2-D STATIC ANALYSIS OF FAILURE BEHAVIOR OF SHIH-KANG DAM UNDER FAULT INDUCED GROUND RUPTURE AND DEFORMATION

● Kawin Worakanchana, Student Member, The University of Tokyo
Kimiro Meguro, Regular Member, The University of Tokyo

1. INTRODUCTION

During the 1999, Taiwan Chi-Chi earthquake, Shih-Kang dam was hit by surface rupture of the Che-Lung-Pu fault. This is the first concrete dam in the history to be directly damaged by active fault[1)]. The description of the damage to the Shih-Kang dam was well collected and explained by Sugimura et al.[1)]. However, the actual failure process during the rupture has never been recorded. With the advantage of newly developed numerical simulation technique, the failure mechanism of the dam during the rupture moment is discussed in the paper. The numerical result provides the useful information for understanding the failure behavior and will be very helpful for enhancing the structural safety under the similar situation in the future. The first objective of this study is to understand the failure behavior of the Shih-Kang dam under the fault induced ground rupture and deformation by using numerical method. The second objective is to carry out a parametric study in order to understand the effect of each parameter on the damage of the dam.

Fig. 1 Shi-Kang dam after being damaged

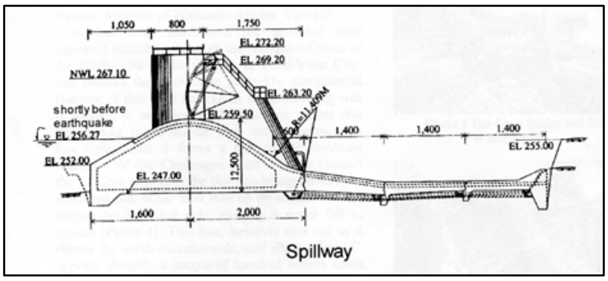

Fig. 2 Shi-Kang dam cross section

2. SHIH-KANG DAM AND DAMAGE DESCRITPION

Shih-Kang dam is a concrete gravity dam with the tainter gates. Its foundation was placed on the underlying rock surface beneath the excavated shallow sandy and gravelly soil deposit. Fig. 1 and 2 show the Shi-Kang dam after being damaged and its cross section's geometry[1)], respectively. The dam on the most left end in Fig. 1, struck by reverse fault of 10 m vertical and 3.5 m horizontal displacements (dip angle=20^o), was severely damaged. Moreover, the other parts of the dam were also damaged but less severed. This damage was due to the bed rock deformation and the strong ground motion. Fig. 3 shows the crack distribution on the dam body. Excepted from the damage on the spillways just above the fault, the other major cracks are consisted of cracks on the transverse joints between each dam block, diagonal cracks on the spillways and cracks on the horizontal construction joints on the pier.

3. NUMERICAL MODEL

The dam was modeled using Applied Element Method (AEM)[2)]. The AEM mesh and the input displacement are shown in Fig. 4. Based on specified W/C ratio, the compressive concrete strength of 20 MPa and Young's Modulus of 2x10^4 MPa are used in the model. The sharp change on the left side represents the reverse fault displacement while the curve, calculated based on the deformed shape of the dam body, represents the bed rock deformation.

