Response of a BWR Mark II Containment Structure to SRV Loads

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Actuation of SRVs in BWR plants produces dynamic pressures on suppression pool boundaries. Since the resulting structural vibrations must be considered in the design and/or qualification of plant safety features it becomes important to predict/calculate structural responses in a realistic, yet conservative, manner. SRV actuation tests have been conducted in BWR Mark II plants and test results are available for interpretation/evaluation. This paper summarizes the efforts which, using results of in-plant tests, accomplished the following:

a. developed an improved SRV load definition;

b. developed and qualified a computational methodology to predict structural responses to SRV loads.

Using the improved SRV load definition and the qualified computational methodology, realistically conservative responses are predicted/calculated for a BWR Mark II plant (steel containment). Since responses corresponding to locations outside the primary containment structure are negligibly small, it is recommended that they need not be considered in design and/or qualification of plant safety features.

1. Introduction

Certain conditions in operating boiling water reactor (BWR) plants result in actuation of safety relief valves (SRV) thus providing the required pressure relief to the reactor pressure vessel (RPV) and the connected main steam lines. The ensuing water, air and steam discharge through quenchers, which are used as SRV discharge line (SRVDL) exit devices, produces a disturbance in the suppression pool which results in dynamic pressure loads acting on the pool boundary. Structural vibrations within the reactor building result, and must be considered in determining the design adequacy of plant safety features.

2. Formulation of the Problem

A cross-sectional view of a typical BWR containment of Mark II configuration is shown in Figure 1. The containment includes the drywell and the wetwell separated by the drywell floor. After actuation of SRV's, discharge of water, air and steam through SRVDLs' quencher exit devices introduces a disturbance in the suppression pool which travels through water and, reaching the pool boundaries, acts as dynamic pressure loading on the containment structure, [1]*. The loading is normally defined as the incident pressure, p_i (see reference [2]), also known as the "rigid wall" pressure. During application of p_i the containment structure deforms while interacting with the water in the suppression pool and, as a result, induces in water a hydrodynamic pressure field, p**. At the water-structure interface, Σ , this induced pressure acts as an added component of loading, p_Σ, on the containment structure (references [2-4]).

Details of the problem formulation, including governing equations, assumptions, etc., and the method of solution are described in references [5] and [6], and are very similar to those described in references [3] and [4].

3. In-plant SRV Actuation Tests

Full scale SRV actuation test programs have been implemented in two BWR plants of Mark II containment configuration: CAORSO (Italy), a plant with a concrete containment, and TOKAI-2 (Japan), a plant with a steel containment. Both plants are equipped with cross quenchers, similar to those described in [1]. These tests were instrumented to record the total dynamic pressure loading on the wetted wetwell boundary, i.e., $(p_i + p_\Sigma)$, the corresponding containment/reactor building structural response accelerations, as well as other data. The peak pressures measured on the suppression pool boundary were found to be smaller by approximately a factor of 2, [5], than those

* Reference [1] is also known as the DFFR report.

** This phenomenon is known as fluid-structure interaction (FSI).

recommended to be used for plant design, [1], for comparable plant conditions. This difference indicates that an improved/more realistic design load definition is desirable. More important, the measured maximum structural response accelerations were found to be smaller by an order of magnitude, [5], than those calculated/predicted at critical locations (locations with large calculated/predicted responses), for comparable plant conditions. This - rather significant - difference makes imperative the need for developing an improved load definition and for a review of the computational methodology used to predict structural responses.

