Engineering Design of Wu-Shan-Ling Second Tunnel

Yung Chuan Chou, Kun-Hsien Chou, Chu Bor Tsung, Keh-Chia Yeh, Sheng-Hsueh Yang, and Chung-Ta Liao

Abstract

Wu-Shan-Ling Tunnel is located in Southwestern Taiwan, which is an important hydraulic facilities connected the Tsengwen River to Guantian River for the water resources of Wushantou Reservoir and Chianan Irrigation System. The tunnel was built by Mr. Yoichi Hatta since 1922 to 1929 during the Japanese occupation period. Although the tunnel still works now, the structure is gradually aging and too old to repair. For safety and long-term stable water supply of Chianan Irrigation System, Water Resources Agency and Chianan Irrigation Assocition propose the engineering plan and design of Wu-Shan-Ling Second Tunnel since 2006 to 2015. The project started in 2015 and is expected to be completed in 2019. It would bring a more stable water supply for the water resources in Chianan Irrigation System.

Keywords: Wu-Shan-Ling Tunnel, diversion weir, engineering design, hydraulics

1 Introduction

Taiwan's water resources were quite lacking in the early stage during the Japanese occupation period. In order to improve the number of agricultural and irrigated farming periods, Mr. Yoichi Hatta proposed the project of Chianan Irrigation System since 1920. It used to be the most important hydraulic engineering in Taiwan, and the irrigation area was about 160,000 hectares. The project of Chianan Irrigation System includes the building of Wushantou Reservoir, which was the largest reservoir in Southeast Asia at that time. In addition, many irrigation channel system connected the water from Tsengwen River, Guantian River, and Choushui River were established.

Wu-Shan-Ling Tunnel was built by Mr. Yoichi Hatta since 1922 to 1929, which connected the Tsengwen River to Guantian River for the water resources of Wushantou Reservoir. Although the tunnel has operated more than 80 years and still works now, the structure is gradually aging and too old to repair. For safety and long-term stable water supply of Chianan Irrigation System, Water Resources Agency and Chianan Irrigation Assocition propose the engineering plan and design of Wu-Shan-Ling Second Tunnel since 2006 to 2015 (shown as Figure 1). The project started in 2015 and is expected to be completed in 2019. It would bring a more stable water supply for the water resources in Chianan Irrigation System.

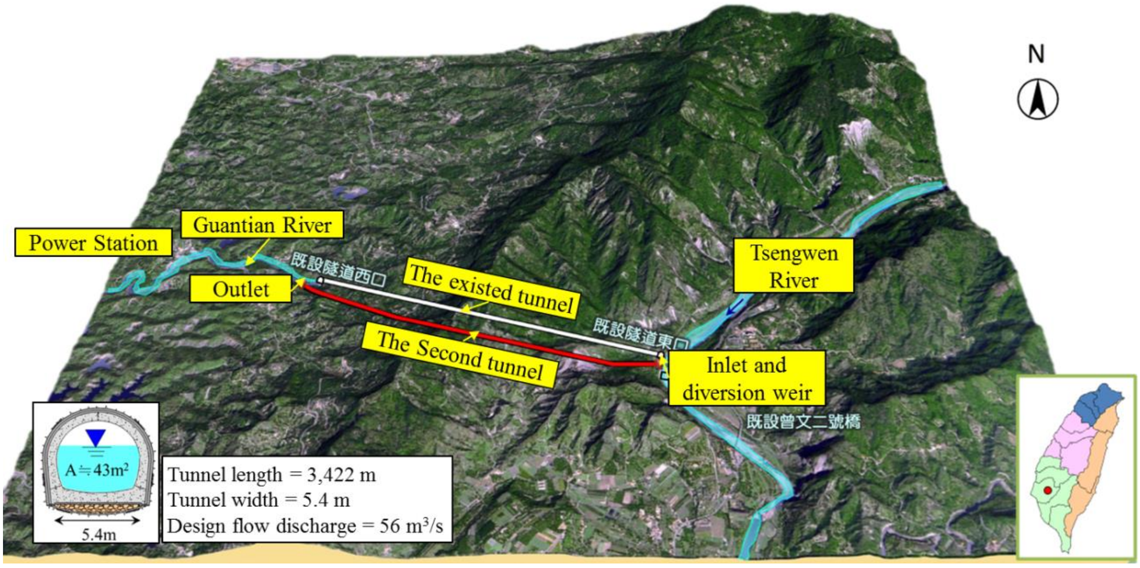


Figure 1 The engineering layout of Wu-Shan-Ling Tunnel located in Southwestern Taiwan.