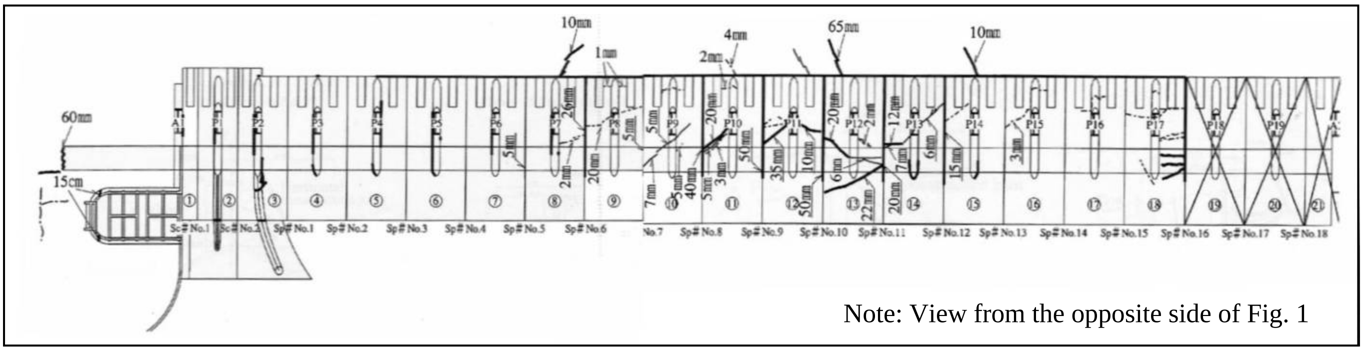

Fig. 3 Crack distribution on Shih-Kang Dam

4. ANALYSIS RESULT AND DISCUSSION

4.1 Dam Just Above the Fault Rupture

At the initial state, fault movement causes tensile stress at the boundary between dam and underneath bed rock. At δ_h=0.5 mm, a crack starts propagating at the boundary (Fig. 5.1). Simultaneously, stiffness reduction can be observed (① in Fig 6). It is worth noting that this crack will cause the water leakage unless the proper remedial method is provided beforehand.

Key words: fault induced ground rupture, concrete, Shih-Kang dam, 1999 Chi-Chi earthquake, Applied Element Method
Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-Ku, Tokyo 153-8505, Japan
(Tel: 03-5452-6437, Fax: 03-5452-6438)

Later, a crack at the top of the dam starts propagating due to tension stress from bending action at δ=1.7 mm (Fig. 5.2). After the δ=16 mm, the crack due to shear action was observed and the dam was severely damaged (Fig. 5.3). The resisting force at this displacement magnitude is diminished (②in Fig. 6). The increasing applied displacement beyond this will not increase strain energy in the dam however it will generate the crack until the dams from both sides are completely separated (Fig. 5.4). At this state, the dam should fully lose its capability to retain the water and flooding from the reservoir is possible. It is noted that although the dam section is total apart from each other, the shear transferring between each dam is still possible due to the friction of the concrete rupture under compression. However, the dam is considered to be unsafe due to the severely damage and expected large amount of water leakage.

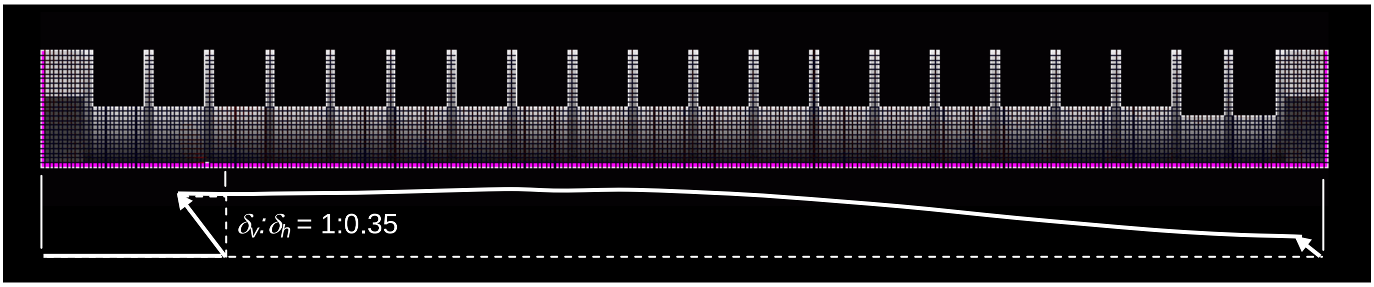

Fig. 4 AEM mesh and input deformation

4.2 Dam in the Farther Area from the Fault

As the deformation increases, the cohesion between dam and bed rock start deteriorating. Later, the tension cracks, resulted from bending effect due to the curve deformation of the ground surface, were observed (Fig. 7). Those cracks propagate very fast from the top to the bottom after its initial appearance because no reinforcement is provided. It is worth noting that although the movement just above the fault stated in previous section has higher displacement magnitude, the fault-induced ground deformation has higher possibility to hit the structures due to its wider effective area. Therefore, this deformation should be carefully considered in the dam designing process.

