

# Seismic Hazard Assessment of Offshore Platforms

F. D. Konstandakopoulou, G. A. Papagiannopoulos, N. G. Pnevmatikos, G. D. Hatzigeorgiou

**Abstract**—This paper examines the effects of pile-soil-structure interaction on the dynamic response of offshore platforms under the action of near-fault earthquakes. Two offshore platforms models are investigated, one with completely fixed supports and one with piles which are clamped into deformable layered soil. The soil deformability for the second model is simulated using non-linear springs. These platform models are subjected to near-fault seismic ground motions. The role of fault mechanism on platforms' response is additionally investigated, while the study also examines the effects of different angles of incidence of seismic records on the maximum response of each platform.

**Keywords**—Hazard analysis, offshore platforms, earthquakes, safety.

## I. INTRODUCTION

UP to now, numerous offshore structures have been constructed in seismic prone areas. The structural and non-structural seismic damage will lead to noteworthy personnel casualty, environmental pollution, oil production stoppage and equipment damage. Thus, the dynamic soil-pile-structure interaction is an essential topic in the assessment of seismic performance of these special structures.

In the past, various studies have been published examining the seismic response of offshore platforms such as [1]-[4], examining pushover methods. Moreover, the dynamic nonlinear response of offshore platforms has been investigated by [5]-[8].

The previous research effort about the assessment of seismic performance of offshore platforms seems to be inadequate and some topics need further investigation. For example, only a few codes consider the earthquake structural design under the action of pulse-type ground motions, e.g. FEMA P-750 [9]. Additionally, the effect of seismic fault mechanism on the offshore platform has not yet examined.

Consequently, the behavior of offshore platforms under near-source pulse-type seismic motions should be more examined.

## II. OFFSHORE PLATFORMS

There are a variety of offshore platforms for oil and gas exploration. Considering that the greater part of these offshore

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structures has been constructed in shallow waters, most of them are jacket constructed, which can be fixed directly to the seabed. The jacket behaves as bracing for the foundation elements (piles) for lateral loads such as sea waves, wind and earthquakes, while the deck is fixed upon the jacket. A typical Jacket Offshore Platform is shown in Fig. 1, while for more information about this type of offshore structures one can consult Nizamani [10].



Fig. 1 Typical Jacket Platform (adapted from offshore-technology.com)

## III. DESCRIPTION OF OFFSHORE PLATFORM AND ANALYSIS ASSUMPTIONS

Two three-dimensional models are developed to describe the jacket platform using the dynamic inelastic analysis program Ruaumoko [11]. A force-based nonlinear beam-column element, employing a concentrated plasticity assumption, is applied to describe all components of the platform structure. All members are simulated by Al Bermani model which is available in Ruaumoko [11]. The yield stress of the material is assumed to be 380 MPa (55 ksi). Second-order effects, i.e. geometric nonlinearities, are precisely taken into account considering the “large displacements formulation” for the equation of motion. For the dynamic analysis problem, the inherent damping ratio of the superstructure is considered equal to 4% for the first and fifth natural modes of the system. Fig. 2 depicts the examined offshore platform.



Fig. 2 Three-dimensional view of offshore platform

#### IV. SEISMIC INPUT

The near-field ground motions under consideration have been recorded up to 15 km from the fault. In this study, 50 seismic triads (two horizontal and one vertical) have been used from the well-known NGA-West2 strong ground motion database [12]. It should be mentioned that the effects that have to do with the near-fault records are strongly depended by the fault mechanism. For example, examining a seismic fault with a strike-slip mechanism, the influence of directivity is mostly focused away from the hypocenter since the energy builds up as the shear waves travel away from the point of dislocation toward the site [13]. Therefore, this paper examines two different sets and fault mechanisms: the first set has to do with nine pulse-like earthquakes recorded closely to faults with oblique-reverse or reverse mechanisms, while the second group is composed by 12 pulse-like earthquakes recorded closely to faults present strike-slip mechanism.

In particular, the following earthquakes correspond to reverse fault mechanism are used:

- Cape Mendocino (1992),
- Chi-Chi/Taiwan (1999),
- Christchurch/New Zealand (2011).
- Chuetsu-oki/Japan (2007),
- Loma Prieta (1989),
- Montenegro/Yugoslavia (1979),
- Niigata/Japan (2004),
- San Fernando (1971) and
- Tabas/Iran (1978).

