COMPLEX DISASTER DAMAGE TO WATER RESOURCES IN TAIWAN

DOMMAGE CUASE PAR LE DESASTRE AUX RESSOURCES EN EAU A TAÏWAN

Yih-Chi Tan[1], Fong-Zuo Lee and Jihn-Sung Lai

ABSTRACT

Taiwan iss located at the junction of Pacific, Eurasian, and Philippine Sea plates is subject to frequent earthquakes. Chi-Chi earthquake had caused major damage, which left 2,505 dead and 11,305 injured. In addition, Taiwan is also vulnerable to damages by typhoons. According 60 years' statistics, 3.6 typhoons strike Taiwan every year. This research is aimed on an oldest reservoir after Chi-Chi earthquake and after typhoon stroke makeing huge sediment yield. The Shihmen reservoir is one of the most important and oldest reservoirs in the northern Taiwan. It is a multi-functional reservoir for irrigation, water supply, hydroelectric power, flood prevention and recreation. In 2004, the inflow of Typhoon Aere brought large amount woody debris with high sediment-laden flow into the Shihmen reservoir. Massive woody debris is carried into the hydroelectric power intake to seriously damage turbines. Sediment concentration of the inflow water in Typhoon Aere rose up to 326,700 mg/L which far-exceeded the water treatment capacity. Such high turbid concentration caused water shortage for two weeks in the Taoyuan area where 2.4 million people live. Afterword, floating barriers had been built at upstream to trap woody debris. However, the flow-sediment interaction mechanism between turbidity current and woody debris motion has not yet been well understand. From field observations, we can learn more details between woody debris and turbidity current in the Shihmen reservoir.

Key Words: *Chi-Chi earthquake , typhoon , woody debris, turbidity current*

RESUME

Le Taïwan situé au carrefour de la plaque des mers Pacifique, Eurasien et Philippines est soumis aux tremblements de terre. Le tremblement de terre Chi-Chi avait causé des dégâts majeurs, qui ont laissé 2,505 morts et 11,305 blessés. De plus, le Taïwan est aussi vulnérable aux dégâts causés par les typhons. Selon la statistique de 60 années, 3,6 typhons frappent

1 Professor, Department of Bioenvironmental Systems Engineering, CEO, Center for Weather Climate and Disaster Research Research Follow, Hydrotech Research Institute, National Taiwan University, Taipei City, 106, Taiwan, Tel: +8862-3366-3453, Fax: +8862-2363-5854, Email: yctan@ntu.edu.tw

la région chaque année. Cette recherche est menée sur un plus vieux réservoir après le tremblement de terre Chi-Chi et le typhon a déposé une grande quantité de sédiment. Le réservoir Shihmen est l'un des plus importants et vieux réservoirs au nord du Taïwan. C'est un réservoir à fonctions multiples de l'irrigation, de l'approvisionnement en eau, de l'énergie hydro-électrique, de la prévention contre les crues et de la récréation. En 2004, l'entrée du typhon Aere a apporté la grande quantité des débris boisés avec le haut débit chargé de dépôt au réservoir Shihmen. Les débris boisés massifs ont sérieusement endommagé les turbines. La concentration de dépôt de l'eau d'entrée dans le typhon Aere s'élevait jusqu'à 326 700 mg/L qui a excédé la capacité de traitement des eaux. Une telle haute concentration a causé le manque d'eau pendant deux semaines dans le secteur Taoyuan où habitaient 2,4 millions de personnes. Donc, les barrières flottantes avaient été construites en amont pour arrêter les débris boisés. Cependant, le mécanisme d'interaction du débit de dépôt entre le courant de turbidité et les débris boisés n'a pas encore bien résolu. L'observation sur le terrain nous donne des informations sur les débris boisés et le courant de turbidité du réservoir Shihmen.

Mots Clés: *Tremblement de terre Chi-Chi, typhon, débris boisés, courant de turbidité.*

1. INTRODUCTION

Taiwan is situated at a geographical location with special climatic condition that brings to the island 3.6 typhoons on an average every year. These typhoons often result in flood disasters that can cause serious damage to properties and sometimes with severe casualties. Besides, typhoons or heavy rain fall generate large sediment yield. Land development in the watershed could accelerate soil erosion. As sediment moves into a reservoir, deposition occurs due to reduction of velocity. In general, the large size sediment may deposit quickly to form delta near the tail of the backwater region. The hydraulic phenomenon of delta area is similar to the shallow water of open channel. The inflow sediment presents two patterns, bed load and suspended load. The bed load may deposit at the front set of delta, and the suspended load may flow through the delta and deposit by sorting. When turbid inflow continues to move, the turbulence energy decreases by resistance. The inflow may plunge into the reservoir to develop turbidity current and move toward downstream. At plunge point, the water near the surface in the reservoir can flow toward upstream due to continuity behavior of the flow. Figure 1 illustrates the flow phenomenon of density current and trapped debris.

