



DAMAGE TO HYDRAULIC FACILITIES FROM THE CHI-CHI (TAIWAN) EARTHQUAKE

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ABSTRACT

On September 21, 1999, the Chi-Chi (Taiwan) Earthquake with a local magnitude of 7.3, struck west-central Taiwan and resulted in tremendous disasters with a death toll over 2,000. Hydraulic facilities such as river banks, levees, dams, weirs, channels, and irrigation systems were seriously damaged in the counties of Miaoli, Taichung, Changhua, Yunlin, and Nantou. In addition, some waterways were blocked by landslide materials, and thus, new lakes were formed. The damage to hydraulic facilities and the causes are thoroughly investigated. The performance of dams under this earthquake is discussed in view of earthquake resistant design. The inundation maps for the downstream lowlands of the blocked creeks are analyzed by using a dam-break flow numerical model. As a result, the damaged facilities are identified and suggestions for restoration are proposed. The results can be used as a reference in proposing strategies for hazard mitigation and recovery plans.

I. INTRODUCTION

A powerful earthquake shattered west-central Taiwan at 1:47 am, September 21, 1999, killing 2,333 people, toppling buildings and trapping hundreds in the wreckage. The Chi-Chi (Taiwan) Earthquake occurred at a depth of approximately 6.99 km beneath

the earth surface. The epicenter, near a small town, Chi-Chi, was 160 km south-south west of Taipei. In west-central Taiwan, including the basins of Taan Creek, Tachia Creek, Wu Creek, and Choushui Creek, there are three important faults trending nearly north-south with moderate dips toward the east. From east to west, they are the Shuangtung fault, the Chelungpu

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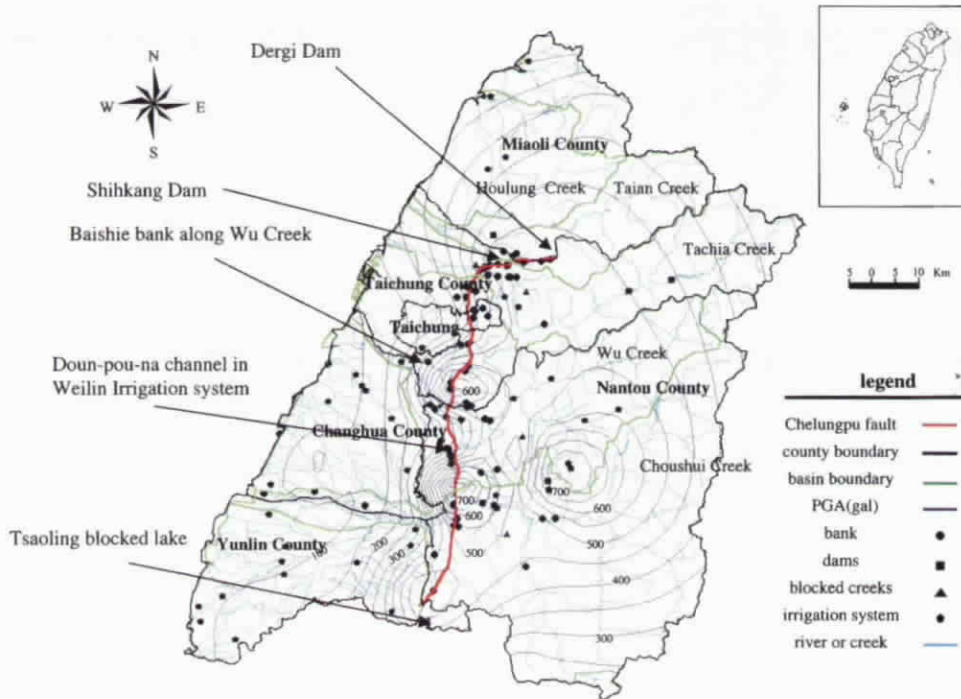


Fig. 1 Relationship between the Chelungpu fault and the locations of the damaged hydraulic facilities

fault, and the Changhua fault. The Chelungpu thrust fault is one of the major geological structures in west-central Taiwan. It runs approximately along the eastern margin of the Taichung basin and extends north-south. Geographically, the Chelungpu fault passes through Tachia Creek, Fengyuan, Takung, Chelungpu, Wufung, Tsaotung, Chung-hsing-hsin-tsun, Nantou, Mingchien, and Choshui Creek. The Executive Yuan of the R.O.C. assigned the National Center for Research on Earthquake Engineering (NCREE) to investigate the damage from the Chi-Chi (Taiwan) Earthquake. As the damage investigations on hydraulic facilities were extensive and urgent, NCREE immediately rallied more than 60 hydraulic and civil engineering experts to join the investigation team and to collect data from any resource to complete the damage investigation in a timely manner.