The total length of Wu-Shan-Ling Second Tunnel is about 3,422 m and 5.4 m width. It crosses the Yenshuikeng Shale, Tangenshan Sandstone, and Liuchungchi Formation during the construction stage. According to the past experience of the Wu-Shan-Ling tunnel construction process, there have been several gas explosions, leaks, and water inrush disasters (shown as Figure 2 and Figure 3). In this study, engineering geology includes the whole domain and the second tunnel is discussed. In addition, numerical models such as SOBEK and CCHE2D are selected and applied to investigate the hydraulics of engineering design and morphological changes around structures. The building of Wu-Shan-Ling Second Tunnel would bring a more stable water supply for the water resources in Chianan Irrigation System and a connection for friendship between Taiwan and Japan.

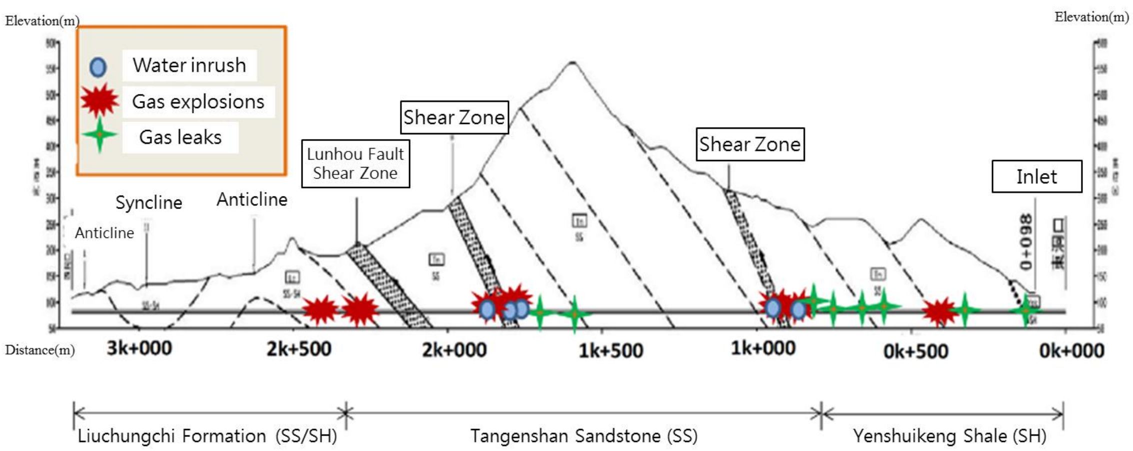


Figure 2 There have been several gas explosions, leaks, and water inrush disasters during the past experience of Wu-Shan-Ling tunnel construction process.

Figure 3 Building process of Wu-Shan-Ling Tunnel (historical photo).

2 Engineering layout and geology

2.1 Engineering layout

The engineering layout of Wu-Shan-Ling Second Tunnel includes the concrete diversion weir, cut-off wall, sluice, water intake, flooding prevention wall, protection works, flow leading dike, water diversion tunnel, and outlet structures (shown as Figure 4). The new diversion weir is located downstream the old weir about 80 m. The new water diversion tunnel is about 3,422 m long with a horseshow cross-section and 5.4 m width. The tunnel slope and design flow discharge are 1/1,200 and 56 m^3/s. From the tunnel terminal to Guantian River, there are outlet structures included the culvert and expanding open channel.

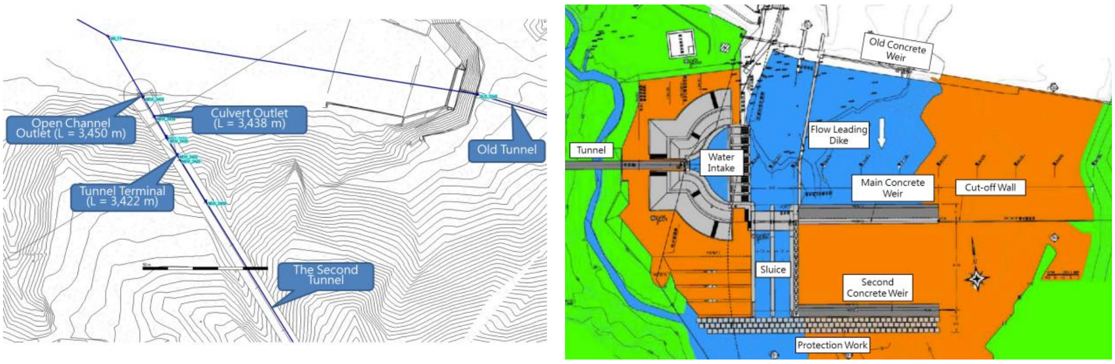


Figure 4 The engineering layout of inlet and outlet structures.

