"A STUDY ON SEISMIC BEHAVIOUR OF BUILDING USING DIRECT DISPLACEMENT BASED DESIGN"

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Abstract:-

Earthquake-resistant design is essential for ensuring the safety and performance of reinforced concrete (RC) buildings under seismic loading. This study presents a comparative evaluation of the conventional Force-Based Design (FBD) approach and the Direct Displacement-Based Design (DDBD) methodology for multi-storey RC buildings. The structural models are analyzed using the Response Spectrum Method in ETABS software for different seismic zones in accordance with relevant Indian Standard codes. Key seismic performance parameters, including storey displacement, storey shear, and overturning moment, are evaluated to assess the effectiveness of each design approach. The study also demonstrates the application of an Excel-based DDBD tool to simplify displacement-based design calculations and improve design efficiency. The results indicate that DDBD provides better control over structural displacements, more realistic prediction of seismic behavior, and enhanced overall structural performance compared with the conventional force-based method, making it a reliable and effective approach for the seismic design of earthquake-resistant buildings.

Keywords: Seismic Analysis, Direct Displacement-Based Design (DDBD), Force-Based Design (FBD), Response Spectrum Method, Lead Rubber Bearings (LRB), Multi-story Buildings, Comparative Analysis

INTRODUCTION

The design of buildings with increased resistance to the effects of earthquakes is a major concern in many countries. A properly selected seismic design can reduce the number of casualties, as well as the negative economic consequences associated with the destruction of buildings and structures. Today, researchers have developed several seismic design approaches that allow constructing buildings able to withstand the effects of earthquakes. These approaches are based on different principles and provide a more significant increase in the seismic resistance of buildings compared to traditional methods. The traditional method of seismic design, accepted and supported by most regulatory documents, is based on the force-based design (FBD) philosophy that implies designing structures based on expected forces caused by earthquakes. This approach allows increasing the resistance of buildings to destruction by lateral forces. However, the FBD philosophy has proved to be incomplete and ineffective since, during an earthquake, displacements of structures exceeding acceptable limits can occur. This is especially true for buildings with flexible structures that can vibrate significantly.

The main reason for this phenomenon is that most design standards are based on the force-displacement relationship in structures and do not consider the effect of displacements on the damageability of structures. A promising direction in the seismic design of buildings is represented by the direct displacement-based design (DDBD). Unlike the FBD philosophy, DDBD allows estimating the seismic response of structures based on displacements for a given level of deformation. For example, using the proposed approach, it is possible to estimate the required lateral stiffness, strength, and damping characteristics of the building for target displacements compatible with the planned performance of structures during an earthquake. This allows the designing structure that will be able to withstand seismic loads with minimal damage. The DDBD method has several obvious advantages and disadvantages. The use of this approach makes it possible to construct buildings with excellent energy dissipation characteristics, resistant to the effects of earthquakes. At the same time, the design of buildings using the

DDBD method allows the designer to clearly define the target displacement for the given type of structure. In addition, the direct implementation of this method makes it possible to quickly estimate building performance under the action of seismic waves during an earthquake. However, the described method still seems complicated for application in practice and is not popular among designers due to complex calculations and the need for additional training. Based on the obvious advantages of the DDBD method, this study was aimed at analyzing the use of the direct displacement-based design (DDBD) for seismic analysis and design of buildings. To achieve the goal, the paper examines the characteristics of DDBD structures and evaluates their seismic performance. A comparative analysis of the structural behavior of a building designed on the basis of DDBD was performed within the framework of an example. Moreover, the benefits and limitations of the direct displacement-based design, as well as its potential applications, were discussed.

The results obtained allow concluding on the prospects of using direct displacement-based design in seismic analysis and design of buildings. Thus, based on the analysis of the structural behavior during an earthquake, the target displacement as the key factor in seismic design was highlighted. In addition, the advantages of this approach were confirmed, including the possibility of developing a design with high seismic performance and predictable behavior during an earthquake. Further research should be devoted to examining the DDBD applicability for other structure types.

AIM AND OBJECTIVES

The specific objectives of the research are as follows:

- To assess the seismic response of reinforced cement concrete (RCC) multistoried frame buildings of varying heights and situated in Seismic Zones III, IV, and V using the Direct Displacement-Based Design (DDBD) method.
- To compare the seismic response of structures designed using the DDBD and Force-Based Design (FBD) approach, in terms of storey shear and storey overturning moment.
- To present a design tool that can be used in Excel to design multistoried buildings using the Direct Displacement-Based Method and prove how it can make designing easier and faster.

LITERATURES REVIEW

Murota et al. [1] evaluated high-damping rubber bearings (HDRBs) for seismic isolation in Turkish residential buildings. They employed numerical modeling and experimental testing to assess HDRB performance, focusing on key parameters like displacement, acceleration, and inter-story drift. The study confirms HDRBs' effectiveness in reducing seismic response, aligning with Turkish building seismic code requirements. This research offers vital insights into seismic-resistant design strategies for Turkish residential structures.

Zhang and Ali [2] explored seismic isolation and energy dissipation using friction-based systems. They emphasized the effectiveness of friction devices in controlling structural vibrations during earthquakes. The study covered friction base isolation and smart systems with adaptive controls, showcasing their simplicity and cost-effectiveness. The paper presented experimental results and case studies, highlighting the potential of friction-based strategies for seismic protection.

Talaeitaba et al. [3] studied a base isolation system for low-rise buildings, emphasizing its seismic resilience benefits. They combined experimental tests and numerical analysis to demonstrate the system's effectiveness in reducing seismic forces. The study highlighted its simplicity, cost-efficiency, and improved damping compared to traditional methods. Practical recommendations for real-world applications are provided, offering valuable solutions for low-rise building safety during earthquakes.

