Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

A new simple response spectra transformation method as a useful tool for seismic reevaluation of nuclear power plants

Coman, O., Wilson, P., Ghiocel, D.
Stevenson & Associates Inc, Cleveland, Ohio, U.S.A.

ABSTRACT: The need for seismic reevaluation of older Nuclear Power Plants (NPP) especially in the Eastern Europe countries, represents a significant evaluation effort which includes the necessity to develop In-Structure Response Spectra (ISRS) for a seismic event which in many cases are much stronger as the original design level. In order to provide a useful tool for a quick evaluation of the impact of various soil/structure/equipment and seismic parameter changes, a new transformation method has been developed Figure 1. This method produces accurate results as compared with dynamic time history analysis or direct ISRS generation methods where the dynamic properties of the building model are required. In many situations the preliminary dynamic analyses are performed in parallel with geotechnical and seismic site studies. In such cases the ISRS transformation method is able to provide in advance, a good basis for evaluation of the impact of changing the initial site parameters. A computer code has been developed based on this algorithm and tested for various structure types and transformation parameters sets.

1. ANALYTICAL FORMULATION

Two simplified transformation methods were used to take into account the various parameter changes: The PSD transformation and Amplification Factor (AF) transformation. The PSD transformation is related to equipment damping changes and the AF transformation is related to ground response spectrum and modal damping changes.

1.1 PSD transformation

The response spectrum RS is a plot of the maximum response of the oscillator to the specified input motion u(t), versus oscillator frequency ω_0.. For a zero mean Gaussian random process, specification of its PSD would completely describe the event. It is generally assumed that the earthquake event has zero mean and its standard deviation is usually obtained from its power spectral density function $G(\omega)$ by integration. The PSD of the oscillator $G_y(\omega)$ is [1] :

(1) $G_y(\omega,\omega_0) = G(\omega)\,|H(\omega,\omega_0)|^2$

$$(2)\ H(\omega,\omega_0) = \frac{\omega_0^2 + i2\omega_0\beta\omega}{(\omega_0^2 - \omega^2) + i2\omega_0\beta\omega} \quad \text{transfer function of the oscillator;}$$

The response variance $\sigma^2(\omega_0)$ of the oscillator is obtained from :

$$(3)\ \sigma^2(\omega_0) = \int_0^{\infty} G_y(\omega,\omega_0)\, d\omega$$

and the acceleration response variance is: $\sigma_a^2(\omega_0) = \omega^4\ \sigma^2(\omega_0)$. The mean displacement response spectrum is given by Simos, A.J. Philippacopoulos (1993):

$$(4)\ RS_d(\omega_0) = P_m\,\sigma_a(\omega_0); \quad \text{- displacement response spectrum}$$

$$RS_a(\omega_0) = \omega^2\, RS_d(\omega_0); \quad \text{- acceleration response spectrum}$$

The P_m is an amplitude factor by which the standard deviation must be multiplied to account for the expected peak response :

$$(5)\ P_m = [2\ln(\nu_e T)]^{1/2} + \frac{0.5772}{[2\ln(\nu_e T)]^{1/2}}$$

$$\nu_e T = \max(2.1, 2\delta\nu_0 T); \quad 0.00 < \delta < 0.10$$
$$\nu_e T = (1.631\delta^{0.45} - 0.38)\nu_0 T; \quad 0.10 < \delta < 0.69$$
$$\nu_e T = \nu_0 T; \quad 0.69 < \delta < 1.00$$
$$\nu_0 = (1/\pi)(\lambda_2/\lambda_0)^{1/2}$$
$$\delta = (1 - \lambda_1^2/\lambda_0\lambda_2)^{1/2} \quad \text{- shape factor or bandwidth measure}$$

where T is the duration of the strong motion, and λ_i is the i^{th} moment of the power spectral density function $G_y(\omega,\omega_0)$. Equation (4) maps the power spectral density function into an acceleration response function. The inverse transformation which maps an acceleration response spectrum into an equivalent power spectral density function is an iterative process. An approximate solution for the initial PSD is given by the equation :