Moreover, the following earthquakes correspond to strike-slip fault mechanism are used:

- Bam/Iran (2003),
- Coyote Lake (1979),
- Chi-Chi/Taiwan-04 (1999),
- Darfield/New Zealand (2010),
- Imperial Valley-06 (1979),
- Kobe/Japan (1995),
- Morgan Hill (1984),
- Parkfield-02 (2004),
- San Salvador (1986),
- Superstition Hills-02 (1987),
- Tottori/Japan (2000) and

- Westmorland (1981).

Fig. 3 depicts the acceleration spectra for damping ratio  $\zeta=5\%$ . For comprehensiveness reasons, this figure also shows the mean spectra (mean) and the mean spectra minus or plus one standard deviation (mean $\pm$ StDev).

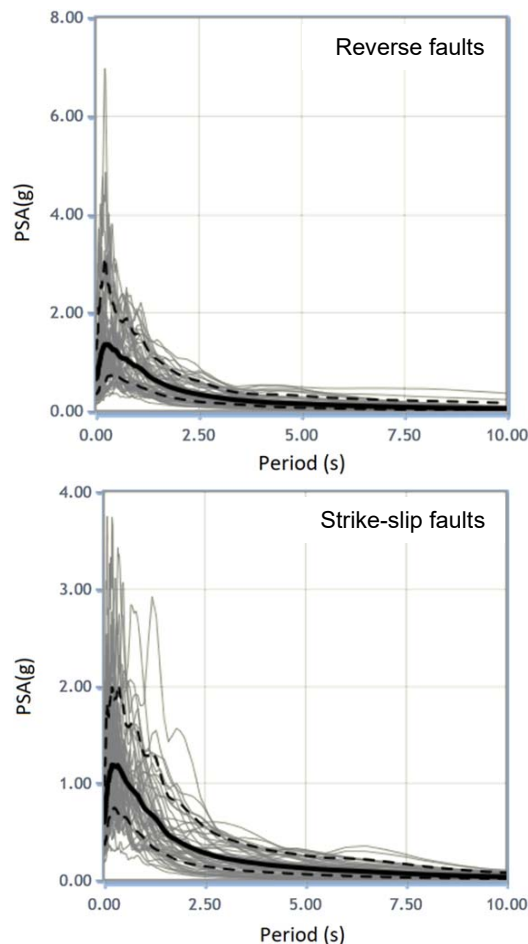


Fig. 3 Acceleration response spectra

#### V. PILE-SOIL-STRUCTURE INTERACTION

Two different jacket offshore platforms are examined herein where the first platform has fixed supports on the seafloor, assuming rigid soil. On the other hand, for the second case, a pile foundation is applied where the soil appears to be deformable. In these platforms, all structural members' configuration, geometry and properties are identical between themselves, with the exception of piles. In order to consider the soil - pile - structure interaction for the second platform, non-linear springs were applied along the piles' length to describe the soil deformability using of p-y, t-z and q-z curves, as proposed by [14] and [15].

#### VI. RESULTS

Nonlinear models were created and analyzed using the dynamic inelastic program Ruaumoko [11]. This analysis program is suitable for modeling offshore platforms due to ability to evaluate reliably the dynamic inelastic behavior of

structures.

This section focuses on deformation demands (in terms of maximum values or time-histories of displacements as well as of residual displacements), on damage assessment (in terms of hysteretic energy) and on maximum internal forces.

The structural damage and the produced dissipated energy are strongly depended by the angle of incident of seismic records. As an example, Fig. 4 depicts the dissipated energy for the Pylon No.1 of the fixed jacket platform under the action of Morgan Hill earthquake, for various incidence angles of seismic waves.

