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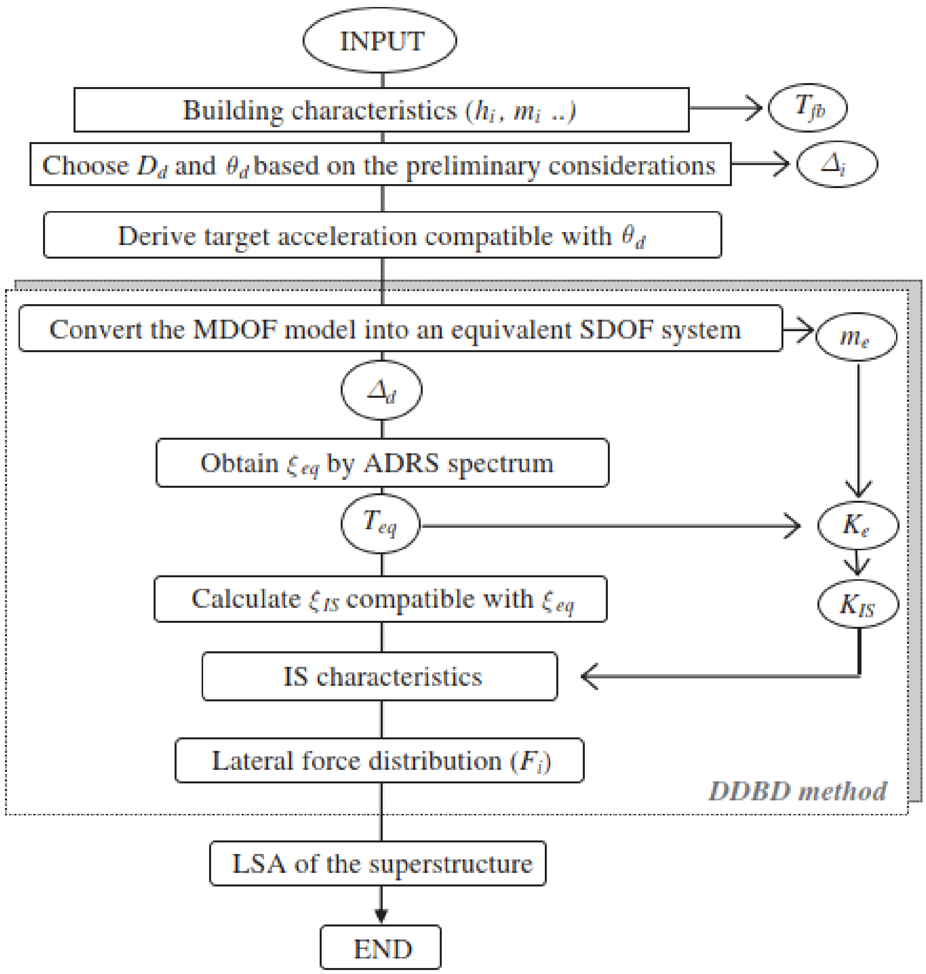

Fig. 2 Flowchart of the proposed DDBD procedure for base-isolated buildings (Cardone et al., 2010)

The seismic performances of the base isolated buildings are determined by choosing appropriate base displacement (D_d) and maximum inter-storey drift (θ_d). The design displacements typically vary in the range of 120 -350 mm and maximum inter-storey drift vary 0.2%-0.5% according to the SEAOC (1995) Vision 2000 document in order to protect non-structural elements. The lead plug of LRB as initial shear modulus of approximately 130MPa and yield strain of 7.7% approximately (Kelly, 2001). The yield displacement (D_y) is equal to 7.7% times height of the isolator which typically vary in range of 100 to 350 mm. Post yield stiffness is expected to be in range of 5-15% and corresponding rubber shear strains and lead ductility ratios of 100-120% and 10-20. For above ranges the damping ratios varies from 15-20%. (Cardone et al., 2010). In the procedure proposed by Cardone and co-workers a concave deformed shape of the superstructure is considered as shown in Fig 1a.

