ASCE 31-03: Seismic Evaluation of Existing Buildings

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Abstract

ASCE 31-03: Seismic Evaluation of Existing Buildings is the next step in a very successful series of evaluation tools used by structural engineers nationwide to evaluate the seismic adequacy of existing buildings. This document has evolved from the tradition of visiting sites damaged by earthquakes and observing what works and what does not work in structural systems. It also embodies the latest efforts in the development of performance-based analysis techniques and reflects the most recent earthquake hazard demand criteria.

This document is the last step in the development of a standard for seismic evaluation of existing buildings applicable across the entire nation. The previous version of this document, *FEMA 310: Handbook for the Seismic Evaluation of Buildings – A Prestandard*, was developed jointly by the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers (ASCE). ASCE has since taken this document through a consensus process to turn it into a national standard. Major changes to this document include a reorganization of the nonstructural checklists and a rewrite of the unreinforced masonry (URM) special procedure. With the publication of ASCE 31-03, the first national seismic evaluation standard reflecting the most current thinking and applying a consistent methodology to the seismic evaluation of existing buildings is now available to the structural engineering community.

Introduction

Over the last two decades, the worldwide economic losses due to moderate to large earthquakes have been significant. The structural engineering community and public policy makers have deemed these losses too large to ignore. As a result, numerous performance-based seismic guidelines have been published with the intent to control and, when appropriate, minimize property and business interruption losses. The publication of *ASCE 31-03: Seismic Evaluation of Existing Buildings* has created a national performance-based seismic evaluation standard, the first of many performance-based structural standards to come for the next generation of practicing structural engineers.

While finally becoming a standard, ASCE 31-03 has evolved from the structural engineering tradition of visiting sites damaged by earthquakes and observing what works and what does not work in structural systems. Furthermore, the document also embodies the latest efforts in the development of performance-based analysis techniques and reflects the most recent national earthquake hazard demand criteria.

History Of Seismic Evaluation Documents

In the past, the seismic provisions of building codes for new buildings were judged to be also adequate for existing structures. This perception grew out of the initial thought that buildings resisted earthquakes by strength alone. With the 1971 San Fernando Earthquake came the understanding that successful earthquake resistance was actually a complex combination of elastic and inelastic behavior of the structural system. The best-performing lateral-force-resisting systems contained ductile details that allowed beneficial inelastic action to occur at key locations in the building. Codes for new buildings quickly developed as a combination of strength and detailing requirements based on the observed behavior of buildings in large and damaging earthquakes.

The ductile detailing provisions in newer building codes limited their applicability to existing buildings because the buildings were already constructed, the materials were defined, and the details of construction were in place. Many of the existing buildings that did not meet the detailing provisions for new design performed fairly well in significant earthquakes. Therefore, the need for a different approach was recognized and some of the early seismic evaluation documents had their roots in the tradition of chasing earthquakes.

Since the 1930s, structural engineers have learned the most about the behavior of structures by visiting sites damaged by earthquakes and observing what works and what does not work in gravity-load-carrying and lateral-force-resisting systems (see Figure 1). The first seismic code provisions were the direct result of observations from earthquakes. Today, the structural engineering community continues to use observations from earthquakes in the never-ending cycle of improving our practice. This cycle also includes research, publication of codes and standards, and engineering practice (see Figure 2). In the past four years, members of the Earthquake Engineering Research Institute (EERI) have visited and collected data on earthquakes in Turkey, Taiwan, India, Italy, Mexico, Alaska and Algeria.