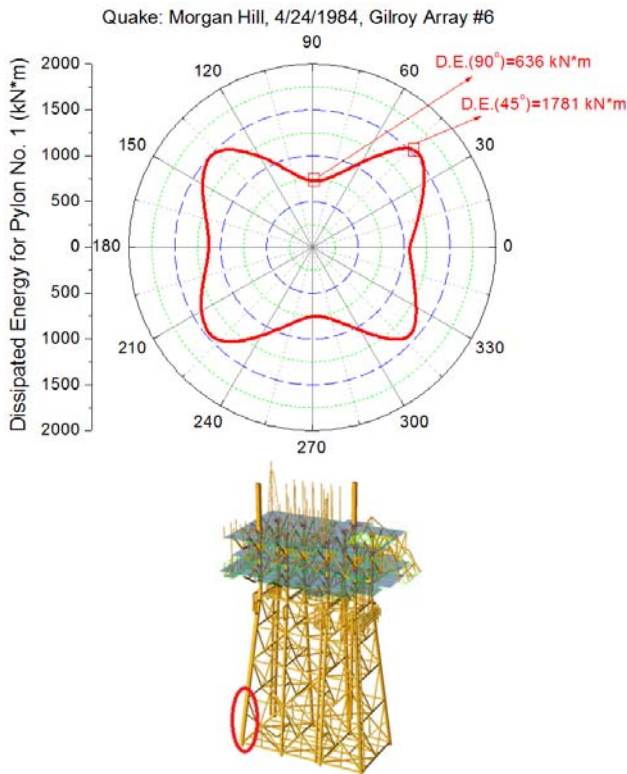


Fig. 4 Influence of incidence angle of earthquake components on the Dissipated Energy

It is obvious that the incidence angle of earthquake components does not only influence the inelastic response of specific structural members, as in the case examined above, but also the overall (global) behavior of offshore platform. In order to make more apparent this situation, Figs. 5 and 6 show the time history of top horizontal displacements, in X- and Y-directions, under Morgan Hill (1984) earthquake. It is apparent from Fig. 5 that for the case where the seismic records are applied in parallel to the main axes of structures (i.e., for incidence angle equal to  $0^\circ$  and  $180^\circ$ ), the structure of jacket platform appears to behave almost elastically where the elastic and inelastic response is almost identical and the maximum displacements in X-direction seems to have minimum values. Similarly, it is evident from Fig. 10 that for the case where the seismic records are applied perpendicularly to the main axes of structures (i.e., for incidence angle equal to  $90^\circ$  and  $270^\circ$ ), the structure of offshore platform appears to

behave almost elastically where the elastic and inelastic response is almost identical and the maximum displacements in Y-direction seem to have minimum values.

