A COMPARATIVE STUDY OF FORCE BASED DESIGN AND DIRECT DISPLACEMENT BASED DESIGN FOR RC DUAL-WALL FRAME STRUCTURE.

Salehali M. Bhaisaheb[1], Dr.Bimal A. Shah.[2]

[1]PG Student, Applied Mechanics & Structural Engineering department, Faculty of Technology & Engineering The Maharaja Sayajirao university Of Baroda , Vadodara, Gujarat , India.
[2]Head & Associate Professor, Applied Mechanics and Structural Engineering Department, Faculty of Technology & Engineering, The M.S. University of Baroda, Vadodara, Gujarat, India

---***---

Abstract – *The Indian Code method for calculating seismic forces for Reinforced Concrete Building ie IS 1893:2002 is Force Based which has some drawbacks such as initial stiffness Characterization, variation in Response Reduction factor, calculation of time period is height dependent. The code cannot calculate force required for specified performance of building. These problems resulted in the need for an alternative design approach, which lead to the Performance Based Design (PBD). Direct Displacement Based Design (DDBD) method is based on PBD. the major aspects of the entire paper in the following prescribed sequence.. Design and analysis is done for reinforced frame buildings of 8, 12, 16 and 20 storey based on following codes IS 456:2000, IS 1893:2002 and the two design approaches are studied. Analysis and design is done using commercial software ETABS 2015. It has been found that the reinforced concrete frame buildings designed by DDBD method is economical than those designed with FBD method under similar conditions of modeling.*

***Key Words*: Force Based Design, Direct Displacement Based design, Is 1893:2002, RC Dual Wall-Frame Structure , Shear-Wall.**

1.INTRODUCTION

The most detrimental effect of all on a building is arguably Earthquake force and still there is no accurate method to predict behaviour of the building during such event. Hence need arises for a design practice that can give assurance for specified performance of a building during earthquake.

Code practices have been Force Based; the current code IS 1893:2002 also uses the same. The methodology used is that the individual components are so proportioned and designed that they can perform specific goal during earthquake ie the structure can sustain the shocks of low intensities without damage, the structure can sustain the shocks of moderate intensities without structural damage and the shocks of heavy intensities without total collapse.

The inelastic effects are indirectly accounted for by using a Response reduction factor R, which is based on some form of the equal-displacement and equal-energy principles. In the code procedures, an explicit assessment of the anticipated performance of the structure is not done. In the force based codal method of design, the base shear is computed based on perceived seismic hazard level, importance of the building and the appropriate force reduction factor. Then this base shear is distributed over the height of building with some prescribed or estimated distribution pattern. Force Based Design (FBD) suffers from many problems such as the assumed stiffness of the different structural elements, inappropriate response reduction factor and calculation of time period. The emphasis is that; the structure should be able to resist design base shear. Force based design method cannot design structures for target design objectives under a specified hazard level

There are some inherent flaws in Force Based Design ie the Strength and Stiffness are considered independent which is Incorrect, Time period Calculations according to code includes height and lateral dimensions, which gives very low time period, Force Reduction Factor shows wide discrepancy when compared to codes of other nations, To mitigate this flaws an alternative design philosophy named “Displacement-Based Design (DBD)” was first introduced by Qi and Moehle (1991), which included translational displacement, rotation, strain etc. in the basic design criteria and then Direct Displacement Based Design (DDBD) was proposed by M.J.N. Priestley (1993) [1]. The Direct Displacement Based Design (DDBD) is based on Performance Based Design (PBD). This philosophy is a very promising design tool that enables a designer to design a structure with predictable performance.

2 Direct Displacement Based Design.

The design procedure known as Direct Displacement-Based Design (DDBD) has been developed over the past ten years with the aim of mitigating the deficiencies in current force-based design.

The fundamental difference from force-based design(FBD) is that DDBD characterizes the structure to be designed by a single-degree-of-freedom (SDOF) representation of performance at peak displacement response, rather than by its initial elastic characteristics.

