LANDSLIDES IN TAIWAN
SOME CASE REPORTS

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SYNOPSIS Seven case histories of landslides are presented in the paper. These slides are of the types which are common in Taiwan. The major causes for the slides were either due to saturation of the soil mass after a heavy rainfall or due to high pore water pressure developed in the subsurface strata. Preventative, control or remedial measures adopted are described.

INTRODUCTION

Taiwan is situated in the subtropical region with high average temperature and precipitation. It is also an area subject to frequent earthquakes and typhoons. The intensity of rainfall may be as high as over 400 mm a day. Three quarters of the land area in the Province are covered by mountain ranges usually with relatively steep slopes. Due to intensive weathering and strong geotectonic activities, landslides are common phenomenon especially after or during rainstorms. These landslides have caused considerable hazards to both lives and properties. In recent years, rapid economic development in the province requires more efficient land utilization. Expansion of the urban areas also demands more lands. Development of hillside terrains becomes a natural process. In view of the geological, topographical and geographical nature of the upland terrains in the Province, control and prevention of landslides must be given utmost attention.

This paper presents 7 case histories of landslides which are the types commonly occurred in Taiwna. Since it is difficult to exactly distinguish a slide of soil masses from a slide composed of weathered rocks, the latter type is also included. Rockslides are being considered in another paper to be presented at his conference.

FUSHAN SLOPE

The area concerned, about 200 m by 150 m, is located immediately east of Shilin, Taipei, at El 10 m to 40 m above mean sea level. Both Chungshan North Road and the Taipei-Tamshui railroad line run along the foot of the slope which declines in a northwestern direction. A location map is shown in Fig. 1. The original slope had an inclination of about 15 to 20 degrees corresponding to a 2 to 1 slope. The slope itself was divided into several terraces and was occupied predominantly by one-storey dwellings. The most significant structure located on the slope was an underground water reservoir built some 50 years ago. The dwellings were constructed between the reservoir and the road. In the development of the hillside for building construction, no measures were taken to provide proper drainage for the slope. Due to percolation of water into the ground and saturation of the subsoils, repeated small movements of the slope had occurred.

In 1972, a series of slides occurred in the area after the construction of a ditch at the toe of the slope in connection with the widening of the Chungshan North Road. Several cracks opened on the slope parallel to the toe, with width varied from a few millimeters to several centimeters. The cracks cut through concrete floor slabs and brick walls of structures situated on the slope. Some of the observed movements indicated block slides whilst there were also evidence of rotational slides.

A thorough investigation of the slide was undertaken by Dorsch Consultants International in conjunction with the National Taiwan University (FRISCH, HUNG, and SIMON, 1975) which consisted of information collection, site survey, borings and laboratory testing. A total of 12 bore holes varying in depth from 4.5 to 9.5 m was drilled to determine the stratigraphy of the slope. A typical bore-hole log is shown in Fig. 2. The subsoil of the area consisted of a thin layer of sandy or silty clay overburden with rock fragments, ranging in thickness from 1 to 4.5 m overlying a weathered sandstone layer, about 0.5 to 5.0 m thick. The sandstone is underlain by sound shale. The shear strength parameters of the overburden soil in terms of total stress as determined by consolidated undrained tests had values of ϕ equal to 17 to 26 degrees and c varying between 0.2 to 0.8 kg/cm^2.

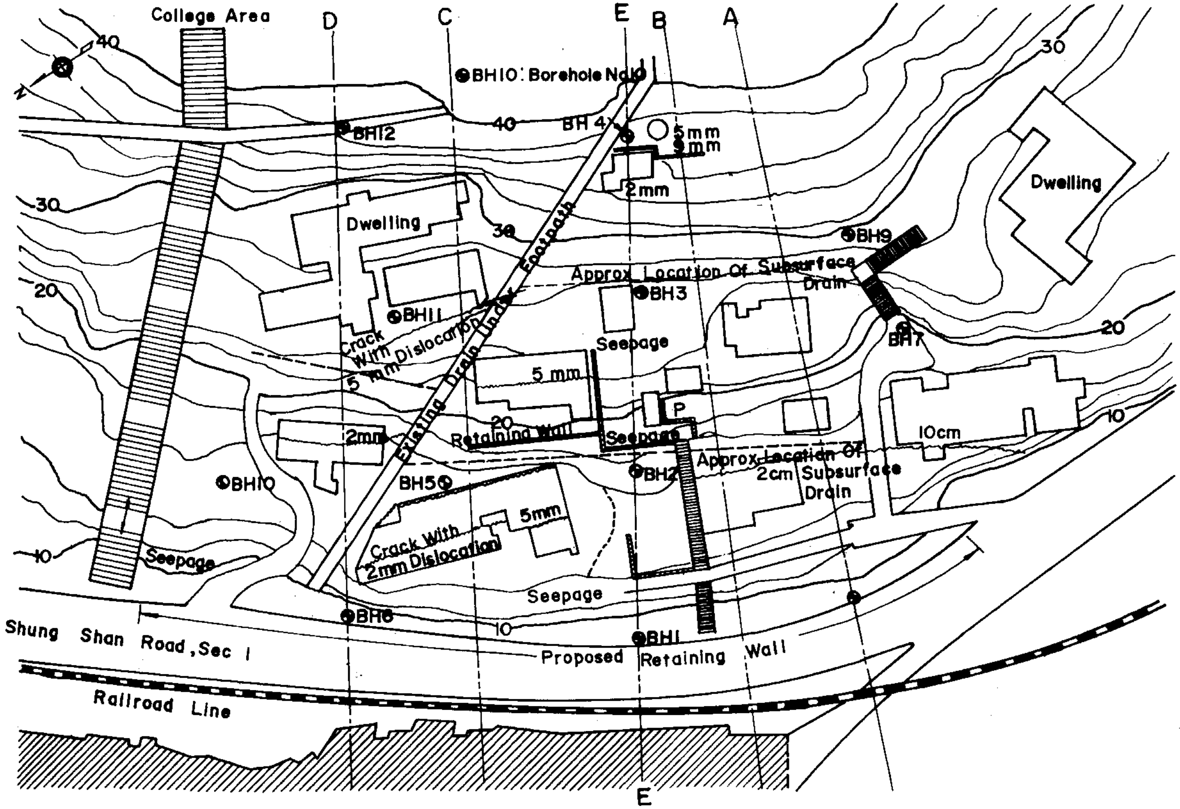


FIG. I LOCATION MAP OF FUSHAN SLOPE

m Depth	BH-10	N	Classification	Test Results								
				W_n	W_L	I_p	% minus 200	γ_d gm/cm^3	e	q_u kg/cm^2	$\bar{C}$ kg/cm^2	$\bar{\phi}$ deg.
0.9		∇G.W.0.7	Sandy Clay With Gravels CL	22.6	26.0	9.0	57	1.99	–	0.21	–	–
		9	SM	18.7	NP	NP	42	1.67	0.59	–	–	–
2.6		12	Clay With Gravels	24.5	47.8	25.4	82	1.61	0.66	–	–	–
3.4			CL-ML	25.2	26.0	5.00	64	1.98	–	–	* 0.18	* 28.4
6.5			Shale									

