K11/1

SBWR - Nuclear Island Parametric Seismic Analysis

M. OLIVIERI, E. TRAVERSONE, G. VITI
ANSALDO S.p.A. C.so, Genova, Italy

1 INTRODUCTION

With the aim of developing a standardized design for different seismic environments and different National licensing positions, a parametric seismic analysis of the SBWR Nuclear Island has been performed by Ansaldo, as part of the SBWR Design Team activities, by assuming various site conditions, and structural configurations, to cope, possibly, with additional requirements, such as external missile impacts.

2 STRUCTURAL LAYOUT AND SEISMIC MODEL

The assumed reference layout of the Nuclear Island and the associated seismic lumped mass model are Shown in fig. 1.

The reference configuration consists of a reinforced concrete containment vessel (RCCV), structurally integrated with the R.B. enclosure, and its internal structures and components (RPV, Sacrificial Shield, Vent Wall & Pedestal), resting on a common foundation square mat (61 x 61 m) significantly embedded into the soil (18 m), with a light flat steel roof on top. But alternative configurations have been parametrically analyzed also, characterized with different R.B. and mat shape (rectangular), different RPV outlines (stepped vs uniform cylinders), different degree of coupling between the RCCV and R.B. structures, adoption of stabilizers between the RPV and its Internals and the Sacrificial Shields, reinforced concrete pedestal, reinforced concrete hardened R.B. roof to cope with specified external missile impact requirements.

The lumped mass seismic model developed for the reference configuration is sufficiently accurate for the subject scope, as it describes main superstructures of the N.I. resting on the common mat, with specific attention given to their interactions through the various structural connections at different elevations; in addition it can easily incorporate various layout parameters modifications.

Stiffness properties of the complex R.B. sections have been evaluated with an authomated procedure (Rif. 1), whereas off-diagonal virtual masses are specified for the RPV-Internals hydrodynamic coupling.

3 ASSUMED SITE CHARACTERISTICS AND SOIL STRUCTURE INTERACTION

In order to cover a significant portion of potential U.S. and European conditions, a broad band of site characteristics is considered, spanning from very soft to soft, rigid and hard sites, with assumed omogeneus, strain reduced, typical shear wave velocities of 200, 300, 750 and 1500 m/s respectively.

US.N.R.C. R.G. 1,60 excitation spectra with 0,3 g max ground acceleration are applied, with the exception of site specific spectra for the very soft case and max ground acceleration reduced to 0,24 g to limit the soil liquefaction potential.

The soil structure interaction has been described for different sites, with lumped spring and damping parameters, simply assumed as frequency independent, based on formulas of Ref. /2/, properly corrected per ref. /3/, to include the stiffness and damping increase, caused by the deep embedment, and the non circular shape of the foundation. Coupled horizontal-rocking effects are obtained by placing horizontal translational springs at a given elevation above the mat by accordingly reducing the rocking springs.

4 FREE VIBRATION CHARACTERISTICS

Foundamental frequencies of main civil structures, for different sites, vary between 1,47 and 5,6 Hz for horizontal directions and between 1,80 and 11 Hz for the vertical direction, for various sites. For softer sites few quasi rigid body mode shapes are dominating. For stiffer sites more coupled modes are contributing, with mixed participations from soil, civil structures and RPV/Internals deformations. For RPV Internals the foundamental frequency of the cantilever shroud-chimney complex would be as low as 4,87 Hz, indicating the need of an upper Internal Stabilizer to the RPV wall, whereas eigenfrequencies of fuel and RPV wall on a fixed base are higher than 7.4 and 14 Hz respectively.

5 MAX STRUCTURAL SEISMIC RESPONSES

Max seismic responses in terms of max displacements, accelerations, forces and moment profiles for individual superstructures and coupling effects have been evaluated for each case and compared to each other, to evaluate governing cases and effects of single parameters.