$$(6)\ \bar{G}(\omega_0) = \frac{2\beta}{\pi\omega_0} RS^2(\omega_0) / \{ -2\ln [(\frac{\pi}{\omega_0 T}) \ln(1-r)] \}; \quad r = 0.5$$

which was shown to yield fairly accurate results for the intermediate range of frequencies from 0.25 to 10.0 Hz and conservative results outside of this range, J.F.Unruh and D. Kana (1981). A number of iterations are performed until the convergence criteria is reached :

$$(7)\ G_{i+1}(\omega_0) = G_i(\omega_0) * (RS_{target}(\omega_0) / RS_{calc}(\omega_0))^2$$

In Figure 2 it is shown that this algorithm produces close results as compared with analysis.

1.2 Amplification factors transformation

For a given ISRS and structure frequencies it is shown a simplified method to approximate the structure modal coefficients (unknown) used to generate the original ISRS. The approximated original ISRS and the transformed ISRS corresponding to a different ground response spectrum and/or different building damping are generated and correction factors are calculated. The ISRS ordinate σ_e corresponding to frequency ω_0 and damping ratio βe is approximated by Vanmarke (1976):

$$(8)\ \sigma_e(\omega_0) = \{ F1 + F2 * F3 \}^{1/2}$$

where:

$F1 = \Sigma\ \alpha_k C_k^2 \sigma_k^2$ - corresponds to structure response

$F2 = 1 + \Sigma\ \alpha_k C_k^2 \omega_e^4 |H_k(\omega_0)|^2$ -corresponds to equipment amplification factor

$F3 = (\sigma_{0g}^2 - \sigma^2\ F^*(\omega_0))$

F2*F3 - corresponds to equipment response

where: $F^*(\omega) = \int_0^\infty G^*(\omega)d\omega$, is the cumulative spectral distribution which increases from 0 to 1 as ω goes fro 0 to ∞; $C_k = \Phi_{kb}\ \gamma_k$ is the modal coefficient, Φ_{kb} is the mode shape ordinate in ISRS point "b" and mode k, γ_k is the participation factor of mode k, α_k = modal correlation coefficient and $H_k(\omega_0)$ represent the transfer function corresponding to oscillator frequency ω_0 and mode frequency ω_k. Replacing σ with S_{A0} and S_{Ak} respectively yields:

$$(9)\ A_e^2(\omega_0) = \Sigma\alpha_k C_k^2 S_{Ak}^2 + [\ 1 + \Sigma\alpha_k C_k^2 \omega_0^4 |\ H_k(\omega_0)\ |^2\ ]\ [S_{Ae}^2 - A_g^2 F^*(\omega_0)]$$

S_{Ak} is the ground RS acceleration corresponding to frequency ω_k and modal damping β_k, S_{A0} is the ground RS acceleration interpolated for the oscillator frequency ω_0 and damping β_e, A_g is the peak ground acceleration.

Starting from a given ISRS corresponding to the original parameter set (original ground response spectrum GRS-old and the original building/modal damping) it is desire to transform the original ISRS to correspond to a new parameter set (GRS-new and new building/modal damping coefficients). Assuming α=1 and F1= floor acceleration, for a set of "n" frequencies, a system of "n" equations was build and solved for C_k factors. The resulting coefficients C_k, k=1,n approximates the original modal coefficients. Then equation (9) was used to generate the old ISRS - which approximate the ISRS corresponding to the original GRS and damping coefficients and the new ISRS - corresponding to the new GRS and damping coefficients. Correction factors are calculated as the ratio between the ISRS-new and ISRS-old to take into account the effects of GRS and building damping changes. The correction factors are then applied to the original ISRS. In Figure 3 it is shown that this algorithm produce close results as compared with analysis.

