AN IMPROVED SEISMIC DESIGN APPROACH FOR TWO-COLUMN REINFORCED CONCRETE BENTS OVER FLEXIBLE FOUNDATIONS WITH PREDEFINED DAMAGE LEVELS

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ABSTRACT:

A variety of new seismic response measures have been recently developed relying mostly on the computation of concrete and steel strains to assess target damage levels for structural seismic design. Two-column reinforced concrete bents over flexible foundations are not investigated extensively in design oriented seismic performance studies. In this research a seismic design guideline is proposed for two-column reinforced concrete bents over flexible foundations utilizing an improved seismic response measure. The improved seismic response measure is quantified by computing the ratio of bent top displacement capacity to demand (C/D). Shifting away from the strain based seismic response measures, ratio of displacement capacity to demand (C/D) can be limited for each three predefined damage levels being 1) minimal damage, 2) repairable damage, and 3) significant damage. A set of limiting ratios corresponding to predefined damage levels are computed based on an extensive analytical study.

KEY WORDS : bridge, seismic, damage

1. INTRODUCTİON

Structural damage measured by material strains, and non-structural damage measured by drift are directly related to structural displacements. Displacement-based seismic design of structures has been researched by a number of scientists, such as Priestley, et al. (2007), Nielsen and DesRoches (2007), Lu et al. (2005), Lehman et al. (2004), Mo and Nien (2002), Park et al. (2001), Kowalsky (2000), Whittaker et al. (1998), Williams and Sexsmith (1995), Moehle (1992), and Floren and Mohammadi (2001), among others. However, two- column reinforced concrete bents over flexible foundations are not studied in detail.

ATC-32 (1996) proposed a two-level performance objective related to seismic intensity and importance factor. Required performance objectives of CALTRANS (2006) and AASHTO-Seismic (2009) were almost identical to the ones in ATC-32 (1996). In these specifications, performance design criteria were established for bridges classified as “ordinary” but not for bridges classified as “important” for a safety evaluation earthquake.

ATC-32 (1996) adapted three damage levels:

Minimal damage: Damage is limited to minor flexural cracking, and minor inelastic response is permitted to develop at structural elements.
Repairable damage: Concrete cracking, reinforcement yielding and minor spalling is allowed, but limited to avoid closure of the structure during minor repair work.
Significant damage: Similar to repairable damage, except during repair, the structure needs to be closed for major repair work.

In this research, a commonly used seismic response measure has been modified to develop a classification for different damage levels for two-column reinforced concrete bents over flexible foundations to be used in proposed seismic design guideline. In this new approach, for the selected damage level design, similar damages are targeted to be observed after the earthquake to maintain uniformity in repair works.

2. MODIFIED SEISMIC RESPONSE MEASURE

In the CALTRANS (2006) approach, ordinary bridges are not allowed to collapse under the safety evaluation earthquake (SEE). The bent top displacement capacity to demand ratio is limited to

$$\frac{\Delta_C}{\Delta_D} > 1.0 \qquad (1)$$

Damage levels of reinforced concrete elements are generally evaluated using concrete and steel strains. A correlation between concrete and steel strains and the displacement-based seismic response measure is constructed to estimate the damage levels. A modification of Eq. (1) is suggested to classify the damage target levels specified in ATC-32 (1996) and CALTRANS (2006). In engineering practice, this methodology has been adapted in the design of Cooper River Bridges at South Carolina (PBQD 2009).

$$\frac{\Delta_C}{\Delta_D} > \beta_{di} > 1.0 \qquad (2)$$

where β_{di} is the target damage level index to be used in classification of damage. In a new bridge design, the target damage level index can be selected based on the importance factor of the bridge and the return period of the design earthquake at the site of the bridge.

Target damage level index has been investigated analytically for bents with different column slenderness, column longitudinal reinforcement ratios and foundation flexibilities at the safety evaluation earthquake level with a return period of 1000 years per AASHTO (2009). Each bent is designed per the requirements of the AASHTO-LRFD (2007) and absolutely no brittle shear failure is allowed. Displacement capacities have been determined from pushover analyses and demands have been obtained from inelastic time-history analyses. The average of eight inelastic time history analysis results has been used to determine the demand for each bridge model. The details of the extensive analytical study can be found at the work of Yilmaz (2008) also available online at the Middle East Technical University's library website and algorithm of tasks is illustrated in Figure 1. The theories behind the non-linear analysis can be found at the works of Caner and Hsu (1999), Clough and Penzien (1993), Cook et. al. (1989), Karakaplan et. al. (2009), and Sivaselvan and Reinhorn (1999).

