PRISM - Beyond SSE Non Linear Seismic Analysis

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1 INTRODUCTION

The PRISM reference configuration adopts steel laminated rubber type seismic isolators for the reactor module. In order to provide input data for the PRA evaluation, an investigation on the maximum seismic capability of the reactor has been performed in Ansaldo, in the frame work of a design joint effort with GE, with main attention focused on possible lift-off non linear effects, induced on the seismic isolators by hypothized beyond design seismic excitations.

2 STRUCTURAL LAYOUT AND SEISMIC MODEL

The analyzed structural layout of the reactor is shown in fig. 1 A sufficiently detailed lumped mass seismic model has been developed, shown in fig. 2, describing main structural elements and components of the reactor; single isolators are explicitly modelled, at their specific spatial locations, with gap conditions specified in the vertical direction to allow possible lift-off phenomena. All isolators are connected with rigid links, simulating the foundation slabs, to both the superstructures and the soil structure interaction lumped parameters. A linear behaviour is simply assumed for the soils structure interaction, on the basis of the complete embedment of the reactor module into the soil. It is also assumed that the soil has the capability to transmit the hypothized excitation to the embedded reinforced concrete Silo, enclosing the reactor module, and that the soil bearing capacity verification at the interface with the structure be implicitly verified.

3 ANALYSIS METHOD

To model the basemat uplift with seismic isolators, the ANSYS LINEAR DYNAMIC ANALYSIS (KAN=5) is used allowing gap non linearities (Ref. /1/).

The gap is treated as an explicit force (equal to the interference times the constant stiffness) and affects only the load vector calculation, and not the reduced stiffness matrix. A sufficiently short integration time step (I.T.S.) (0,001 sec) is chosen for the implicit direct integration scheme to avoid solution instabilities.

The isolator constant horizontal siffness (derived from isolators one half scale test results of Ref. /2/) and the soil structure interaction parameters are modelled with spring-damper elements (ANSYS STIFF14 elements).

A 10% fraction of critical damping can be assumed for the isolation horizontal behaviour, according with Ref. /2/.

For the selected ANSYS analysis method, such damping is modelled with the term C_v given by:

$$C_v = C_c\beta = \beta 2\sqrt{K \cdot m} = \beta \cdot 2 \cdot m\ Wn$$

where:

β = fraction of critical damping;
C_c = critical damping;
m = mass associated to the single damper;
Wn = frequency of the isolated mass.

Along the vertical direction, an almost rigid behaviour is expected for the isolators and damping can be conservatively neglected.

Soil structure interaction dampings are modelled as shown for the horizontal isolators. In the context of the adopted direct integration method, a uniform mass and structural damping formulation is needed.

The viscous damping matrix /C/ is assumed as

$$/C/ = \alpha /M/ + \beta /K/$$

where /M/ and /K/ are the mass and stiffness matrices respectively; α and β are constant to be determined from two given damping ratioes that correspond to two unequal reference frequencies of vibration. It is assumed that α and β satisfy the following relation:

$$\xi_i = \frac{\alpha}{2\, w_i} + \frac{\beta\, W_i}{2}$$

where W_i = natural frequency
ξ_i = corresponding modal damping ratio.

4 SEISMIC EXCITATIONS AND ANALYZED CASES

Synthetic acceleration time histories matching the U.S. NRC R.G. 1.60 design response spectra, for a reference max ground acceleration of 0.24 g are used as base case of seismic extitation. To comply with the requirements of the ANSYS Code, the acceleration time history must be converted into a displacement time history and subsequently imposed to the free ends of the soil structure interaction springs. Three different cases are here analyzed, obtained by applying scaling factors of increased magnitude, to the reference acceleration time history:

case 1. scale factor 2.5 - $a_g = 0,6$ g
case 2. scale factor 3 - $a_g = 0,72$ g
case 3. scale factors 4 - $a_g = 0,96$ g

No change of the shape of the excitation spectra is assumed, for sake of simplicity. A further case with scale factor = 1 has been solved first, with model checking purposes.