* FROM MULTISTAGE CU TRIAXIAL TESTS

FIG. 2 TYPICAL BORE LOG AT FUSHAN SLOPE

According to available geological information, the bedrock in the area belongs to the Mushan Formation of the miocene, dipping with a strike of N70^{O}E. The overburdens were weathered talus deposits, rock fragments, loosened from outcrops or cliffs, moved downward in a series of freefalls, bounces and slides. The materials so piled up were repeatedly relocated during the weathering process and resulted in unconsolidated sediments which often existed in a state of limiting equilibrium.

The groundwater condition of the area was governed by the shale which acted as an impervious layer and the overlying weathered sandstone and talus deposit serving as water bearing strata. At the time of the investigation, groundwater was encountered at depths ranged from 0.1 m to 5.0 m below the surface. The thickness of the groundwater layer ranged from 1.5 m to 3.5 m depending upon the relief of the shale stratum. Around the toe of the slope, the groundwater lied immediately below the ground surface and often appeared on the slope or retaining walls in the form of seepage. It was found that the drainage pipe from the reservoir as well as many waterpipes and sewerlines from the buildings were leaking. These facts could be responsible for the extremely high groundwater level in the area.

Laboratory test results indicated that the overburden silty and clayey soils are very sensitive to moisture. Even a small change in the moisture content could lead to signnificant decrease in the shear strength and thus stability of the slope. Stability analyses were performed on observed slides as well as on potentially dangerous slopes. The in situ shear strengths of the soil masses were evaluated by backfiguring from observed slips. Fig. 3 shows one of the critical sections. Results of stability analysis indicate that the slope has been in a delicate equilibrium condition. The shearing strength of the soil masses is barely enough to resist the active forces, including the superimposed loads, soil weight and seepage forces. Any disturbance of the balance such as digging of ditch at the toe, saturation of soil due to heavy rainfall, new constructions, and earthquake, would result in slides. The following recommendations were made in order to improve the stability condition of the area. They include:

(1) Repairing all faulty waterpipes, drainpipes and sewers.

(2) Preventing excessive runoff water from percolating into the ground by landscaping and drainage control.

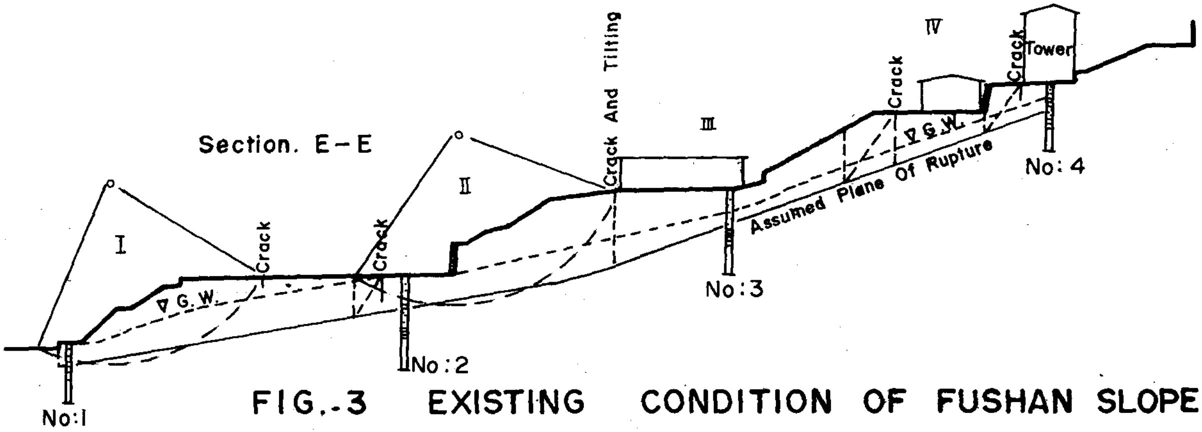


FIG.-3 EXISTING CONDITION OF FUSHAN SLOPE

Notes

The F. S. for all blocks was approximately 1.0

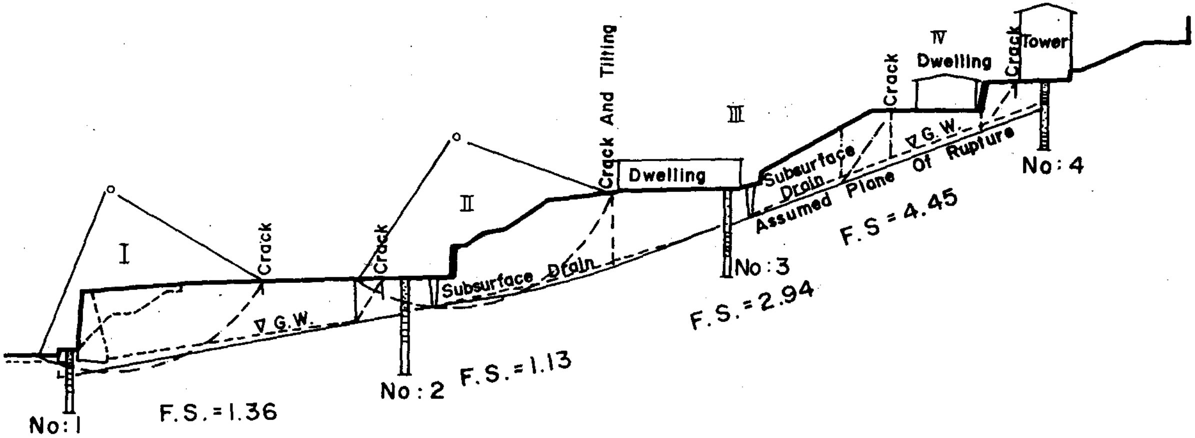


FIG. 4 CONDITION OF FUSHAN SLOPE AFTER IMPROVEMENT

(3) Lowering the groundwater table by installing two parallel underground drains on the slope to intercept seepage above the critical area.

