CERTIFICATE

This is to certify that the project entitled **"Design of R.C.C Structure Using Direct Displacement Based Design"** is a bonafide work of **Ansari Mohd Shadab Alam (Roll No. 14CES06), Mohd Irfan Abdul Salam (Roll No. 14CES29), Qureshi Mohd Ayaz (Roll No. 14CES38), Siddiqui Faizan Ahsan (Roll No. 14CES48)** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of "Undergraduate" in "Civil Engineering"

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Date: 05-05-2018

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DECLARATION

We declare that this written submission represents my ideas in our own words and where others ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that, we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

In recent years, design emphasis is shifting from "*Strength*" to "*Performance*". Structures designed with current seismic design codes and standards, should be able to satisfy specific performance level, defined as life safety performance level, for a specific intensity of ground motion. However, economic losses and occupancy interruptions are not provided (i.e. human lives are protected, but the damages are not limited which may not be economic to repair, the period for re-occupancy is not given). In addition, although life safety performance level is obtained for different structures, the concept of uniform risk is not satisfied (i.e. the response of various structures is different in terms of damages for the same earthquake hazard levels) ***Direct-Displacement Based Design (DDBD)*** approach, proposed by Priestley for structures, is one of the simplest design approaches, widely accepted by researchers and it is based on PBSD approach. In DDBD approach maximum displacement in inelastic deformation of the structure is considered, and in contrast with Force-Based Design (FBD) approach, *displacement response spectrum* is used for obtaining base shear force. In this study it is proposed to evaluate DDBD with reference to Indian scenario, in consistence with IS codes and practice.

Keywords—*Force Based Design, Direct Displacement Based Seismic Design, ETABS 2016, IS 456-2000, IS 1893-2002.*

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ABBREVIATION NOTATION AND NOMENCLATURE

FBD	Force Based design
DDBD	Direct Displacement Based design
PBD	Performance Based Design
SMRF	Special Moment Resisting Frame
SDOF	Single Degree of Freedom
MDOF	Multi Degree of Freedom

Chapter 1

Introduction

1.1 General

India is a developing country with a variety of building practices, social and economic structures. Now-a-days major concept for design the building is to make building resistance against the forces or jerk due to earthquake. Due to these lateral forces of earthquake huge amount of stress or displacement in structure, the strength gets weaken down resulting in catastrophic failure of the structure. Over the period, *Earthquake Engineering* has evolved and it is the right time to adopt advances in the research into the design practice. Based on the design approach, seismic design is broadly classified in the following two categories, Force Based Design, and Displacement Based Design. In this study both approaches are studied and compared to check the performance of Displacement Based approach in design practice.

1.2 Recent Earthquake in India

The table 1.1 gives an overview of recent earthquakes in India along with magnitude and loss of life and property

Table 1.1 Recent Earthquakes in India

Date	Time	Location	Epicenter	Death	Magnitude
03 January, 2017	2:39 IST	India, Bangladesh	24.015°N, 92.018°E	8	5.7
4 January, 2016	04:35 IST	North East, India	24.8°N, 93.6°E	11 dead, 200 injured in Manipur & Assam	6.7
26 October, 2015	14:39 IST	Northern India, Pakistan, Afghanistan	36.524°"N, 70.368°"E	280 in Pakistan, 115 in Afghanistan and 4 in India	7.5
12 May, 2015	12:35 IST	Northern & North East India	27.794°N, 85.974°E	218	7.3
25 April, 2015	12:19 IST	Northern India	28.230°N, 84.731°E	8857	7.8
1 May, 2013	06:57 IST	Kashmir	33.1°N, 75.84°E	3 dead, 100 injured	5.7
5 March, 2012	13:10 IST	New Delhi	28.6°N, 77.4°E	1	5.2
18 September, 2011	18:10 IST	Gangtok, Sikkim	27.723°N, 88.064°E	118	6.9
10 August, 2009	01:21 IST	Andaman Islands	14.1°N, 92.8°E	26	7.5
6 February, 2008	11:39 IST	West Bengal	23.468°N, 87.116°E	50	4.3
6 November, 2007	05:58 IST	Gujrat	21.28°N, 70.7°E	5	5.1
8 October, 2005	08:50 IST	Kashmir	34.493°N, 73.629°E	130,000	7.6

26 December, 2004	09:28 IST	India Maldives	3.30°N, 95.87°E	283,106	9.1
26 January, 2001	08:50 IST	Gujarat	23.6°N, 69.8°E	20,000	7.7
29 March, 1999	00:35 IST	Chamoli district, Uttarakhand	30.408°N, 79.416°E	103 Approx.	6.8
22 May, 1997	13:41 IST	Jabalpur, Madhya Pradesh	23.18°N, 80.02°E	39	6.0
30 September, 1993	09:20 IST	Latur	18.08°N, 76.52°E	9,748	6.2
20 October, 1991	02:53 IST	Uttarkashi, Uttarakhand	30.73°N, 78.45°E	>2,000	7.0
21 August, 1988	04:40 IST	Udaipur, Nepal	26.755°N, 86.616°E	1,000	6.7
19 January, 1975	13:32 IST	Himachal Pradesh	32.46°N, 78.43°E	47	6.8

1.3 Need of the Project

Earthquake Engineering has grown in leaps and bounds through extensive research and experimentation. Many researchers have pointed out the shortcomings of the current force based design approach. It is therefore necessary to study reliable alternative to the force based design approach.

1.4 Organization of Report

First chapter presents brief introduction to the topic and necessity of the project. Second chapter presents review of literature pertaining to the topic. Third chapter illustrates the computational modelling. Fourth chapter presents the results of the analysis and its discussion. Fifth chapter presents the conclusion and future scope of the study.

Chapter 2

Literature Review

2.1 General

Current codes, which are based on force, based lack in achieving uniform risk. Many engineered buildings have collapsed in recent earthquakes, which has resulted in painful loss of life and property. This calls for a critical evaluation of the current approach and scout for alternatives to the current philosophy. Direct Displacement Based Seismic design is one promising method, which can be an alternative to the current Force-Based approach. This chapter presents the brief review of both methodologies.

2.2 Technical Papers

M.J. Nigel Priestley (1993) suggested that design is based on a static 'snapshot' simulation of the dynamic event, using methods extrapolated from approaches felt to be adequate and conservative for gravity load design. A major difference between gravity load effects and seismic response is that ultimate strength should never be developed under gravity load; ductile seismic response implies greater dependency on displacements than forces. It appears however that the extra ordinary approximations involved in seismic deign are perhaps becoming less appreciated rather than more as sophisticated analytical techniques become specified by codes and accepted into common design practice as matter of routine. The analyst is typically more involved in the analytical process than the correct simulation of member characteristics, with potential dangers. The result of the separation of design and analysis tends to be that analysis drives the design process, rather than the reverse, which might seem to be more appropriate.

In this paper, some of the accepted seismic design and analysis procedures are identified as 'myths' or 'fallacies' an overstatement perhaps, to make a rather dry topic seem more interesting. Nevertheless, a critical examination of the bases of our design processes is always appropriate, since the origin of these are often obscure, and lost in the history of design practice, or worse, in code committee minutes. Some of the points to be made are well known, others perhaps less so.

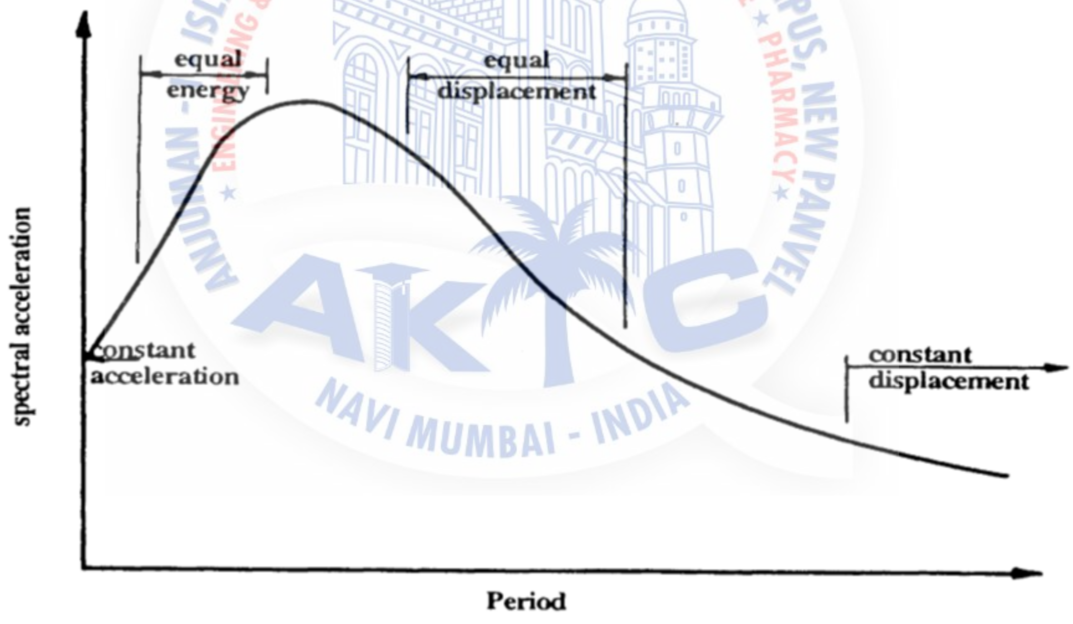

Figure 2.1 Design Acceleration Response Spectrum. [1]

Some Limitation of response spectrum summarize by fallacies

1. Response is based on a snapshot of structural response at the moment of peak base shear for an equivalent elasticity responding structure. During effects, which tend to be period-dependent with short period structure suffering a greater number of response cycles than long – period structure are not considered.

2. The elastic acceleration approach places excessive important on elastic stiffness characteristics of the structure and element and he found that they are less careful about determining these characteristics. The remains as to whether better alternatives might be considered. He believes that they can and that a more consistent approach may be achieved by complete inversion of the design process.

M. J. N. Priestley (2000) analyzed the development of capacity design principles in New Zealand in the 1970's (Park and Paulay, 1976) was an expression of the realization that the distribution of strength through a building was more important than the absolute value of the design base shear. It was recognized that a frame building would perform better under seismic attack if it could be assured that plastic hinges would occur in beams rather than in columns (weak beam/strong column mechanism), and if the shear strength of members exceeded the shear corresponding to flexural strength. This can be identified as the true start to performance based seismic design, where the overall performance of the building is controlled as a function of the design process.

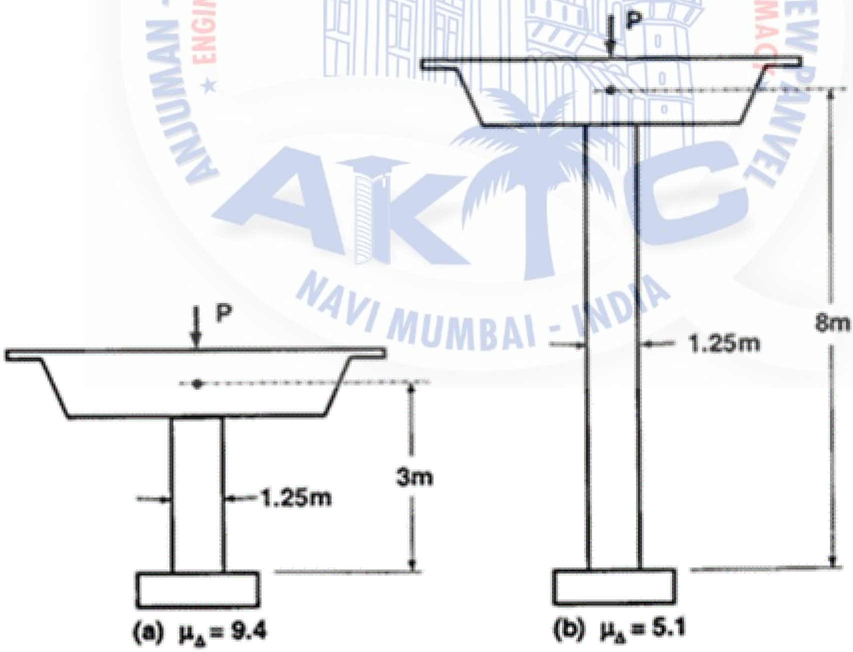

Figure 2.2 Influence of Height on Displacement Ductility Capacity of Circular Bridge Piers. [2]

Ductility capacity of concrete and masonry structures depends on a wide range of factors, including axial load ratio, reinforcement ratio, and structural geometry. Foundation compliance also can significantly affect the displacement ductility capacity.