Lin et al. [4] introduced a smart base isolation system that combines earthquake early warning (EEW) technology with traditional methods. The system dynamically adjusts base isolation devices based on real-time EEW data to improve structural performance during earthquakes. Through a case study, the paper demonstrated significant enhancements in seismic safety. The integration of EEW technology offers a promising avenue for strengthening structural resilience.

Bhandari [5] presented an enhanced pushover analysis method for predicting inelastic responses in base-isolated building frames. This paper highlighted the importance of precise assessment in earthquake-resistant design and offers an efficient tool for capturing both isolator and frame behavior. The proposed procedure ensures accurate evaluation and enhanced seismic resilience in base-isolated structures.

Zhang and Li [6] investigated the use of base isolation to enhance the seismic resilience of damaged precast shear wall structures. Their experimental study confirmed that base isolation effectively reduces damage, inter-story drift, and accelerations in these structures. This research has practical implications for retrofitting and strengthening precast concrete buildings, improving their seismic performance.

Tesfamariam et al. [7] explored seismic risk assessment for hybrid reinforced concrete (RC)-timber structures, combining sustainability and innovation. They propose a displacement-based design (DBD) method with specific fragility curves and performance criteria. A case study validates its efficacy, offering practical tools for evaluating seismic safety in these structures. The study contributes to seismic risk understanding in hybrid RC-timber systems and suggests future research directions.

Heerema et al. [8] focused on quantifying seismic design parameters for asymmetrical reinforced concrete masonry buildings. They emphasized the importance of system-level performance and proposed a methodology using experimental data. The research contributes to seismic design understanding, offering practical insights for engineers and future design guidelines, ultimately enhancing structural safety in seismic regions.

Khan et al. [9] focused on DDBD for seismic design of reinforced concrete arch bridges. They stressed the importance of considering actual displacement response in design and propose a comprehensive methodology. The study enhances understanding and provides a rational framework for engineers to ensure structural safety in seismic regions. Future research should refine guidelines, explore arch geometries, and investigate multi-hazard scenarios.

Deng et al. [10] focused on seismic design using displacement-based methodology for rocking shallow foundations in bridge structures. This rational approach considered foundation–soil structure interaction and displacement response as design parameters. The research offered energy dissipation and reduced seismic forces as potential benefits. A detailed methodology is presented, with case studies demonstrating its effectiveness. This work enhances foundation resilience and seismic performance in bridge applications, emphasizing the role of damping mechanisms for improved performance.

SYSTEM DEVELOPMENT

In this research, the seismic behavior of reinforced cement concrete (RCC) multi-story frame buildings of different heights has been studied using direct displacement-based design (DDBD) with response spectrum method as per IS 1893 (Part 1): 2016. The study includes buildings situated in different seismic zones like Zone III, IV, and V. ETABS has been used for modeling of structures having 3.2 m height of each story. The size of each structural member has been selected as per design requirement to meet out the Indian Standards.

The research consists of three different seismic design methods like force-based design (FBD), direct displacement-based design (DDBD), and seismic isolation with lead rubber bearings (LRB). The FBD analysis has been done as per IS 456:2000 and IS 1893 (Part 1): 2016 whereas, DDBD has been done as per suggestions of Priestley et al. And other researchers. The response of the designed structure has been checked in terms of story displacement, story drift, story shear, base shear, and overturning moment.

In order to check the accuracy of proposed excel sheet for DDBD design of buildings, G+2, G+4, G+6, G+8, G+10, G+12, and G+14 buildings have been analyzed. The excel sheet has been prepared to reduce calculation efforts for DDBD analysis. In this study, G+14 (having 15 stories) has been taken for explanation purpose. The design inputs, calculation done in excel sheets, and their outputs have been shown in Table 1, 2, and 3 respectively while comparison of results, structural configuration, and other details have been presented in Figure 1, 2 and 3. The outcomes of this study concluded that excel-based displacement-based design is appropriate for the seismic analysis and design of multi-story buildings constructed with reinforced cement concrete (RCC).