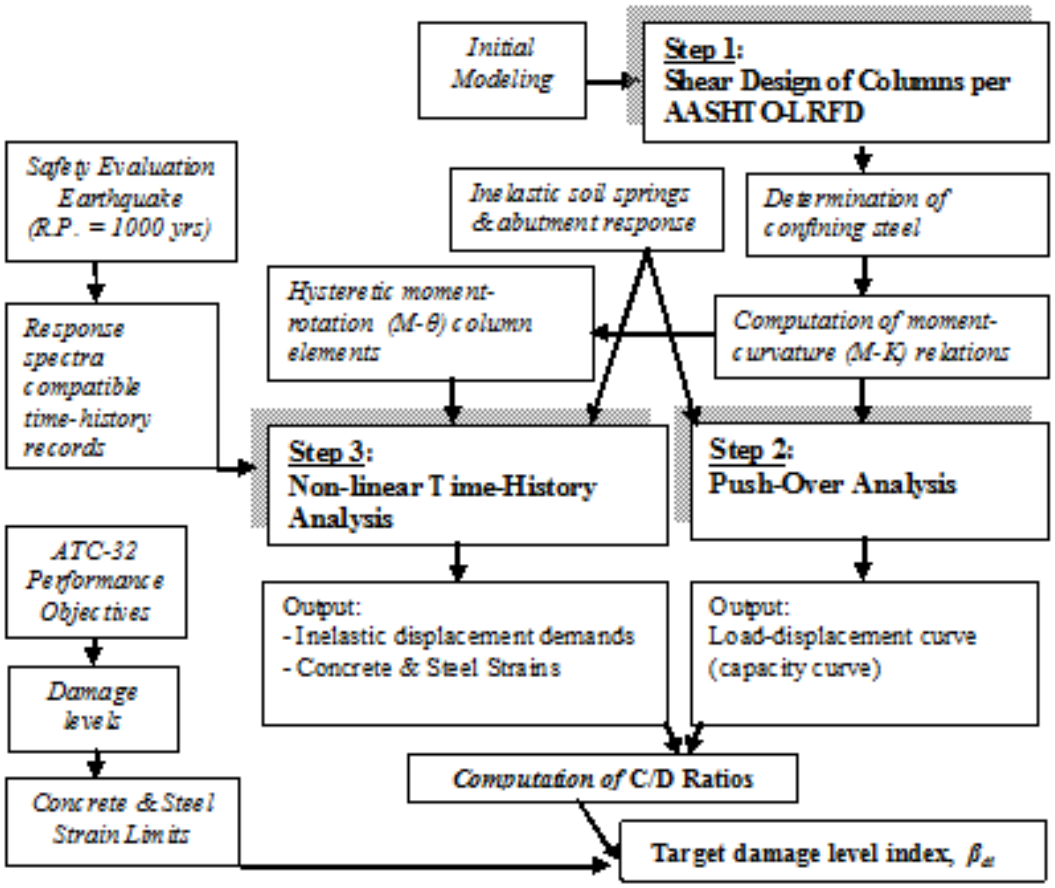

Figure 1. Algorithm for Analytical Works

Target damage index values for safety evaluation earthquake are suggested based on the detailed research conducted by Yilmaz (2009) in Table 1. The definitions of the poor and competent soil are adapted from CALTRANS (2006).

Table 1. Computed Limiting C/D Ratios and β_{di} Values

		Damage Level		
Definition		Significant	Repairable	Minimal
Competent Soil	*C/D* Ratio	1.03	1.48	2.27
Poor Soil	*C/D* Ratio	1.04	1.41	2.46
Suggested	β_{di}	**1.10**	**1.50**	**2.50**

3. PROPOSED SEISMIC PERFORMANCE ASSESSMENT GUIDELINE

A seismic performance assessment guideline is prepared for the end user of the proposed displacement to capacity ratio.

- Conduct an elastic dynamic analysis to determine the displacement demand at the top of the bent. In analysis, use effective soil springs along the pile at certain depths and iterate the elastic dynamic analysis till effective soil springs determined from the non-linear p-y curves (API 1993) converge to previous selection. The effective section properties of columns can be either determined from the moment-curvature analysis or from related figures presented in ATC-32(1996). If the equivalent displacement rule does not hold, use the suggestions presented in ATC 32(1996) to make corrections to the bent top displacement determined from the elastic dynamic analysis.

- Conduct a non-linear static pushover analysis of a bent to determine the top displacement capacity of the bents. The model can include non-linear representation of the plastic hinge zone, non-linear representation of pile springs and geometric non-linearity.

- Compare the ratio of bent top displacement capacity to demand with the proposed limits of target damage presented in Table 1. If the current design is not satisfying the target damage design level, improve the design and rerun all the analysis.

4. CONCLUSION

The following conclusions can be drawn from this research as follows:

- The investigated parameters: column size, column longitudinal reinforcement, column slenderness and local soil condition directly affect the target damage state defined for seismic performmance assessment of a new design. The proposed analysis guideline is found to be an effective approach in predicting damage states.

- Based on the correlation of seismic response measures with damage levels, displacement capacity-demand ratios of 1.1, 1.5 and 2.5 are suggested for significant, repairable and minimal damage levels for the safety evaluation earthquake with a return period of 1000 years, respectively.

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