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Direct Displacement Based Design : A Review

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ABSTRACT

Presented in this paper is an updated literature review of the journey of the direct displacement based design method right from its evolution to where it stands today. Furthermore, the approaches developed and suggested by researchers on this method have been reviewed. The structural performance is directly related to displacement and in performance based seismic design methods, the displacement has been addressed as the key design parameters. Since the damages are related directly to displacements therefore, in this paper Direct Displacement-Based Design (DDBD) approach in the content of performance based seismic design is implemented.

Keywords: Direct displacement based design, Performance objectives, seismic evaluation.

I. INTRODUCTION

Structural engineering design the structure that ensure to sustain various types of load imposed by various activity. Now a day's design using various seismic codes and standard procedure to satisfy some performance level and life safety parameter (earthquake design). Current design of structure is only ensuring that the structure did not collapse so the structure have adequate strength but the cost factor is less attention. in addition, although life safety performance level is obtained for different structures, the concept of uniform risk is not satisfied.

Performance-Based Seismic Design (PBSD) is continuously under development and a new approach for the design of new structures and evaluation and retrofitting of existing structures, which attracts many professionals and researchers, recently. Structures can be designed with PBSD approach with more understanding of the risk of casualties, economic losses and occupancy interruption. Furthermore, structures designed through PBSD approach, would be able to show different performance levels for different earthquake ground motions. Performance objectives are the combination of performance levels and hazard levels, and Performance levels can be determined by damage states of the structural and non-structural components. Since the damages are related directly to displacements, therefore, in this study Direct Displacement-Based Design (DDBD) approach in the content of PBSD is implemented.

Nigel Priestley identified some of fundamental shortcomings with existing force-based seismic design methodology so they introduce the direct displacement based design.

The objective of this paper is to review literatures and codes related to PBSD of structures and recent developments suggested by authors.

II. PBSD STATE OF DEVELOPMENT

As stated earlier the social demand and multiple performance objective pushed the practice to performance based design framework while retrofitting existing buildings, in 1980s in the United States. To achieve high level of performance following document were established in first generation procedure of performance based design: SEAOC Vision 2000, ATC 40(1996), and FEMA273 and 274(1996).

Structural Engineer Association of California (SEAOC) in 1995 developed PBSD of building known SEAOC Vision 2000. The goal of mentioned document is to develop the framework for procedures that lead to design of structures of predictable seismic performance and is able to accommodate multiple performance objectives. The document elaborates the concepts and addresses the performance levels for structural and nonstructural systems. Performance levels such as fully operational, operational, life safety and near collapse are described with specified limits of transient and permanent drift. The capacity design principles should be applied to guide the inelastic response analysis of the structure and to designate the ductile links or forces in the lateral force resisting system. Possible design approaches include various elastic and inelastic analysis procedures such as: 1. conventional force and strength methods, 2. displacement-based design, 3. energy approaches, and 4. Prescriptive design approaches.

Applied Technology Council (ATC) provided ATC 40 document, performance-based design concept refers to the methodology in which structural criteria are expressed in terms of achieving a performance objective. The document was limited to concrete buildings and emphasizes the use of the capacity spectrum method. The procedure is determining the capacity and demand spectra. To developed the capacity spectrum, the force displacement curve of a point on the structure is determined using nonlinear static (pushover) analysis. The forces and displacements are converted to spectral accelerations and spectral displacements using an equivalent SDOF system. Demands of the earthquake are defined by highly damped elastic spectra. At the performance point the seismic capacity is assumed equal to the demand, which provides an estimate of acceleration (strength) and displacement (demand). Probability of occurrence of the earthquake may be related to the risk of occurrence of the associated damage state. Not all the components of the procedure are well established. For example, an attempt was made to develop relationships between ductility and damping using perfect, hardening and softening models, however, further research and development will have required. Although the capacity spectrum is simple, the theoretical basis and physical interpretations are questionable.

