GEOLOGICAL MODEL OF HSUEHSHAN TUNNEL

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ABSTRACT

From experimental modeling, geological field survey, and tunnel excavation, three kinds of faults could be deciphered in the east part Hsuehshan Tunnel rock mass. The first one is thrust along the sandstone and shale contact surface. The second is strike-slip fault, which cut through the first stage thrust faults. It is also the major one. The dilatational behavior of the strike-slip fault formed a flower structure that made the rock mass serious broken with shear and secondary fault zones. Finally, the change of the principle stress direction results in rock slip along the fracture surface and forms the extensive type normal fault. It caused more serious rock mass loosening. This is the cause why the excavation of Hsuehshan Tunnel had encountered so many unknown faults or shear zones and so abundant groundwater inflow in this area. Because there are not just one fault but are many fault zones connected together.

Keywords: Hsuehshan Tunnel, strike-slip fault, flower structure

INTRODUCTION

TBM excavation of the Hsuehshan pilot Tunnel had encountered 10 times trappings from the beginning to the distance of 1600 meter. Many unexpected shear fractures that are complex and extended not distantly in the middle of the main faults caused these trappings. These unexpected shear zones also carry abundant groundwater inflow.

Because quartzite is not a good water container, groundwater inflow in this area could be inferred that was influenced by the geological structure. If we could realize the geological structure in this area, it is not only beneficial to understand the cause of the difficulty in the construction but also could we under the proper model to infer the hazard we might encounter, and then could prepare how to deal with beforehand.

This paper attempts to investigate the geological condition of east Hsuehshan Tunnel from the geological structure model. Under the reasonable model estimates the probability problem in tunnel excavation. It hopes that would benefit to the tunnel construction in the future.

GEOLOGICAL STRUCTURE MODEL OF HSEUHSHAN RANGE

Taiwan is located on the plate boundary. The Philippine Sea plate is moving towards Taiwan presently along the Longitudinal Valley. Lu & Hsü proposed that in the Mid-Miocene to Pliocene (about 15~5My) , Philippine Sea plate moved toward the Eurasian plate with Lishan fault as the plate boundary (Lu & Hsü, 1992) . In this collision, very complex geological structures were formed. The Hsuehshan Range also created in this stage. In 1994 Lu & Malavieille used a sand table to model the collision of Phillipine Sea plate and Eurasian plate (Lu & Malavieille, 1994) . The model was built by laying horizontal layers of colored sand onto a PVC plate. A rigid mobile backstop pushes the sand over the basement plate. The continental margin is oriented about N60E, the same as Lishan fault orientation. The trend of the Ryukyu Trench is as the eastern boundary of Northern Taiwan. The Phillipine Sea plate move towards the Eurasian plate in the N55W direction (Fig.1, Lu & Malavieille, 1994) . The experimental results are in Fig.2 and the vertical cross sections are in Fig.3.

Based on the results of the experimental modeling, there are very complex mountain belt structures in front of the backstop. Each vertical sections of Fig.3 are characterized by three different domains (A, B and C) . The A domain is dominated by imbricate

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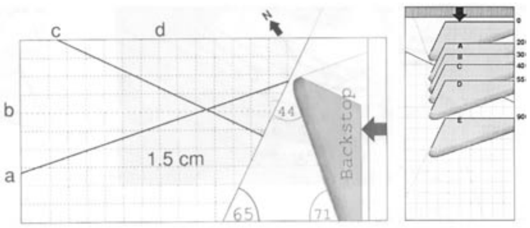

Fig.1: The experimental model of the Phillipine Sea plate collides with the Eurasian plate (Lu & Malavieille, 1994, fig.4&5).

thrust. The C domain is dominated by backthrust. The B domain is characterized by strike-slip faults which cut or superimpose on the previous imbricate thrust (Lu, et. al, 1997). The northern section (section 2 in Fig.2, 3) which Hsuehshan tunnel passes through is characterized by a flower structure, that is formed by strike-slip faults.

We could simply illustrate the occurrence of these faults with Fig.4 (Lu, et. al., 1997). When the plates oblique converge, first of all the rock mass will shrink and the thrusts (B) will be formed. When the force continually to push the plates, the strike-slip faults (C) or the pop-up structures (D) will be developed. At last, when the force push the plates further, the rotational deformation, with bookshelf-type strike-slip faults will be developed (E).

