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NOTES AND CORRESPONDENCE

Turbidity Currents, Submarine Landslides and the 2006 Pingtung Earthquake off SW Taiwan

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ABSTRACT

Submarine landslides or slumps may generate turbidity currents consisting of mixture of sediment and water. Large and fast-moving turbidity currents can incise and erode continental margins and cause damage to artificial structures such as telecommunication cables on the seafloor. In this study, we report that eleven submarine cables across the Kaoping canyon and Manila trench were broken in sequence from 1500 to 4000 m deep, as a consequence of submarine landslides and turbidity currents associated with the 2006 Pingtung earthquakes offshore SW Taiwan. We have established a full-scale scenario and calculation of the turbidity currents along the Kaoping canyon channel from the middle continental slope to the adjacent deep ocean. Our results show that turbidity current velocities vary downstream ranging from 20 to 3.7 and 5.7 m s^{-1}, which demonstrates a positive relationship between turbidity current velocity and bathymetric slope. The violent cable failures happened in this case evidenced the destructive power of the turbidity current to seafloor or underwater facilities that should not be underestimated.

Key words: Submarine landslide, Turbidity current, Pingtung earthquake, SW Taiwan, Cable break

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1. INTRODUCTION

At least sixteen modern submarine cables used for telephone, internet and data transmissions in Southeast and East Asia pass through south of Taiwan within a 150-km wide E-W stripe (Fig. 1). On 26 December 2006, at 20:26 and 20:34 (local time), two almost simultaneous double-event earthquakes of the same magnitude 7.0, only kilometers apart in distance and 8 minutes apart in time, occurred off southwest Taiwan (Pingtung earthquakes marked by EQ1 and EQ2 in Fig. 1) (Liao et al. 2008). Shortly after the Pingtung earthquakes, local fishermen working in that area reported disturbed waters. Within the following 14 hours most of the cables broke at least once (stars in Fig. 1), causing major failures in international telecommunication affecting not only Taiwan but all the Southeast and East Asia countries alike. Alternative transmission systems were immediately overloaded and failed to transfer data smoothly through the world. The condition of cable break points demonstrate the violence of the mass flow carrying sediment particles and pebbles (e.g., Fig. 2). The aim of this paper is to show possible submarine landslides associated with the 2006 Pingtung earthquake; we use the telecommunication cable failure information to provide a full-scale scenario and calculation of the velocities of the turbidity currents (Kuenen and Migliorini 1950) under the assumption that those submarine telecommunication cables were broken due to the abrupt tension induced by the turbidity currents.

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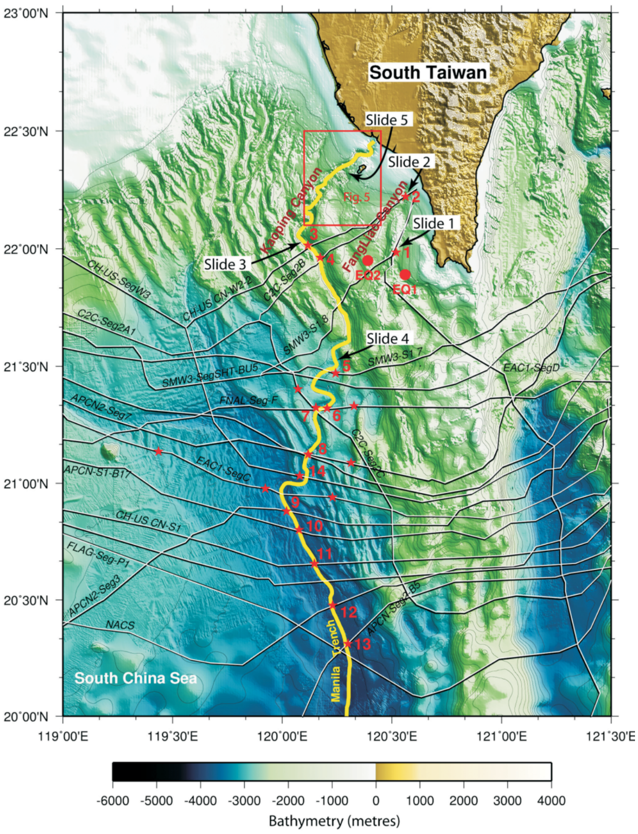