4. SRV Design Load - Improved Definition

Since tests were performed in BWR Mark II plants equipped with cross-quenchers, it was rational to define the SRV loading as an incident (rigid wall) pressure; such a definition would be applicable to other BWR Mark II plants equipped with quenchers of similar design. A study of the recorded pressure traces has indicated the random nature of the SRV load and, consequently, the recommended improved SRV design load was derived statistically to correspond to the desired/required probability of non-exceedance limit and confidence level: 90%/90%. The recommended improved SRV design load definition consists of the three elements described below, [5].

a. A pressure amplitude, smaller by approximately a factor of 2 than the maximum positive pressure design value (MPPDV) recommended in [1] for same design conditions.

b. Pressure wave forms with a frequency content statistically enveloping the test data and with the characteristic/dominant frequency in the range of 4.0 to 12.0 Hz; typical Fourier amplitude spectra of the design pressure wave forms corresponding to a characteristic/dominant frequency of 6 Hz are shown in Figure 2 and, for comparison purposes, similar information is provided in Figure 2b for the wave form recommended in [1].

c. A spatial distribution for the pressure loading is described in Figure 3* and derived from test data (vertical) and from suppression pool acoustic analyses (circumferential); for comparison purposes the distribution recommended in [1]is also shown.

* This spatial distribution corresponds to a single SRV actuation event; spatial distribution for multiple SRV actuation events are discussed in reference [5].

5. <u>Improvement and Verification of the Computational Methodology to Predict Structural Responses</u>

Availability of detailed results from CAORSO in-plant SRV tests, suppression pool boundary pressures and corresponding containment/reactor building structural response accelerations, provided a good opportunity to verify the adequacy of the computational methodology (structural modeling techniques and analysis procedures) used to calculate structural responses to SRV loads. An improved (axisymmetric) finite element model for the CAORSO reactor building structure was developed, the key feature being a more adequate representation of the relatively thick suppression pool boundary structures (the RPV pedestal, the concrete containment and the foundation mat) with solid elements. A combination of shell and solid elements was used to simulate the sacrificial shield wall composite structure. Hysteretic damping was used in the analysis (this enabled the structural analyst to assign different damping values to different structural components). The model (see Figure 4) was subjected to a measured pressure time history applied over the wetted wetwell perimeter and its (structural) responses were computed (see reference [6] for details). Responses computed at two locations, (the RPV support and the containment structure at the drywell elevation indicated) are shown in Figure 5 together with measured responses at same locations. A comparison between computed and measured responses indicates good agreement, thus verifying the adequacy of the computational methodology used to calculate/predict structural responses to SRV loads.

It is significant to note that both computed and measured responses were negligibly small at all locations outside the primary containment.

6. <u>Mark II Containment Structure Response to SRV Loads</u>

A typical BWR Mark II reactor building structure (similar to that shown in Figure 1) was analyzed using the computational methodology discussed in Section 5 (see references [4] and [6]) for SRV loads defined as described in Section 4 (see reference [5]). Structural responses computed at the RPV support and the containment structure at the drywell elevation indicated are shown in Figure 6*. Comparison of responses shown in Figures 5 and 6 indicates that although the responses of Figure 6 are larger, as expected because of the more flexible steel containment structure analyzed in this section, these responses are realistic (i.e., not overly conservative) for use in design and/or qualification of plant safety features. It is important to

* It is a good engineering practice to introduce a design margin (to be determined by the engineer) for actual applications. Figure 6 includes such a design margin.

note here also that the responses computed at all locations outside the primary containment are negligibly small.

7. Summary and Conclusions

In-plant SRV actuation tests have been implemented in two BWR Mark II plants: one with a stiffer concrete containment (CAORSO, Italy) and the other with a more flexible steel containment (TOKAI-2, Japan). Results of these tests - measured suppression pool boundary dynamic pressures and corresponding structural response accelerations - indicate that the SRV load definition recommended in [1] for Mark II plants design is too conservative and furthermore that the computational methodology used earlier to calculate structural responses was inadequate (resulted in unrealistic over-predictions of responses). The efforts summarized in this paper accomplished two things:

a. An improved definition for SRV design loads is obtained using results of in-plant SRV actuation tests;

b. A computational methodology is developed for predicting structural responses to SRV loads; this methodology was qualified by the good agreement noted between predicted/calculated and measured responses.

