Investigation of Piers Suffered Landslides Impact on the Main Deep Trough of River Bed by 2D Unsteady Flow Simulation

K.H. Cheng
The Sustainable Engineering Research Center
Kao Yuan University,Taiwan

C.H. Lin
The Sustainable Engineering Research Center
Kao Yuan University,Taiwan

C. Chao
T he Sustainable Engineering Research Center
Kao Yuan University,Taiwan

M.C. Chang
The Sustainable Engineering Research Center
Kao Yuan University,Taiwan

C.M. Yu
The Sustainable Engineering Research Center
Kao Yuan University,Taiwan

Abstract—Debris flow is a serious disaster which always leads to huge damages in Taiwan. After typhoon or downpour, the fluid pressure and the impact of the huge rocks and floating woods brought by debris flow may contribute to structural damage of bridges, or damage the bridge base which is attributed to the washout of the riverbed. These phenomena would seriously influence works concerning shelter-seeking and damage-relieving. Case studies in this research consist of two phase. For the first phase, data of debris flow cases such as typhoon and rainfall information Kaohsiung Baolai No.2 Bridge in Taiwan as case in 100/200 years return flood peak flow. Numerical simulation was performed using SMS-2D, result were presented in the main deep trough and area. For the second phase, this study designed a checking evaluation procedure of concrete cracking failure of foundation of bridge by using mathematic algorithm. This author certainly expects this procedure could be a further reference for pier and foundation of the bridge design.

Keywords- debris flow, impact force, main deep trough, SMS-2D.

I. INTRODUCTION

In recent years, due to climate changes and landslides caused by heavy rain disaster, riverbed erosion causes sufficient support in exposed bridge, coupled with the impact of the fluid pressure and boulders entrained landslides, resulting bridge subsidence or pipe cracking damage, such as Fig .1. Moreover, the meandering banks of the reflection diffraction phenomenon in river, making the main river channel scouring and unpredictable deep grooving, but also causing difficulties in bridge reinforcement. Therefore, the erosion of bed particle by water driven to downstream and the formation of a shallow scour hole in upstream, said bridge safety hazards[1].

Figure 1. Examples of landslides destroyed bridges

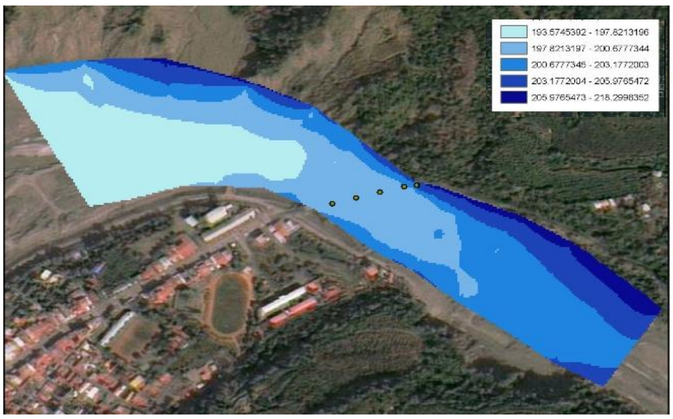


Figure 2. Space ilustration in Baolai No.2 Bridge

Baolai No.2 Bridge is located in Liouguei District, Kaohsiung City, Taiwan, with length-220m, width-9m, a total of five cylindrical diameter-2.5m piers across LaoNong River, whose foundation in diameter-6m, buried in the depth of 12m, group pile length-25m. In this study, data were measured within the river bed elevation interpolation space, shown in Fig .2, pier sizes and particle size distribution in field applied for SMS-2D gridding and further subsequent hydrological analyses as case study.

In recent years, due to the dramatic change of climate, the significantly increasing trend in meanwhile short-time and large-number rainfall causes erosion in river, thus, this study select near rainfall station to statistic water level and flow data from 1994 to 2014. With HEC-RAS backwater calculations performed, in order to achieve a 100-year and 200-year peak flow as boundary conditions subsequent calculation of water treatment, as shown in the relevant parameters detailed in Table 1.

TABLE I. PARAMETERS RELATED TO HEC-RAS BACKWATER CALCULATIONS

Catchment area	return peak flow		Water level	
625.02 km^2	100-year	200-year	100-year	200-year
	7812cms	8241cms	EL 405.96m	EL 406.46m

