# COMPARISON OF EVALUATION GUIDELINES FOR LIFE-SAFETY SEISMIC HAZARDS

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## ABSTRACT

The guidelines presented in "Design Evaluation guidelines for Department of Energy Facilities Subjected to natural Phenomena Hazards" (UCRL 15910 Draft; May 1989) include evaluation criteria for existing Department of Energy buildings subjected to earthquakes. These criteria were developed at the Lawrence Livermore National Laboratory for use in both the seismic design of new structures and the evaluation of existing structures.

"ATC-14: Evaluating The Seismic Resistance of Existing Buildings" developed by the Applied Technology Council, consists of guidelines and criteria for "identifying the buildings or building components that present unacceptable risk to human lives."

This paper compares and contrasts the two evaluation guidelines for existing buildings using a prototype building as an example. The prototype building is a seven story, concrete shear wall building assuming a General Use Occupancy.

## INTRODUCTION

The Department of Energy (DOE) has numerous facilities throughout the United States. These sites have many General Use or Low Hazard buildings designed and built according to earlier Codes that do not address the some of the seismic hazards that affect the strength and ductility of the structure. There is a current interest in the evaluation of these existing buildings considering the probable hazards and the consequences of those hazards on the both the occupants and the functions of these facilities.

The DOE has published draft guidelines in order to provide uniform design and evaluation criteria for protection against hazardous natural phenomena. These guidelines, entitled "Design Evaluation Guidelines for Department of Energy of Energy Facilities Subjected to Natural Phenomena Hazards," (UCRL 15910 Draft; May 1989) have been referenced by the General Design Manual, DOE Order 6430.1A, as an acceptable approach to the evaluation of facilities. This UCRL document was prepared for the Lawrence Livermore National Laboratory (LLNL) under the direction and review of the DOE natural Phenomena Hazards Panel.

In a parallel effort by the private sector, the Applied Technology Council, with funds provided by a grant from the National Science Foundation, has published guidelines and criteria for evaluation of seismic hazards in existing buildings. The document, published in 1987, is entitled "ATC-14; Evaluating the Seismic Resistance of Existing Buildings." This document was prepared by H. J. Degenkolb Associates and reviewed of a Project Engineering Panel composed of practicing engineers and academicians. (There is currently an effort, sponsored by FEMA, to develop a handbook on seismic evaluation of potentially hazardous buildings. This document, ATC-22, is based upon the ATC-14 methodology. The document is currently under review the Building Seismic Safety Council.)

Both documents are intended to provide guidance to the Engineer in the evaluation of existing structures against seismic hazards. The UCRL document is broader in that it also provides guidance for other natural phenomena as well as the design of new structures. However, the two documents differ in several ways that relate to similar types of buildings and may lead to different conclusions regarding the most appropriate methods for analyzing, evaluating, and eventually strengthening existing structures. The similarities and differences are explored in order to comment on the final results of evaluations for seismic hazards in existing buildings.

PROTOTYPE STRUCTURE

For the purpose of comparison, a prototype structure has been chosen to compare the two guidelines. The building is a General Use office structure located at the Lawrence Livermore National Laboratory in California. The structure is a reinforced concrete building with seven stories. The lateral force resisting system is comprised of concrete shear walls. Particular attention will be paid to the evaluation of the shear capacity, boundary elements and coupling beams of a shear wall element.

PRIMARY COMPONENTS OF A SEISMIC EVALUATION

A seismic evaluation of a building should include a description of the desired performance goals of the building, the ground motion criteria, the basic lateral strength requirements, the acceptance criteria, system configuration, and ductile detailing requirements. The following sections discuss relevant issues for each of these elements.

PERFORMANCE GOALS

UCRL 15910 establishes performance goals for each of four facility-use categories. These facility categories include 1.) General Use facilities, 2.) Important or Low Hazard facilities, 3.) Moderate Hazard facilities, and 4.) High Hazard facilities. The performance goals are stated in terms of the annual probability of exceedance of an event that causes a prescribed level of damage.