Many flume experiments and field measurements have shown that the occurrence of the turbidity current at plunge point can be related to velocity, depth and fluid density before plunge point (Graf 1983). In 2004, Typhoon Aere attacked north Taiwan. The Shihmen reservoir water supply suffered from a shortage of water for 14 days in the Taoyuan area where 2.4 million people live. The watershed of Shihmen reservoir is shown in Figure 2. The Figure 3 shows that woody debris distribution was near the dam site after Typhoon Aere. It is seen IIn the figure that massive woody debris floated and got trapped in front of the dam. The extraction volume was about 5.4×10^5 m^3. The field survey shows that when the hydropower plant was in operation, the turbine was damaged by woody debris that was carried into the hydroelectric power intake by flow to clog up the facilities (Figure 4).

This study presents the annual extraction volume of woody debris from 2004 to 2008 when typhoons with heavy rainfall occurred. A regressed formula was used to estimate the volume of woody debris. The plunge point variation was calculated by an empirical formula. The mechanism between woody debris and turbidity current was preliminarily discussed through field observations.

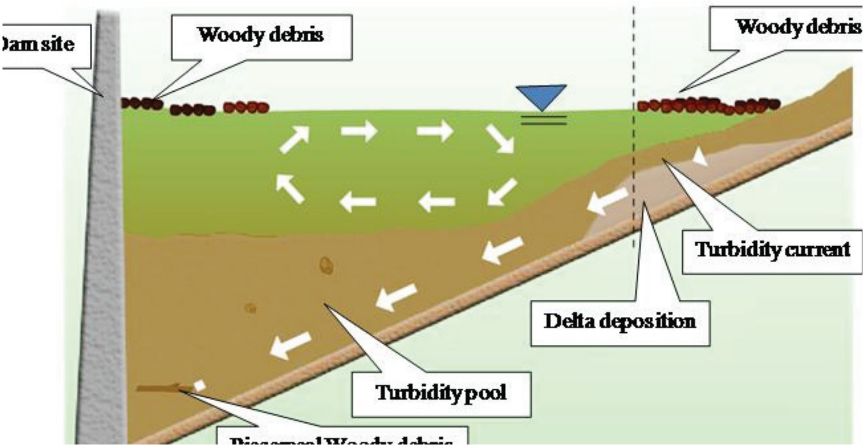

Fig. 1. Relationship between woody debris and turbidity current

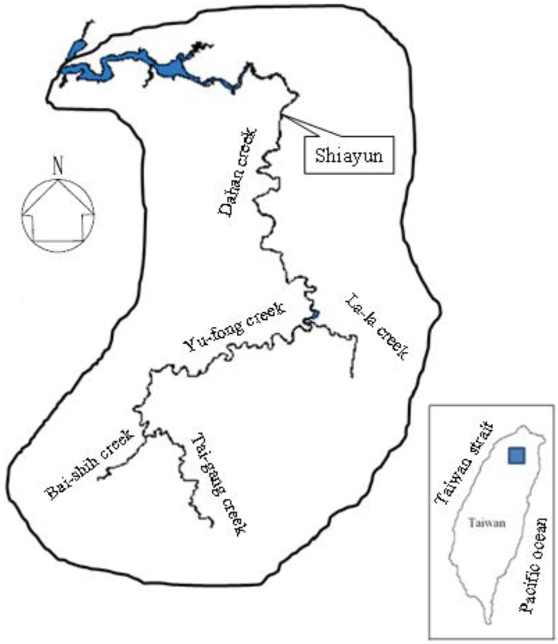

Fig. 2. Watershed area of Shihmen reservoir (Moulin and Piegay, 2004)

Fig. 3. The woody debris of Typhoon Aere (Young and Lai, 2008) [6]

Fig. 4. The turbine was clogged with woody debris (Young and Lai, 2008)

2. SITE DESCRIPTION

The Shihmen reservoir is a multi-functional reservoir and its functions include irrigation, water supply, generating electric power, preventing flood and recreation. The irrigation districts include Taoyuan, Hsinchu and Taipei for a total of 3.65 x10^8 m^2. The reservoir supplies drinking water to 28 districts and 3.4 million people. It is a very important water resource for the livelihood of the people in the northern Taiwan. Making use of the water impoundment at Shihmen dam, the Shihmen Power Plant generates 2.3 hundred million KWH annually, a vital contribution to help electric power demand at peak demand hours and industrial development. The reservoir's main function is to prevent flood during typhoon and heavy rain seasons.

