

THE ATC-78 METHODOLOGY FOR EVALUATION AND MITIGATION OF NONDUCTILE CONCRETE BUILDINGS

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Abstract

Faced with evidence that some older nonductile concrete buildings may pose a significant risk of structural collapse, some municipalities are considering legislation mandating identification, evaluation and, in some cases, retrofit of these structures. However, not all older concrete buildings pose a substantial seismic risk. This paper describes a new methodology that can be used to evaluate a concrete building to determine whether it is an “exceptionally high seismic risk” building. These exceptionally high seismic risk buildings are candidates for more detailed evaluation and, possibly, retrofit. The methodology presented is under development by the ATC-78 project team and requires the engineer to estimate drift demands and drift capacities of key components in the structure, *e.g.* columns or slab-column connections. These drift demands and capacities are used to compute column ratings, which are then used to determine story ratings and, finally a building rating. These ratings represent the likelihood of collapse for the column, story or building, respectively, and vary between 0 and 1. The drift demands depend on the building strength, period, and the expected drift distribution. The drift capacities are based on experimental data quantifying failure of different types of reinforced concrete components with varying levels of detailing. The methodology also accounts for torsional irregularities and lap-splice deficiencies. The methodology is intended to be relatively quick to perform and a structural analysis model is not needed.

Introduction

The ATC-78 methodology addresses the vulnerability of older (pre-1980) nonductile concrete buildings persisting in a number of cities and states in the U.S. It is well known that some of these concrete buildings represent a significant threat to life safety (Liel et al. 2011). However, it is also clear that many buildings constructed during the same time period may not represent such a threat. The ATC-78 methodology aims to provide a procedure whereby exceptionally high seismic risk “killer” buildings, may be identified from among a large group of potentially vulnerable buildings. It is anticipated that the methodology will be used to evaluate a group of buildings, such as pre 1980 concrete buildings in a city’s building inventory, to identify those that are high collapse risks and high priorities for retrofit.

In this context, the ATC-78 procedure intends to quantify the propensity of a structure to suffer global collapse. The completion of the method does not require a structural analysis model, instead relying on linear and hand (spreadsheet) calculations. These features are intended to reduce the time required to evaluate each building and to ensure, through prescriptive criteria, that results for one building can be easily compared to results for another building obtained by a different engineer, enabling consistent ranking of building inventory in terms of collapse risk. By evaluating the likelihood of global collapse, rather than component failures, the methodology tries to avoid excessive conservatism inherent in other seismic evaluation documents, such as ASCE 41 (2013). In its current form, the methodology is limited to frame buildings, but includes (a) lateral force resisting frames, (b) gravity framing systems, and (c) frames with slab-column connection systems. The procedure development is led by Bill Holmes, with a Project Technical Committee consisting of Jack Moehle, Michael Mehrain, Peter Somers and Abbie Liel.

In this paper, we introduce the guiding principles of the methodology development and provide a brief overview of the steps required to evaluate a building.

Methodology Overview

The outcome of an ATC-78 evaluation of a building is a building rating. The building's rating depends on a number of factors, including building strength, building period, column-to-beam strength ratios, shear criticality of columns, and detailing features. These factors influence calculation of column drift demands and column drift capacities, which are used to identify component failures. Global collapse is predicted from the combination of column (component) failures observed.

Initial Calculations and Story Demand-Capacity Ratios

To carry out the methodology, the analyst begins by collecting building drawings, information about expected material strengths, and seismic hazard for the building location. The methodology recommends carrying out the analysis at the spectral acceleration level corresponding to the 5% in 50 year hazard level. Once this information is obtained, the methodology provides rules wherein column, beam and other member strengths can be combined and compared to estimate the base shear strength of the structure. Story demand-capacity ratios are determined by comparing the strength of each story to the force demand obtained by an assumed distribution of story drift demands (inverted triangular for constant story height and masses). These demand-capacity ratios are used to identify critical stories. At this stage in the calculations, the building period is computed from the building strength and building height; the relationship between strength and building period is intended to quantify a secant stiffness for later analyses.