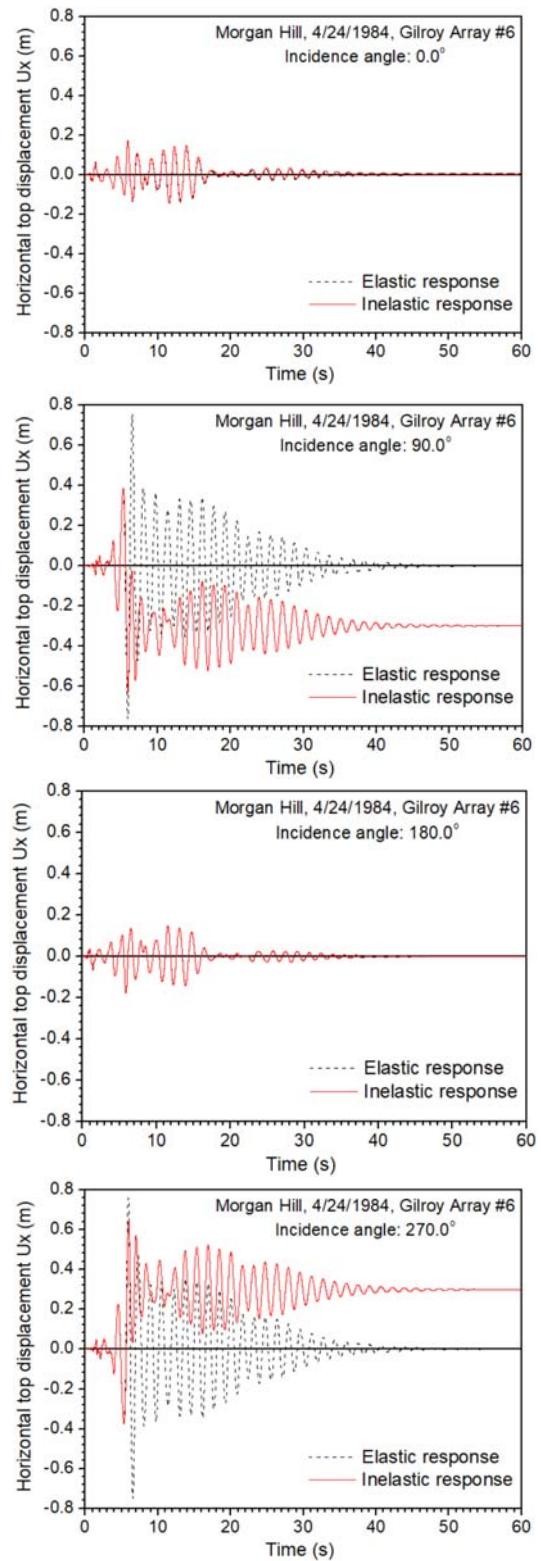


Fig. 5 Time history of horizontal top displacement,  $U_x$

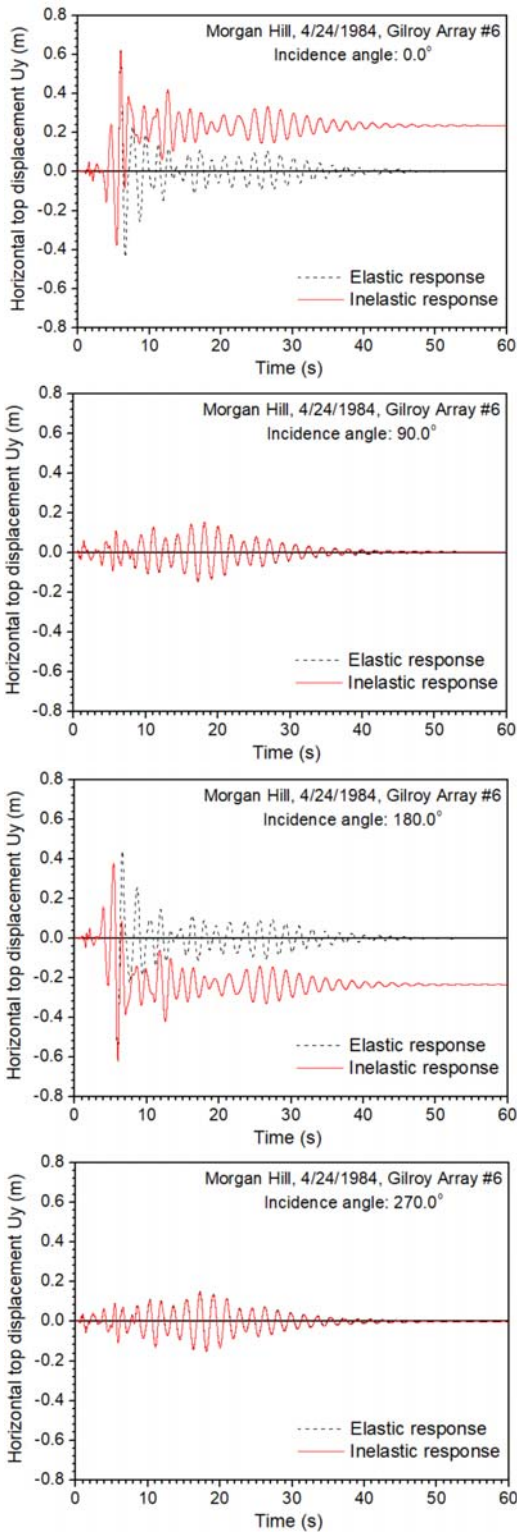


Fig. 6 Time history of horizontal top displacement,  $U_y$

The effects of soil deformability on the seismic response of offshore platforms are presented in Fig. 7 for Christchurch New Zealand (2011) earthquake. More specifically, these figures show the time-history of horizontal top displacement in X-direction, examining both cases of rigid and deformable soil. It is evident that different angles of incidence for the

seismic input can lead to quite different response. Furthermore, the influence of soil deformability, taking into account the seismic soil-pile-structure interaction, on the dynamic response of jacket platforms is worth-noticing.

