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Geological Investigation and Sliding Mitigation in Jiufen Area

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ABSTRACT: Jiufen's orographic and geological characteristics together with frequent typhoons and heavy rain make it potentially vulnerable to landslides. The landslide problems could be disastrous not only to the 2,300 local residents, but also to the constant flow of tourists visiting the town. After the site investigations, it is concluded that both of the colluvium and groundwater are the most important geological factors to the slope stability problems. According to the long-term groundwater level monitoring result, it varied from 8m to 12m during the period of typhoon and heavy rainfall. And the displacement induced by the groundwater level rising was found. Four underground flow lines were located based on the resistivity image profiling and self-potential investigation. Then five water collection wells were planned to construct according to the locations of underground flow lines. The level lowered down about 15m after the wells completed and the slope became stable. It is suggested that the depth of colluvium in Jiufen area needs to be investigated in more detail.

KEYWORDS: Landslide, Site investigation, Geological survey, Monitoring, Slope stability analysis

1. INTRODUCTION

Jiufen village is located in north-eastern part of Taiwan. It is famous for its old-golden mine field and old mining cultural atmosphere in the streets. There are more than one million tourists visiting here per year. However, the cracks on ground surface and house structure which respond the land sliding have been found due to the lack of an appropriate drainage system and house quantity control regulation. The long term monitoring system for the observation of the land slide behavior has been taken since 1997 [1]~[6].

In order to protect the lives and properties of residents, sightseeing location and culture heritage, a mid-term to long-term prevention and reinforcing project has been proposed by the New Taipei City since 2010 [7]. The work items include geological survey, underground flow investigation, monitoring system installation and data analysis, slope stability analysis, etc.

2. SITE INVESTIGATIONS

The scope of investigation is shown in Figure 1. The total investigation area is about 100 hectares. Many outcrops were found as indicated in Figure 1. Jiufen area is defined as the landslide problem to deal with, The sources of groundwater collection areas were taken into consideration.

The area of supplementary topographic survey was enlarged from 20 hectares to 56 hectares. The site topographic and geological map is shown in Figure 2.

Using the orthophotos base maps of Taiwan area (Ruibin and Jiufen, 1/5000) provided by Aerial Survey Office, Forestry Bureau and the map from supplementary topographic survey, the surface geological surveys were conducted. The surveying centre was at Jiufen, the eastern boundary extended to Giamy fault, the northern to the southern part of Keelung Mountain, the western to the entrance of Yuansantze Flood Diversion Project and the southern to the district of Houtong and Xiaojingua. The survey results are plotted to geological map as shown in Figure 2 and the sectional diagram (B-B cross-section) is shown as Figure 3.

3. ENGINEERING GEOLOGY CHRATERISTICS

There are three different formations in this area. From bottom to up, they are Daliao formation, Shidi formation and Nangang formation, respectively. Sandstone, shale and few coals are the major rock layers in these formations. Four major geological structures have been found, i.e., Houtong anticline, Giamy fault, Ruifang fault and Dieyuken fault. According to the result of site investigation, the characteristics of engineering geology can be described as followings:

3.1 Topography

The elevation of Jiufen area ranges from the lowest 225 m of the Taiyang parking lot to the highest 360 m of the Qinxian junior high school above the sea level. The basic slope strike is approximately directing to the north eastern 30 degrees and inclining to the west. Under the actions of the geological forces to the topography, three ditch valleys which incline to NNW direction and convex ridges or steep slopes among valleys are developed. The rock layers of valleys are mainly thick shales or interbedded sandstones and shales. On the other hand, the ridges or steep slopes are composed by thick or mass sandstones.

3.2 Strikes and Dips of Rock Layers

The strikes of rock layers in this area are ranging about the north 50 to 80 degrees to the west and they are 20 to 30 degrees dip to the NNE direction. Most of them belong to anaclinal slopes. It is noted that the small scopes of rock falls could happen.

3.3 Colluvium

The thickness of colluvium over the rock layer ranges from zero (rock exposed) to 20 m. It contains surface soil, fill, rock fragments with different sizes, etc. But the area above the village to the Qinxian junior high school has the large thickness about 28 to 39 m. It is conjectured that some soils and rock debris were put directly downward during school structure and sports field construction. It is also noted that there is comparatively broken shale beneath this area. The total thickness of loosen zone is evaluated about 50 m. These loosen zones interacted with groundwater are considered as the most influential factors to the slope stability of this area.