Fig. 1. Location of submarine telecommunication cables and cable breaks offshore SW Taiwan. EQ1 and EQ2 are the two major Pingtung earthquakes of magnitude 7.0. The yellow continuous line underlines the channel of the Kaoping canyon and Manila trench. Red stars correspond to the locations of cable breaks. Numbered stars are used in Fig. 3. Five submarine landslides are identified. Cable break times and locations are given in Table 1.

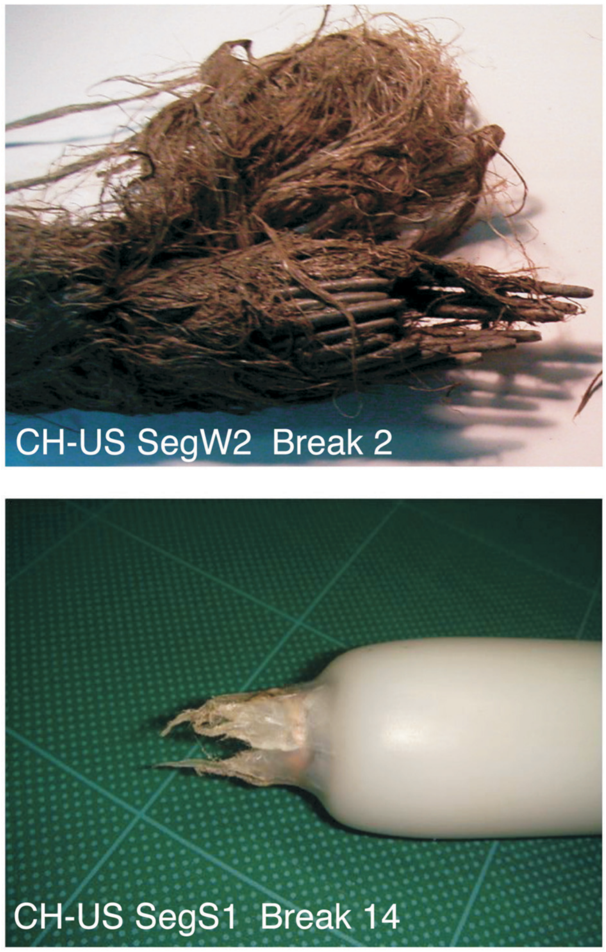

Fig. 2. Broken cables recovered during cable repair operations. Upper piture: break of an armoured type cable recovered during break 2 repair (located in Fig. 1). Lower picture: break of a lightweight type cable recovered during break 14 repair (located in Fig. 1).

2. CABLE BREAKS AND VELOCITY OF TURBIDITY CURRENTS AND SUBMARINE LANDSLIDES IN THE KAOPING CANYON

Based on reports of cable repair operations from involved telecommunication companies, actual break times and locations of the cable failures were obtained (Table 1). The cable breaks mainly occurred near the Fangliao canyon and the Kaoping canyon, which extend southward into the Manila trench (Fig. 1). These cable breaks were due to massive slumps, sediment slides or turbidity currents triggered by the main shocks and/or their aftershocks. Six cable breaks happen outside of canyon channels, presumably caused by overflows of turbidity currents from the canyon channels. Cable breaks 1 and 2 in Fig. 1 occurred along the Fangliao canyon at the time almost simultaneous as the first main shock (Table 1).

Some occurrence instances indicate that they may be caused by separate mass slumps or slides (slides 1 and 2 in Fig. 1) rather than turbidity currents. For example, the time interval between breaks 1 and 2 is only one minute and the distance between them is as far as 30 km, too long to be caused by a turbidity current.

Figure 3a shows the depth profile along the channel axis of the Kaoping canyon and Manila trench, starting at the head of the Kaoping canyon, Ten locations of the cable breaks are regularly distributed in the lower portion of the canyon (black squares), at depths larger than 2780 m. Only two locations of broken cables appear in the upper portion of the canyon, at depths of 1511 and 1570 m. Along the Kaoping canyon, only four cables were left intact (white squares in Fig. 3a).

