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Effect of cyclic wave loading on scouring stability of geotube dams

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ABSTRACT

Cyclic wave loading on geotube dams creates a cyclic flow in seams between geotubes regime distinct from the uni-directional flow that has been previously studied. A new laboratory apparatus was used to investigate the effects of hydraulic conditions on the core sand of geotube dams with seams between tubes. With this apparatus, a series of tests was conducted. Various maximum pressure heads (0.25, 0.3, 0.35, and 0.4 m), periods of cyclic wave loading (6, 7, 8, and 10 s) and particle porosities (34%, 35%, 40%, and 45%) were used in this test series. In the test series, the erosion development process of sand was analyzed. The results also indicate that the sand in the dam core can still perform satisfactorily after being scoured into the seam and extending a certain length. This critical length was found to be a function of the sand porosity, cycle period and maximum pressure head.

1. Introduction

With the development of protective measures on coasts, geotube dams are increasingly used in estuarine and coastal engineering such as in reclaiming tidal flats, avoiding saltwater intrusion and storing freshwater. The construction of geotube dams involves filling large geotubes on opposite sides to form a cofferdam, placing sand inside the cofferdam and stacking additional geotubes to create a water-retention dam (Fig. 1).

A geotube dam may be as many as tens of kilometers long. Geotube dams must be constructed of many geotubes connected end to end, which inevitably involves the installation of many seams between geotubes (Fig. 2). During the construction and operation of geotube dams, seams between geotubes become scour channels for dam core sand. The sand in dam cores and seams tends to be washed away by flowing water along the joint. Furthermore, geotube dams are typically used in estuaries and coastal areas, where currents are bidirectional and unstable. When seams between geotubes are subjected to cyclic water action, such as wave loading and water level fluctuations, the sand in the dam cores and the seams is easily scoured. Therefore, seams between geotubes pose a great potential safety hazard to these dam structures.

In many countries with mature technology on geotube, geotubes are mostly composed of high-strength geotextiles. Thus, individual geotubes can be very large, and the problem of erosion stability caused by seams is not serious. Studies by researchers in these countries have focused more on construction technologies, structural stability of geotube dams and related features of geotube materials.

The structural stability of geotubes under wave loading has been studied in several experiments. Erosion and deformation of geotubes under wave loading were investigated by combining an indoor model test with a numerical simulation method (Recio and Oumeraci, 2009a, 2009b). The effect of wave loading on the stability of geotubes was revealed through large-scale physical model tests (van Steeg et al., 2013). The settlement deformation of geotubes filled with various filling materials was studied in laboratory tests (Shin and Oh, 2003, 2007). An empirical formula for calculating the settlement deformation was developed and verified via laboratory model tests.

The erosion characteristics and dewatering features of sand in geotubes have been investigated in laboratory experiments. The erosional stability of punctured geotextile filters under cyclic wave loadings was tested using a cyclic flow apparatus (Koerner and Koerner, 2006; Moo-Young et al., 2002). The test results indicated that the soil-geotextile interface can be stable even when the geotextile is punctured, provided that the holes do not exceed a critical size. The effects of various factors including the water content, grain composition and thickness of the geotextiles on the dewatering performance of geotubes were systematically studied (Muthukumaran and Ilamparuthi, 2006). Geotubes were shown to be viable in dewatering sediment with a high moisture content (Chew et al., 2003).

In China, geotubes are composed of burst-film woven geotextiles. Due to limitations in material strength, these geotubes are small and require the joining of many geotubes with seams to construct a dam. With the emergence of structural failure caused by seams between the tubes, the erosion of geotube dams through seams has become a focus of study.

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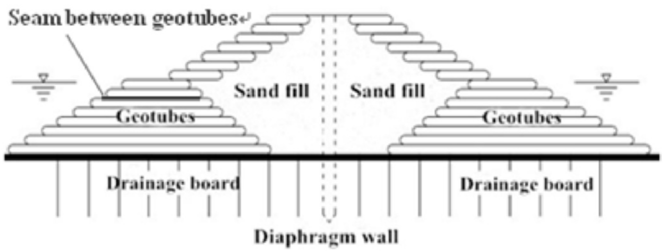

Fig. 1. Diagrammatic section of a geotube dam.

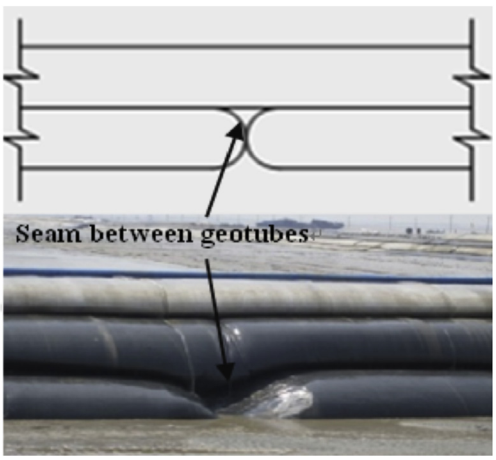

Fig. 2. Seam between geotubes of geotube dams.