3.4 Groundwater

According to the previous site investigations, it is considered that there is abundant groundwater in Jiufen area. The groundwater levels are obviously influenced by the volumes of rainfalls.

The permeability of fresh/tight sandstone or shale is very low. If there are shear zones, broken belts or tension cracks inside the rock layers, the rock mass permeability can be increased and a certain volume of water can be contained inside. It is a very complicated system and hardly to get comprehension information. Because there are many deep pits below this area, a large volume of deep groundwater is draining through these pits. Its influence to the slope stability is little.

Due to the impermeable silts contained in faults, there might collect a large volume of groundwater in broken zones above fault and become the source of groundwater under the slope.

Because of the loose structure of colluvium, its permeability is high. The groundwater level can go up and down very quickly following the rainfall volume variation. It is believed that the great rising of the groundwater level inside the colluvium is the most unfavourable factor to the slope stability condition.

3.5 Pits

There are three ramp pits below the Jiufen village. The depths of them are more than 90 m around this area. The main lodes are along Giamy fault and several parallel faults in the southern zones. These dense distribution pits are located at south eastern parts of Jiufen area. For the excavation to the southern direction, it becomes deeper and farther away from this area. Therefore these pits are very little influences to the slope stability problems.

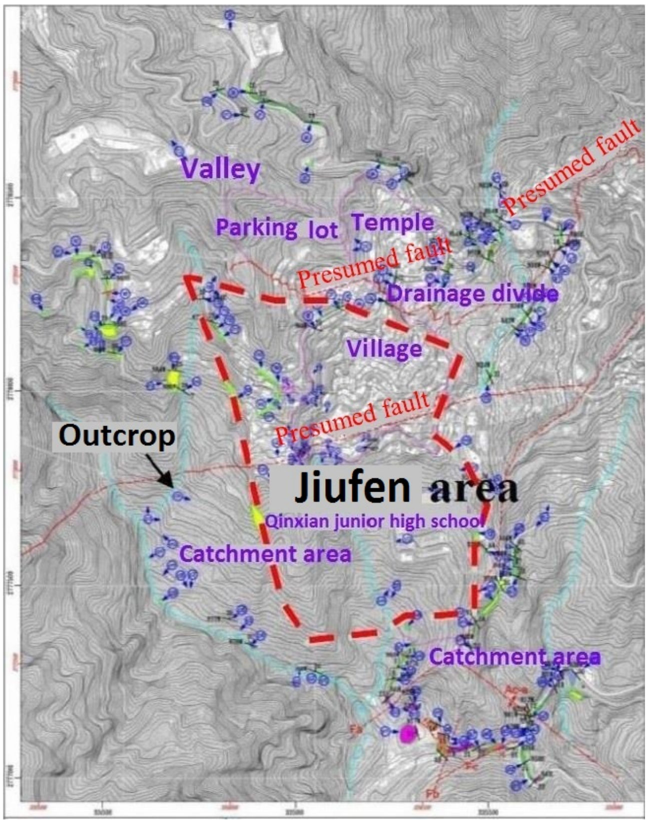

Figure 1 The scope of site investigation and Jiufen area defined as the landslide problem to deal with