Ground motion in the Chi-Chi (Taiwan) Earthquake may be characterized as high accelerations, large velocity pulses, and permanent tectonic displacement. The nature of ground motion is related to the direction and mechanics of the fault rupture as well as the path of the seismic wave to the site. Fig. 1 shows the relationship between the Chelungpu fault and the locations of the damaged hydraulic facilities in the counties of Miaoli, Taichung, Changhua, Yunlin, and Nantou. It clearly points out that the damaged locations were concentrated along the Chelungpu fault. Recorded peak horizontal accelerations typically ranged between 0.4g to 0.8g in the

regions that suffered significant hydraulic facilities damage. Some riverbanks along Tachia Creek, Choshui Creek, and Wu Creek were cracked. Shihkang Dam was severely damaged. Landslide materials blocked five different creeks and formed new lakes. The irrigation systems of west-central Taiwan were also seriously damaged.

The main purpose of this paper is to delineate the damage to hydraulic facilities from the Chi-Chi (Taiwan) Earthquake and to analyze the causes resulting in the destruction of important hydraulic facilities. Three major parts are included in this paper: (1) damage to dams, (2) inundation map of the main blocked creek, and (3) damage to river banks and irrigation systems. The damaged areas are identified and some suggestions for the restoration of hydraulic facilities are also proposed. A discussion of the damage to and earthquake resistant design of dams is herein presented. Inundation analyses for the downstream lowlands, in case of the landslide materials breaking in creeks were also carried out. They can assist relevant authorities in proposing strategies for hazard mitigation and recovery plans.

II. DAMAGE TO DAMS

Immediately following the Chi-Chi (Taiwan) Earthquake, the investigation teams visited more than 16 dams within 80 km of the epicenter and seven of them were found with some cracks or movement, but none were judged to be a safety hazard. These dams