2.2 Engineering geology

Figure 5 shows the engineering geology layout of Wu-Shan-Ling Second Tunnel. The principal mountain range runs northeast to southwest. The water diversion tunnel connects the Tsengwen River on the east side and the Guantian River (Wushantou Reservoir) on the west side. The ridgeline crossing the middle tunnel is the branch of the southern margin of Alishan Mountains. The mountainous terrain is a low hilly area on the west side, and the elevation of this area is between 400 and 700 m.

Figure 6 shows the longitudinal distribution of tunnel geology. From the tunnel inlet to the outlet, there are recent alluvium, Yenshuikeng Shale, Tangenshan Sandstone, Liuchungchi Formation and Kanhsialiao Formation. In addition to the dense sandstones of the Tangenshan Sandstone, which is formed by the ridgeline, the strata in this area are mainly shale or mudstone. There is a large anticline structure in the range of about 5-10 km below the area, so there should be water inrush, oil and gas leaks phenomenon. In order to avoid these disasters, the strategies including strengthen ventilation, diligent detection, reduce blasting, and enhanced tunnel support are carried out.

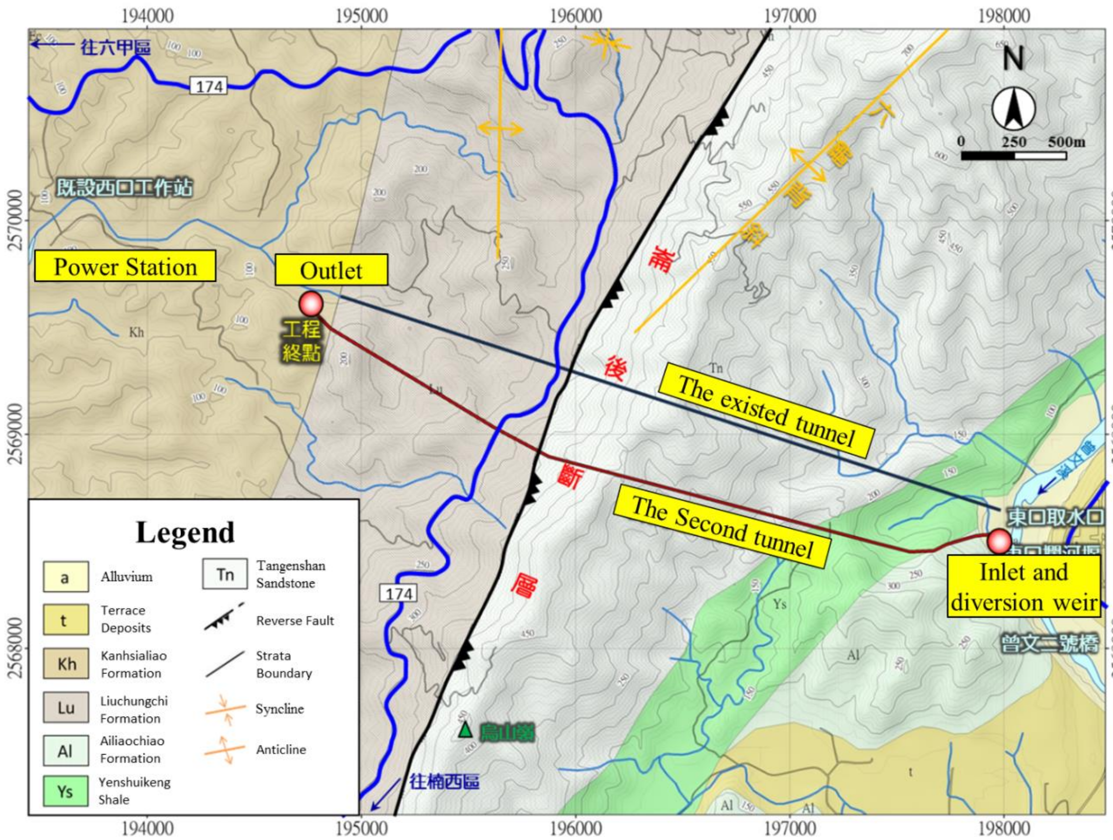


Figure 5　The engineering geology layout of Wu-Shan-Ling Second Tunnel.

