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Experimental study on impact behavior of submarine landslides on undersea communication cables

Fawu Wang, Zili Dai *, Yasutaka Nakahara, Tomokazu Sonoyama

Department of Geoscience, Shimane University, Matsue, Shimane 690-8504, Japan

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A B S T R A C T

Submarine landslides, which are characterized by large scale and long run-out distance, could destroy undersea communication cables, thus resulting in a great number of economic losses. In this work, an experimental apparatus is designed to simulate the relative motion between the submarine landslide and undersea communication cable, and investigate the impact behavior of a submarine landslide. The test results show that submarine landslide with larger thickness and larger particle size can generate larger impact force on the communication cables. With an increase of the sliding velocity, the evolution of the flow behavior and impact force of the soil-water mixture can be divided into three stages: 1) landslide stage, the mixture consists a water layer and a sand layer, the impact force increases with the sliding velocity and reaches a peak value at this stage; 2) transforming stage, sand particles start to be eroded by water, and result into a turbidity current layer above the soil-water interface. At this stage, the impact force decreases to a minimum value; 3) turbidity current stage, all of the sand particles are eroded by water, and the impact force increases again when increasing the velocity continuously.

1. Introduction

Submarine communication cables are laid on the sea bed between land-based stations to carry digital data across stretches of ocean with speed and security, including telephone, Internet and private data traffic. The total length of submarine communication cables in the world's oceans is over 1 million km (Carter et al., 2009). These cables are usually buried 1 m and exceptionally up to 10 m beneath the seafloor, or placed on the seabed where water depths are greater than 1500 m. The undersea environment is unfavorable for the submarine communication cables. For example, continental shelves are typically exposed to wave and current actions that move seabed sediment and result in the exposure or even undermining of a submarine cable. Submarine geological activities, such as earthquakes, mud volcanoes, submarine landslides and turbidity currents, pose serious natural threat to the submarine communication cables (Kvalstad et al., 2001). Submarine landslides are perhaps the most significant of them, which occur frequently on continental margins and slopes, releasing huge sediment volumes that may travel distances as long as hundreds of kilometers. They could easily damage submarine cables and lead to interruption of data transmission and international communications. According to the statistics (Carter et al., 2009), there were 2162 cable breaks globally between 1960 and 2006, of which at least 20% were directly influenced by submarine landslides or turbidity currents. One serious event occurred on 19 November 1929. A strong earthquake shake the continental slopes south of the Grand Banks, off the eastern coast of the United States and Canada, and caused a lot of submarine landslides on the continental slopes. Some of these slope failures transformed into high-velocity turbidity currents, which traveled over 720 km from the source area. In 13 h following the earthquake, submarine communication cables near the earthquake epicenter were broken in sequence from north to south with the passage of time (Heezen and Ewing, 1952; Hasegawa and Kanamori, 1987; Canals et al., 2004; Fine et al., 2005). Since then, similar cases have been reported around the world, especially in earthquake-prone regions. For example, Krause et al. (1970) recorded an earthquake-triggered submarine landslide which disrupted a telephone cable at least 280 km away in water depths over 6600 m in the New Britain Trench in 1966. The 2003 Boumerdes earthquake in Algeria damaged six cables and disrupted all submarine communication networks in the Mediterranean region (Joseph and Hussong, 2003). More recently, as a consequence of submarine landslides and turbidity currents associated with the 2006 Pingtung earthquakes offshore Southwest Taiwan, eleven submarine cables across the Kaoping canyon and Manila trench were broken in

* Corresponding author.
E-mail address: zili.dai@riko.shimane-u.ac.jp (Z. Dai).

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sequence from 1500 to 4000 m depth (Hsu et al., 2008). The interruptions in international telecommunication affected all the East and Southeast Asian countries. The violent cable failures that happened in these cases are evidence of the destructive power of the submarine landslides. Therefore, the propagation of submarine landslides is one of the most serious threats to undersea communication cables. Investigation on the impact force of submarine landslides during the propagation is of great importance to maintain the safety of submarine communication cables.

Due to the extreme undersea environment, it is nearly impossible to directly observe submarine landslides and measure the impact force, therefore, the investigation on post-failure behavior of submarine landslides is a big challenge. Most of the previous studies used the flume tests. For example, Zakeri et al. (2008) designed and conducted a series of flume tests to investigate the impact force exerted by a clay-rich submarine landslide on two pipelines. Based on the experimental results, they proposed a method to estimate the drag forces normal to the pipeline axis. Combining with numerical analysis, Zakeri (2009) proposed a method to estimate the normal and longitudinal drag forces on a suspended pipeline. Based on Zakeri's work, Randolph and White (2012) proposed a failure envelope to estimate the interaction force between offshore pipelines and submarine landslides. However, the available literature is still insufficient in providing a comprehensive method to estimate the impact forces of submarine landslide and turbidity current on seafloor installations, such as communication cables and oil/gas pipelines.