These aspects were discussed in relation to bridge structures in a summary paper (Priestley and Park, 1985). An example of the influence of structure geometry on displacement ductility capacity is provided in Figure .2.2 (Kowalsky, 1995), which compares the ductility capacity of two bridge columns with identical cross sections, axial loads and reinforcement details, but with differing heights.

Moehle (1992) later suggested a similar approach to that of Priestley and Park (1985), for building structures. These approaches recognize some of the imperfections of a pure force-based design, by requiring calculation of the ductility capacity of structures, and checking this against estimates of the ductility demand corresponding to the design level of seismicity and force reduction factor adopted for design. In New Zealand and Europe this is still considered to be force-based design, while in the US the addition of the displacement check, possibly with modification of the design strength as a consequence of the displacement check, has come to be known as displacement-based design, or performance-based design.

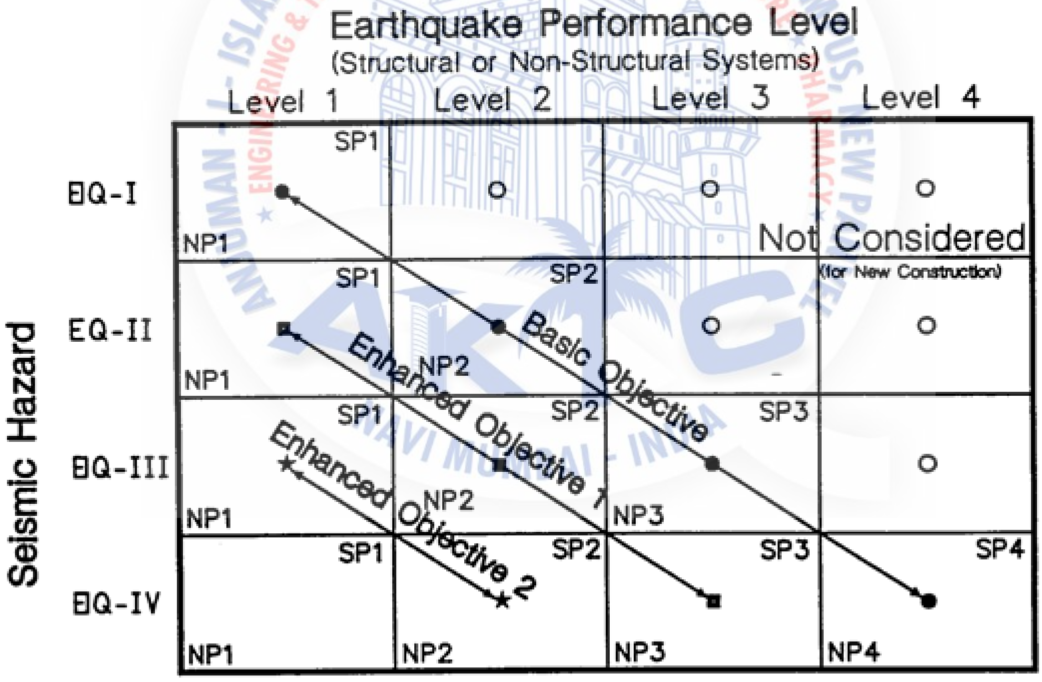

Figure 2.3 Relationship Between Earthquake Design Level and Performance Level (After OES, 1995). [2]

A crucial catalyst for this interest has been the Vision 2000 document, (OES, 1995) prepared by the Structural Engineers Association of California. The core of this document is the selection of "seismic performance objectives" defined as the "coupling of expected performance level with expected levels of seismic ground motions". Four performance levels are defined:

- **Fully Operational.** Facility continues in operation with negligible damage.
- **Operational**. Facility continues in operation with minor damage and minor disruption in nonessential services.
- **Life Safe**. Life safety is substantially protected, damage is moderated to extensive.
- **Near Collapse**. Life safety is at risk, damage is severe, structural collapse is prevented.

Direct Displacement-Based Design

It is apparent that the various procedures outlined above all advocate only minor changes to existing design approaches, and in fact do not advance beyond procedures which have been incorporated in the New Zealand Loadings Code for many years. There are also some conceptual and philosophical problems associated with force-based/displacement-check design:

- Thus, two different buildings designed to the same code and with the same force-reduction or ductility factors may experience different levels of damage under a given earthquake. This seems philosophically incompatible with the use of uniform-risk design spectra.
- For many, if not most structures, code drift limits will be found to govern, when realistic values are used for stiffness in displacement checks. Therefore, force-reduction factors will be less than code indicative limits. This implies the need for iterative design, and increased design complexity.
- It is generally accepted that damage is strain related (for structural components), or drift related (for non-structural components). There is no clear relationship between strength and damage. This is also obvious from point 1 above.

Figure 2.4 Failure of Approximately Similar Buildings During Bhuj Earthquake 2001[IITK]

At the same time, it is clear that increasing the computational effort of design, by requiring 3D elastic analysis, is not likely to result in better characterization of structural response than more simplified SDOF representations, unless structural response is essentially elastic. As a consequence of these considerations, an alternative design procedure known as "Direct Displacement-Based Design" has been developed (Priestley (1992), Priestley and Calvi (1997), Priestley and Kowalsky (2000), that attempts to recognize deficiencies in the current force-based approaches, and to characterize the structure by a SDOF representation of performance at peak displacement response.

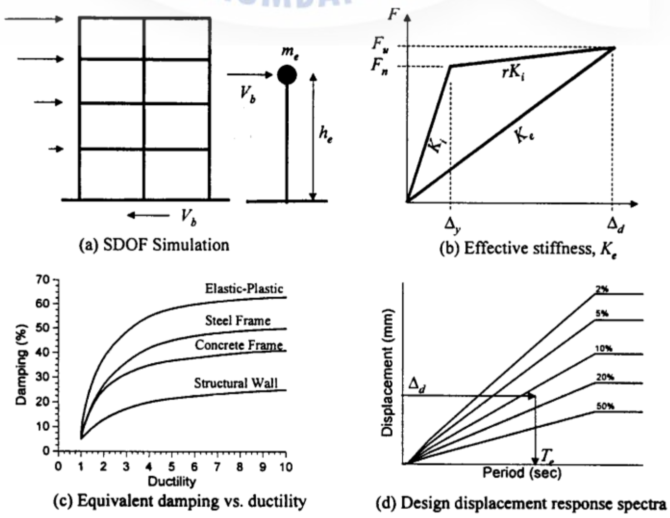

Figure 2.5 Fundamentals of Direct Displacement-Based Design. [2]

With the design displacement Δd determined, as discussed subsequently, and the damping estimated from the expected ductility demand, the effective period Te at maximum displacement response can be read from a set of design displacement spectra, as shown in the example of Figure 2.5(d). Representing the structure (Figure 2.5(a)) as an equivalent SDOF oscillator, the effective stiffness Ke at maximum response displacement can be found by inverting the equation for natural period of a SDOF oscillator, namely:

$$T_e = 2\pi\sqrt{\frac{me}{Ke}}$$

to provide

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

where me is the effective mass:

From Figure 2.5(b), the design base shear at maximum response is thus:

$$V_B = K_e * \Delta_d$$

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

It concluded that direct displacement based design method use for seismic design. It provide better safety and characterization of structural response as compare to force based design method.

M.J.N. Priestley and M.J. Kowalsky (2000) showed that the procedure is simple to apply, and results in significant differences from the more conventional force-based procedure. Designs for multi-storey frame and wall buildings were presented, and target displacements were compared with results from inelastic time history analysis. In the displacement-based design procedure, the design ductility level is determined based on damage and drift limitations at the start of the process, Influences of foundation flexibility could be simply and correctly incorporated in direct displacement-based design, but that care must be exercised when incorporating foundation flexibility into force based design, as the resulting reduction in ductility capacity is not recognized in the New Zealand design codes.

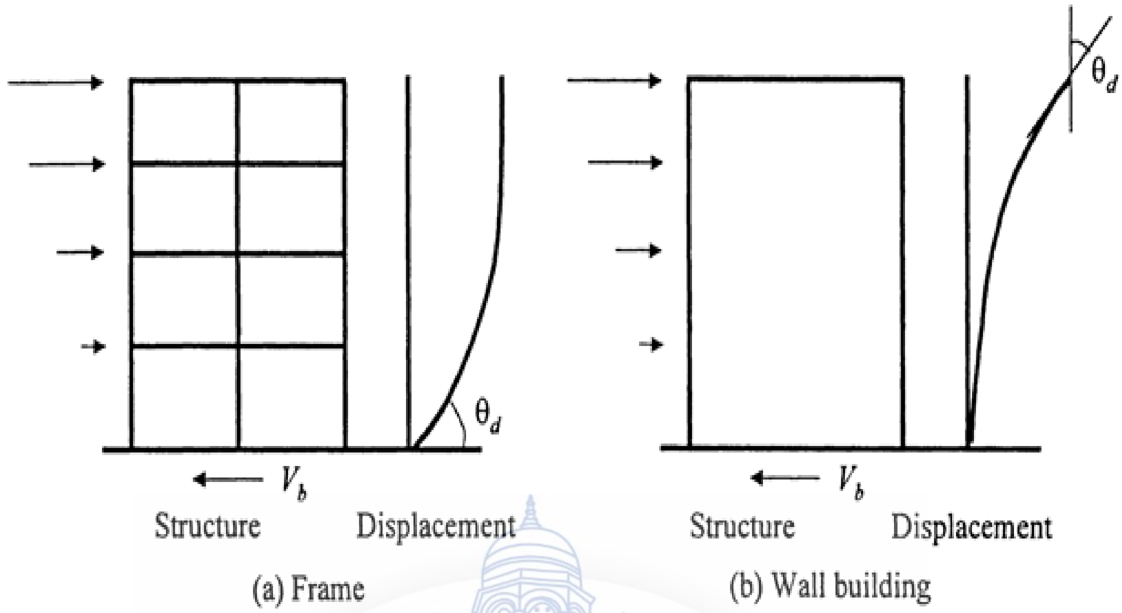

Figure 2.6 Critical Drifts for Building Structures. [3]

Qiang Xue, Cheng-Chung Chen (2003) suggested that the current seismic design regulations or design code should, in general, satisfy the following rules. First, resist minor level of earthquake ground motions without damage; second, resist moderate earthquakes without structural damage, but may experience some non-structural damage; and finally, resist major earthquakes without collapse. earthquake resistant design has been based on a force/strength approach employing only one response parameter-the base shear, at one specific level (generally 475 years return period) of earthquake ground motion (EQGM) to achieve the single performance objective-life safety. Although a structure is safe against collapse, it may deflect or vibrate excessively, or the non-structural elements are badly damaged so as to interfere with the further use. From past experience, we have learned that great losses comes from the non-structural damage and/or breaking off the normal work until further dam- age evaluation and rehabilitation are completed.

The purpose of performance-based earthquake engineering is to ensure that the engineered facilities whose performance under common and extreme earthquake ground motions respond to the diverse needs and objectives of the owners, users and society. To achieve this objective, the concept of direct displacement-based seismic design has received a lot of attention in recent years because such design focuses on displacement instead of force as the direct performance or damage indicator. Therefore, studies on the direct displacement-based design methods in the preliminary design phase, which deal with the characteristics of the design EQGM, are of particular importance.