Figure 3b shows the distance along the Kaoping canyon as a function of the cable break time since the occurrence of the first main shock. Except for cable break 14, which occurred about 9 hours later than expected, all cable breaks happened in sequence, indicating turbidity currents generated by landslides triggered by the earthquakes or its aftershocks.

Table 1. Summary of the submarine telecommunication cables breaks after the 2006 Pingtung earthquakes, offshore SW Taiwan.

Number	Break time (local time)	Cable name	Location of cable break (WGS84 system)		Water depth (m)
1	Dec.26-20:26	SMW3-S1.8	E120 31.161	N21 59.101	612
2	Dec.26-20:27	CH-US CN-W2-1	E120 33.722	N22 13.287	347
3	Dec.26-20:27	CH-US CN-W2-2	E120 7.005	N22 0.895	1511
4	Dec.26-20:37	C2C Seg2B	E120 10.397	N21 57.751	1690
5	Dec.26-20:41	SMW3-S1.7	E120 14.584	N21 28.195	2780
6	Dec.26-21:39	FNAL Seg-F	E120 12.274	N21 19.241	2964
7	Dec.26-22:58	C2C Seg2C	E120 9.204	N21 19.408	2956
8	Dec.27-00:06	APCN2-S7	E120 7.105	N21 7.423	3065
9	Dec.27-02:00	APCN2-S3	E120 1.170	N20 52.841	3638
10	Dec.27-02:15	APCN-S1-B17	E120 4.605	N20 48.049	3702
11	Dec.27-03:02	CH-US CN-S1	E120 8.798	N20 39.340	3784
12	Dec.27-04:42	NACS	E120 13.808	N20 28.624	3846
13	Dec.27-04:55	APCN-S2-B5	E120 17.968	N20 18.693	3967
14	Dec.27-10:04	CH-US CN-W1	E120 4.751	N21 1.948	3250

