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REVIEW CRITERIA FOR ARC ALWR EQUIPMENT QUALIFICATION[1]

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ABSTRACT

Advanced Reactor Corporation has developed a methodology for seismic qualification of equipment in Advanced Light Water Reactor plants by use of experience data. The exiting criteria for review of seismic qualification available in the industry standards and NRC Regulatory Guides and Standard Review Plans are inadequate for this purpose. This paper presents an alternative framework and a set of criteria that can be used for review of the ARC qualification methodology.

INTRODUCTION

The seismic qualification of equipment in nuclear power plants is typically performed in the USA by following the guidelines of IEEE Std. 344 (Reference 1). This standard has been endorsed by the U.S. Nuclear Regulatory Commission (NRC) (Reference 2). The NRC uses its Standard Review Plan to evaluate the seismic qualification of equipment in current plants (Reference 3).

For seismic qualification of equipment in Advanced Light Water Reactor (ALWR) plants, Advanced Reactor Corporation (ARC) has recently prepared a methodology based on experience data (Reference 4). A Panel[3] supported by the NRC is currently evaluating the ARC methodology. The current qualification and review criteria as embodied in the IEEE Standard, Regulatory Guide and Standard Review Plan (References 1, 2 and 3) are too broad for seismic qualification by use of experience data. More specific criteria are needed for evaluation of the ARC methodology.

This paper presents a set of criteria that can be used for evaluation of the experience-based seismic qualification approach developed by ARC.

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ARC METHODOLOGY

By use of earthquake, testing and analysis experience data, ARC has developed seismic qualification requirements for the following nine classes of ALWR equipment:

1. Horizontal pumps
2. Vertical pumps
3. Motor-operated valves
4. Air-operated valves
5. Manual and check valves
6. Temperature sensors
7. Diesel generators
8. Transformers
9. Batteries on racks

These nine classes of equipment have been identified as falling into one of two general groups, related to the potential for applying seismic experience data. The first seven equipment classes have been categorized into one group (Group 1) and the other two into another group (Group 2). The design, installation and maintenance specifications for each of these nine equipment classes have been developed by use of experience data. Equipment items in ALWR plants procured and operated according to those specifications will qualify to the desired levels of earthquake excitations.

The desired qualification (excitation) levels have been categorized as Level A and Level B. Level A with a 5% damped spectral acceleration of 1.2g and ZPA of 0.5g is the lower of the two excitation levels and the same as the Reference spectrum developed by the Senior Seismic Advisory and Review Panel (SSARP, Reference 5). Unlike Level A, Level B varies and depends on the specific equipment class.

REVIEW CRITERIA

The essence of the criteria of the current industry and regulatory documents (e.g., References 1, 2 and 3) is that a seismic qualification methodology can be considered acceptable as long as it provides high confidence that when implemented the candidate equipment item will perform its intended function for a target earthquake excitation level. This fundamental criterion of seismic qualification must be satisfied by the ARC methodology. However, difficulties arise in applying the current review criteria as embodied in the fore-cited documents since there is a "paradigm shift" with the ARC approach. The fundamental difference is that the conventional seismic qualification methods allow the vendors to manufacture products to <u>their specifications</u> as long as they can demonstrate by use of qualification tools (e.g., testing and structural analysis) that these products will qualify to the required excitation level. In the ARC approach, the emphasis is on the products so that the vendor will manufacture equipment to the <u>ARC specifications</u> for qualification to the pre-set excitation levels. Thus, with the conventional qualification approach, a reviewer is concerned with the qualification data rather than the product specifications; whereas, with the ARC methodology, the reviewer will

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review the product specifications and the qualification will be automatically assured. This implies that the reviewer must have knowledge of the strengths and vulnerabilities of the candidate equipment classes under vibratory environments. Fortunately, in the past two decades extensive studies have been performed to understand equipment characteristics and its performance in vibratory environments including earthquakes, shake table testing and computer simulation (References 5-11). These studies have examined malfunction mechanisms and identified robustness of certain equipment classes and weaknesses of others. If the malfunction mechanisms are well understood, a simplified qualification approach can be employed by avoiding such vulnerabilities through the product specifications. Thus, the rigor of the qualification and review approach depends to a great extent on the knowledge of the equipment design and performance characteristics. This leads to a grouping technique that can be used for both qualification and review purposes. Depending on inherent equipment characteristics and performance complexities, candidate equipment classes can be placed into one of several groups and be reviewed according to the criteria appropriate for that particular group. Since the review criteria are different for different groups as will be discussed in the following sections, it is important that a candidate equipment class is categorized into the appropriate group. Three such groups[4] will be discussed for understanding of the grouping concept. Acceptance criteria for each group will also be presented.

GROUP 1 EQUIPMENT

Equipment classes that perform best in the earthquake environment belong to Group 1. These equipment classes are inherently strong due to their normal design. The review and acceptance criteria for this group of equipment are as follows:

1. Equipment functional operability depends on structural integrity alone, i.e., operability can be assured if structural integrity is demonstrated.

2. Equipment design, and past earthquake, testing and operational experience data support the argument of inherent strength and resistance to vibratory motion.

3. Malfunction mechanisms, if any within anticipated earthquake levels, are well understood so that they can be avoided by design.

4. The fundamental frequency is high enough to allow static analysis.

5. Structural analysis is performed to verify load transfer and avoid structural weaknesses as a source of malfunction.

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[4]Three groups are selected only to present a systematic framework for criteria development. One can also divide the equipment population into more than three groups for further refinement of the criteria.

6. A large number of diverse products from various manufacturers and of different designs are examined for adequate understanding of equipment design and performance characteristics.

