EARTHQUAKE RESILIENT BUILDING DESIGN– FROM PRESCRIPTIVE TO PERFORMED BASED DESIGN

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ABSTRACT

The paper provides insight into seismic design concepts using structural dynamics, their incorporation into seismic design codes, prescriptive methods in seismic design codes, and movement towards more realistic performance based design. The intent of current design codes are to provide life safety in an relatively infrequent earthquakes. Historically code based building seismic lateral forces have taken into consideration seismic hazard, the performance of the structural system, and the dynamic properties of the structure. Over the years the code provisions for lateral load calculations have being modified to include better representation of these parameters. Special detailing provisions have been continually improved to provide ductility to handle inelastic response of structures resulting from earthquake forces that are well beyond the design forces. Currently there is a great interest to move from prescriptive earthquake resistance design to a performed based design of a building. In this concept acceptability of varying levels of damage is determined based on frequency of such damage is expected. In this regards performance levels are determined such as i) Fully operational ii) Operational iii) Life safety iv) Near collapse. The capacity of the structure must takes in to account the nonlinearity of the force displacement relationships as the structure would go into non linear region. The structural analysis may consider non linear modeling based on techniques such as push over analysis or non linear time history analysis. If the capacity of the building so determined exceeds the demand of the earthquakes considered then the performance objective is satisfied.

***Key words*:** building design, performance based design, earthquakes forces, performance levels, non linear analysis, push over analysis

1. PRESCRIPTIVE DESIGN

Historically code based building seismic lateral forces have taken into consideration seismic hazard, the performance of the structural system, and the dynamic properties of the structure. A simple zone factor is used to acount the seismic hazard of a region in older codes while the newer codes incorporate effect of seismic sources in the vicinity of the structure. The vibration motions causes inertia forces on the structure. If the structure is rigid and rigidly attached to the foundation then the inertia force is equal to the mass of the structure multiplied by the ground acceleration at the given time. If the structure is flexible then the inertia forces on the structure may be much larger than the mass multiplied by the ground acceleration. As a result knowledge of structural properties such as structural stiffness, mass (hence natural period) and damping and their distribution along the height of the structure is important for seismic analysis. Another important aspect of seismic design is to ensure availability of sufficient ductility of the structure. The structure should be able to deform many times as large as yield deformation. This means that not only the strength criteria but performance at large deformations should be considered. The detailing at structural connections is very important to ensure that the structure will stick together without failing at large deformations. This is ensured by evoking a systems quality factor R based on the quality of detailing of a structure. Over the years the code provisions for lateral load calculations have being modified to include better representation of these parameters. Special detailing provisions have been continually improved to provide ductility to handle inelastic response of structures resulting from earthquake forces that are well beyond the design forces

The primary objective of design codes is to protect lives by providing integrity, strength, and toughness to resist collapse in relatively infrequent earthquakes. The secondary objective is to minimize property damage in more moderate events. California and elsewhere has become the laboratory to judge the effectiveness of building codes in recent times. In addition to loss of life the economic damage from an earthquake can be so severe that engineers are looking at options of designing beyond life safety requirements of design codes.

2.PERFORMANCE BASED DESIGN

Performance based design is an alternative to prescriptive design where performance objectives of clients and designers can be incorporated. These alternate methods were acceptable in the codes for years even though not utilized. This is done by specifying an acceptable level of damage to earthquakes considered. The performance levels that can be considered after an earthquake of particular intensity are

i) Structure fully Operational (essentially no damage has occurred)
ii) Immediate Occupancy (moderate damage to non structural elements but no damage to structural elements)
iii) Life safety (no major building damage but structural damage)
iv) Collapse prevention (near collapse)

The basic safety objectives consists of Collapse Prevention performance for Maximum Considered Earthquake (MCE) and Life Safety Performance for Design Earthquake as defined in ASCE 7 standard [1]. Maximum considered earthquake is defined as an earthquake that has a return period of about 2500 years while a design earthquake as that with 500 years. In order to ensure the structural performance of above levels structural analysis needs to be performed with seismic loads. Currently accepted analysis types are

i) A linear static analysis (similar to current equivalent lateral force procedure in design codes
ii) A linear dynamic analysis (that includes response spectra analysis or linear time history analysis)
iii) A non linear static procedure (a push over analysis)
iv) A non linear dynamic analysis (non linear time history analysis)

In non linear analysis component nonlinear curves are developed and used for structural analysis. The figure 1 is such a curve with performance levels defined in FEMA 365 [2].