The Shihmen reservoir has a natural drainage area of 762.4 km^2. It is formed by the Shihmen dam located at the upstream reach of the Dahan River. The Dahan River is one of the three tributaries of the Tamshuei River which flows westward the Taiwan Strait. A map of the watershed area of the Shihmen reservoir is presented in figure 2. The Shihmen dam was constructed in 1963 is a 133.1m high embankment dam with spillways, permanent river outlet, power plant intake and flood diversion tunnels controlled by tailrace gates. The elevations of the spillway crest, permanent river outlet, power plant intake and flood diversion tunnels are EL.235 m, EL.169.5m, EL.173m and EL.220m, respectively. The total discharge of spillways is 11,400 m^3/s, permanent river outlet is 34 m^3/s, power plant intake is 137.2 m^3/s and flood diversion tunnels is 2,400 m^3/s. With a maximum water level of EL.245 m, the reservoir pool is about 16.5 km in length and forms a water surface area of 8.15 km^2. The initial storage capacity was 30,912 x 10^5 m^3, and the active storage was 25,188 x 10^5 m^3. Due to a lack of sufficient de-siltation facilities, incoming sediment particles have settled down rapidly along the reservoir since the dam was completed. Based on the survey data, the Shihmen reservoir has accumulated a significant amount of sediment after dam completion. The depositional pattern has become wedge-shaped since 2000. From recent survey data in 2007, the storage capacity was estimated to be 69.28% of its initial capacity.

3. WOODY DEBRIS

Woody debris is a structure element of river systems, which provides habitats for aquatic communities in the mountain area. But, due to steep slope and rain fall intensity, turbid inflow discharge is often supplied with dead trees coming from the watershed of reservoir. In 2004, the inflow discharge of Typhoon Aere brought large amount woody debris with high sediment concentration into the Shihmen reservoir. Massive woody debris was carried into the reservoir and drifted into power intakes to damage hydroelectric power generation facilities. The extraction volume was about 5.4 $\times 10^5$ m^3. In addition, sediment concentration of the inflow water in Typhoon Aere rose to 326,700 mg/L which was far-exceeded water treatment capacity. Such high turbidity water leads to water shortage for two weeks in the Taoyuan area where 2.4 million people live. In 2005, as Typhoon Haitang, Matsa and Talim attacked Taiwan, it resulted in 2 $\times 10^5$ m^3 extracted volume of woody debris, as shown in figure 5. Based on empirical formula of Rhone's river in winter presented by Moulin (2004), the inflow volume of woody debris can be estimated by inflow peak discharge. The assessment volume of woody debris during Typhoon Aere is about 6 $\times 10^5$ m^3 which is closed to field extraction volume (5.4 $\times 10^5$ m^3). According to taxonomic genus, most floating pieces belong to conifer and sinking pieces belong to broad-leaved tree. Based on filed survey, the floating pieces include Chamaecyparis formosensis, Calocedrus formosana, Cunninghamia lanceolata and Cryptomeria japonica. And, the sinking pieces include Cyclobalanopsis gilva, Cinnamomum camphora, Michelia formosana and Alnus formosana. Because of the different hydrological and morphological characteristics, the empirical formula needs to adjust by historical data of Shihmen reservoir. Therefore, the empirical formula does not apply to assess the woody debris volume of typhoon from 2005 to 2008. The annual woody debris was decreasing against the time. From 2006 to 2008, the extracted volume of woody debris was about 15,000 m^3, 10,000 m^3 and 5,000 m^3, respectively. Even though this tendency, the floating barriers had been installed at upstream at section 24 and section 27 to prevent woody debris into the reservoir area by Shihmen reservoir government (Young 2008). The conceptual idea is assumed that inflow woody debris flowing with turbid inflow and its flow mechanism is related to turbid inflow. Therefore, the floating barriers were established at upstream before turbid inflow plunged into reservoir bottom.