In the presented work, an annular trough which can rotate in a vertical plane at a controlled velocity is developed and used to simulate the relative motion between a submarine landslide and an undersea cable. The main advantage of this apparatus is that the sliding velocity of the soil-water mixture could be easily controlled by adjusting the rotation velocity of the trench. Through the tests, the flow behaviour of the soil-water mixture at different velocities (from a submarine landslide to a turbidity current) is observed, and its impact force exerting on an underwater cable is investigated. The influence of the landslide volume, soil type and sliding velocity is considered and discussed.

2. Experimental program

2.1. Experimental setup

Fig. 1 shows the experimental apparatus to simulate a submarine landslide and the relative motion between the submarine landslide and undersea cable. The main part of the apparatus is an annular trough, with an axle in the centre. The outer radius, inner radius and width of the trough are 0.9 m, 0.6 m and 0.4 m, respectively. Its frame is made of steel and the front is transparent plexiglas, through which the motion of the sand and water inside the trough could be easily observed. The axle of the apparatus is connected to a motor so that it could rotate in a vertical plane at a controlled velocity. The sketch of the test apparatus is shown in Fig. 1(b). A certain amount of water and soil material are placed in the apparatus to simulate the submarine landslide. In this paper, the term “submarine landslide” is used to refer to the subaqueous mass motion; the soil-water interface is obvious in this status. With the increase of the flowing velocity, the water and soil material are mixed completely and the interface disappears, this flowing mixture is defined as “turbidity current”. A cable is installed in the bottom of the annular trough paralleling to the axel. The cable is made of stainless steel with a length of 370 mm. Two load cells are set at two sides of the cable to measure the impact force from the water and landslide mass, as shown in Fig. 1(b). The height of the cable from the frame bottom could be easily adjusted. During the rotation of the trough, the soil-water mixture always stay in the lower part of the apparatus under the action of gravity, and the relative motion between the apparatus bottom and cable shows in a similar way to a real submarine landslide on the seabed. To monitor the behavior of the soil and water mixture during rotation, three types of sensors are fixed inside the frame bed at a line just below the cable and paralleling to the axle, so that the three sensors can reach the lowest point at the same time with the cable: 1) Load cell used to measure the weight of water and soil when the sensor comes to the lowest point, then normal stress can be calculated; 2) Shear stress sensor used to measure the shear resistance at the bottom of the soil and water mixture; 3) Water pressure transducer used to measure the water pressure when the sensor reaches the lowest point. The sensors are distributed in section A just below the cable, as shown in Fig. 1(b).

Rotation velocity of the trough is controlled by a motor. A data logger and battery are fixed in the axial part of the apparatus, see Fig. 1(b), so that data collection is carried out in an independent unit during rotation.

2.2. Materials used in the tests

In this study, fine silica sands no. 7 (S7) and no. 8 (S8) were used to simulate the submarine landslide mass. Their physical properties are presented in Table 1. Fresh water was used in this study.

2.3. Test procedure

In this study, four types of tests were carried out to investigate the impact force of submarine landslides, and the effect of landslide sliding velocity, landslide volume, soil types, and diameter of the cable are considered and discussed. The details are listed below:

1) Tests were conducted at 13 different constant velocities (the linear velocity of the trough bottom), i.e., 0.02, 0.07, 0.13, 0.20, 0.26, 0.32, 0.38, 0.45, 0.51, 0.58, 0.65, 0.72, and 0.77 m/s. Three circles were rotated at each velocity, because the stable impacting can be achieved at this state. Noting that the maximum linear velocity of the trough was about 0.77 m/s due to the output power limitation of the motor. Therefore, the velocity range of the tests was set to be 0.02–0.77 m/s, though the maximum velocity recorded for real submarine landslides could be much larger (Heezen et al., 1954).
2) Tests were conducted using four different constant masses and keeping the water level at the same height. The dry mass quantities are 10, 20, 30, and 40 kg, respectively.
3) To investigate the effect of soil characteristic, two types of soils (silica sand no.7 and no.8) were used in the tests, and the results were compared.
4) Cable with three different diameters of 0.01, 0.02 and 0.03 m were used to evaluate the effect of cable dimension. The material of the cables were the same stainless.

In these tests, the bottom of the cable was set at a height of 0.02 m above the trough bottom (point A in Fig. 1). The maximum depth of the water was kept at 0.2 m for all tests. For comparison purpose, water-only-tests and sand-only-tests were conducted at first.

3. Test results

In this work, the cable is installed paralleling to the axel of the annular trough and perpendicular to the flow direction of the submarine landslide. Therefore, the “*impact force*” discussed in this section refers to the normal force exerting on the cables due to the submarine landslide propagation. The tangential force along the axel of the cable is not discussed in this work.

3.1. Water-only-tests

Water-only-tests were conducted at first, and the impact forces on the cable due to water were investigated at different rotation velocities. In these tests, the diameter of the cable was 0.02 m. Fig. 2 shows the results