T. J. Sullivan, G. M. Calvi, M. J. N. Priestley & M. J. Kowalsky (2003), carried out the case study which consist of eight different of direct-displacement based design on applying five different type of structure investigate the which method can be effectively use for different structure to get better result in terms of performance, economy, life safety, capacity etc. They are doing because of resent few year many procedure of DDBD is came out so which can be adopted. After this case study they are provided brief description.

They have successfully applied each method on structure and they have found that many methods is obtaining god and expected performance and all are giving significant design strength to the structure. The large difference in result arise is the case where methods have low influence on peak displacement due to the relationship between stiffness and displacement and all the methods which is limitation is has minor or may be major but it can overcome all those limitations.

T. J. Sullivan, G. M. Calvi and M. J. N. Priestley (2004) reviewed four of the most recent DBD methods that utilize response spectra, two of which were initial stiffness based and two of which were secant stiffness based. The results of the study infer that DBD utilizing response spectra with either initial stiffness or secant stiffness structural characteristics may be equally effective. There are three principal forms of analysis adopted; (i) Response Spectra - Initial Stiffness Based, (ii) Response Spectra - Secant Stiffness Based, and (iii) Time History Analysis Based. Out of these different approaches, those utilizing response spectra based on either initial stiffness or secant stiffness are generally faster than methods incorporating time history analyses.

Initial stiffness based use of response spectra in DBD- Figure 2.7 illustrates the concept of initial stiffness for a structure responding into the inelastic range to a displacement ΔD and strength level VB. A commonly adopted relation between the elastic and the inelastic response is the equal displacement approximation. This approximation argues that the displacement of the elastic system of initial stiffness, Ki, will be equal to that of the inelastic system. The performance of this and other R-μ-T relations.

Secant stiffness based use of response spectra in DBD-Figure 2.7 also illustrates how the secant or effective stiffness, Keff, is defined as the ratio of the strength, VB, to the maximum displacement ΔD. To facilitate design using the linear secant stiffness, an equivalent viscous damping coefficient is used to account for the energy dissipated during the actual non-linear structural response.

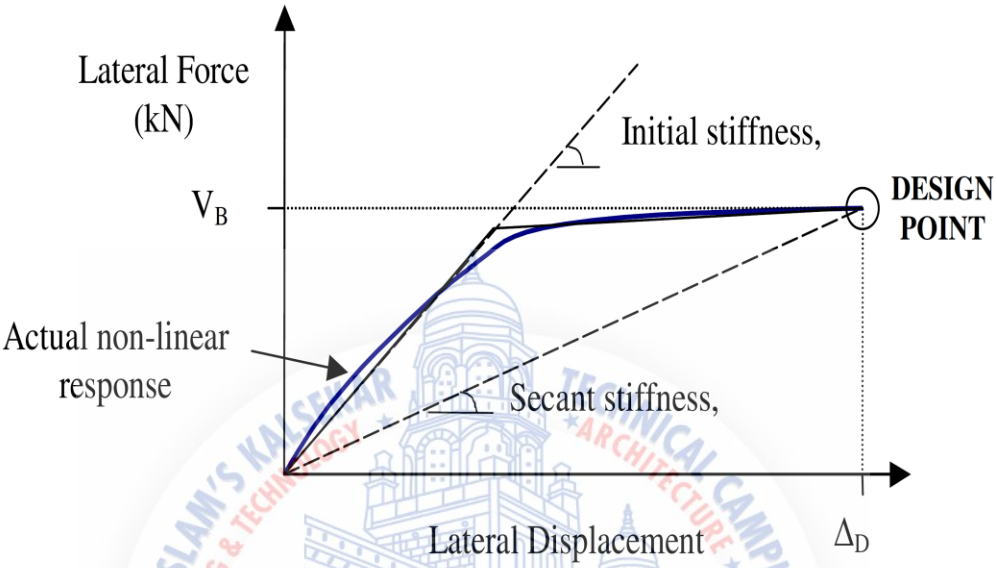

Figure 2.7 Illustration of Initial-Stiffness and Secant Stiffness Concepts Related to A Structure's Full Non-Linear Response. [6]

The two initial stiffness procedures to be used for the case studies are:

- INSPEC method = Inelastic Spectra method presented by Chopra.
- YPS method = Yield Point Spectra method presented by Aschheim.

The two secant stiffness procedures to be used for the case studies are:

- CASPEC method = Capacity Spectrum method presented by Freeman.
- DDBD method = Direct Displacement Based Design method presented by Priestley.

Five different buildings of similar height but with significantly different characteristics were selected to assess the performance of the DBD methods. The five case studies considered include three wall structures and two frame structures as shown in Figure 2.7. Case Study 1 is an eight storey wall structure with regular layout on a rigid foundation. Only one earthquake direction is considered and the contribution of walls perpendicular to the earthquake direction is neglected. The Case Study 2 is identical to the first except that a flexible foundation beam is introduced. This case study was useful in identifying any methods that have difficulty incorporating foundation flexibility in design. The Case Study 3 is also a wall structure, however, the walls are arranged in an irregular layout as shown in the top part of Figure 2.8. The irregular layout causes the building to twist during an earthquake and therefore assesses each design method's ability to design for torsion problems. Case Study 4 is a seven-storey regular frame structure on a rigid foundation whereas the fifth case study examines an eight-storey frame building with a vertically irregular layout. This last case study (Case Study 5) considers the performance of design methods when applied to a vertically irregular but realistic structural shape.

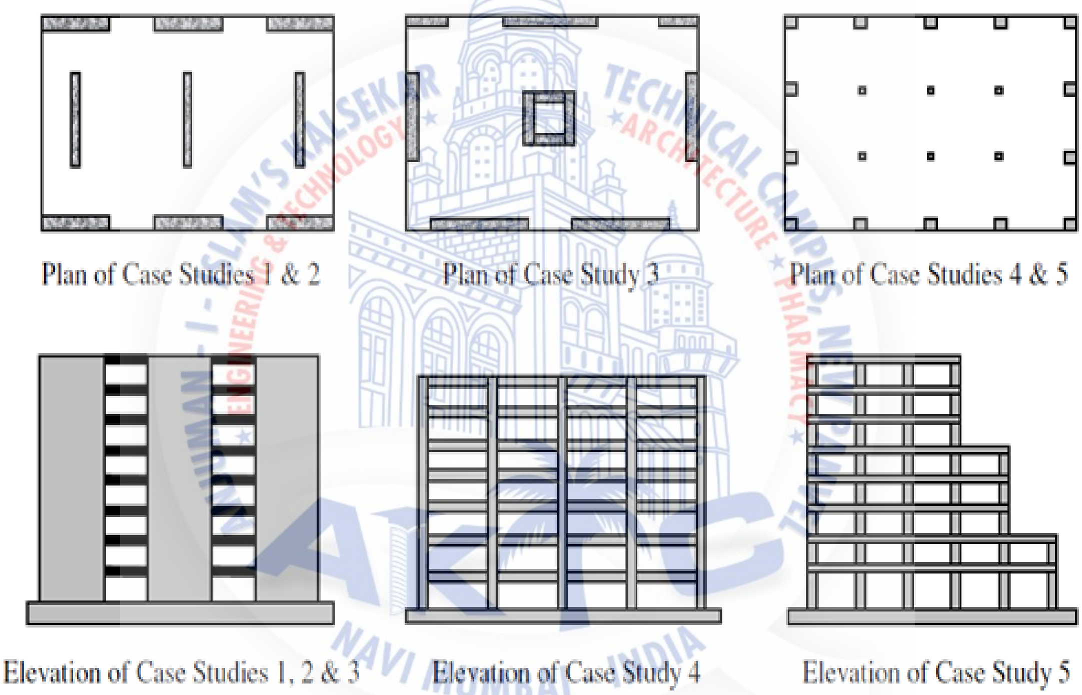

Figure 2.8 Schematic Plans (Top) and Elevations (Bottom) of the Five Case Studies Considered. [6]

They concluded that the results of the study infer that DBD utilising response spectra with either initial stiffness or secant stiffness structural characteristics may be equally effective.

M.J.N Priestley, D.N Grant, and C.A Blandon (2005) shown that the important on secant stiffness to maximum displacement, rather than initial stiffness (as in force-based seismic design) is important for rational force-distribution to different seismic-resisting structural elements, and in most cases obviates the need for iteration in the design process, which is inherent in displacement-focused force-based seismic design. It is shown that the influence of hysteretic characteristics has been underestimated in recent force-based studies.

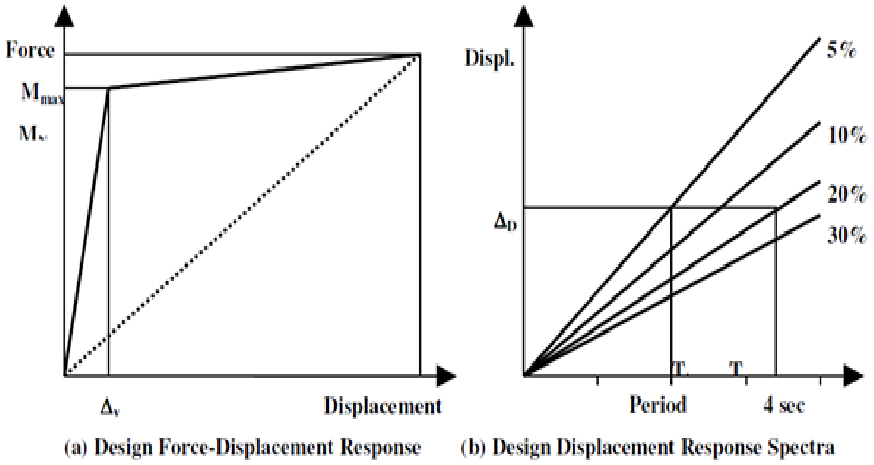

Figure 2.9 Essential Differences Between Force-Based and Direct Displacement-Based Design. [7]

The essential differences between force-based and direct displacement-based design are summarized in Figure 2.9. Force-based design uses an initial stiffness ki, a nominal strength FN, and an acceleration response spectrum, (not shown in Figure 2.9) based on 5% elastic damping. Direct displacement-based design uses an effective secant stiffness ke to the design displacement Δd, the strength Fmax corresponding to the design displacement, and displacement spectra for different levels of equivalent viscous damping.

They concluded that rational reasons were advanced for distributing seismic forces between structural elements based on secant stiffness to the design displacement, (as in DDBD) rather than on initial stiffness (as in DFFBD). It was shown that conclusions from earlier time-history analyses may be suspect because of the use of initial-stiffness proportional elastic damping, rather than tangent-stiffness proportional damping. Analyses using tangent-stiffness damping indicate that commonly accepted relationships between elastic and inelastic displacements are inappropriate.

G.M. Calvi, M.J.N. Priestley, and M.J. Kowalsky (2008) analysed concept of designing structures to achieve a specified performance limit state defined by strain or drift limits which was first introduced, in New Zealand, in 1993. Over the following years, an intense coordinated research effort has been underway in Europe and the USA to develop the concept. Different structural systems including frames, cantilever and coupled walls, dual systems, bridges, wharves, timber structures and seismically isolated structures have been considered in a series of coordinated research programs

Table 2.1 Comparison of DDBD and DFFBD Design Steps. [8]

Direct Displacement-Based Design	Displacement-Focused Force-Based Design
1. Assume Structure Geometry (spans, heights, sections) 2. Determine design displacement (normally drift based) 3. Calculate yield displacement, hence ductility 4. Determine equivalent viscous damping 5. Determine effective period from displacement spectra 6. Determine effective stiffness from SDOF Eqn 7. Determine design base shear strength 8. Distribute base shear and analyse structure	1. Assume Structure Geometry (spans, heights, sections) 2. Estimate member stiffnesses (assumed rebar) 3. Analyse structure for dynamic characteristics (periods) 3. Select design ductility (normally code-specified) 4. Determine design base shear strength 5. Analyse structure for required member strengths 6. Determine reinforcement contents; revise stiffness 7. Cycle 2 to 6 8. Determine design displacement limit (DDBD, step 2) 9. Calculate limit elastic period T_e (5% damping) 10. Check structure period $T<T_e$ 11. Revise stiffness if necessary or desired so that $T=T_e$

In the 1940's and 50's the influence of structural period in modifying the intensity of the inertia forces started to be incorporated into structural design. Ductility considerations were introduced in the 1960's and 70's as a consequence of the experimental and empirical evidence that well- detailed structures could survive levels of ground shaking capable of inducing inertia forces many times larger than those predicted by elastic analysis. Gradually this lead to a further realization, in the 1980's and 90's that strength was important, but only in that it helped to reduce displacements or strains, which can be directly related to damage potential. This realization has lead to the development of a large number of alternative seismic design philosophies based more on deformation capacity than strength. These are generally termed "performance-based" design philosophies.