$$\Phi_i=\cos[(\frac{1}{I_r})\times(1-\frac{h_i}{H})\times\frac{\pi}{2}]-\cos[(\frac{1}{I_r})\times\frac{\pi}{2}], \qquad (6)$$

Where h_i is height of i^{th} storey, H represents total height of the building, and I_r is the ratio of effective time period of base isolated building to fundamental time period of fixed base. At this moment the effective time period of the isolated building is unknown and after some iterations the I_r value is found and Cardone has given the final iterated values (Cardone et al., 2010). Maximum inter-storey drift will come at the first storey and it is analytically shown as:

$$\theta_d(\%)=100\cdot D_1/h_1. \qquad (7)$$

The target displacement profile of the base isolated building as shown in Fig 1a is given by:

$$\Delta_i=D_d+\theta_d\cdot c_1\cdot\Phi_i. \qquad (8)$$

Where,

$$c_1=h_1/(100\cdot\Phi_1) \qquad (9)$$

Both the fixed base and base isolated buildings has same design acceleration irrespective of their two different design displacements, corresponding to selected drift limit θ_d in the superstructure as shown in left side graph of Fig 3 and is given by below analytical expression:

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$$S_{ad} = \theta_d \cdot c_1 \cdot [\sum_{i=0}^{n} (m_i \cdot \Phi_i^2) / \sum_{i=0}^{n} (m_i \cdot \Phi_i)] \cdot (m_1 / m_e^{'}) \cdot (2\pi / T_{fb})^2 = \Omega \cdot \theta_d, \quad (10)$$

Where $m_e^{'}$ is the effective mass from equation 3 assuming D_d as zero and I_r as actual ratio of time period of base isolation to fixed base and m_1 is calculated using D_d as 0 and I_r as 1.

The time period of fixed base T_{fb} is given by following equation taken from EC8 (CEB, 2004):

$$T_{fb} = C_t \cdot H^{3/4} \quad (11)$$

Where C_t for RC frame buildings is given as 0.075. From T_{fb}, the stiffness of fixed base can be calculated by using:

$$K_{fb} = m_1 \cdot (2\pi / T_{fb})^2, \quad (12)$$

In terms of yield drift θ_y, Priestley (2003) suggested a semi-empirical relationship for reinforced concrete frames:

$$\theta_y = 0.5\varepsilon_y l_b / h_b, \quad (13)$$

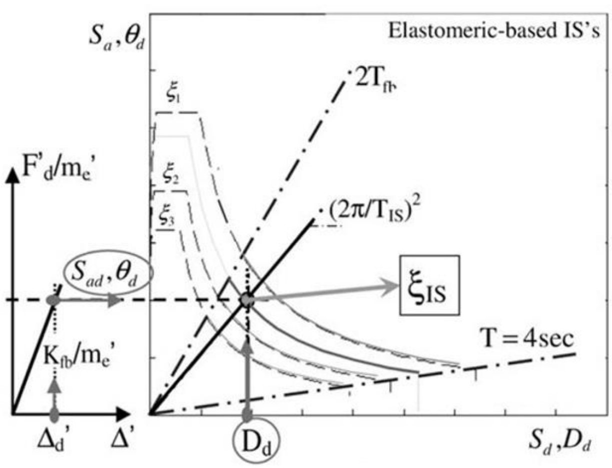

Fig. 3 Preliminary design of elastomeric-based isolation system. (Cardone et al., 2010)

Where, ε_y is the yield strain, l_b is the beam span in meters and h_b is the beam depth in millimetre. The demand ductility (μ_d) is the ratio of design drift (θ_d) to yield drift (θ_y) and should vary in between 1.5 to 2.5 for damage-control limit state of RC frame buildings.