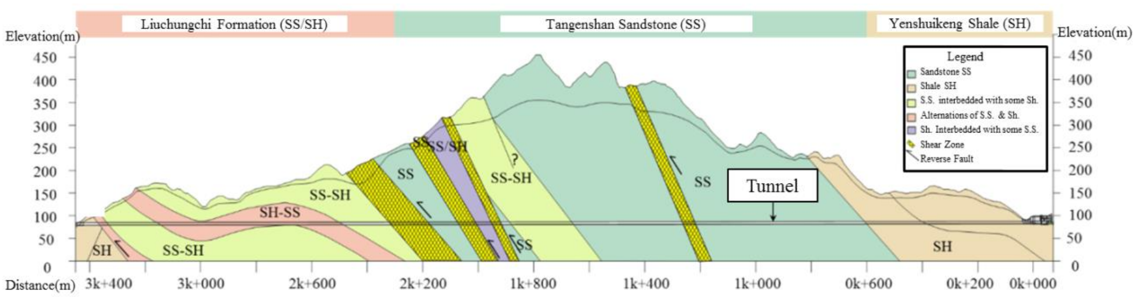


Figure 6　The longitudinal distribution of tunnel geology.

3 Numerical models

3.1 SOBEK model

SOBEK model is an integrated software package for river, urban or rural management. Several program modules work together to give a comprehensive overview of waterway systems. Its integrated framework also means that SOBEK can link river, canal and sewer systems for a total water management solution. It simulates the water flows, and it is able to work with complex cross-sectional profiles consisting of various sub-sections, tunnel, and culvert. For engineering desigh, the 1-D flow module of SOBEK model is selected to simulate the water surface elevation and mass conservation from the inlet to the outlet of water diversion tunnel.

3.2 CCHE2D mobile-bed model

CCHE2D model is developed at the National Center for Computational Hydroscience and Engineering (NCCHE), School of Engineering, the University of Mississippi, US. It is a hydrodynamic model for unsteady turbulent free surface flows and sediment transport simulations. In this study, CCHE2D is selected and applied to simulate the morphological changes around structures. The governing equations of the flow are two-dimensional depth integrated Reynolds equations in a Cartesian coordinate system are:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial \eta}{\partial x}+\frac{1}{h}\left(\frac{\partial h\tau_{xx}}{\partial x}+\frac{\partial h\tau_{xy}}{\partial y}\right)-\frac{\tau_{bx}}{\rho h}+f_{Cor}v \tag{1}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial \eta}{\partial y}+\frac{1}{h}\left(\frac{\partial h\tau_{yx}}{\partial x}+\frac{\partial h\tau_{yy}}{\partial y}\right)-\frac{\tau_{by}}{\rho h}-f_{Cor}u \tag{2}$$

where u and v are depth-integrated velocity components in x and y directions, respectively; t is the time; g is the gravitational acceleration; η is the water surface elevation; ρ is the density of water; h is the local water depth; f_{Cor} is the Coriolis parameter; τ_{xx}, τ_{xy}, τ_{yx}, and τ_{yy} are depth integrated Reynolds stresses; and τ_{bx} and τ_{by} are shear stresses on the bed and flow interface. The shear stress terms at the water surface are dropped since wind shear driven effect is not considered in this version of the model.

Free surface elevation for the flow is calculated by the depth-integrated continuity equation:

$$\frac{\partial h}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=0 \tag{3}$$

Two methods for calculating eddy viscosity are available in the current model, including the depth integrated parabolic eddy viscosity formula and depth integrated mixing length eddy viscosity model. (Jia, et al. 1999, 2002, 2008)

3.3 Sediment transport module

The sediment transport model consists of suspended sediment transport and bed load transport simulation models for non-uniform sediment. The model is also designed to simulate channel bed with large slopes and curved channel secondary flow effects. The depth-integrated convection diffusion for the suspended sediment is solved.

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}-\frac{\partial}{\partial x}[\beta v_t\frac{\partial C}{\partial x}]-\frac{\partial}{\partial y}[\beta v_t\frac{\partial C}{\partial y}]=S+S_r \tag{4}$$

where C is the depth-integrated sediment concentration, and β is the coefficient to convert the turbulence eddy viscosity to eddy diffusivity for sediment. S is a source term representing the balance of sediment pick up and deposition near the surface of the bed. More detail of this term can be found in the technical report of the sediment model (Wu, 2001).