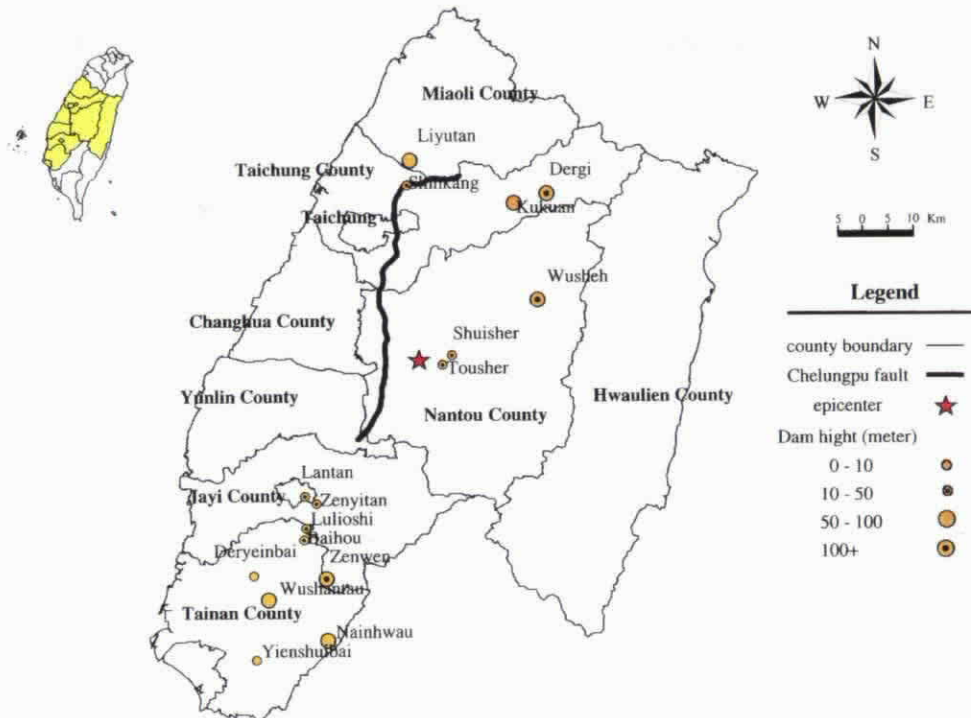


Fig. 2 Locations of dams in west-central Taiwan

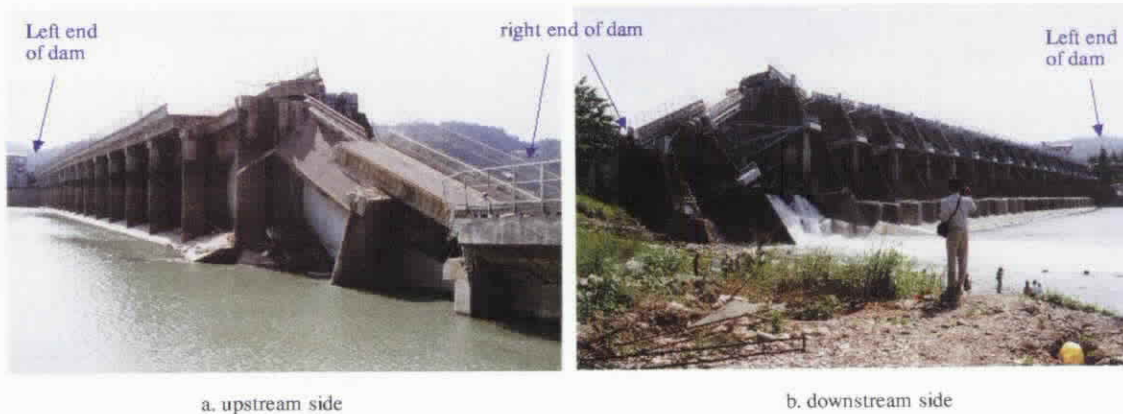


Fig. 3 Damage to Shihkang Dam

were inspected at least 1 month after the earthquake and had only minor cracks.

1. Shihkang Dam

The most serious damage occurred at Shihkang Dam, a 25-meter-high dam located on a river channel of great capacity (Tachia Creek) and administered by Taichung County. The structure is a relatively low diversion dam. Shihkang Dam is located near the Chelungpu fault and about 40 kilometers from the epicenter as shown in Fig. 2. During the earthquake, the reservoir was 30 percent full with a volume of 0.5 million cubic meters, and the water surface was 5.2 meters below the crest.

Peak horizontal accelerations on the abutments were ranged from 0.6g at the foot of the dam to 0.9g on the sidewall near the crest. Damage visible at the site was consistent with the strong shaking indicated by the strong ground motion and the rupture of the Chelungpu fault. The sluice gate on the left end of the dam and six of eighteen spillway gates are still operational. Fig. 3 shows the four gates at the right end of the dam were severely damaged and cannot be easily repaired. In addition, the crest elevations of all the sluice gates and spillway gates should be surveyed and new rating curves should be computed. The design and construction of a new replacement structure at an alternative site would take years to complete. However, this structure provides vital

water supply benefits to Taichung City. The restoration of Shihkang Dam must be done within a reasonable time.

2. Sun Moon Lake

Technical review of the instrumentation monitoring data and visual inspection results for two embankment dams, Shuisher Dam and Touser Dam at Sun Moon Lake, which is about 10 kilometers from the epicenter, are presented herein. The conditions of the dams were inspected and evaluated.

(i) Shuisher Dam

As a result of the earthquake, seven longitudinal cracks with opening up to about 7 cm occurred on the dam crest, and the upstream and downstream faces of the dam. Cracks occurred on both sides of the dam crest paving and in the center of the paving. Three cracks occurred on the upstream face of the dam. The cracks on the upstream face appeared to be associated with construction joints in the upstream concrete slope protection. Maximum settlement of the dam was about 13 cm. Minor increases in seepage flows were detected and the seepage flows carried sediments on September 29. However, the seepage flow became clear in early October.

The cracks in the crest of dam were sealed to prevent water from entering by the Sun Moon Lake Administration Bureau. Daily monitoring of the instrumentation was continued for a month to assure that the measurement had stabilized. The investigation of the bulge in the roadway at about the center of the dam determined that no obvious buried structural features exist and the bulge was not associated with cracking or deformation of the corewall. However, the cracks should be sealed to prevent undermining of the slope protection and erosion of paving.

(ii) Touser Dam

According to the investigation results, there is no apparent reason for concern related to the performance of the structure during the earthquake. The cracking and settlement of the random fill over the concrete slope protection paving is not a concern, and is not an evidence of embankment instability. A visual inspection of the dam embankment was carried out and the cracks observed on the downstream side of the reservoir rim appear to be associated with sliding of superficial materials and roadway fill, and do not indicate deep-seated failure. The cracks along the roadway have been sealed by the Sun Moon Lake Administration Bureau to prevent water from penetrating and saturating the slide areas. Slide material above the roadway was also removed and the slope

was repaired to provide a more stable surface. The reservoir rim area should be visually inspected, particularly after any significant rainfall or further earthquake activity to determine if there is any indication of instability.

The reservoir can be returned to normal operations after the cracks on the main dam are sealed, and the bulge area is investigated if continued monitoring and inspection do not indicate any concerns.

