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Direct Displacement Based Design (Based on Priestley and Kowalsky) versus Force Based Design for wall structures

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Abstract: A seismic design procedure is developed to enable design of concrete wall buildings in order to achieve a specified acceptable level of damages under the designed earthquake.

The practice shows the simplicity of procedures based on direct displacement based design method in comparison with force-based design method.

In order to explain the differences between these two methods we demonstrated their application in wall buildings of four, eight and twelve multi storey buildings. The results obtained are showing significant differences, thus we recommended one of these two methods.

***Keywords*: Direct Displacement Based Design, Force Based Design, yield displacements, ductility, RC Walls, limit states.**

Introduction

In anti-seismic design principles of reinforced concrete structures under seismic codes that are based on strength ("Force Based Design - FBD "), initial basis is setting the stiffness directly from the cross-section dimensions.

In fact, the distribution of forces becomes in function of the initial stiffness, in these cases, the stiffness remains constant size. However, experimental data's from several prominent researchers of the field as Priestley etc. showed that the yield curvature is base quantity which depends on the cross-sectional dimensions (*Fig 1-b)*. For this, stiffness determined in the initial stage of design can change significantly, and the distribution of forces based on the initial stiffness contain errors.

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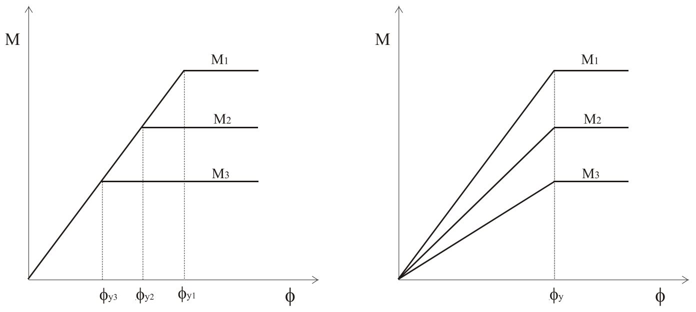


a)Constant stiffness *b) constant yield curvature*

Fig. 1, Influence of strength on Moment - curvature relationship

The concept of design "Direct Displacement Based design- DDBD" is an alternative "philosophy" of the seismic design. Input parameter to this method is the maximum allowable displacement. Though, a seismic design is oriented in such a way that structural limit state is expressed by acceptable maximum deformation (displacement).

Based on Priestley and Kowalsky [2-8] curvature on the limit state of the wall console, which is subject of study in this paper, is given by:

$$\phi_y = \frac{2\varepsilon_y}{l_w} \pm 5\% \qquad (1)$$

where l_w is wall length and ε_y is relative deformation of the reinforcement at the limit state.

The formulation of the DDBD methods [2-7]

The procedure applied to a seismic design according to this method that dedicates to equivalent substitute structure is illustrated in Fig.2.

Bilinear inelastic behavior of the system is presented in Fig.2b. As it is seen from the figure, in the procedure according to Priestley's DDBD is operating with secant effective stiffness Ke that corresponds with maximum displacement Δd. A total effective damping ξd is used as well. Size ξd is taken as a sum of elastic damping and hysteretic damping. The size of hysteretic damping is estimated based on the expected characteristics of hysteretic and the level of structure ductility (Fig.2c.). The period of vibration of the structure in design is extracted by using the accepted displacement spectrum that reflects the parameters of the earthquake magnitude, hypo central distance and a wide range of damping values (Fig.2d.).

$$K_e = \frac{4\pi^2 m_e}{T_e^2} \qquad (2)$$

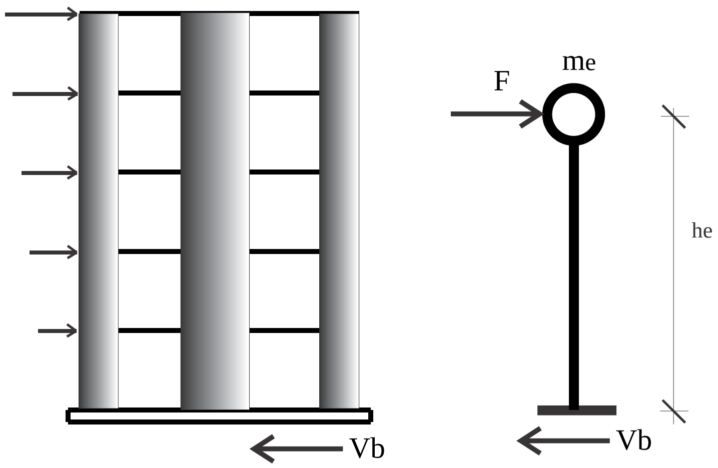
where $\mathbf{m_e}$ is the effective mass of structure.