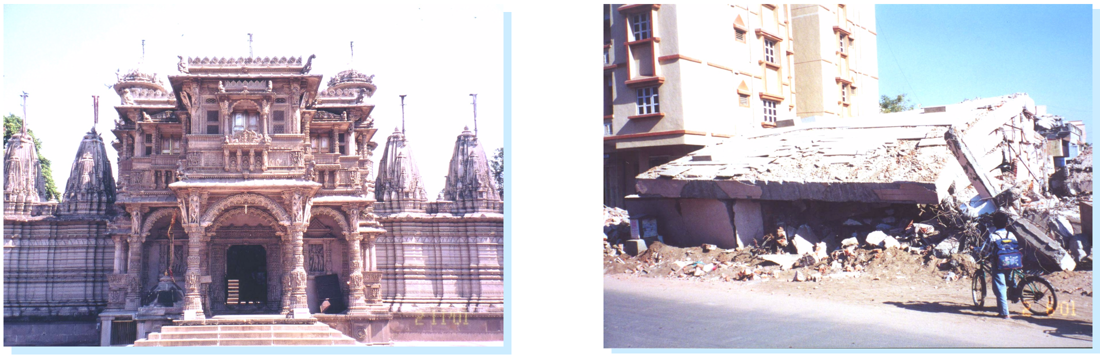

Figure 1. Earthquake reconnaissance observations from India showing structural systems that did and did not perform well.

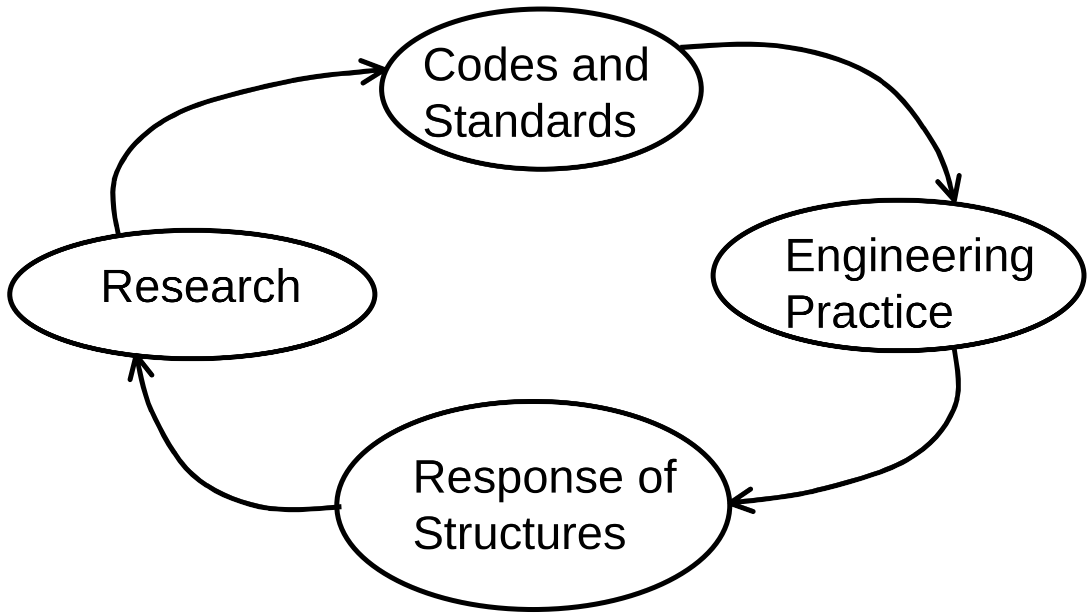

Figure 2. Cycle of codes and research.

ATC-14: Evaluation The Seismic Resistance Of Existing Buildings. In 1983, the National Science Foundation (NSF) funded the next in a series of efforts to create a methodology for evaluating the seismic strength of existing buildings. Various previous attempts had focused on establishing a minimum strength needed and attempted to deal with all buildings with a single methodology. The Applied Technology Council (ATC) published an open request for proposals and awarded the contract to a team that offered a new concept: evaluation subjectively based on earthquake damage observations. Knowledgeable earthquake chasers had come to recognize patterns of weaknesses in the various types of buildings that made them vulnerable. The new idea was to subjectively identify, by building type, when a fatal flaw existed in a building that would lead to unacceptable levels of damage.