III. PRELIMINARY STUDY OF DAMS

When a structure is excited under an earthquake motion, its base tends to move with the ground where it is supported. Since the ground motion is relatively strong, it causes stresses and deformations in the structure. If the structure is assumed to be rigid, it will move with the ground motion of its base, and the dynamic forces acting on it are almost the same as those associated with the base accelerations. On the other hand, large relative motions or deformations will be induced if the structure is very flexible. Thus, the structure must be strong and ductile enough in order to survive strong earthquake motions. However, it should be mentioned that the level of earthquake hazard for which a structure should be designed is highly uncertain.

Unlike a general building design, where the design force to resist earthquake motions can be obtained from the building code directly, the site-dependent earthquake design force is often used for a dam. In fact, in the previous earthquake resistant design of dams in Taiwan, three design earthquakes (Housner, 1985) of different magnitudes are usually used and they are the:

- (1) maximum credible earthquake (MCE),
- (2) design basis earthquake (DBE), and
- (3) operating basis earthquake (OBE).

A maximum credible earthquake for design is the maximum earthquake that is possible to occur, tectonically, although its probability of occurrence is very small. Under this earthquake, only limited damage is allowed to the dam and the safe control of the water stored must be achieved. A design basis earthquake is the maximum earthquake that is possible to occur during the lifetime of the dam. In general, its return period is chosen to be 100 years. In addition, the major facilities must remain operating after this earthquake and only minor damage is allowed. An operating basis earthquake is generally defined as the earthquake whose return period is 25 years for the general design of a dam in Taiwan. Under this seismic excitation, no damage to major facilities is allowed. In addition, all the major facilities should remain functional after the earthquake.

All the design earthquakes mentioned above can

Table 1 Comparisons of design earthquake to the PGA induced by the Chi-Chi (Taiwan) Earthquake

Name of Dam	Height (m)	Capacity (10 ⁶ m ³)	MCE (g)	DBE (g)	OBE (g)	R (km)	a_{PGA} (g)	Damage Type
Shihkang	25	3.3	–	–	–	1.00	0.72	Broken
Liyutan	96	126.1	0.24	0.22	0.20	6.00	0.52	Cracked
Kukuan	85	13.2	0.24	0.22	0.20	11.9	0.38	Cracked
Tousher	20	0.3	0.24	0.20	0.18	12.9	0.36	Cracked
Shuisher	30	171.6	0.24	0.20	0.18	13.9	0.35	Cracked
Lantan	31	9.4	0.24	0.20	0.18	16.9	0.30	=
Zenyitan	28	29.1	0.24	0.20	0.18	17.9	0.29	=
Dergi	180	232.1	0.24	0.22	0.20	19.9	0.27	Cracked
Lulioshi	30	3.8	0.24	0.20	0.18	22.8	0.24	=
Baihou	43	25.1	0.24	0.20	0.18	27.8	0.20	=
Wusheh	114	148.6	0.24	0.20	0.18	33.8	0.17	=
Tsengwen	133	708	0.24	0.22	0.20	34.8	0.16	=
Deryeinbai	7	0.1	–	–	–	37.7	0.15	=
Wushantau	56	154.2	0.24	0.20	0.18	41.7	0.13	=
Nainhwau	88	158.0	0.24	0.20	0.18	46.7	0.12	=
Yienshuibai	9	0.8	–	–	–	54.6	0.10	=

Note: “–” and “=” denote no information and no damage, respectively.
(source : NCREE)

be estimated based on an extensive history of seismicity, as well as tectonic and geologic investigations. In fact, reliable estimates of the possible magnitudes and the locations of future earthquakes that may affect a site can be made. In addition, the earthquake motion intensity propagated to the site also can be estimated by using an appropriate attenuation law. The detailed procedure to obtain these design earthquakes will not be elaborated here. However, the design earthquakes for each dam if available will be listed for comparison purposes.

In order to explore, roughly, the causes of damage to each dam in view of the seismic design, it is very interesting to compare the peak ground acceleration induced by the Chi-Chi (Taiwan) Earthquake to the design earthquakes for each dam near the epicenter. In this preliminary study, the earthquake intensity at each different site will be computed from the attenuation law which was developed by Lee and Loh (1999) according to the seven strong ground motions occurring and recorded from 1993 to 1995 in Taiwan area. It can be expressed in a Campbell form and is:

$$a_{PGA} = 0.02968 \exp^{1.20M} (R + 0.1464 \exp^{0.6981M})^{-1.7348} \quad (1)$$

where the value of R in km is calculated as the shortest rupture distance and the symbol M denotes the local magnitude used in Taiwan. As a result, the value of a_{PGA} is the peak ground acceleration, which is measured in gravity units g , for the site with the shortest rupture distance of R under the earthquake with a

local magnitude of M .

