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SEISMIC EVALUATION METHODOLOGY ISSUES

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ABSTRACT

There are a number of standards and methodologies available for the seismic evaluation of existing buildings. Some of these standards are intended to be used for specific building types, such as unreinforced masonry buildings, while other standards are intended to be applied to more general types of buildings. ASCE 31-03 has evolved over time through a series of earlier guidelines and is a standard that has been developed to be applied to a variety of building types.

Each seismic evaluation method that has been developed has a specific purpose and audience for which it has been targeted. As such, these methodologies have advantages and limitations. While some limitations are obvious, others are more fundamental and not as apparent. Some of these fundamental limitations with respect to ASCE 31-03 are discussed. In addition to limitations in the applicability of the methodology within the ASCE 31-03 standard, there are issues with how the standard correlates with other design and evaluation standards that are currently in use.

Recommendations are made to changes in the basic concept of ASCE 31-03, which relies on standard building types based on material and lateral force resisting system, to a methodology that focuses primarily on seismic behavior. The characteristics that affect seismic behavior include height, lateral force resisting system, materials, and configuration. Different techniques can then be used to evaluate the performance of buildings for each of the behavior types.

Introduction

Seismic design requirements for buildings have changed dramatically over the last fifty years. As a result, there is considerable uncertainty regarding how older buildings will perform during an earthquake. To address the concern for safety of existing buildings, structural engineers are often tasked to evaluate the seismic safety of an existing building.

One of the first nationally recognized guidelines for evaluating the seismic performance of existing buildings was *ATC 14 Evaluating the Seismic Resistance of Existing Buildings*

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(Applied Technology Council, 1987). The basic methodology introduced in ATC 14 was updated and published as *FEMA 178 NEHRP Handbook for the Seismic Evaluation of Existing Buildings* (FEMA 1992). In 1998, FEMA published, further refined, and updated the guidance document, *FEMA 310 Handbook for the Seismic Evaluation of Buildings - A Prestandard* (FEMA 1998). This prestandard was then advanced through the consensus process of the American Society of Civil Engineers (ASCE) and was published as an ASCE standard *ASCE/SEI 31-03 Seismic Evaluation of Existing Buildings* (ASCE 2003). ASCE 31-03 is the currently accepted standard for the seismic evaluation of existing buildings throughout the United States.

In publishing a "standard" for seismic evaluation of existing buildings, ASCE sought to provide a document that could be used for a majority of buildings throughout the country. It also sought to use a methodology consistent with the latest understanding of how buildings perform in earthquakes. By definition, a standard represents a baseline requirement that needs to be followed; thus it becomes a prescriptive set of rules to be followed when evaluating buildings for their seismic resistance. Advantages of this approach are first that it provides consistent criteria for comparing buildings and second, it affords engineers a comprehensive set of guidelines to ensure that all potentially critical aspects of seismic performance have been evaluated. The disadvantages of a prescriptive methodology are that engineers are inhibited from exercising their judgment regarding aspects of a building's seismic performance. By following a prescriptive approach, engineers may focus too much on following the procedure and thus fail to understand some of the aspects of the seismic behavior of the building.

ASCE 31-03 Methodology

ASCE 31-03 provides a three-tier procedure for evaluating the seismic performance of buildings. The basic approach of the procedure is to first define the building type using one of twenty-four common building types. These building types are listed in Table 1 with a brief description of each type. The methodology also allows for assessing buildings for one of two performance levels: Life Safety or Immediate Occupancy.

Table 1. Designated Building Types.