The performance goal for a General Use occupancy is a $10^{-3}$ annual probability of exceedance for the onset of major structural damage that might endanger the life-safety of the occupants. This is equivalent to a five percent chance of exceedance over a fifty year lifetime of the building, or ten percent chance in 100 years. This performance goal is essentially a life-safety goal with little concern for the post-earthquake building functions.

ATC-14 also establishes a performance goal related to the life-safety of the occupants of a building. Future use of the building is not a consideration in the performance goals. The criteria are intended to identify potentially hazardous buildings. ATC-14 defines a hazardous building as one where the entire building collapses, a portion of it collapses, components fail and fall, and/or exit routes are blocked preventing evacuation or rescue of the occupants. The criteria are based on a ten percent chance of exceedance in 50 years.

Because both ATC-14 and UCRL-15910 General Use criteria are primarily intended for life-safety considerations, it is appropriate to compare their respective provisions for ground motion, lateral strength requirements, system completeness, and ductile detailing provisions.

GROUND MOTION CRITERIA

UCRL specifies three alternative methods for determining the ground motion criteria for a particular site. These sources include Newmark-Hall spectral construction, site-specific spectra, and the 1988 Uniform Building Code (UBC).

For use in any of the three methods, UCRL 15910 specifies the expected maximum peak horizontal ground surface acceleration (PGA) as a function of the performance goal and the specific DOE site. Because the expected PGA represents a maximum spike that may only occur once during a seismic event, this maximum peak ground acceleration may be reduced ten percent to establish an "effective" peak acceleration (EPA). UCRL 15910 defines the effective peak ground acceleration as a repeatable level of acceleration in the frequency range that adversely affects structures. The EPA has been shown to be a better indicator of the damage potential of an earthquake. The maximum peak ground acceleration for the LLNL site is 0.41g for the General Use performance goal. Therefore, the effective peak acceleration is 0.37g. This EPA factor may be used to create a Newmark-Hall spectrum, anchor a normalized site specific spectrum, or to substitute in place of the Zone factor, Z, in the UBC base shear equation.

ATC-14 describes ground motion criteria with an effective peak velocity-related acceleration (EPA) coefficient, $A_v$. A contour map of the United States indicates the $A_v$ values for use in the seismic evaluation. This coefficient represents the effective peak acceleration for a site with a ten percent chance of exceedance in 50 years.

There is an anomaly between the UCRL and ATC-14 effective peak acceleration values in that the UCRL 15910 criteria establishes a lower EPA correlated to a lower probability of exceedance than the ATC-14 effective peak acceleration.In order to compare EPA values with the same chance of exceedance, for example, five percent in 50 years, the ATC coefficient would have to be increased from 0.4g to 0.5 g. Therefore, using a five percent exceedance EPA for both criteria, the UCRL value is 0.37g while the ATC-14 value is 0.50g. This anomaly may be explained by the site specific nature of the studies that established the UCRL 15910 PGA as opposed to the more general studies available for ATC-14 criteria.

LATERAL STRENGTH REQUIREMENTS

The lateral strength requirement for a structure is most often defined by a required design base shear force. The design base shear of a structure is a function of the effective peak ground acceleration, the structural amplification of the ground acceleration, the period of the structure, the soil characteristics, and the structure's inertial mass. The design base shear, as a function of building period, is best shown in a response spectrum as the product of the effective peak ground acceleration, Z, and an amplification factor, C. The ZC values as a function of the building period are shown in Figure 1. The amplification factor includes the effect of the period of the structure, the assumed damping, as well as the soil characteristics.

For General Use facilities, UCRL-15910 specifically references the criteria of the 1988 UBC for determining the design base shear requirements for existing buildings. The base shear equation of the 1988 UBC, $V=ZICW/R_w$, is used to establish seismic strength requirements for static analyses of regular buildings and/or dynamic analyses of irregular buildings. However, UCRL permits some modifications to the definitions of the equation terms. The first modification relates to the Zone factor, Z, earlier referred to as the effective peak acceleration. The effective peak ground acceleration, Z = 0.37g, may be substituted for the UBC Zone factor, Z = 0.4g for the LLNL site.