By using of known static relationship can be evaluated the following expression of horizontal strength:

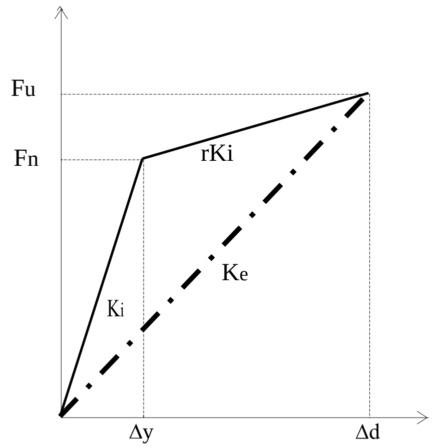
$$F = V_B = K_e \Delta_d \qquad (3)$$

where *F*- design base shear

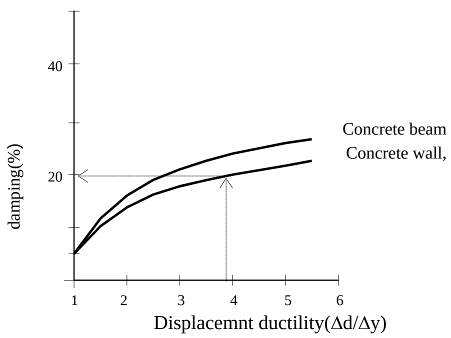
The procedure followed by Priesley's method for the implementation of the project is simple. However, the steps that impose this procedure are accompanied with the complexity of determining the characteristics of the substitute structure. The particular attention should be paid during the distribution of the horizontal forces and analysis of the structure under the action of distributed seismic load.



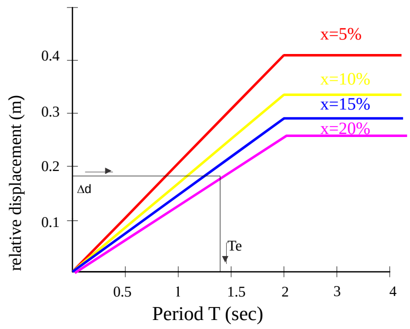
(a)simulation of the system with single degree of freedom



(b) Effective stiffness Ke



(c)equivalent damping versus ductility



(d) design displacement respons spectra

Fig. 2, Fundamentals of direct displacement based design

Further, the effective stiffness of equivalent system with single degree of freedom for maximum displacement can be determined by the expression:

Designed displacement is dependent on the type of structure and limit state. Given limit state (serviceability limit state, deformability control limit state etc) conditions required performance of structure. Thus, structural performance depends on deformation limit state in the material, while damages are residual deformation of structural elements. From the engineering perspective it is

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reasonable setting of designed displacement from limit deformations.

Equivalent viscous damping

$$\xi_d = 5 + \xi_{hist} \ \% \tag{4}$$

$$\xi_{hist} = 100 \cdot \frac{A_h}{2\pi F_m \Delta_m} \ \% \tag{5}$$

Column or concrete wall:

$$\xi_d = 5 + 95\left(\frac{1-\mu^{-0.5}}{\pi}\right) \tag{6}$$

In the above equations $\mu = \Delta_d / \Delta_y$ is the displacement ductility, for designed displacement.

Design displacement spectra

$$\Delta_{T,5} = \frac{T^2}{4\pi^2} a_{T,5} g \tag{7}$$

where, $\Delta_{(T,5)}$ and $a_{(T,5)}$ are displacement and acceleration for damping 5% in period **T**, while **g** is acceleration due to gravity.:

For other levels of damping displacement is determined by the expressions

$$\Delta_{T,\xi} = \Delta_{T,5} \cdot \left(\frac{10}{5+\xi}\right)^{0.5} \tag{8}$$

and, finally from equation 3: 4

$$V_B = K_e \cdot \Delta_d = \frac{4\pi^2 m_e}{T_D^2} \cdot \frac{\Delta_{D,5}^2}{\Delta_d} \cdot \left(\frac{10}{5+\xi}\right) \tag{9}$$

In addition, in Figure 3 is shown schematically, according to EC-8 2003 design displacement spectra for type 1 to earthquakes, land category B and acceleration 0.3g and 0.4g.