A response spectrum approach has been used with U.S.N.R.C. R.G. 1.61 structural dampings, composite modal dampings evaluated with the Roesset (Ref./4/) weighting procedure, modal response contributions superimposed with the General Modal Combination Rule suggested in Ref, /2/ (similar to CQC).

For civil structures max responses increase with site stiffness as indicated in fig. 2: max vertical dynamic amplifications, i.e. ratioes respect max mat acceleration, are small (less than 1,7 and 2,2 for concrete structures and steel roof) whereas they are larger horizontally (up to 2,35 and 8,8 respectively) but still acceptable. An hypothetical structural disconnection would significantly increase (by more than 50%) the response of the RCCV and internal structures, compensated by a small reduction (about 10%) of the R.B. response, with almost unaffected global soil seismic reactions, indicating a global advantage of structural coupling from a seismic view point.

A reinforced concrete roof hardened configuration, impling a roof weight increase of about 10.000 tons would cause reduced roof responses and somewhat increased reactions on the supporting structures (5% and 30% for shear and moment R.B. base reactions respectively and lower increment for the RCCV) and could be therefore accepted.

The adoption of an RPV stabilizer to the Sacrificial Shield wall provides a 10% max response reduction of the RPV top and of the RPV Skirt shear load; the reduction of the RPV Skirt overturning moment is slightly larger than 20%. The effect on the Sacrificial Shield is on the contrary a substantial increase (38%) of max shear force and a 18% increase of the overturning moment. Its use can be proposed therefore as an option for sites of high seismicity.

The main effect of the RPV Internal Stabilizer consists on significant response reductions of:

- shroud head (56%) and steam separators top (30%) max horizontal accelerations
- reactions loads at bottom of steam separators (40%)
- reaction loads at shroud support (64% for shear and 95% for overturning moment).

The effect on the RPV wall response is small.

Its use is therefore recommended as a standard. Further details can be found in Ref. /5/ and /6/.

6 INSTRUCTURE RESPONSE SPECTRA

Instructure response spectra have been developed, at selected key locations of civil structures and RPV & Internals, "directly" from the response spectrum modal responses with Cyrano 2 Code (Ref. /7/).

Single response spectra have been properly enveloped for different site conditions, direction of excitation, response locations.

As an example, an envelope horizontal spectrum developed for all site conditions and locations of the civil structures is shown in fig. 3, where the first and second peaks (at about 1,5 and 6 Hz) are originated by global modes interacting with very soft and hard soil respectively and the third peak (at 14 Hz) denotes a resonance of a specific superstructure (the Sacrificial Shield): Further details can be found in Ref. /6/ and /7/.

7 SEISMIC GLOBAL STABILITY

For different assumed site conditions, consistent soil types (sand, clay, weathered soft rocks, hard rocks) and idealized soil strenght properties have been defined; global stability of the N.I., for different analyzed cases and calculated soil seismic global reactions, have been investigated with the VIP code (Ref. /8/) against bearing capacity, sliding and overturning. For soft and intermediate sites (Vs | 1000 m/sec) the bearing capacity has been verified with the Meyerhoff-Vesic procedure (assuming a soil shear failure with a continuous slip surface from the edge of the footing to the ground surface) whereas for rock type sites max induced soil stresses have been compared with allowable soil compression limits. The max soil stress prediction included possible basemat uplift and the supporting effect of the lateral soil of the deep embedment with an Energy Balance Method similar to Ref. /10/.

The sliding verification included the stabilizing forces originated by friction with soil of the building embedded slabs and walls along the direction of motion and also, by soil pressures against embedded walls orthogonal to the direction of motion.

The overturning verification was also made with a refined comparison between the seismic induced max kinetic energy on the building-foundation system, properly computed in the dynamic structural response evaluation stage, with the work required to cause instability, i.e. while the center of gravity reaching a position right above either edge of the base.

Preliminary investigations on other two causes of instability i.e. soil liquefaction (for cohesionless soils) and long term consolidation settlements (for clay sites) were finally performed with simple procedures implemented in codes SOILAN /Ref. 11) and LASSET (Ref. 12). Additional details can be found in Ref. /9/.