The above cases refer to soft soil conditions and assume that the Silo structure has a finite stiffness. Two additional cases are considered also, characterized with an almost perfectly rifig Silo structure and typical hard site conditions.

5 SEISMIC RESPONSES

Time histories and max values of gap reaction forces, nodal point displacements and accelerations and element forces have been computed for each case as documentated in Ref. /3/ and are hereinafter briefly discussed.

a) Case 1 - Initial lift-off is found to occur, at some gaps, for a max ground acceleration of 0,6 g, but due to its limited amplitude and duration, the global response is still almost linear. The time history of the horizontal differential displacements applied at the top and bottom ends of the seismic isolators, shown in fig. 3, indicates a foundamental frequency of about 0,7 Hz (typical of the isolation system) and a max value of 216 mm.

b) Cases 2 and 3 - For a max ground acceleration of 0,72 g (case 2) gap opening events occur for all isolators, but at different times, with max duration of 0,05 sec, as typically shown in fig. 4. Horizontal instructure response spectra, typically computed at top and bottom elevations of the reactor vessel, shown in fig. 5, indicate that while the top response is mainly at the isolators frequency (0,7 Hz) responses at lower elevations have increasing moderate contributions at higher frequencies (5 and 12 Hz) proper of the reactor itself; with insignifcant contributions at frequencies higher than 14 Hz, due to the isolators filtering effect. For a max ground acceleration of 0,96 g (case 3), significant rebound compressive reactions are monitored for all isolators at three specific times (9, 13 and 15 sec) (as typically shown in fig. 6) and gap opening events occur to such a large extent that the mathematical solution becomes unstable and it stops during the transient response evaluation.
Despite the increased extent of gap openings, max isolator differential displacements still vary linearly with respect to case 1 and result 259 and 346 mm for case 2 and 3 respectively, less than the

expected ultimate capability, determined in Ref. /2/.
Computed acceleration time histories are more sensitive to the gap opening/closing non linear effects and, in addition to a low pass filtered shape due to the isolators, and significant time interval of quasi linear type of response, they exhibit few spikes concomitant with above-mentioned instants of rebound reactions.

c) Site condition effect. Reevaluation of case 1, with "hard" site conditions and related soil structure interaction parameters, indicates that the isolated structure horizontal response in practically unaffected, with a limited increase (5%) of the Reactor Vessel to Silo wall differential displacement only. The vertical response increases more however, as typically shown in fig. 7 for the Closure Head, due to the rigid vertical behaviour of the isolators and the frequency change of the vertical soil structure interaction modes.

6. CONCLUSION

With reference to the assumed reactor layout, site properties and seismic exitation characteristics, no significant non linear effects, arising from lift-off of the seismic isolators, can be expected for maximum seismic ground accelerations up to 0,6 gs.

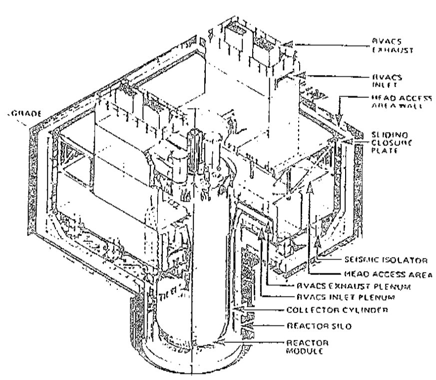
For higher excitations significant non linear response increases, severely affecting the seismic capability of the reactor, can be envisaged only for excitations with max ground accelerations higher than about 0,75 g.