Totally there are 16 dams located within the area affected by the Chi-Chi (Taiwan) Earthquake. In order to show the spatial distribution of the 16 dams, their locations are shown in Fig. 2. The basic data and computed peak ground acceleration a_{PGA} are summarized in Table 1 for each dam. In addition, the damage to each dam caused by the Chi-Chi (Taiwan) Earthquake is also indicated in the last column of Table 1. It should be mentioned that the shortest rupture distance for each dam is cautiously determined and thus its peak ground acceleration a_{PGA} can be calculated by using Eq. (1) with the use of $M=7.3$ which is the local magnitude for the Chi-Chi (Taiwan) Earthquake. As an example, the shortest rupture distance for the Shuisher dam from its site to the Chelungpu fault is determined to be 13.9 km, hence the value of a_{PGA} for this dam is found to be 0.35 g after substituting $R=13.9$ km and $M=7.3$ into Eq. (1). Employing the same procedure, the values of a_{PGA} for all the 16 dams can be determined as listed in Table 1.

It can be found that the peak ground accelerations for the Shihkang dam, Liyutan dam, Kukuan dam, Tousher dam, Shuisher dam, Lantan dam, Zenyitan dam, and Dergi dam are larger than their maximum credible earthquakes, and thus damage occurred, except for the Lantan dam and Zenyitan dam. On the other hand, it also can be observed that for all the other dams their peak ground accelerations are less than or equal to their maximum credible earthquakes and hence no damage occurred. Even though

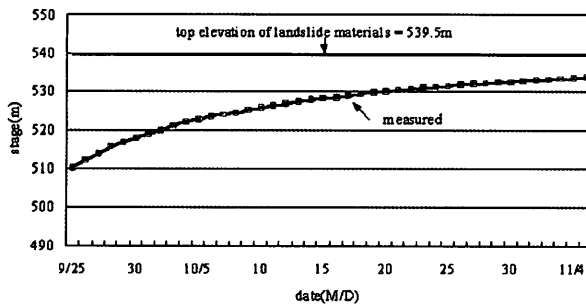


Fig. 4 Measured water stage of Tsaoling lake

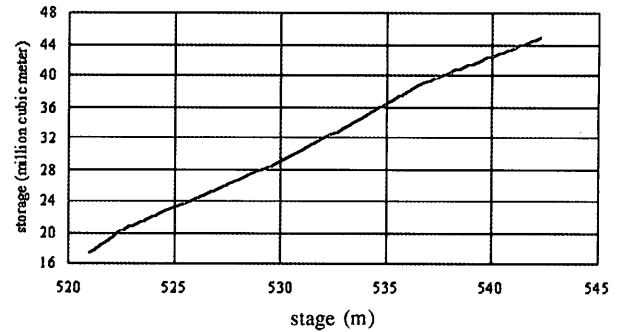


Fig. 5 Storage curve of Tsaoling lake

the peak ground acceleration is not the only factor to consider when explaining the damage to the dams, it provides a very good and consistent indication in this preliminary study. It might be very interesting to further investigate why there does not exist any damage to the Lantan dam and Zenyitan dam since their peak ground accelerations are larger than their maximum credible earthquakes.

This preliminary study only considers the peak ground acceleration induced at the dam sites. In fact, many other factors should be included such as the site-soil conditions, geologic conditions, etc. (Dowrick, 1977). Thus, a detailed investigation and evaluation of all damaged dams is necessary even though they survived the earthquake.

IV. INUNDATION MAP OF TSAOLING BLOCKED LAKE

Landslides triggered by earthquakes can themselves cause secondary disasters. Five new blocked lakes caused by landslide materials blocking creeks, such as Tsaoling, Chishin-shang, Geofung-ur-shang, Sherchikung and Toubenking, may collapse or break due to the overtopping flow in the coming rainy seasons. As a result of the breakage of landslide material, inundation will occur downstream, in the lowland. According to the magnitude of landslide scale and the history of landslides location, the assessment of inundation potential of the Tsaoling blocked lake is indicated. Near the village of Tsaoling, massive landslide materials with a volume in excess of 120 million cubic meters blocked the waterway of Chinshui Creek, which is one of the tributaries of Choushui Creek. The distance of the landslide is about 5 kilometers along the waterway. Therefore, the landslide materials formed a new lake near Tsaoling with a storage capacity of 43 million cubic meters.