Building Type	Description
Wood Light Frame	W1: Single or multiple family dwellings with wood floor and roof faming on wood studs
	W1A: Multi-story, multi-unit residential wood frame buildings greater than 3000 square feet
Wood Frames, commercial and industrial	W2: Wood frame commercial or industrial buildings greater than 5000 square feet with few interior walls
Steel moment frames	S1: Steel moment frame buildings with stiff diaphragms
	S1A: Steel moment frame buildings with flexible diaphragms
Steel braced frames	S2: Steel frame buildings with braced frames and stiff

Building Type	Description
	floor diaphragms
	S2A: Steel frame buildings with braced frames and flexible floor diaphragms
Light steel frames	S3: Pre-engineered light frame buildings
Steel frames with concrete shear walls	S4: Steel frame buildings with concrete shear walls
Steel frames with infill masonry shear walls	S5: Steel frame buildings with infill masonry shear walls with stiff diaphragms
	S5A: Steel frame buildings with infill masonry shear walls and flexible diaphragms
Concrete moment frames	C1: Concrete buildings with reinforced concrete moment resisting frames
Concrete shear walls	C2: Buildings with reinforced concrete shear walls and stiff diaphragms
	C2A: Buildings with reinforced concrete shear walls and flexible diaphragms
Concrete frames with masonry infill	C3: Concrete frame buildings with infill masonry shear walls and stiff diaphragms
	C3A: Concrete frame buildings with infill masonry shear walls and flexible diaphragms
Precast/Tilt up concrete shear walls	PC1: Buildings with precast concrete wall panels and flexible diaphragms
	PC1A: Buildings with precast concrete wall panels and stiff diaphragms
Precast concrete frames	PC2: Buildings with precast concrete frames and concrete shear walls
	PC2A: Buildings with precast concrete moment resisting frames
Reinforced masonry bearing walls	RM1: Reinforced masonry bearing wall buildings with flexible diaphragms
	RM2: Reinforced masonry bearing wall buildings with stiff diaphragms
Unreinforced masonry bearing walls	URM: Buildings with unreinforced masonry bearing walls and flexible diaphragms
	URMA: Buildings with unreinforced masonry bearing walls and stiff diaphragms

Tier One Evaluation

In the three-tier methodology of ASCE 31, the first tier is a screening phase that utilizes a series of checklists to evaluate whether the building complies with certain criteria. The criteria and checklists generally vary depending on the building type and the performance level. Some of the Tier One checklists rely on pseudo lateral forces and prescribed lateral force capacities for structural elements that are different than those calculated by any building code. The methodology employed in assessing structural elements is a so-called "displacement-based" procedure in which the forces imposed are intended to result in design displacements that correspond to realistic earthquake displacements.

Each building being evaluated using this procedure is evaluated by a checklist with a series of statements based on the building type. The checklists include a number of statements regarding the building's structural system, lateral-forces-resisting system, and connections. Some of these statements require an analysis of one or more aspects of the building, while other statements are evaluated qualitatively. The building is either found to be Compliant or Noncompliant for each of the checklist statements.

Tier Two Evaluation

A second tier of evaluation is provided in the methodology that can be used either to evaluate buildings that fail to comply with all of the required Tier One checklist statements or to evaluate specific deficiencies identified by the Tier One checklist. The Tier Two procedure requires a more detailed structural analysis of the building using a permance-based procedure. In the performance-based procedure, which is similar to the procedure in ASCE 41-06 (FEMA 2006), each element of the lateral force resisting system is defined as either force-controlled or deformation-controlled; then specific acceptance criteria are provided for the elements based on the behavior mode and the performance level of the building.

Tier Three Evaluation

ASCE 31 defines a third tier of evaluation, which is referred to as the Detailed Evaluation Phase. The Tier Three evaluation is intended to be used for those buildings that fail to meet the Tier One and Tier Two evaluation procedures. ASCE 31 does not provide specific guidance for this evaluation phase but rather references other procedures, such as building code requirements for new buildings and seismic rehabilitation guidelines, as acceptable methodologies that can be used for the detailed evaluation. The intent of this phase is to allow existing buildings to be evaluated by verifying that the building could comply with current design requirements. Alternately, the building can be evaluated using a document such as ASCE 41-06, which was being developed but had not been published when ASCE 31-03 was completed.

Procedure Implementation Issues

Since ASCE 31-03 is published as an ASCE Standard, the intent is that the methodology be straightforward such that the it can be consistently applied and interpreted for all buildings.

Unfortunately, there are a number of issues with the procedure that result in implementation being excessively complex or failure of the standard to be rationally interpreted by the evaluating engineer.