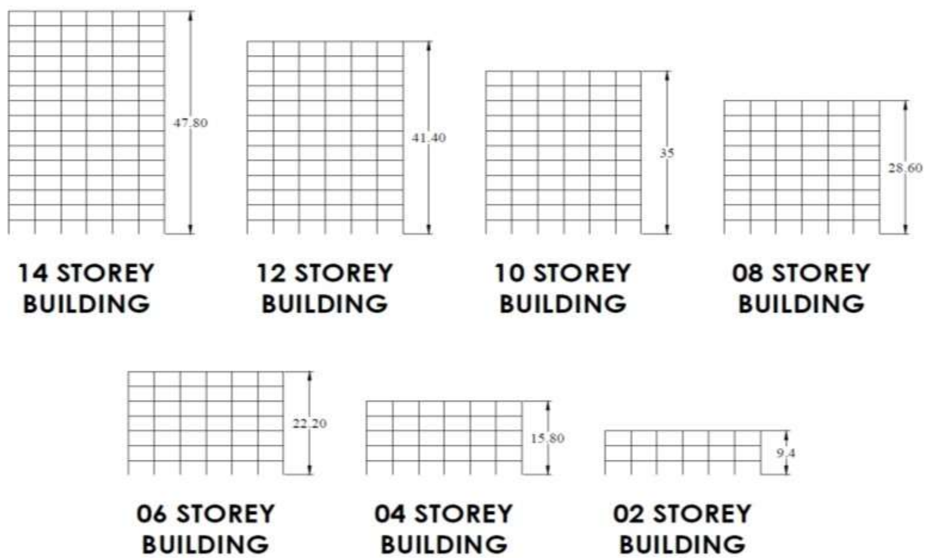
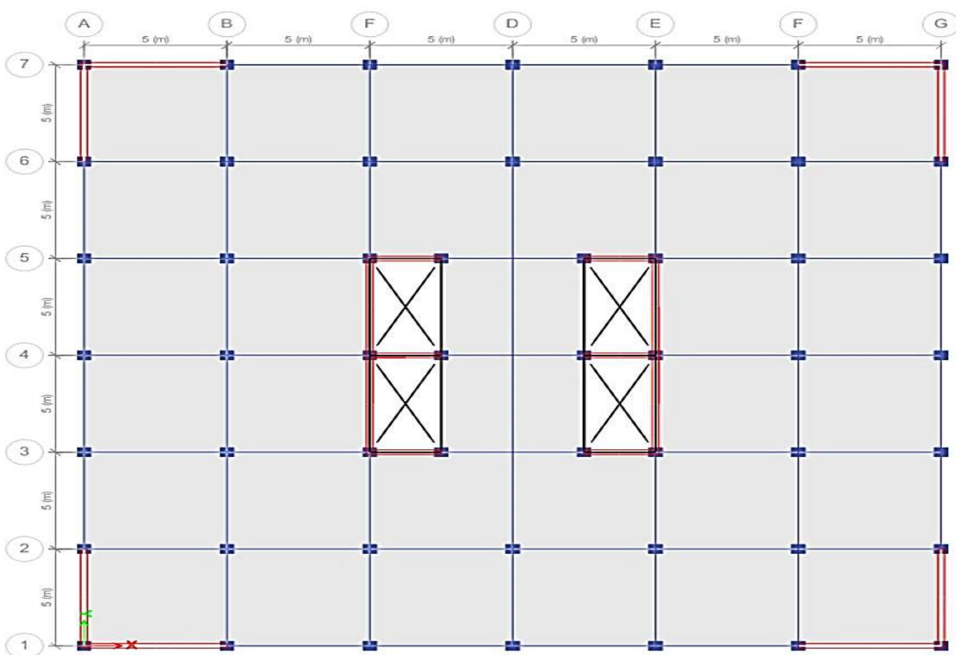


Figure 1. Elevation view of the studied frame buildings.

Figure 2. Plan view of the building.



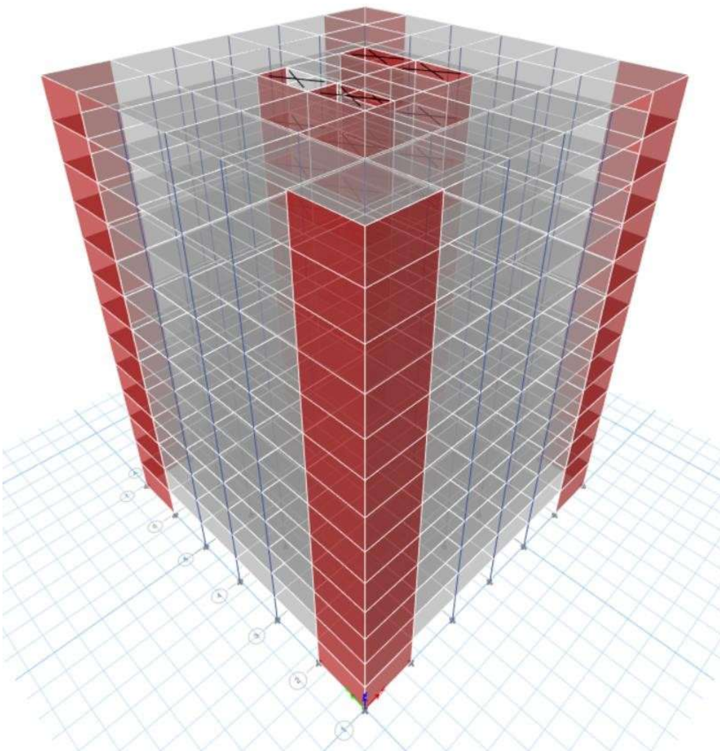


Figure 3. Three-dimensional view of the building.

Table 1. Geometric parameters of the model.

Parameter	Value
No. of stories	G+14
Length of each bay in X-direction	5 m
Length of each bay in Y-direction	5 m
Grade of steel	Fe500
Grade of concrete	M35
Column size	500 × 500 mm
Beam size	300 × 600 mm
Slab thickness	130 mm
Shear wall thickness	230 mm
External wall thickness	230 mm
Internal wall thickness	150 mm
Bottom story height	3 m
Typical story height	3.2 m

Table 2. Dimensions of columns.

No. of Story	Dimensions of Column (mm)
2–8 stories	400 × 600
10–14 stories	500 × 500

Table 3. Dimensions of beams.

No. of Story	Dimensions of Beam (mm)
2–8 stories	400 × 400
10–14 stories	300 × 600

Table 4. Input values for software for lead rubber bearing isolator for G+14 building.

