Experimental and Analytical Investigations on Caorso BWR Mark II Containment Dynamics Response Following Safety Relief Valve Discharge

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SUMMARY

In conjuction with normal start up-testing,an in plant safety relief valve (SRV)discharge test program was performed at the Caorso Plant in Italy. The overall objective of this program was to provide measurements of loads and dynamic responses of principal structures and components following SRV actuations with a discharge quencher device. In this paper the portion of the program in the AMN scope, is mainly addressed, called STRET, and the attention is focused on the dynamic response of main structures; test results are presented and compared with pretest predictions. 52 valve actuations, performed during the second phase of testing will be considered;they envelope the results measured during the first phase and include different types of actuation such as single or leaking valve and multiple valve actuations with 2,3,4 and 8 valves. In order to assume that plant operating conditions during were within safety limits, several key items were monitored and continuonsly compared with predicted values; these items encompass floor response spectra derived from four accelerometer located at key elevation on the civil structures.Major findings related to the measurement of pool boundary pressure oscillations are first summarized . Max dynamic responses measured at selected sensors during all tests are subsequently presented and discussed and for some locations, distributions of max accelerations and floor response spectra are also shown. Max measured accelerations were everywhere below 0.2 g: max radial values were measured at the lower portion of the containment wall,directly subjected to the pressure wave load ; max vertical accelerations resulted at the peripheral of the diaphragm drywell floor, as a direct effect of the dynamic reactions on the SRVD piping supports.Although some types of actuations produced pressure time histories with higher frequency content than the idealized shape assumed for the design, max measured pressures and responses were always within predicted values with the only exception of the diaphragm floor for which the prediction neglected the pipe reactions effect. The margin between floor response spectra predicted on the basis of the design pressure values and spectra associated with measured acceleration time histories varies with frequency and generally reduces but still persists at higher frequencies.

1. Introduction

In Boiling Water Reactors, such as CAORSO, the actuation of safety-relief valves,causes the discharge of compressed air into the suppression pool chamber;high pressure originated air bubbles periodically expand and contract and apply an oscillating pressure field on the pool boundaries.

An in-plant test program has been performed with the aim of defining basic characteristics of this transient loading, its potential consequencies on dynamic responses of structures and components, and also to verify the conservatism and improve the accuracy of the design predictions.

In this paper the attention is focused on the response of main structures of the Reactor Building and some background information on the characteristics of the measured excitations is provided.

Tested containment configuration, mathematical model to predict structural response , quencher arrangement in the suppression pool and profile of a single quencher are schematically shown in figg. 1÷4 respectively. Figure 1, in addition, presents most of the 62 accelerometers mounted at key locations in the Reactor Building,namely RPV Pedestal, Primary Containment, operating and diaphragm floors, basemat and Shield Building ; remaining accelerometers are mounted at different azimuth locations (90 and 135 degrees) in the lower portion of the Primary Containment.

Furthermore accelerometers were installed on some typical equipment and pressure , temperature,level sensors were used to characterize the performance of the quencher device and the resulting forcing functions on the pool boundaries.

A summary of the basic characteristics of the 52 tests performed during the Phase II is reported in Table I; another 52 tests of single or consecutive actuations of one valve were performed during the Phase I of testing . Most of the discharges occured in a region close to an azimuth of 180° degrees.

2. Pressure loads

Typical pressure time histories measured under different test conditions are schematically shown in fig.5.

- Type a) is the idealized shape (Theoretical Raleigh Bubbles) used for the design /1/
- Type b) is typical of single valve actuation with normal water level in the cold discharge pipe (CP, NWL, SVA) ; initial sharp overpressure and underpressure spikes ($\simeq$ 25 Hz) are followed by a quasi sinusoidal pressure oscillation containing most of the energy input.
- Type c) is typical of consecutive valve actuations with water level depressed below 3 meters, hot pipe or leaking valve (HP,DWL,CVA and LV,DWL,CVA);a shape similar to the idealized one is shown throughout the entire transient

- Type d)is typical of consecutive valve actuations with elevated water level and hot pipe (HP,EWL,CVA): high magnitude spikes are followed by an erratic pressure oscillation
- Type e)is typical of single actuations of one leaking valve with depressed water level (LV,DWL,SVA); high magnitude spikes occur again at the beginning of the transient, followed by an erratic pressure oscillation with frequencies higher than type d)
- Type f)shows the steam condensation effects observed after the air bubble oscillation phase; low amplitude (typical mean values about ± 2 psid) and frequency content higher than 40 Hz were noted.