The initial literature for the procedure was presented by M.J.N Priestley, G.M. Calvi , M.J.Kowalsky in the form of book Displacement Based Seismic Design Of Structures. In the DDBD, the multi degree of freedom structure is converted into equivalent single degree of freedom system. For multi-degree-of-freedom (MDOF) structures the initial part of the design process requires the determination of the characteristics of the equivalent SDOF substitute structure which is shown in fig-1.

There are systematic steps defined in the book for calculation of base shear and also it's distribution at various storey levels for fulfilment of specified goals to be achieved by building during an earthquake, primarily in the form of storey drifts. These steps for finding base shear for RC Dual Wall-Frame Structure[1} are defined below.

Step 1:- (a) Frame Shear Ratio

The proportion β_f of total base shear V_{base} carried by the frame is selected. Hence

$$V_f = \beta_f * V_{base}$$

$$V_w = (1- \beta_f) * V_{base}$$

Where V_f and V_w are the base shear force carried by the frames and walls respectively.

Step 2:- Yield deformation of the wall and frames

As the walls tend to control the response of frame-wall structures, the wall yield curvature and displacements at yield are important for the development of the design displacement profile. The yield curvature of the walls, at base is firstly obtained using

$$\Phi_{yw} = 2\varepsilon_y / l_w$$

The displacement profile of the structure at yield of the wall, Δ_{iw} can then be established using the wall yield curvature, inflection height and storey height in accordance with Eq.

$$H_I \leq Hcf \quad \Delta yw = \theta y * \left[\frac{Hi^2}{2} - \frac{Hi^3}{6Hcf}\right]$$

$$H_I \geq Hcf \quad \Delta yw = \theta y * \left[\frac{Hi * Hcf}{2} - \frac{Hcf^2}{6}\right]$$

The frame yield drift θ_{yframe} used to estimate the ductility and equivalent viscous damping of the frames, is obtained in accordance with Eq

$$\theta_{yframe} = \frac{0.5 * l_b * \varepsilon_y}{h_b}$$

Where l_b is the average beam length, ε_y is the yield strain of beam longitudinal reinforcement and h_b is the average depth of the beams at the level of interest.

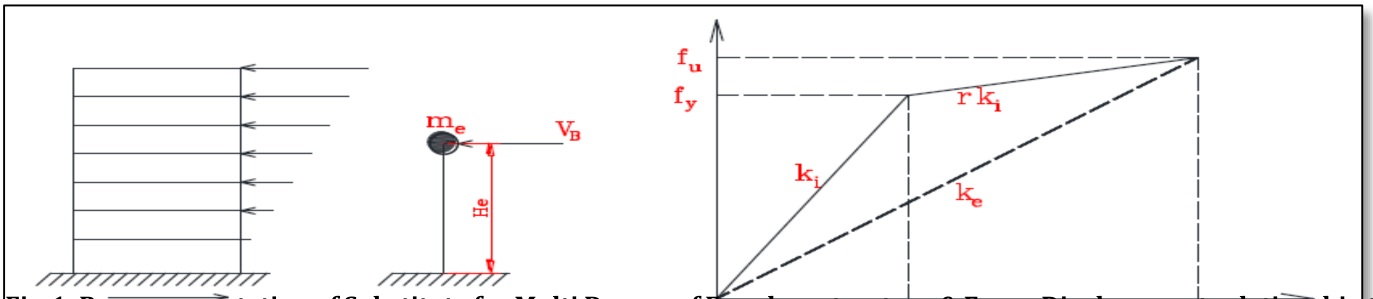

Fig-1: Reprepresentation of Substitute for Multi Degree of Freedom structure & Force-Displacement relationship till failure.

Step 3 Design displacement profile and equivalent SDOF characteristics

The design displacement profile is developed using the various values obtained in the preceding subsections, together with the design storey drift, as shown in Eq.

$$\Delta_{di} = \Delta_{yi} + (\theta_c - \Phi_{yw} \frac{Hcf}{2}) * H_i$$

Where Δ_{di} is the design displacement for level i, Δ_{yi} is the displacement at level i at yield of the walls; θ_c is the design storey drift, Φ_{yw} is the yield curvature of the walls, H_{cf} is the inflection height, H_i is the height at level i. Correction for drift amplification: higher mode effects can amplify the drifts above the design targets implied by the first-mode design displacement profile for buildings with large numbers of storeys, and where β_f is high. For these cases,they recommend that the drift limit to be used in Eq to be reduced by multiplying a drift reduction factor W_θ

$$\theta_{Dc} = \theta_c * W_\theta = \theta_c * [(1-\frac{n-5}{100}) * (\frac{M_{otmf}}{M_{otm}} + 0.25)]$$

n= number of storey.