The equivalent damping ratio is calculated by combining the effects of damping ratio of super structure from SDOF (ξ_s) system and damping ratio of base isolation (ξ_{IS}). The damping ratio of super structure can be adopted as 5% assuming the superstructure respond with in its elastic limit range.

$$\xi_{eq} = [\xi_{IS} \cdot D_d + \xi_S \cdot (\Delta_d - D_d)] / \Delta_d. \quad (14)$$

From Fig. 3 by interpolation S_{ad} and D_d the damping ratio of isolation system from the Acceleration Displacement Response Spectrum (ADRS) can be found out and the slope between the point of intersection and origin will give the time period of the isolated system.

Once we get equivalent damping ratio (ξ_{eq}), the time period of the base isolated building can be found out using displacement response spectrum as shown in Fig 1c and then the equivalent stiffness of the base isolated building is calculated using equation 2. Through which the base shear can be calculated using equation 4 and distributed among floor levels using equation 6. Finally, at the target displacement Dd, the effective stiffness of the isolation device is calculated as:

$$K_{IS} = V_b / D_d. \quad (15)$$

The isolation system is modelled using its efficient stiffness K_{IS} at the target displacement in a Linear Static Analysis of the building. The design strengths of structural members are allocated based on the results of the Linear Static Analysis, in accordance with the seismic code criteria for base isolated buildings and then performance-based design is carried out by performing nonlinear pushover analysis.

The Design And Characteristics Of LRB's:

The design and characteristics of Lead Rubber Bearing's (LRBs) are determined separately for Force-based design (FBD) models and for Direct displacement-based design (DDBD) models. The characteristics of LRBs for DDBD models are found out using the procedure given by Cardone et al., 2010. The LRB properities for FBD models are calculated and determined according to the UBC – 97. Lead rubber bearing proprieties of G+3 and G+5 base isolated buildings has been done according to UBC – 97:

TABLE I Results of Lead Rubber Bearing Isolator Design For G+3 Building Obtained From DDBD Approach.

Characteristics	G+3 DDBD
Time period of isolator	2.09
Design Displacement, $D_d(m)$	0.25
Damping of isolator, ξ_{IS}	20%
Stiffness of isolator $K_{IS}(kN/m)$	2555
Post yield stiffness ratio, n	0.1

TABLE II Results of Lead Rubber Bearing Isolator Design For G+5 Building Obtained From DDBD Approach.

Characteristics	G+5 DDBD
Time period of isolator	2.5
Design Displacement, $D_d(m)$	0.3
Damping of isolator, ξ_{IS}	19.40%
Stiffness of isolator $K_{IS}(kN/m)$	2205
Post yield stiffness ratio, n	0.1

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TABLE III RESULTS OF LEAD RUBBER BEARING ISOLATOR DESIGN FOR G+3 BUILDING OBTAINED FROM UBC – 97.

Characteristics	G+3 FBD
Max Vertical Load, (kN)	750
Shear Modulus, G (kN/m^2)	700
Design Time Period, T_D (sec)	2.5
Seismic Zone Factor, Z	0.36
Effective damping	20%
Damping Coefficient (β_d)	1.5
Design Displacement, D_d (m)	0.17
Bearing effective stiffness, $K_{eff}(kN/m^2)$	482.43
Energy Dissipated per cycle, $W_D(kN-m)$	16.66
Characteristic strength, Q (kN)	25.12
Pre yield in rubber, $K_2(kN/m)$	381.95
Post yield stiffness ratio, n	0.10
Post yield stiffness, $K_1(kN/m)$	3819.47
Yield Displacement, $D_y(m)$	0.01
Recalculation of force Q to Q_r	26.28
Yield strength of lead, MPa	10.00
Area of plug required, A (m^2)	0.00
Diameter of plug, d (m)	0.06
Recalculation of Rubber stiffness K_{effr}	323.96
Max Shear Strain of rubber	1.00
Total thickness of Rubber, $t_r(m)$	0.17
Area of bearing, $A_{LRB}(m^2)$	0.00
Diameter of bearing, $D_{LRB}(m)$	0.01
Yield Strength, F_y	27.91

TABLE IV RESULTS OF LEAD RUBBER BEARING ISOLATOR DESIGN FOR G+5 BUILDING OBTAINED FROM UBC – 97.

