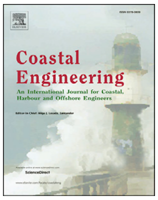
Coastal Engineering 129 (2017) 50–58

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng



Stability of scour protection due to earthquake-induced liquefaction: Centrifuge modelling

D.E. Escribano [a,1], A.J. Brennan [b,*]

[a] *University of Concepción, Department of Civil Engineering, Edmundo Larenas 219, 4030000, Concepción, Chile*
[b] *University of Dundee, Department of Civil Engineering, Fulton Building, DD1 4HN, Dundee, UK*

ARTICLE INFO

Keywords:
Scour protection
Sand
Shaking table
Centrifuge modelling
Liquefaction
Monopile

ABSTRACT

A key aspect of permanent offshore structures is protection against scour. This is typically in the form of a blanket of coarse gravel or cobbles surrounding the structure. These coarse particles are selected for their high resistance to being displaced by strong currents and thus protect the underlying finer sand particles from scour. However, in the event of an earthquake, the foundation sand may be susceptible to some degree of liquefaction. This research investigates the effects of seismic-induced liquefaction over a scour blanket, and if sinking is inhibited by some combination of the additional effective stress imposed by the gravel together with the interlocking resistance that develops when coarse particles are subjected to relative displacements.

In order to evaluate the stability of scour protection blankets, a programme of physical modelling was carried out, involving the assessment of different configurations of stone layers over a liquefiable material, and a monopile-type foundation. Models were subjected to scaled base shaking equivalent to earthquake loading. A mass-balance of particle sinkage showed that a filter layer was critical for maintaining the integrity of the armour stones. Based on displacement and pore water pressure measurements, it was found that the presence of the scour protection blankets improved the response of the liquefiable sand under seismic loading, and even inhibited the occurrence of liquefaction. This implies that a well-designed scour protection blanket can assist in protecting against earthquake effects also.

1. Introduction

One of the major challenges facing offshore structures is the possibility of liquefaction of the seabed. Earthquake loads and strong storms are both major causes of liquefaction in marine deposits. As well, an offshore foundation will be subjected to continuous cyclic loading due to waves during its lifetime, which may progressively lead to liquefaction. Evidence of liquefaction around offshore structures has been reported in the literature. Christian et al. (1974), and Herbich et al. (1984) have reported the phenomenon of floatation of pipelines due to storms produced by liquefaction of the seabed. Miyamoto et al. (1989) reported the subsidence of offshore breakwaters at the Nigata Coast, Japan. Sawicki and Mierczynski (2006) and Sawicki (2014) provide an extensive literature review regarding the practical implications of liquefaction and the dynamics of seabeds and marine structures. Reports on earthquake induced liquefaction in marine structures have been summarized by Sumer et al. (2007). The main differences between wave and earthquake loading is that the stress fluctuation is different (De Groot et al., 2006). In the case of a storm, the loading propagates from the seabed into the subsoil whereas earthquake loading propagates from the ground and moving up to the mud line. Storm waves also have a lower frequency and rather longer durations compared to earthquakes.

A commonly used foundation for marine structures, and especially for offshore wind turbines, is the monopile, which is feasible to install for water depths up to 35 m (Lesny and Hinz, 2007). Because of the effects of currents, and the combined effects of waves and currents, erosion or scouring of the seabed material may occur around such a foundation. The effects of scour produced around an offshore foundation can be mitigated by protecting the soil surrounding the pile with rocks or an armour layer, and its design depends mainly on the shear stresses applied to the soil by currents and waves. To prevent the particles of the seabed soil from washing away through the stones a filter layer can be used, and its design depends on the dimensions of the rock armour and the seabed soil, although this layer is not always considered for scour protections. Fig. 1

---

[*] Corresponding author.
E-mail addresses: describano@udec.cl (D.E. Escribano), A.J.Brennan@dundee.ac.uk (A.J. Brennan).
[1] Formerly University of Dundee, UK.

http://dx.doi.org/10.1016/j.coastaleng.2017.08.015
Received 11 January 2017; Received in revised form 4 July 2017; Accepted 25 August 2017

0378-3839/© 2017 Published by Elsevier B.V.

shows a typical monopile of diameter D_p, surrounded by an armour layer of height t_a and diameter b_a as well as a filter layer between armour and seabed of height t_f and diameter b_f.

Many site investigations indicate that numerous structural failures can be attributed to the effects of wave-induced liquefaction of the seabed, which will affect the scour protection. Physical model tests have been performed to study the pore pressure response around a monopile due to wave action (Sumer et al., 1997; Qi and Gao, 2014), but these were carried out in the absence of the scour protection layer which will affect the response. Previous studies on the effect of liquefaction in the presence of scour protection layers have been focused on the wave-induced liquefaction (Sassa and Sekiguchi, 1999; Sumer et al., 2010) showing that the process of pore pressure build-up and subsequent liquefaction can affect the stability of stone protections (Sassa and Sekiguchi, 1999; Sumer et al., 2010). The experiments of Sassa and Sekiguchi (1999) and Sumer et al. (2010) showed that cover stones such as the ones used for scour protections can sink when the seabed liquefies. Yet, having a cover of stones above the liquefiable layer may increase the liquefaction resistance as the stones increase the effective stress of the seabed soil. There remain questions over (i) the effect of seismic loading on scour protection layers, (ii) the effect of scour protection on the liquefiability of the seabed soil and (iii) how this interplays with the presence of a substantial monopile-type foundation.