S.N.	Details	Values
1	Rotational Inertia	0.02421 kN/m
2	For U1 effective stiffness	6968053.7 kN/m
3	For U2 and U3 effective stiffness	6968.0537 kN/m
4	For U2 and U3 effective damping	0.05%
5	For U2 and U3 distance from end J	0.0025427 m
6	For U2 and U3 stiffness	64210.614 kN/m
7	For U2 and U3 yield Strength	164.676 kN

DESIGN OF LEAD RUBBER BEARING ISOLATOR

Lead rubber bearing type isolator has been selected as a base isolator for the project and the design has been done according to the total axial load (maximum) that will be transferred to the base isolator as per Uniform Building Code 97. The properties of the base isolator such as the height, number of layers, the diameter of the isolator alongside the other properties including the vertical and horizontal stiffness, damping, and yield strength of isolators are determined. The design of lead rubber isolator is tabulated below in Table 4.

PROCEDURE OF DIRECT DISPLACEMENT-BASED DESIGN

In the above introduction, DDBD is introduced which is reproduced here. The first stage of design procedure is representation of multi-degree of freedom structure by an equivalent single degree of freedom structure modelling the first inelastic mode of response. The following equations were used from 'Displacement based seismic design of structures' by Priestly [21].

Design Storey Displacements

The design floor displacements of the frame are related to a normalized inelastic mode shape δ_i where i = 1 to n are the storiess, and to the displacements Δ_c of the critical story by the relationship

$$\Delta_i = \delta_i \left\{\frac{\Delta_c}{\delta_c}\right\}$$

where the normalized inelastic mode shape depends on the height H_i and roof height H_n according to following relationships:

$$\text{for } n \leq 4 \ \delta_i = \left\{\frac{H_i}{H_n}\right\}$$

$$\text{for } n \geq 4 \ \delta_i = \frac{4}{3}\left\{\frac{H_i}{H_n}\right\}\left\{1 - \frac{H_i}{4H_n}\right\}$$

Equivalent Single-Degree-of-Freedom Design Displacement

Equivalent single-degree-of-freedom (SDOF) design displacement is related to story displacements by the relationship

$$\Delta_d = \sum_{i=1}^{n} (m_i\Delta_i^2) / \sum_{i=1}^{n} (m_i\Delta_i)$$

where m_i is the mass at height H_i associated with displacement Δ_i.

Equivalent Mass

The equivalent SDOF mass m_e is given by

$$m_e = \sum_{i=1}^{n} (m_i\Delta_i) / \Delta_d$$

Effective Height

The effective height H_e of the SDOF structure is given by

$$H_e = \sum_{i=1}^{n} (m_i\Delta_i H_i) / \sum_{i=1}^{n} (m_i\Delta_i)$$

Design Displacement Ductility

The SDOF design displacement ductility factor is related to the equivalent Δ_y by

$$\mu = \frac{\Delta_d}{\Delta_y}$$

The yield drift of a story in a frame depended on geometry, the following expression were developed

For reinforced concrete frame $\theta_y = 0.5\,\varepsilon_y \frac{L_b}{h_b}$

For steel frame $\theta_y = 0.65\,\varepsilon_y \frac{L_b}{h_b}$

where L_b and h_b are the beam span between column centrelines and beam depth respectively, and ε_y is the yield strength of flexural reinforcement or structural steel. It is generally sufficiently accurate to assume a linear yield displacement profile for the purpose of estimating ductility demand and hence yield displacement is given by

$$\Delta_y = \theta_y H_e$$

Equivalent Viscous Damping

Equivalent viscous damping of substitute structure for frames can be conservatively related to design displacement ductility demand as follows:

For reinforced concrete frame $\xi_{eq} = 0.05+0.565\left(\frac{\mu-1}{\mu\pi}\right)$

Effective Time Period

The effective period at peak displacement response is found from the displacement spectra, entering with the design displacement, and determining time period T_e

Effective Stiffness

The effective stiffness at maximum displacement response of structure F/Δ_d is given by

$$K_e = 4\pi^2\, m_e/T_e^2$$

Design Base Shear (V_b)

The design base shear for multiple-degree-of-freedom (MDOF) structure is given by

$$V_{base} = K_e\,\Delta_d$$

Distribution of Base Shear (V_b) to Floor Levels

The base shear force distributed to floor levels in proportion to product of mass and displacement and given by

$$F_i = F_t + 0.9\,V_{base}\,(m_i\,\Delta_i)/\sum_{i=1}^{n}(m_i\Delta_i)$$

where $F_t = 0.1\,V_{base}$ at roof.

Overturning Moments

The lateral seismic forces induce column base moments and axial forces in the columns. The total overturning moment *(OTM)* induced by the lateral forces at the base of the building is

$$\text{OTM} = \sum_{i=1}^{15} F_i(H_j - H_i)$$

Development of Spread Sheet for Direct Displacement-Based Design

The forthcoming presentation of detailed DDBD calculations is of paramount importance within the seismic design context. DDBD signifies a departure from conventional seismic design by focusing on displacement resilience rather than force-based criteria. The Microsoft Excel sheet captures the practical embodiment of this progressive approach, showcasing the intricate evaluation of engineering parameters which are presented in Figures 4 and 5.

CODE DRIFT LIMIT θc	0.02		
CODE DRIFT LIMIT Δc	0.06	θc*LOWER STOREY HEIGHT	
DESIGN DISPLACEMENT Δd	0.5197665	M	
Effective mass me	155057.05	15806	Tonne
Yield drift θy	0.0104167		
Effective height He	31.462822	M	
Yield displacement Δy	0.3277377	M	
Displacement ductility μ	1.585922		
Equivalent damping ξeq	0.1164778		
Effective time period Te	6.5	SEC	
Effective stiffness Ke	14754.779	KN/M	
Base shear Vb	7669.0393	KN	

Figure 4. Evaluation of engineering parameters for direct displacement-based design (DDBD).