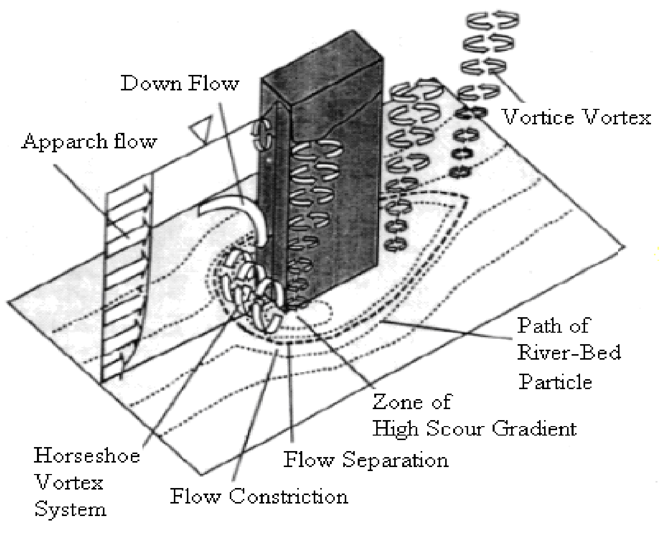
According to drilling data in field, following depth in 8-m to 12-m below riverbed is sand and gravel mixed layer, and therefore depth 12m is gravel, bedrock with 25-m thickness. Assumed landslides occur set for the full water level, whose unit weight $\gamma m = 2.3$ (t/m3) and historic largest record in 3-m diameter. In this study, SMS (Surface Water Modeling System) established river model, with the appropriate parameters and boundary conditions are set for two-dimensional water calculus, then with formula estimating scour depth and the main deep channel flows, to evaluate landslides impact and dynamic pressure on bridge pipe in scouring hole, and additional moment caused by the dumping, assess the minimum diameter and the steel version pier piers around against the crack for its reinforcement.

II. LITERATURE REFERENCES

Piers set in the river causes water cross-section narrowed, thus, water flow through the pier near the river through the water section, due to obstruction of bridge pier narrowing, resulting in water flow conditions change in around the pier riverbed. The bow wave to down-flow in front of pier occurring stagnation pressure that the pressure intensity and flow velocity is proportional to the square, the trend for the closer to the river bed surface at its pressure strength is smaller, the formation of a vertical down the main cause of the pressure gradient, and favorable pressure gradient increases with the water-blocking area and to accelerate the flow rate, resulting pier upstream section of water level rising and causes the flow constriction and local scour around piers, Moreover, horseshoe vortex by the role of the cushioning effect combining down-flow in front of pier and the second lateral flow along the pier surrounding the formation of spiral motion to three-dimensional vortex. The vertical pressure gradient due to the dissipation of eddy current, formed by lift silt from the riverbed surface to stir up the band to the downstream siltation, said that cast-off vortices and the wake. Above detailed are as shown in Fig .3 and Table 2. [2,3,4] Scour hole on both sides between piers began to develop, followed quickly by around the pier extending upstream, and then converge in front of piers, whose erosion of the bed material by water driven moved downstream, upstream pier is formed around a shallow scour hole [5, 6]. Chuanyi Wang (2009)[7] found the relationship between scour and bed particle size indicating that local scour on the coarse river bed, the maximum equilibrium scour depth occurred in both sides of the pier, and the main accelerating erosion mechanism on both sides and cast-off vortices and wake. This study applies SMS-2D to simulate the main flow and changes in water depth of the deep grooves, with the appropriate formulas of landslides and erosion, Kaohsiung Baolai No.2 Bridge in Taiwan as case in 100/200-year return peak flow for piers suffering landslides, impacting pipe on the main deep trough of river bed to discuss the extra dumping moment and its reinforced protection. [8]

TABLE II. THE BRIDGE SCOUR IMPACT TO THE PIER CORRESPONDING LOCATION

Occurred position	Pier upstream	Around pier	Pier downstream
Project	Bow wave	river width narrowing	river width enlarger
phenomenon	Down-flow	flow velocity and bed shear increasing	flow velocity and bed shear decreasing
Scouring	Local scouring	Constriction scouring	Downstream deposition



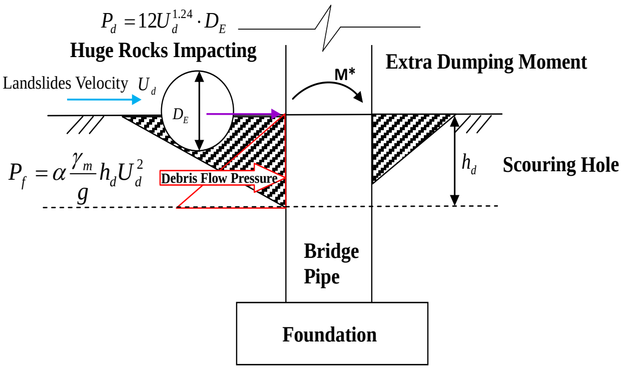
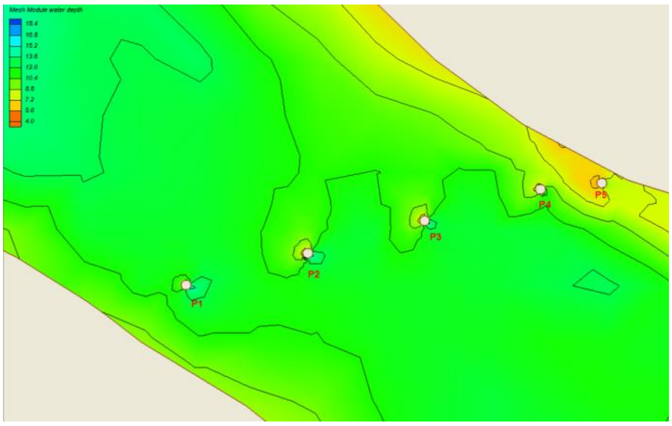