Design displacement

In many cases, the design displacement will be dictated by different codes in the function of the angle of rotation θ_c.

$$\Delta_d = \sum_{i=1}^{n}\left(m_i \Delta_i^2\right) / \sum_{i=1}^{n}\left(m_i \Delta_i\right) \quad 6 \tag{10}$$

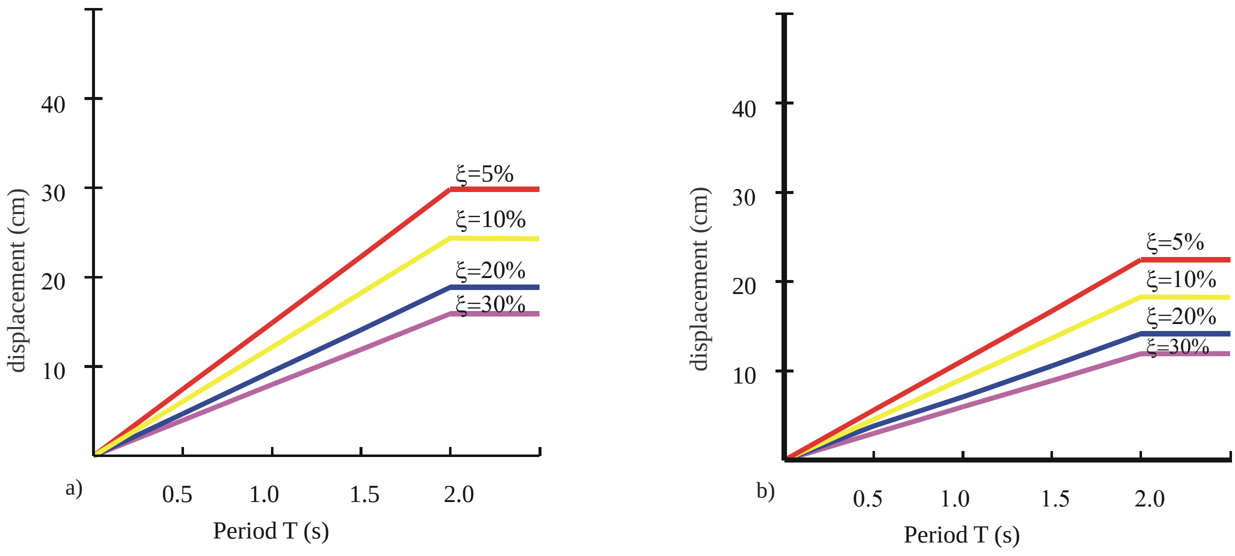


Fig. 3, Design displacement spectra-a)acceleration 0.4g; b)acceleration 0.3g

Lateral force analysis

Shear force base should be distributed on the wall proportionally to the square of the length of walls and after the analysis can be done separately for each wall.

$$V_{wi} = \frac{l_{wj}^2}{\sum_{j=1}^{m} l_{wj}^2} V_B \quad (11)$$

Summary of Steps of two methods

DDBD - Direct Displacement Based Design

1. ***Defining the maximum allowable displacement for different limit state***
2. ***Choosing acceptable level of the system viscous damping***
3. ***Choosing displacement design spectrum for different levels of damping and getting effective period for maximum allowed displacement. Effective period presents in-elastic response of the structure***
4. ***Determining of the base shear force***
5. ***Using of proper method for structural analysis and determining design demands***

FBD - *Force Based Design*

1. ***Determining the stiffness of structure based on reduced cross section of elements***
2. ***Determining elastic period of the system and assessing the response of factor q***
3. ***Choosing the design response spectrum and determining "peak" acceleration of reaction***
4. ***Using peak acceleration and defining lateral forces in structure***
5. ***Checking of displacements***

