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ATC-14: A METHODOLOGY FOR THE SEISMIC EVALUATION OF EXISTING BUILDINGS

Chris D. POLAND[1], James O. MALLEY[2], and Christopher ROJAHN[3]

[1]Senior Principal/Structural Engineer, H.J. Degenkolb Associates, San Francisco, California, USA
[2]Structural Engineer, H.J. Degenkolb Associates, San Francisco, California, USA
[3]Principal Investigator/Executive Director, ATC, San Francisco, California, USA

SUMMARY

Because of the large life safety hazard posed by existing buildings, and the lack of evaluation consistency amongst engineers, the development of a comprehensive methodology for the seismic evaluation and strengthening of existing buildings is necessary. The ATC-14 project is intended to meet this need. The methodology commences with the collection of information about the structure and the classification of the building into one of fifteen building types. The evaluation procedure begins as a qualitative investigation to determine if the building might possess any of the life-threatening performance characteristics which similar structures have demonstrated in previous earthquakes. If any potential life safety hazards are identified, an appropriate detailed evaluation is recommended with permissible capacity/demand ratios suggested. It is anticipated that ATC 14 will draw some consistency to the evaluation process and broaden the experience based upon which this ultimate and all important decision is made.

INTRODUCTION

Modern building codes (hereafter referred to as the code), such as the NEHRP Provisions, are written to guide the construction of new buildings. They hopefully gather up all of the available collective experience in the behavior of structures and present it in a way that is applicable to all forms of construction. Within the seismic provisions, building code standards are developed with life safety, damage control, and cost in mind. Hopefully, the result is a complete building system that costs slightly more to build and has the proper strength and connection details necessary to successfully resist earthquake forces. Experience has shown that this successful performance depends on the base shear strength of the main structural elements, the connection strength and ductility of the connections, the building configuration, the material type, and the interconnection of the structural parts.

Unlike the traditional structural design for dead and live loads, seismic design anticipates that the buildings will be damaged after a truly major event. To design buildings to be damage-free would not only be very expensive but would also severely limit the permissible styles of construction. New buildings are generally designed to be strong enough to resist small earthquakes without damage and major earthquakes without collapse. To accomplish this goal, the structural design based on the code involves a combination of basic lateral force resisting strength, with a proper structural configuration, and appropriate interconnection of the structural elements. In fact, within the code, there is a direct relationship between how a building is configured, detailed, and tied together and the amount of lateral for which it is designed. This interrelationship does not exist in most existing buildings. For that reason, the code is not a suitable standard for their evaluation.

A proper detailed seismic evaluation of a building needs to focus on the "weak links" of the structure which have been shown to be critical in past earthquakes and those need to be assessed for and their susceptibility to catastrophic damage. If the level of expected damage is determined to be unacceptable, then these "weak links" need to be strengthened and/or new seismic resistant systems installed.

The Applied Technology Council has developed and published a methodology for evaluating specific buildings that is tailored for use by practicing structural engineers, which leads not only to conclusions concerning the adequacy of the structure for a given event, but also identifies the structure's weaknesses and, therefore, areas of needed rehabilitation. It has been structured to permit the rapid screening of a large inventory of buildings followed by detailed evaluation where necessary.

The Applied Technology Council (ATC) is a non-profit, tax-exempt corporation established in 1971 through the efforts of the Structural Engineers Association of California. The purpose of ATC is to assist the design practitioner in structural engineering (and related design specialty fields such as soils, wind and earthquake) in the task of keeping abreast and effectively utilizing technological developments. To this end, ATC also identifies and encourages needed research and develops consensus opinions on structural engineering issues in a non-proprietary format. ATC thereby fulfills a unique role in funded information transfer.

The project was organized around a steering committee, the ATC Project Engineering Panel made up of Engineers and Researchers, two special consultants on strong ground motion, a subcontractor, the ATC staff, and an NSF program manager. H.J. Degenkolb Associates were the Subcontractor and were responsible for the development of the methodology under the supervision of the Project Engineering Panel. The Special Consultants developed the nationwide strong motion criteria to be used in the evaluation procedure.

THE METHODOLOGY

ATC-14 has been developed consistent with the latest building codes but tailored to the often non-conforming characteristics of the variety of buildings in existence. It is specifically aimed at assessing a building's life safety level of resistance, with a recommendation that all buildings be strengthened to this minimum level.

Life safety in this work has been defined broadly as damage that would likely kill an occupant, cause injury to the point of immobility or block any of the dedicated means of egress from the building. The process also identifies areas of potential damage, including "non-structural" elements, but stops short of determining actual expected damage levels. It has been developed for application throughout the United States.

It is important to note that ATC-14 has set an evaluation standard that is less stringent than modern building codes. It is applicable only to existing buildings and anticipates that in the worst case a building meeting its requirements may be severely damaged and perhaps irreparable after a major earthquake. The building will have hopefully provided a safe refuge during the event for its occupants. This level of performance is not acceptable for new construction because superior earthquake performance can be accomplished through proper design and at little added construction costs.