The basis of this approach is the procedure termed "Direct Displacement Based Design" (DDBD), which was first introduced in 1993 (Priestley, 1993), and has been subjected to considerable research attention, in Europe, New Zealand, and North America in the intervening years. The fundamental philosophy behind DDBD is that structures should be designed to achieve a specified performance level, defined by strain or drift limits, under a specified level of seismic intensity.

Problems with initial-stiffness structural characterization in conventional force-based seismic design, and use of a code-specified ductility capacity have been identified in several previous publications (Priestley 1993, Priestley 2003) was briefly listed in this paper:

- The stiffness depends on the strength. Increasing or decreasing reinforcement content to satisfy results of the force-based design proportionally changes the member stiffness.
- Ductility capacity is a function of structural geometry, not just of structural type. Hence it is inappropriate to specify a displacement ductility factor for all structures of the same type (e.g. reinforced concrete frames)
- Seismic design of building structures will generally be governed by drift limits, when realistic estimates of building stiffness are used to determine displacements.

They concluded that stiffness depends on the strength and ductility capacity is a function of structural geometry therefore the fundamental philosophy behind DDBD is that structures should be designed to achieve a specified performance level, defined by strain or drift limits, under a specified level of seismic intensity.

B. Massena; R. Bento; H. Degee (2010) carried a case study of DDBD at different peak ground acceleration (0.35g, 0.27g). They had concluded that peak ground acceleration of 0.35g, the design displacement capacity of the frame structure obtained through the direct displacement based design procedure is less than the maximum possible displacement demand for the consideration damping level for the low seismicity case (0.27g) the displacement capacity exceeds the maximum possible displacement demand. They had also concluded that the direct displacement based design procedure can be more difficult to apply becoming an iterative procedure in some cases for very flexible structure or low seismic intensity they are suggested that needed to develop an automatic program or software etc.

Jiji Anna, Varughese Devdas Menon & A. Meher Prasad (2012) carried a case study on buildings with set-back building and stepped building. In stepped building, vertical irregularity was considered. A new distribution for base shear among orthogonal frames was proposed considering torsional effects.

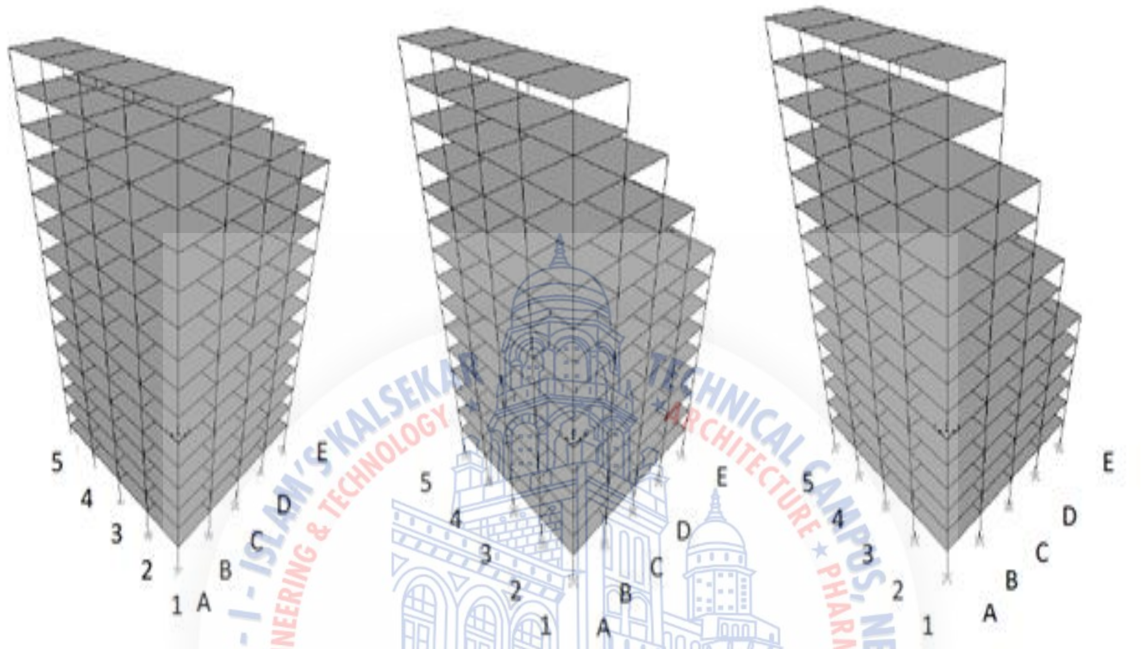

Figure 2.10 3D Models of Stepped Buildings with Steps Having 1,2 and 3 Floor Heights.[10]

The most irregular among the selected buildings was designed as per the proposed method and the subsequent time history analysis shows good performance in terms of inter storey drift. When the lateral dimension of the maximum offset at the roof level exceeds 25% of the lateral dimension of the building at the base (IS 1893:2002). As per ASCE 7: 2005, when the horizontal dimension of the building in any storey is more than 130% of that in the adjacent storey, this building should be considered as vertically irregular. The codes recommend dynamic analysis for the design of this building category Based on an experimental study on set-back and stepped buildings, Wood (1992) concluded that the behavior of stepped and set-back buildings is not much different from that of regular ones. However, Aranda (1984) found that the ductility demand for set-back buildings is more, in the storeys above the set-back level and hence needs special care while designing the top portions of the building. The analytical works of Sharooz and Moehle (1990) also agree with this observation and they found that there is more inter-storey drift damage in the tower-base junction. But, based on their experimental study on set-back buildings, they concluded that the fundamental mode dominates in the direction parallel to set-backs and hence static analysis is sufficient for set-back buildings. Pinto and Costa (1995) evaluated the non-linear behaviour of set-back buildings of 4, 8 and 20- storey buildings. They observed a greater concentration of ductility demand in the lower storey However, some critical zones at intermediate heights were also observed.

They derived simplified DBD procedure for stepped building in stepped building and found that the flexible side attracts higher base shear force as compared to the stiffer side. Additional care must be taken while designing orthogonal frames because due to the torsional rotation developed due to differential lateral displacements between the taller and shorter sides of the building and also due to lesser seismic weight near the shorter edge. The procedure for DBD of stepped buildings was proposed in such a manner that the design of stepped frames and orthogonal frames can be done separately and hence the designer needs to analysis only planar 2-D frames. Higher mode effects are in stepped buildings and to reduce this undesirable effect, suitable modifications are made in the design procedure after performing several analyses, designs and verifications.

B. Massena, R. Bento & H.Degee (2012) considered A set of reinforced concrete structures and designed them according to DDBD procedure. Further their assessment was conducted with pushover and non-linear time-history dynamic analyses, performed with Seismostruct. A comparison of frames characterized by a same overall geometry (number of storeys, bay length and storey height) and designed respectively according to DDBD and to the traditional force-based design method (FBD), as proposed in Eurocode 8 (EC8), was carried out and the differences are outlined.

They considered two groups of plane frames with three spans with 5m length each, three and four number of stories. Each group comprises a vertically regular structure (hi=3m) and two are characterized by vertical irregularities likely to induce a ground-storey mechanism (first floor with 4m and 5m height respectively (see Figure 2.11). Mechanical properties of materials were: fck equal to 25MPa (C25/30) and fy equal to 500 MPa (B500). In addition to the self-weight of the beams and the slab, a distributed dead load of 1.5kN/m^2 due to floor finishing and partitions was applied, as well as an imposed live load with nominal value of 2kN/m^2. The slab thickness is equal to 0.15 m and its contribution to the structural response was taken in account by considering an effective beam width according to Eurocode 8 (EC8, 1998). Adopted dimensions of beams are a width equal to 25 cm and a depth equal to 50 cm.

The column cross sections were defined accordingly, in order to limit the normalized axial force (EC8, 1998). In order to simplify the procedure, equal dimensions were considered for external and internal columns, without variation in height. The seismic action was defined according to Eurocode 8 and Portuguese National Annex with the elastic acceleration response spectrum Sa for subsoil class A (rock), pga 0.25 and 5% damping for 2sec for DDBD overall drift 2.5% and structure analyzed by both pushover analysis and non-linear dynamic analysis and result are compared with seismic behavior expected from design. Pushover analyses was developed according to the N2 method proposed in Eurocode 8 (EC8, 1998). Non-linear dynamic analyses were performed using a group of seven accelerograms, generated with the GOSCA software (Denoël, 2001). Reinforcement schemes have been selected and the criteria for ductile behaviour of concrete sections defined in Eurocode 8 fulfilled (Ductility Class Medium- DCM).

They found that the structures designed according to FBD procedure presents, as expected, smaller displacements and inter-storey drift ratio when compared with those obtained by means of the DDBD procedure; i.e. the results are significantly more conservative. To fulfill the requirements of EC8, and especially the capacity design principles, the design according to FBD implies larger sections of the columns. The obtained inter-storey drifts from analyses at the first storeys resulted in values smaller than the design ones, particularly for the vertically regular frames without a soft storey (configuration 1 and 4). The development of a soft storey can be observed in the frame deformation.

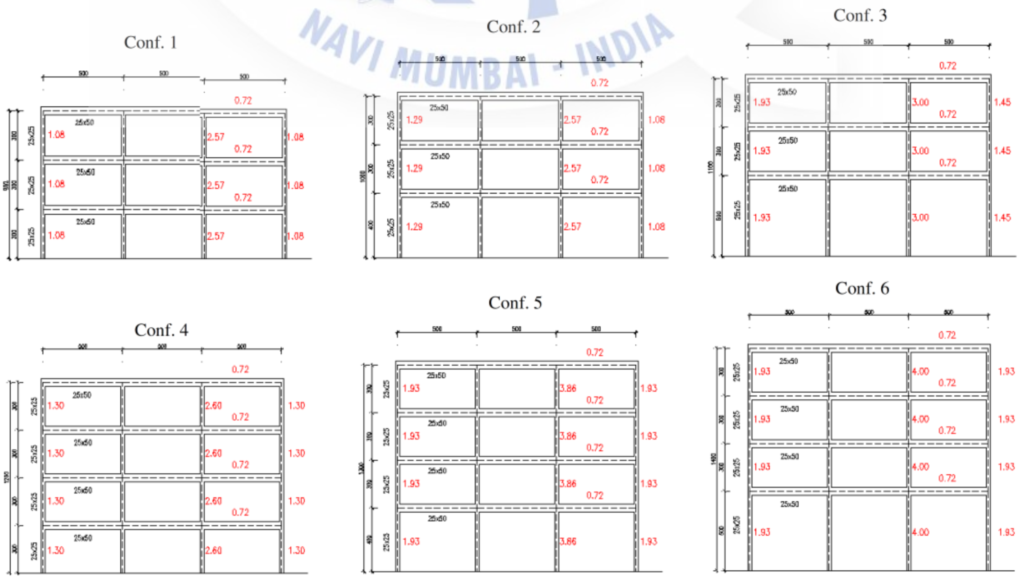

Figure 2.11 Structures Under Study (dimension in cm, reinforcement ratios in %). [11]

They concluded that drifts results smaller than the design drift limit imposed by the design procedure in terms of displacement profile for all configurations and for both design procedures. Therefore and based on the results obtained for the set of frames analyzed it seems that DDBD methodology can cope with the vertical irregularities studied and the results are significantly less conservative than the ones obtained by FBD according to EC8 rules.