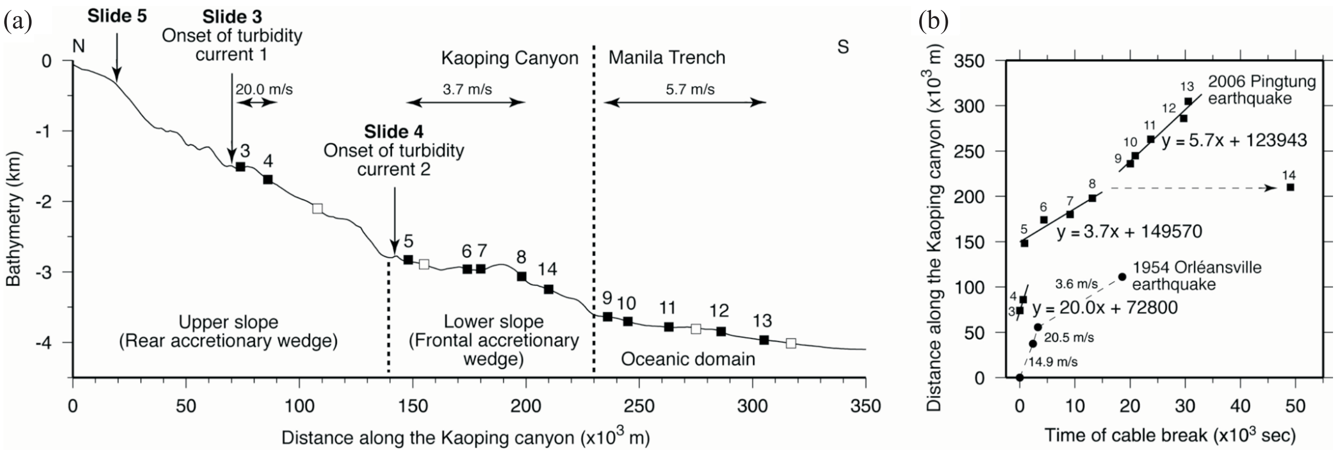

Fig. 3. Cable breaks along the Kaoping canyon and calculation of turbidity current velocities. (a) Bathymetric profile from the head of the Kaoping canyon to the Manila trench (cf. Fig. 1) with cable positions. Black squares with numbers indicate locations of cable breaks in Fig. 1. White squares indicate locations of non-ruptured cables. Submarine landslides and onsets of turbidity currents 1 and 2 are inferred. (b) Relationship between distance along the Kaoping canyon and Manila trench and cable break time. Numbered black squares same as in (a). The three thick lines fitting data correspond to turbidity current velocities of 20, 3.7, and 5.7 m s^{-1}. Cable breaks associated with a turbidity current for the Orléansville earthquake (*9-11*) are also displayed (black dots).

Based on cable breaks 3 and 4, a turbidity current velocity of 20 m s^{-1} is obtained. However, it is only estimated by two points, implying a potential velocity range of between 17 and 25 m s^{-1} if we take into account the one-minute precision of the cable break times. A submarine landslide (slide 3 in Fig. 1), which gave rise to turbidity current 1 is supposed to originate at about 1.2 km upstream of cable break location 3 (Fig. 3a) because the cable break 3 happened just 1 minute after the main shock. Between cable breaks 4 and 5, the time span is only 4 minutes for a distance of 62 km, suggesting the existence of another submarine landslide (slide 4 in Fig. 1) located less than 3.4 km upstream of location 5 (turbidity current 2 in Fig. 3a). Between cable breaks 5 to 8 and 9 to 13, linear regressions gives velocities of 3.7 and 5.7 m s^{-1}, respectively (Fig. 3b). The linear relationship suggests that the cables were probably ruptured as soon as the turbidity current passed through and that the turbidity current flows at a near constant velocity along the quasi-linear bathymetric segments. Because cable breaks 8 and 9 display a continuous increase in break time, the turbidity current associated with breaks 6 to 13 is probably originated from the same submarine landslide (slide 4 in Fig. 3a). Our three estimated turbidity current velocities of 20, 3.7, and 5.7 m s^{-1} are located on three different slopes: 18×10^{-3}, 3.5×10^{-3}, and 4.2×10^{-3} which correspond to the upper and lower slopes of the accretionary prism and to the oceanic domain. The turbidity current velocities and the bathymetric slopes show a positive correlation (Fig. 4).

Figure 5 shows two intersecting sub-bottom profiles collected near the Kaoping canyon head before (29 Sept. 2006) and after (8 Jan. 2008) the Pingtung earthquakes. Although they are 3 km apart at their southeastern ends, there is a strong possibility that the submarine landslide imaged in Fig. 5c was due to a submarine landslide (slide 5 in Fig. 1) triggered by the earthquakes. This landslide has ~3-m vertical offset and a ~60-m long rupture surface (Fig. 5c). In total, the Pingtung earthquakes triggered at least three submarine landslides identified in the Kaoping canyon, and two in the close vicinity of the Fungliao canyon.

3. COMPARISONS WITH OTHER TURBIDITY CURRENT VELOCITY MEASUREMENTS

Turbidity currents associated with landslides caused by earthquakes or storm waves could be recorded by current

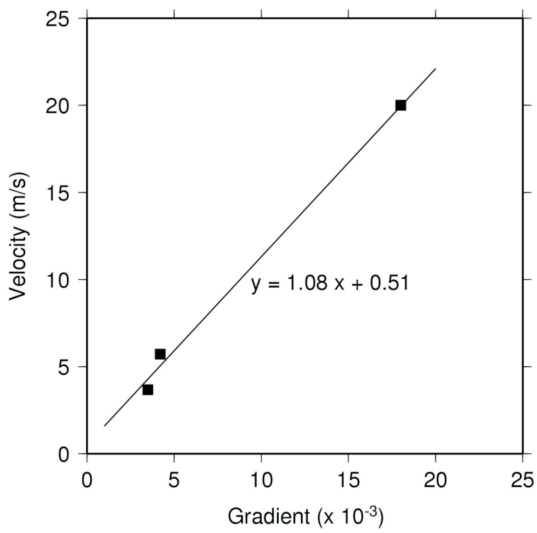

Fig. 4. The relationship between the estimated turbidity current velocity and bathymetric slope.

