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Lateral deflection of piles in a multilayer soil medium. Case study: The Terengganu seaside platform

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ABSTRACT

Vibrations from earthquakes can be felt through structures on the ground. One of the characteristics of soil is that it can absorb vibrations to varying degrees depending on its type and properties. The soil profile and depth of each layer of soil is not the same for every place. Therefore, consideration of soil profile and the depth of each layer is important in structural design, especially for offshore structures. In this article, the lateral deflection of piles constructed in a multilayer soil medium is assessed. The evaluation was performed on the Terengganu seaside platform located approximately 350 km away from the Sumatran seismic zones, the Sumatran subduction and fault zones. To model an earthquake, a recently developed attenuation equation was used, and the effect of the shear wave velocity was investigated, considering the soil profile. The results showed that the effect of the wave reduced as it moved further from the epicentre of the earthquake. The piles experienced complete failure when the magnitude of the earthquake was 8.0, with some loss of pile capacity for a magnitude of 7.5 and below. Considering the effect of shear wave velocity (Vs) of the multilayered strata, and using the new attenuation equation, accurate pile deflections, which were in excellent agreement with previously used methods, were obtained.

1. Introduction

In offshore structural design, the effect of earthquakes is the most important issue that needs to be considered, especially in an active seismic area. An earthquake-proof design requires consideration of the dynamic response of the piles of offshore structures. The dynamic response includes the characteristics of loading, the dynamic characteristics of the pile structural system, and the dynamic pile-soil interaction. The consideration of soil-pile-structure interaction (SPSI) is important in designing a pile foundation or a stiff structure. Dongmei and Truman [1] state that a dynamic analysis and seismic design of a rigid structure has an important effect on SPSI. An earthquake is a common dynamic load on the SPSI. Even though Malaysia is not located in an actively seismic area, the energy of earthquakes can sometimes still be felt in some states. For example, the vibrations from the earthquake that occurred in Sumatran Indonesia could still be felt in areas such as Penang Island, Kedah and other northern and southern areas in Malaysia. The earthquake which occurred in Ranau, Sabah, with a magnitude of 5.9 on 5 June 2015, proves that Malaysia is not an earthquake-free area. Therefore, the study of SPSI is relevant for the situation in Malaysia.

There are many methods that have been developed for analysing the dynamic response. The beam on non-linear Winkler foundation (BNWF) method is commonly used by professional engineers and researchers to analyse non-linear SPSI. In the BNWF method, several factors need to be considered, such as the different soil properties for each layer, the behaviour of the soil and the soil-pile interface, due to the non-linear condition and energy release. Energy is released because of the radiation or hysteretic damping. According to Kimiaei et al. [2], BNWF models are based on the p-y curve approach. The p-y curves can establish the stiffness of the soil and the damping is established either using analytical and/or empirical solutions. BNWF models are cost-effective and can account for various complex problems using an easy

Abbreviations: BNWF, Beam on non-linear Winkler foundation; FEM, Finite element method; MMD, Malaysian Meteorology Department; NERA, Non-linear response analysis; PGA, Peak ground acceleration; RSA, Response spectrum analysis; S_A, Spectrum acceleration; SPSI, Soil-pile-structure interaction

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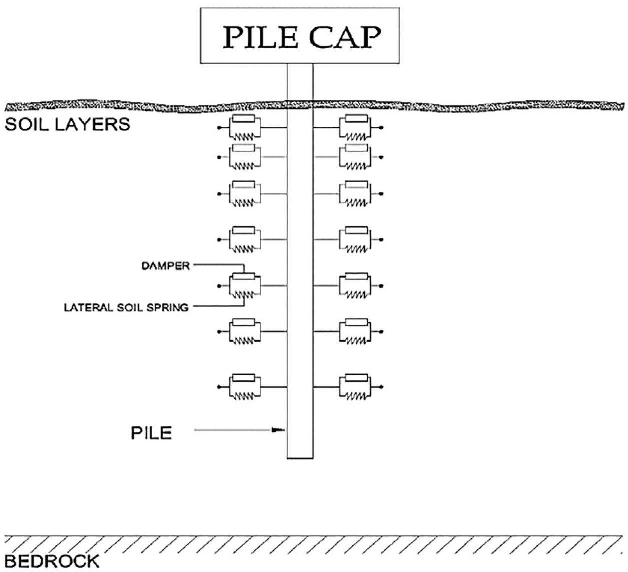

Fig. 1. General view of beam on non-linear Winkler foundation (BNWF) models for non-linear dynamic response analysis of offshore piles [3].

method.

The BNWF method considers the damping and discontinuity conditions to produce an exact analysis of a site's condition. For an earthquake-responsive design, free field ground motion is performed and must be considered in the analysis of the response to the seismic activity. However, the free field motion histories must be calculated in a separate site response analysis. The ground motion is computed at the different levels of soil and then applied to the nodal boundary supports. Nodal boundary supports represent the support motion. Fig. 1 shows the general view of a BNWF model and its main components in a dynamic non-linear response analysis of offshore piles. Fig. 2 shows the single degree of freedom for the spring-mass-damper model.