(4) Improving the stability of the lower part of the slope by increasing the weight of the toe, such as the use of gravity retaining wall.

If all these measures were executed the factor of safety of the slope would be increased to about 1.3 as shown on Fig. 4.

SLIDE OF AN EXCAVATED SLOPE

The north section of the South-North Freeway has experienced numerous slides of cut slopes since its construction started in 1973. The following describes a major slide occurred at the east cut slope near Station 62 k which had caused considerable difficulty and delayed construction for several months. Although several shallow drainage ditches, both parallel and perpendicular to the slope bench, were provided during the construction stage, a large landslide occurred due to a heavy rainstorm in May 1973. Subsequently a series of slides of various scale had taken place during the following raining season.

The South-North Freeway passes through Hu-Kou village and runs to south along the west margin of Hu-Kou terrace then down to Phon-Shan river. The cut area concerned, nearly 700 m in length, is located on the Hu-Kou terrace. The subsoil profile, as revealed by a series of 9 borings in the area, consisted of a 1 to 2 m thick layer of firm reddish brown lateritic soil overlying a layer of poorly cemented lateritic gravels and boulders which is roughly 10 m in thickness. Underlying the lateritic gravels are strata of soft to compacted siltstone and mudstone from the Pleistocene to upper Pliocene. The strata had strikes N80^{o}W and dip S5^{o}W. Groundwater table in the area was found to be relatively high. Excavation of the cut intercepted the original groundwater flow path and it was found that water seeped out on the surface of the cut slope. The seepage obviously had caused a reduction of the effective stresses and softening of the soil masses and thus brought the slope to a critical condition.

A thorough geotechnical investigation was undertaken to delineate the geological and subsoil conditions at the site. The program included 12 borings, seismic and electric resistivity investigation. From the investigation it was concluded that it was necessary to control the groundwater condition.

The remedial scheme adopted is the use of drainage tunnel. A series of 5 vertical shafts were driven down to suitable depths. Shafts were then connected with a horizontal adit. The drainage tunnel collects water from the east and drains gravitationally to the drainage system at the foot of the cut slope. Fig. 5 shows a layout plan of the drainage tunnel scheme and Fig. 6 shows a schematic drawing of the design.

WU-CHIA LANDSLIDE

Wu-Chia landslide is located at the upstream of Mu-Kua Chi, one of the important stream in eastern Taiwan. This landslide has been recognized for at least fifty years, and is believed to be the major source of the river sediments of the Mu-Kua Chi. The increasing sedimentation in this river resulting from the continuous supply of materials from this landslide raised the river bed for about 20 meters within only 3 years. A hydro power station located at the right bank of Mu-Kua Chi, about 8 km away from the landslide area was burried in August 1944, only 3 years after its completion in October 1941. The landslide covers about 5 hectares. The sliding area is mainly composed of highly weathered, decomposed, and severely fractured metamorphic complex, consisting of quartz-graphite schist, quartz-mica schist and chlorite-sericite schist. A fault runs through the area. It was reported that this landslide is still unstable up to the present time. Sliding always happens right after heavy storms.

The engineering geological study for the Mu-Kua Chi hydro electric power project showed that the rock terrain of the sliding area was extremely influenced by the fault as mentioned above. The rock exposures around the sliding area are mostly sheared, contorted, and severely fractured. Bend ing-bed on the upper portion of the slope is apparent. The schistosity becomes phyllitic-like and open. It is believed that these weak zones are considerably deep inward from the unstable slope. Once a sliding took place, the slope became a little flatter, however, continuous scoring of the stream water at the toe of the slope which carried away the sliding material, and again, would decrease the equilibrium of the stress conditions with time. Failure would occur again. It is expected that this landslide will keep going until the fresh, stable rock is exposed.

For such type of landslide, any remedial or preventive measures for slope stabilization would be proven to be economically unfeasible, even though it is technically possible.