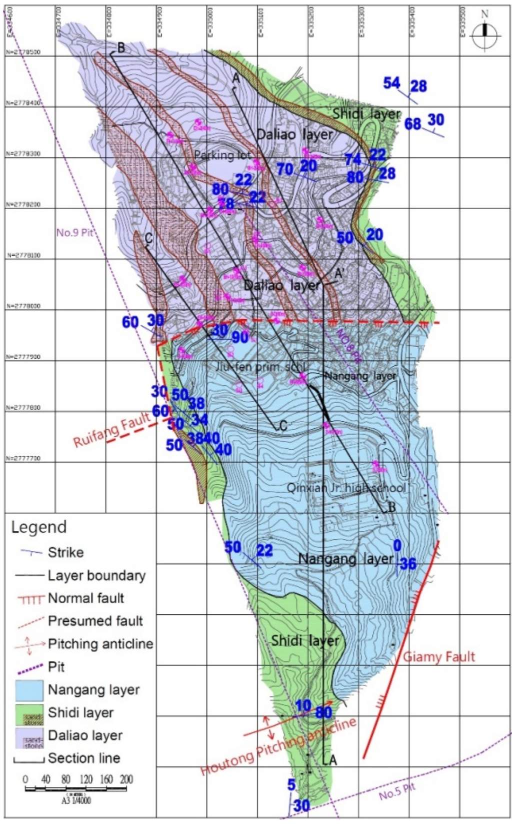

Figure 2 Site topographic and geological map

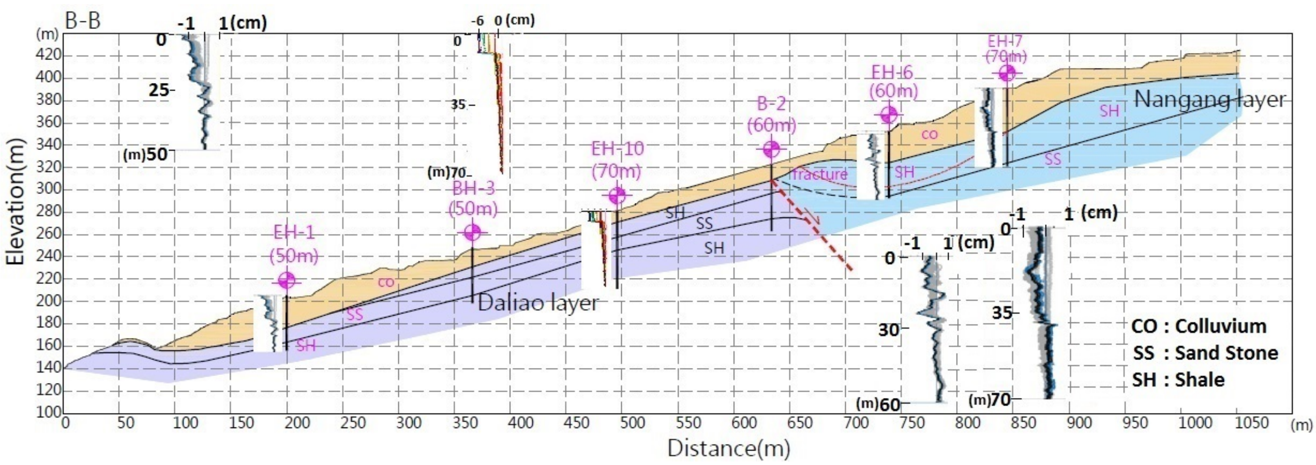

Figure 3 B-B cross-section of Figure 2 and four ground displacement records measured by inclinometers

4. LANDSLIDE MONITORING

In order to prevent the landslide disasters and reduce loss and damages, monitoring stations have been established by the New Taipei City. Preventive measures are taken so that infrastructures are regularly maintained to enforce physical stability of the landscape; and geological and meteorological parameters are regularly monitored to assess potential risks. Within the Juifen Landslide Monitoring system, there are 16 manually-operated inclinometers, and 27 automatic monitoring devices (Table 1).

Four displacements recorded by inclinometers can be seen in Figure 3. Figure 4 shows the monitoring data of groundwater and ground displacement recorded more than one year. It can be seen that the ground displacement increased with the heavy rainfall quantity. Comparing to the monitoring rainfall results in Juifen area and the nearby Keelung rainfall station data of Central Weather Bureau during the Nanmadol typhoon, it is noted that the groundwater level rose about 9.02m and the increasing groundwater volume not only from the rainfall in Juifen area but also from the underground flow of surrounding area as shown in Figure 5. Since the groundwater associated with the stability of Juifen landslide area, it was very important to investigate the underground flow distribution and constructed the drainage well.

Table 1 Facilities and monitored parameters

Monitoring devices/ structures	Functions/monitored parameters	# of device
Groundwater level observation well	Groundwater level	5
Rainfall sensor	Precipitation	1
Ground surface extensometer	Ground surface displacement	3
Crackmeter	Structure crack	3
Structure biaxial surface clinometer	Structure inclination	11
Ground surface biaxial surface clinometer	Ground surface inclination	3
Anchor load cell	Anchor stress	1
Inclinometer	Stratum deflection	16