Determination of Drift Demands

The next step in the methodology is the determination of story drift demands. These drift demands are based on the predicted displacement of an equivalent single degree of freedom oscillator under the spectral acceleration of interest. This displacement is predicted from the spectral displacement, modified with coefficients accounting for elastic response and hysteresis parameters. Once the displacement of the equivalent oscillator is obtained, the drift demands at each story are obtained from the product of the equivalent drift and a set of modification factors that depends on the building design and framing characteristics. Three types of modification factors are employed. The first factor, α , amplifies the story drifts in certain stories to represent typical patterns of drift concentration. α factors are defined in a table, and describe the typical distribution of drift demands over the height of the building, accounting for the number of stories and the ratio of column to beam strengths. The second factor, β_{ci} , further amplifies drifts at designated critical stories, capturing drift concentrations for buildings that have an uneven distribution of demand-capacity ratios over the height of the building. Finally, the β_{sl} factor amplifies drifts further in stories that have deficient lap splices in longitudinal reinforcement.

In the next step, story drift demands are used to determine drift demands on every column. In particular, a torsional amplification factor is used to increase the estimated drift demands at the edge of the building. The methodology also accounts for the fact that columns and beams together share the story drift demand. A column drift factor estimates the fraction of the drift going to the column depending on column to beam strength ratios.

Determination of Drift Capacities for Column Ratings

Column drift capacities are based on experimental data quantifying the deformation a column is capable of undergoing before losing vertical load carrying capacity. The ATC 78 methodology provides tables that provide column drift capacity as a function of column axial load and transverse reinforcement ratio. The development of these tables utilized a suite of data collected by Elwood et al. (2007) and expanded to

include shear critical columns tested to axial failure in recent years. Unlike ASCE 41 (2013), the predicted drift capacities are explicitly defined as median values, such that there is a 50% chance a column with the characteristics of interest will have a true capacity that is greater than the tabulated value. The use of the axial failure criteria and median values for column drift capacities are intended to avoid some of the conservatisms that are problematic for using evaluation methodologies to prioritize buildings as retrofit candidates. If a building has slab-column connections, these columns may be the critical component. In this case, the drift capacity of the slab-column connection is computed from median values provided in a different table. The analyst must compute the drift capacity of every column in the building.

Column ratings are based on the ratio of column drift capacity to drift demand, and represent the probability that drift demand exceeds drift capacity or the likelihood of column failure. Column ratings vary from 0 and 1, where a rating of 1 indicates the very worst columns. Column ratings are determined from structural reliability methods. These reliability methods relate a lognormal distribution of drift demand, defined by a median value obtained from the drift demand calculations and uncertainty reflecting record-to-record variability in structural response, and a lognormal distribution of drift capacity, defined by a median value obtained from the tabulated values and uncertainty reflecting epistemic and aleatory uncertainty in column capacities. In the methodology, these structural reliability calculations are streamlined, such that the analyst needs only to find the tabulated column rating for a given ratio of median column drift capacity to median column drift demand.

Story Ratings and Building Ratings

Once all columns (or slab-column connections) are rated, the methodology proceeds to the determination of a rating for each story, and finally a building rating. Like column ratings, story ratings and building ratings vary from 0 to 1, representing low to high probability of failure. The conversion between column ratings and story ratings provided in the methodology is essentially a proxy for nonlinear structural analysis, and relates the failure of individual columns to the global collapse of the story. Story ratings are based on the ratings of columns in that story and the proximity of poor columns to each other, representing progressive collapse of a story. To determine story ratings, the analyst needs only to compute the average column rating, which is then related to a story rating. This relationship was developed from Monte Carlo simulation of column drift demands and column drift capacities to determine what combinations contribute to story failure. Story failure is defined to occur if 25% or more of the columns in that story fail.

Column ratings and story ratings are to be computed in both orthogonal directions for the building, and the building rating is taken as the worst story rating in either of the two directions. The building rating represents the likelihood of building failure.

Calibration

Calibration and validation of the ATC 78 methodology is ongoing. As a preliminary beta test, University of Colorado graduate students enrolled in a course on earthquake engineering were asked to carry out the methodology. Each pair of students worked with plans for a real existing nonductile concrete building, and reported intermediate and final results associated with the methodology. The rankings of the buildings obtained from the student work were compared to practitioner judgment. Feedback from the beta-test led to clarification of editorial aspects of the document, as well as modification of some specific technical features of the methodology.

Conclusions and Future Work

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The ATC-78 methodology addresses the need for a relatively quick procedure that can be used to identify the most seismically vulnerable older non-ductile concrete buildings. Such a tool is needed to prioritize retrofit of the most dangerous buildings, given limited resources. At the current time, the methodology is a work in progress. In 2015, the project team will focus on further validation, to be conducted by engineers in Southern California, and the expansion of the methodology to account for the influence of concrete and masonry walls that may influence the response of the structure. The ATC-78 project is funded by FEMA.

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