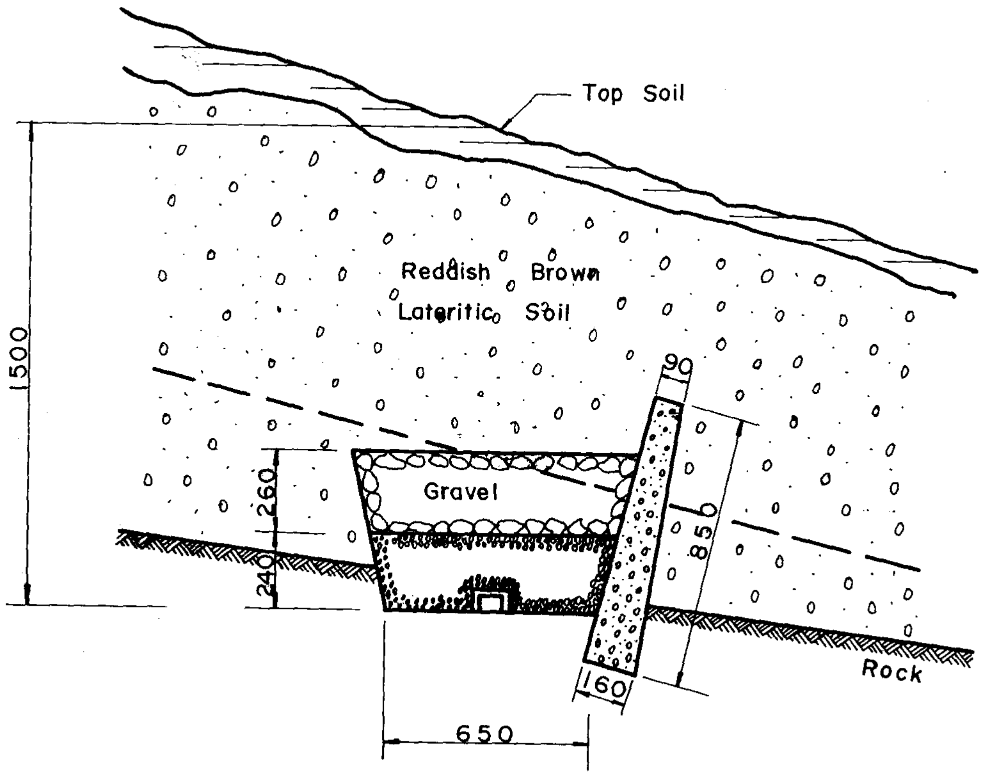


FIG. 6 DESIGN OF DRAINAGE TUNNEL AT STA. 62 K OF S-N FREEWAY

Similar situations of such kind of landslides are commonly observed in the Central Mountain Range, particularly on its eastern slope where the superficial deposits are not so deep. The slip plane of this type of landslide is usually within the fractured rock and is irregular, other than the circular shape.

PI-TAN CHI LANDSLIDE

This landslide is located at the upstream of Ta-Chia Chi, one of the largest river in western Taiwan at Tai-8 of the E-W Cross Island Highway Sta. 63 k + 700 m. As shown in Fig. 7, the sliding area is situated close to the spillway and intake structures of the Teh-Chi Reservoir. Prior to and during the construction of the reservoir, slope failures had occurred several times. Attention has been given to the safety of the construction of the spillway structure. Some bank protection measures including land reformation and buttress structure at the toe of the unstable slope have been carried out. Several slope indicators were installed to monitor the displacement of the slope. According to the records of the slope indicators, the slip plane located somewhere at the depth of 30-35 m below the ground surface, and was in the loose superficial slope out-wash or in the highly weathered slaty rock. The endangered area consisted of a steep slope at about 35-40 degrees. The excavation of the E-W Cross Island Highway destroyed the vegetation cover planted on the slope and bared the underlying rock to air-slacking. After the completion of the Teh-Chi Reservoir, it was reported that the sliding area appeared to be gradually enlarged and becoming more unstable.

A remedial measure was proposed and construction was completed in early 1977. The primary purpose of the remedial scheme is to lower the groundwater table and to intercept surface runoff. Several shafts about 50 m long were driven normal to the surface of the slope at different elevations. These shafts are connected by a longitudinal shaft as shown in Fig. 8. Open ditches were constructed along the sliding area to intercept surface runoff. Further investigation of the mechanism of this landslide and the effectiveness of the remedial measures is underway.

CHIA-YANG LANDSLIDE

This landslide located at Tai-8 of the E-W Cross Island Highway Sta. 69 k + 100 m, has been noted as an unstable zone in the reconnaissance study for the Teh-Chi Project. From the geomorphological expression, the sliding area was a