An upstream impoundment of water above the streambed elevation of approximately 509 meters, was formed below the village of Tsaoling. Fig. 4 shows

the measured water surface level of the blocked lake. It was 534 meters on November 7, 48 days after the earthquake. The digital terrain model and geographic information systems were employed to calculate the storage curve of the blocked lake. The computed result is shown in Fig. 5. It represents an estimate volume of about 34.8 million cubic meters, for an average baseflow of less than 5 cubic meters per second. The minimum crest of the landslide materials at the impoundment is measured to be at elevation 540 meters, with a total storage capacity of 43 million cubic meters.

A temporary spillway was constructed by the Water Conservancy Bureau (WCB) for an emergency use to avoid the flow overtopping. Significant improvements have already been made by the WCB to the current channel by flattening the actual slope over the last 1 kilometer and adding larger rock-fill at the downstream toe. These would serve to reduce channel flow velocities during overtopping, provide an additional buttress for the slope, mitigate potential piping concerns by loading and filtering the exit point, and reduce potential surface erosion.

Considering that the collapse of landslide materials with its full water capacity of 43 million cubic meters would be disastrous for those living downstream, the inundation map due to the flood wave propagation was carried out herein. The DAMBRK model, developed by the U.S. National Weather Service (NWS), is adopted to calculate the potential discharges after the landslide material failure and the flood wave propagation in the valley from the breach site to Nanwein bridge at 27.2 km downstream.

The model consists of three functional parts, namely: (1) description of the landslide material failure mode, i.e., the temporal and geometrical description of the breach; (2) computation of hydrograph of the outflow through the breach as affected by the breach description; and (3) routing of the outflow hydrograph through the valley so as determine the

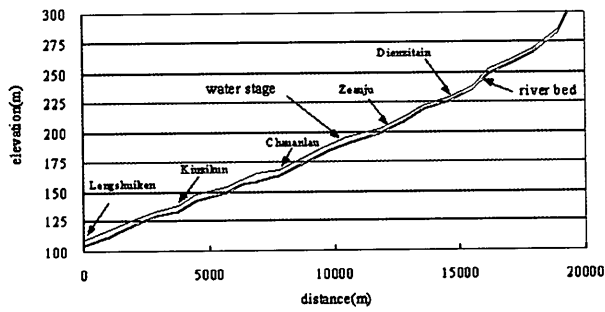


Fig. 6 Simulated water stages of Chinshui Creek

changes in the hydrograph due to valley storage, frictional resistance, downstream bridge and to determine the resulting water stage and flood wave travel times. The dynamic wave method based on the de Saint-Venant equations is used to route the flood hydrograph through the downstream valley. The de Saint-Venant equations consist of a conservation of mass equation, i.e.,

$$\frac{\partial Q}{\partial x} + \frac{\partial(A + A_o)}{\partial t} - q = 0 \quad (2)$$

and a conservation of momentum equation, i.e.,

$$\frac{\partial Q}{\partial t} + \frac{\partial(Q^2/A)}{\partial x} + gA\left(\frac{\partial h}{\partial x} + S_f\right) = 0 \quad (3)$$

where A is the active cross-sectional area of flow, A_o is the off-channel storage cross-sectional area, x is the longitudinal distance along the channel in the valley, t is the time, q is the lateral inflow or outflow per linear distance along the channel, g is the gravity acceleration, and S_f is the friction slope. The friction slope is evaluated from the Manning's formula for uniform, steady flow, i.e.,

$$S_f = \frac{n^2 |Q| |Q|}{A^2 R^{4/3}} \quad (4)$$

in which n is the Manning's coefficient of frictional resistance and R is the hydraulic radius.

Fig. 6 shows the simulated results of the water stage of Chinshui Creek under the conditions of collapse of landslide material with a full storage of water and the design storm with a rainfall of 600 mm in 24 hours. Fig. 7 maps out the inundation zone that covers 14 villages in the downstream lowland of Chinshui Creek, such as Lengshuiken, Tauziyen, Chentain, Kiuzikun, Dershien, Futain, Liyui, Chauanlau, Paijaishen, Linan, Moogautain, Zeauju, Tuntau, and Dienzitain, where there are more than 20 thousand people. The inundation map can show areas of potential flooding. It also helps local authorities to adopt emergency procedures for the

Table 2 Damage to river and sea banks during the Chi-Chi (Taiwan) Earthquake

Type	Contents	Length or site
River banks	banks	12,447 m
	Levees	3,268 m
	Channels	46,821 m
	Revetments	4,500 m
	Miner blocked materials	900 m
	Maintaining Roads	2,100 m
	Flood gates	8 sites
Sea banks	Levees or banks	8,458 m
	Maintaining Roads	300 m
	Tide lock	2 sites

(source : WRB)

evacuation and security of populated areas below the new blocked lake. It is suggested that the inundation mapping for different scenarios of landslide material failure must be calculated and duly provided to the authorities concerned in proposing strategies for flood hazard mitigation plans.