Building Types

For each of the building types defined in ASCE 31-03, there are separate checklists to be used in the Tier One procedure. While it is reasonable that steel frame buildings do not have the same set of evaluation statements as concrete buildings, it seems unnecessary for the procedure to include separate checklists for W1 (wood frame) buildings and W1A (multi-story wood frame) buildings, for example, when the checklists are identical. In an ideal world, every building would fit one of the designated building types, but this is often not true. For example, the building shown in Figure 1 is framed with steel studs supporting precast concrete plank floors. This building type does not fit any of the building types in ASCE 31-03. Although it could be argued that this example is unusual, the author's experience is that many buildings are not readily identified as one of the standard building types.

Figure 1. A building under construction with steel stud walls and concrete plank floors that does not correspond to one of the standard building types.

The fundamental purposes for identifying different building types are to recognize that the seismic behavior of a building can vary depending on some important characteristics of the construction of the building. Then it is possible to evaluate specific details of the building that are critical to the seismic behavior of the building. For example, single-story buildings with rigid walls and flexible diaphragms, such as tilt-up concrete buildings, behavior in a different manner than multi-story steel frame buildings. Tilt-up buildings respond to earthquake shaking primarily with horizontal deformation of the roof diaphragm. Multi-story steel frame buildings however, respond to earthquake shaking primarily with deformation of the vertical framing system. This fundamental difference in behavior is not apparent in the current ASCE 31-03 methodology.

Tier One Analysis

The Tier One evaluation requires some limited calculations to evaluate specific aspects of the building. These calculations include determination of a seismic lateral force and determination of the structural capacity for specific structural elements of the lateral-force-resisting system. Unlike in past or current building code requirements for design of new buildings, the lateral force determined by the Tier One procedure is not reduced to a magnitude of lateral force that would be used by engineers when designing new buildings. Instead the evaluation uses pseudo-static lateral forces intended to produce elastic displacements that would approximate the inelastic displacements that may be expected. Force reductions using m-factors are made on an element basis depending on the type of structural element and the performance level being evaluated for the building.

While the use of this type of deformation-based analysis is currently favored for rehabilitation of existing buildings, its use as an initial seismic screening has questionable benefits. The component demands calculated using the Tier One procedure are conservatively simple. For example, the shear stresses in shear walls are taken as the total shear divided by the total length of wall, without consideration of the relative stiffness of the walls. In addition, the ductility factors (m-factors) used to modify the capacity are approximate and do not account for actual component detailing. Thus, because of the approximations used on both demand and capacity in the procedure, the ability of this Tier One analysis to predict actual deformations or ductility demands is limited at best.

Engineers unfamiliar with ASCE 31-03 or ASCE 41-06 are often confused by the unexpectedly large lateral force determined by applying ASCE 31-03 procedures. Some engineers have incorrectly compared the forces determined by ASCE 31-03 to current design allowable values for new building components and found that existing buildings are grossly inadequate. Another consideration is that engineers evaluating existing buildings may have access to calculations or seismic design values used for the original design. A rational procedure in the initial steps of the seismic evaluation of an existing building is to compare the lateral forces used in the original design to those that would currently be required based on the latest seismicity and structural performance knowledge. By radically changing both the demand and the capacities, ASCE 31-03 inhibits the ability of an engineer to make use of existing design information for the seismic evaluation.

Prescriptive Versus Subjective Checklist Statements

The Tier One checklists in ASCE 31 include statements regarding a number of factors considered important to the seismic behavior of existing buildings. Some of these statements prescribe specific, numeric criteria that must be demonstrated while other statements require a subjective determination of compliance. Although most of the concepts that are being addressed by the checklist statements can be justified as affecting the seismic behavior of buildings, the inconsistent treatment of these issues in the checklist statements may lead to engineers focusing on compliance of some of the prescriptive provisions rather than spending time to understand the seismic behavior of the building and the key components.