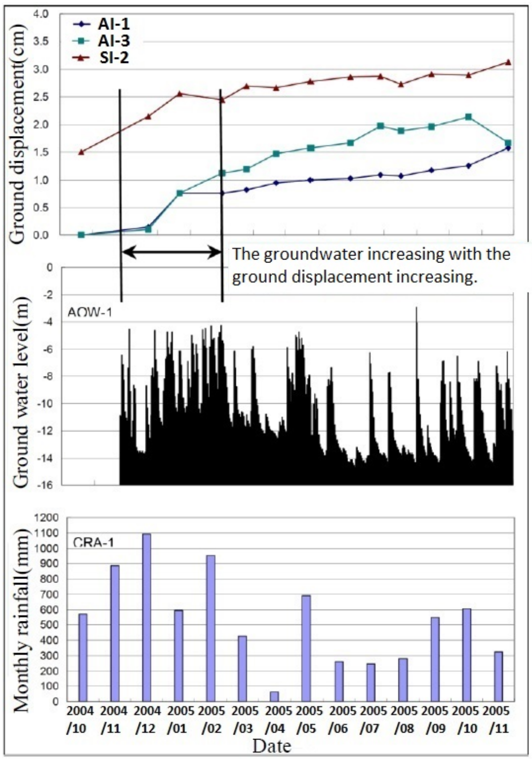

Figure 4 Ground displacement and ground water level vs. rainfall

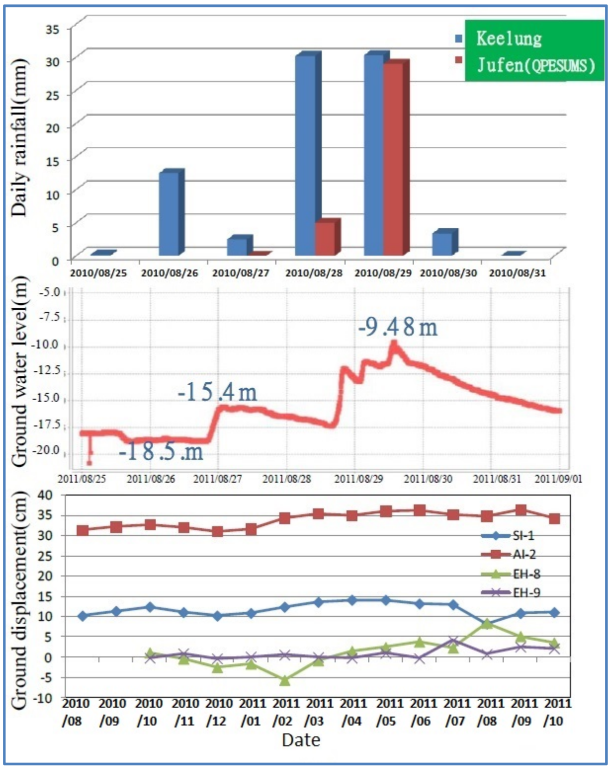

Figure 5 The relationship between rainfall and ground water level during Nanmadol typhoon

5. UNDERGROUND FLOW

Both RIP(Resistivity Image Profiling) and self-potential (SP) survey were used to investigate the distribution of the underground flow. Figure 6 shows the RIP results from 12 profiles and their resistivity distribution zones with different colors. Base on RIP results, there was one main line of the underground water flow passing through the area as shown in Figure 7. The relative voltage contours from SP surveys are shown in Figure 8. Figure 9 shows that the underground flow lines were located both from the RIP and SP survey results. There are four underground flow lines and the main line passed through the middle part of the area. The direction was from the south to the north.