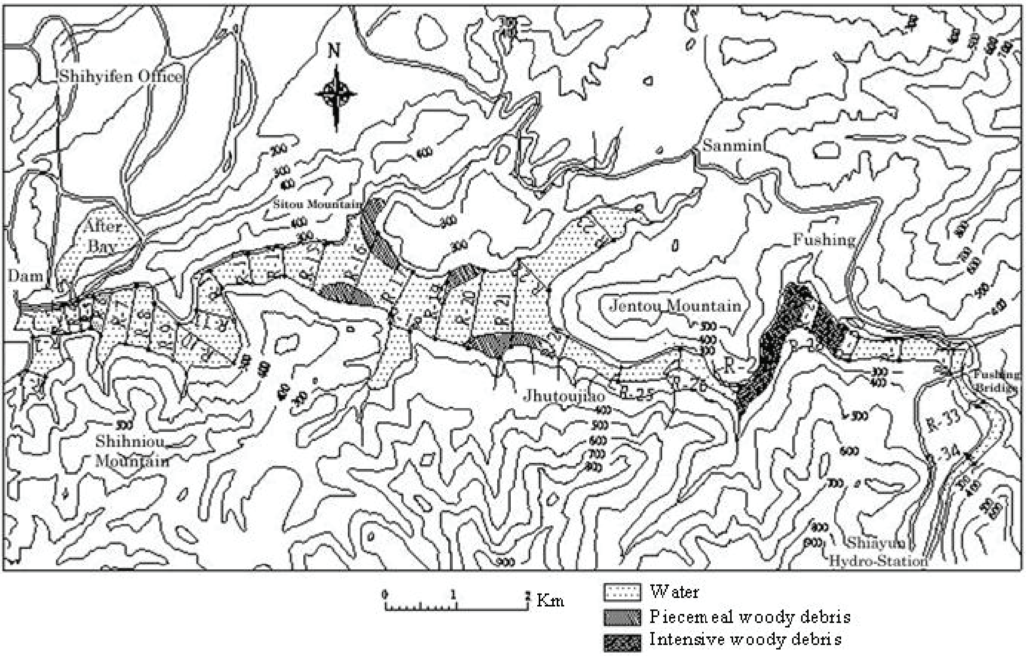

Fig. 5. Distribution of woody debris in Aug. 11 of 2005 after Typhoon Haitang and Typhoon Matsa (Young and Lai, 2008)

4. TURBIDITY CURRENT

As mentioned before, in order to prevent woody debris flowing with turbidity current and plunge into the reservoir bottom, the plunge point of turbidity current should be estimated. Therefore, the objective of this component was to calculate plunge point evolution by means of an empirical equation with inflow hydrology. The following equation is an empirical formula in calculating plunge point (Lee and Yu 1997).

$$V_o = F_{rd}\sqrt{\frac{\Delta\gamma}{\gamma'} g h_o}$$

where V_0 average velocity of plunge point; $\Delta\gamma$; $\gamma' - \gamma_0$; γ' = specific gravity of turbidity current; γ_0 specific gravity of fluid current ; h_0 water depth of plunge point; g = gravitational acceleration; F_{rd} = densimetric Froude number.

Based on the continuous field measurement, the suspended sediment concentration in Shihmen reservoir could be linked to the discharge by following formula:

$$Q_s = aQ^m = 0.00257Q^{2.08} \qquad R^2 = 0.801$$

where a, m = empirical rating coefficients; Q_s = suspended sediment concentration (kg/sec); Q = inflow discharge (m^3/s). According to Mulder and Syvitsky (1995), for many rivers the rating exponent *m* are typically between 0.5 and 1.5, and if m is determined from daily averaged or instantaneous measurements, it can frequently reach 2. Figure 6 shows the hydrograph of inflow discharge and inflow concentration by mentioned formula. Then, the specific gravity of turbidity current can be estimated by this formula. On the other hand, according to cross section and water level, the average velocity of plunge point and water depth of plunge point can be estimated. Therefore, the densimetric Froude number of each section is calculated, as shown in figure 7. Figure 7 is the results of densimetric Froude number variation during Typhoon Jangmi and it shows that the variation of densimetric Froude number was changing with flow condition. At beginning of Typhoon Jangmi, the plunge position was between section 30 and section 29. Then, high turbidity current accompanied by increasing inflow discharge and forced plunge point moving to downstream. When peak inflow is coming, the plunge point was between section 27 and section 26. But, when inflow discharge was decreasing to instream-flow, the plunge point was between section 29 and section 27.