7. Vulnerabilities are precluded through sound product, installation and maintenance specifications.

8. The target qualification (excitation) level is supported by a combination of experience data and structural analysis.

If a particular class of equipment satisfies the above criteria, it can be accepted to belong to Group 1 with the appropriate qualification level. It is emphasized that the equipment designs that will satisfy the above criteria and be screened through procurement specifications will belong to a *subset* of the given generic class. Thus, a review process will verify that only the *subset* of the generic equipment class and not the entire class is a candidate for qualification. Multiple such subsets may be defined for each class of equipment for different excitation levels. Of course, the subset is expected to be narrower as the target excitation level increases. This can be illustrated by considering extreme conditions. For example, if the excitation level is very low (e.g., 0.05 ZPA), an entire equipment class with all diversities may qualify; whereas, if the excitation level is very high (e.g., 10g ZPA), only a few specific designs may qualify. Thus, subsetting should be reviewed in light of the qualification level.

GROUP 2 EQUIPMENT

An equipment class that is not as earthquake-resistant as Group 1 equipment and that does not satisfy all the criteria for Group 1 may be a candidate for Group 2. As a minimum, the malfunction mechanisms for a Group 2 equipment class can be identified with a high degree of certainty. The following are review and acceptance criteria for Group 2.

1. A detailed examination is performed on the equipment design and performance characteristics.

2. All potential malfunction mechanisms are explored, verified with experience data, and well understood.

3. The root causes of the malfunction mechanisms are analyzed.

4. All known and potential malfunction mechanisms are precluded through strict product, installation and maintenance specifications.

5. The load transfer is verified by structural analysis.

6. A well-defined and well-documented experience data base that supports the product specifications is maintained.

7. The data base includes a wide variation of products (e.g., manufacturer, model number, size, weight, etc.) and input motions (e.g., over a broad frequency range).

8. The target qualification (excitation) level is established from the data base and with high confidence, and is supported by structural analysis.

Similar to Group 1, the above screening will produce a *subset* within a given equipment class and only this *subset* defined by specifications can be a candidate for qualification. Multiple subsets may be created for an equipment class depending on the desired qualification level. As explained for Group 1, the equipment subset in a given class is expected to be narrower as the qualification level increases. In general, subsetting and product specifications for Group 2 are more explicit and restrictive than Group 1.

GROUP 3 EQUIPMENT

Equipment classes that do not satisfy the criteria for Group 1 or Group 2, are more susceptible to seismic motion and belong to Group 3. Traditional shake table testing or a more rigorous similarity approach may be an acceptable method of qualification. The ARC report does not include any equipment as a candidate for Group 3.

EXCITATION LEVEL

The need for establishing an excitation level for qualification has been mentioned above but the acceptance criteria for arriving at this level have not been presented. In general, this is a complex issue and depends very much on the type (e.g., testing and earthquake) and quality of the data base. The following discussion will shed some light in this regard.

For experience data collected from test programs, the input motion is controlled, usually well documented and mostly broad-banded with multifrequency contributions. Each of these input motions contains a definite amount of *damage potential* for a particular equipment item. The damage potential also depends on the equipment item, e.g., its fundamental frequency, malfunction mechanisms, etc. Thus, the *damage potential* varies depending on the combination of the input motion and the equipment characteristics exhibiting a particular malfunction, and is difficult to quantify because of this interactive behavior, although this is the target parameter in comparing various input motions for qualification.

Typically, input motions are expressed in terms of acceleration response spectra, and the damage potential may be represented by the ZPA, peak spectral acceleration, average spectral acceleration over a frequency range of interest (e.g., fundamental frequency band), ratio of the peak spectral acceleration to ZPA, etc. Even with well-defined experience response spectra, such as test response spectra, a question remains as to how to draw the qualification response spectrum for a given number of experience response spectra. A lower envelope of the experience response spectrum set or a spectrum with an average of the spectral responses at each frequency may be considered as a potential candidate. But, each approach will provide a very different confidence level. Thus, there is no unique way to establish the qualification or excitation level. There are many other factors that complicate this matter further. For example, the resonant frequency corresponding to a given malfunction is mostly unknown and this frequency for each equipment of the same class can be significantly different. There could be multiple malfunction mechanisms which need to be considered in comparing the response spectra. Thus, there could be a substantial amount of diversity of damage potential within a given subset of any equipment class and, for equipment qualification, there is no simple tool to derive a unique qualification excitation level from a given set of test response spectra.

In the above discussions, it has been assumed that the excitation levels of the experience data base are well-controlled and well-documented. This assumption is mostly true for testing experience data but definitely not true for earthquake experience data. There are two major sources of uncertainties in estimating the motion at the location of equipment in the earthquake experience data. Ground motion is typically recorded at a reasonably far distance (e.g., 1-2 km) from the site so that the ground motion estimate at the equipment site has a high uncertainty. The equipment item itself could experience a motion different from the ground motion at the site. The motion that a particular piece of equipment has been subjected to could be, for example, as low as half or as much as twice the estimated motion. Because of these complexities, the development of a qualification level requires the exercise of considerable judgment.

Thus, no definitive acceptance criteria can be prescribed for establishing the qualification level from a given set of experience excitation data. Instead, if there has to be a method to integrate all these factors, it is through the use of expert judgments. A group having joint expertise in various aspects of equipment qualification and structural dynamics, as cited above, may attempt to draw a qualification excitation level. Again, in an interactive mode, the qualification excitation level can vary depending on the reliability of the subsetting of equipment that will be a candidate for qualification, as explained earlier.

CONCLUSIONS

Although experience data have been used for seismic verification of equipment in existing nuclear power plants, its use by ARC for qualification in ALWR plants is a new concept. The criteria presented in this paper provide an initial framework for reviewing the ARC methodology. It is recognized that these criteria need to be expanded with more definitive guidance (e.g., similar to other criteria in the SRP).

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