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COMPARISON BETWEEN FORCE BASED SEISMIC DESIGN AND DISPLACEMENT BASED SEISMIC DESIGN OF TALL RC STRUCTURES

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ABSTRACT - Most of forced based seismic (FBD) design codes are intended to provide design and analysis such that, structure will resist small earthquakes without damage, moderate earthquake without major structural damage, severe earthquake without collapse. These current provisions attempt to achieve all three performance objective by specifying only one design earthquake level. The Force Based Design (FBD) include the determination of the required strength based on estimated stiffnesses which in fact depend on the final allocated strength. 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. The emphasis is made on that, the structure should able to resist design base shear. Performance based design methods are viable alternative for seismic design and are emerging as latest tool in which, the design is done for an intended displacement or, an intended performance under a perceived hazard level. A displacement-based design of buildings for seismic forces is better able to meet the desired performance criteria than a force-based design. Direct Displacement-Based Design (DDBD) was firstly proposed by M.J.N. Priebstley (1993). The theoretical formulation of DDBD is done confirming to IS code provisions. Illustrative problem for R.C. buildings of 16, 20 and 25 storey building with varying bay side are considered for study. Base shear and lateral load distribution are obtained as per FBD and DDBD. The performance evaluation of frames designed by FBD & DDBD s done using Static Push- over Analysis and Non-Linear Time History Analysis in Seismostruct. The P-M and M-ϕ non-linear parameters are considered as per Indian Standards.The parameters like Base Shear, Lateral Load Distribution, Reinforcements in Structural Members, Interstorey Drift Ratio and Displacement Profile of the Structure are compared for DDBD and FBD. The work carried out determines that displacement-based design

is suitable for low-rise to mid-rise buildings. However, for tall structures, the applicability of displacement-based method is questionable..

INTRODUCTION

The earthquake forces are most destructive forces among all natural hazards. The behavior of earthquake forces is random in nature and unpredictable, so Design processes for making structure seismic resistant needs to be clear, definite and better. These approaches have focused design attention away from the importance of structural deformation as a main determinant of damage in structures subjected to earthquake.

Actual seismic codes are generally based on force-based design procedures, which are characterized by check that strength of structural members is larger than seismic induced force determined by applying a force reduction factor. This factor depends on ductility of the structure, which for new buildings is implicitly assured by design rules.

The emphasis is made out that, the structure should able to resist Design Base Shear. For Design calculations of seismic resistance, strength and performance should be compactible to each other. Over last two decades Researchers and professionals has realized that increasing strength may not actually increase the safety, neither necessarily reduce damage. This leads to a new design approach called “Performance Based Seismic Design”, which is expressed in terms of achieving stated performance objectives.

Literature Review

General

Performance Based Seismic Design Performance-based design is a design philosophy in which the design criteria are expressed in terms of achieving stated performance objectives when the structure is subjected to stated levels of seismic hazard.

Performance Based Seismic Design

In the performance-based design approach, acceptability criteria are established in term of performance level or damage levels for a specified earthquake ground motion. As per current performance-based design practice, the structures are considered capable to resist minor earthquake without significant damage, moderate earthquakes with repairable damage and major earthquakes without collapse. A performance level is described in term of limiting damage condition which may be considered satisfactory for a given building. The target performance objective is divided into Structural Performance Level and Non-structural Performance Level. Based on the combination of these two performances the overall building performance is determined.

Performance Level

Structural and non-structural performance levels are described by the document “Seismic Evaluation and Retrofit of Concrete Structures”, ATC 40. They are as follows.

Structural Performance Level

Immediate Occupancy (SP-1): Limited Structure damage with basic vertical and lateral force resisting system retaining most of their pre earthquake characteristics and capacities.

Damage Control (SP-2): This term is actually not a specified value but damage is considered somewhere between Immediate Occupancy and Life Safety.

Life Safety (SP-3): Significant damage with some margin against total or partial collapse. Repair may not be economically feasible.

Limited Safety (SP-4): This term is actually not a specific level. It is somewhere between Life Safety and structure stability.

Structural Stability (SP-5): Substantial Structure damage in which the structure system is on the verge of experiencing partial or total collapse. Significant risk of injury exists. Repair may not be technically or economically feasible.

Not Considered (SP-6): Placeholder for situation where only non-structural seismic evaluation or retrofit is performed.

Non Structrual Performance level

Operational (NP-A): Non-structural elements are generally in place and in working condition. Backup system for failure of external utilities, communications and transportation has been provided.

Immediate Occupancy (NP-B): Non-structure elements are generally in place but may not be working in condition.

Life Safety (NP-C): Considerable damage to non-structural component and system but no collapse of non-structural heavy items.

Reduced Hazards (NP-D): Extensive damage to non- structural component but should not include collapse of large and heavy items that can cause significant injury to groups of people.