Story	Hieght	Mass(mi)	δi	Δi	miΔi	miΔi^2	miΔiHi	Fi	Vs	OTM
(m)	Hi(m)	M(kN)						(kN)	(kN)	FiHi
14	47.8	8745.22	1.000	0.72843	6370.27	4640.29	304499.12	1312.46	1312.46307	0
13	44.6	13068.45	0.954	0.69483	9080.37	6309.32	404984.32	777.655	2090.11821	4199.881838
12	41.4	13068.45	0.905	0.65906	8612.85	5676.35	356571.82	737.616	2827.73428	10888.26011
11	38.2	13068.45	0.853	0.62111	8116.88	5041.44	310064.95	695.141	3522.87545	19937.00981
10	35	13068.45	0.798	0.58098	7592.48	4411.06	265736.76	650.23	4173.10588	31210.21124
9	31.8	13068.45	0.740	0.53867	7039.63	3792.06	223860.3	602.884	4775.98973	44564.15004
8	28.6	13068.45	0.678	0.49419	6458.34	3191.67	184708.6	553.101	5329.09117	59847.31717
7	25.4	13068.45	0.614	0.44754	5848.61	2617.47	148554.73	500.883	5829.97436	76900.40892
6	22.2	13068.45	0.547	0.3987	5210.44	2077.42	115671.71	446.229	6276.20347	95556.32688
5	19	13068.45	0.477	0.34769	4543.82	1579.86	86332.61	389.139	6665.34265	115640.178
4	15.8	13068.45	0.404	0.29451	3848.76	1133.49	60810.459	329.613	6994.95608	136969.2745
3	12.6	13068.45	0.328	0.23915	3125.26	747.393	39378.309	267.652	7262.6079	159353.1339
2	9.4	13068.45	0.249	0.18161	2373.32	431.011	22309.206	203.254	7465.8623	182593.4792
1	6.2	13068.45	0.167	0.12189	1592.93	194.165	9876.1944	136.421	7602.28343	206484.2386
GF	3	12991.36	0.082	0.06	779.482	46.7689	2338.4446	66.7559	7669.03931	230811.5455
Base	0	0	0.000	0	0	0	0	0	7669.03931	253818.6634
Total					80593.5	41889.8	2535697.5	7669.04		

Figure 5. Developed Microsoft Excel sheet for direct displacement-based design (DDBD) of G+14 building.

RESULTS AND DISCUSSION

In the present work, a seismic analysis of the proposed multistoried building with G+2, 4, 6, 8, 10, 12, and 14 story having different heights is carried out using the DDBM and force-based method. In addition, base isolated buildings were also analyzed. The results were obtained using the response spectrum method for seismic zone III, IV, and V. The seismic performance of the bifurcations was evaluated in terms of story shear and overturning moment.

Story Shear Comparison Between DDBM, FBDM, and LRB for Zone V

The comparison of base shear forces for zone V, obtained through the DDBM using the provided Microsoft Excel sheet, with those derived from force-based design method (FBDM) and lead rubber bearing (LRB), utilizing both simplified modal response spectrum method and inelastic modeling via computer software ETABS, is presented in Table 5 and illustrated in Figure 6.

From Table 5 and Figure 6, one can deduce the following:

- The DDBD consistently results in lower maximum base shear forces compared to traditional force-based design (FBD).

- Therefore, FBD tends to overestimate the base shear forces relative to DDBD.
- The difference in base shear values between LRB and the other methods varies depending on the building height. The difference is more significant for taller buildings compared to shorter ones.

Story Shear Comparison Between DDBM, FBDM, and LRB for Zone IV

The comparison of base shear forces for zone IV, obtained through the DDBM using the provided Microsoft Excel sheet, with those derived from FBDM and LRB, utilizing both simplified modal response spectrum method and inelastic modeling via computer software ETABS, is presented in Table 6 and illustrated in Figure 7.

Table 5. Comparison of base shear (kN) for the studied buildings for Zone V.

No. of Floors	FBD	DDBD	LRB
14	10850.4	7669.039	5582.406
12	7906.732	6568.053	5170.9371
10	8597.223	5562.035	4644.4191
08	5271.374	4365.559	3574.213
06	4891.705	3777.428	2634.509
04	4939.107	2508.724	1996.1553
02	3882.914	2117.626	1285.1215

DDBD, direct displacement-based design, FBD, force-based design; LRB, read rubber bearing.

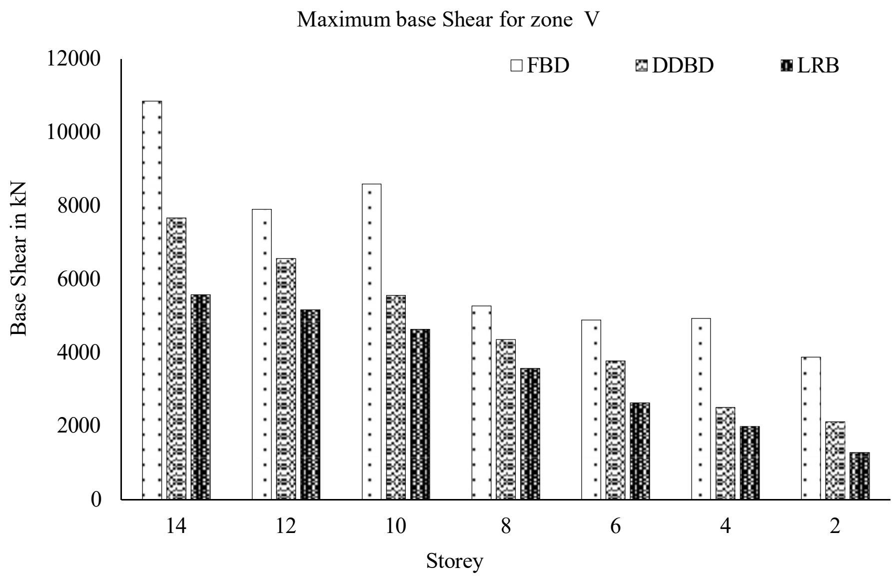


Figure 6. Comparison of base shear (kN) for the studied buildings for Zone V.