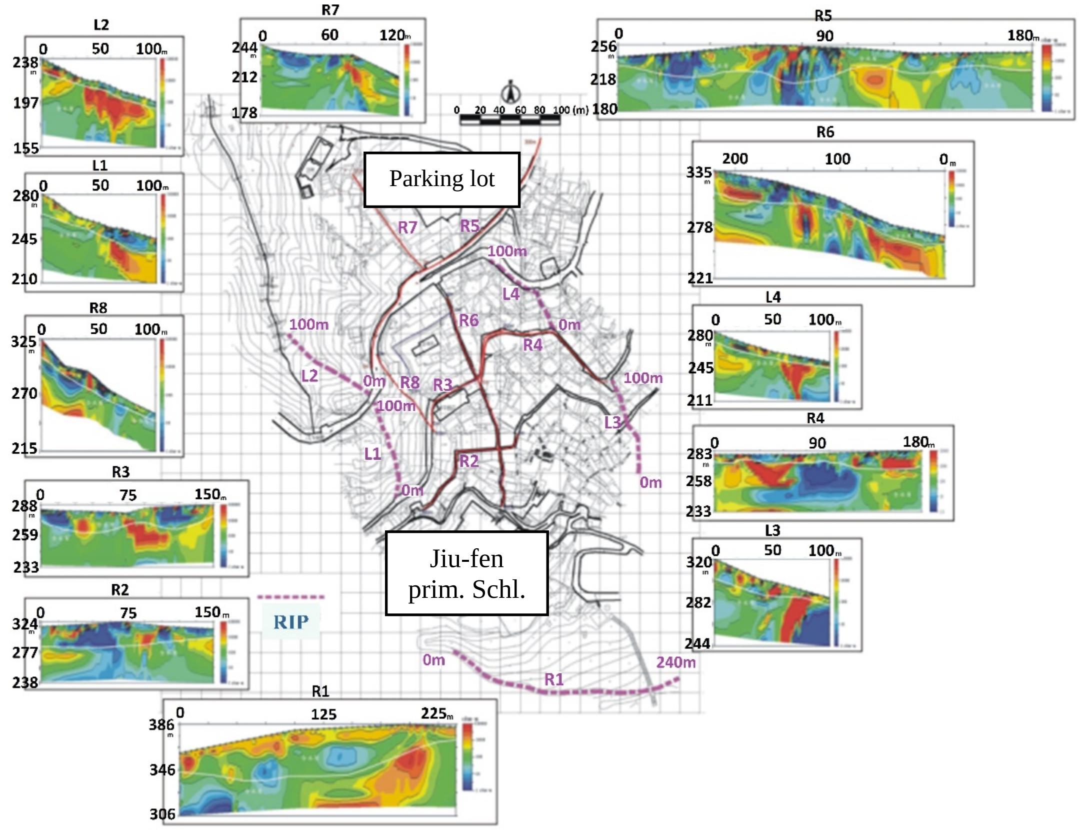

Figure 6 The RIP results from 12 profiles and their resistivity distribution zones with different colors