The result was *ATC-14: Evaluating the Seismic Resistance of Existing Buildings*, published by ATC in 1987. The document published a catalog of potential weak links in the structural system for fifteen model building types based on earthquake observations. For each potential weakness, appropriate triggering conditions were defined and analysis procedures were offered on how to determine if the potential weakness was, in fact, a fatal flaw. The analysis procedures were based on the equivalent lateral force procedures of the Uniform Building Code (UBC), including R-factors for fully compliant buildings. Adjustments were made to the acceptance criteria based on the degree of ductility determined in the zone of weakness. Zones judged to have limited or no ductility were required to have sufficient strength to remain nearly or fully elastic. It was an extension of the idea that strength could be exchanged for a lack of ductility; a concept not unlike the force-controlled elements developed in performance-based methodologies today.

FEMA 178: NEHRP Handbook For The Seismic Evaluation Of Existing Buildings. The next step in the seismic evaluation document evolution was *FEMA 178: NEHRP Handbook for the Seismic Evaluation of Existing Buildings*. The document was developed by the Building Seismic Safety Council (BSSC) for the Federal Emergency Management Agency (FEMA) based on *ATC-22: A Handbook for Seismic Evaluation of Existing Buildings (Preliminary)*. ATC-22 was a republication of ATC-14 that included an update of the information based on recent earthquakes at the time, included commentary to explain the necessary calculations that were needed to determine if the weak links were actual fatal flaws, and converted the analytical procedures to be consistent with the *1988 NEHRP Seismic Design Provisions*, a nationwide consensus methodology. ATC-22 maintained the same general, fatal-flaw philosophy of ATC-14, and the evaluation procedure used code-like R-factors similar to design procedures for new buildings. Adjustments were made to the procedure when the weak links did not have sufficient ductility to justify the expected inelastic behavior. ATC-22 was then taken through a national consensus process by BSSC. Along the way, numerous refinements were made to the contents to improve the acceptability of the procedure to a broad group of engineers. The most significant change installed in the process was the shift in the analysis assumptions from element-based adjustment criteria for individual components to a reduced R-factor for the system as a whole. FEMA 178 was published in 1992 and has been widely used throughout the world.

FEMA 310: Handbook For The Seismic Evaluation Of Buildings – A Prestandard. Since the publication of FEMA 178, numerous significant earthquakes occurred, including the 1989 Loma Prieta earthquake, the 1994 Northridge earthquake, and the 1995 Hyokogen-Nanbu (Kobe) earthquake. These earthquakes gave new significant insights into potential weaknesses in structural systems, and led to the first call for performance-based seismic engineering guidelines. A joint effort by the American Society of Civil Engineers (ASCE) and FEMA was undertaken to update FEMA 178. The result was the publication of *FEMA 310: Handbook for the Seismic Evaluation of Buildings – A Prestandard* in 1998. This was the first step in the ASCE process of developing an American National Standards Institute (ANSI) approved standard for the evaluation of existing buildings.

FEMA 310 took both the checklists and the analysis procedures from FEMA 178 and combined them into a well-defined three-tier evaluation procedure. The checklists were updated with new statements from lessons learned from recent earthquakes and included expanded commentary on each potential deficiency. A new performance-based methodology was adopted with the adequacy of the building being evaluated at the expected displacement of the structure during the demand earthquake. The procedure also addressed multiple performance and seismicity levels, allowing the design professional to tailor the seismic evaluation effort to the needs of the client.

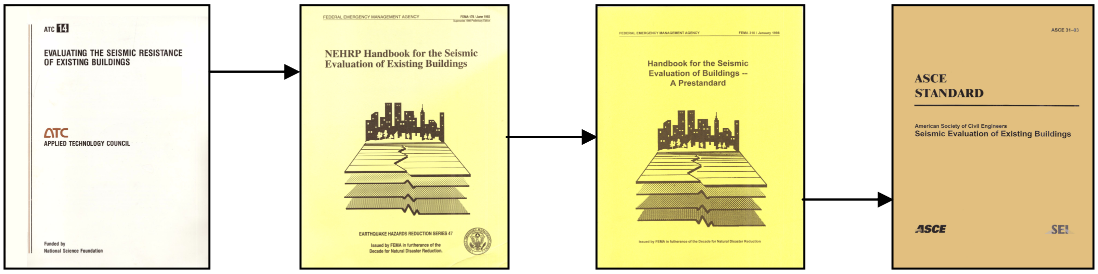

Figure 3. Evolution of seismic evaluation documents (from left): ATC-14 (1987), FEMA 178 (1989/1992), FEMA 310 (1998), and ASCE 31-03 (2003).