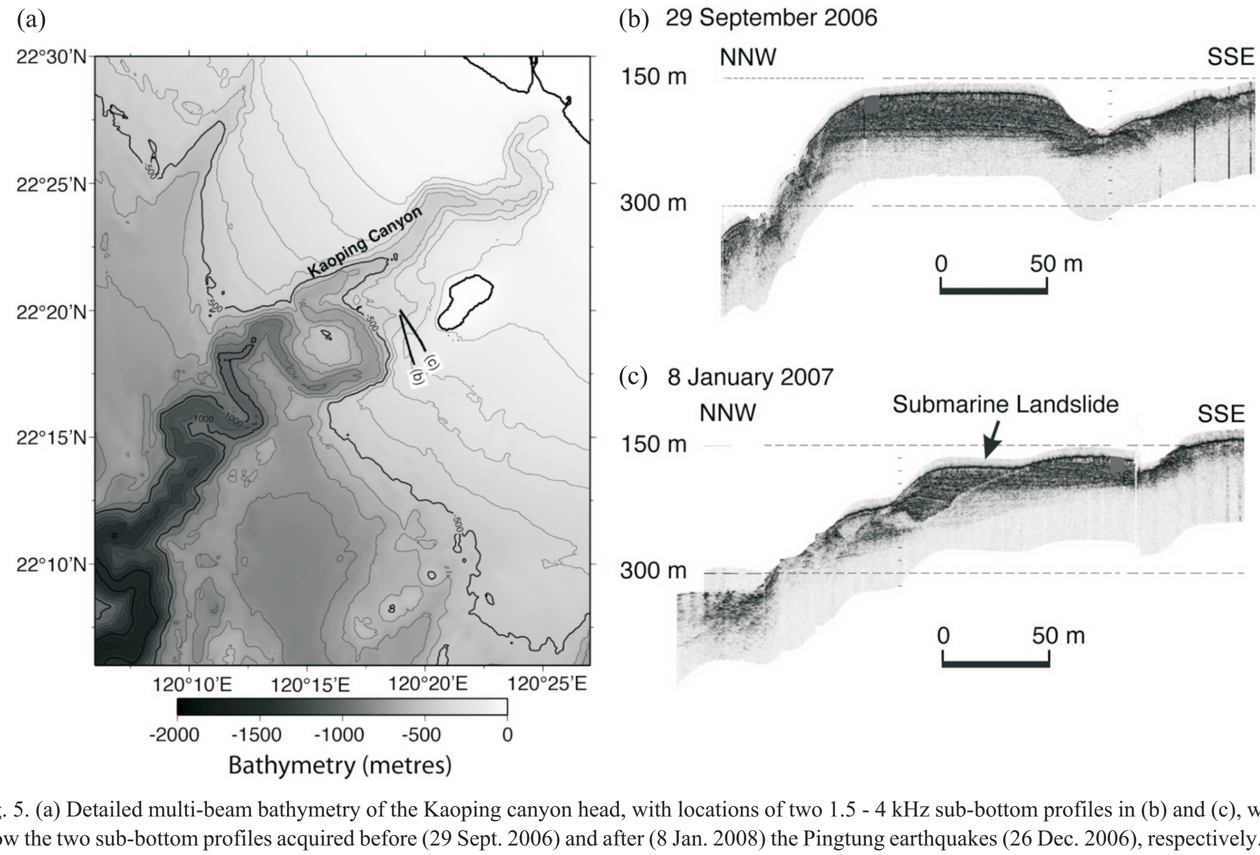

Fig. 5. (a) Detailed multi-beam bathymetry of the Kaoping canyon head, with locations of two 1.5 - 4 kHz sub-bottom profiles in (b) and (c), which show the two sub-bottom profiles acquired before (29 Sept. 2006) and after (8 Jan. 2008) the Pingtung earthquakes (26 Dec. 2006), respectively. The possible submarine landslide is indicated in (c).

meters and light transmission instruments moored in canyons whether connected or not by submarine cable to land. However, data are generally scarce and moorings are often either destroyed or too high above the seafloor to give true turbidity current velocities (e.g., Kripounoff et al. 2003), or only minor turbidity currents are measured (e.g., Mitsuzawa et al. 2004; Xu et al. 2004). Unless equipments are designed to monitor deep stations in severe conditions, an effective way to get turbidity current velocities is to use cable break information.