Characteristics	G+5 FBD
Max Vertical Load, (kN)	900
Shear Modulus, G (kN/m^2)	700
Design Time Period, T_D (sec)	2.5
Seismic Zone Factor, Z	0.36
Effective damping	20%
Damping Coefficient (β_d)	1.5
Design Displacement, D_d (m)	0.17
Bearing effective stiffness, $K_{eff}(kN/m^2)$	578.91
Energy Dissipated per cycle, $W_D(kN-m)$	19.99
Characteristic strength, Q (kN)	30.14
Pre yield in rubber, $K_2(kN/m)$	458.34
Post yield stiffness ratio, n	0.10
Post yield stiffness, $K_1(kN/m)$	4583.36
Yield Displacement, $D_y(m)$	0.01
Recalculation of force Q to Q_r	31.53
Yield strength of lead, MPa	10.00
Area of plug required, A (m^2)	0.00
Diameter of plug, d (m)	0.06
Recalculation of Rubber stiffness K_{effr}	388.75
Max Shear Strain of rubber	1.00
Total thickness of Rubber, $t_r(m)$	0.17
Area of bearing, $A_{LRB}(m^2)$	0.00
Diameter of bearing, $D_{LRB}(m)$	0.01
Yield Strength, F_y	33.49

MODELLING AND ANALYSIS

Plans of G+3 and G+5 buildings are same 3 spans in x and y directions with span length of 5m and 3m respectively as shown in Figure 4.

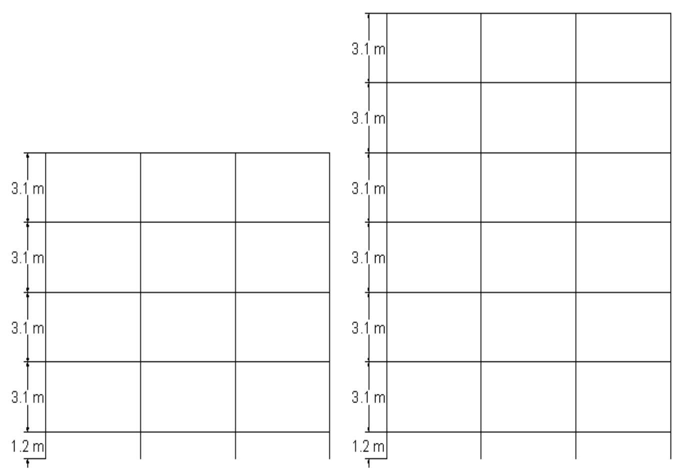

Fig 4 (a) Elevation view of G+3 and G+5 building frame.

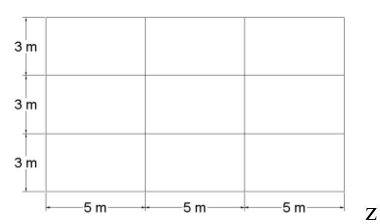

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Fig 4 (b) Plan view of G+3 and G+5 buildings

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TABLE V DIMENSIONS OF COLUMNS AND BEAMS CONSIDERED.

Members	FBD G+3	DDBD G+3	FBD G+5	DDBD G+5
Column (m)	0.5×0.5	0.35×0.35	0.55×0.55	0.45×0.45
Beam (m)	0.3×0.45	0.3×0.45	0.4×0.5	0.4×0.5

For DDBD model's column dimensions are determined taking 0.25% drift ratio into consideration and for FBD models the column dimensions are assigned according to IS 456:2000. The dimensions of members and data of structure are shown in table V and table VI:

TABLE VI DATA OF THE STRUCTURE.

