

DYNAMIC ANALYSIS OF OFFSHORE PLATFORMS UNDER
SEISMIC EXCITATION

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SUMMARY

A dynamic response analysis of an offshore platform subjected to design earthquake ground motion is presented. Soil-structure interaction and hydrodynamic effects have been considered in carrying out the analysis.

The results include a complete modal analysis of the system and floor response spectra at each of the deck levels of the platform. A detailed three dimensional mode frequency analysis of the most critical deck was carried out. Member forces and bending moments at this deck due to design earthquake ground motion were computed. A simplified modal analysis of the system was also made using a crude lumped-mass approach and significant differences were observed between the two methods in terms of modal frequencies. Possible torsional effects were also considered and it was concluded that they will be insignificant in the dynamic response of the platform.

INTRODUCTION

The dynamic analysis of offshore platforms against earthquake ground motion has received considerable attention in the past decade and has now become very important, since petroleum and gas exploration has been extended to seismic zones worldwide. The dynamic behavior of offshore platforms may be different under seismic loading and wave loading. These differences as reflected in mathematical modeling of offshore platforms have been illustrated by Berge and Penzien (1974) and Penzien and Tseng (1976).

Under wave loading the excitation is transmitted to the structure through the relative motion between the structural elements and water. Therefore the response of the structure is very sensitive to the hydrodynamic modeling, i.e., water structure interaction. Seismic motion, on the other hand, is transmitted through the ground, therefore the dynamic interaction effects between soil, piles and structure attain particular importance. The difference in response is also due to the differential spectral characteristics of waves and earthquake ground motion.

A production platform is planned for a field in the Mediterranean area. The area is seismic, and D'Appolonia has assessed the vibratory ground motion characteristics of the site, and had recommended a design earthquake and response spectrum. This paper contains a brief summary of the design

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seismic input, followed by a description of the structural modeling and analysis. Results of the modal analysis and floor response spectra are presented and other considerations such as torsion are discussed.

SEISMIC INPUT

The design earthquake response spectrum proposed by Newmark et al. (1973) scaled to 0.15 g horizontal peak ground acceleration has been adopted. The horizontal time histories used in the analysis were generated using the method outlined by Rizzo et al. (1975) and matching the above spectrum at a damping of two percent of critical. The same time history scaled to 0.075 g peak ground acceleration was used in determining the vertical response of the platform, following API (1979) recommendations.

When several artificial seismic histories are used simultaneously as input to the dynamic analysis, the components should not, in general, be systematically correlated to one another (Newmark and Hall, 1973). Guidelines as to the degree of statistical correlation of the components of ground acceleration are given by Chen (1975).

For the subject platform two-dimensional analyses were performed using a horizontal component applied simultaneously with the vertical. The artificial time history used as vertical seismic input was shifted by 0.08 seconds in relation to the horizontal component to satisfy the condition of a maximum correlation coefficient of 0.16 (Chen, 1975).

STRUCTURAL MODELING

The structure is comprised of a steel frame supported at each of the four corners by a pile group consisting of four piles. The piles extend to a depth of 83 meters below sea floor while the height of the frame is 117 meters from the seabed standing in 106 meters of water. The structure in three dimensional view is shown in Fig. 1. The structural frame is practically symmetric with respect to vertical planes, although some asymmetry is introduced by the presence of a skid placed against one vertical face of the platform.

Soil-Pile System

A total of sixteen piles, four piles per group at the four corners of the platform, constitute the foundation of the system. The piles are battered at an angle of 6.8° from the vertical. They are made of steel with a hollow cross section of 97 centimeters and 91 centimeters inner diameter. Within each group the piles are arranged in a square pattern spaced at 250 centimeters from center to center. The incorporation of the soil-pile system into the overall dynamic model of the platform requires the calculation of the spring constants of the soil-pile system in the axial and lateral directions, the hysteretic soil damping under the design earthquake ground motion and the radiation damping of the soil-pile system.