Based on investigations of other scour problems (Chen et al., 2012; Zanganeh et al., 2012; Wang et al., 2014), the scouring of a geotube dam through the seams between the tubes under uni-directional flow was researched in a model test (Yu et al., 2014). A relationship characterizing the migration of core sand though seams between tubes was found.

However, cyclic wave loading on geotube dams creates a cyclic flow in seams between geotubes distinct from uni-directional flow. Cyclic flow produces greater sand instability than uni-directional flow (Zhuang et al., 2008). No study of the erosional stability of geotube dams with the seams between geotubes being subjected to cyclic wave loading has been reported. Therefore, the goal of this study was to investigate the scouring of geotube dams through the seams between tubes under cyclic wave loading.

Under cyclic wave loadings, sand is easily scoured into seams from dam cores. When sand system reached a steady state, sand in seams would form sandpile with certain lengths. To estimate the stability of geotube dams, the critical length of sandpile in seams as sand stabilized (L_c) should be compared with the length of seams (L). If $L_c < L$, geotube dams could be considered structurally stable. Therefore, the factors which have effects on L_c could affect the stability of geotube dams. Apparently, L_c is affected by multiple factors, such as the gradation and composition of the sand particles, the porosity of the sand deposit, and the period and energy of the cyclic wave loadings. For simplicity, the maximum pressure head was selected to be the characteristic value of cyclic wave loadings. Therefore, the effect of sand porosity n, cycle period t and maximum pressure head h to the critical length of sandpile in seams L_c was investigated in this study.

2. Test apparatus

The testing apparatus consisted of a cyclic flow apparatus, a sandbox and a pipe (Fig. 3).

The cyclic flow apparatus was composed of a cyclic flow generator and a water reservoir (Fig. 4). Cyclic flow was generated by vertical motion of the piston which was driven by the adjustable-speed motor. Circumrotation movement of the adjustable-speed motor was passed to to-and-fro beeline movement of the piston by the transmission device. Vertical movement velocity of the piston in the water reservoir changed in sine form as rotational speed of the adjustable-speed motor remaining unchanged. Therefore, the water pressure in water reservoir changed in sine form with the sinusoidal speed movement of the piston. Furthermore, the distance of piston motion could be regulated through the regulation of transmission device. The variation of maximum pressure was enabled by the distance of piston motion in the water reservoir. And the cycle period was adjusted by varying the speed of the adjustable-speed motor.

The dam core was simulated by a sandbox, which was divided into two parts: a sand filling chamber and an infiltration chamber. The sand filling chamber was used to fill dam core sand. And the infiltration chamber provided water for the sand filling chamber when needed. The sizes of these two chambers of the sand box respectively are 30 cm*50 cm and 20 cm*50 cm. These two parts were separated by a porous board. Non-woven fabric attached to the porous board produced a uniform current and prevented the sand in the sand filling chamber from flowing into the infiltration chamber.

A pipe was used to simulate a seam between geotubes. Generally, seams between geotubes in practical engineering applications are 2–10 m long and approximately 50 mm in diameter. Thus, in section, the pipe was a square with a side length of 50 mm, and the pipe was 2 m long. The pipe was connected the cyclic flow apparatus to the sandbox. One side-wall of the pipe was equipped with many access points for water pressure sensors. Ten water pressure sensors were seted on the side wall of the pipe with nine intervals of 20 cm. The signal of water pressure sensors was relayed to a computer in real time dynamically. And the Fig. 5 was created by the computer during a measurement of water pressure in pipe.

3. Test program

Before initiating the tests, the apparatus was checked for leaks, and the water pressure sensors and flowmeters were installed and calibrated. Sand sample was prepared according to the gradation. Quartz sand with a typical particle size distribution was used in the tests. The particle size distribution was identical to that used in geotube dams constructed in Jiangsu Province, China (Fig. 6). The median particle size of the sand sample with typical grading in tests is small relatively. To coarser grained sand, the tests results are relatively safe. Meanwhile, finer grained sand could not be used in practical engineering due to difficulties in dewatering of geotubes. Then the sand sample was added to the sand chamber in layers. The weight of sand in each layer was calculated and weighed with electronic scale according to the design porosity. This way ensured the homogeneity of filling and met the requirement of design porosity. After the sand was placed, the water was slowly added to the sandbox and pipe. In addition, the sand was soaked for 12 h under a static head after being filled with water. After sand fully saturation, cyclic flow apparatus was started to generate cyclic flow according to design conditions on period and pressure. The information, such as water pressure and particle migration, was collected in real time. Finally, the lengths of sand in pipe were measured at the end of tests. After tests, the sand in sandbox and pipe was sampled with cutting ring from characteristic parts. Porosity, distribution and graduation could be analyzed with the sample.

The tests were conducted under different conditions. Particle porosities of 34%, 35%, 40%, and 45% were used. The period of cyclic wave loadings was set at 6, 7, 8 and 10 s. The maximum pressure head was set at 0.20, 0.25, 0.30 and 0.40 m. The test series consisted of several combinations of these three factors.