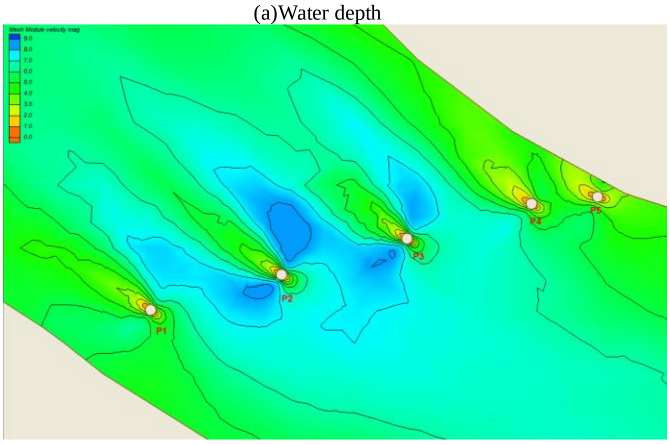
Figure 3. Mechanistic drawing of Piers Suffered Landslides Impact on the Main Deep

III. Results and discussion

Surface Water Modeling System is two-dimensional flow simulation software (SMS-2D), developed by the United States Army Corps of Engineers Hydraulics, Laboratory (USACEWES), Environmental Modeling Research Laboratory (EMRL) of Brigham Young University, and the United States Federal Highway, Administration (FHWA), using the finite element method with the continuous flow equation and momentum equation solving, the topographic distribution grid, the rivers around the structure as a boundary, to analyze the local river flow field, water depth, the water of higher phenomena, to better explore the piers or structures near the water level, flow velocity, and local eddy current situation[7]. In this study, the SMS-2D is applied with 100/200-year frequency peak flow for simulation with reinforced steel sheet setting around pipe to protect the piers against landslides and erosion. In general, river conditions with Manning n value is about 0.016 to 0.05, but subjected to different bed material, experienced with water flow area using 0.041, flood plains using 0.081, and circular pier area using 0.200 [5,6,7]. The finite element mesh and flow field with 200-year return period for example is shown in Fig .4. In Fig .4(a) can be seen that the main deep trough is from P1 to P3, so that the river washed by the fast flow rate can not form a stable flow state. In Fig .4(b) can be seen that the main deep trough is from P2 to P3 due to the main velocity distribution in channel erosion, whose largest flow rate about 8-9 m/s in front of piers. Blow descriptions are evaluated for reinforced steel sheet setting around pipe for the benefit landslide impact and its influence of flow rate in the main deep trough of river bed, as shown in Table 3. Numerical simulation was performed using SMS-2D, result were presented in the main deep trough and area. Table 3 shows evaluation procedure of concrete cracking failure of foundation of bridge by using mathematic algorithm in both consideration for the enlarge size or using steel sheet reinforced around pipe, could be a further reference to discuss the extra dumping moment due to landslide impact in scouring hole for pier and foundation of the bridge design.



(a)Water depth



(b) Surface Velocity

Figure 4. 200-year return period simulation for bridge piers in river in the current status

TABLE III. LANDSLIDE IMPACT TO THE PIER IN SCOURING HOLE CORRESPONDING REINFORCEMENT

pier	Return year	U_d (m/s)	h_d (m)	P_d (ton)	P_f (ton/m)	M^* (ton-m)	Pier diameter against landslide(m)	
							Enlarge size	Steel sheet reinforced
P1	100	1.98	3.87	83.98	3.56	207.92	2.85	0.61
	200	2.37	5.13	104.95	6.76	410.64	3.57	0.77
P2	100	2.53	4.86	113.81	7.30	411.14	3.58	0.77
	200	2.98	6.54	139.42	13.63	799.85	4.46	0.96
P3	100	2.1	4.2	90.33	4.35	256.68	3.06	0.66
	200	2.64	5.78	119.98	9.45	566.14	3.98	0.86

IV. CONCLUSIONS

Flow through the pier, erosion phenomenon around piers caused by bow wave with fast flow rate is obvious, especially a great flood with 100/200-year peak flow to except the bridge safety due to the river main channel erosion and landslide impact in scouring hole. The study assumes that the bridge can be improved and used under landslide occurs in the scouring hole, ignoring the water pressure above river bed, to analyze dynamic pressure and impact force, calculate the extra bending moment. Resulting that steel sheet around pipe setting in the main deep trough to avoid excessive erosion of pier and huge rock impact. To avoid concrete cracking or exposed possible, should strengthen reinforced concrete piers trails in enlarge size or steel sheet around pipe against landslide impact.

Furthermore, location-oriented scour by enlarge pipe setting likely result in excessive cost, thus, the reasonable reinforced steel sheet of pipe depending local scour and landslide impact in the main deep trough in river bed can effectively protect critical pier. In addition, if the reinforcing construction method is still not completely resistant to landslides hit, the front apron protection is suggested set in upstream simultaneously, providing reliable information and references for bridge engineers.

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