Data of structure	
Grade of Concrete	M 20
Grade of Steel	Fe 415
Height of storey	3.1 m
Dead load	Self
Imposed load on floors	4.5 kN/m^2
Imposed load on roof	2.25 kN/m^2
Slab thickness	0.15 m
Seismic Zone	V
Response reduction factor	5
Importance factor	1
Site type	II

All buildings are designed according Indian Standards – IS 456:2000 for all RC frame members and seismic design is done according to IS 1893:2016. Considered 50% of Live loads at floor, 25% of Live load at roof level and total Dead load and seismic for seismic design.

RESULTS AND DISCUSSIONS

Design drift ratio of 0.25% is taken for base-isolated buildings and the results of G+3 and G+5 LRB base isolated buildings from DDBD approach are stated in table VII and table VIII respectively. The column dimensions are determined through effective stiffness values obtained from DDBD approach. Non-linear pushover analysis is performed for DDBD and FBD models and capacity curves are compared along with inter-storey drift ratios.

The capacity curves obtained from non-linear pushover analysis (NLPA) using SAP2000 are compared and observed that the base shear is comparatively less for DDBD models in both G+3 and G+5 LRB base isolated buildings in figures 6 and 7 shown below. The inter-storey drift ratios obtained non-linear pushover analysis using SAP2000 are compared and observed that the drift ratios are comparatively less for DDBD models in both G+3 and G+5 LRB base isolated buildings in figures 8 and 9 shown below. Details of hinge formations achieved from non-linear pushover analysis for G+3 and G+5 of DDBD and FBD models are tabulated in tables IX, X, XI, XII. Figure 4 represents plastic hinge model as per FEMA 356 (2000),

TABLE VII RESULTS OF G+3 LRB BASE-ISOLATED BUILDING OBTAINED FROM DDBD APPROACH.

G+3 LRB	X – Direction	Y - Direction
Design displacement $\Delta_d (m)$	0.358	0.358
Effective height $H_e (m)$	9.54	9.54
Equivalent mass $m_e (kg)$	578000	578000
Isolated system damping $\xi_{IS} (\%)$	20	20
Isolated system stiffness $K_{IS} (kN/m)$	2416	2416
Ductility μ	2.25	3.75
Effective period T_{eff} (sec)	3.9	3.9
Equivalent viscous damping $\xi_{eq} (\%)$	14.77	14.79
Effective stiffness $K_{eff} (kN/m)$	1523	1523
Base shear force $V_b (kN)$	484	484

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TABLE VIII RESULTS OF G+3 LRB BASE-ISOLATED BUILDING OBTAINED FROM DDBD APPROACH.

G+5 LRB	X – Direction	Y - Direction
Design displacement $\Delta_d(m)$	0.533	0.533
Effective height $H_e(m)$	13.77	13.77
Equivalent mass $m_e(kg)$	780000	780000
Isolated system damping $\xi_{IS}(\%)$	19.4	19.4
Isolated system stiffness $K_{IS}(kN/m)$	2119	2191
Ductility μ	2.5	4.16
Effective period T_{eff} (sec)	5	5
Equivalent viscous damping $\xi_{eq}(\%)$	13.04	13.04
Effective stiffness $K_{eff}(kN/m)$	1232	1232
Base shear force $V_b(kN)$	657	657

where points A, B, C, D and E are points representing hinge points in force displacement graph and YP, IO, LS and CP represent Yield Point, Immediate Occupancy, Life Safety and Collapse Prevention respectively.