Table 6. Comparison of base shear (kN) for the studied buildings for Zone IV.

No. of Floors	FBD	DDBD	LRB
14	8721.147	5062.764	3721.604
12	7884.792	4391.558	3447.291
10	7233.6	3707.152	3096.279
08	3514.249	2918.244	2382.809
06	3292.738	2518.595	1756.339
04	3261.137	1675.131	1330.77
02	2588.61	1003.548	856.7476

DDBD, direct displacement-based design, FBD, force-based design; LRB, read rubber bearing.

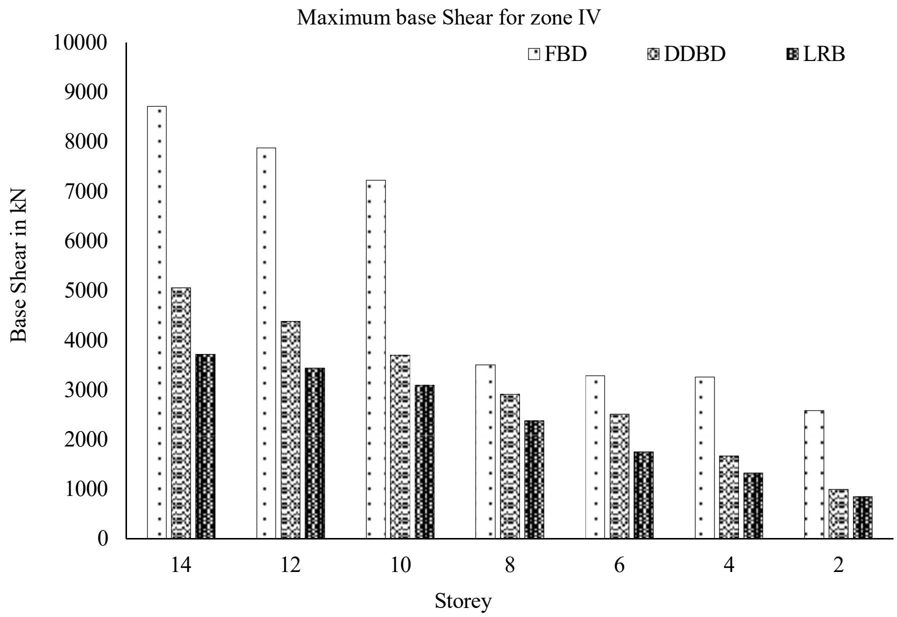


Figure 7. Comparison of base shear (kN) for the studied buildings for Zone IV.

Table 7. Comparison of base shear (kN) for the studied buildings for Zone III.

No. of Floors	FBD	DDBD	LRB
14	5814.098	3373.77	2481.069
12	5256.528	2925.526	2298.194
10	4822.4	2479.356	2064.186
08	2342.833	1947.865	1588.539
06	2195.159	1671.486	1170.893
04	2174.091	1127.217	887.1802
02	1725.74	674.4601	571.1651

DDBD, direct displacement-based design, FBD, force-based design; LRB, read rubber bearing.

From Table 6 and Figure 7 one can deduce the following:

- At the lower building heights (G+2 to G+4), DDBD consistently estimates lower base shear values and as the building height increases to G+6 and G+14, the trend continues, with DDBD providing lower base shear estimates compared to FBD.
- The difference in base shear values between LRB and the other methods varies depending on the building height. The difference is more significant for taller buildings compared to shorter ones.

Story Shear Comparison Between DDBM, FBDM, and LRB for Zone III

The comparison of base shear forces for zone III, obtained through the DDBM using the provided Microsoft Excel sheet, with those derived from FBDM and LRB, utilizing both simplified modal response spectrum method and inelastic modeling via computer software ETABS, is presented in Table 7 and illustrated in Figure 8.

From Table 7 and Figure 8, one can deduce the following:

- The DDBD consistently results in lower maximum base shear forces compared to traditional FBD.
- Therefore, FBD tends to overestimate the base shear forces relative to DDBD.
- The difference in base shear values between LRB and the other methods varies depending on the building height. The difference is more significant for taller buildings compared to shorter ones.

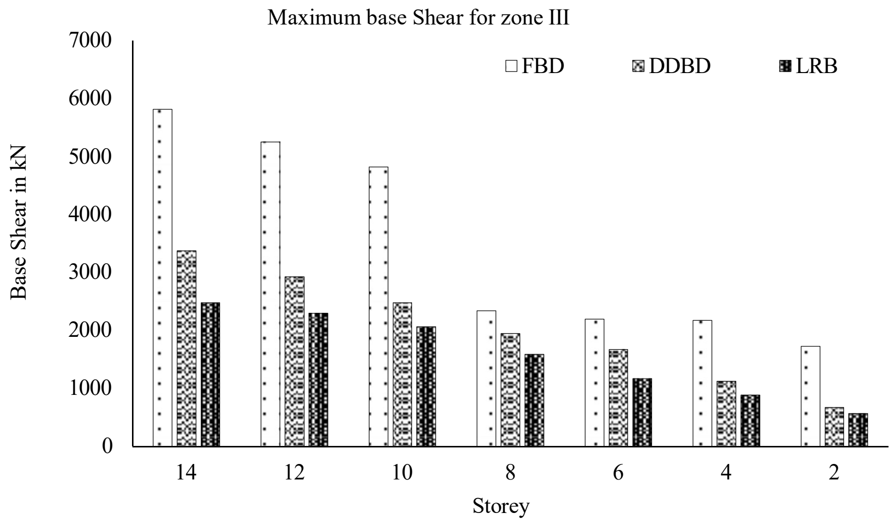


Figure 8 Comparison of base shear (kN) for the studied buildings for Zone III.