Following the 1929 Grand Banks earthquake, Heezen and Ewing (1952) determined a maximum velocity of turbidity currents of 28 m s^{-1} on the mid-slope, slowly decreasing to 6 m s^{-1} in the deep abyssal plain. A series of simultaneous slides or an enormous slump located on the upper to middle slope of more than 100 km in diameter broke eleven cables in the same geographical area and at the exact time of the earthquake. Most of the outer broken cables were buried beneath a one-metre thick turbidite layer (Heezen and Drake 1964) so that they could not be recovered for repair. These high turbidity current velocities were later put in question and a more reasonable interpretation appears to be that the times between outer cable breaks only indicate a turbidity current velocity of about 7.7 m s^{-1} without significant velocity change from the lower slope to the abyssal plain (Heezen and Drake 1964; Shepard 1964). In that case, the slump originating the turbidity current was assumed to be deeper than the one suggested by Heezen and Ewing (1952). A comparison of the portion of bathymetric profile deeper than the enormous slump (> 3500 m) with the corresponding portion of the Kaoping canyon profile (deeper than 3500 m in the oceanic domain of Fig. 3a) shows that the slopes of the profiles are similar. Although the 7.7 m s^{-1} velocity determination is not accurate, this value is in the same range than the one for the corresponding portion of the Kaoping canyon (5.7 m s^{-1}).

The turbidity current triggered by the September 1954 Orléansville earthquake (Rothé 1955) on the northern Algeria margin cut five telephone cables; however, the time of cable breaking was known for only three of them. Bourcart and Glangeaud (1956) and Heezen and Ewing (1955) believe that the breaks in submarine cables were caused by the motion of a landslide detached from the shelf edge by the earthquake and transformed into a strong turbidity current, which swept out across the Balearic abyssal plain, rather than directly by earthquake movements. Turbidity current velocities are 20.5 m s^{-1} between the two cables closest to shore (Heezen and Ewing 1956), 3.6 m s^{-1} between two more remote cables (Bourcart and Glangeaud 1956) and 14.9 m s^{-1} between the shelf edge and the nearest broken cable (El-Robrini et al. 1985) (Fig. 3b). For comparison, cable breaks associated with a turbidity current triggered by the Orléansville earthquake (Heezen and Ewing 1955; Bourcart and Glangeaud 1956; El-Robrini et al. 1985) are displayed on the same figure (black dots). Note the parallel curves between turbidity current velocities for the Pingtung and Orléansville earthquakes.

Likewise, 15 minutes after the 1980 El-Asnam (Algeria) earthquake (Yielding et al. 1981), the control signal was lost on the Alger-Las Palmas cable. The ground noise increased for 5 minutes and then the cable ruptured at a depth of 1470 m (El-Robrini et al. 1985). Assuming that the turbidity current started at the shelf break, the estimated velocity of the turbidity current was 10 m s^{-1}, an estimate comparable to that determined at the Nice margin (Gennesseaux et al. 1980).

4. CONCLUSION

This study reports the submarine telecommunication cable failures off the coast of SW Taiwan due to the submarine landslides and turbidity currents induced by the 2006 Pingtung earthquake. The turbidity current velocities are estimated to be several to tens of meters per second, depending on bathymetric slopes. Although there was some overflow, turbidity currents generally flow along canyon channels and transport sediment or particulate material into deep ocean basin. The violent cable failures happened in the case of the 2006 Pingtung earthquakes evidenced the destructive power of the turbidity current to seafloor or underwater facilities that should not be underestimated.

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