Two of the prescriptive provisions in the checklists for each building type deal with the assessment of whether the building has a weak or soft story. The Tier One checklists require that the stiffness of a story not be less than 70 percent of the adjacent story and that the strength of a story not be less than 80 percent of the adjacent story. Certainly, buildings with soft and weak stories have shown extremely poor performance in past earthquakes. Thus, a check to verify that a weak or a soft story does not exist is an important step in the seismic evaluation of an existing building. However, to verify that the building meets these prescriptive values may require an extensive numeric analysis of the building. ASCE 31-03 includes an approximate procedure for determining story drifts for moment frames, but does not provide a comparable procedure for assessing drifts for shear wall buildings or for evaluating relative strength of a story. Considering that this document is a Standard and therefore defines the standard of care for practicing engineers, the lack of guidance as to acceptable methodologies for assessing relative strength and stiffness leads engineers to perform unnecessarily elaborate analyses to verify conformance with these checklist statements. In addition, the prescriptive limits of 70 percent and 80 percent are somewhat arbitrary and are based on building code design limits rather than being based on data gleaned from specific building performance.

In contrast to the prescriptive limits for evaluating soft and weak stories, the checklist statement for evaluating the load path is rather nebulous, stating that there should be at least one continuous load path. One can easily envision a building with a complete load path but where there are deficiencies in the strength of one or more elements within the load path, rendering the load path ineffective. Without more specificity regarding the strength and stiffness of elements within the load path, the load path statement alone is irrelevant. It is hard to imagine a building that would not have a complete load path, but would pass the remainder of the applicable checklist statements. Although the intent of providing a checklist statement is certainly noble, that of focusing the evaluating engineer on the need for a complete load path, more often than not, engineers will gloss over this statement without a significant effort at a detailed evaluation of the load path. If there is an obvious discontinuity in a load path, the engineer will likely abort the evaluation and proceed directly to rehabilitation.

A similar dichotomous approach to a specific seismic vulnerability is for the evaluation of load transfer to shear walls. For buildings being evaluated to a Life Safety performance level, the Tier One checklist merely requires a connection of diaphragms to shear walls without regard for the strength of this connection. Without some correlation of the connection strength to the demand, deficient connections could easily be overlooked. In contrast, for buildings being evaluated to an Immediate Occupancy performance level, the connection of the diaphragm to the shear wall needs to be shown to develop either the full strength of the diaphragm or of the shear wall, whichever is less.

Tier Two Evaluation

If deficiencies are identified in the Tier One evaluation, the engineer is directed to the more-detailed Tier Two evaluation procedure. The Tier Two evaluation can be used to evaluate either the entire building or can be used to evaluate specific deficiencies identified in Tier One.

The Tier Two evaluation requires a structural analysis of the building using either a linear static or a linear dynamic procedure. Similar to the Tier One analysis, the forces used in the Tier Two analysis are pseudo static lateral forces using the displacement-based evaluation methodology. For the special case of Unreinforced Masonry Bearing Wall Buildings, a special procedure similar to that which has been used for many years for that building type has been incorporated into the ASCE 31-03 Tier Two evaluation as an option.

The Tier Two analysis procedure is considerably more elaborate than the analysis required for Tier One. A mathematical model must be created for the building to assess the actual forces on each element and the capacities for each element need to be calculated based on actual material properties. Although the Tier Two evaluation procedure includes a number of performance-based concepts, the overarching philosophy is very prescriptive and general, except for the special procedure provided for Unreinforced Masonry Bearing Wall Buildings.

Tier Three Evaluation

The Tier Three evaluation recommendation include two disparate options: either evaluate the building using the procedures from the current building code or use guidelines for seismic rehabilitation. These two options are considerably different in their philosophy and generally produce differing results. The current seismic rehabilitation standard, ASCE 41-06, is one option for performing the Tier Three evaluation and is a performance-based standard using the concepts of deformation controlled and force controlled components; whereas the current building code provisions for seismic design are based on equivalent lateral forces and prescriptive detailing provisions to provide ductility.