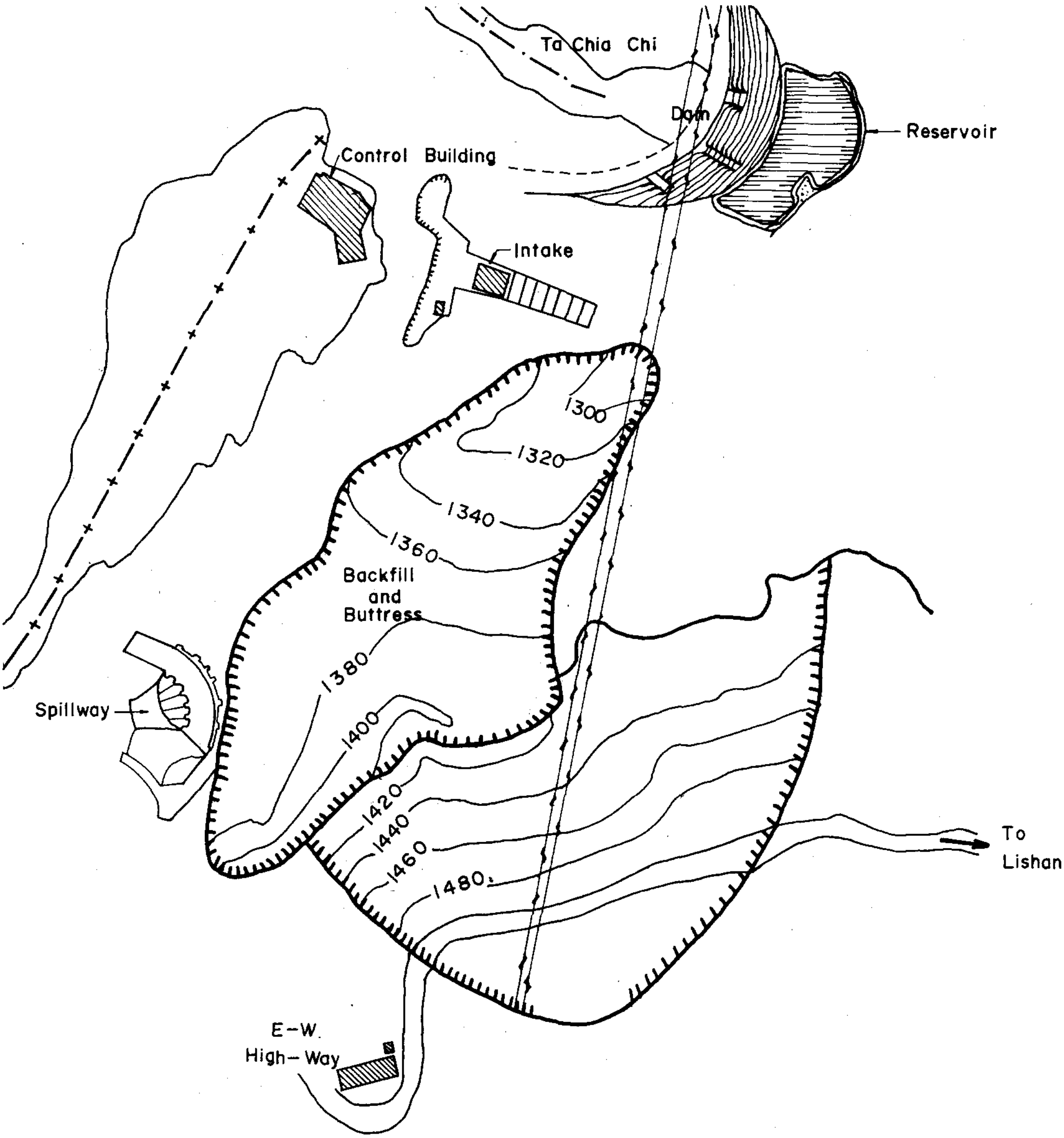


FIG. 7 LOCATION OF PI - TAN - CHI LANDSLIDE

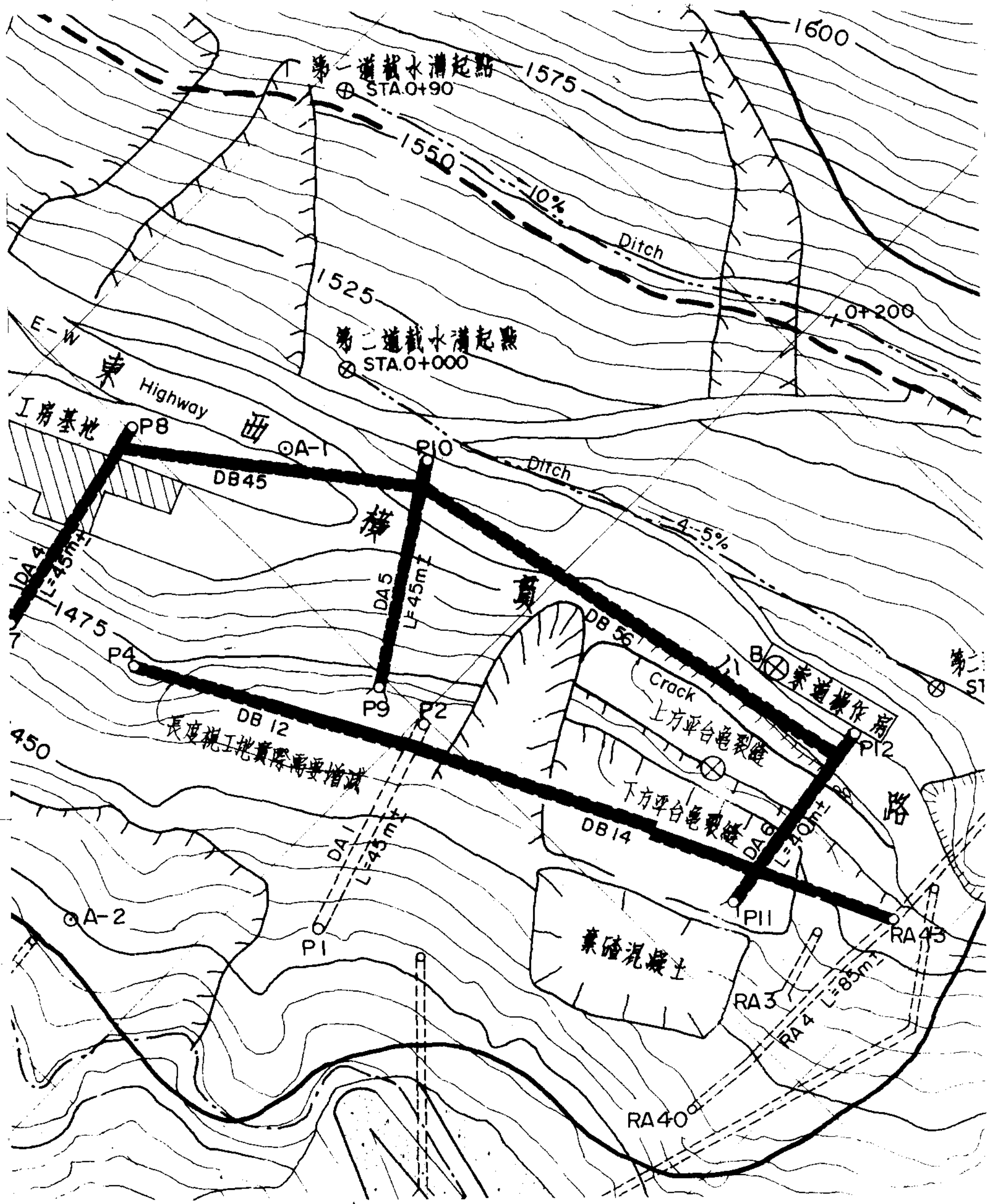


FIG. 8 SITE PLAN SHOWING DRAINAGE SCHEME FOR PI-TAN CHI LANDSLIDE

typical old landslide. It seems that the sloping area was well recovered. After the completion of the Teh-Chi Reservoir, change of the groundwater condition destroyed the stress equilibrium of the stability. A sudden failure of the slope in this old sliding area took place in October, 1975, after a heavy storm and prolonged raining season and blocked the highway traffic for about one month. The surface of the E-W Cross Island Highway settled for about 20 m. Immediate action including drilling to clarify the depth of the unstable material and removal of partial sliding material have been taken. Fig. 9 and Fig. 10 show that the slip plane located about 20-35 m below the surface. It is estimated that the sliding material liable to slide down into the reservoir is at least 1,000,000 cu.m. At the present, about 20,000 cu.m. of the sliding material resting on the slope above the highway has been removed. Recent heavy rains in June have proven that reducing of the loading by removing part of the sliding material did work well.

In order to have a more thorough understanding of the slide and to reduce the possibility of future slides, further investigation of this slide is being undertaken in conjunction with the Pi-Tan Chi Slide.