When using the improved SRV design loads and the qualified computational methodology realistically conservative responses are predicted/calculated for a BWR Mark II plant. The responses corresponding to locations outside the primary containment structure are very small (results corroborated by test data) and, consequently, is recommended to be neglected in design and/or qualification of plant safety features.

References

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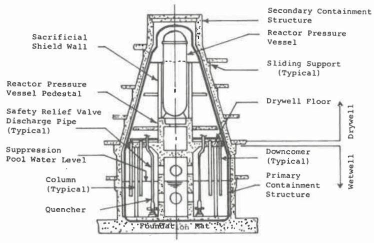

Figure 1 Mark II Containment: Cross Sectional View

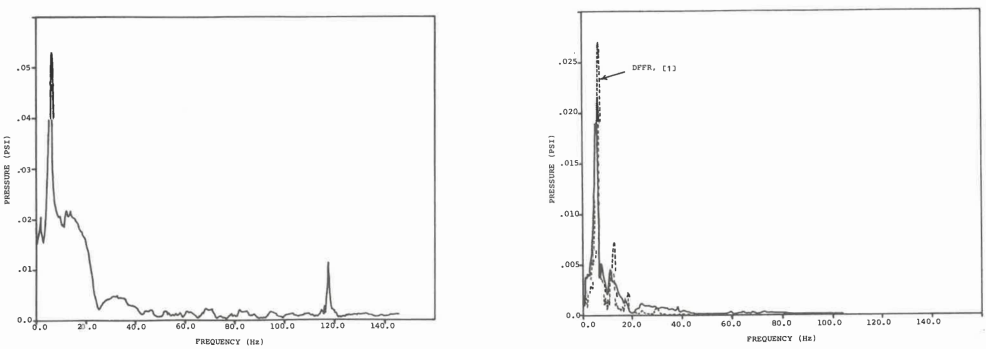

Figure 2 Recommended design pressure wave forms - Fourier Amplitude Spectra (normalized to + 1 psi pressure amplitude; corresponding to 6 Hz characteristic frequency)
a. Multi-frequency type
b. Single-frequency type

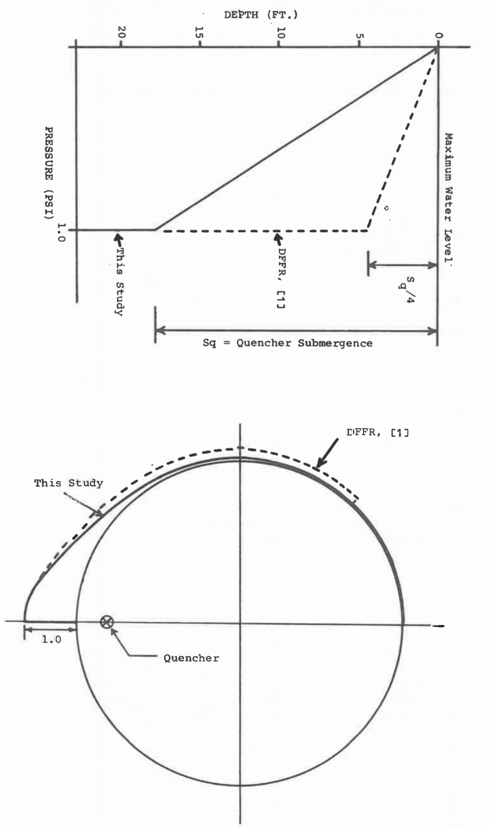

Figure 3

Recommended Spatial Distribution of Pressure Loading - Single SRV Actuation Event
a. Vertical
b. Circumferential