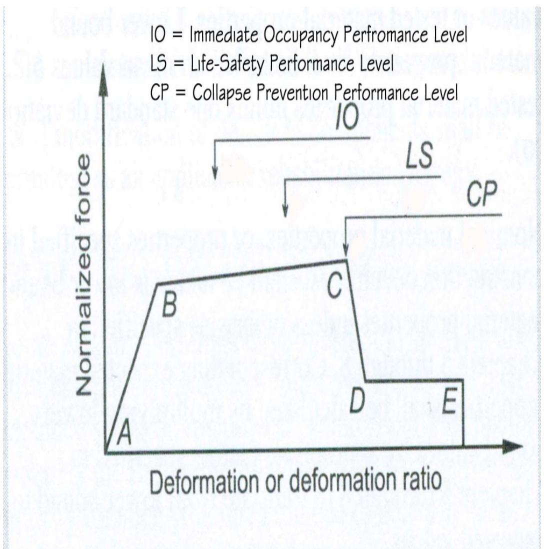

Figure 1: Acceptance Criteria of Performance levels in relation with Component Force-Deformation Curve (FEMA 356)

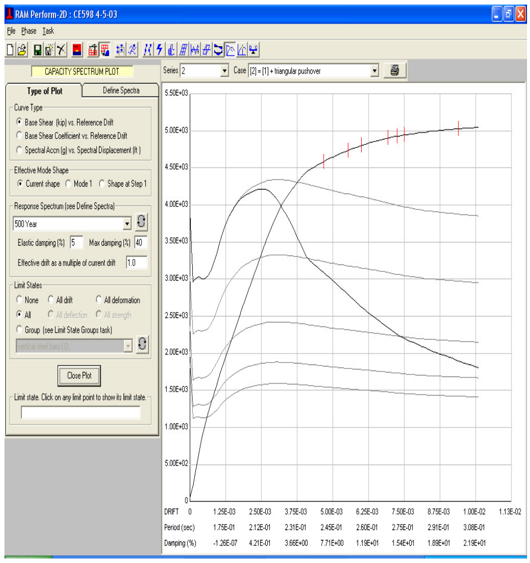

Figure 2: Demand Capacity Plot for a Perforated Shear Wall in a Push Over Analysis for a 500 year earthquake.

The figure 2 shows a demand capacity plots for a push over analysis of a non linear static analysis. The vertical lines on the capacity curve are the limit states which are above the performance point (where the capacity curve crosses the demand curve) meaning that the shear wall satisfys the performance criteria of life safety.

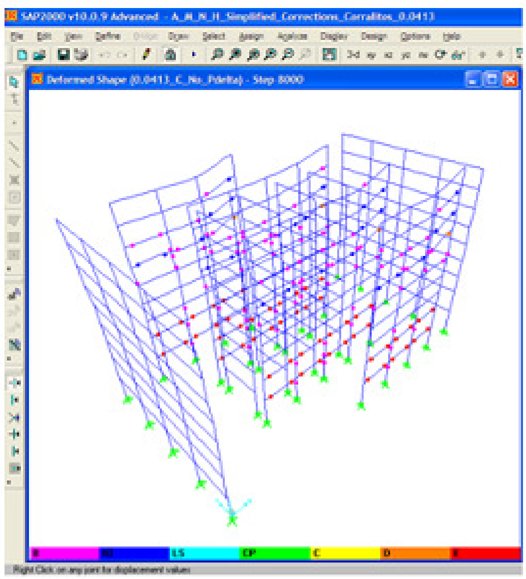

Figure 3: Results of a non linear dynamic analysis of a steel building with joint hinges formed

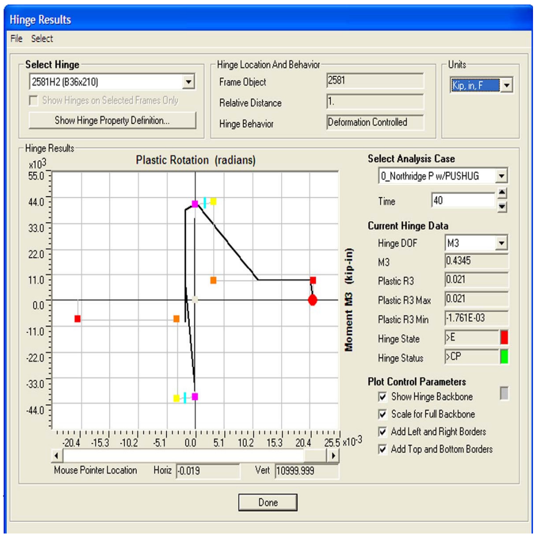

Figure 4: Plastic Moment vs. Rotation at a Moment Connections

The figure 3 depicts a building model with non linear SAP 2000 [3] analysis results of a time history dynamic analysis using the maximum considered earthquake. The figure 4 shows the plastic moment vs. plastic rotation of a moment connection of the building. The plastic deformation has reached beyond the collapse prevention level and hence the performance objective is not satisfied i.e. collapse prevention is not satisfied for a maximum considered earthquake of 2500 return period.

The next generation of Performance Based Design is to use uncertainties (probability of incurring casualties, retrofit costs and retrofit time) as measures of performance. The guidelines for this is being developed as FEMA 58 (ATC 58). This method has a more realistic performance levels defined including building life cost analysis.

3. CONCLUSION

The paper describes the prescriptive methods of seismic design as well as the performance based seismic design for buildings. It is expected that more and more buildings will be designed to Performance Based Design guidelines there by reducing loss of life and retrofit costs.

4. REFERENCES

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