PIN-ZAU-NAIR LANDSLIDE

The area concerned is located about 750 m south-east of the Pin-Zau-Nair Station of the Alishan Forestry Railroad. In geological terms, it is situated between the Luchushan syncline of the Kiuantaoshan sandstone, Keichulin formation and north of the Shihtzulu fault of the Nanchuang formation as shown in Fig. 11. A typical profile is shown in Fig. 12. In this area, the slopes are steep, the rock formations are rather weak and heavily fractured. The Alishan Forestry Railroad cuts across this fracture zone, and numerous slides took place after heavy rainfalls. A study was undertaken by the Department of Soil and Water Conservation of the National Chung Hsing University for the Taiwan Forestry Bureau in 1971 to study causes of slides and to determine methods for slide control (CHOU, 1973). The study program included topographic survey, extent of landslide area, temperature variation, geological formation, groundwater conditions and various types of laboratory tests in determining the physical characteristics of the rock formation. Some of the salient results obtained from the extensive investigation are summarized below:

(1) Laboratory test results indicated that majority of the rocks, sandstones and shales, had high capacity for water absorption. The compressive strength of the shale in wet

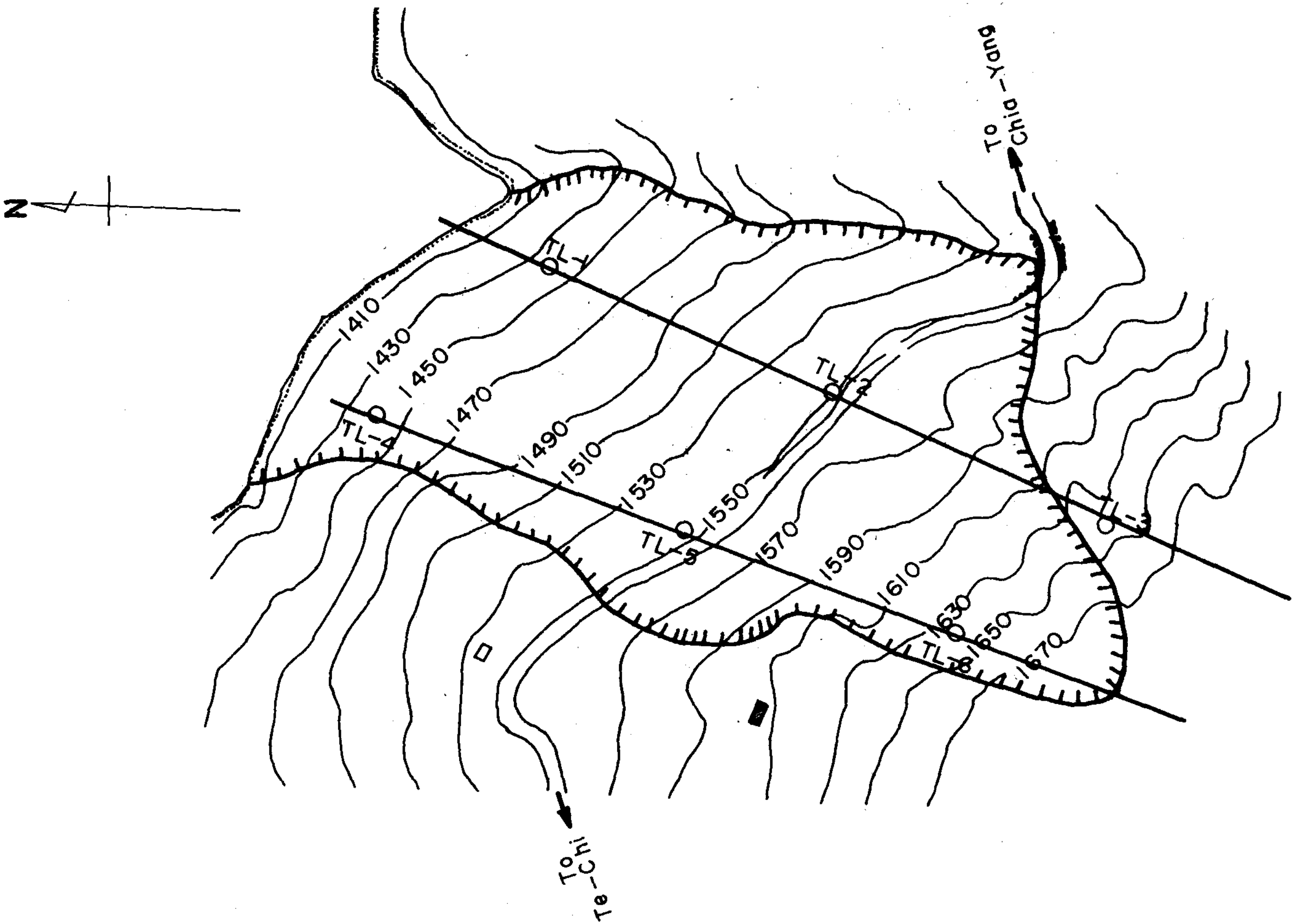


FIG. 9 SITE PLAN SHOWING EXTENT OF CHIA – YANG SLIDE

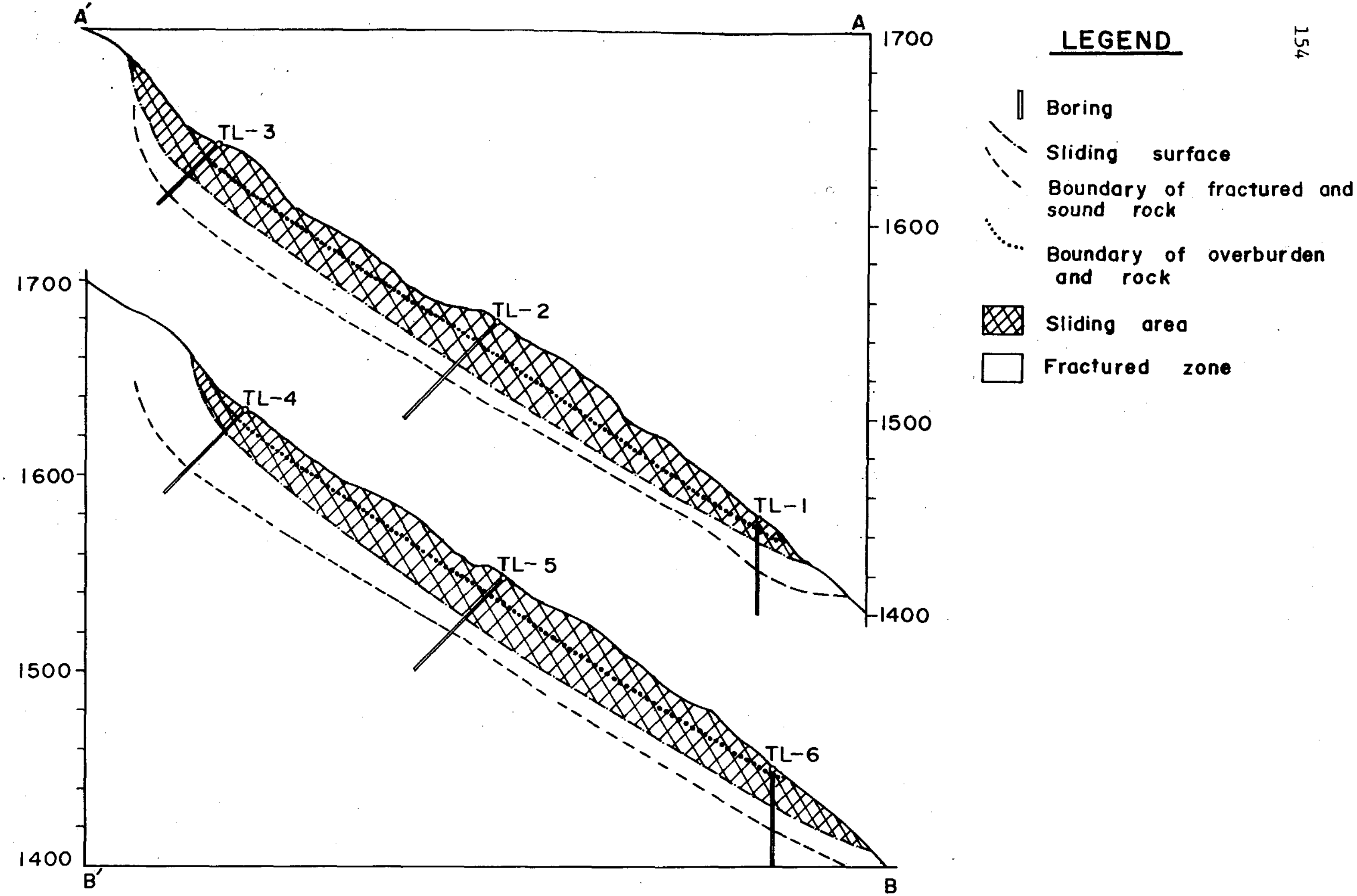
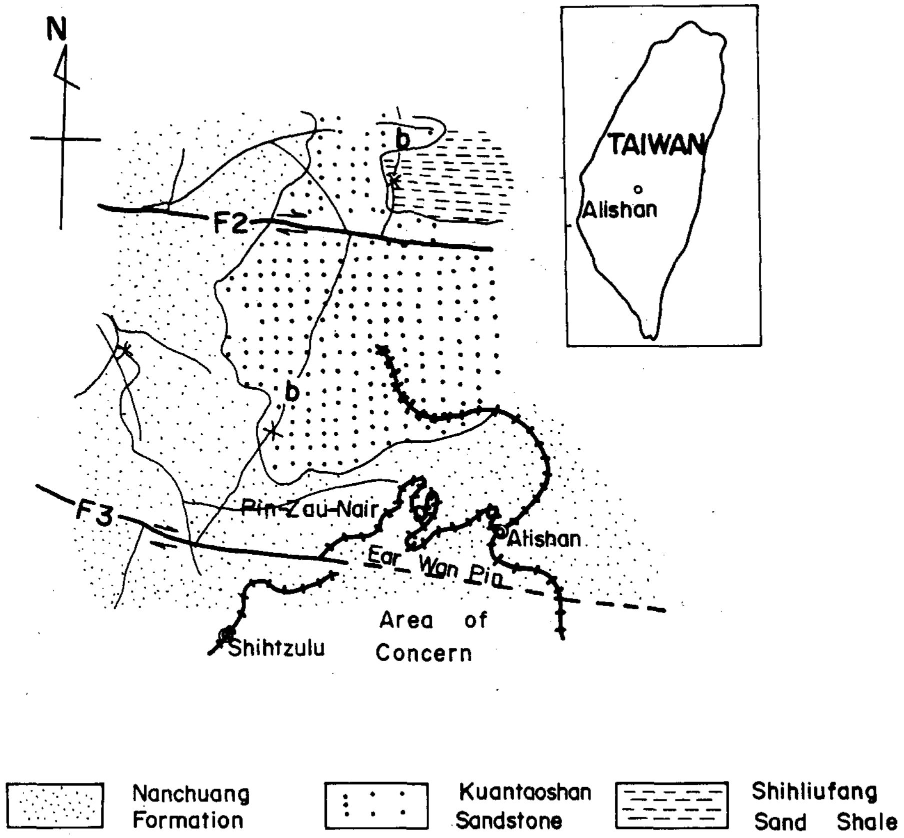