Where $W_\theta \leq \theta_c$,M_{otmf} Is the overturning resistance of the frame and M_{otm} is the total overturning resistance of the structure. As mentioned earlier, the ratio of frame to total overturning resistance can be obtained in terms of the base shear using the strength assignments made at the start of the design procedure.

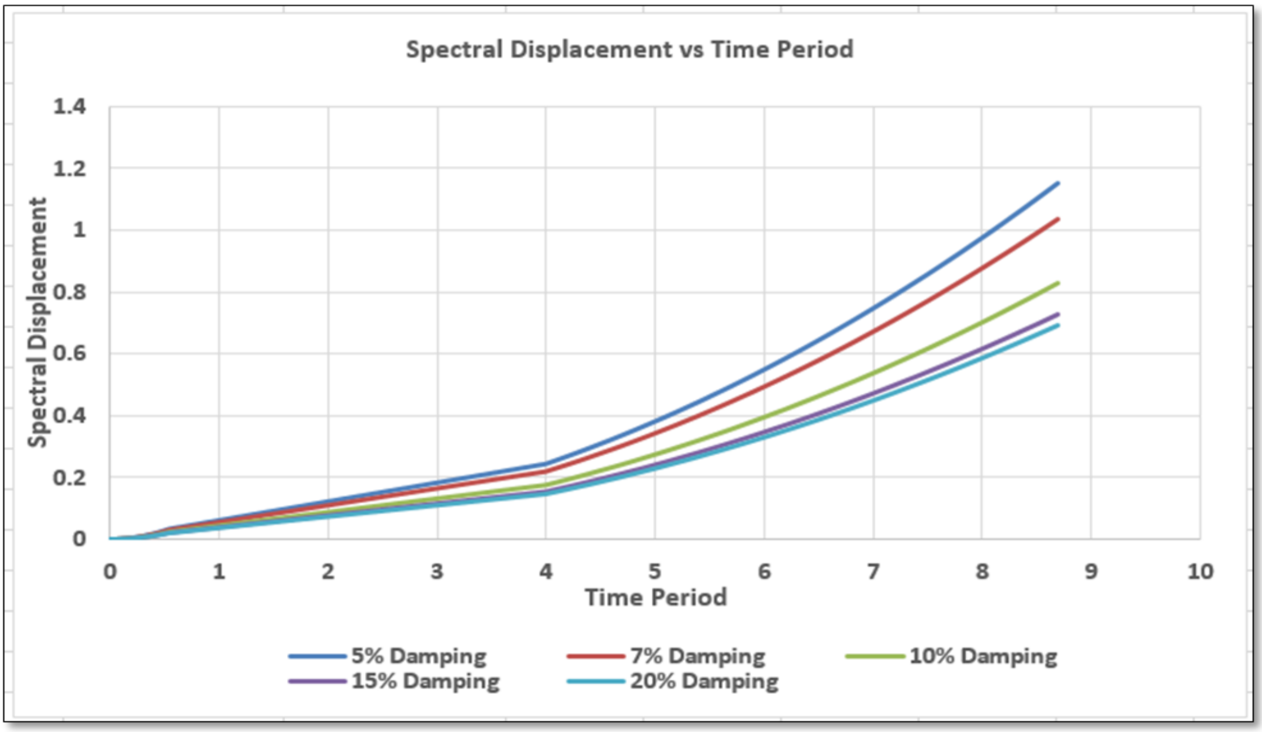

Fig-2 : Spectral Displacement vs Time Period

Step 4 Design Displacement Design Displacement of frame wall structure is given by following equation

$$\Delta d = \frac{\sum_{i=1}^{n}(m_i \Delta_{di}^2)}{\sum_{i=1}^{n}(m_i \Delta_{di})}$$

