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Comparative Study of Direct Displacement Basedand Forced Based Design Method

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ABSTRACT

The structure of seismic design has traditionally been force based. The major factor for damage is displacement rather than force. The most popular alternative procedure for seismic design, is performance based design method. The global parameter of performance based design method is displacement. For seismic design of structure direct displacement based design method has been used. Using Displacement based design method and Forced based design method the paper attempts to design moment resisting RC-frame G+7-storey building. The parameters like base shear and lateral load distribution are taken for the study. It has been observed that base shear of RC building calculated by DDBD is compared to FBD. It is noticed that fully Operational, Immediate Occupancy, Life Safety, and Near Collapse are the four performance levels. In this paper, a G+7 structure is lay to ground vibrations from earthquakes in India. The standard used to categorize the performance levels is displacement. Operational, Immediate Occupancy, Life Safety, and Collapse Prevention performance levels are 0.37 %, 0.70 %, %, and 5.0 %respectively of the overall height of the building. To perform non-linear dynamic analysis time History Analysis is used. The STAAD Pro software is used for analysis. The change in displacements which in turn brought changes in Performance levels was observed.

***Keywords:** Performance Based Seismic design, Performancelevels.*

1. INTRODUCTION

1.1 Performance Based Seismic Design

Earthquakes release energy in earth's crust, that creates seismic waves. Earthquakes are destructive forces, which damage the structure. This design will evaluate earthquake force (base shear) and minimize the damage in structure. The performance-based design is another approach for the seismic design of structure. Direct displacement based design is based on performance based design. Priestly (1993) proposed direct displacement based design (DDBD). The goal of DDBD is to obtain a target displacement profile when the structure is exposed to earthquake [1]. This is an approach for analysis of multi-degree freedom system.

In this procedure, the secant stiffness and equivalent damping of an equivalent single degree of freedom system identify the structure. The strength at assigned plastic hinge location to obtain target displacement is obtained by DDBD approach.

1.2 Performance levels of Performance Based Seismic Design

Performance level selection is made by the client, indiscussion with the design professionals, based on consideration of the client's demand, the seismic danger exposure, economic analysis, and acceptable risk. Following are the performance level defined by them:

- Fully Operational (SP1). The facility continues in operation with zero damage.
- Operational (SP2). The facility continues in operation with less damage and less disruption in nonessential services.
- Life Safe (SP3). Life Safety is considerably protected, the damage is medium to extensive.
- Near Collapse (SP4). Life Safety is at hazard, the damage is intense, structural collapse is prevented.

As per the guidelines, the design steps involve determining thebase shear as per performance level and designing the structure against that base shear. The design steps todetermine the base shear is as follows:

i. Target displacement is designed based on the drift limit of every performance level, the height of the building and the shape factor which depends upon the height of the structure.

ii. The time period of the SDOF structure is obtained from Spectral Displacement vs Time Period curve for the given earthquake zone and soil type. The curve is obtained using theresponse spectrum given in IS 1893 (Part 1)-2016 [1].

iii. The stiffness of SDOF structure is determined based on the effective time period and effective mass of the structure.

iv. The effective stiffness and the target displacement of the building is used to determine Base shear.

Displacement based seismic design of concrete building was designed by Priestley and Kowalsky (2000) . This method was designed for structure to satisfy pre-defined drift level in a direct manner. This method shows design procedure, code drift, inelastic rotation capacities of the structure, initial stiffness are the parameter. The displacement profile of structure is used to determine the system displacement. For the analysis purpose the multi storey frame and wall buildings are taken. The target displacements are correlated with results from inelastic time history analysis. From the analysis purpose it is observed that the required base shear strength in DDBD method proportional to square of seismic intensity [4].

2. METHODOLOGY

To determine the structure's performance level, the time history approach is employed in this analysis. A nonlinear dynamic analysis is time history analysis. The earthquake data, which is ground motion data, is used in the time history analysis. The earthquake data is information on previous earthquakes around the world.