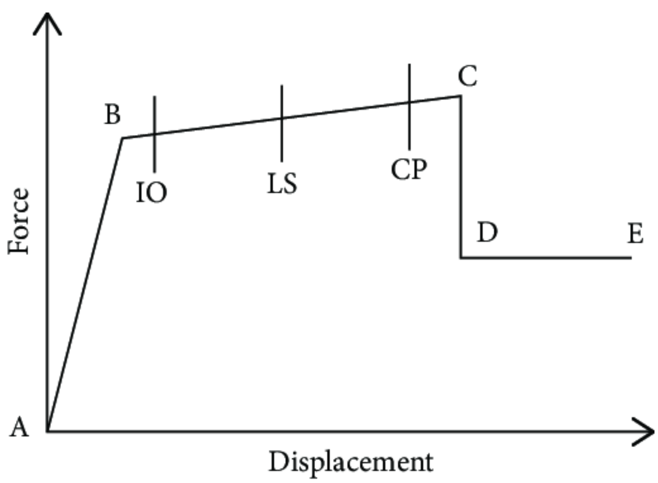

Fig. 5 Force versus Displacement plastic hinge model (FEMA 2000.)

Acceptable performance levels, damage states, and drift limitations for columns and beams of a RC frame buildings according to FEMA 356 is given in table IX.

TABLE IX ACCEPTABLE PERFORMANCE LEVELS, DAMAGE STATES, AND DRIFT LIMITATIONS (Sharma et al., 2020.)

Performance Levels	Damage state	Drift limitations
Immediate occupancy (IO)	No damage	1%
Life safety (LS)	Repair damage	2 – 2.5%
Collapse prevention (CP)	Severe damage	>2.5%

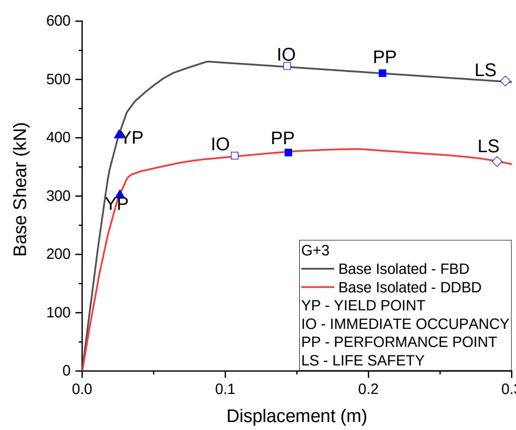

Fig. 6 Comparison of DDBD and FBD G+3 LRB base isolated building's Base Shear (kN) versus Displacement (m) graph.

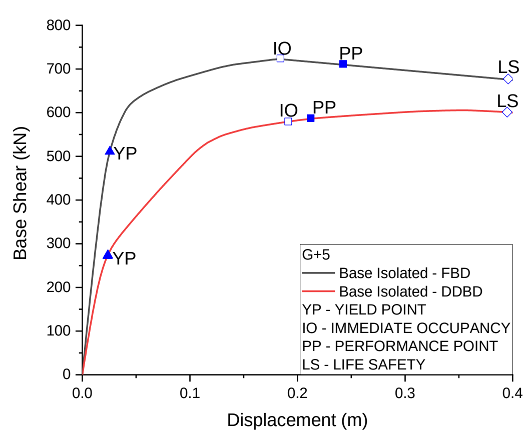

Fig. 7 Comparison of DDBD and FBD G+5 LRB base isolated building's Base Shear (kN) versus Displacement (m) graph.

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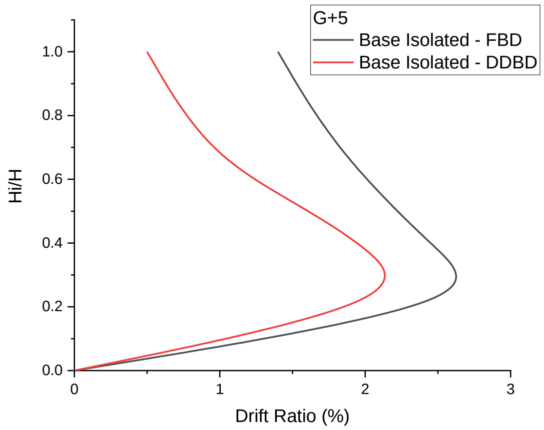

Fig. 9 Comparison of DDBD and FBD G+5 LRB base isolated building's Drift ratio.