Following indications on the pool boundary pressure loads were derived :

- max and min measured pressures were generally below 50% of the predicted values (max values were about 9 psid): the prediction was based on a statistical analysis of results previously obtained with small and large scale tests ;
- attenuations with time and distance from the discharge of the measured pressure traces were higher than predicted;
- all boundary pressures, measured from a single quencher actuation, appeared to oscillate in phase;
- CVA pool boundary pressures were higher than CP, NWL,SVA values;
- during multiple valve actuations (MVA) the oscillations from different quenchers were closely phased after the characteristic initial high frequency spikes ;
- interaction from adjacent quenchers did not significantly affect the boundary loads;
- the CP,NWL,SVA tests at low reactor pressure exibited a trend toward lower pressures and bubble frequency as reactor pressure was reduced.

3. Pressure responses

Max measured accelerations , for each superstructure, from all SVA and MVA conditions are listed in Table II. All measured values were below 0.2 g; max radial accelerations were found at the lower portion of the containment wall, as a direct effect of the pressure load application, whereas max vertical accelerations resulted from local out of plane vibrations of the peripheral portion of the diaphragm floor, induced by local anchor reaction of the S/R discharge piping, with these two exceptions, accelerations were ewerywhere less than 0.1g.

Distributions along the containment wall of enveloped max radial and vertical accelerations among all tests are shown in fig. 6: max radial accelerations occurred in the lower portion at 180° azimuth during actuation of four adjacent valves; significant attenuation was found with height and circumpherential distance; at the containment top values tend to be equal at different azimuths.

More uniform values were found for max vertical accelerations expecially at 0° and 90°; at 180° a significant attenuation with height wass still observed although minor of the radial one.

Similar acceleration profiles are presented in fig.7 for the secondary containment: max radial and vertical accelerations were lower than 0.05 and 0.03 g respectively and mainly occured during actuation of 8 valves. Max values at the top are three or two times the radial and vertical responses at the mat level. The heighest vertical response was measured at 0° on the diaphragm floor only during a MVA test including actuation of one valve located at 0° azimuth; reduced responses were measured at the same location with other tests; confirming its local nature.

Measured responses exhibit a significant high frequency content : typical indications are provided in fig.8 (for the suppression pool walls and actuation of eight valves) where well correlated acceleration time histories at different elevations are shown with fundamental frequency of about 30 Hz, (as indicated by their Fourier spectra); in the same figure a predicted modal shape with eigenfrequency close to 30 Hz is also shown.

4. Comparison with predictions

Structural responses have been predicted by mean of the global shell model of fig.4 , analyzed with a modified version of the ASHSD-2 program /2/ to include the soil-radiation damping effect according to /3/.

Both consecutive actuation of one valve and simultaneous actuation of all valves were analyzed with pressure time histories predicted on the pool boundary as per ref./1/. The envelope of the predicted responses was compared with the envelope of the measured responses (single comparisons were also made) and following conclusions were derived :

- max accelerations were generally overpredicted by a factor larger than 2 and 1.5 for vertical and horizontal directions respectively with few local exceptions only ;
- the higher frequency content of the measured forcing functions, compared with the idealized shape,reduces the overprediction of max radial responses (governed by high frequency eigenmodes) below the overprediction of max bubble pressures;
- fig.9 compares distributions of max responses along the primary containment wall : a good correlation is indicated for the radial responses with a rather constant overprediction factor at different elevations, whereas vertical responses are substantially overpredicted at higher elevations.

Floor response spectra were also derived from measured acceleration time histories and compared with predicted spectra. Typical results are presented in fig.10, at the elevation on the containment wall where max radial and vertical responses have been measured for sensor A 13 (envelope values are considered for both tests and predictions) : significant overpredictions are indicated, expecially for low and medium frequencies. At other elevations similar comparisons are obtained for radial spectra and even higher overpredictions are found for vertical spectra, despite the consideration of the soil radiation damping.

For other superstructures vertical spectra are again largely overpredicted; the over-prediction of radial spectra tends to decrease at higher frequency and, in a few cases , disappear at frequencies higher than 30 Hz, as a consequence of the abovementioned richer frequency content of the measured excitations and of some local secondary effects neglected during the prediction.

These local exceptions occur where relatively smaller responses are determined and have no consequencies on the design.

References

/1/ NEDO 21061 "Mark II Containment Dynamic Forcing Functions Informatio Report" June 1978

/2/ Ghos S., Wilson E.L. "Dynamic Stress Analysis of Axisymmetric Structures Under Arbitrary Loading" Report n. E.E.R.C. - 69-10, revised September 1975 by C.J. Lin

/3/ Lysmer J. Kulmeyer R.L. "Finite Dynamic Model for Infinite Media" ASCE Journal of the Engineering Mechanics Division Vol. 95 - August 1969.