2. EXAMPLE

The above transformation methods are included in the computer code S&A computer code FRSTRANS (1993). This sample presents the comparison of the ISRS produced by

FIGURE 1. FRS TRANSFORMATION FLOW CHART

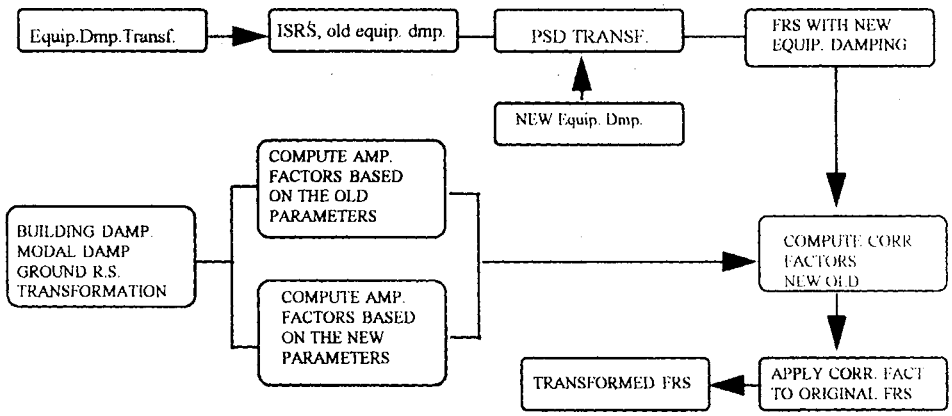


Figure 2 Equipment Damping Transformation
Comparison between Analysis and Transformation Method

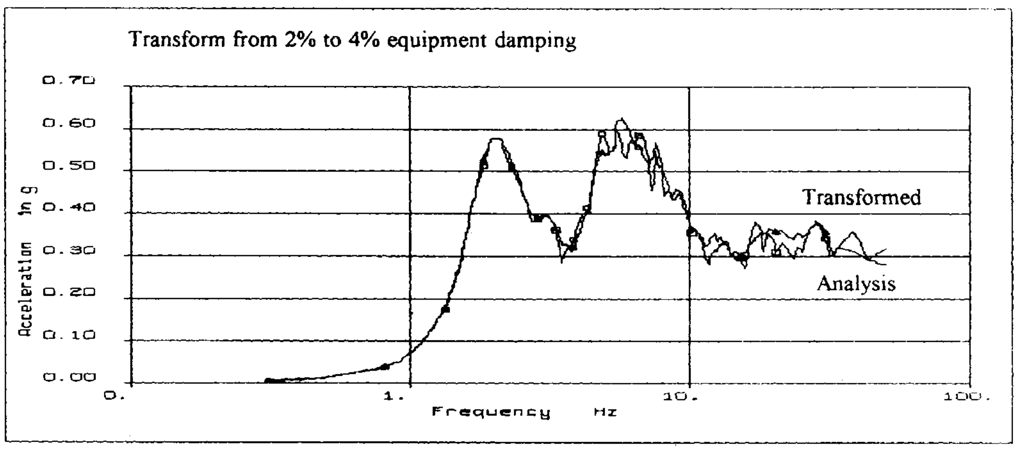


Figure 3 Ground Response Spectrum Transformation
Comparison between Analysis and Transformation Method