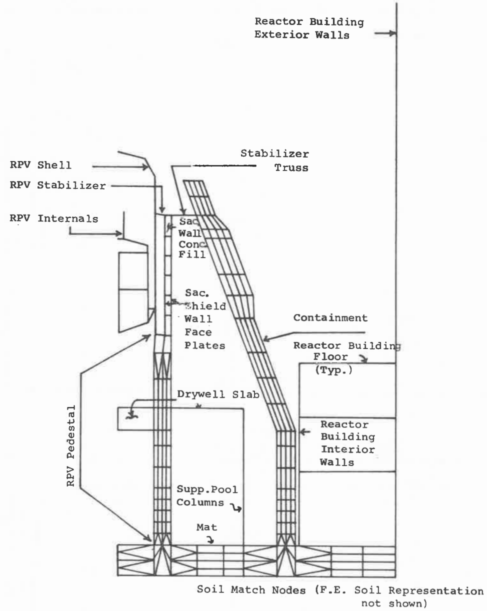

Figure 4

CAORSO Reactor Building F. E. Model

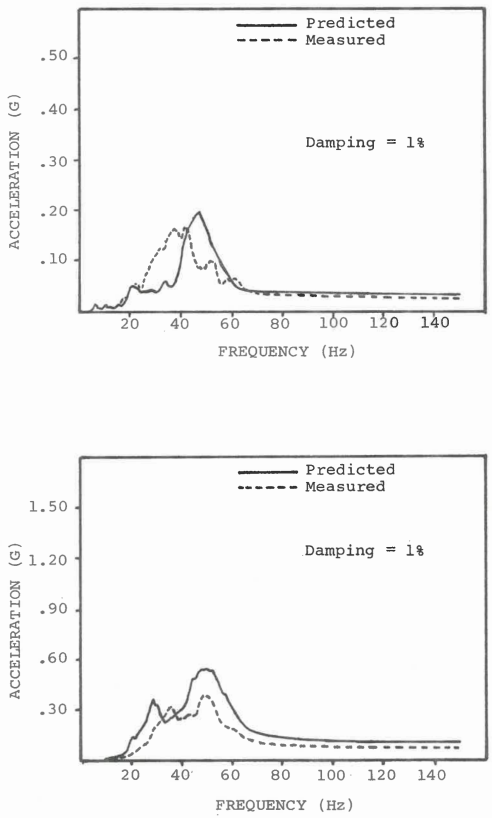

Figure 5

Horizontal responses (floor response spectra) for CAORSO at:
- a. RPV support
- b. Containment structure at an elevation approximately 21 ft. above drywell floor

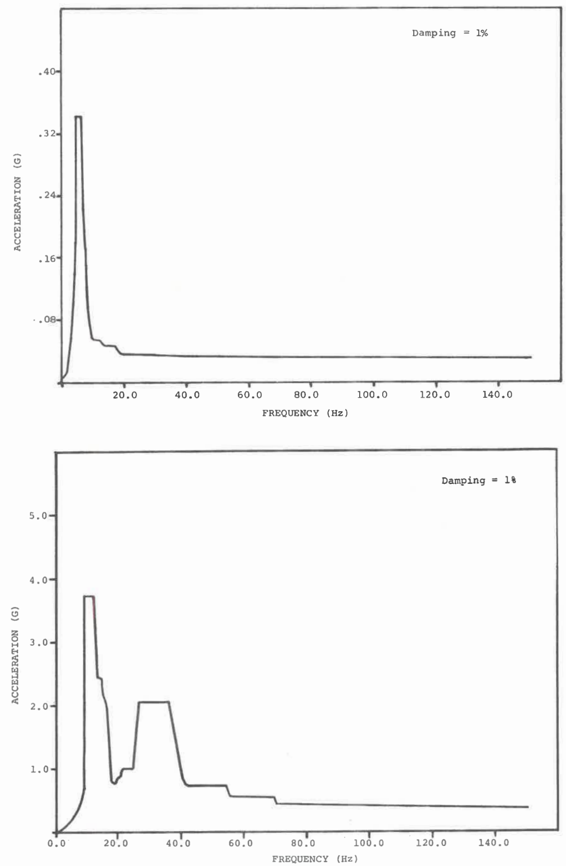

Figure 6

Horizontal responses (floor response spectra) for a BWR Mark II (steel containment) at:
- a. RPV support
- b. Containment structure at an elevation approximately 21 ft. above drywell floor.