3. MODELLING

3.1 Preparation of Floor Plan

The G+7-storey RC moment resisting frame has been taken. The building design of FBD approach is done using IS 1893:2002[2]. The geometry of building is shown in Figure 1. The storey height of building is 3.2 m. It is located in Zone-III and constructed on medium type of soil. The response reduction factor (R) of building is 5 and Importance factor (I) has been take as 1. The other building specification is show inTable 1

Table 1

Sr. no.	Elements	Description
1	Slab thickness	150mm
2	Imposed load	3.5kN/m2
3	Floor finish	1kN/m2
4	Wall load	15 kN/m (All storey)
5	Concrete grade	M25

(a) 1.5(DL+LL) (b) 1.2(DL+LL±EL) (c) 1.5(DL±EL) as per IS 456:2000[6]. The spectral acceleration and displacement spectra were used as per IS 1893 (part-I): 2002 for medium soil of 5% damping. To compare the base shear for DDBD and FBD approach, the dead load of the building has been kept same and the beam-column sizes are shown in Table 2.

Table 2 FBD Parameters

Parameters	Value
Time Period (sec)	0.425
Spectral Acceleration Coefficient, (Sa/g)	2.5
Horizontal Seismic Coefficient, Ah	0..04
Base Shear, VB (kN)	1813.96

Table 3 DDBD Parameters

Parameters	SP-1	SP-2	SP-3	SP-4
Δ1	0.05	0.015	0.03	0.04
ΔT (m)	0.13	0.34	0.64	0.83
Teff (sec)	2.6	7.86	15.71	20.94
Keff (kN/m)	17441.9	5769.59	2886.63	2165.66
Vbase (kN)	2267.45	1961.66	1847.44	1797.50

The base shear obtained from both the methods is applied to building modelled in STAAD.Pro V8i and designed as per IS 456-2000 [5] in the software. Various parameters of the designed building are determined and compared among various performance levels and force-based design.

3.2 Modelling in STAAD Pro Software

The STAAD Pro software was used to design G+7 school Building along with the AutoCAD plan prepared in the step before. The model was prepared step by step as described below:

i. With the help of dimensions obtained from the centerlineplan nodes were placed.
ii. Using the add beam command Nodes created wereconnected to each other.
iv Between the Stores Columns were Assigned .v Diaphragm was assigned for the slab element.

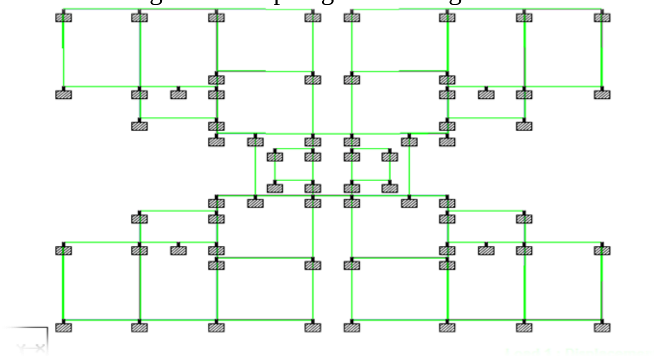


Fig 1 Plan view of STAAD Pro Model

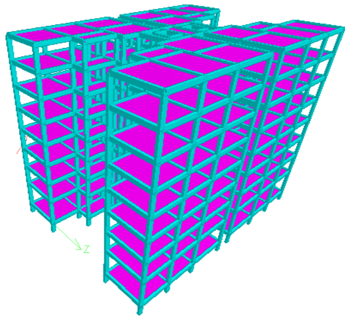


Fig 2 3D view of STAAD Pro Model

Assigning of Supports: Fixed Supports were assigned to the structure.
Section Properties: For the Initial analysis the following sections were used i.e.
i) Beam 0.50m x 0.23m,
ii) Column 0.50m x 0.23m and
iii) Slab of 0.150m thickness. Assigning of Load cases:

Assigning of Load cases:

1. Dead Load = Self weight of -1 factor
2. Live Load = 3.5 kN/m2
3. Member Load = wall height x wall width x density of masonry wall

= 3.0 x 0.23 x 20.65

= 14.25 kN/m^2

4. Dynamic Load: Self-weights of -1 factors were assigned in X, Y, and Z directions. Floor loads of 5kN/m^{2}were applied in X, Y and Z directions. Also, Time history load was assigned having Arrival time = 3:0.01 and Force Amplitude factor of 1.2.

5. Time History definitions:The website www.strongmotioncenter.org. Was used to collect Earthquake data of Bhuj earthquakes that occurred in India. The data Collected was of the form Time Vs. Acceleration. The data can be put into STAAD Pro either by manually or in the form of a text file. The Picture below shows an example of data entered in a manual form.