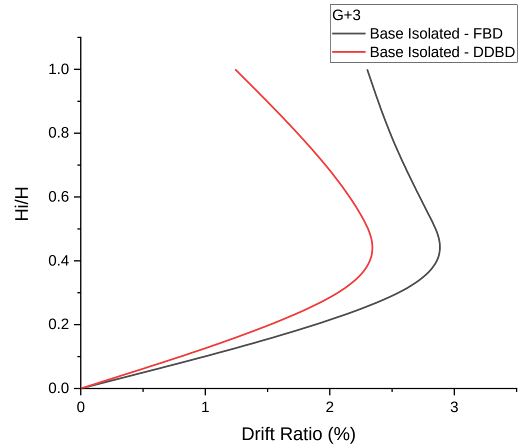

Fig. 8 Comparison of DDBD and FBD G+3 LRB base isolated building's Drift ratio.

Performance point is the point at which the reduced response spectrum intersects capacity spectrum, it can also be said as it is a point at which capacity is equal as demand.

It is observed that performance points in DDBD models are comparatively earlier than FBD models, stating that demand is reduced in DDBD models.

TABLE IX DETAILS OF HINGE FORMATIONS OBTAINED FROM NLPA ON G+3 LRB – DDBD MODEL.

G+3 LRB - DDBD	A	YP	I0 START	PP	END OF IO – LS
Displacement(m)	0.005	0.025	0.1	0.144	0.29
Base Shear (kN)	75	298	367	364	368
A – B	398	298	298	294	280
B – IO	-	102	96	58	24
IO – LS	-	-	6	48	87
Total Steps	400	400	400	400	400

TABLE X DETAILS OF HINGE FORMATIONS OBTAINED FROM NLPA ON G+3 LRB – FBD MODEL

G+3 LRB - FBD	A	YP	I0 START	PP	END OF IO – LS
Displacement(m)	0.016	0.025	0.1	0.21	0.3
Base Shear (kN)	303	402	522	517	490
A – B	393	360	280	280	280
B – IO	-	102	114	84	37
IO – LS	-	-	6	36	120
Total Steps	400	400	400	400	400

TABLE XI DETAILS OF HINGE FORMATIONS OBTAINED FROM NLPA ON G+5 LRB – DDBD MODEL

G+5 LRB – DDBD	A	YP	I0 START	PP	END OF IO – LS
Displacement(m)	0.005	0.025	0.18	0.21	0.4
Base Shear (kN)	84	293	574	585	595.4
A – B	560	560	449	438	371
B – IO	-	3	111	121	93
IO – LS	-	-	4	22	96
Total Steps	560	560	560	560	560

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TABLE XII DETAILS OF HINGE FORMATIONS OBTAINED FROM NLPA ON G+5 LRB – FBD MODEL

G+5 LRB - FBD	A	YP	I0 START	PP	END OF IO – LS
Displacement (m)	0.01	0.03	0.17	0.24	0.4
Base Shear (kN)	246	555	720	710	674
A – B	560	509	404	392	392
B – IO	-	51	150	96	57
IO – LS	-	-	6	72	168
Total Steps	560	560	560	560	560

CONCLUSIONS

The performance of G+3 and G+5 lead rubber bearing base isolated buildings of both FBD models and DDBD models are conducted and following comparisons are made.

- ✓ In DDBD method, as it is shown in the study the effective stiffness of the building is determined for DDBD models and thus column sizes are adopted appropriately with surety. Because of this accuracy the column sizes can be adopted more wisely when compared to FBD method.
- ✓ Base shear in DDBD models from the capacity curve is comparatively less in both 4 storey and 6 storey buildings, resulting in lesser stiffness thus the column member sizes can be reduced and cost and material of the construction can be saved.
- ✓ Inter-storey Drift ratios of DDBD models are comparatively lesser for both 4 storey and 6 storey LRB base isolated buildings and drift ratios are within the limit drift of 2.5% by which we can say that DDBD models are safer comparatively.
- ✓ Performance points in DDBD models are comparatively lesser in both 4 storey and 6 storey buildings, thus resulting reduction in demand. Since demand is reduced in DDBD models, it can be said that it provides good stability of the building in DDBD when compared to FBD.