In the processes of vertical integration, one has to either assume the water is shallow and the vertical variation of the flow is negligible or keep the dispersion terms to preserve the effect of vertical sediment profiles on bed form change.The source term S_r sometimes would not be zero, but representing the dispersion terms. Computing the dispersion term is complicated and requires the knowledge of the vertical velocity and suspended sediment profiles in x and y directions.

4 Hydraulics of Wu-Shan-Ling Second Tunnel

4.1 Hydraulics of diversion tunnel

Because the design of water diversion tunnel is non-full flow, the 1-D flow module of SOBEK model is selected to simulate the water surface elevation and mass conservation from the inlet to the outlet of tunnel. Figure 7 shows the simulated water elevation near the intake under different intake discharges. By building the diversion weir in Tsengwen River on the east side, the water level in the upstream reach would rise. It is very important and needed to verify whether the engineering design of diversion weir agrees the required intake discharge. In addition, the effects of flooding and safety of levees in upstream reach are also needs to be confirmed. From the simulated results, the construction of diversion weir would not affect the embankment.

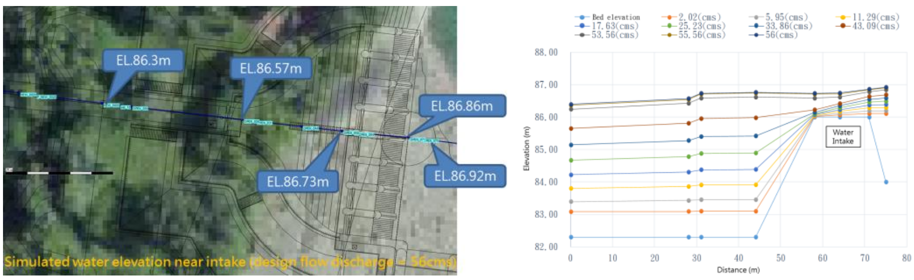


Figure 7 Simulated water elevation near intake.

4.2 Morphological changes around diversion weir

The 2-D mobile-bed model is used to simulate and compare the morphological changes around diversion weir before and after setting up the weir in the river. Figure 8 shows the computational domain and initial bed elevation for 2-D simulation, which are interpolated and obtained using the DEM data of 2012, and the data of 2015 is used for the model validation. The significant flood events during 2012 to 2015 are simulated. The bed geomety of concrete weir, sluice, leading dike, protection work and intake are considered in the model. Four size classes ranging from 0.0625 mm to 135 mm are selected to compute the associated sediment transport. The inflow discharge and downstream water stage hydrograph are the measured data, and the upstream sediment concentration is evaluated using the rating curve obtained from the measured suspended load data. After the complete of model validation, different return period floods are selected and simulated to evaluate the impacts of setting up the new diverion weir.

