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Performance Based Seismic Design of R.C. Framed Structure using Direct Displacement Method

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Abstract - *Traditional IS code method of design is force based. It is clear that damage is very much dependent on the displacement of the structure rather than the force. These results in the requirement of seismic deign approaches that are based on displacement design. Also, the displacement based method is quite complex and time consuming. This gives rise to the rational and fast method known as "Direct Displacement Based Design" which is used as preliminary design of performance based design, the method needs to be validated and explored in detailed manner. As IS code design cannot give the various types of performance levels therefore there is need to see the results of design of RCC building designed with IS code method with the performance based design.*

Present study deals with the analysis and design of G+5 building with the IS code method and Performance based seismic design with Direct Displacement based Design offshoot. The comparison is based on various parameters such as Base shear, Drift and IDR. This analysis and design is carried out with the help of SAP2000 software and MS- Excel.

***Key Words*: IS code Method, Direct Displacement based Design (DDBD), Base Shear, Interstorey Drift Ratio (IDR), SAP2000**

1. INTRODUCTION

Buildings are critical life-line facilities which should remain functional without damage after an earthquake to facilitate the daily work and various types of operations. In recent years, several types of buildings have been constructed such as Residential, Commercial and Industrial, which results in a great demand to evaluate the effects of seismic behaviour of the buildings, and properly reflect it in their seismic design.

Considering all the loading conditions, apart from gravity loads, the structure will experience major lateral forces of greater magnitude during earthquake events. It is necessary to estimate and specify these lateral forces on the structure in order to design the structure to resist an earthquake. It is not possible to exactly determine the earthquake induced lateral forces that are expected to act on the structure during its lifetime. However, after considering the consequential effects of earthquake due to successive failure of the structure, it is very much important to estimate these forces in a rational and realistic manner and the design can be made on the basis of these forces considering economy factor.

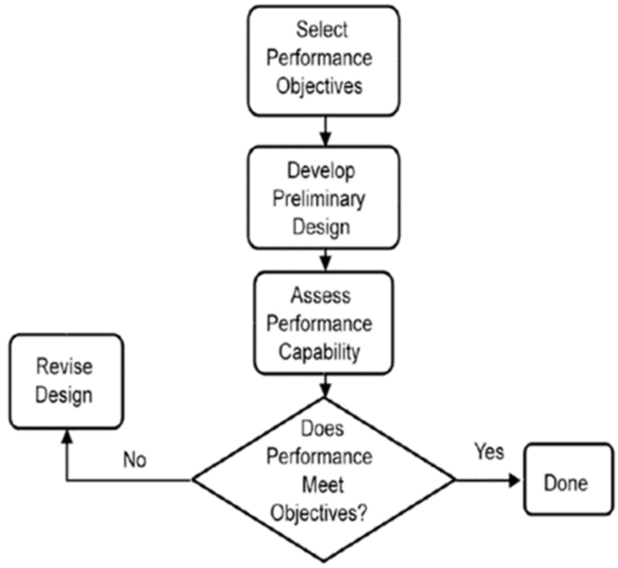

Fig-1: Performance based seismic design

2. FUNDAMENTALS OF DIRECT DISPLACEMENT BASED DESIGN

The objective of this section is to establish the fundamentals of the direct displacement-based seismic design of frame buildings. This method utilizes the substitute structure approach. The method fundamentals have been shown in Fig.2. It considers SDOF representation of MDOF system as shown in fig.2(a). The bilinear envelope of lateral force displacement response of ESDOF representation is shown in fig.2(b).

An initial elastic stiffness is followed by post yield stiffness of r*Ki. While force based seismic design characterizes a structure in terms of elastic pre yield properties (initial stiffness Ki, 5% elastic damping), DDBD characterizes the structure by secant stiffness Ke at maximum displacement Δd.