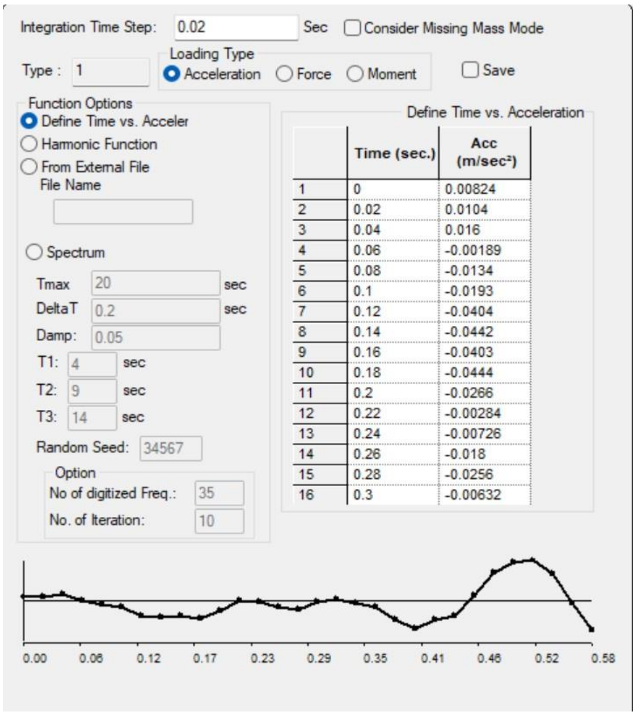


Fig 3 Input of Time History definition of earthquake data

The Structure modelled in STAAD Pro was analysed for Bhuj Earthquake data that occurred in India in recent times. The Data was collected in the form of Time VS. Acceleration.
Earthquake: Bhuj/Kachchh 2001-01-26 03:16:40UTCStation: Ahmedabad, India

Station Owner: Dept of Earthquake Eng., Indian Inst. ofTechnology, Roorkee, India

Station Latitude & Longitude: 23.0300, 72.6300Hypocentral Distance: 239.0 km

Plot:

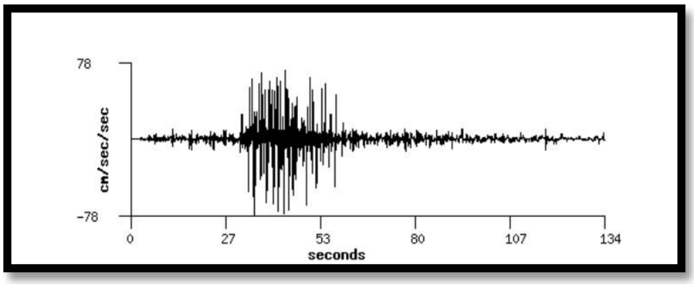


Fig 4 Acceleration Plot of Bhuj Earthquake

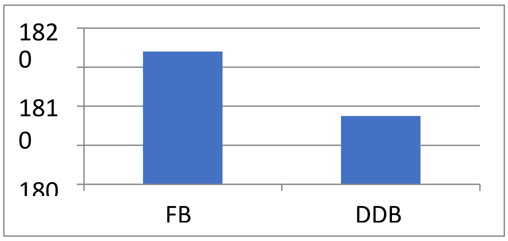
The structure was studied in order to obtain the max Time History displacement occurring at the roof level in order to getthe performance level of the structure. Hence the structure in consideration was analysed for different cross sections of Beams, Columns and slab thicknesses and the performance levels were found out. Based on the data given below in the table Fig 5 the Performance levels were obtained . For e.g., the structure modelled is a G+7 school building having afloor-to-floor height of the 3Sm. Hence the building is 25m Tall. If the Max roof displacement occurs in the range of 0mm
– 103.6mm (0.37% of 25,000mm = 92.5mm) then the buildingis said to achieve a performance level of IMMEDIATE OCCUPANCY.