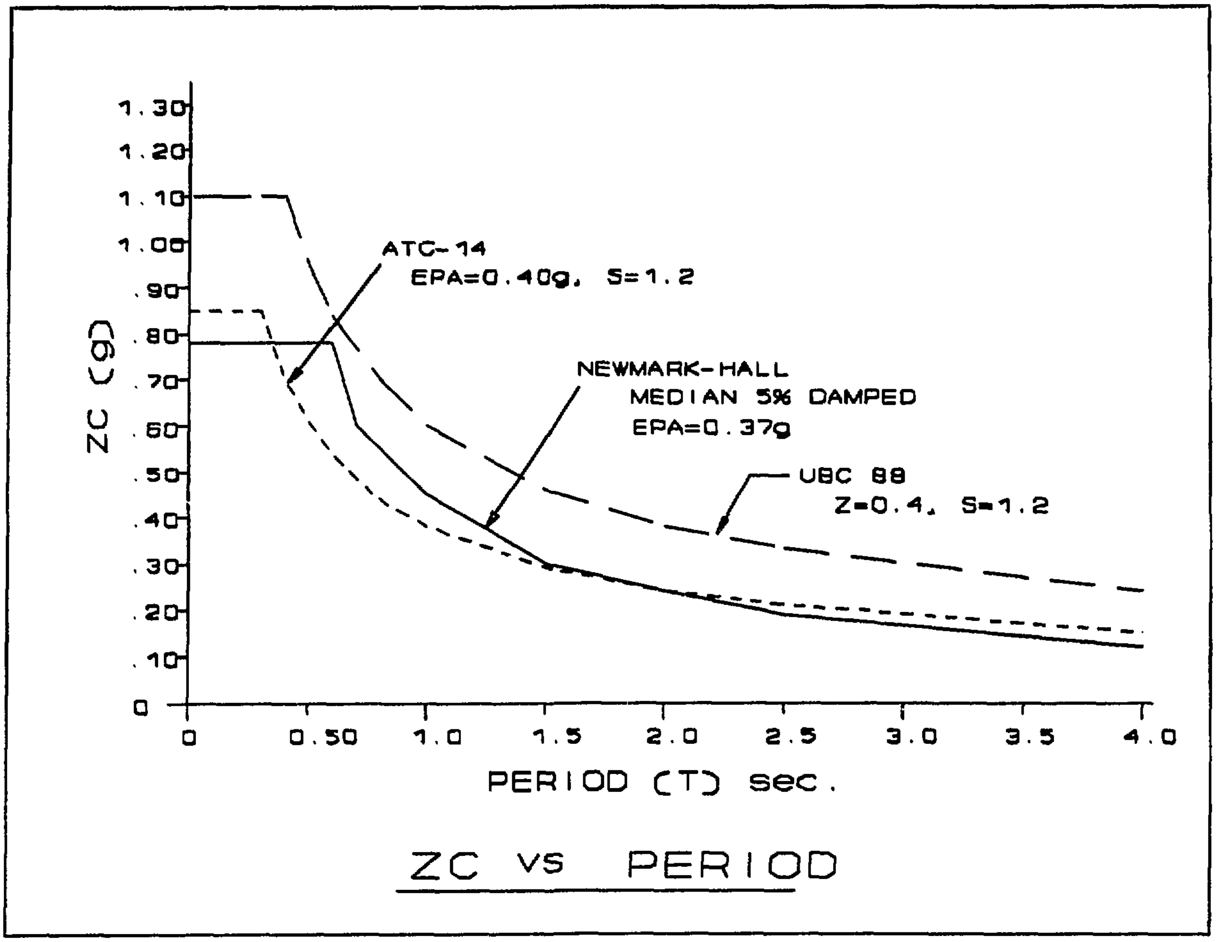


**Figure 1** ZC versus PERIOD

The second modification to the 1988 UBC is related to the amplification factor, C, in the base shear equation. Instead of using the UBC equation, $C = 1.25xS/ T^{2/3}$, the amplification coefficient may be determined from either a median (50th percentile) Newmark-Hall spectrum or from a median site specific spectrum. Note that the UBC equation defining C is closely based on the median plus one standard deviation (sigma) spectrum, also referred to as a one sigma spectrum. The difference between the median and the one sigma spectra is evident in Figure 1 by comparing the Newmark-Hall median spectrum with the 1988 UBC spectrum. In the short period range, up to 0.5 seconds, the 1988 UBC spectrum is 40 percent greater than the median Newmark-Hall spectrum.