ASCE 31-03 Evaluation Process And Methodology

Once FEMA 310 was published, the ASCE Standards Committee on Seismic Rehabilitation took the document and began the consensus process to turn FEMA 310 into a seismic evaluation standard. The reason for turning FEMA 310 into a standard was to create a nationally applicable standard that could be adopted and enforced by jurisdictions. The standard would also have a mandatory update and revision process rather than be revised based on available funding from government agencies and engineering societies.

First, comments from the committee were submitted to the chair of the standards committee in ballot form. The chair was then responsible for resolving all negative comments by either revising the document or finding the comment non-persuasive with the backing of the rest of the committee. This committee revision cycle continued until no more substantial revisions were made to the document and all negative comments were resolved. Once the committee ballot was complete, the document was opened to a public ballot cycle. The same process was followed on the public ballot until no more substantial revisions or negative comments remained. The result is *ASCE 31-03: Seismic Evaluation of Existing Buildings*.

Three major revisions were made to ASCE 31-03 during the committee and public ballot process. The special procedure for unreinforced masonry (URM) buildings in FEMA 310 was a simple conversion of the procedure from FEMA 178. During the ballot process, the URM special procedure was rewritten to be compatible with the rest of the document, including new checklists, testing requirements and member capacities. The Tier 1 procedure for nonstructural components was revised to better identify nonstructural performance with both level of performance and level of seismicity. As a result, the nonstructural checklists were expanded from two to three checklists with revised parameter criteria. Finally, the ASCE Standards Committee on Seismic Rehabilitation is also charged with the consensus process of turning *FEMA 356: Prestandard and Commentary for the Seismic Rehabilitation of Buildings* into a standard. The two documents were written independently of one another but follow the same performance-based methodology. ASCE 31-03 was modified such that terms and procedures in both documents are consistent with the intent that both documents will complement one another seamlessly.

Evaluation Requirements. Prior to a seismic evaluation of an existing building, the evaluation requirements of Chapter 2 determine the level of effort that will be required. Included in these provisions is an examination of existing documents, the determination of the building type, testing requirements, a site visit to determine existing conditions, the desired level of performance for the building, and the level of seismicity.

All requirements affect the amount of effort the design professional will need to complete the evaluation, especially the levels of performance and seismicity. For a building being evaluated to the Life Safety Performance Level, only the basic checklists need to be used. However, a building being evaluated to the Immediate Occupancy Performance Level requires the use of basic and supplemental checklists as well as more restrictive criteria.

For structures located in levels of low seismicity, only minimal requirements are required with the use of a special checklist. Buildings in levels of moderate seismicity require the use of basic checklists while buildings in levels of high seismicity require the use of both basic and supplemental checklists.

Tier 1 – Screening Phase. Once the evaluation requirements of Chapter 2 have been met, a Tier 1 Evaluation is performed. A Tier 1 Evaluation is a rapid evaluation with the purpose of screening out good buildings or identifying potential deficiencies.

Due to some incompatibility of the checklist and performance-based methodology with the design provisions in current codes, it is possible for modern buildings built to current code to not meet the chosen performance level in ASCE 31-03 without extensive Tier 3 evaluation. In order to address this discrepancy, a Benchmark Building provision was included. For buildings designed and constructed to a certain benchmark code document, a structural evaluation does not need to be performed. However, the requirements of Chapter 2 still need to be met and nonstructural and geologic site hazard evaluations still must be performed.

Based on the levels of performance and seismicity determined in Chapter 2, the design professional chooses the appropriate structural, geologic and nonstructural checklists and proceeds to fill them out using information from existing documentation, testing results and site visits. In some statements, a quick calculation of forces and stresses is required. These calculations, called Quick Checks, are to provide an average estimate of the demands on the structure and to determine if a more detailed calculation is required.