Saleh Malekpour, and Farhad Dashti (2013) investigated the direct displacement based design (DDBD) approach for different types of reinforced concrete structural systems including single moment-resisting, dual wall-frame and dual steel-braced systems. The displacement profile was calculated and the equivalent single degree of freedom system was then modeled considering the damping characteristics of each member. Having calculated the effective period and secant stiffness of the structure, the base shear was obtained, based on which the design process was carried out. For each system, three frames are designed using DDBD approach.

The design selection criteria in DDBD as per the flow-chart for each system 4, 8 and 12-story models. The models were RC Frame System, RC Wall System, RC Steel Braced Frame Systems.

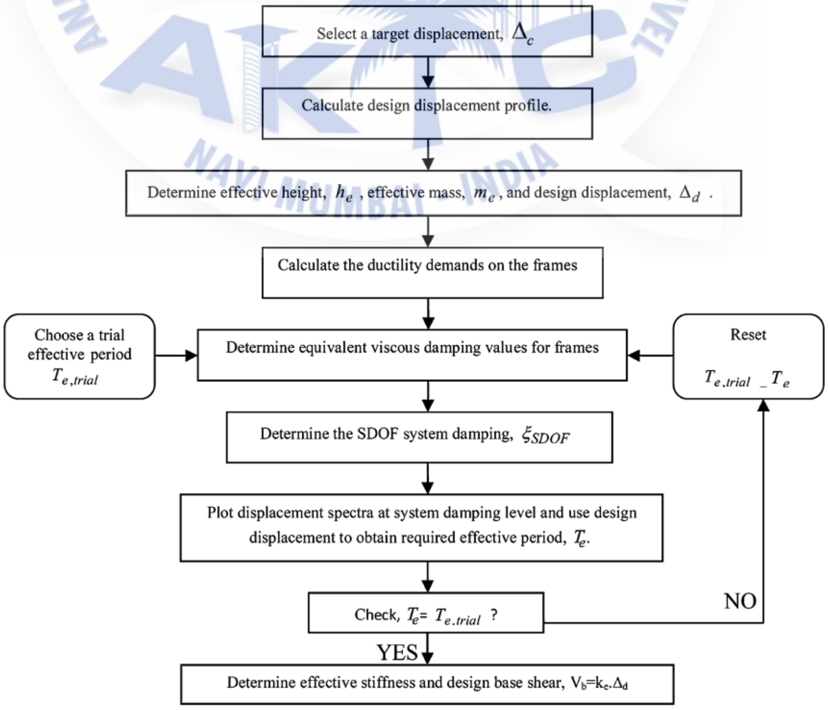

Figure 2.12 DDBD flowchart for RC Frames. [12]

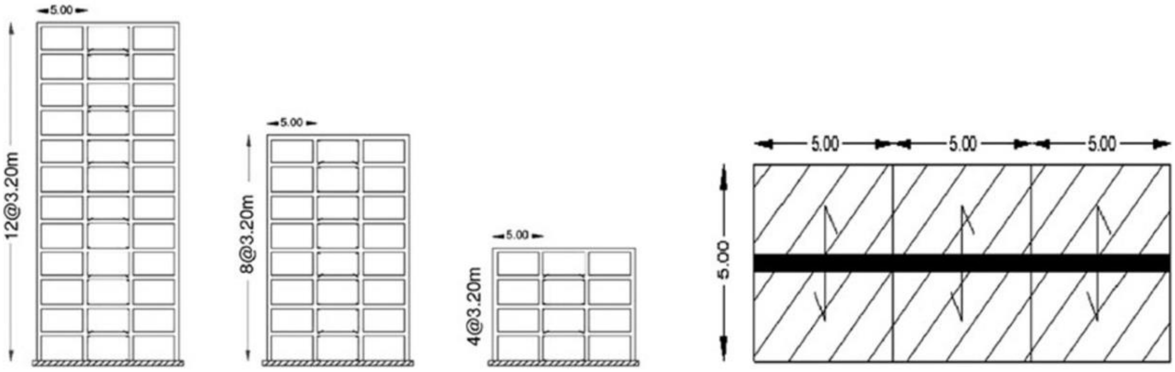

Figure 2.13 Plan and Elevation of the RC Frame Models. [12]

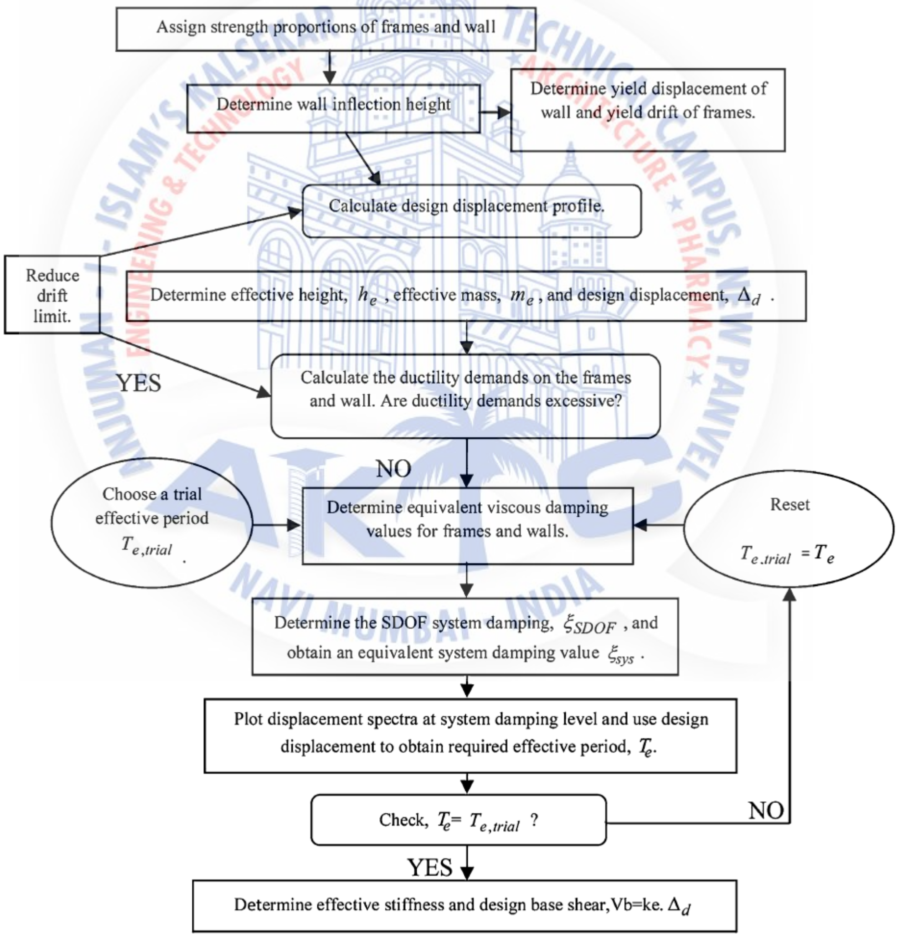

Figure 2.14 DDBD Flowchart for RC Wall-Frames. [12]

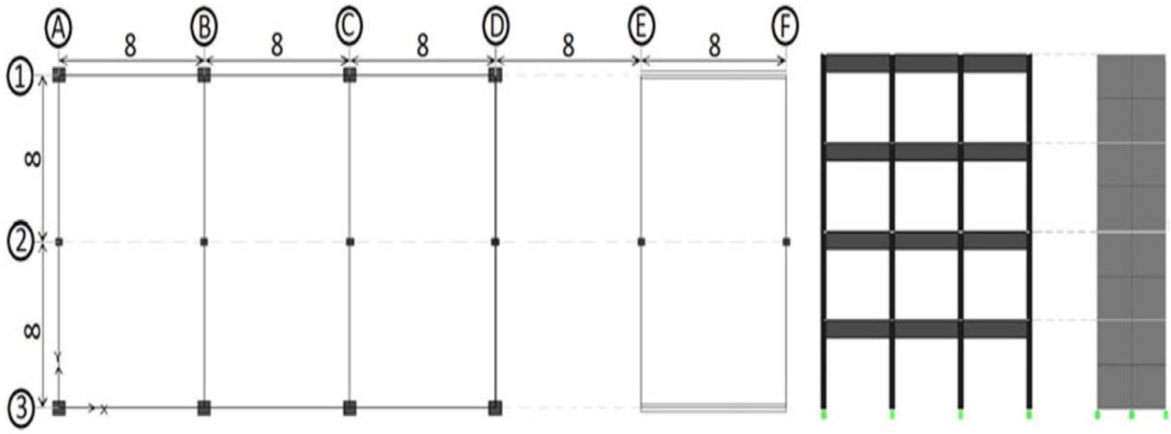

Figure 2.15 Plan and Elevation of The RC Wall-Frame Models. [12]

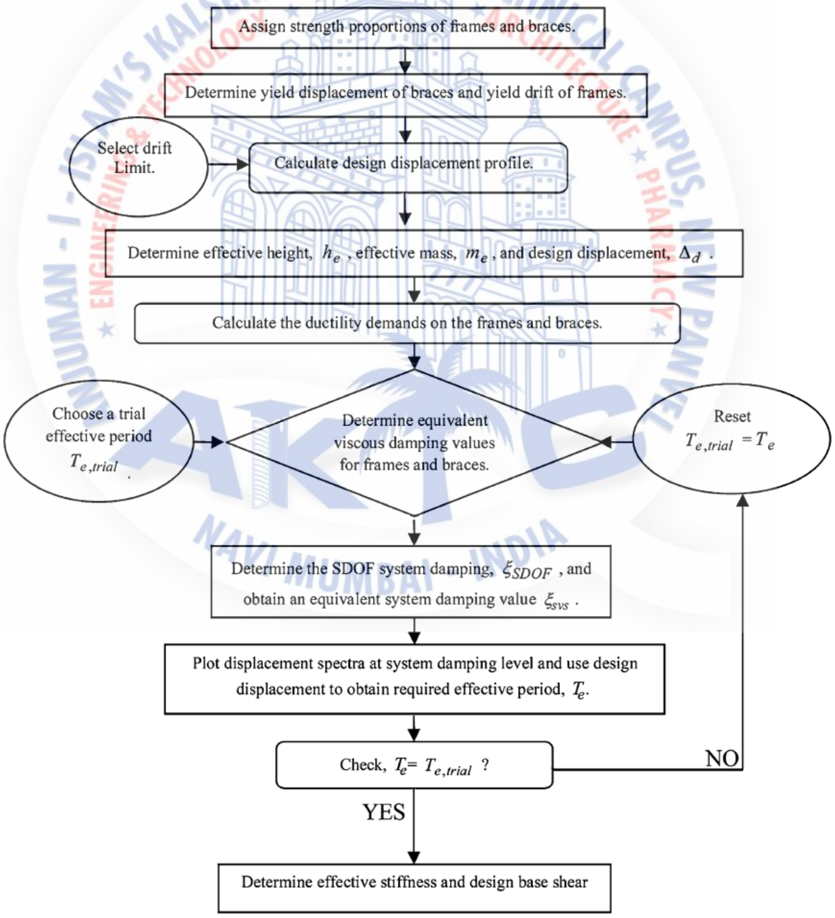

Figure 2.16 DDBD Flowchart for Steel Braced RC Frames. [12]