TABLE 1 - CAORSO STRET - SUMMARY OF PHASE II TESTS

Test Condition	Number Performed
(CP, NWL, SVA) valve A	5
(WP, DWL, CVA, 10-inch VB) valve A	3
(WP, EWL, CVA, 10-inch VB) valve A	1
(HP, DWL, CVA, 10-inch VB) valve A	8
(CP, NWL, SVA, two 10-inch VB) valve U	1
(HP, DWL, CVA, two 10-inch VB) valve U	4
(CP, NWL, SVA, low reactor pressure 10-inch VB) valve A	6
(LV, DWL, SVA) valve A	5
(LV, DWL, CVA) valve A	8
(CP, NWL, MVA) valves A & F	2
(CP, NWL, MVA) valves A, F, E	1
(CP, NWL, MVA) valves B, C, D, L	1
(CP, NWL, MVA) valves A, E, F, U	6
(CP, NWL, MVA) valves A, B, D, H, K, L, R, V	1
Total	52

TABLE 2 - MAX MEASURED ACCELERATIONS (G's)

STRUCTURE	CONDITIONS	MAX RADIAL ACCELERATION		MAX VERTICAL ACCELERATION	
		SENSOR N°	ACCEL. VALUE	SENSOR N°	ACCEL. VALUE
BASEMAT	ENVELOPE OF SVA	A05x	.036	A02y / A04y	.010
SECOND.CONT.		A09x	.044	A07y	.026
PRIMARY "		A17x	.133	A13y	.05*
PEDESTAL		A28x	.019	A28y	.020
SACRIF.SHIEL		A30x	.036	A30y	.066
DIAPHR.FLOOR		- -	- -	A29y	.094
BASEMAT	ENVELOPE OF MVA	A05x	.047	A04y	.028
SECOND.CONT.		A09x	.041	A09y	.029
PRIMARY "		A13x	.1420	A13y	.058
PEDESTAL		A28x	.017	A28y	.046
SACRIF.SHIELD		A30x	.056	A30y	.051*
DIAPHR.FLOOR				A29y	.188