The soil-pile interface and soil-pile interaction refers to the same entity. The perfect pile-soil interaction is when the pile and soil contact with no relative sliding occurring. The perfect sliding condition is when no friction develops along the shaft of the pile. The soil and pile are deformable bodies. Therefore, the analysis assumes that the soil and piles undergo finite sliding. Special interface elements, such as relative movement and soil nodes, are needed to account for the gapping and discontinuity condition of the pile-soil interaction. The development of gapping is different for different types of soil. In clay soil, a tensile stress helps to develop gaps where they are detected in the soil spring and the disconnection of the interface element occurs at pile and soil nodes. In cohesionless soil (e.g., sand), the development of gapping is not fixed because the movement of the pile is away from the soil Naggar et al. [4]. Fig. 3 shows the typical gapping soil reaction–pile deflection behaviour for cohesive soil and Fig. 4 shows the cave-in soil reaction–pile

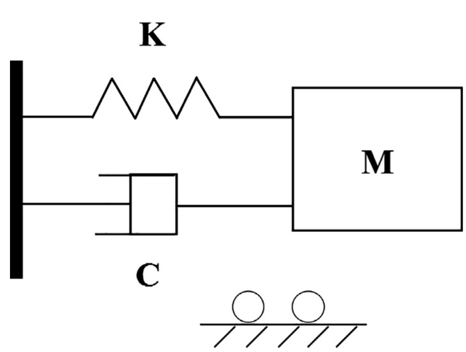

Fig. 2. Single degree of freedom for the spring-mass-damper model [3].

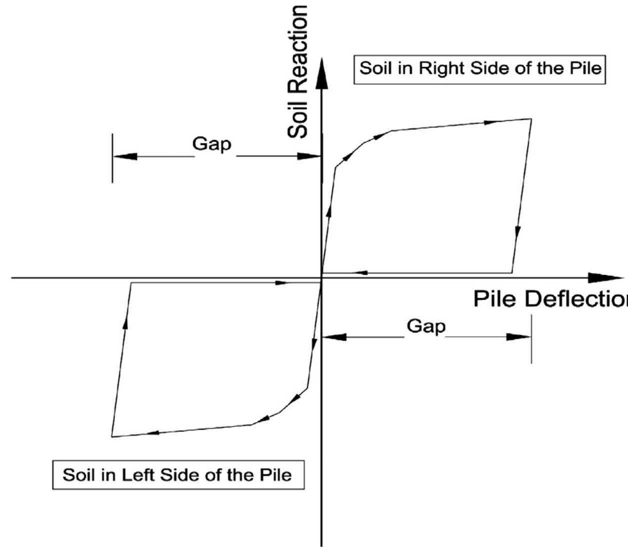

Fig. 3. Typical gapping soil reaction–pile deflection behaviour for cohesive soil [2].

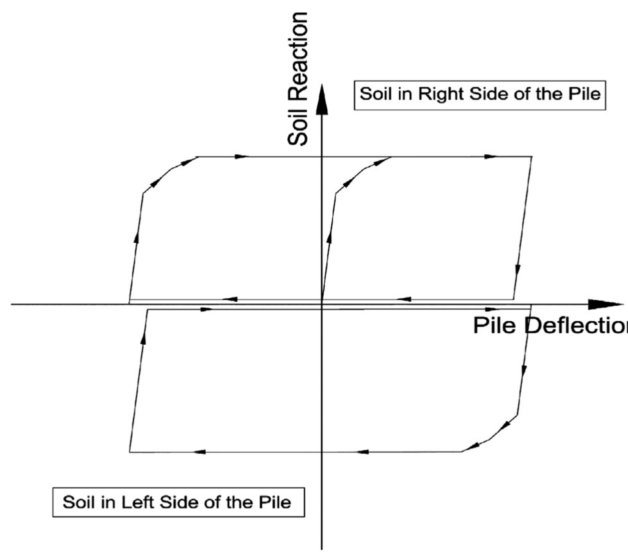

Fig. 4. Cave-in soil reaction–pile deflection behaviour for cohesionless soil [2].

deflection behaviour for cohesionless soil. The summary of some of the previous research on soil-pile interaction is presented in Table 1.

The main objective of this study was to assess the lateral deflection of piles constructed in a multilayer soil medium. A case study assessment was conducted on the Terengganu seaside platform located approximately 350 km away from the Sumatran seismic zones, namely the Sumatran subduction and fault zones, and the evaluation was performed using a newly developed attenuation equation.

2. Material and methods

2.1. Pile modelling

The modelling of the pile and surrounding soils were divided for the different layers. The lateral soil spring and the damper methods were used to perform the non-linear dynamic analysis for the BNWF model. According to Kimiaei et al. [2], BNWF is used to approximate the lateral response of flexible piles embedded in layers of soil to seismic loading, such as earthquakes. The model was used in a finite element method (FEM) software program (ANSYS) to analyse the response of laterally