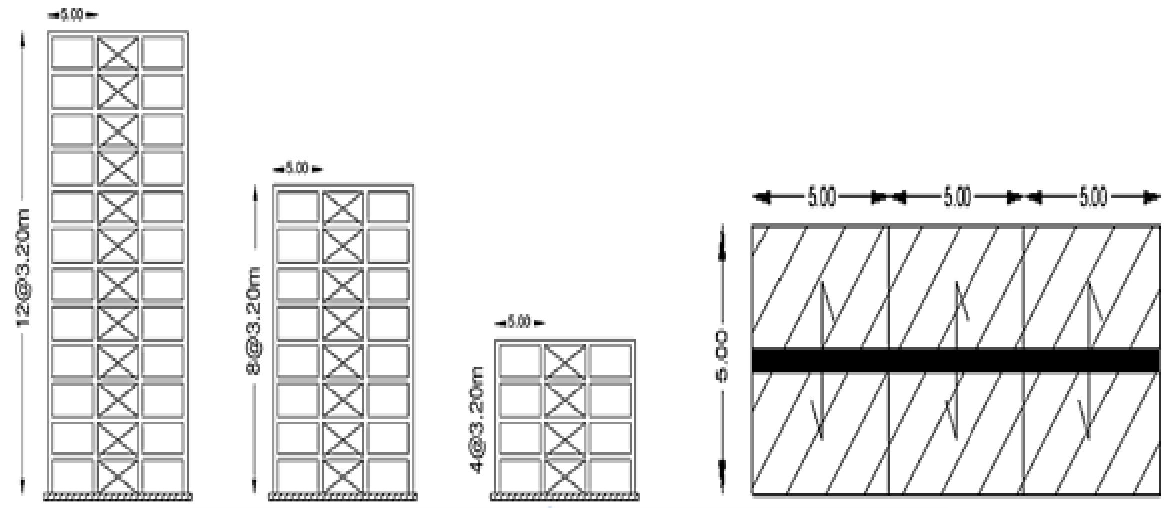

Figure 2.17 Plan and Elevation of the Steel Braced RC Frame Models. [12]

They concluded that the method performed quite satisfactorily in term of maximum inter-story drift, even for tall models. Some deviations, especially in tall models, from design values were mainly due to the complex and highly varying nature of frequency content of near-fault records. Another important finding of the study is that, the DDBD methodology was able to design structures with quite controlled residual behavior.

Adel ElAttar, Abdel Hamd Zaghw and Ahmed Elansary (2014) applied (DDBD) on different reinforced concrete frame buildings. The base shear force calculated by (DDBD) was compared with those calculated by (FBD) that is defined in the Euro-Code (EC8). The concept of response spectrum, where a spectrum of responses is plotted for a very wide range of single degree of freedom periods, was introduced in 1990. After calculating of the structure periods, these spectrum graphs are used to deduce the expected response of the structure under the effect of earthquakes.

The base shear force is an estimate of the maximum expected total lateral force that may occur due to seismic ground motion at the base of a structure. Calculations of the base shear (V) depend on many factors such as the soil conditions at the building site, the epicentral distance, the probability of occurrence of the earthquake, and the fundamental (natural) period of vibration of the structure.

Force-Based Design, (FBD): The force-based design, FBD, procedure is based on calculating the base shear force resulting from the earthquake dynamic motion using the acceleration response spectrum and the expected elastic period of the building. In this procedure the static loads are applied on a structure with magnitudes and directions that closely approximate the effects of dynamic loading caused by earthquakes.

Displacement-Based Design, (DBD): This approach uses the displacement response spectrum as a basis for calculating the base shear force. It also depends on studying the building considering its inelastic phase. This paper presents the fundamentals of the new seismic design method known as Direct Displacement-Based Design (DDBD). It is considered as one of the simplest design approaches for analysis of the multi-degree of freedom structures. In this method, the structure is characterized by the secant stiffness and equivalent damping of an equivalent single degree of freedom structure. This design is based on achieving a specified displacement limit state, defined either by material strain limits, or non-structural drift limits obtained from design codes under the design level seismic intensity.

Direct Displacement-Based Design, DDBD Method: To start performing DDBD, the design drift of the building, is determined according to the type of the building and its performance level. The drift slope is defined by the following equation

$$\theta_d = \frac{\text{Inter} - \text{story displacement}}{\text{Storey height}}$$

In this method, the structure is characterized by the secant stiffness and the damping at maximum displacement. The calculated base shear is applied to the structure and the assumed level of damping is checked, the design forces are then adjusted, if necessary. It is usually not necessary to adjust the forces as the adjustments are generally not significant.

When DDBD is performed, the secant stiffness, Ke, is used at maximum displacement, Δmax, at the level of equivalent viscous damping. On the other hand, in FBD, the elastic stiffness and elastic damping (ξ=5%) are used.

A single degree of freedom (SDOF) representation is used in DDBD, which was developed by Shibata and Sozen. In this representation the characteristics of the substitute structure are used. These characteristics are the secant stiffness at maximum displacement, equivalent viscous damping, effective mass, and the effective height as shown in Figure 2.18

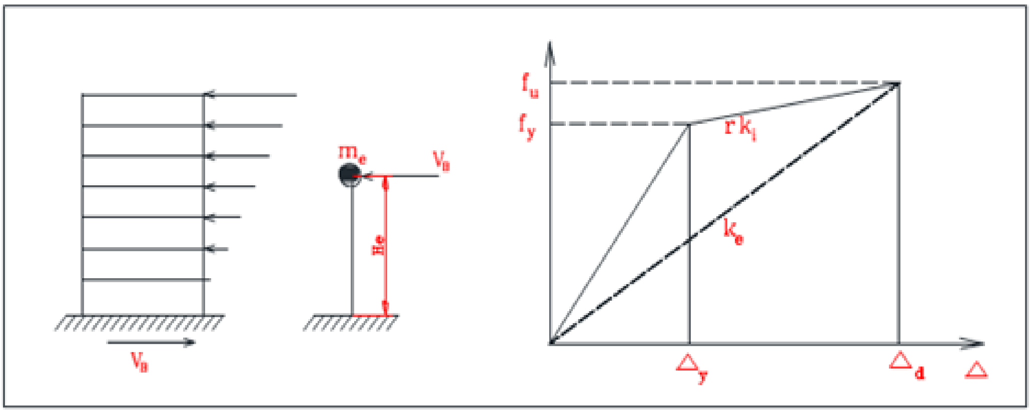

Figure 2.18 Substitute Structure Representation for Multi-Degree of Freedom Frame and the Displacement Relation Up to Failure (Elastic and inelastic stages). [13]

A full description of the steps needed for applying the DDBD method in the design of reinforced concrete moment resisting frame buildings follows:

Step1 Determine Displacement shapes**:**

The following equation is presented by Calvi and Sullivan to estimate the inelastic displaced shape of the building.

$$\Delta_i = \omega_\theta \theta_d h_i \frac{(4H_n - h_i)}{(4H_n - h_i)}$$

where: Δ_i Displacement at level i.

ω_θ : Drift reduction factor to include allowance for higher mode amplification of drift by reducing the design floor displacement

H_n, h_i: are the total building height, and height of floor i.

Step 2 Determine the design displacement.

Design displacement for the substitute structure

$$\Delta_d = \frac{\sum m_i \Delta_i^2}{\sum m_i \Delta_i}$$

where: m_i, Δ_i Mass and displacement at significant mass locations

Step 3 Calculate the effective height

$$H_e = \frac{\sum m_i \Delta_i H_i}{\sum m_i \Delta_i}$$

Step 4: Calculate yield drift slope θ_y:

$$\theta_y = 0.5\varepsilon_y \frac{l_b}{h_b}$$

Where: l_b is the beam span between column centreline, h_b is the overall beam depth

εy is the yield strain of flexure reinforcement.

Step 5 Calculate yield displacement,

$$\Delta_y = \theta_y . H_e$$

$$\Delta_y = 0.5\varepsilon_y \frac{l_b}{h_b} H_e$$

Step 6 Calculate the displacement ductility (μ),

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

Step 7 Estimate the equivalent viscous damping:

The formula of the equivalent viscous damping is deduced from best fittings of certain experiments. Through this study, the following formula was adopted

$$\xi = 0.05 + 0.565 \frac{(\mu - 1)}{\mu\pi}$$

Step 8 Plot the elastic displacement response spectrum for (ξ =0.05)

Firstly, the acceleration response spectrum is plotted from the code (according to type of soil and peak ground acceleration), then the displacement response spectrum is deduced using the following formula.

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

Where: Response displacement at ξ = 0.05 (5%)

Response acceleration at ξ = 0.05 (5%)

Step 9 Plot the displacement response spectrum for ($\xi = \xi_d$)

A damping modifier Rξ is applied to the displacement spectrum obtained in the previous step to obtain the displacement spectrum at different levels of damping. The following eaqaution is the damping modifier Rξ suggested by the Euro Code EC8 in 2003.

$$R_\xi = \left(\frac{0.10}{0.05 + \xi}\right)^{0.5}$$

Typical shapes for the displacement response spectrum at different damping ratios are shown in Figure 2.19. From this figure 2.19, it can be found that when the damping increases, the corresponding displacements decrease.

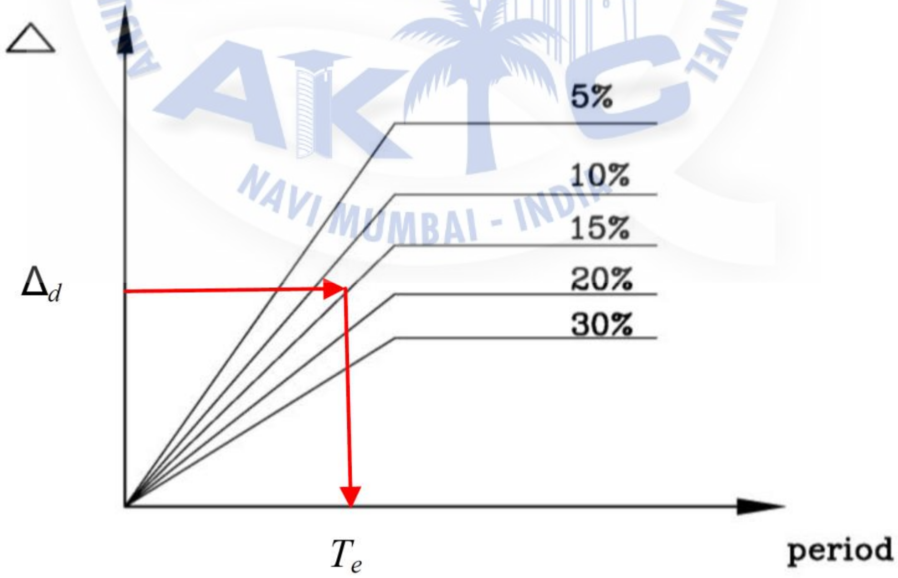

Figure 2.19 Displacement Response Spectrums for Different Effective Damping Ratio.[13]

Step 10 Calculate the effective period, T_e:

The effective period can be obtained from the displacement response spectrum (using the design displacement) (calculated from step 2)

Step 11: Calculate the effective mass, (mass of the substitute structure):

$$m_e = \frac{\sum m_i \Delta_i}{\Delta_D} = \frac{(\sum m_i \Delta_i)^2}{\sum m_i {\Delta_i}^2}$$

Step 12 Calculate the effective stiffness of the building:

$$k_e = \frac{4\pi^2 m_e}{{T_e}^2}$$

Step 13 Calculate the design base shear force:

$$V_b = k_e . \Delta_d$$

Step 14 Distribute the base shear force at different levels of the building using the following equation:

$$F_i = V \frac{m_i h_i}{\sum m_i \, h_i}$$

Step 15 Calculate the straining actions:

Using any finite element program same as (SAP) the building can be modeled then the forces are assigned at each floor level. Finally the corresponding straining actions and design moments at plastic hinge regions can be calculated.

Step 16 Design the structural elements and calculate the displacements at each level using the designed member dimensions.