The result of experiments and theory must be proved in the field. There are several methods to check out the attitude of the fault movement. Indirect method is to observe the correlation of the strata, for example, according to the contact relationship of the old and new strata beside the fault zone, normal faults or thrusts can be decided. Direct method is to decide the direction of the fault movement by checking the slickenside and microstructures on the fault scarp, and furthermore to infer the direction of tectonic pressure in the happening of the fault by statistical analysis.

There are very good occurrence of the northern Hsuehshan Range strata along the northern coast. Very good conjugated strike-slip faults or bookshelf-type strike-slip faults can be observed along the northern coast way Mao-ao to Dali (around 116k-128k)(Lu, et. al., 1994). The most complicated deformation located at the way between 118k to 122k. By the middle-structure, the folded strata were cut to very complicated mass by strike-slip fault, and even some local strata were rotated (Fig.5).

From sand-model imitation to field geological investigation, it is discovered that the strike-slip faults almost dominated in the structure faults of the northern Hsuehshan Range.

Is it also dominated by the strike-slip faults in the area of Hsuehshan tunnel? This paper will introduce Chingyin

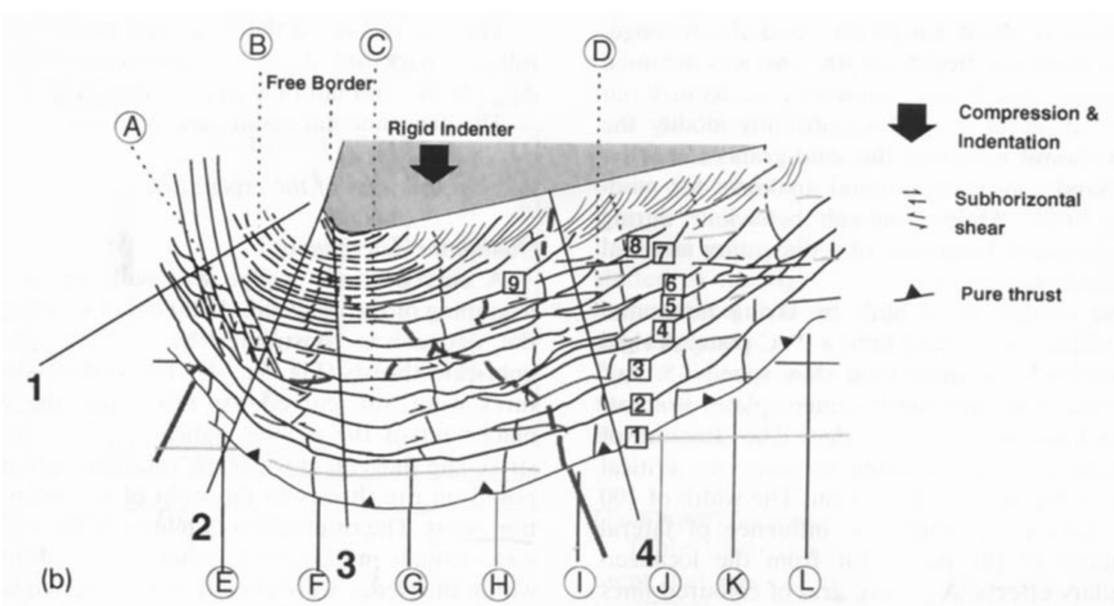

Fig.2: The results of the sand table experiment (Lu & Malavieille, 1994, fig.5).

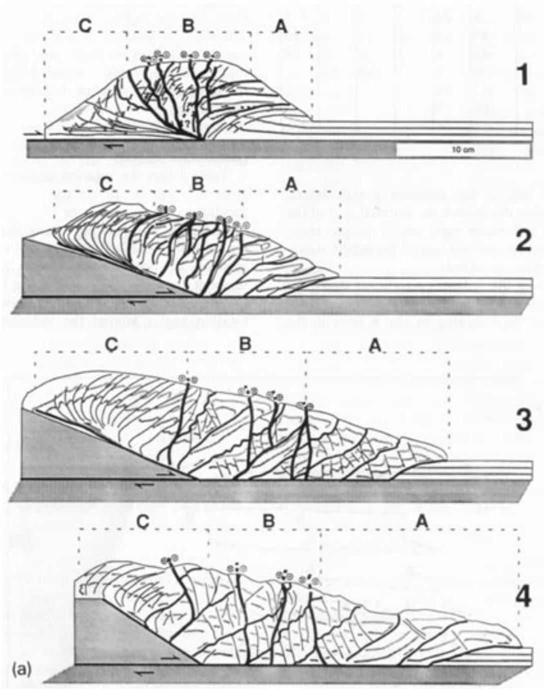

Fig.3: The vertical cross sections of Fig.2 (Lu & Malavieille, 1994, fig.7).