However, the practical difference between the two spectra may be only academic because, unless a special site specific study is done to justify a lower spectrum, UCRL 15910 requires that the product of the Zone factor and the amplification factor, ZC, be compared with that obtained from the standard 1988 UBC coefficients. The larger of the two values must be used. As seen in Figure 1, the 1988 UBC spectrum, or ZC, exceeds the UCRL modified spectrum at all periods of vibration. Thus, the engineer must evaluate the structure using full UBC level forces unless special site specific justification is provided.

If a site specific spectrum is used, a lower ZC product is acceptable as long as any significant discrepancies between the site-specific spectrum and the UBC a.. justified and accepted by the DOE. Criteria for this justification is not provided in UCRL 15910.

The ATC-14 base shear determination is developed from a median spectrum with assumed five percent damping of the system. The effective peak-velocity-related acceleration, $A_v$, is similar to the UBC zone factor, Z. Both represent an effective ground acceleration for analysis purposes. The $A_v$ values are presented in a national map showing contour lines of equivalent peak accelerations. The spectral amplification factor, C, is given by the equation, $C = 0.8xS/ (T)^{2/3}$. Note that this equation is about 65 percent of the UBC 1988 amplification factor in the short period range. This is indicative of the practical difference between the one sigma and the median response spectra. Therefore, the ATC-14 design base shear of the structure represents a median spectrum while the UCRL base shear represents a one sigma spectrum value.

Using the prototype building as an example for comparison, and assuming a structural period of 0.5 seconds, the ATC-14 base shear coefficient is 0.076 W. The UCRL 15910 base shear coefficient, using the modifications to the EPA and amplification factors, is 0.098 W, an increase of about 30 percent over ATC-14. Using the 1988 UBC, the base shear coefficient would be 0.119 W, an increase of about 55 percent over ATC-14. As stated above, without special site studies, the Engineer must use the greater of the two UBC coefficients, ultimately evaluating the building for a significantly higher force than ATC-14.

The last factor necessary for determination of the base shear is the $R_w$ factor. This factor reflects the expected performance of the structural system in the post-elastic range. A system with greater ductility may be designed for lower seismic forces than a less ductile structural system. However, the $R_w$ factors given in the UBC are predicated on ductile details required of the particular system under consideration. Without these special details, the UBC $R_w$ factors do not correspond to the expected seismic performance of the building. The consequences of this problem and possible approaches are discussed in later sections.

EVALUATION OF SEISMIC CAPACITY

UCRL-15910 provides a general comments for the evaluation of existing General Use facilities and a specific reference to "all 1988 UBC provisions,... regardless of whether they are discussed herein." Realistic estimates of the dead and live loads for all elements are combined with the seismic forces using appropriate load factors to establish demand forces for all members. Member demand forces are then compared with member capacities. If the member demand force is less than the member capacity, the element is deemed acceptable.

In addition to the capacity, the members must be reviewed to assure that the special detailing requirements of the 1988 UBC are satisfied for Zone 3 and Zone 4 sites. The special detailing review requirement is appropriate to assure that the structural system has the ductility that is assumed in the development of the $R_w$ reduction factors. However, the reduction factors assume a level of ductile detailing frequently not found in existing buildings. For example, the boundary elements of shear walls may require closely spaced ties in order to confine the concrete core and prevent buckling of the compression reinforcement. This requirement for shear wall buildings was not a part of the UBC until 1985. Prior to 1985, ductile boundary elements for shear walls were only required for dual system buildings.