V. DAMAGE TO RIVER BANKS AND IRRIGATION SYSTEMS

The damage locations of river and sea banks are not only along the Chelungpu fault but also highly concentrated in the areas with the ranges of PGA value greater than 450 gal. Because the Chelungpu fault trends nearly north-south and the Chi-Chi (Taiwan) Earthquake produced strong ground motions and intense shaking, the damage to river and sea banks with the same trending as the Chelungpu fault were cracked or shifting. The river and sea banks with the east-west trending were ridgy, distorted, or tumbling.

The Water Resources Bureau (WRB) immediately reported the damage investigation results of the river and sea banks after the Chi-Chi (Taiwan) Earthquake as shown in Table 2. There are more than 15 kilometers of river and sea banks that need to be rebuilt and twice as much needs to be repaired. The WRB claims 360 million NT dollars are need to reconstruct these hydraulic facilities (WRB, 1999). Table 3 lists the detailed damage to Choushui Creek in the Chi-Chi (Taiwan) Earthquake. Because of the strong heed to prevent secondary damage in the coming rainy season, hydraulic facilities must be functional again as soon as possible.

The Chi-Chi (Taiwan) Earthquake has caused significant damage to the components of irrigation systems. Their vulnerability is further enhanced by their large areas, which means that at least some portions of each network may have been impacted by the earthquake from any of several sources. The

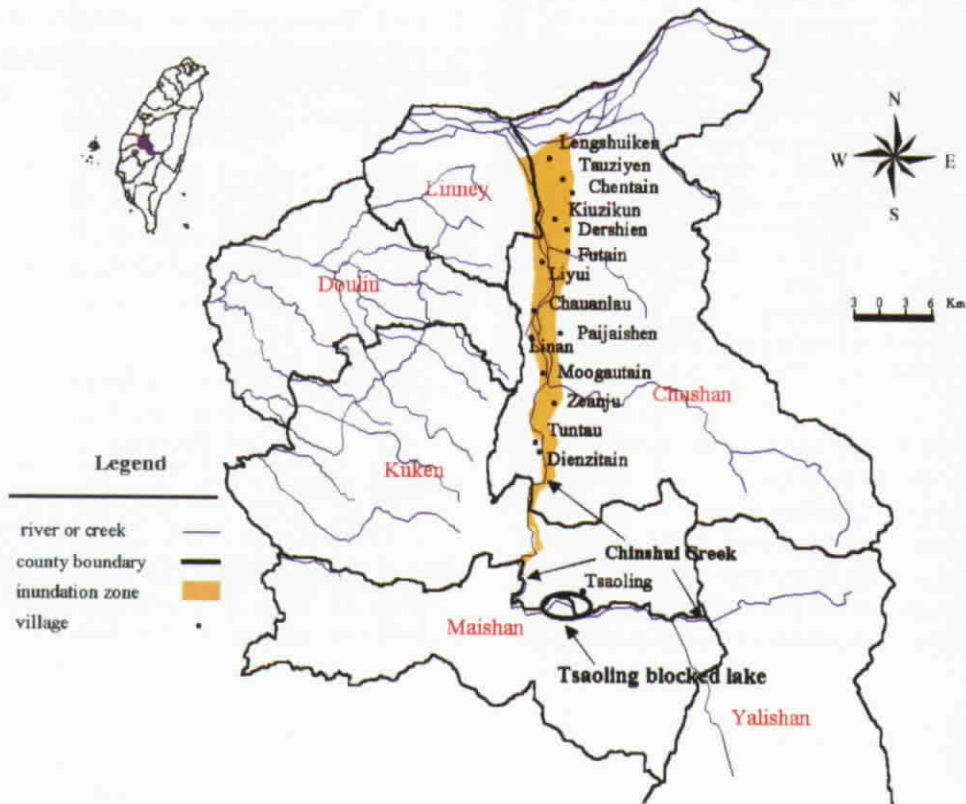


Fig. 7 Inundation potential for the downstream lowlands of Chinshui Creek

Table 3 Detail damage to Choushui Creek during the Chi-Chi (Taiwan) Earthquake

Title of Bank	Damage Type	Restoration Items
Han paosea bank	Slumping	Retaining wall
Haipu sea bank	Slumping	Retaining wall and road
Wang kung sea bank	Distortion	Tide-proof gate
Choshuihis bank	Shift	Bank and maintenance road
Chaoyangtsuo bank	Slumping	Retaining wall
Hsiahschien bank	Slumping	Gabion
Fantzuliao bank	Rupture	Bank
Pashepu bank	Rupture	Bank and Gabion
Shankeng bank	Slumping	Gabion
Hsiahaichien bank	Slumping	Retaining wall
Revetment near Liyu bridge	Rupture & Slumping	Surface of revetment
Tungtou revetment	Rupture & Slumping	Front surface and top of bank
Revetment near Aikuo bridge	Slumping	Surface of bank and gabion
Revetment near Yenping bridge	Rupture & Slumping	Surface of bank and stream way
Waipu bank	Rupture	Surface of bank
Tungpujui bank	Rupture	Surface of bank and stream way