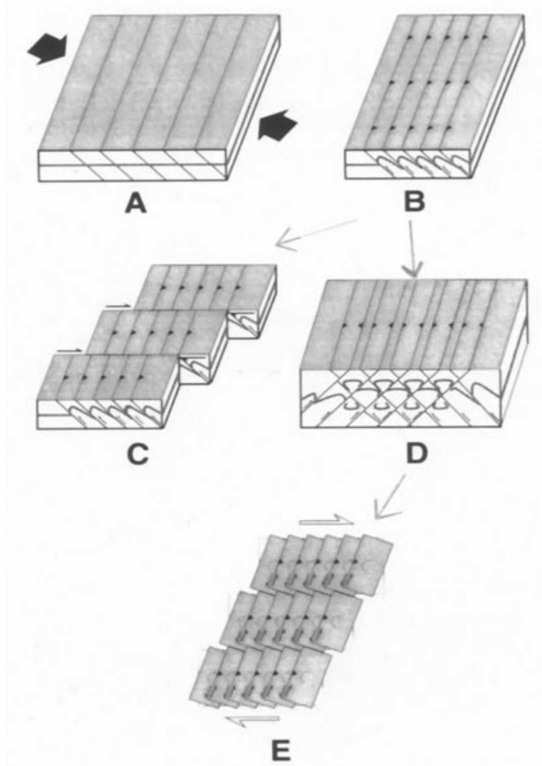

Fig.4: When the plates oblique converge, first of all the rock mass will shrink and the thrusts (B) will be formed. When the force continually to push the plates, the strike-slip faults (C) or the pop-up structures (D) will be developed. At last, when the force push the plates further, the rotational deformation, with bookshelf-type strike-slip faults will be developed. (E) (Chu, et.al.,1996)

Fault only, and the other faults, Shanghsin and Shihpai Faults have the same structure model.

There are very good Chingyin Fault outcrops in Chingyin Valley. Three kinds of faults could be deciphered from slickensides on fault surfaces in the Chingyin Fault zone. One is on the sandstone and shale contact surface. In these shear fractures, thrust slickensides could be seen. In the main fault plane, two types of slickensides appear on it. One is strike-slip fault, which altitude is 120, 77S, 25W. The other is normal fault, which altitude is 120, 77S, 54E (Fig.6, 7).

The relationships of these three kinds of faults is that the oldest thrust faults were cut through by the strike-slip fault and then normal fault moves down along the strike-slip fault surface. The strike-slip fault slickensides are dominant in this area. From the counter map, the direction of the principle stress was N130 degree (Fig.8).

From theory, experimental modeling and geological field survey, that the eastern part of the Hsuehshan Tunnel are located in a strike-slip faults dominantly geological condition.

Fig.5: Bookshelf-type strike-slip faults along the northern coast way between Mao-ao to Dali (Lu, et. al., 1994)

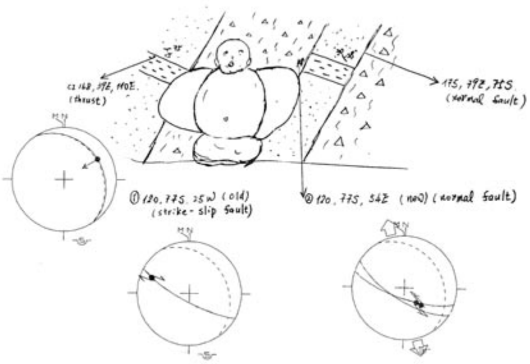

Fig.6: The Chingyin Fault outcrops in Chingyin Valley. Three kinds of faults could be deciphered from slickensides. The oldest thrust faults were cut through by the strike-slip fault and then normal fault moves down along the strike-slip fault surface. The high of the Buddha figure is 2.5 meter.