REFERENCES

[1] Calvi, G.M., Priestley, M.J.N. and Kowalsky, M.J., 2007. Displacement based seismic design of structures. In *New Zealand Conference on Earthquake Engineering* (p. 740). IUSS press.

[2] Cardone, D., Dolce, M. and Palermo, G., 2008, October. Force-based vs. direct displacement-based design of buildings with seismic isolation. In *The 14th World Conference on Earthquake Engineering* (Vol. 1).

[3] Cardone, D., Palermo, G. and Dolce, M., 2010. Direct displacement-based design of buildings with different seismic isolation systems. *Journal of Earthquake Engineering*, *14*(2), pp.163-191.

[4] Code, P., 2005. Eurocode 8: Design of structures for earthquake resistance-part 1: general rules, seismic actions and rules for buildings. *Brussels: European Committee for Standardization*.

[5] FEMA, F., 2006. 445. Next-Generation Performance-Based Seismic Design Guidelines Program Plan for New and Existing Buildings. *Redwood City*.

[6] FEMA, N., 2000. *NEHRP, Prestandard and commentary for the seismic rehabilitation of buildings* (No. 356). Report.

[7] Kelly, T.E., 2001. “Base isolation of structures: Design guidelines.” Auckland: Holmes Consulting Group Ltd.

[8] Lashgari, M., 2014. Comparative study of base-isolated and fixed-base buildings using a damage/cost approach.

[9] Mondal, G. and Jain, S.K., 2005. Design of non-structural elements for buildings: A review of codal provisions. *Indian concrete journal*, *79*(8), pp.22-28.

[10] Pettinga, J.D. and Priestley, M.N., 2005. Dynamic behaviour of reinforced concrete frames designed with direct displacement-based design. *Journal of Earthquake Engineering*, *9*(spec02), pp.309-330.

[11] Priyanka, B. and Mayur, B., Analysis and Capacity Based Earthquake Resistance Design of Multy Bay Multy Storeyed Residential Building. *Int. Journal of Engineering Research and Applications www. ijera. com ISSN: 2248*, *9622*, pp.78-84.

[12] Seismic Safety Council IS:1893-Part 1, 2016. Criteria for earthquake resistant design of structures, part-1 general provisions and building sixth revision. *New Delhi: Bureau of Indian standards*.

[13] Sharma, A., Tripathi, R.K. and Bhat, G., 2020. Comparative performance evaluation of RC frame structures using direct displacement-based design method and force-based design method. *Asian Journal of Civil Engineering*, *21*(3), pp.381-394.

[14] Sharma, A., Tripathi, R.K. and Bhat, G., 2020. Seismic assessment of RC building frames using direct-displacement-based and force-based approaches. *Innovative Infrastructure Solutions*, *5*(3), pp.1-12.

[15] Vidot-Vega, A.L. and Kowalsky, M.J., 2013. Drift, strain limits and ductility demands for RC moment frames designed with displacement-based and force-based design methods. *Engineering structures*, *51*, pp.128-140.

[16] Yan, L. and Gong, J., 2019. Development of displacement profiles for direct displacement based seismic design of regular reinforced concrete frame structures. *Engineering Structures*, *190*, pp.223-237.

[17] Ye, K., Xiao, Y. and Hu, L., 2019. A direct displacement-based design procedure for base-isolated building structures with lead rubber bearings (LRBs). *Engineering Structures*, *197*, p.109402.

[18] Zameeruddin, M. and Sangle, K.K., 2016, May. Review on Recent developments in the performance-based seismic design of reinforced concrete structures. In *Structures* (Vol. 6, pp. 119-133). Elsevier.