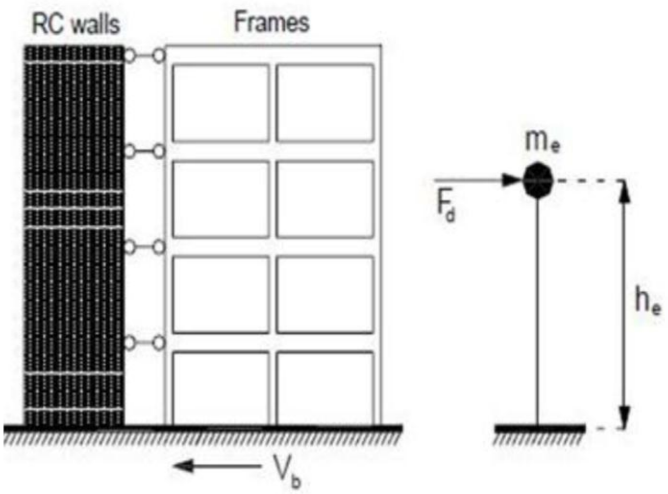

Fig-2(a): Equivalent SDOF system

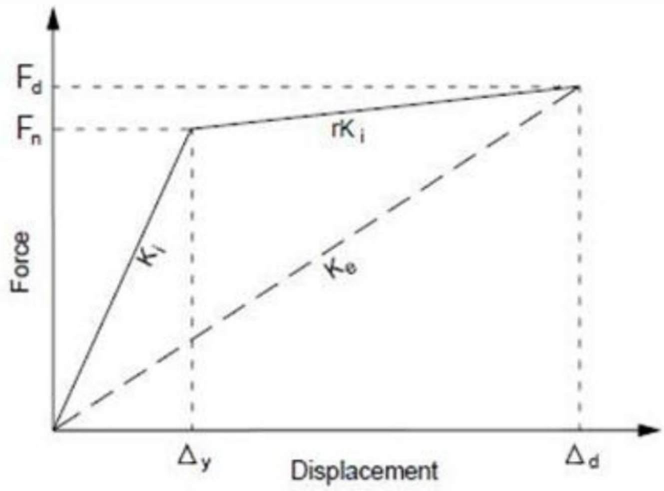

Fig-2(b): Effective Stiffness K_e

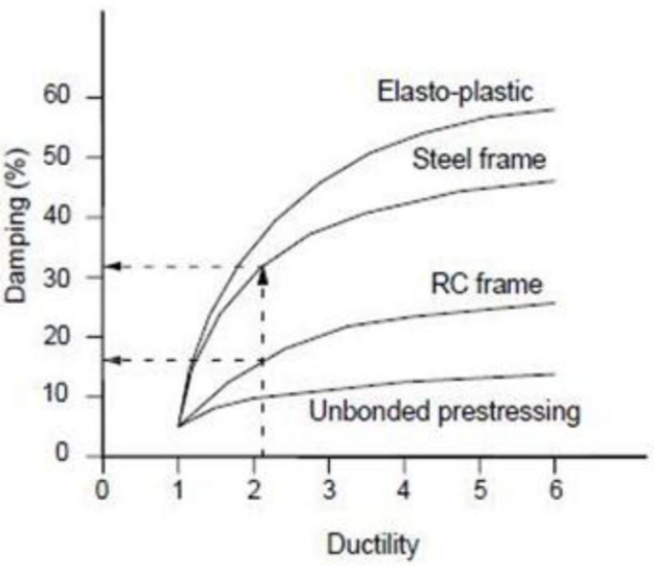

Fig-2(c): Equivalent Damping vs. Ductility

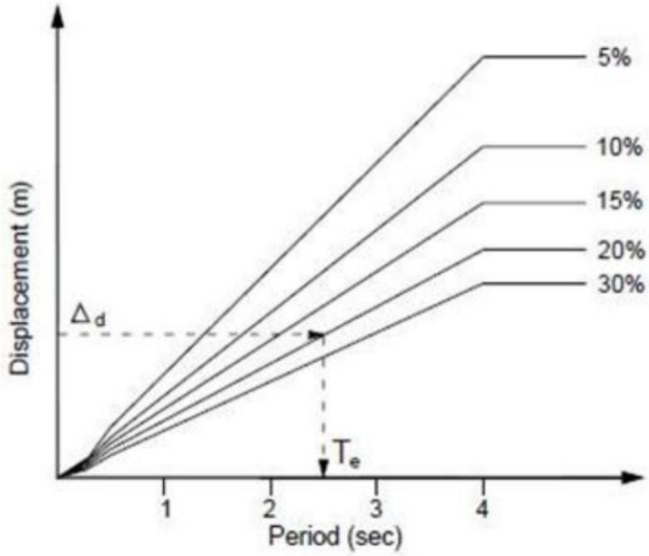

Fig-2(d): Design Displacement Spectra

A level of equivalent viscous damping ξeff, representative of combine elastic damping and the hysteretic energy absorbed during inelastic response as shown in fig.2(c). The corresponding estimated from the expected ductility demand, the effective time period Te at maximum displacement response, measured at effective height He can be read from set of displacement spectra for different level of damping as shown in fig. 2(d). Hence required effective stiffness is given by:

$$K_e = \frac{4\pi^2 m_e}{T_e^2} \quad \text{.................... (1)}$$

Where,

me= Effective mass of ESDOF participating in fundamental mode of vibration.