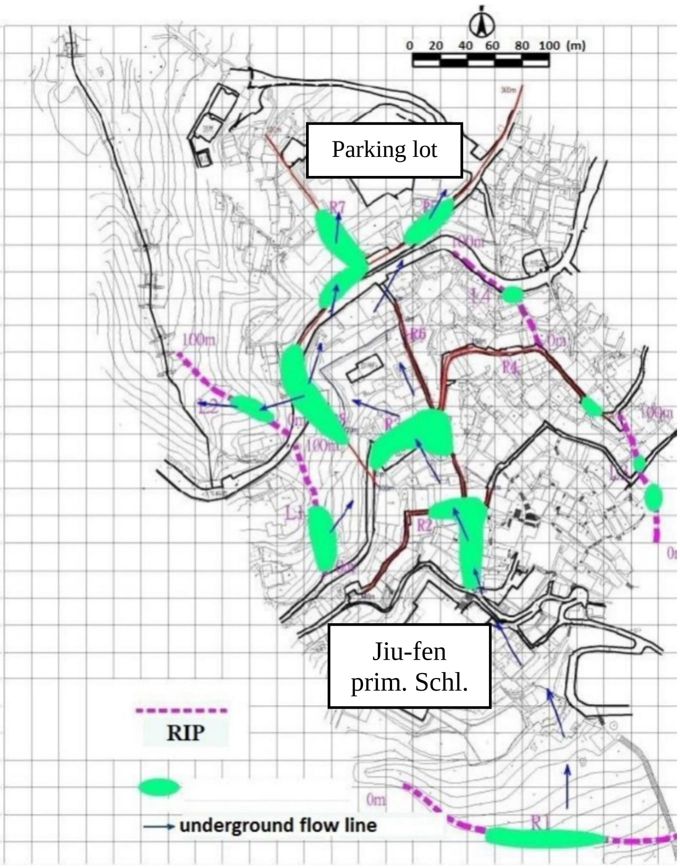

Figure 7 The underground flow line located by RIP

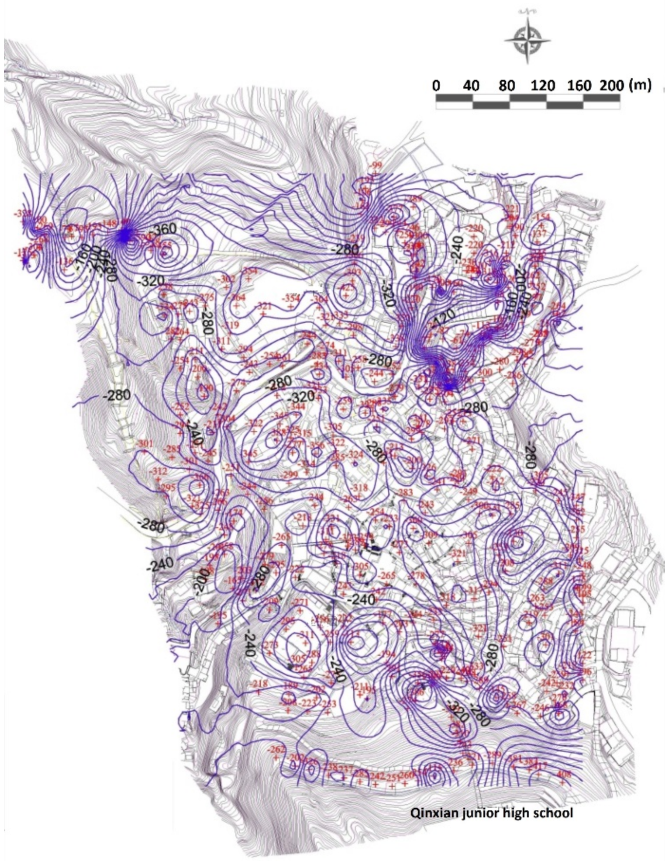

Figure 8 The relative voltage contours obtained from SP surveys

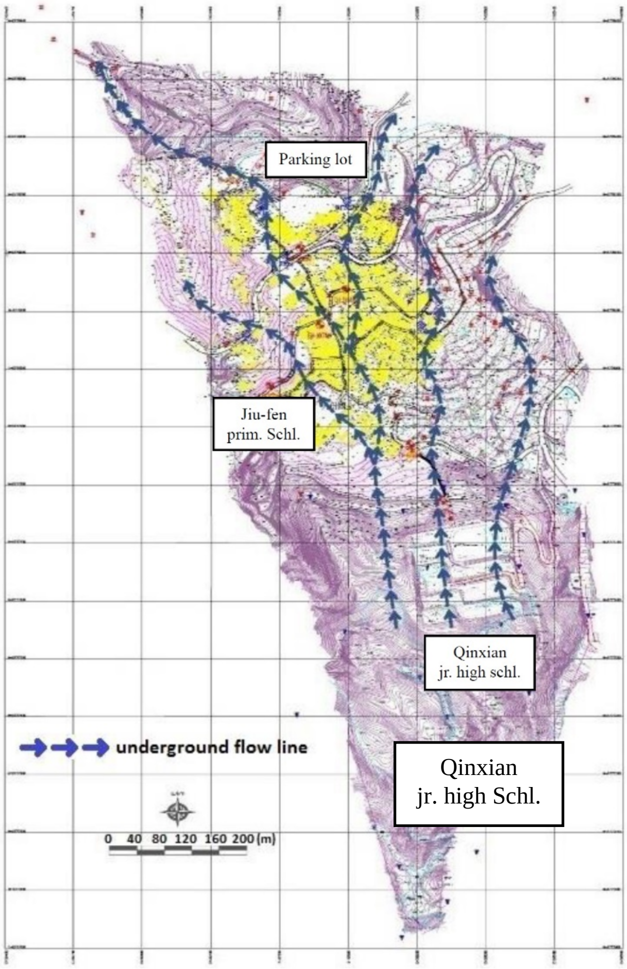

Figure 9 The underground flow lines located both from RIP and SP survey results

6. LANDSLIDE MITIGATION

Analyses were conducted at several different cross sections. The slope stability analysis results of B-B section is shown as Figure 10. It is found that the safety factor is 1.02 in the high groundwater level during typhoon. In order to increase the slope stability, it should lower down the groundwater level. Five groundwater drainage wells were constructed according to the four underground flow distribution as shown in Figure 11. There are two construction stages shown in Figure 11. After the first stage completed, the groundwater level lowered from 12 m to 18.5 m below ground surface. Following the second stage completion, the groundwater level further lowered from 18.5 m to 27.5 m as shown in Figure 12. The ground displacements also decreased. The safety factor increased to 1.41.