Step 17 Compare the displacements with those assumed in step 1

If the calculated displacements are equal to those assumed in step 1, the design of the structural elements can be completed and the reinforcement can be designed. If the calculated displacements are not equal to those assumed in step 1 go back to step 2 and repeat the remaining steps using the displacements calculated in this step.

They concluded that DDBD is based on achieving a specified displacement limit state, defined either by material strain limits, or non-structural drift limits obtained from design codes under the design level seismic intensity. Therefor DDBD is more safe and economical then FBD.

Vivin kumar.R.V, Karthiga.S (2015) done design and analysis on two dimensional bare frames of four, eight and twelve stories based on following codes IS 456, IS 1893:2002, FEMA 356 and the two design approaches were studied. Analysis and design for this study was done using Structural Analysis Program software (SAP 2000). Both design approaches is validated using non-linear time history analysis for 16 different ground motion of PGA =0.32g. Structural parameters like Drift Ratio, Ductility Demand and Base shear were compared within the frames of different stories and between design approaches.

Force Based Design: Force based design method practised in India, which focus on the seismic force over the structure. In this method, the design procedure is carried out for the seismic force acting on the system where stiffness, time period and strength are the initial properties of the design. FBD method is performed based on IS1893 (Part 1):2002.

Performance Based Design: performance objective for the buildings and gives certain expected performance level for ground motions at a specific site to define the acceptability criteria for the structure. Performance objectives are _Life Safety (LS), Collapse Prevention (CP), Operational Level (O), in which LS was the major focus to reduce the threats to the life safety of the structure.

Direct Displacement Based Design: The fundamental goal of DDBD is to obtain a structure which will reach a target displacement profile when subjected to earthquakes consistent with a given reference response spectrum. The performance levels of the structure are governed through the selection of suitable values of the maximum displacement (D_d) and maximum interstorey drift (θ_d).

Interstorey Drift: Inter storey drift is defined as the difference in the displacement values of adjacent storey divided by the storey height.

interstorey drift(d) = $((\partial_{n+1}-\partial_n)/(h))$

∂_{n+1} = displacement at n+1 storey

∂_n = displacement at n storey

h = storey height.

Drift is an important parameter used in both design approaches. The Inter storey drift parameter is considered in comparing the results which explains the non-structural damage of the structure as FBD is a strength based design approach and base shear is the fundamental parameter for the design of structures. The structural damage of a building cannot be evaluated using the above parameter alone.

Ductility Demand: Ductility is the capacity to undergo large inelastic deformations without significant loss of strength. Reduce in ductility value results in better strength. Ductility demand is calculated from the time history by finding the displacement for each time for each storey and then the absolute maximum value is taken as the ductility in ratio with the yield displacement of that particular storey.

ductility demand = $(\Delta_m)/(\Delta_y)$

Δm = maximum displacement and Δy = yield displacement

They concluded following points

- Maximum Inter storey drift occurs at bottom of the framed structure as the base will be more rigid.FBD and DDBD shows the drift values less than the actual design drift limit (d=0.02).
- Force Based Design shows higher value of Base shear than Direct Displacement Based Design. As reduction in base shear values represents DDBD structure has less acceleration demands.
- Direct Displacement Based Design shows lesser ductility value than the Force Based Design as DDBD undergoes flexible deflection.

T.J. Sullivan (2015) analyzed background and motives for displacement-based design.

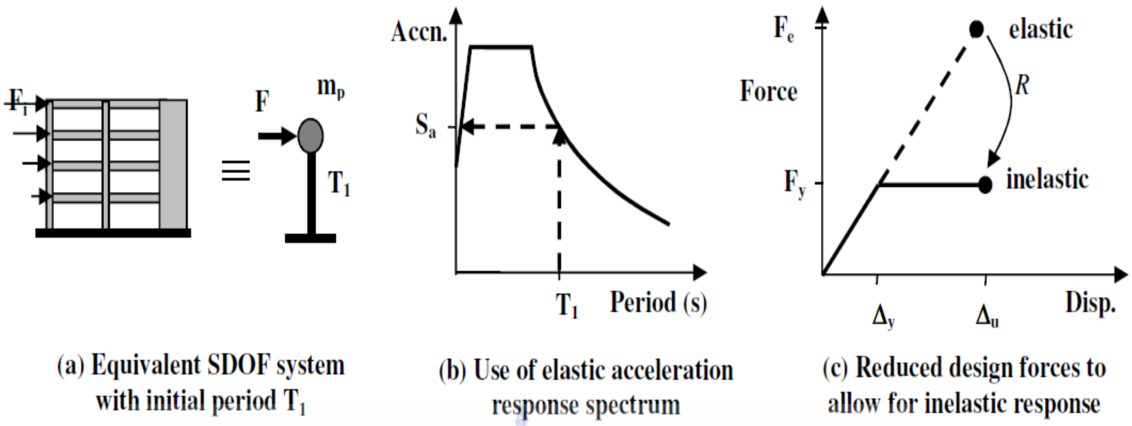

Figure 2.20 Conceptual Overview of the ELF Design Procedure. [15]

FBD procedures recognise that certain structural systems tend to possess greater ductility capacity than others. For example, a well detailed RC wall structure can rightly be expected to possess a greater ductility capacity than a masonry block wall building without reinforcement.

The geometrical proportions of structures do not affect their allowable ductility demand. For example the variation in displacement ductility capacity obtained for two RC cantilever piers with the same section diameter of 1.0m, detailed to possess the same curvature ductility capacity of 18.0, but with pier A possessing a height of 3.0m and pier B possessing a height of 8.0m. Even though the only difference between the two piers are their geometric proportions (or height, in this case), it can be shown (according to Direct DBD provisions detailed in Priestley et al. 2007) that the displacement ductility capacity of pier A is around 9.4 whereas the ductility capacity of pier B is closer to 6.7. This underlines the fact that large variations in ductility capacity can exist between structures that belong to the same structural typology; a fact that appears to be ignored in FBD.

There are also other issues with FBD methods, such as insufficient consideration of hysteretic type when estimating the inelastic displacement demands from elastic response spectra or the incorrect use of cracked stiffness estimates in RC structures that are independent of the section strengths, and for more detail readers should refer to Priestley et al. (2007).

He concluded the Direct DBD approach is now well developed and tested, with numerous scientific publications, a text and a model code offering guidance on its application for a wide range of structural typologies and technologies. This paper reviews the background and motivations for Direct DBD, highlights the performance of the method, identifies current impediments to its use and suggests and discusses possibilities for its further development.

Prof. Moustafa Kamel M.Zidan,Tamer Mohamed Abdel Rahman, Dr. Mohamed Korashy (2016) analytically examined the use of DDBM in seismic design of different types of structural systems (frame, wall, and dual wall-frame buildings) and compare it with the traditional Force Based Design Method (FBDM). Using a developed Excel spread sheets for DDBM procedure, a set of buildings with different heights (2, 4,6,8,10,12,14,16,18, and 20 stories) and different structural systems (frame buildings, wall buildings, and dual wall-frame buildings) are analyzed and the results are compared with those of (Force Based Design Method) FBDM modeled using computer programs SAP and ETABS. This comparison proved that Direct Displacement Based Method is more reliable as it is based on a secant stiffness (rather than initial stiffness) representation of structural response, using a level of damping equivalent to the combined effects of elastic and hysteretic damping.

Dual Wall-Frame buildings:

The procedure adopted for applying DDBM in analyzing dual frame-wall building system goes through the following steps:

1. Assign the percentage of distribution of base shear between frames and walls
2. Determine the walls contra flexure heights
3. Calculate the walls yield displacements
4. Draw the design displacement profile for the building
5. Design of the SDOF displacement scheme
6. Determine the Effective Height of walls
7. Evaluate the displacement ductility demands of walls and frames
8. Calculate the base shear forces in frames and walls

The dual wall-frame buildings possessing the plane shown in Figure 2.21 are reanalyzed using the Force Based Design approach. The Simplified Modal Response Spectrum Method (elastic response) recommended by the Egyptian Code for load calculation of structures 2012 was applied for base shear calculation. The computer programs Multi-response spectrum SAP and ETABS were used also for the inelastic modeling of the dual wall- frame buildings. This modeling was executed with reduced stiffness to 70 % of the gross section (cracked sections) as recommended by the Egyptian Code for load calculation of structures 2012. The results of these analyses (adopting FBD approach) will be compared with those of the DDBM. As also drifts of DDBM are also compared with that of 70% (as recommended by Egyptian code) of SAP and ETABS.

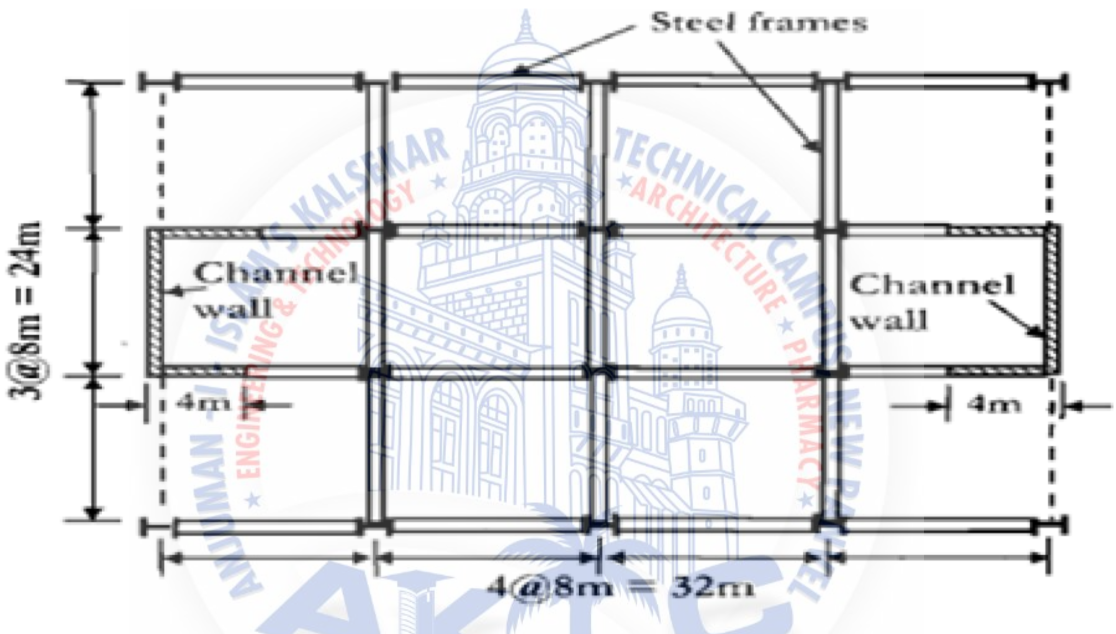

Figure 2.21 Plan View for the Studied Dual Frame-Wall Buildings. [16]

They developed a comprehensive Excel sheet to deal with the seismic analysis of RC buildings using the direct displacement based design method (DDBM). The applications covered different structural systems (framed, walled, and dual frame-wall buildings) with variable height ranging from 6 m to 60 m. The results of DDBM were compared with those of the force based design methods (FBDM) including the Egyptian Code Method as well as the finite element modeling through the computer programs ETABS and SAP.

Whatever is the type or the height of the RC building, the effective period given by (FBDM) proposed the Egyptian Code gives less than the effective period by (DDBM). This can be attributed to the fact that the period given by (FBDM) represents the building at its elastic stage while the period given by (DDBM) represents it at its inelastic phase.

Sallehali M. Bhaisaheb, Dr.Bimal A. Shah (2017), designed using force based design and displacement based design and compared there size, concrete required, and Area of steel required all they did in software ETABS 2015. Need of this comparison because the Indian code method for calculating seismic forces for R.C Building in IS 1893:2002 is forced based which has some draw back such as initial stiffness characterization variation in response reduction factor calculation of time period is height dependent.

There has been lots of research on the building design to achieved the performance of building at the time of earthquake but yet not get any accurate method to get such performance at the time of earthquake, to overcome this DDBD is come in to picture they showing better result.