The spring constants were calculated using the formulation of Poulos (1978, 1979). As the system is highly non-linear, the magnitude of the loads for calculation of the spring constants was selected to be compatible with those induced by the design earthquake ground motion.

The shear modulus and material damping of the soil were determined using the method proposed by Hardin and Drnevich (1972). Radiation damping values for the soil-pile system were evaluated on the basis of the study by Roesset and Angelides (1979). A summary of the spring constants and damping ratios adopted is given in Table 1. The radiation dampings given are defined at a frequency of one Hertz.

TABLE 1

SPRING CONSTANTS AND DAMPING RATIOS FOR SOIL-PILE SYSTEM

	VERTICAL	HORIZONTAL
Spring Constants (t/m)	1.216×10^5	6.652×10^3
Material Damping (%)	7.5	7.5
Radiation Damping (%)	3.5	4.5

It is noted that the radiation damping values are significantly lower for this soil-pile system than would be anticipated for a gravity base. A typical value for a gravity base could be an order of magnitude greater.

Structure-Water System

The dynamic analysis of an offshore platform requires that two effects be considered, in addition to the usual consideration for on-shore structures. Namely, the inertia effect of the platform body accelerating under water and the effect of hydrodynamic drag on the structural members. The inertia is included in the analysis by means of the so-called "added" or "virtual" mass, while the drag is included in the form of damping, as explained below. The procedure followed for hydrodynamic (or drag) damping is similar to that of Berge and Penzien (1974) and consists of a linearization of the velocity term according to the technique recommended by Kryloff and Bogoliuboff (1943). The element drag damping can be expressed as:

$$D_H = \frac{1}{2} C_D \rho a \sqrt{\frac{8}{\pi}} \sigma_{\dot{u}} \quad (1)$$

where D_H is the hydrodynamic damping coefficient, C_D is the drag coefficient, ρ is the mass density of water, and a is the exposed area of members in the direction of motion. $\sigma_{\dot{u}}$ stands for the standard deviation of the relative velocity between water and structure. This term was estimated by calculating the power spectral density function of the response velocity, assuming still water conditions, and integrating this function in the frequency domain to find the mean square value. For a zero mean random process, $\sigma_{\dot{u}}$ is simply the square root of the mean square value. Element hydrodynamic damping terms were then converted to modal hydrodynamic damping values. Theoretically, the procedure is iterative, until satisfactory convergence is reached on the structure velocity. In this case the resulting hydrodynamic damping is in fact insignificant, i.e., on the order of 0.0003 percent, so that no iteration was needed. This value is in agreement with Penzien and Tseng (1976) who found that hydrodynamic damping is generally insignificant for seismically excited offshore structures.

ANALYSIS OF DYNAMIC RESPONSE

The response of the platform to the design earthquake ground motion was assessed in several phases, using D'Appolonia's in-house computer program, DAPSYS (D'Appolonia, 1977). The first phase was the modal analysis to determine the modal frequencies and shapes of the system considering all structural elements and soil-pile springs. Then a modal analysis of a simplified lumped mass model was carried out for comparison purposes. This model consisted of masses concentrated at each platform deck level connected to each other by springs and dashpots. The third phase consisted of the calculation of floor response spectra at all the deck levels. Then at a critical deck level, all the member forces due to earthquake loading were computed. Possible torsional effects due to the presence of the skid were also evaluated.

Modal Analysis

Ten modes were found to be sufficient for representing over 90 percent of the energy absorbed by the system. The natural frequencies for these ten modes for the full structural model and for the simplified one are given in Table 2. As there is a slight asymmetry due to the presence of the skid, modal frequencies and modal shapes were determined for both horizontal directions (X-Z and X-Y), each time coupled with the vertical mode. It may be seen from Table 2 that the differences in modal frequencies for the two directions are generally small and for the first three modes, insignificant. It may also be observed that the simplified model predicts modal frequencies which can vary considerably from those obtained using the full structural model.