Fig.7: In the main fault plane of the Chingyin Fault, two types of slickensides appear on it. The older one is strike-slip fault, which altitude is 120, 77S, 25W (upper). The newer is normal fault, which altitude is 120, 77S, 54E (lower).

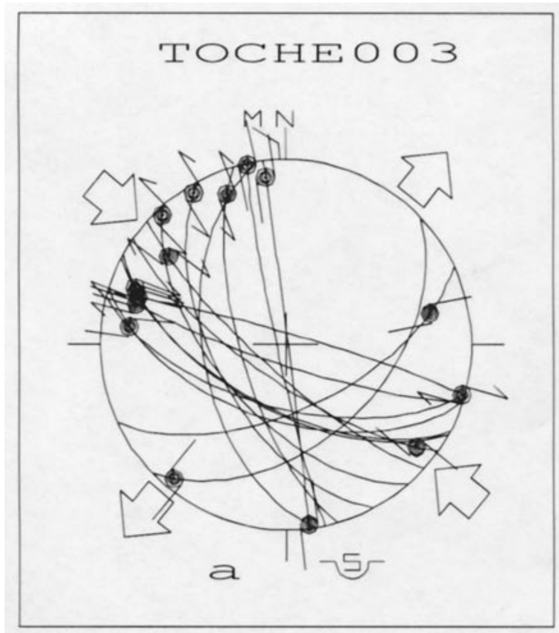

Fig.8: The counter map of the slickensides of strike-slip fault in Chingyin Valley, the direction of the principle stress was N130 degree.

GEOLOGICAL STRUCTURE OF THE EAST SECTION OF HSUEHSHAN TUNNEL

Strike-Slip Fault

Both the tectonic and local geological structure reveal that the strike-slip fault dominate in this area, then in this paper the strike-slip fault were used to deduce the geological situation of the Hsuehshan Tunnel.

1. Strike-slip fault are with principle stress ($\sigma 1$) and minimal stress ($\sigma 3$) in the horizontal direction, and the secondary stress ($\sigma 2$) in the vertical direction. The rock mass were torn along the horizontal direction. The differences between the normal fault and strike-slip fault are: the former were formed by tension stress and the latter were formed by convergent stress. The strike-slip fault often caused greater shear zones, finer fault gouge and more swelling clay minerals; therefore the security of the construction is more seriously than the normal fault.
2. Under the tectonic stress dominated with the horizontal stress, in the rock mass the Riedel-Shear fracture will be developed at first, and then the P-Shear fracture, therefore a series of regular and continuous fractures will be produced. Tacking the Chingyin Fault as

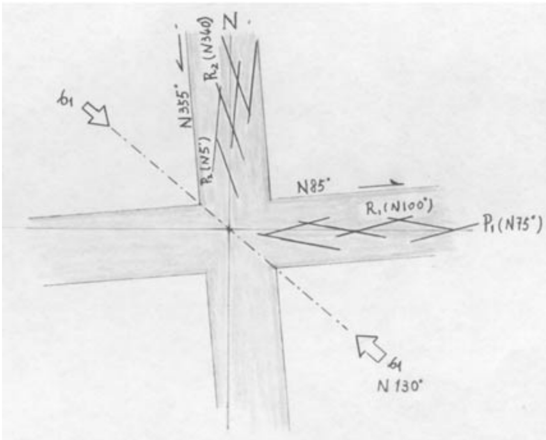

Fig9: The altitude of the fracture direction, N10E, N75E, N15W, N50W and N80W, produced from the principle stress N130°.

an example, its principle stress is N130 , and its theoretical principle shear stress is N85 and N355 , which will produced (a) the Riedel-Shear fracture, its direction is the direction of the principle shear stress plus about 15 degree (N100 and N340) . (b) the P-Shear fracture, its direction is the direction of the principle shear stress minus about 10

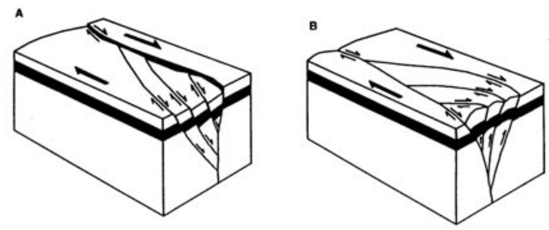

Fig10: The negative (a) and positive (b) flower structures of strike-slip fault (George & Stephen, 1996) .

degree (N75 and N5) . (c) the Tension fracture, its direction is about the same of the direction of the principle shear stress (N130) . Therefore the altitude of the fracture direction in this area are N10E, N75E, N15W, N50W and N80W (Fig.9) .