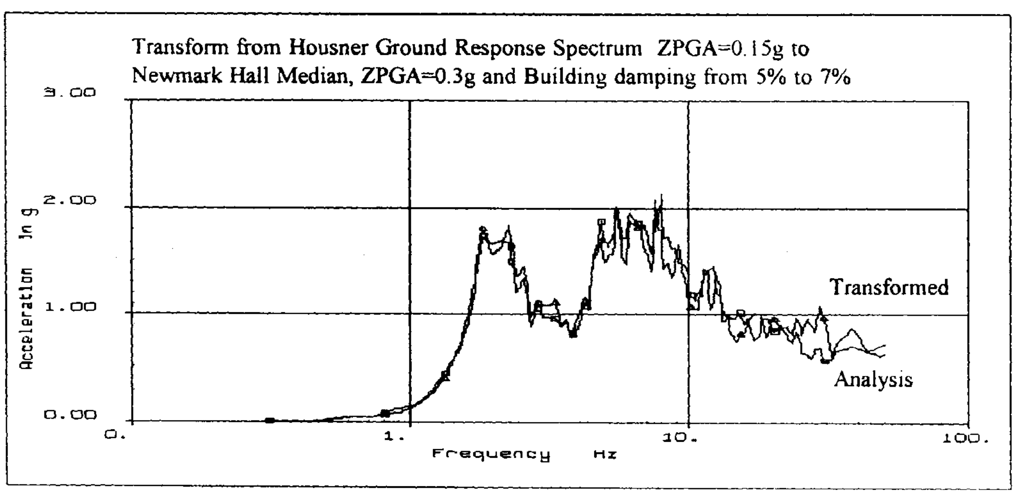


Figure 4 ISRS produced by Analysi for two sets of parameters

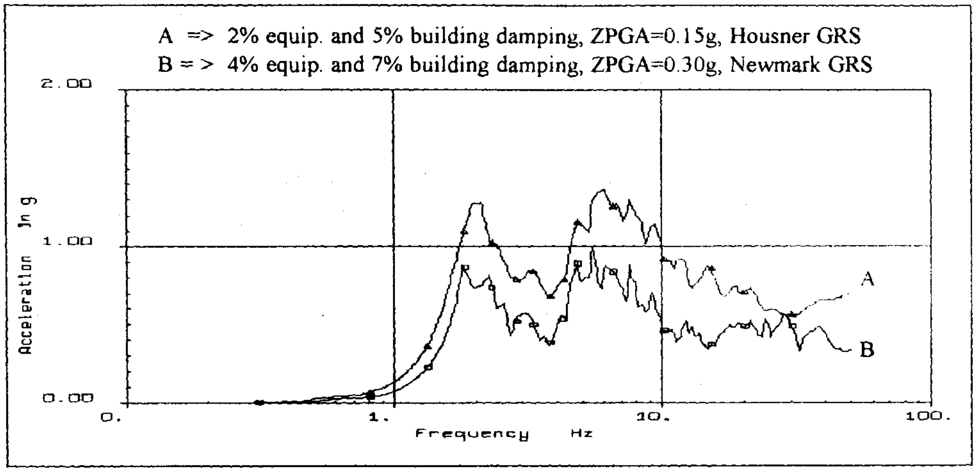


Figure 5 Comparison between ISRS produced by Analysis and Transformation Method

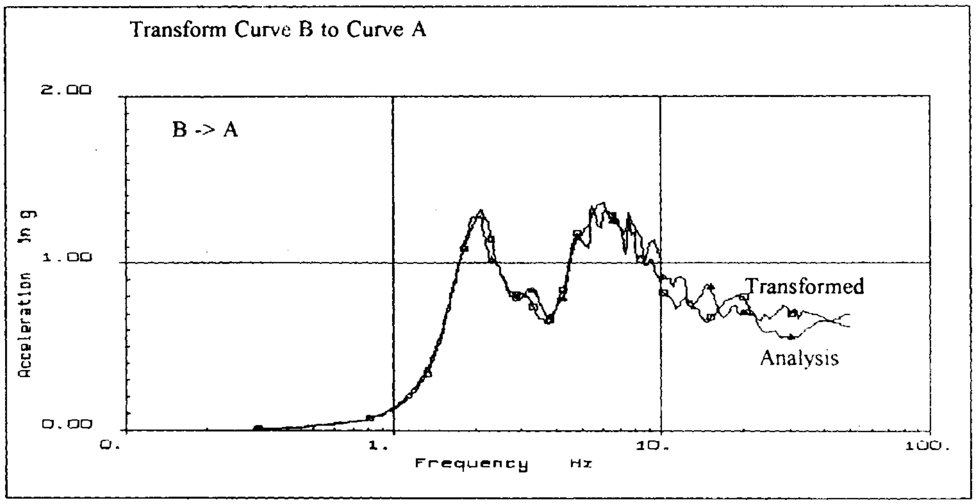
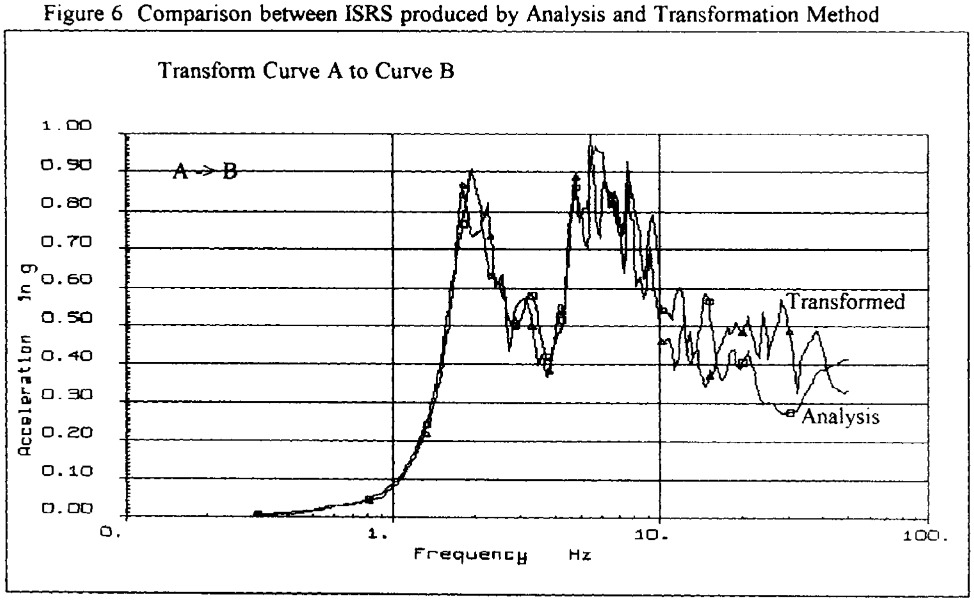


Figure 6 Comparison between ISRS produced by Analysis and Transformation Method



transformed ISRS for changes of the ground response spectrum, equipment and building damping. The input consists in the original ISRS, corresponding set of original parameters and the new set of parameters. In Figure 4 are presented two ISRS for two sets of parameters, both curves are produced by dynamic time history analysis:

Curve A = 2% equipment damping, 5% building damping, Housner ground response spectrum with zero peak ground acceleration ZPGA=0.15g

Curve B = 4% equipment damping, 7% building damping, Newmark Hall Median shape ground response spectrum with ZPGA=0.3g.

The computer code FRSTRANS was used to transform the curve A to curve B. The comparison between curve B* produced by transformation and curve B produced by analysis is presented in Figure 5. Then the curve B was transformed to A and the comparison between curve A* produced by transformation and curve A produced by analysis is presented in Figure 6. The results show a good agreement between ISRS produced by analysis and ISRS produced by the transformation method.

3. CONCLUSIONS

One advantage to this method is that the transformed ISRS are based on the existing design ISRS and there is no need to rebuild the analysis model. The design base reconstruction may represent a significant effort. It is obvious that the transformation method assumed that the structure frequencies and mode shapes remain unchanged. Only parameters such as ground response spectrum, equipment damping building damping or modal damping are possible to be changed. The results recommend this method as a very efficient and effective tool for ISRS reevaluation.

REFERENCES

James F. Unruh , Daniel D. Kana - A Power/Response Spectrum Consistent Procedure for Dynamic Qualification of Components. Southwest Research Institute, March 1981.

N.Simos, A.J. Philippacopoulos, Theoretical Basis of DIGES, Brookhaven National Laboratory, October 1993.

Stevenson & Associates, computer code FRSTRANS, 1993.

Vanmarcke, E.H., Chapter 8 of Seismic Risk and Engineering Decisions, Lomnitz C and Rosenblueth E., Editors, Elsevier Publishing Co. 1976.