A New Model for Pore Pressure Generation for Evaluating Wave-induced Liquefaction

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Seabed stability is affected by factors pertaining to cyclic wave loading, such as wave-induced single external stress or internal stress, the number of cycles in the seabed, and the pore pressure generation model (i.e., the earthquake mechanism). On the basis of cyclic triaxial tests, this study proposes a pore pressure generation model for seabed subjected to long-term wave loading by using a hyperbolic sine function and suggests a testing parameter to predict the curve of pore pressure under different test conditions with various $T_i$. Moreover, the proposed model is integrated with a simple evaluation methodology for liquefaction analysis considering wave loading.

INTRODUCTION

According to a report by Dilley et al. (2005) on global regions that frequently experience disasters (typhoons, floods, landslides, earthquakes, etc.), 73% of Taiwan’s population resides in areas that experience three of these natural disasters and 99% in areas that experience two.

Ishihara and Yamazaki (1984) asserted that although waves and earthquakes are both cyclic forces, the primary difference between the effects of waves and that of earthquakes on the seabed depends on the cyclic shear stress changes caused by waves. The internal seabed dynamic stress produced by waves is considered one of the primary failure factors that causes seabed instability. The failure mechanisms of waves are generally categorized as seabed soil shear failure and seabed soil liquefaction. Since the 1970s, numerous scholars have indicated that seabed instability is one of the primary causes of damage and failure of seashore structures (Bea et al., 1983; Rahman, 1991; Rahman and El-Zahaby, 1997; Chang, 2002; Jeng, 2003; Sharma and Fahey, 2003).

Transient liquefaction and residual liquefaction are two liquefaction mechanisms that correspond to the elastic seabed and elastoplastic seabed, respectively. Residual liquefaction can occur only in an elastoplastic seabed because of the pore pressure buildup caused by the compaction of soil under cyclic wave loading. Residual liquefaction is the main risk for the stability of marine structures constructed on elastoplastic seabed foundations. Seed and Rahman (1978) developed a simple one-dimensional finite element model for earthquake-induced liquefaction to describe the accumulation of pore pressure under progressive waves. This model has been further extended analytically and numerically to examine wave-induced residual soil response. Numerous laboratory experiments (Sumer, 2014; Sumer et al., 1999, 2012) have reported the wave-induced pore pressure accumulation mechanism and the existence of residual liquefaction. Wave-induced transient liquefaction in elastic seabed environments has been investigated widely in previous studies (Ye et al., 2015).

Zen et al. (1998) indicated that under some combination of wave and soil conditions, seabed instability (shear failure, liquefaction, or both) may occur, depending on the magnitude of the effective stress and excess pore pressure. Jeng and Lee (2001) reported that of these two disruptive mechanisms, soil liquefaction has the more unstable seabed failure patterns and that it can move sediments vertically.

Some studies on the wave-induced seabed response problem have also considered the isotropic soil behavior of a porous seabed (Zhou et al., 2014). Most importantly, a series of analytical solutions has been presented for the soil response in a porous seabed subject to wave loading; such solutions apply to a broad variety of seabed environments, including infinite seabed and finite seabed environments (Jeng, 2013). These solutions have been used to predict various forms of wave-induced seabed instability, such as liquefaction and shear failure. Moreover, Wang et al. (2016) proposed that shear stress variation is an almost linear function of the wave action and that shear stress is not likely to cause shear failure under a certain type of wave action. This implies that it is more difficult for wave action to trigger the accumulated liquefaction or shear failure of a seabed than it is for excess pore water pressure to trigger liquefaction.

Because wave-induced dynamic excess pore water pressure in internal seabed soil is the primary cause of reductions in that soil’s shear-stress strength, Jeng et al. (2010) indicated that the phenomenon of pore pressure within a seabed is an important feature in coastal engineering problems such as the stability of breakwaters and the sinking or uplifting of pipelines. Ocean waves and currents can generate significant dynamic pressures on a seabed, which can induce pore water pressure and effective stresses within the seabed. With excess pore pressure and diminishing vertical effective stress, part of the seabed may become unstable or even liquefied. Once liquefaction occurs, the soil particles are likely to be carried away as a fluid by any prevailing bottom current or mass transport owing to natural loadings such as waves and currents.

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