Hence the design lateral force, i.e. design base shear is:

$$F = V_{base} = K_e * \Delta_d \quad \text{...................(2)}$$

The design concept is thus very simple. Such complexity that exists relates to determination substitute structure characteristics, the determination of design displacement and development of design displacement spectra.

3. GEOMETRICAL MODELLING OF STRUCTURE

The software SAP2000 is utilized to create model and run all analyses. The software is able to predict the geometric nonlinear behavior of space frames under static or dynamic loadings, taking into account both geometric nonlinearity and material inelasticity. The software accepts static loads (either forces or displacements) as well as dynamic (accelerations) actions.

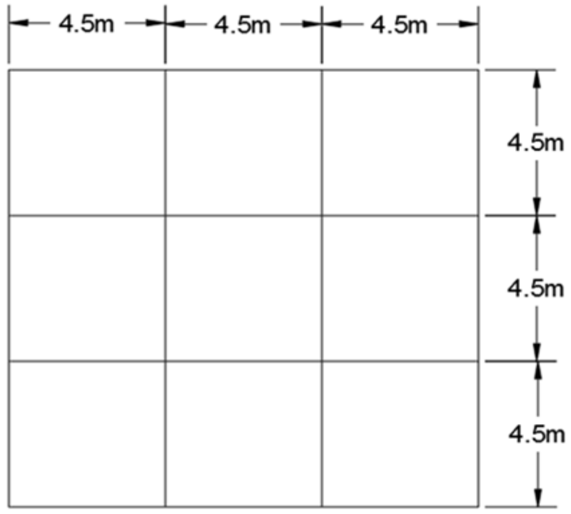

Fig-2: Plan of Building

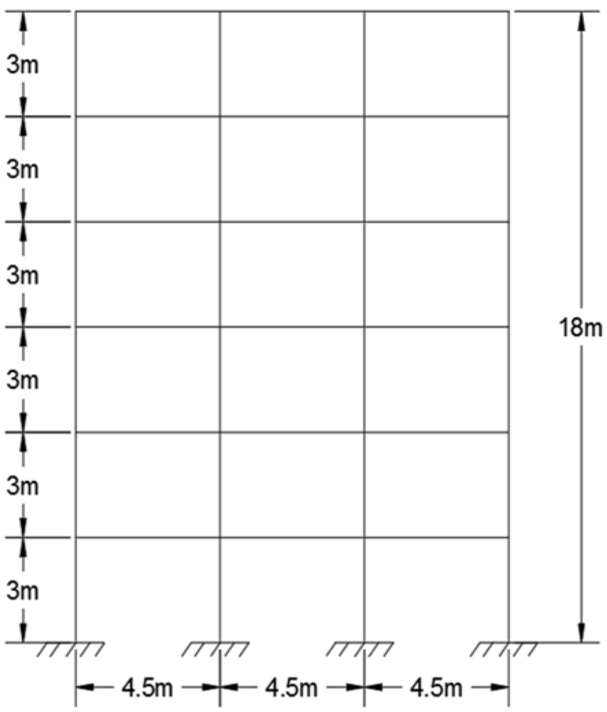

Fig-3: Elevation of Building

4. RESULTS

The geometrical modelling of frame referred in previous chapter is carried out using SAP2000 software. The analysis and design is carried out by using IS 1893 (Part I): 2002 and various results are drawn which are stated in this chapter.

4.1 Base Shear for IS code Method

Analysis is done with the help of software and various results are drawn for the study purpose. The base shear from the software is given in table 1:

Table-1: Base Shear for various load combinations

Output Case	Global FX	Global FY
	KN	KN
Ex	701.51	2.83E-10
Ey	3.07E-10	647.382
1.5(DL)	2.46E-14	2.03E-15
1.5(DL+LL)	3.63E-14	1.47E-15
1.2(DL+LL+Ex)	841.813	3.39E-10
1.2(DL+LL-Ex)	841.813	3.39E-10
1.2(DL+LL+Ey)	3.68E-10	776.859
1.2(DL+LL-Ey)	3.68E-10	776.859
1.5(DL+Ex)	1052.266	4.24E-10
1.5(DL-Ex)	1052.266	4.24E-10
1.5(DL+Ey)	4.60E-10	971.074
1.5(DL-Ey)	4.60E-10	971.074
0.9(DL)+1.5(Ex)	1052.266	4.24E-10
0.9(DL)-1.5(Ex)	1052.266	4.24E-10
0.9(DL)+1.5(Ey)	4.60E-10	971.074
0.9(DL)-1.5(Ey)	4.60E-10	971.074

The various parameters for Direct Displacement based method are given in table 2.