(source : NCREE)

hydraulic design of an irrigation system may in some cases add to its vulnerability, since a gravity-flow system is wildly employed in Taiwan, which may be associated with potential landslide and surface fault movements. Avoidance of regions of potential liquefaction or ground failure may also be impossible

in developed area or areas where development is likely. Other areas of vulnerability include power supplies for pump and treatment facilities and the proximity of groundwater wells and other underground components to sewage lines and other sources of contamination.

Table 4 Damage to irrigation system during the Chi-Chi (Taiwan) Earthquake

County Damage	Miaoli	Taichung	Nantou	Changhua	Yunlin
Retaining wall (m)	14	—	—	—	—
Revetments (m)	232	460	—	—	—
Lining structure (m)	551	31,379	23,777	—	2,200
Control gate (site)	3	5	—	2	—
Pumping station (site)	3	—	1	—	—
Culvert (m)	5	300	1,266	—	—
Bank (m)	80	1,980	1,572	—	80
Flume (m, sites)	—	3 sites	182 m, 3sites	—	3 sites
Tunnel (m)	—	7,750	2,820	—	—
Siphon (sites)	—	2	2	—	—
Weir (sites)	—	1	1	—	—
Channel (m)	—	15,687	10,440	10,501	13,237
Restoration budget (million NT\$)	11.5	397.5	352.8	109.7	109.0

Note: “—” denotes no damage.

(source : Council of Agriculture)

Some irrigation canals and concrete-lined aqueducts crossing faults were severely damaged during the Chi-Chi (Taiwan) Earthquake. But the performance of the irrigation system, at regional level, was generally acceptable. As a result of significant improvements made after the 1981 secondary agrarian demarcation in Taiwan, the irrigation system can be repaired efficiently. The Council of Agriculture of the Executive Yuan reported approximately 1,400 repairs within their system. (Miaoli, Taichung, Changhua, Yunlin, and Nantou irrigation association, 1999). Table 4 shows the damage to irrigation during the Chi-Chi (Taiwan) Earthquake. The Council of Agriculture claims 980 million NT dollars are need to reconstruct these hydraulic facilities. (Public Construction Commission, 1999)

VI. CONCLUSIONS

The Chi-Chi (Taiwan) Earthquake was shocking and damaged, intensively, the hydraulic facilities in Taiwan. More earthquakes like the Chi-Chi (Taiwan) Earthquake and possibly a major earthquake reminiscent of Taiwan in 1900 will strike before Taiwan significantly reduces its seismic risk. Since the investigations of the damage are the primary work to propose strategies for a hydraulic facilities recovery plan after seismic incidents, the distribution of damaged areas and some suggestions for the restoration of the hydraulic facilities are herein presented. Preliminary studies of dams and inundation of blocked creeks are also carried out in this paper. The results can assist the authorities concerned in proposing strategies for hazard mitigation and recovery plans.

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Discussions of this paper may appear in the discussion section of a future issue. All discussions should be submitted to the Editor-in-Chief.

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台灣集集大地震水利設施之損壞

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摘要

台灣中西部於 1999 年 9 月 21 日發生芮氏規模 7.3 的大地震，給該地區帶來了一個嚴重的大災難，其中包括 2,333 人的死亡。並對苗栗縣、台中縣、台中市、南投縣、彰化縣以及雲林縣等地區的水利工程設施造成嚴重的破壞，受創的水利設施包括河堤、海堤、水庫、水壩、攔河堰以及灌溉系統等。另外，尚有多處地區發生山崩阻塞河道的現象，有的甚至於形成新的堰塞湖。集集大地震中，水利設施的受損概況將在本文中說明，並進一步分析與研究重大水利設施的受損原因。重大水利設施災情進行分析研究方面則分為兩項主題，其一為水庫與水壩之災損分析與耐震設計檢討；其二為探討山崩土石嚴重阻塞河道形成堰塞湖之潛在危險，分析一旦天然壩體潰決後形成之洪流，將對下游河川兩岸低窪地區所造成影響之淹水圖。本文內容可提供相關主管機關，進行水利設施災後復建及相關防災措施擬定之參考。

關鍵詞：集集大地震，地震災害，水利設施，水庫損壞，淹水圖。