Not Considered (NP-E): Non-structural element, other than that have an effect on structural response, are not evaluated. The point of localized damage in structure is often called as hinge. As per above performance level, force versus

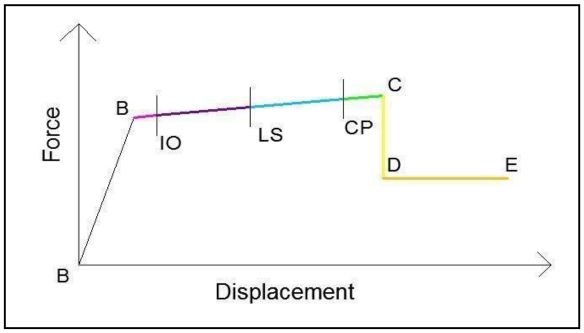
applied loads has led to earthquake resistant design approaches in which ductility demands are derived based on calculated force demand-capacity ratiosWhere,

IO = Life Safety CP = Collapse Prevention C = Strength Fig2.1 Performance Levels

Degradation C-D = Initial failure of component D-E = Residual Resistance

Various performance levels are considered depending on type of damages in the structure. Negligible impact on building is considered at an operational level. Building is

Fig-1 Performance Levels



safe to occupancy but possibly not useful until the repaired is considered as an immediate occupancy level. Building is safe during event but possibly not afterward is considered as a life safety level and building is very near to collapse is considered as collapse prevention. These stages are shown in fig. 2.2.

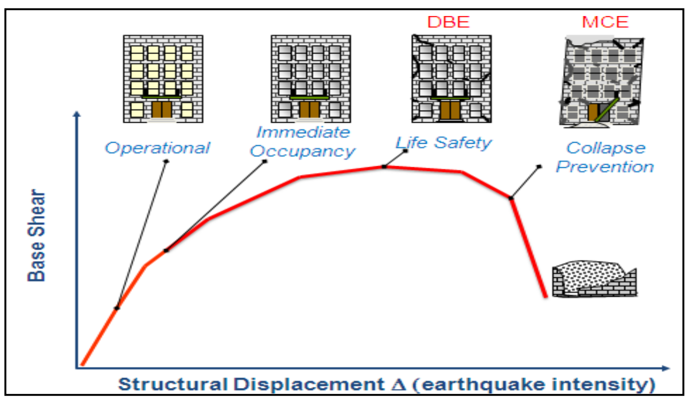


Fig2. Performance Stages

1.1 Formulation of 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 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. This is based on the Substitute Structure approach pioneered by authors

1.1.1Direct Displacement Based Method for SingleDegree of Freedom System

The design method is illustrated with reference to Fig.(a),which is a single degree of freedom system. The bi-linear envelope of the lateral force- displacement response of the SDOF representation is

shownin Fig.(b). an initial elastic stiffness Ki is followed by apost yield stiffness of rKi

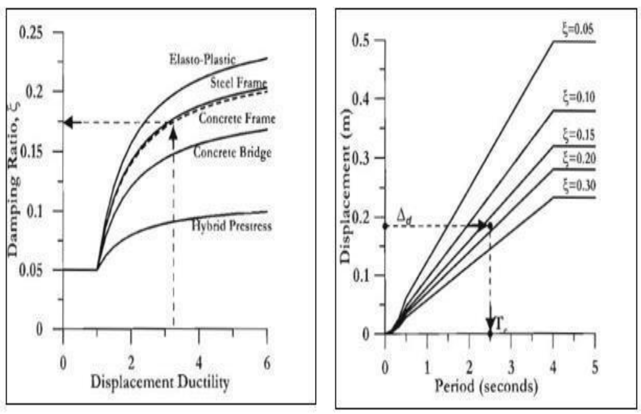


Fig 3.1 (c): Equivalent Damping vs Fig 3.1 (d): Design Displacement

force-based seismic design characterizes a structure in terms of elastic, pre-yield, Properties (initial stiffness Ki, elastic damping), DDBD characterizes the structure by secant stiffness Ke at maximum displacement □d (Fig.3.1 (b)), and a level of equivalent viscous damping □, representative of the combined elastic damping and the hysteretic energy absorbed during inelastic response. Thus, as shown in Fig. 3.1(c), for a given level of ductility demand.

As the design displacement (Δd), at the starting of analysis will be known, displacement ductility may be known. Damping ratio, ξ may be readily obtained from the Fig(c), which is developed from the common structural force- displacement hysteresis response shapes.