The aim of this work was therefore to fill this knowledge gap and to study the influence of earthquake shaking and seismic-induced liquefaction on scour protection on offshore foundations. As part of EU funded MERMAID project on the use of Multi-purpose offshore structures, the University of Dundee undertook an experimental study to analyse the effects of dynamic loading upon scour protections. Five centrifuge model tests were carried out on liquefiable seabed soils with different configurations of scour protection layer and foundation. Based on the measured generation and dissipation of excess pore pressure (EPP), the process and mechanism of settlement of the liquefied soil and the stone layers, and a comparison between wave-induced liquefaction and earthquake-induced liquefaction, the principal target is to evaluate the risk of sinkage of scour protection stones in order to inform future design.

2. Centrifuge modelling

Small scale physical modelling of larger geotechnical prototypes here would fail to adequately model the important increase in self-weight stresses provided by the armour layers, as well as any inertial stresses induced by soil structure interaction. Therefore, to model effective stresses correctly, the 3 m radius geotechnical centrifuge at the University of Dundee, UK is used (Fig. 2a). Centrifuge modelling permits small scale models to be tested at elevated stress levels (Schofield, 1980). Therefore a model that is N times smaller in length scale than its larger prototype can be accelerated on the centrifuge to N times greater gravity in order to create identical stress conditions at homologous points in model and prototype, and hence match soil response. Table 1 presents a summary of the scaling laws used in geotechnical modelling.

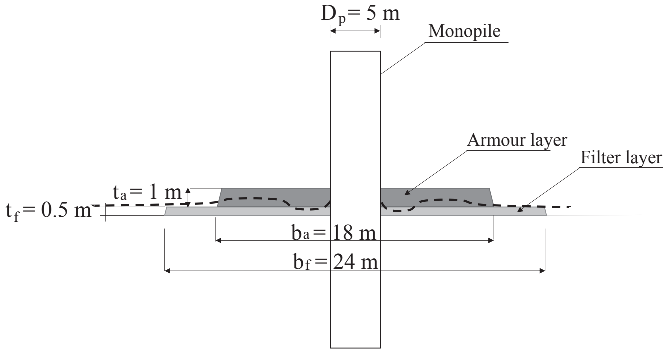


Fig. 1. Sketch of monopile foundation with scour protection. Armour layer deformation represented by dotted lines.

Earthquake loading was achieved using a servo-hydraulic Actidyn Systems QS67-2 in-flight earthquake simulator (Fig. 2b) as described by Brennan et al. (2014). A length scale factor of 1:50 was adopted, and testing correspondingly carried out at 50 times Earth's gravity. The use of this scaling allowed modelling of a 5 m diameter monopile foundation with scour protection, and with enough soil depth to capture liquefaction phenomena. An equivalent shear beam (ESB) container was used to prepare the models and installed on top of the earthquake simulator (Fig. 2b). The ESB container has been extensively used and studied for different soil types as well as the evaluation of the boundary effects on the soil model (Brennan et al., 2006; Bertalot, 2013). The internal dimensions of the ESB container are 280 mm × 675 mm × 334 mm. The surface of test model S04 is exhibited in Fig. 2c before the saturation stage, and additionally its condition after testing and drainage of the fluid in Fig. 2d. A schematic diagram of the five tests carried out is shown in Fig. 3; further details about material properties, model preparation and instrumentation are provided below.

2.1. Material properties

The sand used to model the seabed was HST95 Congleton sand, which is a specific fraction of the sand extracted at Bent farm, Congleton, Cheshire. It is classified as an even graded fine grained sand and its mineralogical composition consists at 94% quartz (Lauder, 2010). The roundness index (R) is 0.53 (Lauder, 2010) classifying this material as round particle shape. The physical properties of HST95 sand are given in Table 2, where D_{10}, D_{30}, and D_{60} define the diameter corresponding to the 10%, 30%, and 60% finer in the grain size distribution. The uniformity coefficient ($C_u = D_{60}/D_{10}$) is a measure of the grading of the material, the specific gravity G_s, Minimum and maximum dry density γd_{min} and γd_{max}, respectively, and the minimum and maximum void ratio $e_{\min}$ and $e_{\max}$, respectively.

The stones used for scour protection had an irregular shape and two different sizes: $D_{50} = 10$ mm, and $D_{50} = 2$ mm, for the armour and filter layers, respectively. The grading, thickness, and extension of each scour protection layer will depend on the design values of waves and currents (Den Boon et al., 2004). From a scale modelling viewpoint, it was decided that the important factors in the behaviour of this material were that the applied self-weight stresses were appropriate and the ratio of particle size between armour, filter and seabed soils was appropriate. In terms of the design requirements, it is necessary to consider the ratio of the median grain size (D_{50}) between the seabed D_s and the top layer (D_f: grading size for filter layer; D_a: grading size for armour layer) in order to prevent migration of the seabed material. In this case $D_f/D_s = 15$ and $D_a/D_f = 5$, which is in the range for the design of scour protections for a monopile foundation of a 6 MW offshore wind turbine (Halfschepel, 2003). Hence, the scour protection particles were scaled to match the grading of the prototype model, and at the same time, the seabed was modelled as a continuum.

2.2. Model preparation and instrumentation

For the centrifuge model tests, the seabed sand was placed by air pluviation method. First of all, the sand was passed through a mesh from a storage hopper. The density obtained was continually monitored through the pluviation process in order to maintain a constant value. The models were fabricated with two uniform layers of different relative density I_D and thickness (Fig. 3). The achieved I_D varied between 35% and 40% and a thickness of 6.50 m for the loose layer, and I_D between 80% and 83% and thickness of 6.0 m for the dense layer.

For the saturation the model container has 5 inlets in the base in order to distribute the pore fluid homogeneously at the bottom of the soil model. The saturation process was carried out slowly under controlled head and flow rate to avoid piping of the soil model and provide uniform

Download English Version:

https://daneshyari.com/en/article/5473422

Download Persian Version:

https://daneshyari.com/article/5473422

Daneshyari.com