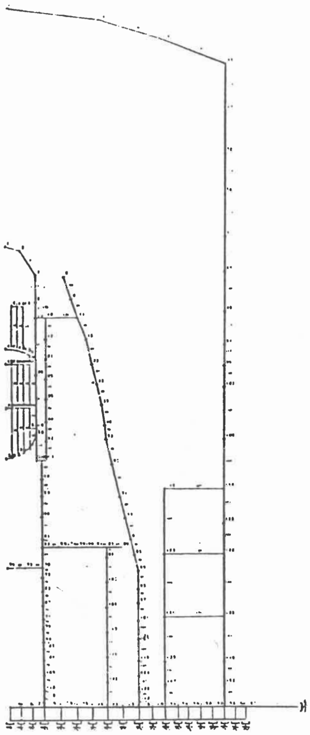

FIG.4 - CAORSO
AXISYMMETRIC SHELL MODEL

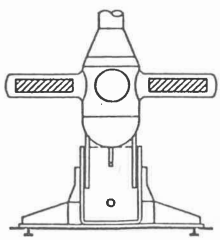

FIG.3 - CAORSO QUENCHER
AND SUPPORT

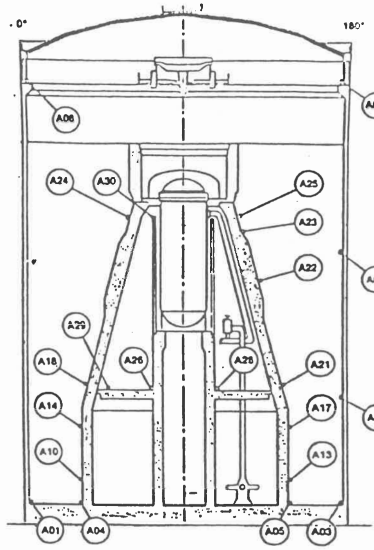

FIG.1 - STRET ACCELEROMETER LOCATIONS
ON 0°-180° PLANE

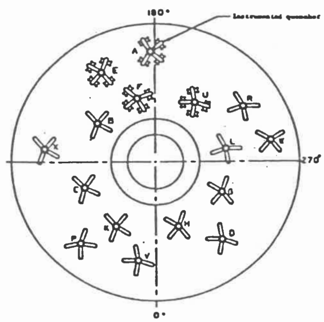

FIG.2 - QUENCHER LOCATIONS

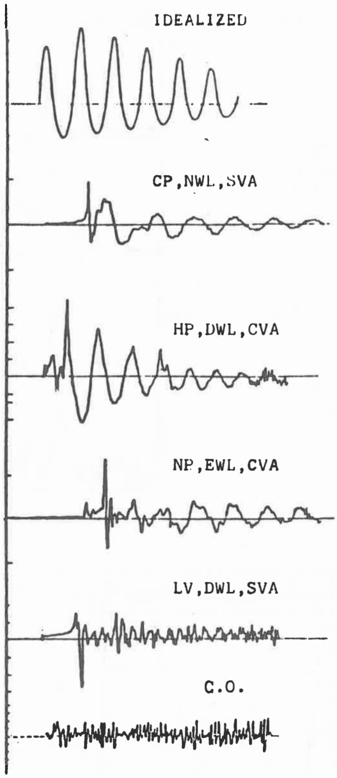

FIG.5 -TYPICAL POOL BOUNDARY PRESSURE TRACES

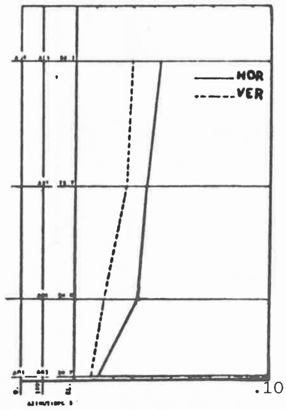

FIG.7 - GLOBAL ENVELOPE OF MAX MEASURED ACCELERATIONS (G's) ON SECONDARY CONT.

FIG.6 - GLOBAL ENVELOPE OF MAX MEASURED ACCELERATIONS (G's) ON PRIMARY CONTAINMENT

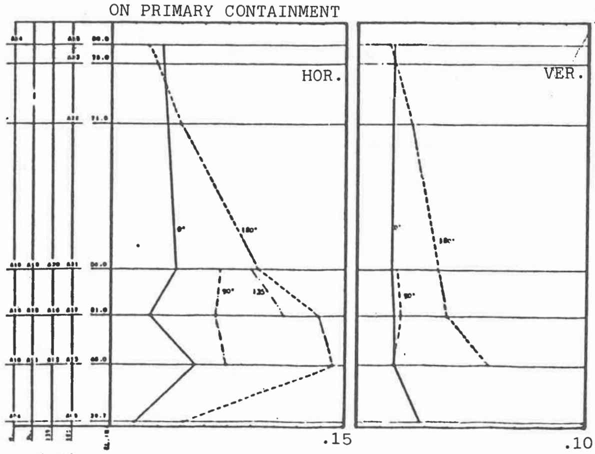

FIG.8 - TEST 32. 8 S/RV ACTUATION, ACCELERATION TIME-HISTORIES AND CORRESPONDING FOURIER SPECTRA AT SELECTED LOCATIONS

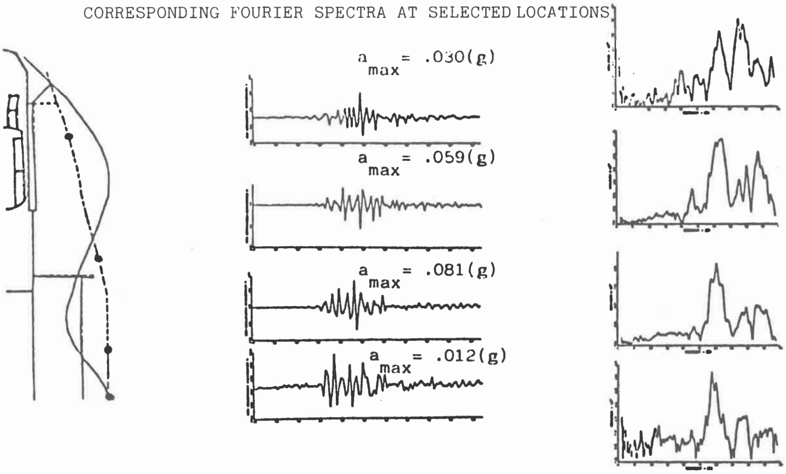

FIG.9 - MEASURED VS PREDICTED MAX ACCELERATIONS ALONG PRIMARY CONTAINMENT

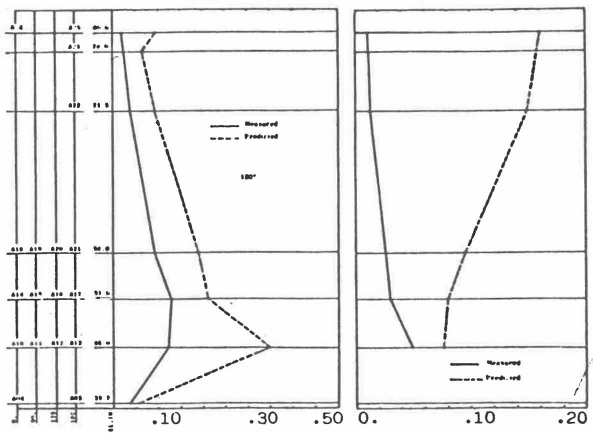

FIG.10- MEASURED VS PREDICTED FLOOR RESPONSE SPECTRA