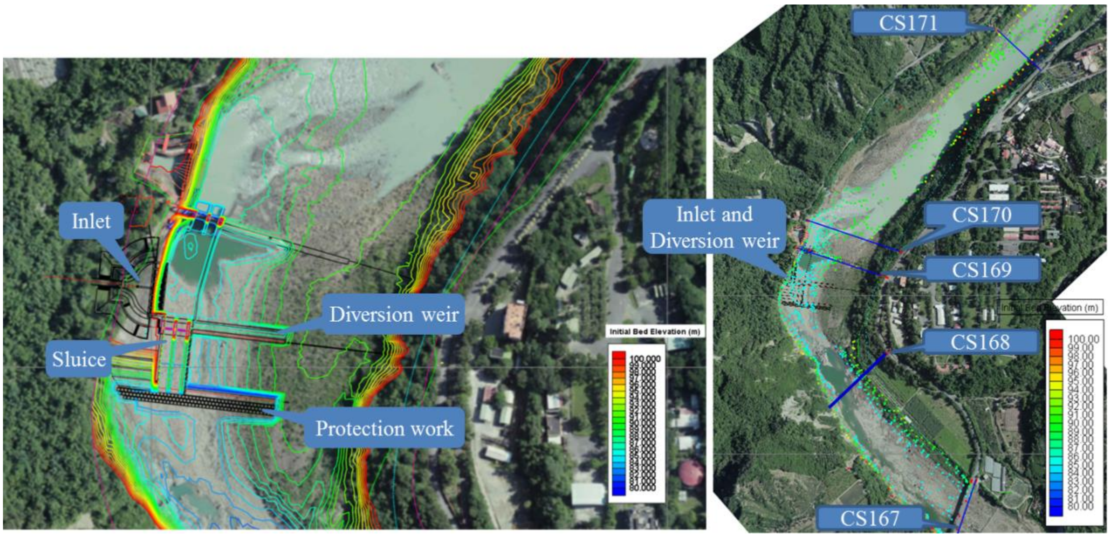
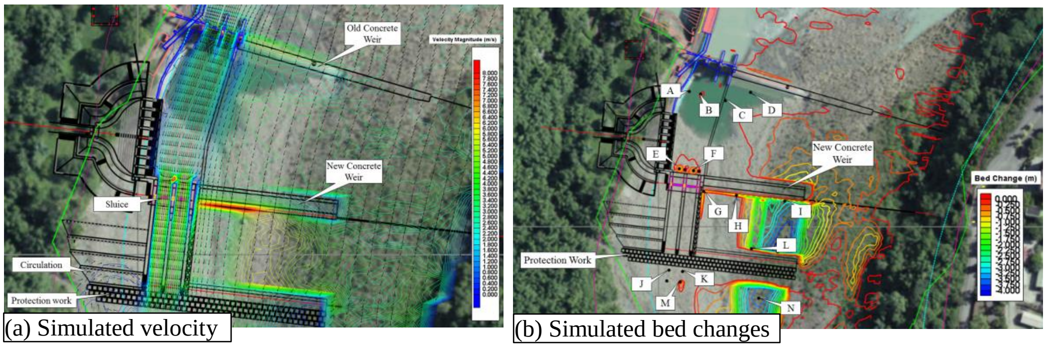


Figure 8 The computational domain and initial bed elevation for 2-D mobile-bed simulation.

Figure 9(a) shows the simulated velocity field and bed changes near diversion weir when the inflow is 2,510 m^3/s (2 year retun period flood). From the simulated results, the flow passes through the sluice and concrete weir, and there are high velocity magnitude in the downstream region of new concrete weir and sluice. It can be seen that there are circulation near the right bank side of embankment. Figure 9(b) shows the simulated morphological bed changes in the study reach under Q_2 flood event. The negative values of bed changes relative to the initial bed elevation represent bed degradation. The maximum erosion depth is about 4 m where occurs near the downstream region of new concrete weir and protection work. There are also erosion near the downstream of sluice. The associated erosion depth are calculated for the engineering design of structual foundation.



(a) Simulated velocity (b) Simulated bed changes

Figure 9 Simulated velocity field and bed changes near diversion weir when the inflow is 2,510 m^3/s.

5 Conclusions

In this study, the engineering geology of Wu-Shan-Ling Second Tunnel includes the whole domain and the second tunnel is discussed. Numerical models such as SOBEK and CCHE2D are applied to investigate the hydraulics of engineering design and morphological changes around structures. The engineering project started in 2015 and is expected to be completed in 2019. It would bring a more stable water supply for the water resources in Chianan Irrigation System and a connection for friendship between Taiwan and Japan.

References

Jia, Y., Wang, S.S.Y. (1999). Numerical model for channel flow and morphological change studies. *Journal of Hydraulic Engineering*, ASCE, Vol. 125, No. 9, pp. 924-933.

Jia, Y., Wang, S.Y.Y., Xu, Y. (2002). Validation and application of a 2D model to channels with complex geometry. *International Journal of Computational Engineering Science*, Vol. 3, No. 1, pp. 57-71.

Jia, Y., Zhang, Y., Wang, S.S.Y. (2008). Numerical modeling of bank erosion processes and its field application. *Proceedings of the International Conference of Hydroscience and Engineering*, Nagoya, Japan, September, 9-12, 2008.

Wu, W.M. (2001). CCHE2D Sediment transport model. Technical report No. NCCHE-TR-2001-3, National Center for Computational Hydroscience and Engineering, The University of Mississippi.

Authors (Text style: Authors Address)

Yung Chuan Chou
Kun-Hsien Chou
Chu Bor Tsung
CECI Engineering Consultants, Inc., Taiwan
Keh-Chia Yeh
Sheng-Hsueh Yang
Chung-Ta Liao (corresponding Author, Email: zeromic@gmail.com)
National Chiao-Tung University, Taiwan