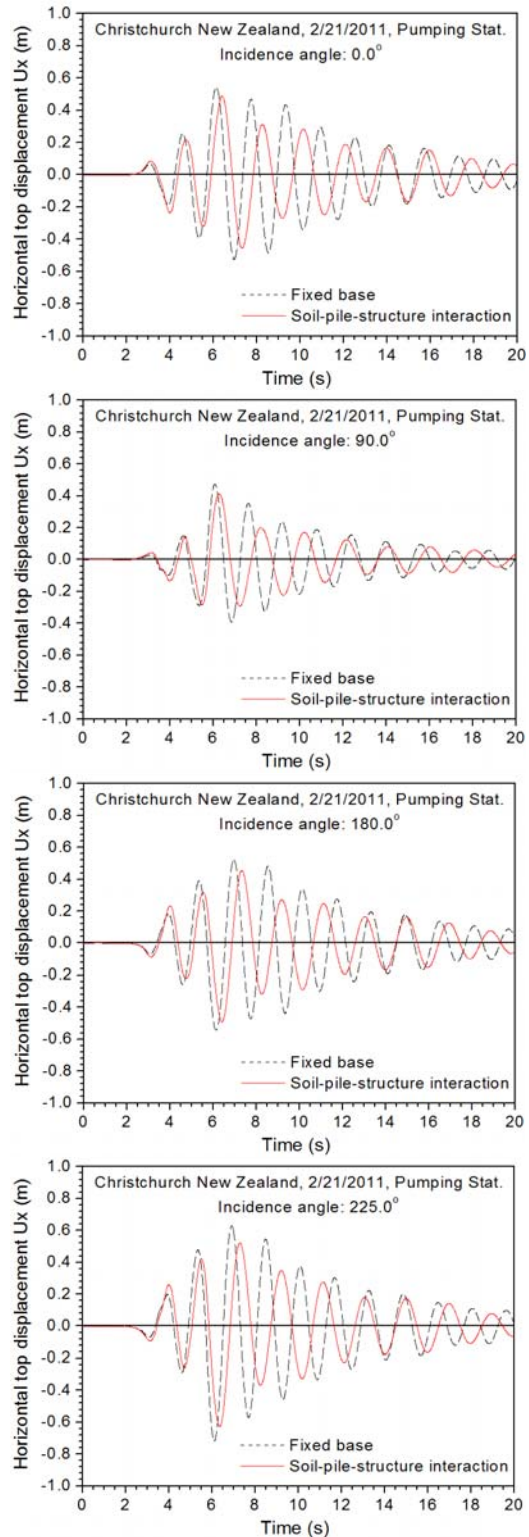


Fig. 7 Influence of soil deformability and of incidence angle of earthquake components on the structural response of jacket platform

Two important topics are simultaneously investigated in the following. The first one has to do with the assessment of residual deformation of jacket platform after the abovementioned strong ground motions. The second topic focuses on seismic nonlinear analysis of offshore structures adopting either the Small-Displacements-Formulation (S-D-F) or the Large-Displacements-Formulation (L-D-F), i.e., the offshore platform has only material-nonlinearities or both material and geometric nonlinearities, respectively. Without loss of generality, the Westmorland (1981) earthquake is applied and the Incremental-Dynamic-Analysis approach is used to evaluate the residual displacements in X-directions, for various intensities of ground motions. Thus, Fig. 8 shows the residual horizontal displacements in X-direction for the top of jacket platform.

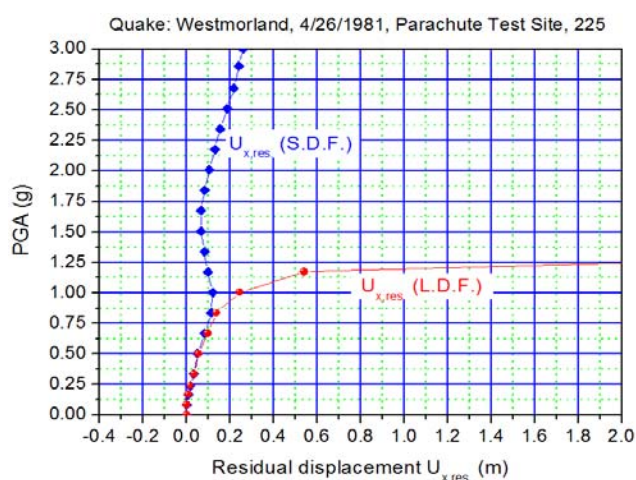


Fig. 8 Influence of analysis type (small- or large-displacement-formulation) on the top horizontal residual displacements

## VII. CONCLUSION

This study investigates the seismic hazards of three-dimensional offshore platforms subjected to earthquakes, which have been recorded within a close proximity to the fault region with oblique-reverse or reverse and strike-slip mechanisms. The three-dimensional character of these special structures and other topics and phenomena such as material and geometric nonlinearities, soil-pile-structure interaction and incidence angle of seismic waves are also examined. The following findings and conclusions can be mentioned:

The material nonlinearity should be considered in order to optimize the selection of structural members.

The incidence angle of seismic waves is a very important parameter where for some crucial angles, the internal forces and the maximum deformations can be doubled or more in comparison with the ones corresponding to other, less crucial angles.

The assumption of rigid soil leads to erroneous results. Thus, the soil-pile-structure interaction should be taken into account to assess reliably the seismic behavior of offshore platforms.

The geometric nonlinearities, using large-displacement-

formulation for the equation of motion, must be taken into consideration in any case.

Seismic motions that have been recorded within a close proximity to the fault region can lead to nonlinear behavior for offshore platforms.

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