3. Consequently the fracture model under this tectonic stress will be more complex than that under the normal fault stress. The strike-slip fault don't appear alone, but form the complex flower structures (Fig.10) , which cause many secondary shear zones beside the principal fault zone.

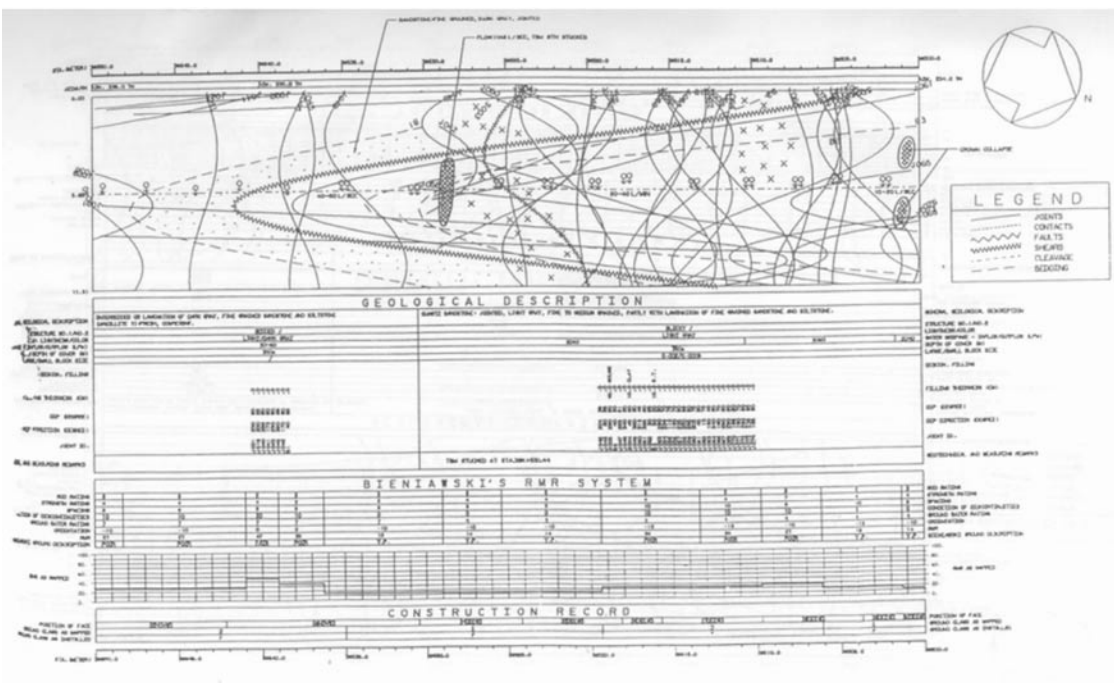

Fig11: Hsuehshan pilot tunnel, tunnel meter 39k+550 to 500

Geological Situation in the Pilot Tunnel

The Chingyin fault exposes in station between 39k+842 to 816 in the pilot tunnel. In the rock mass encounters by serious tear, 14 meters wide fault breccias and 15 meters wide fault gouge were developed. The total fault zone is about 30 meters. There are highly disturbed situation and water inflow beside the main fault. Except the main fault, several secondary faults and shear zones were developed very well. The altitudes of these secondary fault (or shear zone) are (a) the movement along the sand and shale contact plane and (b) the shear fracture of the five altitudes mentioned above (Fig.11) . For that reason a seriously shear fracture rock mass was developed between a principle main fault (for example Chingyin Fault) and another principle main fault (for example Sanshin Fault) .

CONCLUSION

In the strike-slip fault dominating fault zones, the main fault cannot be the only focus. Between the main faults, there are many secondary faults developed by P-Shear and Riedel-Shear, which cause bigger threat to the security of tunnel excavation than normal faults.

All of the five main faults of east section of the Hsuehshan Tunnel, because of the strike-slip faults, the degree of the rock fracture and the water contain were greater than that were estimated. After the geological structure was more carefully studied, the reason why there are so many unexpected shear zones besides the main faults in the east section of the Hsuehshan tunnel will be known clearly.

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