Step 5 Effective mass Effective mass is given by following equation

$$m_e = \frac{\sum_{i=1}^{n}(m_i \Delta d_i)}{\Delta d}$$

Step 6 Effective height Effective height is given by following equation

$$He = \frac{\sum_{i=1}^{n}(m_i \Delta_i H_i)}{\sum_{i=1}^{n}(m_i \Delta_i)}$$

Step 7 Equivalent Viscous Damping

The equivalent elastic damping to be used in design is

$$\xi_{sys} = \frac{\xi M_{otmf} + \xi_w M_{otmw}}{M_{otm}}$$

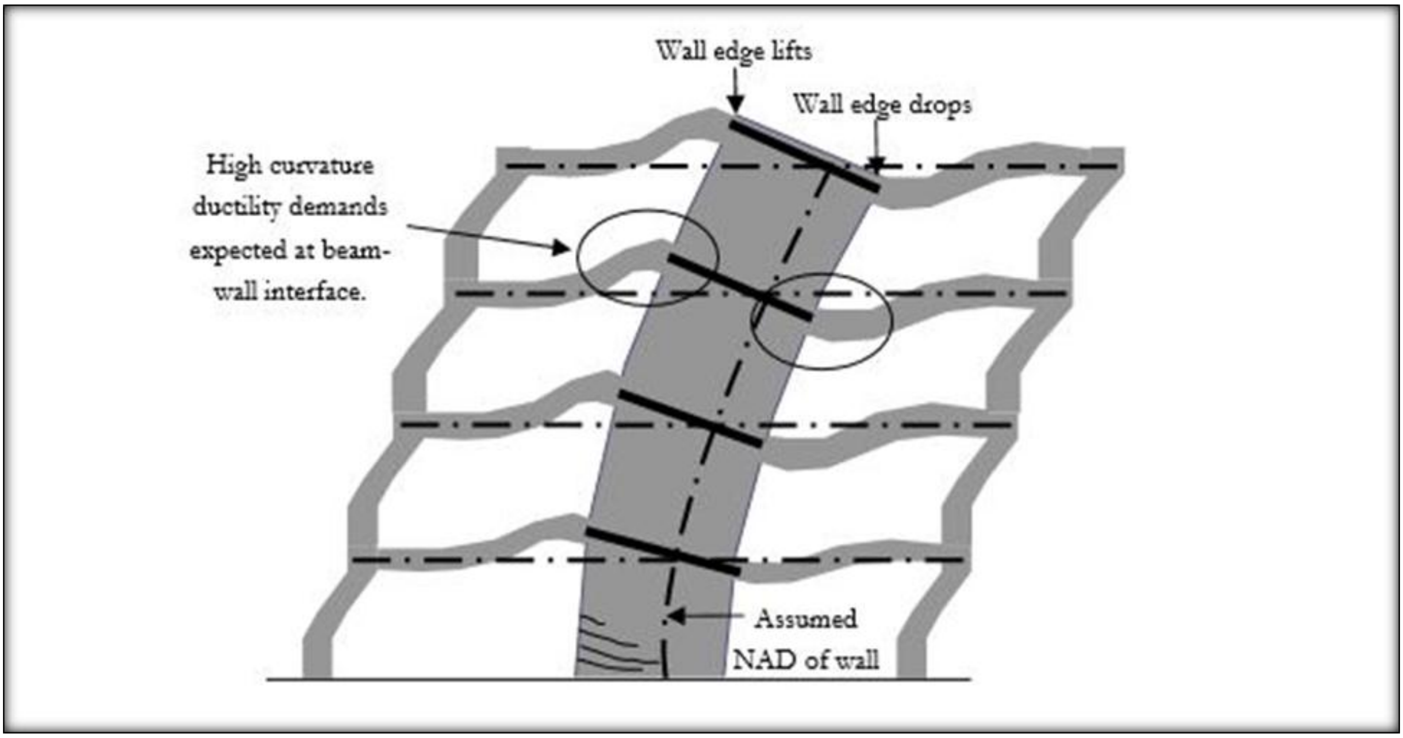

Fig-3: Shear Walls With Link Beams.[3]

Where ξ_w and ξ_f are the damping associated with ductile wall and frame response respectively.

