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COMPARISON OF NONLINEAR SEISMIC BEHAVIOR OF BUILDINGS DESIGNED USING THE FORCE AND DISPLACEMENT-BASED PROCEDURES

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Seismic resistant design of buildings traditionally has been performed using the force-based design (FBD) procedure. In such an approach, the maximum lateral force sustained by a building system due to its mass and maximum acceleration during the earthquake shaking is reduced using a response reduction (or, R) factor to make a seismic design affordable to building owners. On the other hand, the minimum seismic safety is retained by making a structural system that benefits from enough redundancy and ductility. In this approach, value of the R-factor has to be decided upon more or less by "tuning" the response such that there is not much difference between the outcome of gravity and seismic load combinations overall. Then, it is inevitable to check for the ductility demand using real displacements of stories that are thesmselves nonlinear in nature, i.e., they are quantities not proportional to lateral forces by having much faster rates of change in large earthquakes than the forces. This requires use of another "tuning" coefficient called the displacement amplification factor.

Use of the above two essential modification factors for a seismic design initially based on forces has been the subject of intense discussions and challenges during the last 30 years. It is argued that whether it is possible to find a more "direct' way to design buildings based on a pre-selected level of seismic displacements according to the performance desired for the building. This procedure has flourished practically in calculating the lateral forces associated with the design displacements of stories and following the same route as the force-based approach in analysis and design of building afterwards. This is made possible by using a design displacement spectrum, calculated for various levels of ductility. Nowadays, this procedure is called the displacement-based design (DBD). Since displacements are more or less bound to certain seismic performances, the displacement-based approach is taking more momentum towards being established in the future design codes.

The first steps towards formulation of a displacement-based procedure for seismic design were taken by Kowalsky et al. (1994) and Priestley and Kowalsky (2000). In their works, they developed a step-by-step methodology for DBD of reinforced concrete buildings. The deisplacement-based approach was extended to seismic design of steel structures by Medhekar and Kennedy (2000a and 2000b). Chopra and Goel (2001) evaluated different linear and nonlinear design displacement spectra as essential ingredients of a DBD and recommended use of nonlinear spectra for the same purpose. A relatively untouched aspect of DBD is its application for torsionally-coupled buildings. Paulay (1997) developed a method for calculating the nonuniform plan displacements due to torsion for DBD of eccentric buildings. Recently, Sabet-Rasekh and Behnamfar (2019) modified the mentioned approach by including concurrent bi-directioanl nonlinear behavior of torsional buildings.

In this paper, similar buildings designed using force-based and displacement-based approaches are compared and judged based on their final seismic behavior by calculating the maximum rotation of their plastic hinges. For this purpose, several moment frame buildings having 4 to 12 stories are desinged using the FBD and DBD approaches. They are then evaluated using the nonlinear dynamic analysis. At the design stage, the buildings are assumed to be regular in plan and elevation. They are then made torsionally-coupled when being evaluated under earthquake ground motions. The eccentricity is assumed to be due to the mass eccentricity up to 30% of the plan dimension. Eleven pairs of ground motions are selected and scaled carefully for the dynamic analysis of the buildings using OpenSEES. Nonlinear modeling of the building members is accomplished using concentrated plasticity assumption as bending plastic hinges concentrated at the ends of the members of the reinforced concrete special moment frames. Results of the design stage show that the outcome of the DBD and FBD approaches are buildings similar in weight and fundamental periods, but somewhat different in stiffness distribution especially in the shape of larger columns with DBD. The nonlinear dynamic analysis of buildings results in their story drifts and total plastic hinge rotation of the stories. For instance, for the 4-story building, variation of the story drifts along building height shows that the trend of the drift values is very similar between the two approaches. The maximum value is somewhat larger with DBD but the difference remains below 5% between the two approaches. The difference, however, is much larger when comparing distribution of the maximum total plastic hinge rotation of different stories between the two approaches for various torsional eccentricites. This is shown in Figure 1. As observed, plastic action, hence seismic damage, can be more than 4 times the DBD values with FBD approach for certain eccentricities.

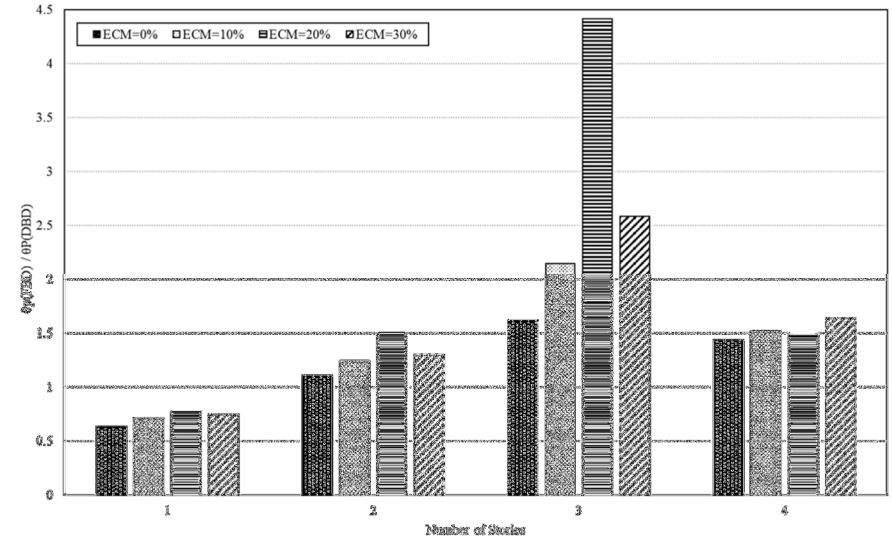

Figure 1. Averaged maxima of total plastic hinge rotation with SSI normalized to those without SSI (ECM=Eccentricity ratio of mass).

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