8 CONCLUSIONS

The analized reference configuration of the Nuclear Island appears to be feasible from a seismic point of view, for a wide range of site characteristics. The assumed structural integration of the superstructures reduces the seismic response of the critical RCCV at the expense of the less stressed RB structures, for the hard site governing case. Such benefit diminuishes for softer sites, making structural disconnections (and roof hardening), useful for missile protection of the internal structures, easier.

The RPV/Internals response is appreciably affected, by the adoption of stabilizers.

The obtained results together with those produced by other partners of the SBWR Design Team Hitachi (Ref. 13) and Toshiba (Rf. 14), will be used for the detailed design of structures and components and for the evaluation of seismic safety margins against beyond SSE seismic excitations.

REFERENCES

/1/ Kamel et al "Gift 5 Theoretical Manual" University of Arizona, May 1979.
/2/ ASCE Standard "Seismic Analysis of Safety Related Nuclear Structures" Sept. 86.
/3/ G. Gazetas "Analysis of machine foundation vibrations; state of the art". Soil Dynamics and Earthquake Engineering, 1983 Vol. 2 N. 1.
/4/ J. Roesset, V. Whitman "Modal Analysis for Structure with Foundation Interaction", Journal of Structural Division, March 1973.
/5/ Ansaldo Report "SBWR Reactor Building Seismic Analysis" N. SBW 2110 TCLX C004 000 dated 3.30.90.
/6/ Ansaldo Report "SBWR Preliminary Seismic Analusis with RPV Stabilizers" N. SBW 2110 TCLX C011 000 dated 12.21.90.
/7/ Ansaldo Report "SBWR Reactor building Seismic Response Spectra" N. 2110 TCLX C00600 dated 7.30.90.
/8/ Ansaldo Code "VIP: Programma per la verifica di stabilità globale delle fondazioni" Report N. RSG 001 TCLX 001-4000 dated september 90.
/9/ Ansaldo Report "SBWR Reactor Building Seismic Global Stability" N. SBW 2110 TCLX C005000 dated 6.15.90.
/10/ Tseng W.S., Lion D.D. "Simplified Method of Predicting Seismic Basemat Uplift of Nuclear Power Plant Structures" SMIRT 6 Paris, 1981.
/11/ Ansaldo Code "SOILAN: Programma per la verifica dei suoli a liquefazione" Report N. RSG 0001-TCLX-0015-000 dated 9.28.90.
/12/ Ansaldo Code "LASSET: Programma per la valutazione dei cedimenti di suoli stratificati" Report N. RSG 0001 TCLX-0007-000 dated 1.18.90.
/13/ Hitachi Report "SBWR - RCCV and RB Seismic Analysis" N. LE-ST-8035 dated August 1990.
/14/ Toshiba Report "Seismic Analysis Result of SBWR (Horizontal)" N. SED-2849 dated sept. 90.