ATC 14 is based on a lengthy review of the available literature, a State of Practice review, seismic design provisions currently in use [1,2,3,4] and lengthy discussions between the Subcontractor and the PEP regarding all aspects of the project. It has been published as a complete document that includes the actual methodology, all background material and four examples. It was written not only as a working handbook but also as an educational tool. The persistent reader will also be rewarded with an overview of the State of Practice in this field, a discussion of ground motion criteria, a detailed description of structural behavior in past earthquakes and an extensive list of references and related material.

State of Practice Review The format and theme of ATC 14 was dictated by the current State of Practice in the U.S. The State of Practice review, conducted prior to writing ATC 14, showed clearly that there is a wide range of attitudes toward the evaluation of existing buildings and the expected performance. This led to the conclusion that a new, systematic procedure was needed.

ATC 14 is designed to bridge over the wide range of results. It is formatted to provide a broad base of experience regarding the actual behavior of buildings in earthquakes. It is intended as a tool that can be used to guide but not restrict an evaluating engineer so that consistent and complete thinking can be brought to bear on each seismic evaluation. It stands as a catalog of the profession's collective earthquake experience that has been incorporated with appropriate analysis and design techniques into a concise format that can guide a knowledgeable engineer in the evaluation of an existing building.

Data Collection and Screening The methodology begins with data collection procedures which are required to gather the information necessary to classify the building and perform the evaluations. The appropriate procedures for using existing documents, performing site investigations, and testing the structural materials are outlined. While the methodology is tailored to the evaluation of buildings on an individual basis, it is structured to permit preliminary screening of an inventory of buildings in order to identify the ones that need to be evaluated at length. Simple, small-to-medium sized, regular buildings, with a good performance record in past earthquakes are screened out. Others are identified for additional evaluation in the specific areas that they are possibly deficient.

Based on a brief field inspection, and a review of the available drawings, each building is classified according to an appropriate model building type. Considering the possible combinations of materials, framing types, and non-structural elements, ninety-eight building types have been identified and grouped into fifteen model buildings. Each model building has a set of performance characteristics representative of its building types. These fifteen model building types are intended to cover the vast majority of existing buildings. Provisions are included for dealing with structures that do not fall into any specific classification given. A list of the model building types is included in Figure 1.

Figure 1   List of Model Building Types

I. Wood Buildings

- Building 1 - Wood 1 - Wood Frame Dwellings and Light Frames
- Building 2 - Wood 2 - Commercial or Industrial Wood Structures

II. Steel Buildings

- Building 1 - Steel Moment Resisting Frame Buildings
- Building 2 - Braced Steel Frame Buildings
- Building 3 - Light Moment Frame Buildings with Longitudinal Tension Only Bracing
- Building 4 - Steel Frame Buildings with Cast-in-Place Concrete Shear Walls
- Building 5 - Steel Frame Buildings with Infilled Walls of Unreinforced Masonry

III. Cast-in-Place Reinforced Concrete Buildings

- Building 1 - Reinforced Concrete Moment Resisting Frame Buildings
- Building 2 - Shear Wall Buildings
- Building 3 - Reinforced Concrete Frame Buildings with Infilled Walls of Unreinforced Masonry

IV. Buildings with Precast Concrete Elements

- Building 1 - Tilt-up Buildings with Precast Bearing Walls
- Building 2 - Buildings with Precast Concrete Frames and Concrete Shear Walls

V. Reinforced Masonry Buildings

- Building 1 - Reinforced Masonry Bearing Wall - Wood or Metal Deck Diaphragm Buildings
- Building 2 - Reinforced Masonry - Precast Concrete Diaphragm Buildings

VI. Unreinforced Masonry

- Building 1 - Unreinforced Masonry Bearing Wall Buildings

Initial Evaluation The evaluation of a building is directed by a specific section in the methodology written for a related model building. It includes a building description, a summary of the performance characteristics based on past earthquake observations, paragraphs related to the expected building loads and load paths, references for examples of performance in past earthquakes, and a rapid evaluation procedure. The rapid evaluation procedure attempts to provide a quick method to assess the basic strength and/or drift control provided by the structure, and is shown in Figure 2 for a concrete frame building.

The evaluation procedure consists of a collection of statements with a related concern and suggested, specific analysis technique if further study should be necessary. Each statement relates to a vulnerable area in the structural system that requires specific consideration. A separate set of statements is presented for regions of different seismicity. Two example statements are shown in Figure 3.

The evaluation statements are written such that a positive or "true" response to a statement implies that the building is adequate in that area. If a building then passes all the related statements with true responses, it can be passed without further evaluation. It must be once again stressed that these evaluation statements are intended to flag areas of concern for the evaluating engineer, and by nature, must be quite conservative. They will permit buildings designed under modern seismic codes to pass without detailed evaluation.

Not all critical elements of buildings can be evaluated by simple true or false statements. The final decision regarding adequacy, need for further study, or need for strengthening still rests with the engineer, regardless of the statements. For this reason, these evaluation procedures, even the initial screening procedures, must be applied by a knowledgeable professional engineer.

