On the selection of ground acceleration spectrum for response evaluation of offshore structures

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Introduction: For a typical offshore structure located in a seismically active region, earthquake-resistant design is a must from safety viewpoint. Usually the earthquake ground motions for stationary conditions are represented using the well-known Tajimi-Kanai's expression (TK spectrum) as:

$$S_{\ddot{u}_g}(\omega) = \frac{1 + 4h_g^2\left(\frac{\omega}{\omega_g}\right)^2}{\left[1-\left(\frac{\omega}{\omega_g}\right)^2\right]^2 + 4h_g^2\left(\frac{\omega}{\omega_g}\right)^2} S_0 \qquad \text{where} \qquad S_0 = \frac{\sigma_{\ddot{u}_g}^2}{\pi\left(1+4h_g^2\right)\frac{\omega_g}{2h_g}} \tag{1}$$

in which $S_{\ddot{u}_g}(\omega)$ is the PSDF of ground acceleration $\ddot{u}_g$, ω_g is the characteristic ground frequency, h_g is the characteristic ground damping ratio, S_0 is the earthquake intensity and $\sigma_{\ddot{u}_g}$ is the rms ground acceleration.

But the above formulation does not change the amplitudes as $\omega \to 0$ and some difficulty may arise with very-low frequency components. In particular, the natural frequencies of offshore structures have generally lower values and hence proper selection of the ground acceleration spectrum is necessary for reliable designs. Also the PSDFs for ground velocity and ground displacement are obtained by dividing Eq.(1) by ω^2 and ω^4 respectively. Thus strong singularities are present at $\omega = 0$ which cause the stationary variances of ground velocity and ground acceleration to be unbounded. To remove these undesirable singularities, Eq.(1) is modified by including another filer which attenuates the very-low frequency componenets as:

$$S_{\ddot{u}_g}(\omega) = \frac{\left(\frac{\omega}{\omega_f}\right)^4}{\left[1-\left(\frac{\omega}{\omega_f}\right)^2\right]^2 + 4h_f^2\left(\frac{\omega}{\omega_f}\right)^2} \cdot \frac{1 + 4h_g^2\left(\frac{\omega}{\omega_g}\right)^2}{\left[1-\left(\frac{\omega}{\omega_g}\right)^2\right]^2 + 4h_g^2\left(\frac{\omega}{\omega_g}\right)^2} S_0 \tag{2}$$

where the frequency parameter ω_f and damping parameter h_f are selected so as to give the desired filter characteristics. Eq.(2) is referred to as the modified Tajimi-Kanai expression (MTK spectrum). In the present study, the dynamic response of offshore structure is computed considering the TK spectrum and the MTK spectrum and the results are compared.

Dynamic Response Analysis: Fig.1 shows an offshore structure model including pile-soil foundation considered for the study. The structure is discretized by finite element method. The fluid-structure interaction is represented by modified Morison equation whereas the soil-structure interaction is modelled using frequency-independent impedance functions. The input ground acceleration is horizontal. Fig.2 shows the PSDF of ground accelerations. The difference between the TK spectrum and the MTK spectrum is seen in the low-frequency region. The dynamic equations of motion are derived using the substructure method and the response analysis is carried out using the frequency-domain random-vibration approach. Fig.3 shows the examples of the distribution of rms displacements and Fig.4 shows the displacements at node 1 against rms ground acceleration. Depending on the values of frequency parameter ω_f of MTK spectrum, the response values may be larger or smaller then those computed using TK spectrum. The influence of ω_f on the response values is shown in Fig.5. It is observed that as ω_f becomes less than unity, the responses values are less influenced by the variation in ω_f. Fig.6 shows the first passage probabilities on level crossing of the rms displacement at node 1. For smaller intensity of earthquakes, the reliability varies widely with the values of ω_f. Therefore, depending on the values of the frequency parameter of MTK spectrum, the response values and hence the reliabilities take different values than those based on TK spectrum.