Table-2: Parameters for Direct Displacement based Method

Target displacement (Δ_d)	0.291 m
Effective height of ESDOF system (He)	12.201 m
Equivalent mass (m_e)	886.789 tonnes
Frame yield rotation (θy)	0.014
Equivalent yield displacement (Δy)	0.172
Design displacement ductility factor (μ)	1.699
Equivalent effective damping (ξeq)	13.893 %

4.2 Storey Drift

The story drift is the relative displacement between two floors. It is important to know the storey drift because if the maximum storey drift is greater than the allowable storey drift then it is not permitted in the design procedures. If the storey drift is greater than the allowable storey drift then it is required to revise all the design procedure and follow all the design steps again and make this process till the storey drift has lesser value than the allowable drift.

IS code gives the value for the allowable storey drift and is given by the formula as:

Allowable storey drift is=0.004*storey height
Allowable storey drift is=0.004*3000=12mm

The maximum storey drift is 4.22mm and it is between the second and third floors. The storey drift 4.22mm is less than the allowable storey drift which is 12mm. Therefore the design is safe.

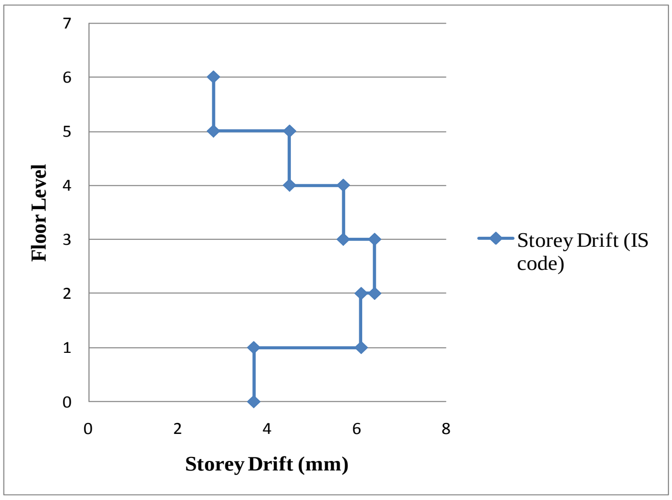

Chart-1: Storey Drift for IS Code Method

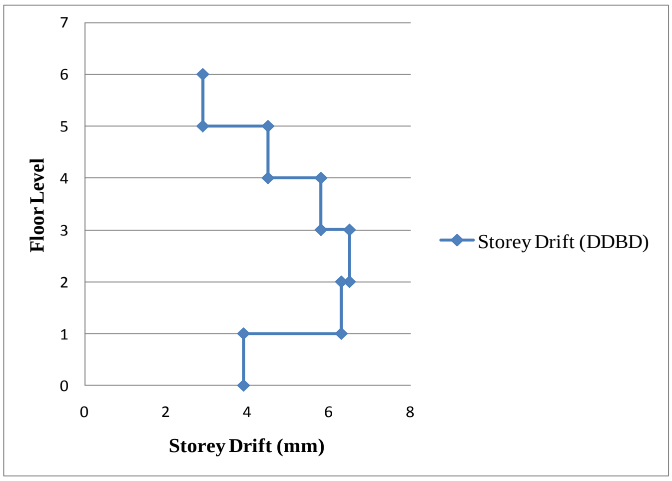

Chart-2: Storey Drift for Direct Displacement Method

4.3 Interstorey Drift Ratio (IDR)

The interstorey drift ratio is calculated from the following formula as:

Interstorey Drift Ratio (IDR) in percentage= (Relative displacement between two floors/Storey height)*100