Example

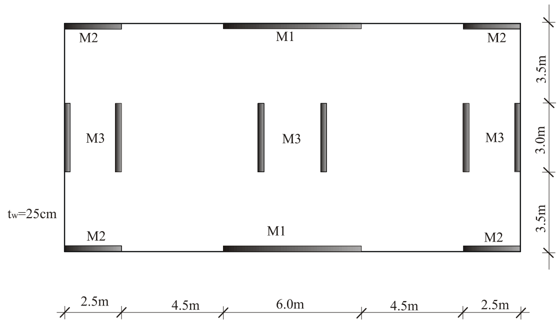
Description of reviewed structures

First case-eight storey building

Second case-four storey and

Third case –twelve storey building

The plan view is same for the three cases



Mass at each level of floors, for both cases is m = 350 Tons

Design spectra based on EC-8,B,I,v.jan.2003, $a_g = 0.5g$

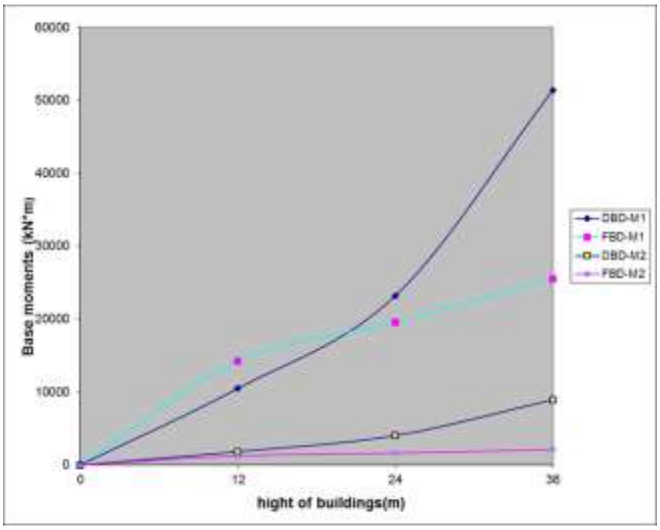
Results are presented in tabular and graphical form

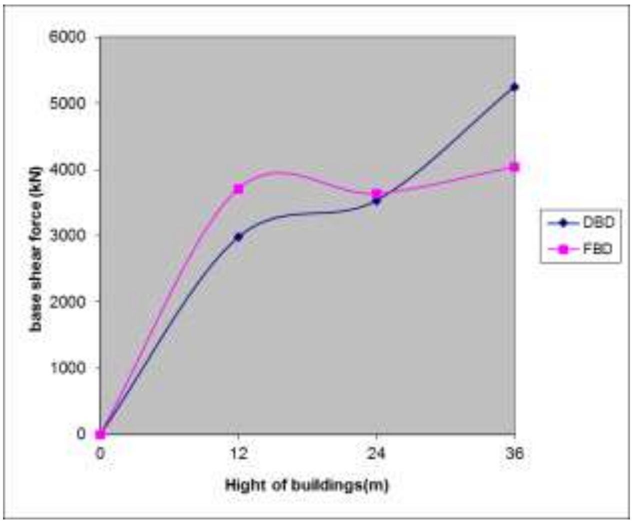
First case

	DBD	FBD
Period	2.92	1.156
Ductility	4.6	4
Damping %	18.22	5
Base shear force kN	3534.06	3639.8
Moments in M1 (kN*m)	23192.4	19562.5
Moments in M2 (kN*m)	4026.39	1609.42

Second case

	DBD	FBD
Period	1.72	0.368
Ductility	9.4	4
Damping %	21	5
Base shear force kN	2978	3707.9
Moments in M1 (kN*m)	10481	14217.18
Moments in M2 (kN*m)	1819.7	1244.29





Conclusion

In this paper is presented another alternative of a seismic design - DDBD for determining the base shear force for different limit state. The DDBD is preferred for the following reasons:

1). DDBD is more direct then FBD, since it is based on the curve of ultimate strength, which actually depends only from the cross height and deformation on the ultimate strength. While FBD depends on the stiffness treated as a constant which actually varies greatly in the process of improving the preliminary design.

2) DDBD makes adequate assessment of ductility demand.

3) For the twelve storey we have an large discrepancy for moments M1- DDBD has the right distribution of forces on the walls

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