Table-4

Sr.No	Performance Levels	Target Roof Displacement (% of height)
1	Operational	0.37
2	Immediate Occupancy	0.70
3	Life Safety	2.5
4	Collapse Prevention	5.0

4. RESULTS

Abbreviations: O = Operational, IO = Immediate Occupancy,LS = Life Safety and CP = Collapse prevention



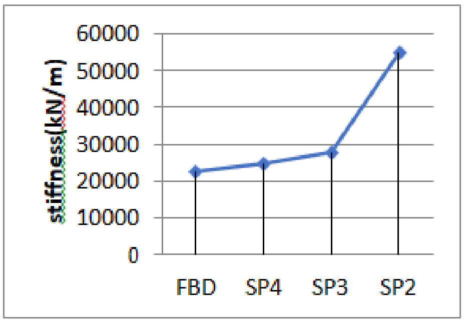
Graph 1 Base shear for G+7 building for IO

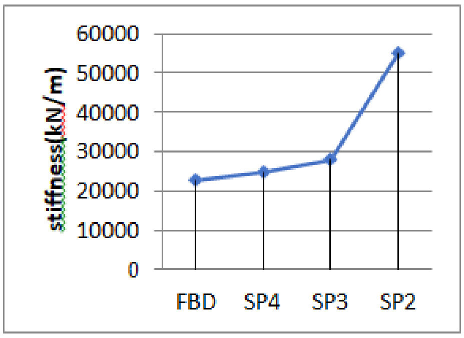
A. Base Shear

As seen from Table 2 and Table 3, the base shear applied to the building will rise with the increase in the performance level and it is least for FBD. The base shear increases by 0.99, 1.1, 2.5 and 8.2 times the base shear of FBD for SP4, SP3, SP2 and SP1 performance level respectively. The rise in base shear infer that the building needs to resist more base shearand hence its member dimensions need to be increased.

B. Stiffness of the building

By taking the ratio of the base shear resisted by the building to the maximum roof displacement the stiffness of the building isdetermined. It is determined in both X and Y directions and shown in Figure. As it can observed from the figure, that for all the cases the stiffness in the Y direction is 10% more than that in the X direction. It is due to less bay spacing in the Y direction as compared to that in the X direction. In both the directions the stiffness increases by 8%, 36% and 174% from FBD, for SP4, SP3 and SP2 performance level. This indicates that the base shear resisting capacity increases by that much amount.

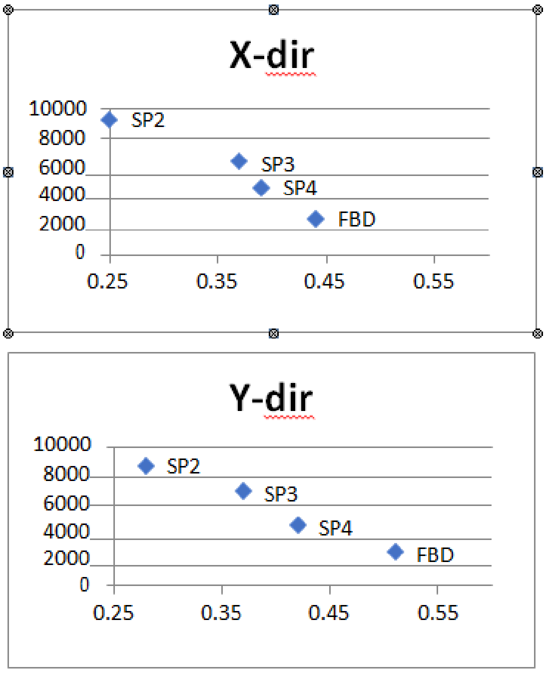




Graph 2 Stiffness of the building in X and Y direction

C. Performance Point of the Structure

Performance point of the building is obtained by theintersection of the demand curve from ATC-40 and the capacity curve of the building. Below shown Figure represent the performance point of the building in X and Y directions at all the performance levels. The performance point of the building in X and Y direction rises with the rise in the performance level and confirms the objective of the direct displacement based design of multi-level performance of the building.



Graph 3 Performance Point in displacement vs Base shear in both direction

5. CONCLUSION

The following conclusions are derived after the design carried out for G+7building. Force based design method and direct displacement-based design method, The base shear of DDBD structure is reduced by 21.80% compare to FBD structure. From lateral load distribution It is clearly observed that the lateral loads are less in DDBD compare to FBD. From the calculations of percentage reinforcement it is observed that less percentage of steel is required in DDBD as compare to FBD. Perhaps it proves that DDBD approach is more effectivecompare to FBD approach.
After comparing all the parameters between force-based design method and direct displacement based design method:
i. The base shear experienced by the building increases with an increase in performance level and it is least for FBD.
ii. Within the feasible size of the structural members design for SP1 performance level is not possible.
iii. The advantage of using direct displacement based design is that the desired performance of the building can be achievedand the increase in the cost with performance is acceptable.

6. REFERENCES

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