Conclusions and Recommendations

The procedures prescribed in ASCE 31-03 for the seismic evaluation of buildings include a number of reasonable and technically sound concepts. However, there are some concepts that are not necessarily compatible with each other. The use of model building types for providing guidance for the evaluation procedure is reasonable when buildings can fall neatly into one of the standard building types. However, this is often not the case, particularly for buildings outside of California. For some buildings, such as Unreinforced Masonry Bearing Wall Buildings, the definition of the building as a unique type allows for the application of a special procedure for that building type. This allows the engineer to evaluate the building using a procedure that takes advantage of the seismic characteristics of the building type.

The initial seismic screening using the Tier One procedure does not benefit from the current imposition of displacement based procedures because of the approximations and conservatism that have necessarily been included in this screening procedure. The important aspects of seismic screening, which are identification of potential seismic deficiencies with a reasonable amount of effort, are obscured within the current Tier One procedure. What is necessary is for the Tier One screening procedure to be modified to provide a more intuitive process of evaluating the seismic resistance of a building using a three-step process based on the load path rather than on the building type. The current building code design approach is to prescribe a minimum strength and then prescribe detailing to provide ductility. The initial seismic screening of buildings should follow a similar approach to avoid unnecessarily identifying buildings as requiring further seismic evaluation by the use of the newer, performance-based approach.

Tier One Load Path Screening Procedure

The first step in the seismic screening should be defining the elements within the load path of the seismic force resisting system. It is not sufficient to ask a question as to whether a load path exists, the engineer must be able to define the load path and identify the elements. As part of this process, the load path should be evaluated for the presence of potentially undesirable characteristics, such as soft stories, short columns, excessive torsion, etc. Rather than imposing a limit on the ratio of story strength or stiffness, the presence of a soft or weak story can be simply evaluated by verifying that the length of shear walls in a building does not vary abruptly from one story to the next, for example, or that the number of braced frames does not vary significantly. The identification of the load path, and the elements within the load path, are necessary to define the elements that participate in the seismic resistance. This in turn defines the seismic behavior characteristics. Rather than relying on building type to define the aspects of the building to be evaluated, the elements within the load path should define the types of evaluations required to determine member strength and needed detailing.

Once the load path is defined, the next step in the process is to evaluate the strength of the critical elements of the load path. The force levels used for evaluation of existing buildings during the initial screening should be based on equivalent lateral forces consistent with the force levels used for designing new buildings. The strength of components in the evaluation should be based on current design provisions. Conservatism in the screening process can be introduced with reduced R factors and maximum required demand-to-capacity ratios.

The final step in the evaluation process is to evaluate the detailing requirements for the elements of the load path. Ductility is important for those elements of the load path that are intended to respond inelastically during a design earthquake. Thus, the evaluation of the detailing of the elements within the load path should be dependent on the anticipated demand to capacity ratio that roughly relates to ductility demand.

Tier Two Detailed Element Evaluation

Because some types of buildings have unique seismic performance characteristics, detailed evaluation procedures should be developed to consider the actual performance of buildings with known certain seismic characteristics. As mentioned above, a special procedure is included for Unreinforced Masonry Bearing Wall Buildings, similar procedures should be defined for other types of buildings such as rigid wall, flexible diaphragm buildings and wood framed shear wall buildings. ATC 50-1 (Applied Technology Council, 2002) provides another example of a seismic evaluation procedure targeted for a specific classification of buildings, namely wood framed residential buildings. Portions of ATC 50-1 could be incorporated into the general building seismic evaluation standard. A general procedure would still be necessary to evaluate those buildings for which there is no special procedure.

Philosophy of Seismic Evaluation

Structural engineers performed seismic evaluations of existing buildings long before the development of ASE 31-03. Experienced structural engineers generally approached the evaluations by looking at concepts such as load path, strength, and detailing. A “standard” for seismic evaluation should follow the same approach. The current procedure in ASCE 31-03 tries to impose concepts of performance-based design at the initial steps of the seismic evaluation process along with standard building types. The result is that the procedure makes it difficult for the engineer to concentrate on understanding how the building will respond to earthquakes, which should be a fundamental purpose of a seismic evaluation. A philosophical change is needed in the ASCE standard for seismic evaluation of buildings. This should be a change from one in which buildings are identified by arbitrary types and then evaluated using prescriptive checklists to one in which the behavior of the building defines the process of the evaluation.

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