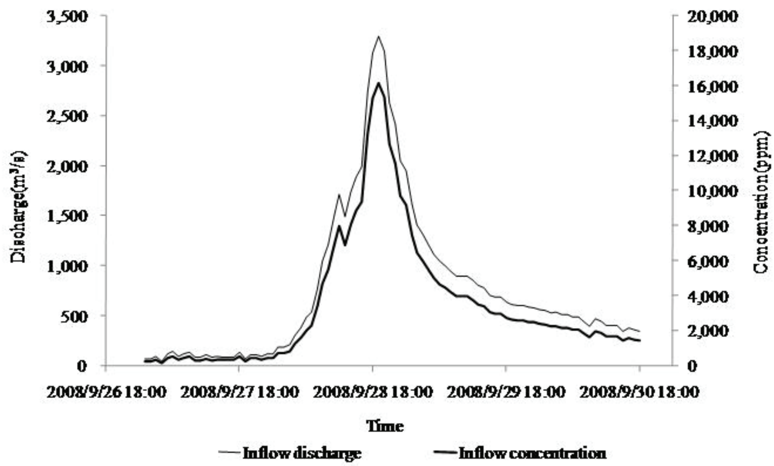

Fig.6. Hygrograph of inflow discharge and concentration

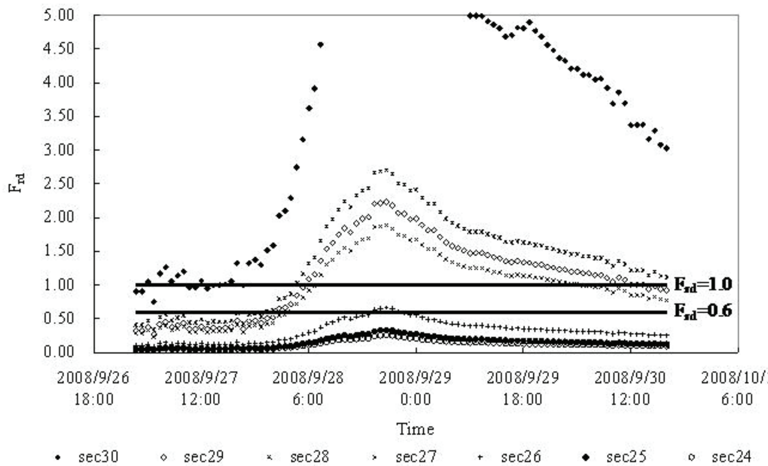

Fig. 7. Densimetric Froude number variation during Typhoon Jangmi

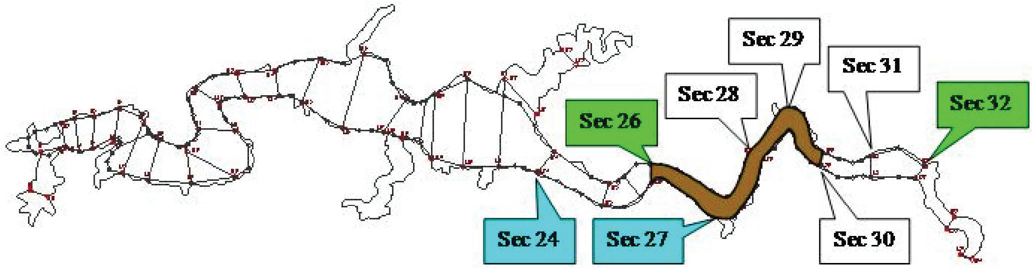

Fig. 8. Plunge point area during Typhoon Jangmi

Fig. 9. Woody debris location after Typhoon Jangmi at section 24

5. CONCLUSIONS

Based on plunge point estimation of Typhoon Jangmi, the plunge point is not fixed. With increasing inflow discharge, the plunge point moves to downstream and with decreasing inflow discharge, the plunge point moves to upstream. According to the assessment, the plunge area was between section 30 and section 26, as shown in figure 8 and this result was closed to the position of intensive woody debris that had been shown in figure 5. The floating barriers had been installed at section 24 and section 27 in 2008 by Shihmen reservoir government to prevent woody debris into the reservoir area. The plunge point variation shows that during Typhoon and heavy rain, some woody debris would overflow the floating barrier at section 27 and some woody debris would plunge into the floating barrier at section 24. On the basis of densimetric Froude number simulation, the described situation probably happened. The figure 9 shows the woody debris location at section 24 after Typhoon Jangmi and confirms the description.

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