The Federal Emergency Management Agency(FEMA) report FEMA 273/356 document which presents a variety of performance objectives with associated probabilistic ground motions. Analysis and design approaches for the multi-level performance range from linear static to inelastic time history analysis. The document defines performance levels for nonstructural elements and systems and assumed drift limits for various lateral load resisting structural systems at different performance levels. However, while ground shaking is defined in probabilistic terms, uncertainty and randomness not considered related to structural demands and capacities.

In 2001, FEMA funded the Applied Technology Council (ATC) to initiate development of next-generation performance-based design criteria with an initial task to develop tools to enable engineers to reliably predict the earthquake performance of new and existing structures. After 10 years, the resulting FEMA P-58 (FEMA, 2012) publication and its companion products are complete. Impacts of earthquake were addressed as repair costs, repair time, serious injuries requiring hospitalization, and deaths.

The methodology enables three different types of performance assessments. Intensity-based assessments enable development of performance functions conditioned on the occurrence of a particular ground shaking intensity, such as that represented by an elastic, 5%-damped, acceleration response spectrum. Scenario-based assessments provide performance functions conditioned on the occurrence of a particular earthquake scenario defined by an event magnitude and distance from the building site, taking into account uncertainty in ground shaking intensity, given a defined event. Time-based assessments produce performance functions considering all possible earthquake scenarios and the annual frequency of exceedance of each scenario, taking into account event uncertainty.

III. Direct Displacement Based Design (DDBD)

The performance level is defined in many document by damage states of structural and non-structural members, and hence damages are directly related to displacement. Further, displacement is a key parameter in DDBD approach, therefore, DDBD approach, among other PBSD procedures, has been developed significantly and it is under improvement.

In DDBD methodology, the original structure is substitute by an equivalent SDOF (fig. 1a). this equivalent system is characterized by secant stiffness K_e at maximum displacement Δ_d (fig. 1-b).Equivalent viscous damping ξ_{els} including of combined elastic damping and hysteretic damping as shown in fig. 1-c. then a design period is obtained directly from fig. 1-d. in according to the specified design.

The base shear is product of design displacement Δ_d and secant stiffness K_e.

DDBD approach has been widely addressed in literature for the seismic design of different types of structures.

Gulkan and Sozen (1974), provided equivalent damping equations for an SDOF system, as a result of study of the non-linear behavior of RC structures for dynamic loadings. Shibata and Sozen (1976), developed a substitute structure methodology for RC structures, which is aimed to devise the Displacement-Based Design (DBD) method. Mohele (1992) , suggested a seismic resistance design and evaluation approach. Initial steps of this approach is the calculation of stiffness, elastic period, and different strengths are included, although, it is different with traditional methods for seismic design of the structure is control of displacements are included directly in this method instead of indirect control using ductility factors. Furthermore, displacement response spectrum is used in the design process.

Kowalsky, M.J., Priestley, M.J.N., and MacRae, G.A., 1995, suggested the initial step for the mentioned approach, was to determine the maximum target displacement for the SDOF structure. To obtain the maximum target displacement for SDOF structure, ductile capacity of the structure is used. In this approach, an acceptable value for yield displacement is assumed, and dividing maximum target displacement of an SDOF system by the assumed yield value gives, demand displacement ductility Using this demand displacement ductility, as mentioned earlier, equivalent viscous damping is obtained, then effective period, effective or secant stiffness, and base shear force calculated. This approach was generalized for MDOF structures by Calvi and Kingsley (1995). Chopra and Goel (2001), applied inelastic design spectra to DDBD approach.

Priestly and Kowalsky (2000), proposed the general procedure of DDBD approach, assuming initial displacement profile For the seismic design of reinforced concrete structures. Later on a DDBD procedure for RC dual wall-frame structures has been suggested by Sullivan et al. 2006.

Priestley M.J.N., Calvi, M.C., and Kowalsky, M.J. (2007), Summarized the DDBD approach and showed the state of development aforementioned approaches is now rather mature, with detail consideration of real engineering issues, such as MDOF system, torsional response, irregularity of structural layout, P- effect, and a wide range of different structural types including walls, frames, dual system, bridges and seimic isolated structure.