Table 8. Comparison of overturning moment (kNm) for the studied buildings for Zone V.

No. of Floors	FBD	DDBD	LRB
14	394078.5	253818.7	202748.8
12	320921.8	188631.9	163031.5
10	229902.5	135408.9	124195
08	115964.7	87371.38	78660.54
06	84999.45	59574.05	45777.86
04	61565.66	29004.48	24881.95
02	30038.56	15168.06	9941.81

DDBD, direct displacement-based design, FBD, force-based design; LRB, read rubber bearing.

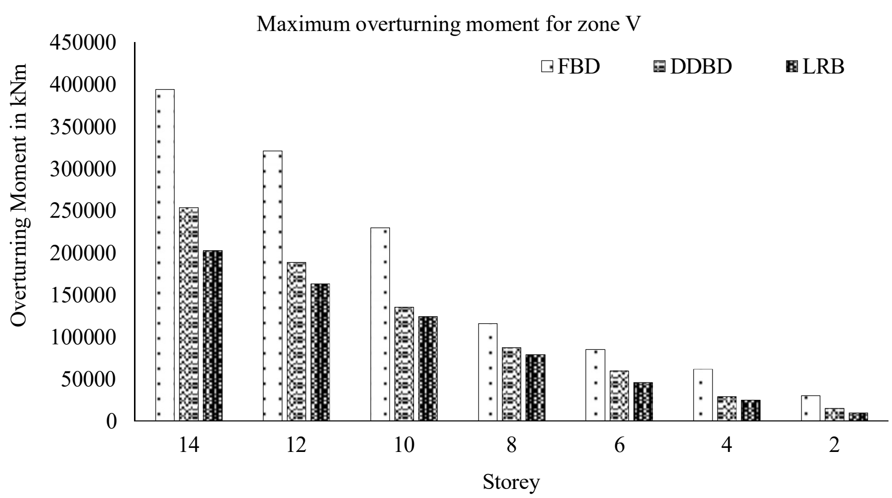


Figure 9. Comparison of overturning moment (kNm) for the studied buildings for Zone V.

Overturning Moment Comparison Between DDBM, FBBM, and LRB for Zone V

The comparison of overturning moments for Zone V, obtained through the DDBM using the provided Microsoft Excel sheet, with those derived from FBDM and LRB, utilizing both simplified modal response spectrum method and inelastic modeling via computer software ETABS, is presented in Table 8 and illustrated in Figure 9.

From Table 8 and Figure 9, one can deduce the following:

- Across all building heights, DDBD consistently estimates lower overturning moments compared to both FBD and LRB.
- Therefore, FBD tends to overestimate the overturning moments relative to DDBD.
- The difference in overturning moment values between LRB and the other methods varies depending on the building height. The difference is more significant for taller buildings compared to shorter ones.

Overturning Moment Comparison Between DDBM, FBDM, and LRB for Zone IV

The comparison of overturning moments for Zone IV, obtained through the DDBM using the provided Microsoft Excel sheet, with those derived from FBDM and LRB, utilizing both simplified modal response spectrum method and inelastic modeling via computer software ETABS, is presented in Table 9 and illustrated in Figure 10.

From Table 9 and Figure 10, one can deduce the following:

- Across all building heights, DDBD consistently estimates lower overturning moments compared to both FBD and LRB.
- Therefore, FBD tends to overestimate the overturning moments relative to DDBD.
- The difference in overturning moment values between LRB and the other methods varies depending on the building height. The difference is more significant for taller buildings compared to shorter ones.

Table 9. Comparison of overturning moment (kNm) for the studied buildings for Zone IV.

No. of Floors	FBD	DDBD	LRB
14	262719	167560	135165.9
12	248595.1	126123.8	108687.7
10	233209.5	90251.39	82796.65
08	77309.82	58405.12	52440.36
06	56666.3	39720.92	30518.58
04	41043.77	19366.94	16587.97
02	20025.71	7188.18	6627.873

DDBD, direct displacement-based design, FBD, force-based design; LRB, read rubber bearing.