With the design displacement (Δd) and damping ratio (ξ), the effective time period can be read from the displacement spectra (FIG.3.1). Effective stiffness (Ke) of SDOF system at maximum displacement may be obtained from following equation

$K=4\ \pi2\ me/\ K2$

Where Ke = Effective Stiffness

me = Effective Mass of the Structure Te

= Time period

Thus, the design lateral force, which is also the deign base shear (Vb)

Vb= Ke Δd

1.1.1 Direct Displacement Based Method for Multi- Degree of Freedom System

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 the Fig 3.2 (a). The required characteristics are Equivalent mass (me), Design displacement (Δd), and Effective damping (ξeq).

When these have been determined, then design base shear of the substitute structure can be determined. The base shear is then distributed between the mass elements of the real structure as inertia forces, and the structure analyzed under these forces to determine the design moments at locations of potential plastic hinges

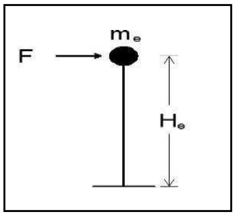


Fig 3.2: SDOF Structure

Software brief

1.1 Introduction:-ETabs was used for analysis and design of tall building. SeismoStruct was used for Static Pushover and NLTHA of Frame and Frame-Wall building. To obtain an accurate model representing complex buildings, nonlinear steel and concrete materials were used in this study. Software uses fibre-based system to define the member's cross- section

ETABS (Extended Three-Dimensional Analysis of Building Systems)

ETabs (v201) is software developed by Computers and Structures, Inc. that is based on the finite element method. ETabs is specially designed for buildings and it is most suitable for tall buildings.

Frame elements in ETABS

Frame elements are used when modelling for instance columns, beams and trusses. The element is described as a combined beam and bar element with twelve degrees of freedom in three dimensions, illustrated in figure 4.1. The frame element can be subjected to axial stress, shear stress and bending. The shape of the element is a straight line with nodes at the ends. The elements have individual local coordinate systems.

Shell elements in ETABS

A shell element is similar to a plate but with curved surfaces. The thickness of the shell is small in comparison to the length and width of the shell (Cook, et al., 2002). The shell element uses a combination of plate-bending and membrane behavior. It can be three-noded or four-noded.

Floors, walls and decks are examples of structures that are modelled with shell elements. The stresses of a shell element are evaluated using four integration points (Gauss points). Similar to the frame elements, the shell elements also have individual local coordinate systems. Figure 4.2 below shows a quadrilateral shell element displacement responses for both two and three-dimensional models subjected to static and dynamic loadings.

Seismostruct

SeismoStruct (v2018), one of the Seismosoft's range, is a finite element software which can determine large SeismoStruct considers both geometric nonlinearity and material inelasticity while analyzing buildings. In addition, it has a 3D element library with different cross-sectional configurations for concrete, steel and composite structural members. To obtain a realistic model of a prototype building, SeismoStruct uses spread inelasticity distribution along the cross-section and member's length. Load application here include static forces and/or displacements

and dynamic accelerations. It has a complete visual interface with no input files or programming scripts requirement.

CONCLUSION

The objective of the present study is Comparison between Force Based Seismic Design and Displacement Based Seismic Design of Tall RC Structures. For performance evaluation 16, 20 and 25 Storey buildings are designed as per force based method and as per displacement based method. For this purpose, the performance evaluation of buildings is done using static pushover analysis and nonlinear dynamic analysis method and results are obtained.

From the comparison of a 16 storey moment resisting frame building and 20 & 25 storey frame wall building following conclusions can be extracted.

- The structures designed by DDBD method gives less base shear compare to frames designed by FBD method. The same is reduced by 33.84% in 16 - storey, 29.83% in 20 - storey and 11.62% in 25 - storey building. Thus, the lateral load for DDBD method is less than FBD method.

- In Response Spectrum Method, structure is treated as MDOF whereas in DDBD structure is treated as SDOF. Thus, in DDBD method, only 1st mode effect is considered and higher mode

effects aren't taken in consideration. In short heights, it may be possible to induce SDOF behavior but there is a limit at some slenderness ratio until a structure can be treated as SDOF.

- Significant Reduction in column reinforcements has been observed. However, reduction in reinforcements in beam and shear wall is negligible.

- FBD and DDBD both structures gave satisfactory results in pushover analysis.

- It is observed from the results of NLTHA, maximum Interstorey Drift Ratio does not exceed target drift limit 2% for all buildings.

Hence, the both methods show satisfactory performance under seismic loading.

- From the comparison of 3 structures, it is seen that as the height of the structure increases, the difference between the base shear of FBD and DDBD decreases. In 25 Storey Frame-Wall

structure, even though base shear is 11.62% lower than FBD, reinforcements in both the structure are almost same. In fact, DDBD has slightly higher reinforcements too in some storeys due to its distribution.

- Thus, DDBD method can be applied in mid-rise structures but it's applicability in Tall structures is questionable.

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