7. REFERENCES

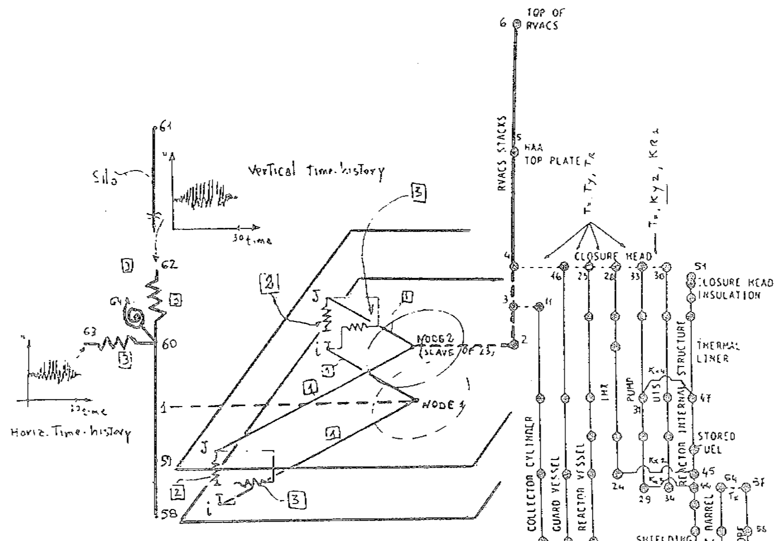
/1/ De Salvo et al "ANSYS User's Manual" Rev. 4.4.

/2/ F.F. Tajirian et al "Testing of Seismic Isolation Bearings for the PRISM Advanced Liquid Metal Reactor Under Extreme Loads" SMIRT 10, Los Angeles 1989, Div. K, pagg. 649-654.

/3/ Ansaldo Report: "PRISM - Lift Off Non Linear Seismic Analysis" N. PRM 0001 - TMLX-0006-000 dated 9/30/89.



PRISM REACTOR ANALYZED CONFIGURATION _ FIG. 1



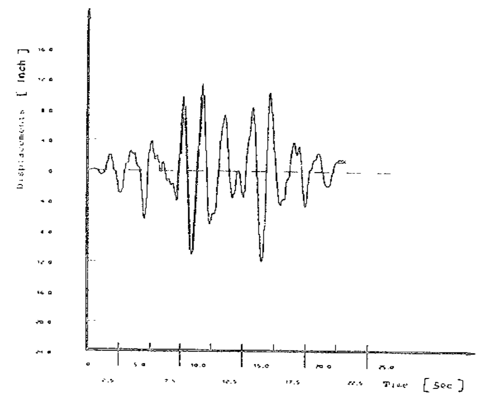
Legenda

[1] Rigid elements

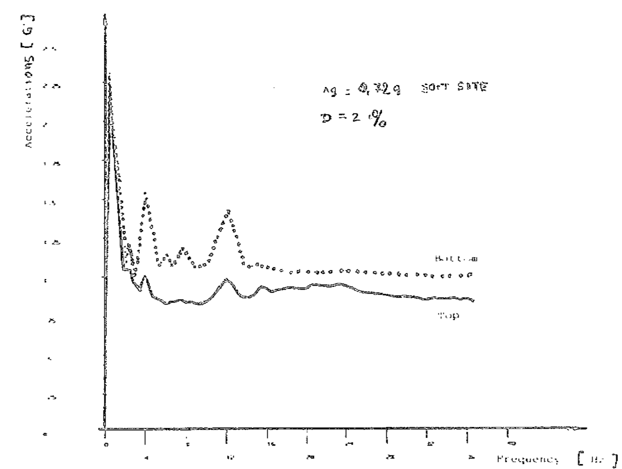
[2] "Gap condition" between nodes I & J

[3] Spring-Damper elements (ANSYS STIFF14)