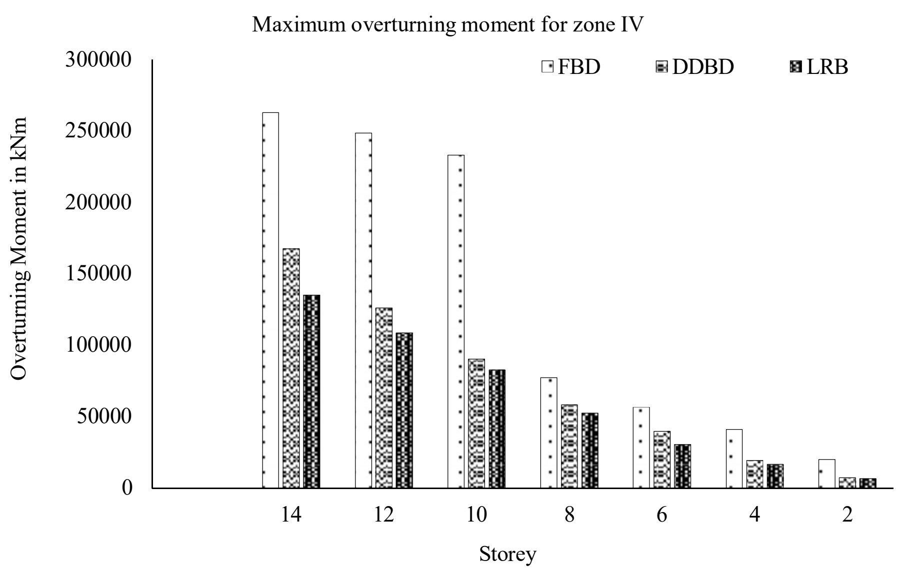


Figure 10. Comparison of overturning moment (kNm) for the studied buildings for Zone IV.

Overturning Moment Comparison Between DDBM, FBBM, and LRB for Zone III

The comparison of overturning moments for Zone III, obtained through the DDBM using the provided Microsof tExcel sheet, with those derived from FBDM and LRB, utilizing both simplified modal response spectrum method and inelastic modeling via computer software ETABS, is presented in Table 10 and illustrated in Figure 11.

Table 10. Comparison of overturning moment (kNm) for the studied buildings for Zone III.

No. of Floors	FBD	DDBD	LRB
14	175146	111660.1	90110.6
12	165730.1	84019.96	72458.45
10	155473	60360.46	55197.77
08	51539.88	38984.15	34960.24
06	37777.53	26361.1	20345.72
04	27362.51	13032.26	11058.65
02	13350.47	4830.998	4418.582

DDBD, direct displacement-based design, FBD, force-based design; LRB, read rubber bearing.

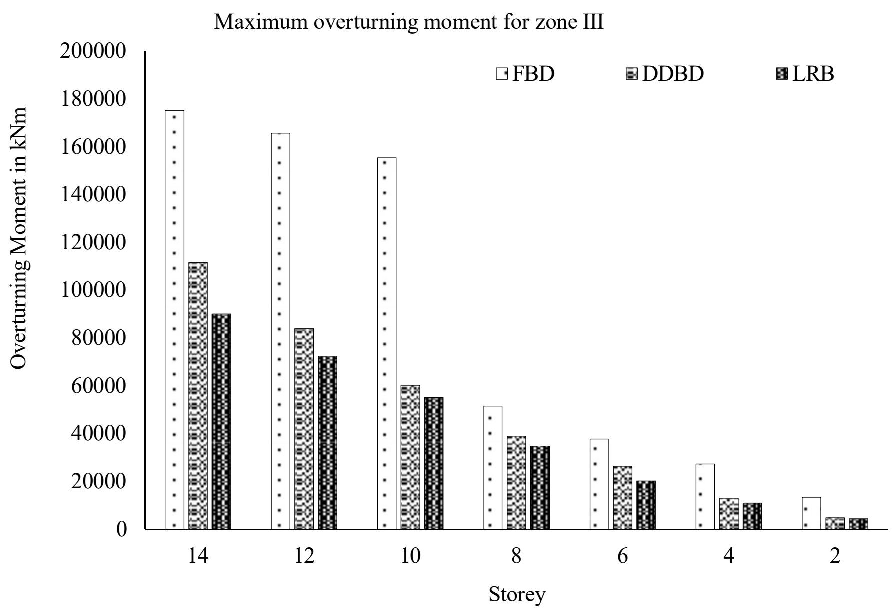


Figure 11. Comparison of overturning moment (kNm) for the studied buildings for Zone III.

From Table 10 and Figure 11, one can deduce the following:

- Across all building heights, DDBD consistently estimates lower overturning moments compared to both FBD and LRB.
- Therefore, FBD tends to overestimate the overturning moments relative to DDBD.
- The difference in overturning moment values between LRB and the other methods varies depending on the building height. The difference is more significant for taller buildings compared to shorter ones.

CONCLUSIONS

An extensive Microsoft Excel spreadsheet is created to facilitate the seismic analysis of reinforced concrete buildings employing the DDBM. The study encompasses shear wall structural systems with variable heights, spanning from G+2 to G+14 story buildings. Comparative analyses are conducted between the DDBM results and those derived from FBDM and LRB, including finite element modeling using computer software like ETABS. The comprehensive findings of this research yield the following conclusions.

- The DDBD shows a decrease of 24% to 61% in the overturning moment as compared to FBD. This suggests that the seismic response of the building has been improved when using DDBD. The reason behind this is because a smaller value of overturning moment leads to a lower torsion effect on the structure.
- There is a significant decrease in base shear values ranging from 17% to 52% for DDBD as compared to FBD. This suggests that using the DDBD for designing buildings is more beneficial than FBD as it reduces the base shear, which ultimately decreases the seismic load acting on the structures.
- The base shear value decreased significantly for DDBD as compared to FBD. This proves that the DDBD is reliable in minimizing the seismic response of multi-story buildings by limiting their base shear values.
- In addition, a comparison of the results of LRB with DDBD shows that the performance of DDBD is better than LRB for all building heights. It was found that LRB can be used for some specific building heights to decrease the seismic load acting on the structures. However, the use of DDBD is recommended in this study due to its outstanding performance for all building heights.This study demonstrates the versatility of DDBD, as it consistently outperforms FBD in controlling overturning moments and base shear values across a range of building heights, from G+2 to G+14. This adaptability underscores its applicability in various multistory structures.

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