The wall ductility demand is directly given by

$$\mu_w = \frac{\Delta_d}{\Delta_{yw}}$$

Where Δ_d is the design displacement, Δ_{yw} is yield Displacement of wall at effective height. Corresponding wall damping can be obtained by following equation ,

$$\xi_w = 0.05 + 0.44 * \left(\frac{\mu - 1}{\mu \Pi} \right)$$

The frame ductility demand may be estimated with adequate accuracy dividing the design displacement by the frame yield displacement at the effective height

Step 8: Effective Time Period (Te) of Substitute Structure:

It is the effective time period of the equivalent SDOF system and can be directly picked up from the displacement spectra which is given in fig.2

The equation of spectral displacement for design basis earthquake confirming to IS 1893:2002[2]

$$S_d = \frac{T^2}{4\pi^2} * \frac{S_a}{g} * g * \frac{Z}{2}$$

Step 9: Calculation of Base Shear

$$Ke= 4*\Pi*\Pi*Me/te^2$$

$$vbase = Ke*\Delta d$$

Step 10: Consideration Of Link Beam

If the shear wall are connected by Link beam then the moment in shear wall will reduce as stated by by M.J.N Priestley, G.M. Calvi , M.J.Kowalsky in their book[1] and also was presented by T.j.Sullivan & G.M.Calvi in their paper[3].

The interaction between the frames and walls of structures with link-beams is more significant than in the classical form of frame-wall structure in which the frames are parallel to the walls. As the walls deform their ends either lift or drop, depending on whether the bending in the wall puts that part of the wall in compression or tension, as illustrated in Figure 3. Additional curvatures are imposed on the link beams due to the change in elevation of the wall ends. The magnitude of these curvatures can be gauged taking the shift in elevation of the wall edge and dividing by the beam length, which gives the equivalent chord rotation imposed on the link beams.

The walls are also affected by the link-beams since the moment and shear from each beam must be carried by the walls. The link beam moments can change the wall moment profile significantly, whereas the shears may affect the axial load on the walls. For the frame-wall structures shown in Figure 3 the wall axial loads are not affected by the link-beam shears which apply equal shears (owing to their equal strength) in opposing directions on either side of the wall and therefore cancel each other out. The moments however will need to be accounted for as these tend to sum together at the wall Centre-line and can reduce the wall inflection height, which in turn affects the design displacement profile.

In fact, as mentioned above and depicted in Figure 3, the seismic shear in the pinned link-beam induces secondary moments in the walls that can be evaluated at the centreline axis as:

$$Mbwall = Mbl + [(Mb-Mbr)*(Lwcl/Lb)]$$

Where

Lwcl is the distance from the integral column centre line to the wall axis;

Lb is the span bay length;

Mbl & Mbr are the moment at the right and left end of the link-beam, that for equal positive and negative moment capacities in the beam can be measured as

$$Mb = Vf*Hs/nbe$$

nbe is no of hinges formed in particular frame , two hinges per beam and if beam is ending into wall then hinge taken for that beam is 1.

3. NUMERICAL MODELLING AND ANALYSIS.

For comparison between the two design method (FBD and DDBD), typical plan as shown in fig-4 is considered. The height of buildings are considered as 8, 12, 16 and 20 –storey having typical storey height 3 m and bottom storey height 4m in each building model. The Bay Length in X Direction is 5m with no of bays 5 giving total length 25m in X-Direction, The Bay Length in Y Direction is 6m with no of bays 3 giving total length 18 m in Y-Direction. The Shear wall are located in middle bay in both direction.

The nomenclature for this purpose is as follows ISLS is used for Indian code IS 893:2002[2] based Linear Static method, ISRS is used for Indian code IS 893:2002 based Response Spectrum method, & DDBD for Direct Displacement Based Design. Suffix of no of storey is added to all of above method for example ISLS-8 for Linear Static method for 8 storey building.

Table-6 Comparison of Consumption of Concrete For DDBD & FBD

Total No. of Storey	Consumption Of Reinforcing Concrete (m^3)		
	FBD	DDBD	RS
20	1410.14	1247.47	1410.14
16	1119.60	919.68	1120.32
12	831.79	697.30	831.79
8	541.80	453.79	541.80

Following points can be concluded

i. DDBD gives less values for both concrete and steel than FBD thus it is economical compared to FBD
ii. As the storey height increases the difference reduces which is obvious as difference in base shear also reduces.