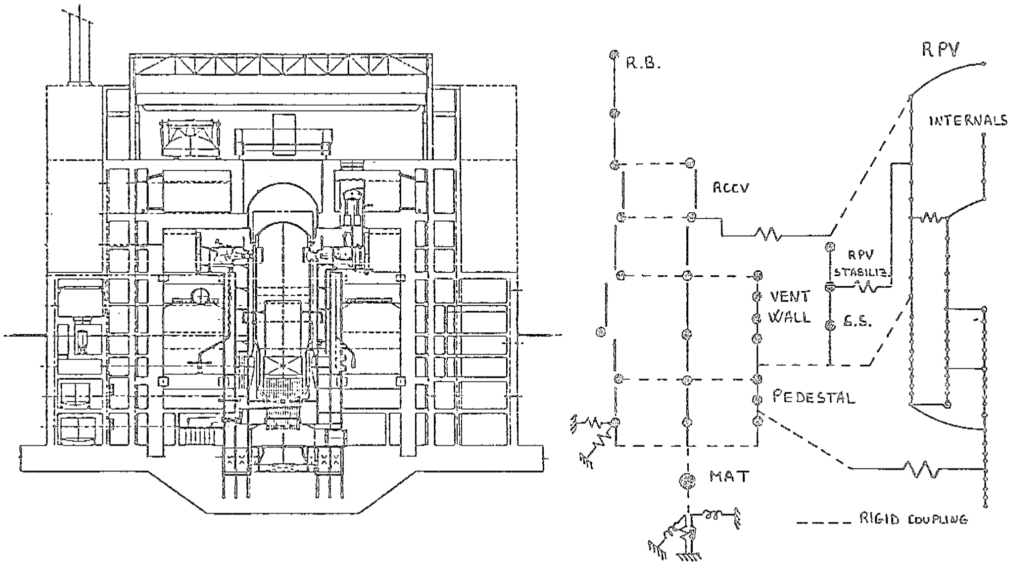
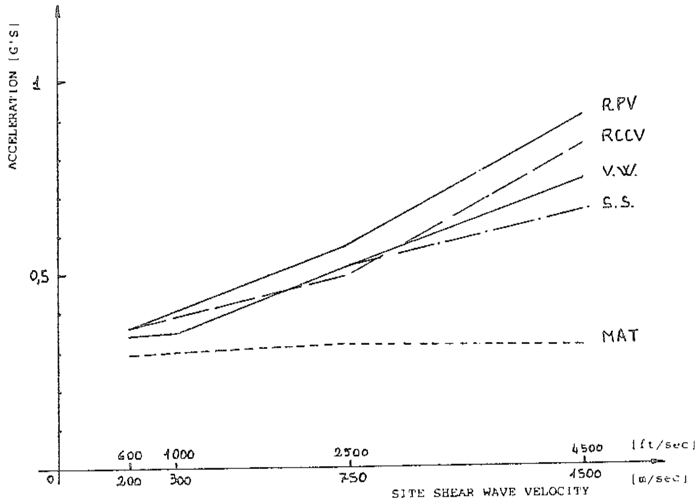
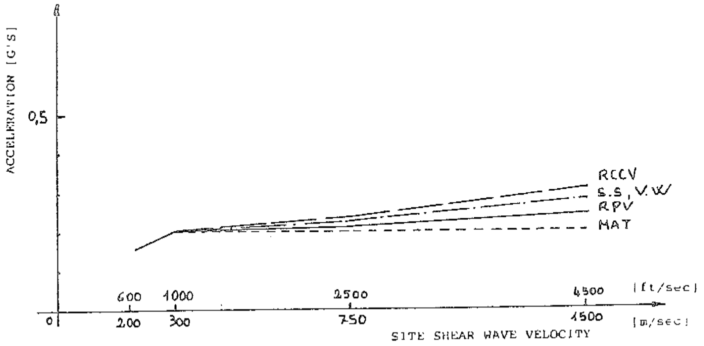


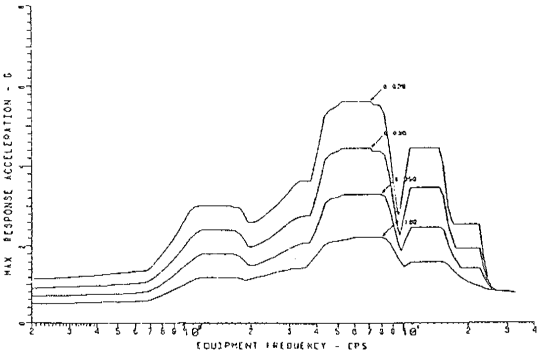
Fig. 1 - SBWR Layout and Seismic Model



MAX HORIZONTAL ACCELERATIONS Vs SITE CHARACTERISTICS - FIG. 2a



MAX VERTICAL ACCELERATIONS Vs SITE CHARACTERISTICS - FIG. 2b



CIVIL STRUCTURES HORIZONTAL ENVELOPE RESPONSE SPECTRUM FIG. 3