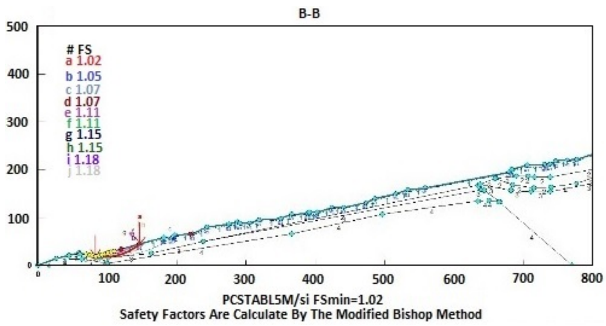

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Figure 10 The slope stability analysis results using STABLE

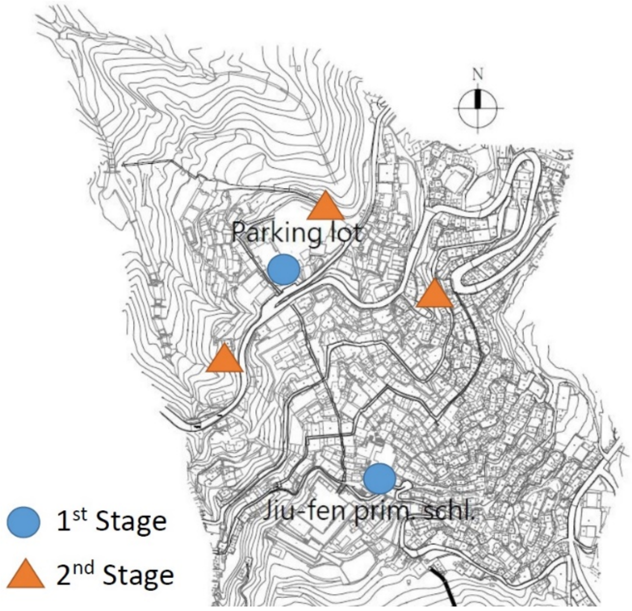

Figure 11 The locations of five groundwater drainage wells and two construction stages expressed by the different symbols

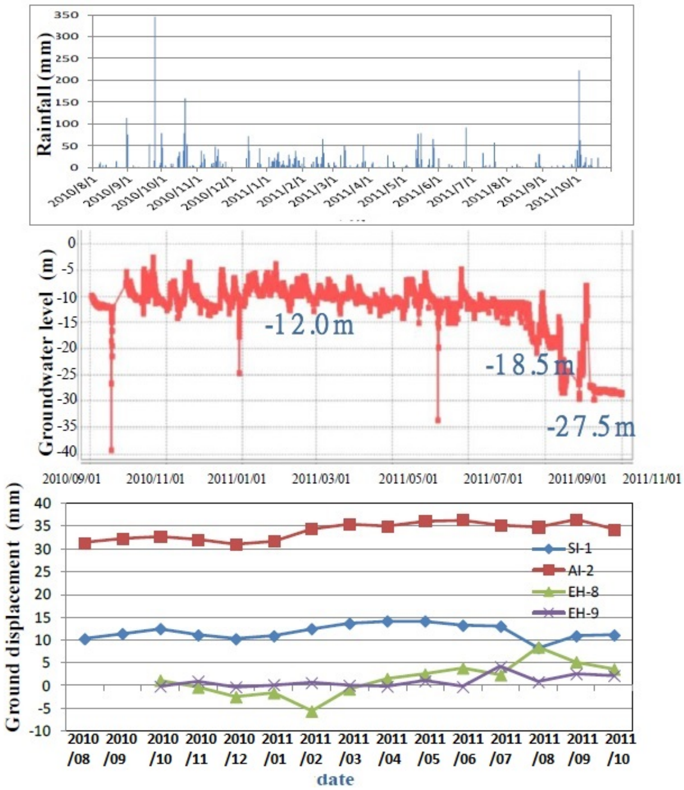

Figure 12 Groundwater level and ground displacements vs. time after five wells completed

7. CONCLUSIONS

After the site investigations, it is concluded that both of the colluvium and groundwater are the most important geological factors to the slope stability problems. Groundwater risings after rainfalls were found to have the negative effects to the slope stability. They were considered to be parts of the major factors affecting the effective stresses and shear strains of the soils in colluviums. Both RIP and SP surveys were used to investigate the distribution of the underground flow at Jiufen area. And from the locations underground flow lines and the long-term landslide monitoring data, the groundwater drainage wells were planned to construct. It is found that the groundwater levels were effectively lower down and the slope stability condition increased. Because the colluvium is the key influence factor and the borehole numbers are still not enough to evaluate the problem, it is suggested that the depth of colluvium in Jiufen area needs to be investigated in more detail.

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