Below showing the result of the design and comparing their base shear, concrete required, reinforcement required: Result shows in ETABS-2015 at the floor level of 8, 12, 16& 20 stories.

Table 2.2 Comparison between Base Shear. [17]

Storey	X Direction		Y Direction	
	ISLS/ISRS kN	DDBD kN	ISLS/ISRS kN	DDBD kN
20	4990	4060	4235	3907
16	4872	3151	4134	3090
12	4272	2123	3625	2113
8	3657	1534	3657	1560

Following Points are observed from Table.

- The Base shear for DDBD is much less than FBD.
- As the storey height increases from 8 to 20 the difference in base shear decreases.

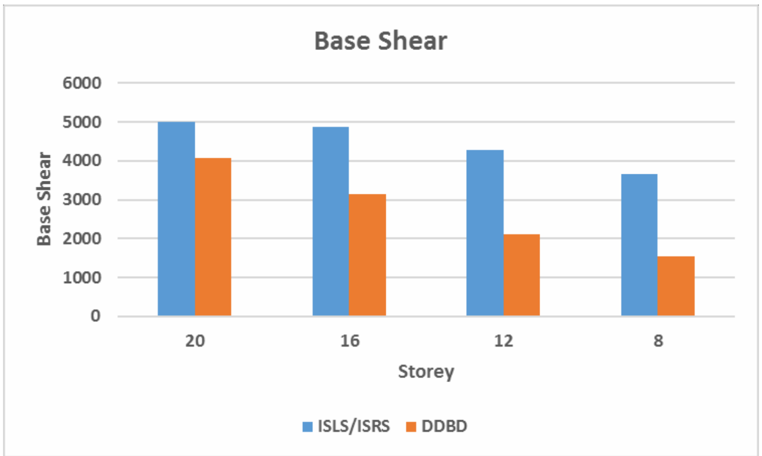

Figure 2.22 Comparison of Base Shear between DDBD & FBD. [17]

Comparison of Steel & Concrete quantities between FBD & DDBD: The Quantities of steel and concrete are calculated from ETABS results. The results are formulated in table below. As specified Earlier the design is done using IS 456:2000, IS 13920:1993 (reaffirmed 2002) & earthquake force is calculated by IS 1893:2002 for FBD. The Results are tabulated below.

Table 2.3 Comparison of Consumption of Reinforcing Steel for DDBD & FBD. [17]

Total No. of Storey	Consumption Of Reinforcing Steel (Tonne)		
	FBD	DDBD	RS
20	98.04	86.20	112.03
16	86.99	61.66	100.87
12	59.03	38.40	70.30
8	32.66	22.71	36.65

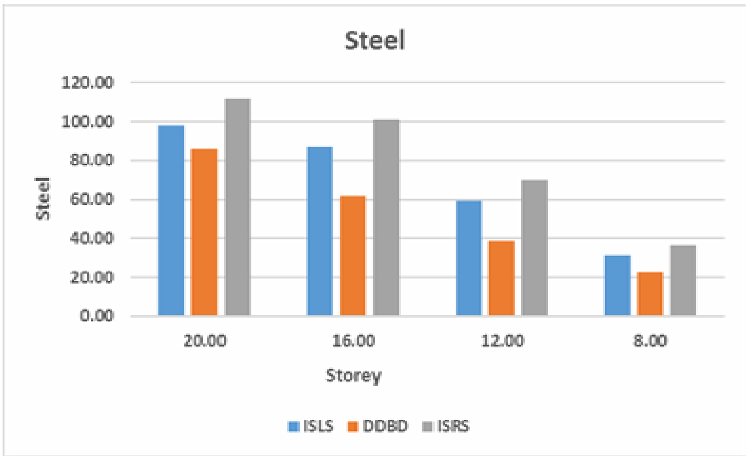

Figure 2.23 Comparison of Reinforcing Steel Required for FBD & DDBD. [17]

Table 2.4 Comparison of Consumption of Concrete for DDBD & FBD. [17]

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

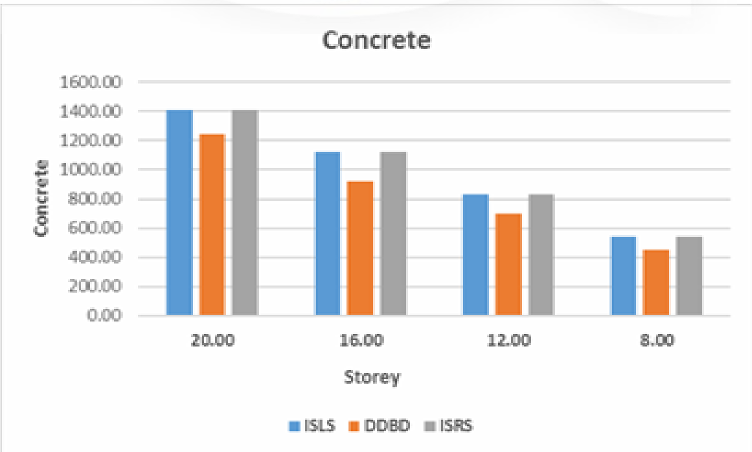

Figure 2.24 Comparison of Concrete Required for FBD & DDBD. [17]

Following points can be concluded:

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

They concluded that by comparing Base shear, quantities of steel and concrete following point can be concluded.

- 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

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.

2.3 Critical Comment on the Literature Review

1. Like most international codes, Indian standard for Seismic Design, Criteria for Earthquake Resistant Design of Structures, (1893 Part 1, 2002), adopts the FBD approach.
2. The empirical formulae given in the IS 1893 to determine time period and response reduction factor may lead to erroneous judgement of the forces.
3. DDBD approach is a rational alternative for seismic design focusing on PBD.
4. DDBD is sensitive to determination of properties of equivalent SDOF structure and is quite simple to apply.
5. Stiffness of the SDOF structure depends on correct determination of equivalent viscous damping.
6. It is required to develop inelastic displacement response spectrum, though current elastic acceleration response spectrums can be utilised to derive displacement response spectrum as the researchers have suggested that there is not a big difference for the first mode elastic and inelastic response.

2.4 Problem Definition

It is proposed to design a regular RCC structure as per Force-Based and Direct Displacement Based Seismic Design.

2.5 Aim

The project aims at understanding force-based and displacement based philosophies of Seismic Design.

2.6 Objectives

Following are the objectives of the study,

1. To understand fundamentals of Seismic Design.
2. To understand force-based philosophy and its limitations.
3. To understand fundamentals of Direct-Displacement Based Seismic Design.
4. To compare seismic design by Force-based and Displacement-Based approach.

2.7 Methodology

In order to achieve above mentioned objectives following methodology will be adopted

1. Study of force based seismic design philosophy.
2. Review of literature pertaining to critical evaluation of Force Based Approach.
3. Review of literature on Direct-Displacement Based Seismic Design approach.
4. Selection of structure for analysis and design by both approaches.

2.8 Scope

The project is confined to understand the fundamental differences in the force based and displacement based approach. A regular structure will be considered without any irregularity and no soil-structure interaction will be considered.

REFERENCES

1. Priestley M. J. N, "Myths and Fallacies in Earthquake Engineering- Conflicts between Design and Reality", (Bulletin of New Zealand National Society for Earthquake Engineering, Vol. 26, No.3, 1993)

2. Priestley M. J. N, "Performance Based Seismic Design" (12th World Conference on Earthquake Engineering, 2831, PP 1-22, 2000)

3. Priestley M. J. N, "Direct Displacement-Baesd Sesmic Design of Concrete Buildings" (Bulletin of New Zealand National Society for Earthquake Engineering, Vol. 33, No.4, December 2000)

4. Qiang Xue, Cheng-Chung Chen, "Performance-Based Seismic Design of Structures: A Direct Displacement-Based Approach" (Sinotech Engineering Consultants Inc., 171 Nanking East Road Sec.5, Taipei 105, Taiwan Received 22 June 2002; received in revised form 19 May 2003; accepted 1 August 2003)

5. T. J. Sullivan, G. M. Calvi, M. J. N. Priestley & M. J. Kowalsky, "The Limitations and Performances of Different Displacement Based Design Methods" (Universita degli Studi di Pavia, ROSE School, Via Ferrata 1, 27100, Pavia, Italy,North Carolina State University, Dept. Civil Engineering , Raleigh, North Carolina, 27695-7908, USA, Published online: 15 Sep 2009, 2003)

6. T.J.Sullivan, G. M. Calvi, M.J.N. Priestley, "Initial Stiffness Versus Secant Stiffness in Displacement Based Design", (13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No 2888, 2004)

7. M.J.N. Priestley, D.N.Grant, And C.A.Blandon, "Direct Displacement-Based Seismic Design", (European School For Advanced Studies in Reduction of Seismic Risk, (Rose School) Pavia, Italy, 2005)

8. G.M. Calvi, M.J.N. Priestley And M.J.Kowalsky, "Displacement–Based Seismic Design of Structures", (IUSS, Pavia, Italy, North Carolina State University, Raleigh, USA, 2008)

9. B. Massena, R. Bento, H. Degee, "Direct Displacement Based Design of a RC Frame-Case of Study", (Relatorio ICIST DTC n 08/2010)

10. Jiji Anna Varughese and Devdas Menon & A. Meher Prasad, "Simplified Procedure for Displacement-Based Design of Stepped Buildings", (15th World Conference on Earthquake Engineering, 2012)

11. B. Massena, R. Bento & H. Degee, "Assessment of Direct Displacement-Based Seismic Design of Reinforced Concrete Frames",(ICIST, IST, Lisbon, Portugal, University of Liege, Belgium 2012)

12. Saleh Malekpour, and Farhad Dashti, “Application of the Direct Displacement Based Design Methodology for Different Types of RC Structural Systems”, (International Journal of Concrete Structures and Materials Vol.7, No.2, Pp.135–153, June 2013 DOI 10.1007/S40069-013-0043-2 ISSN 1976-0485 / Eissn 2234-1315, 2013)

13. Adel Elattar, Abde Lhamd Zaghw and Ahmed Elansary X, “Comparison Between the Direct Displacement Based Design and the Force Based Design Methods in Reinforced Concrete Framed Structures”, (Professor of Reinforced Concrete Structures, Faculty of Engineering, Cairo University, azaghw@link.net, 2013)

14. Vivinkumar.R.V, Karthiga.S, “A Comparative Study on Force Based Design and Direct Displacement Based Design of Reinforced Concrete Frames”, (IJRET: International Journal of Research in Engineering and Technology, Eissn: 2319-1163 | Pissn: 2321-7308, Volume: 04 Issue: 04 | Apr-2015, Available @ http://www.ijret.org. 2015)

15. T.J. Sullivan, “Motives for and Impediments Facing Direct Displacement-Based Seismic Design”, (Proceedings of the Tenth Pacific Conference on Earthquake Engineering, Building an Earthquake-Resilient Pacific, 6-8 November 2015, Sydney, Australia, 2015)

16. Moustafa Kamel M. Zidan, Tamer Mohamed Abdel Rahman, Dr. Mohamed Korashy, “Seismic Analysis of Buildings Using Direct Displacement Based Design Method”, (IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) E-ISSN: 2278-1684,P-ISSN: 2320-334X, Volume 13, Issue 6 Ver. II (Nov. - Dec. 2016), PP 97-112 www.iosrjournals.org, 2016)

17. Sallehali M. Bhaisaheb, Dr.Bimal A. Shah, “A Comparative Study of Force Based Design and Direct Displacement Based Design for RC Dual-Wall Frame Structure.” (International Research Journal of Engineering and Technology (IRJET), Volume: 04 Issue: 02 | Feb -2017 www.irjet.net)

18. IS 456-2000, “Plain and Reinforced Concrete Code of Practice” (Fourth Revision,ICS 91.100.30, BIS)

19. IS 1893-2002 (Part 1), “Criteria for Earthquake Resistance Design of Structure” (Sixth Revision, BIS).

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