If the existing building does not have the ductile details envisioned by the $R_w$ reduction factor, the Engineer must decide how to evaluate the capacity of the existing element. No guidance is provided in UCRL 15910 for this evaluation. One option, albeit a potentially very expensive one, is to discount the capacity of the element and recommend either upgrading the existing element to meet existing 1988 UBC detailing requirements, or replacing the existing element with a new element. This option ignores the potential of the existing element to resist the demand forces in an elastic manner, a possibility if the capacity of the element is sufficiently greater than the normal seismic design force levels would normally require.

ATC-14 provides guidance to the Engineer for evaluating the capacity of existing elements that do not conform to current ductile detailing requirements. This guidance is in the form of Capacity/Demand ratios that reflect the increased elastic capacity required of specific elements if the ductility of these elements is judged insufficient. The ATC-14 requirements depend on the required ductility of the member. For ductile elements, the C/D ratio need only be 1.0. For elements with semi-brittle and brittle failure mechanisms, the required element capacities are $0.2R_w$ to $0.4R_w$ times the code level demand forces on the element.

Using the prototype concrete shear wall example, both the boundary elements and coupling beams must either possess closely spaced ties to confine the core or they must have sufficient strength to resist $0.2\ R_w$, or 1.6, times the code level forces for an $R_w$ equal to eight for shear walls. If the element can meet this criteria, the element is judged adequate without upgrading to 1988 UBC detailing requirements. This represents a significant cost savings if the element meets this criterion and therefore, does not require seismic upgrading.

While ATC-14 provides guidelines for the acceptance of elements that do not meet the Code detailing requirements, at the same time it provides guidelines for the design of the seismic upgrade of existing elements if they do not meet the ATC-14 guidelines. The design of the upgraded element must meet the same ATC-14 C/D ratio used for the evaluation of the original element. Therefore, the design force level must be increased to account for the lack of ductility in the element.

SYSTEM CONFIGURATION

UCRL 15910 provides a general discussion of the beneficial aspects of structural system configuration. It recommends greater care by the Engineer in the evaluation of irregular buildings. Re-entrant corners, soft stories, and large changes in vertical distribution of mass are all mentioned as possible sources of increased local damage to elements of the structure. Particular criteria for the evaluation of these problems must be located in the 1988 UBC.

ATC-14 provides specific guidance for identifying potential weak links caused by irregular structural configurations. For example, significant torsion is defined as a condition where the centers of mass and rigidity are located more than 20 percent of the plan dimension of the structure. If this condition occurs, the building must be evaluated for story drifts that include the torsional response. Vertical load carrying elements must maintain their capacity when subjected to deflections caused by $0.4R_w$ times the design forces. Soft stories, defined in ATC-14 as a 20 percent decrease in yield capacity from one story to the story below, are treated in a similar manner. Seismic forces must be increased by $0.4R_w$ times the equivalent lateral forces to account for this irregularity in configuration.

DUCTILE DETAILING REQUIREMENTS

As mentioned earlier, UCRL 15910 requires the Engineer to review the details of an existing building for compliance with the 1988 UBC requirements for ductile detailing. Many existing buildings will not meet these requirements; some of the ductile detailing requirements are relatively recent additions to the Code. Recommendations for the evaluation of the useful capacity of these non-conforming members is not provided in the UBC.

ATC-14 identifies the areas of the structure where ductile detailing is beneficial to the seismic performance of the building. If the ductile detailing is not present, then the capacity of the element in question must be evaluated against an increased demand force. If the element has sufficient capacity to resist the increased demand force, then the ductile detailing requirement may be waived. The element is judged capable to resist the seismic forces elastically and does not need the ductility normally associated with design level seismic forces.

The boundary element requirements of concrete shear walls are an example of ductile detailing requirements found in the both the 1988 UBC and ATC-14. In ATC-14, the boundary element criterion is automatically satisfied if the spacing of transverse ties is less than eight times the diameter of the longitudinal reinforcement. This criterion is intended to prevent buckling of the longitudinal bars and is based on the critical buckling length of the longitudinal bars.