References: (1) Kawano K. et al. (1991), "Effects on seismic spatial variations to suspention bridge responses", *Mechanics Computing in 1990s and Beyond, Proc. of EM div.*, ASCE, pp.666-670.
(2) Clough R.W. and Penzien J. (1975), *Dynamics of Structures*, McGraw Hill, pp.611-628.

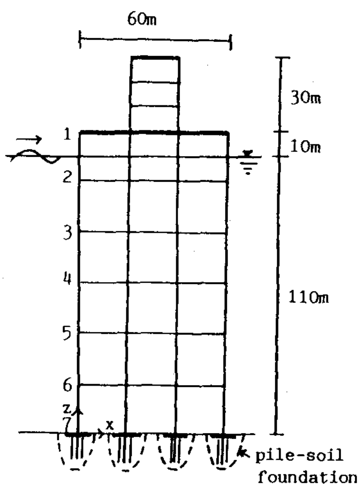

Fig.1 Schematic diagram of offshore structure

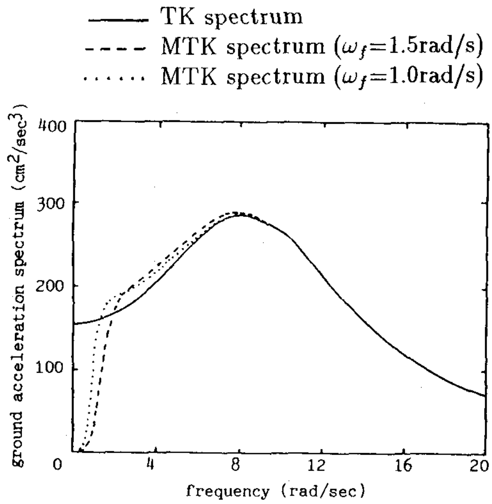

Fig.2 Ground acceleration spectrum

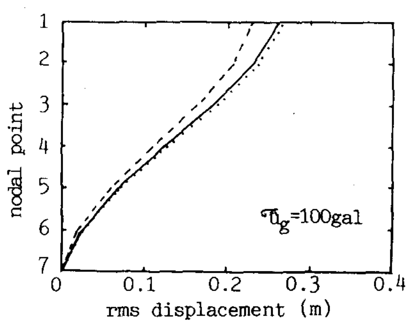

Fig.3 distribution of response displacements

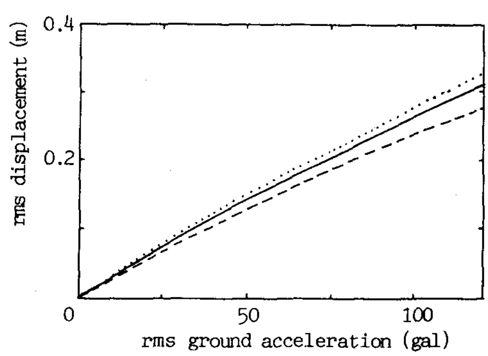

Fig.4 rms displacement at node 1

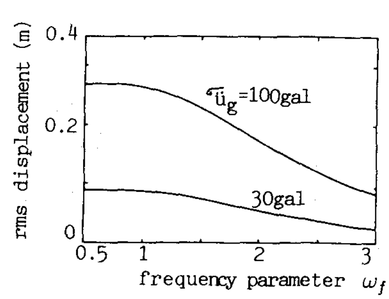

Fig.5 rms displacement at node 1 for different frequency parameters

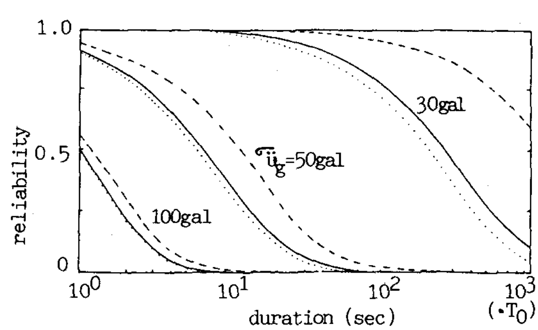

Fig.6 First passage probabilities on level crossing