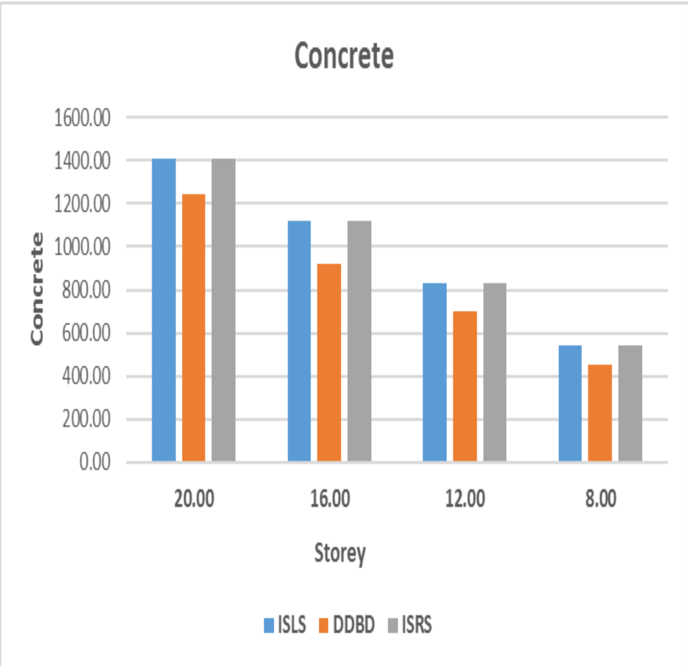

Chart-2 Comparison of Concrete Required for FBD & DDBD

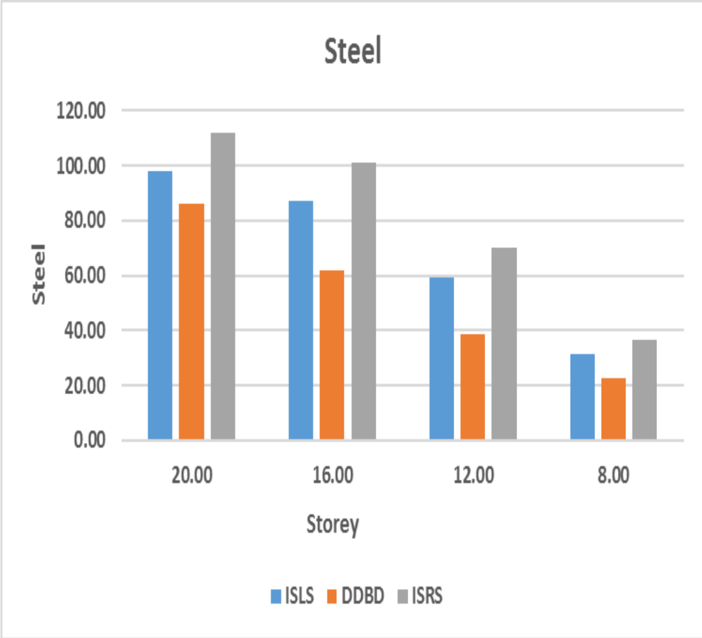

Chart-3 Comparison of Reinforcing Steel Required for FBD & DDBD

5. CONCLUSION.

By comparing Base shear, quantities of steel and concrete following point can be concluded.

i. Direct Displacement Based Design gives much less value of Base shear as compared to IS 1893:2002. Base shear obtained by DDBD for 8, 12, 16, 20 , is less by 58.05%, 50.3%, 35.3%, 9.57% respectively than FBD in X direction and 57.34%, 41.7% , 25.2% , 7.74% in Y direction

ii. The Difference reduces and both method Force Based and Direct Displacement Based Converges as no of storey increases.

iii. For satisfying Design criteria of Indian code the member size required for DDBD are less as compared to FBD.

iv. The Direct Displacement Based method gives less quantities of concrete and steel as compared to Force Based method thus DDBD is Economical as compared to FBD.