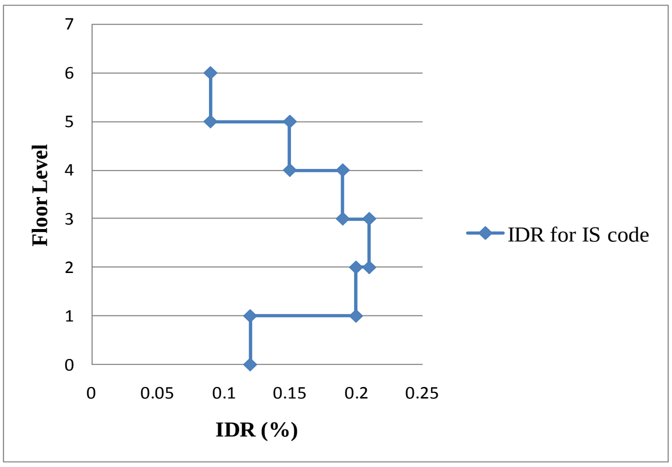

Chart-3: Interstorey Drift Ratio for IS Code method

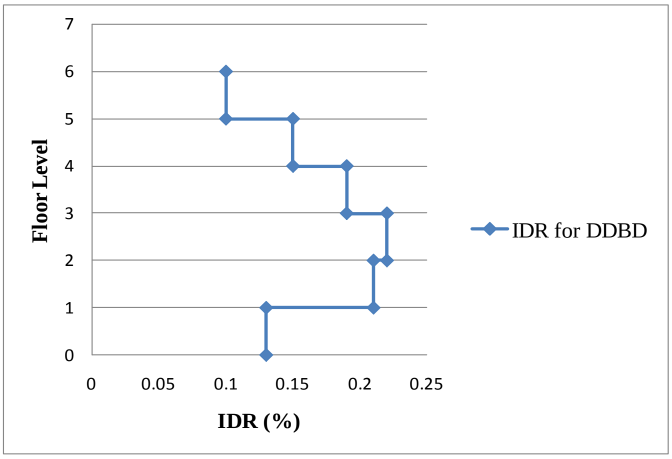

Chart-4: Interstorey Drift Ratio for Direct Displacement Method

4.4 Reinforcement Details

After completion of analysis part, design part gives the required reinforcement details which are given in the table 3 and these reinforcement details are drawn with the help of various design parameters such as Rebar Percentage, Column P-M-M interaction ratios, Column-Beam Capacity Ratios and Joint Shear Capacity Ratios. The above parameters are considered with their limits for the design purpose.

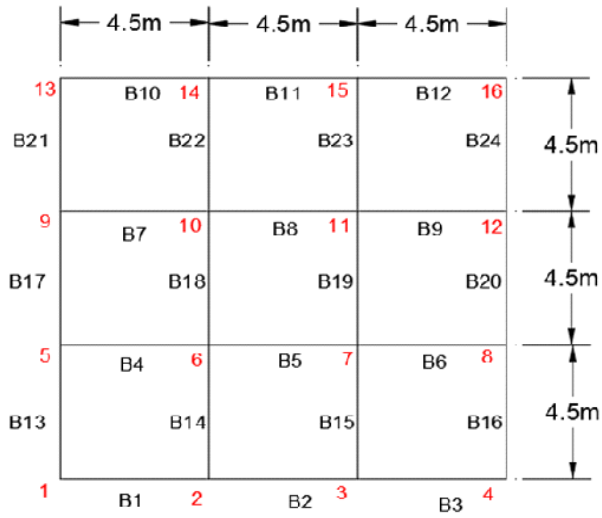

Fig-4: Nomenclature for plan of Building

The grouping for the various columns on the basis of their position in the plan is given as below-

C1- C1, C4, C13, C16
C2- C2, C3, C5, C8, C9, C12, C14, C15
C6- C6, C7, C10, C11

Table-3: Reinforcement Details for Columns of Building

Floor No.	Member	Reinforcement (mm²)	Reinforcement (mm²)
1st	C1	2206	2228
	C2	1962	2026
	C6	1711	1904
2nd	C1	1600	1421
	C2	1629	1549
	C6	1711	1885
3rd	C1	1600	1421
	C2	1629	1548
	C6	1711	1748
4th	C1	1600	1421
	C2	1629	1538
	C6	1697	1593
5th	C1	1600	1421
	C2	1600	1454
	C6	1600	1494
6th	C1	1600	1421
	C2	1600	1421
	C6	1600	1421

5. CONCLUSIONS

- The storey drift for the concerned geometrical model is within the allowable limit of storey drift given in IS 1893 (Part 1):2002
- The maximum Interstorey Drift Ratio (IDR) is less than design drift for the Collapse Prevention (CP) performance level.
- The column beam capacity ratio is greater than 1.1 for concerned member sizes which ensures strong column weak beam philosophy.
- The concerned DDBD philosophy gives economical design.

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