Comparing with the UBC criterion, the ductile boundary elements, where required, must have transverse ties meeting the requirements for concrete columns in a special moment resisting space frame (SMRSF). The transverse ties may be spaced at no greater distance than four inches apart, irrespective of longitudinal bar diameter. This SMRSF spacing criterion was developed primarily to prevent shear failures in columns due to seismic bending moments and to increase the ultimate strain capacity of the concrete through confinement of the column core concrete. A secondary benefit of the close spacing is the prevention of buckling of the longitudinal reinforcement. Because shear failures in the boundary elements of tall shear walls is not a primary concern, such close spacing is not warranted to prevent longitudinal bar buckling. Therefore, using the UBC Code to review the detailing of the boundary member results in a much more restrictive criterion for acceptable spacing of transverse ties. No guidance is provided for evaluation of the shear wall where the boundary element details do not meet the Code requirements.

A second example of the ductile detailing criteria differences between the UBC and ATC is found in the provisions for deep beams between coupled shear walls. The UBC requires special symmetrical diagonal shear reinforcing extending the full length of the coupling beams when the factored shear stress in the beams exceeds 4 $(f'_c)^{0.5}$. Very few existing structures have this special type of detailing.

The ATC-14 criterion applies for coupling beams located over means of egress. In these instances, the coupling beam is deemed adequate if the beam has transverse stirrups spaced at 8 $d_b$ or less and are anchored into the core with 135 degree hooks. If the beam does not meet this requirement, then the capacity must be compared to 0.2 $R_w$ times the demand forces. If the beam capacity is greater than this value, the beam is judged adequate for life-safety. If the beam does not meet this requirement, then either its ductile detailing or its capacity must be upgraded to meet the ATC-14 criterion.

In summary, the 1988 UBC ductile detailing criteria are significantly more stringent than the ATC-14 detailing criteria. This should be expected from a Code intended for the design of new structures. The Code ductile detailing requirements improve the expected seismic performance of the structure to a higher degree than that required for life-safety. The Code criteria are intended to limit structural damage as well as protect lives. This is a higher performance goal than just life-safety and should be recognized as such. If life-safety is the only performance goal, then the ATC-14 detailing requirements are intended to offer a level of protection commensurate with this goal.

## CONCLUSIONS

The stated intention of the UCRL-15910 guidelines for evaluation of existing DOE structures is to provide life-safety level performance of the structure. In referencing the 1988 UBC requirements for the determination of the basic lateral strength, configuration, member capacity determination, and ductile detailing requirements, UCRL 15910 requires the existing building to meet the same requirements as a new structure. As many existing buildings do not have the basic design strength nor the ductile details now required of new structures, it is expected that they will not meet these criteria.

ATC-14 represents a guideline for the evaluation of existing buildings that recognizes that existing buildings should not necessarily have to meet the requirements of the new code. Using a lower basic design force and providing a method to evaluate non-conforming structural details, ATC-14 represents a life-safety level approach to the evaluation and upgrading of existing buildings.

DOE may wish to consider alternatives to the 1988 UBC requirements for the evaluation of life-safety of existing buildings. The use of a lower lateral strength requirement, reflected by a median spectrum, appears proper for evaluation of existing buildings. The requirement that the larger of the two base shear coefficients, ZC from a median response spectrum and ZC from the UBC, results in a significant increase in the required base shear.

In addition to the required base shear issue, the evaluation guidelines should address a method for establishing the reliable capacity of critical elements with non-conforming details in an existing building. This can be done by 1.) either using increased C/D ratios for certain elements of the structure that are critical to the seismic performance of the building, or 2.) decreasing the $R_w$ for the entire structure to account for the lack of ductility in some of the structural details in the existing building. Both methods effectively require greater strength to account for lack of ductility; however, the former method defines only key elements of the building while the latter method affects the evaluation of the entire building. It is the former method of evaluating only the critical elements of a structure for life-safety performance goals where cost savings may be realized. Whatever approach is taken, the evaluation of existing structures for seismic forces requires judgment and care by the Engineer in selecting and utilizing the most appropriate criteria for the task at hand.