Sullivan and Lago in 2012, suggest a simplified DDBD approach for the seismic design of moment resisting frames with viscous dampers. DDBD approach for steel-braced reinforced concrete frames has been investigated by Malekpour et al. 2013.

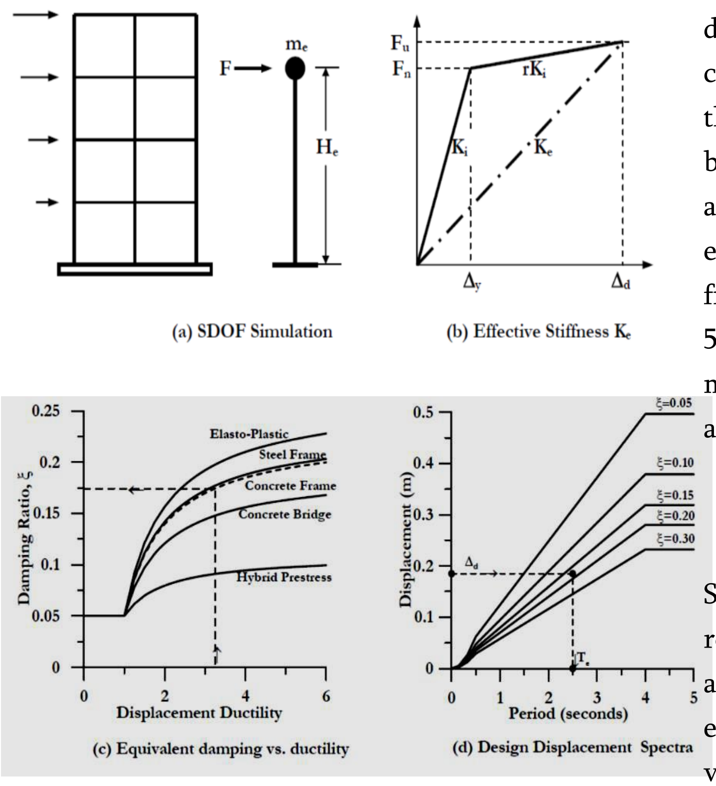

Fig. 1. DDBD Concept (a) Equivalent SDOF system; (b) Secant Stiffness;
(c) Equivalent damping vs. ductility; (d) Design displacement spectra (Priestly, Calvi and Kowalsky 2007).

IV. Advantages of direct displacement based design method

Direct displacement-based design method is considered to offer the following advantages:

1. Displacements play a major role at the preliminary design stage itself resulting in good control on displacements over the entire design process. Target displacement criteria are selected for the serviceability and ultimate limit states and thus damage control is achieved directly.

2. The strength and stiffness of the lateral load resisting system (LLRS) are chosen to satisfy the desired deformation criteria.

3. Empirical equations for estimating the fundamental period of the structure for preliminary design of the LLRS are not required.

4. The selection of a displaced shape at the start of the design process forces the engineer to consider the configuration of the LLRS and the drift tolerance for the non-structural elements. The displaced shape may be linked explicitly to the member ductility demand, as is the case in the CBF. The drift of non-structural elements at various levels of damage can be obtained from experiments and used directly in design.

5. The empirical and somewhat arbitrary force modification factor, *R*, used in the spectral acceleration based design method, is not needed.

V. SUMMARY AND DISCUSSION

Several approaches for the DDBD method proposed by researchers have been briefly reviewed in this paper and it is observed that more research work is needed especially for development of DDBD method for various other different types of structures. It is important to note that in the DDBD method, control of drift and yielding is built into the design process from the very start, eliminating or minimizing the need for lengthy iterations to arrive at the final design. Other advantages include the fact that innovative structural schemes can be developed by selecting suitable yielding members and/or devices and placing them at strategic locations, while the designated non-yielding members can be detailed for no or minimum ductility capacity. All of these would translate into enhanced performance, safety and economy in lifecycle costs. As the DDBD accepts damage in seismic events, and proves to be the most economical solution, and the performance can be quantified and confirmed to the owner‘s desires, it is quite possible that it can be misused by the owner for personal profits.

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