Each statement carries with it a concern which explains in commentary style why the statement was written. These concerns are carefully written and intended to further assist the evaluating engineer in dealing with the issue stated. Obviously, addressing the concern takes precedent over the specific statement.

For statements that are "false", additional evaluation is required. This does not necessarily imply that a complete structural evaluation is necessary, or that the building is automatically deficient. In fact, the suggested procedure limits the evaluation to only the area of concern. It is offered as a suggested procedure since the responsibility for the evaluation rests with the structural engineer, who may elect to perform an alternate evaluation procedure. This is permissible as long as it addresses and leads to an opinion regarding the issue raised in the statement. Deficiencies are, therefore, identified only after an appropriate detailed evaluation has been made.

Figure 2 Example of Rapid Evaluation Procedure

Rapid Evaluation of Reinforced Columns -

Concern: Reinforced concrete frame buildings have sometimes proven to present a life safety hazard in past earthquakes because of inadequate shear column shear capacity. A quick estimation of the shear stress in the concrete frame columns should be performed in all evaluations of this building type in regions of high or moderate seismicity.

Procedure: Generate the loads using the rapid evaluation procedure presented in Section 4.4.2, checking the first floor level and all other levels where the columns could be subjected to high shear stresses. Estimate the average column shear stress, V_{AVG}, as follows:

$$V_{AVG} = \frac{n_c}{n_c - n_f} \frac{V_j}{A_c}$$

where:

- n_c = Total number of columns
- n_f = Total number of frames in the direction of loading
- V_j = Story shear at the level under consideration, determined from the loads generated by the rapid evaluation procedure.
- A_c = Summation of the cross sectional area of all columns in the story under consideration.

If the average column shear stress is greater than 60 psi, a more detailed evaluation of the structure should be performed. This evaluation should employ a more accurate estimation of the level and distribution of the lateral loads by using the procedures suggested in Section 4.4. Calculate the column shear capacities using the provisions of ACI 318 and compute Capacity/Demand ratios.

Recommended C/D Ratio: 1.0. Many of the concerns in the following statements will address the details necessary to provide ductile column behavior.

Figure 3 Example of Evaluation Statements

Example Statement No. 1: There are no infills of concrete or masonry placed in the concrete frames, which are not isolated from the structural elements.

> Concern: Infilled walls used for partitions or walls around the stair or elevator towers, which are not adequately isolated, will alter the seismic response of the structure. Evaluation of considerations for frame structures will therefore be inappropriate.
>
> Procedure: Evaluate the building as an infilled wall structure using the procedures of Section 4.7.3.

Example Statement No. 2: The lateral force resisting elements form a well distributed and balanced system that is not subject to significant torsion. Significant torsion will be taken as any condition where the distance between the story center of rigidity and the story center of mass is greater than 20 percent of the width of the structure in either major plan dimension.

> Concern: Plan irregularities may cause torsion or excessive lateral deflections which may result in permanent set or even partial collapse.
>
> Procedure: Verify the adequacy of the system by analyzing the torsional response using procedures which are appropriate for the relative rigidities of the diaphragms and the vertical elements. Compare the maximum calculated story drift with 0.005H.

Detailed Evaluation The evaluation procedures suggested are based on the ATC-3 and ATC 6-2 type approaches to considering the capacity of the element under review and the demand placed on that element. A recommended Capacity/Demand ratio (C/D) is listed for each statement that is based on the overall system ductility assumed in the demand criteria. The recommended C/D ratio can then be compared to that calculated for the building being evaluated. In this way, not only can the weak links in the structural system be identified, but also their significance can be estimated.

For a building to pass the ATC 14 evaluation procedure and be judged acceptable, all of the issues raised in the statements must either be "true" or the capacity/demand (C/D) ratios determined in the subsequent analysis shown to be within the prescribed limits. One of the values of this technique is that if a building does not pass the evaluation methodology and is judged to be unacceptable, it is clear exactly where the problem is and what its characteristics are. A strengthening technique then can be developed to correct those specific areas of weakness.

Techniques for correcting the deficiencies found during the evaluation can take on one of two major forms. Certain deficiencies can be corrected individually with repair details aimed at an acceptable C/D ratio. Other deficiencies are best corrected by added new systems that supplement the main lateral force resistant system and have the direct effect of reducing the demand on the weak link. The goal is keyed to reducing the C/D ratio to an acceptable level.

The recommended C/D ratios are based on the general concept that available strength beyond the code level demand can make up for a lack of ductility in the weak link under consideration. At the extreme, if the element can carry the actual expected demand load within its elastic strength, then it is judged satisfactory. Based on the system ductility assumed for derivation of the demand forces, the actual forces are expected to be equal to 1.2 to 4.5 times as high (equal to .4Rw). Therefore, given a "non-ductile" weak link, if the C/D ratio is greater than .4Rw, then it is judged acceptable. For weak links with ductile characteristics, the C/D ratio need only greater than 1.0. For weak links with semi-ductile characteristics, a minimum of .2Rw is required.

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