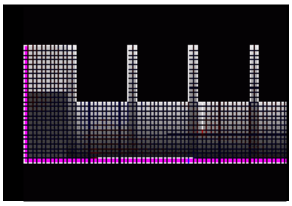

Fig. 5.1 Tension crack

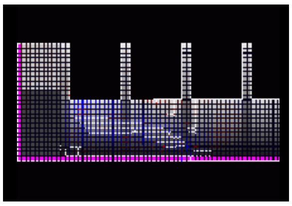

Fig. 5.2 Shear crack

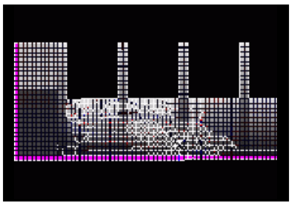

Fig. 5.3 Severely damaged

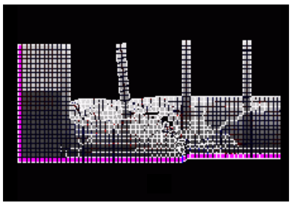

Fig. 5.4 Completely separated

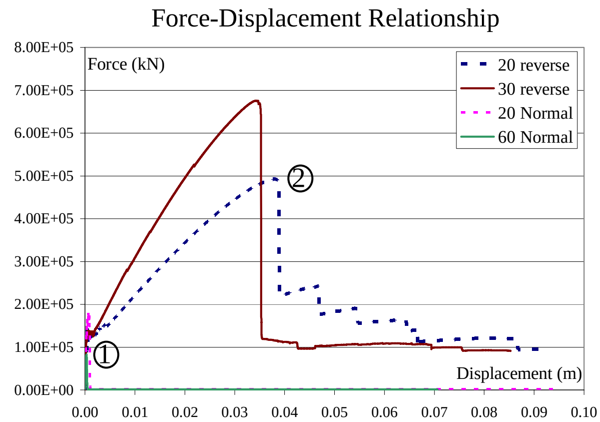

Fig. 6 Effect of dip angle on Force-Displacement relationship

5. FAULT TYPE AND DIP ANGLE EFFECT

As shown in fig. 6, the behavior of the dam under reverse and normal fault is totally different. For the normal fault, the dam will be suddenly broken into two pieces after stress in concrete reach its tensile strength. As a result, it is thought that the normal fault is more dangerous in case that fault movement is occurred. The change in dip angle of reverse fault slightly increases resisting force after separation of the dam from the bed rock. This is due to difference in the compressive stress in the dam. For the normal fault, larger dip angle results in decreasing maximum resisting force but the affect is very small.

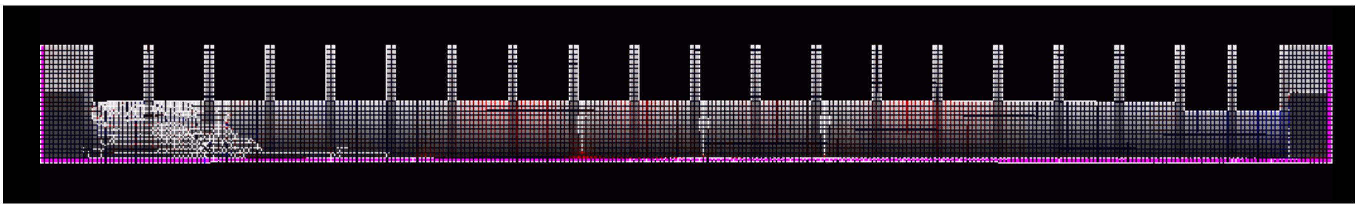

Fig. 7 Crack distribution on the whole dam after applying fault induced ground rupture and deformation

REFERENCES

1. Sugimura, Y., Miura, S., and Konagai K., 2001 Damage to Shih-Kang Dam Inflicted by Faulting in the September 1999 Chichi Earthquake, *Seismic Fault-Induced Failures*. 2001 January: 143-154
2. Meguro, K., and Tagel-Din, H., 2001. Applied Element Simulation of RC Structures under Cyclic Loading. *Journal of Structural Engineering*, ASCE. 127, 11: 1295-1305.