Once the Tier 1 Evaluation is complete, the building will either meet the chosen performance level or have some potential deficiencies. For buildings with potential deficiencies, the design professional may choose to continue on to a Tier 2 Evaluation or stop the evaluation and report his/her findings. In evaluations for some buildings, it was deemed that the checklist methodology may not identify all potential deficiencies and that further evaluation is required (either Tier 2 or Tier 3), even if a Tier 1 Evaluation shows no potential deficiencies.

Tier 2 – Evaluation Phase. Based on the results of the Tier 1 Evaluation and any further evaluation requirements, the design professional is directed to conduct either a Deficiency-Only or Full Building Tier 2 Evaluation. A Deficiency-Only Tier 2

Evaluation examines only the deficiencies identified in the Tier 1 Evaluation and is suitable for simple buildings of regular configuration. A Full Building Tier 2 Evaluation examines all aspects of the structure through a complete analysis. The purpose of a Tier 2 Evaluation is to identify any weak links (fatal flaws) in the structure.

The types of evaluations that can be conducted in Tier 2 can either be linear static, linear dynamic, or the URM special procedure. The seismic demands used in the evaluation are based on the Maximum Considered Earthquake (MCE) as determined from the latest United States Geologic Survey (USGS) maps.

Rather than use the traditional equivalent lateral force methodology in current codes, ASCE 31-03 uses the performance-based methodology of pseudo lateral forces developed in *FEMA 273: NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, the predecessor to FEMA 356. The building is evaluated at the expected displacement of the structure during the demand earthquake. Since the analysis is linear, this means that the forces associated with the expected displacement are unrealistically high. The forces for each component are determined and then the components are evaluated based on the ductility of the element. This ductility, or *m*-factor, reduces to the pseudo force level to a point where the component can be evaluated on a realistic force level. For a comparison and graphical representation of the equivalent and pseudo lateral force methods, refer to Figures 4 and 5.

In order to evaluate the components, the design professional must first classify each element as either deformation- or force-controlled. Deformation-controlled elements are those that provide deformation to the entire building through inelastic behavior. An example of a deformation-controlled action is a flexural hinge in a beam. Deformation-controlled elements are evaluated using *m*-factors, which vary for various elements and materials. Force-controlled elements are those that provide little or no deformation to the entire building through inelastic behavior. An example of a force-controlled action is a shear-critical concrete column. Force-controlled elements are evaluated for the maximum force that can be delivered by surrounding elements. Interestingly enough, this component-based procedure is a refined version of the procedures used originally in ATC-14 and ATC-22.

In order for a building to meet the chosen performance level in a Tier 2 Evaluation, all force-controlled elements must be prevented from yielding by the yielding of deformation-controlled elements, and deformation-controlled elements must not exceed their ductility capacity.

Equivalent Lateral Force:

- $V=S_aW/R$
- All members evaluated for global R factor
- Displacements amplified by factor (.7R, C_d, etc.) for ductility checks

Pseudo Lateral Force:

- $V=CS_aW$
- Members evaluated on a component basis as displacement- or force-controlled
- No amplification of displacements

Figure 4. Comparison of the equivalent and pseudo lateral force methods.