TABLE 2

NATURAL FREQUENCIES FOR THE FIRST TEN MODES USING
FULL STRUCTURAL FRAME AND LUMPED MASS MODELS

MODE NUMBER	X-Z DIRECTION FREQUENCY FULL MODEL HERTZ	Y-Z DIRECTION FREQUENCY FULL MODEL HERTZ	FREQUENCY SIMPLIFIED MODEL HERTZ
1	0.405	0.406	0.556
2	1.473	1.489	2.155
3	2.157	2.157	2.173
4	3.101	2.892	4.005
5	4.505	3.033	5.988
6	4.578	3.129	6.757
7	4.676	3.475	7.888
8	4.731	3.846	8.814
9	4.810	4.242	9.024
10	5.236	4.622	10.940

The first five mode shapes are presented in Fig. 2.

Floor Response Spectra

Vertical and horizontal undamped floor response spectra were computed for every deck level. Floor response spectra have also been computed for damping values of 2,5 and 10 percent for the top deck level. These spectra shown in Fig. 3, may be used in designing equipment on this deck.

Other Considerations

From the modal shapes in Fig. 2, the deck at the 63-meter level (El. -43) was observed to be excited at comparatively low frequencies. This deck level was therefore selected for a detailed mode frequency analysis and member forces and moments were computed. The results of this analysis cannot be presented here due to space limitations.

Due to the presence of the skid some torsional forces may be induced in the platform. To determine the eccentricity due to the shift of the center of rigidity an analysis was performed in which the whole platform with six degrees of freedom per node was subjected to a set of static loads in the X direction. These loads were taken to be proportional to the mass at each node and to correspond to the loading for uniform acceleration. The resulting displacements at all points of interest indicate displacements in the Y direction about four percent of those in the X direction.

In view of the insignificant eccentricity and the good agreement in X-Z and X-Y modal analyses (Table 2), torsional effects did not need to be considered for this case.

CONCLUSION

The methodology and results of an analysis of an offshore platform under seismic loads have been presented. It may be concluded that:

- for seismically excited offshore platforms, the effect of hydrodynamic damping is generally small,
- for piled platforms, radiation damping is significantly smaller than that of gravity platforms,
- a simplified mass model for a framed platform may yield erroneous results especially if closely spaced higher modes exist.

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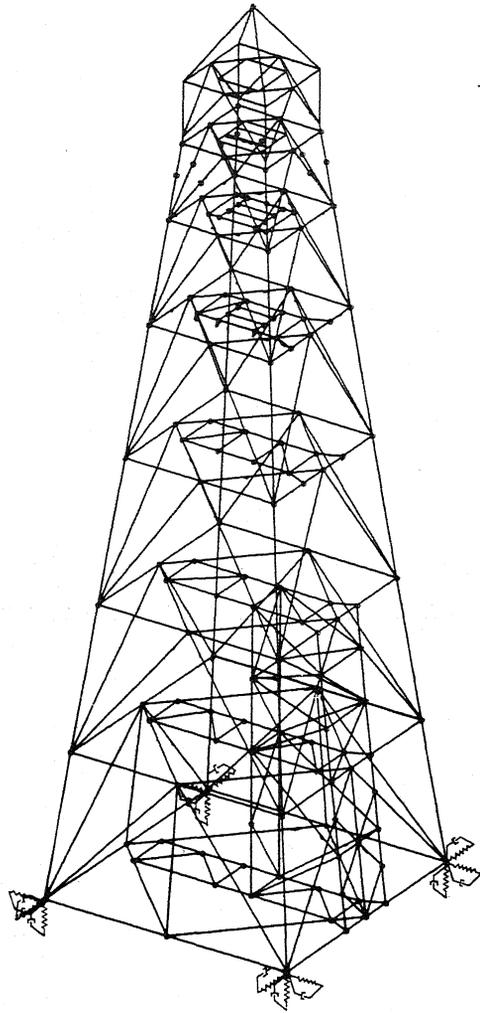


FIGURE I

STRUCTURAL MODEL OF THE PLATFORM