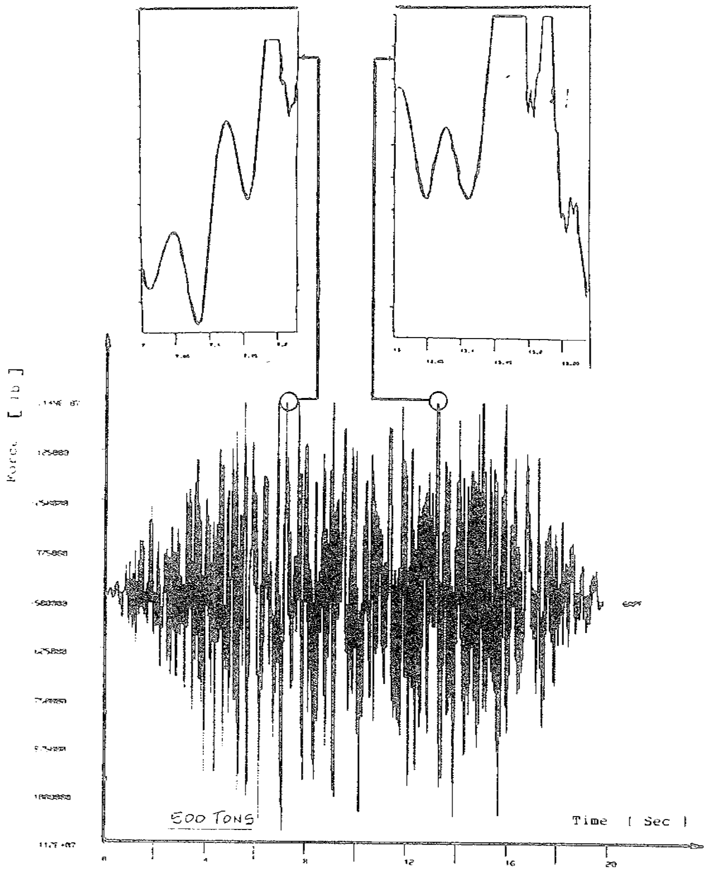
PRISM NON LINEAR SEISMIC MODEL FIG. 2



TOP/BOTTOM ISOLATOR SURFACE HORIZONTAL DIFFERENTIAL DISPLACEMENT FIG. 3

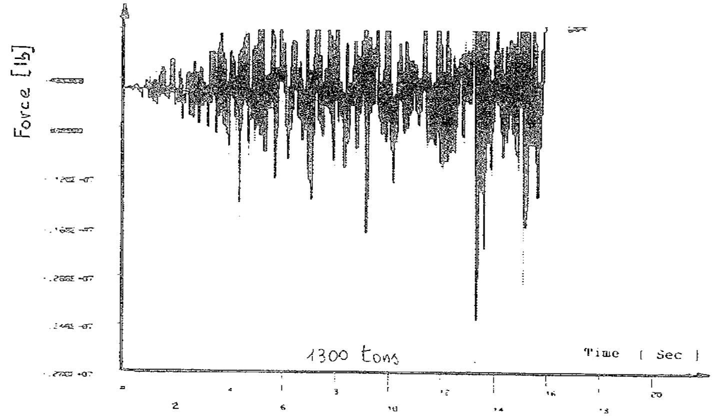


TYPICAL REACTOR VESSEL INSTRUCTURE RESPONSE SPECTRA FIG. 4



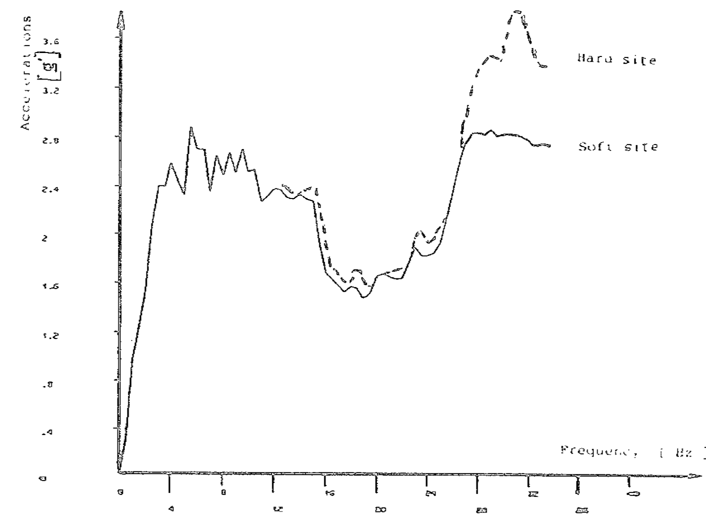
TYPICAL ISOLATOR VERTICAL REACTION FORCE TIME HISTORY Fig. 5

Ag - 0.72 g



TYPICAL ISOLATOR VERTICAL REACTION FORCE TIME HISTORY Fig. 6

Ag = 0.96 g



COVER PLATE VERTICAL SPECTRA - Ag = 0.72 g - D = 2% Fig. 7