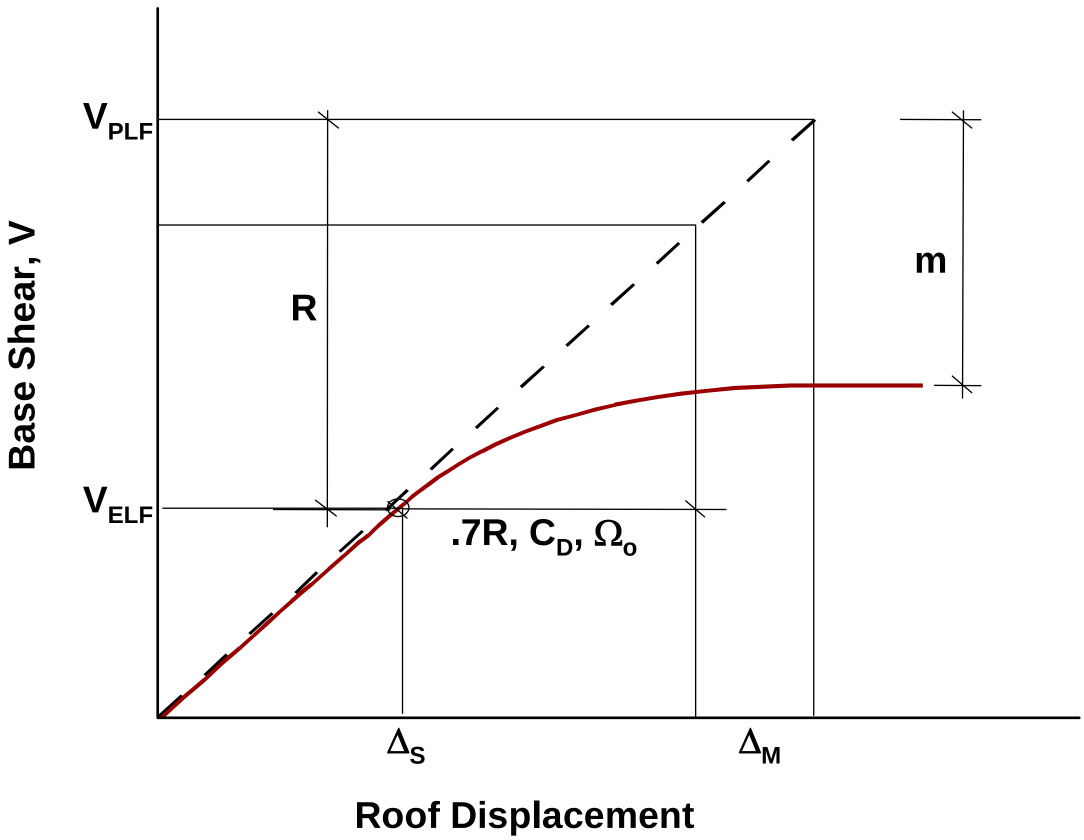

Figure 5. Graphical representation of the equivalent and pseudo lateral force methods.

Tier 3 – Detailed Evaluation Phase. If the structure being evaluated still has deficiencies following a Tier 2 Evaluation, or if further evaluation is required by Chapter 2, a Tier 3 Detailed Evaluation may be performed. The Tier 3 provisions in ASCE 31-03 adopt procedures from design provisions for new buildings or seismic rehabilitation of existing buildings with a modification to the seismic demands. A Tier 3 Detailed Evaluation requires the implicit or explicit modeling of the nonlinear response of the building with the purpose of determining the failure mechanism for the structure.

Because the seismic demand levels in design provisions have a margin of safety to ensure minimum life-safety requirements are met, ASCE 31-03 allows a reduction of the seismic demand level of 25% for evaluation to give existing buildings a "break." This was used in FEMA 178 with the 0.85 and 0.67 factors to the seismic base shear. For the Tier 1 and Tier 2 evaluations, this reduction in seismic demand is accounted for with the use of expected capacities and larger *m*-factors.

Conclusions

With the publication of ASCE 31-03, the first national performance-based seismic evaluation standard is available to the structural engineering community for use. This state-of-the-practice seismic standard has procedures that are founded in the latest engineering principles, are generally applicable to all buildings, are complete and consistent, are written in mandatory standards language, and are validated through extensive research, testing, and the consensus process. ASCE 31-03 can be used by jurisdictions and design professionals to set structural criteria, evaluate the adequacy of an existing building, explicitly consider the characteristics of existing building components, and set public policy to address local socioeconomic issues.

As with all codes and standards, ASCE 31 is not a static document. While the first publication of a seismic evaluation standard is an accomplishment, it is only a step in the never-ending cycle of codes and research. As the structural engineering community continues to learn from earthquakes through research and practice, and creates other performance-based seismic standards, such as the standardization of FEMA 356, ASCE 31 will continue to be revised and evolve to address the needs of those who use it.

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