FIG. 10 GEOLOGICAL PROFILE OF CHIN-YANG LANDSLIDE



b. Luchushan Syncline F2. Shechienhu Fault F3. Shihtzulu Fault

FIG. II GEOLOGY OF LANDSLIDE AREA AT PIN-ZAU-NAIR

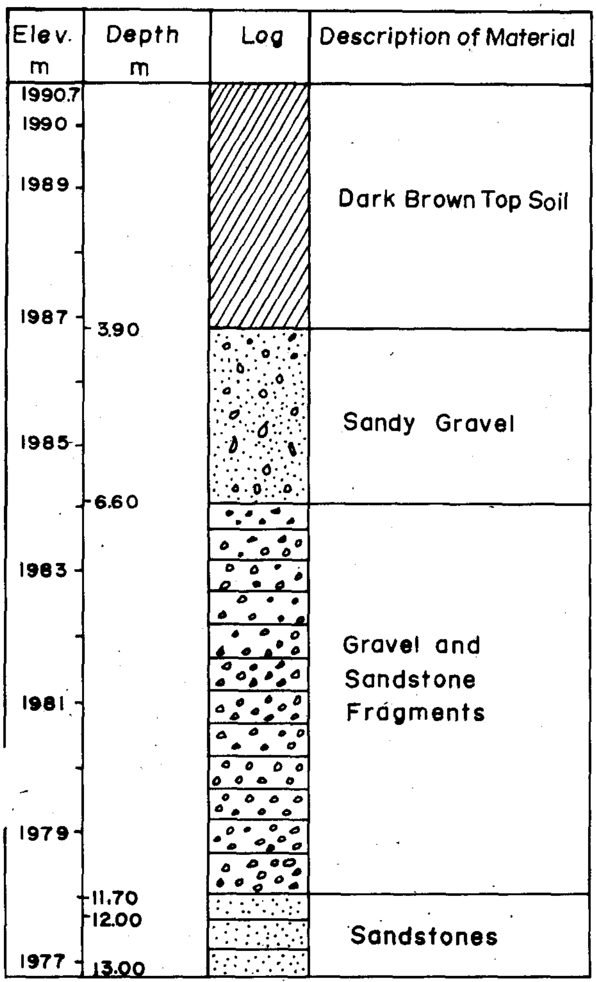


FIG. 12 TYPICAL SUBSURFACE PROFILE AT PIN - ZAU - NAIR

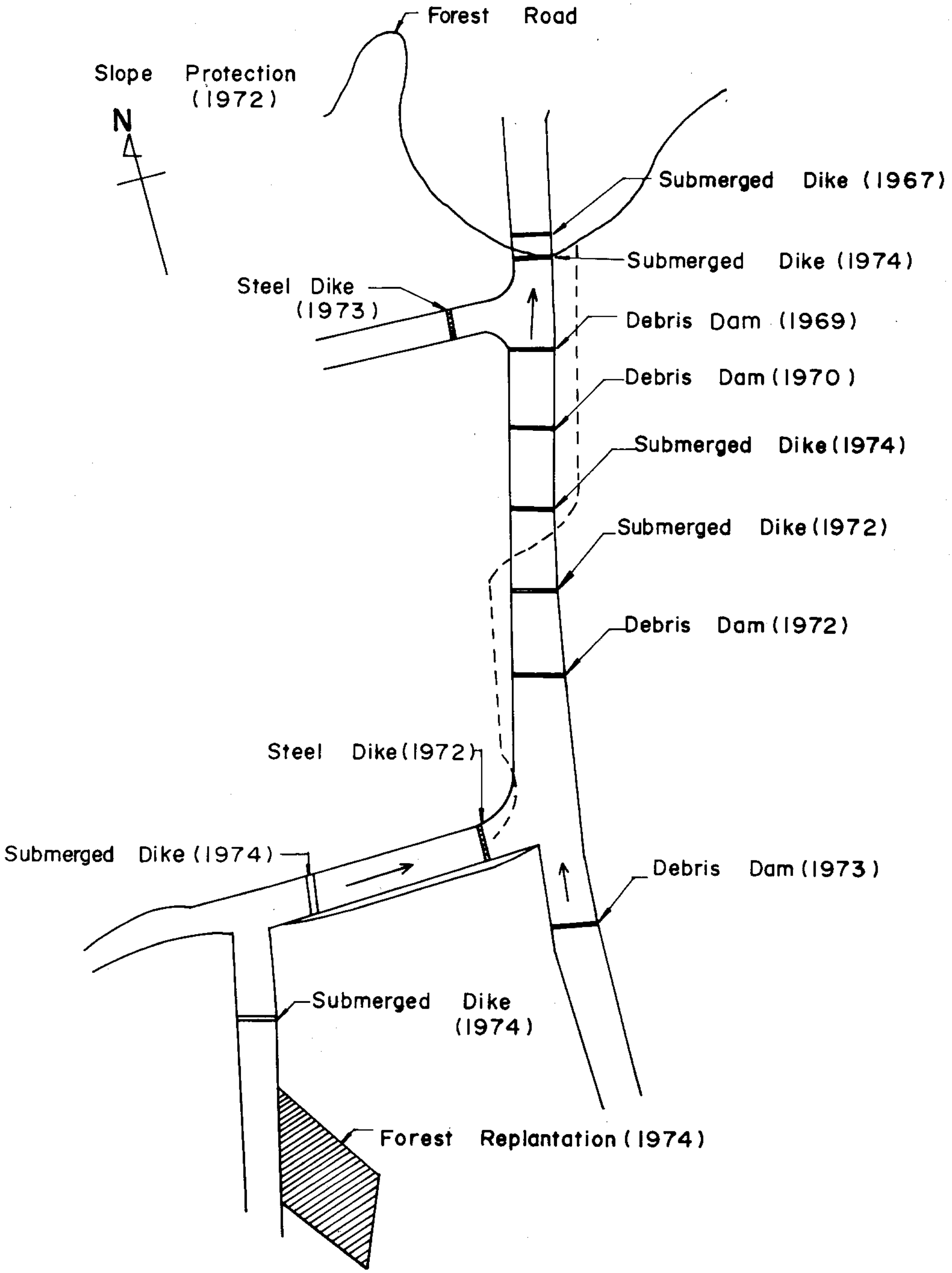


FIG. 14 SITE PLAN SHOWING LOCATION OF CONTROL WORKS AT TU-CHAN-CHI

condition was only about 20 to 60% of the strength in dry condition.

(2) Pumping tests of drainage wells placed in the landslide area indicated that the subsurface formations were quite permeable. One of the wells had a discharge rate as high as 18 liter/min.

(3) In the slide area, the average surface temperature was about 23°C higher than that at 50 cm depth. This difference was much larger than the average condition existed in neighboring areas (i.e. the difference was only 2 to 4°C). This large thermal gradient was believed to be responsible for disintegration of many of the exposed rock formation in the area.

(4) Preliminary test results using radioisotopes indicated that the velocity of the groundwater movement was in the order of 0.0024 m/sec.

From results of the study, it was concluded that the primary cuase for the landslide in the area was due to movement of the groundwater. It was necessary to control the rate of subsurface water flow as well as the gradient of the groundwater. For slide control and stabilization, it was suggested that a combined soil conservation scheme including construction of preventive structures, forest plantation, and erosion control should be adopted. A scheme for treatment and control was proposed which include the following measures, as shown in Fig. 13.

(A) Treatment for surface runoff by constructing water saving dams and diversion culvert.

(B) Treatment for subsurface water by using pumping wells and longitudinal drainage wells.

(C) Surface stabilization by constructing retaining walls and replantation.

TU-CHAN CHI LANDSLIDE

The Tu-Chan Chi watershed is located in Wu-Fun county of Hsin-Chu Hsian and occupies a total area of 557 hectares. Over 70% of the area is being used for forest growth. In 1963 Typhoon Gloria brought a very heavy rainfall to the area, amounted to 1136 mm in a three-day period. As a consequence, numerous landslides took place, large quantities of soil and rock masses moved downstream and buried the Chin-Jou village.

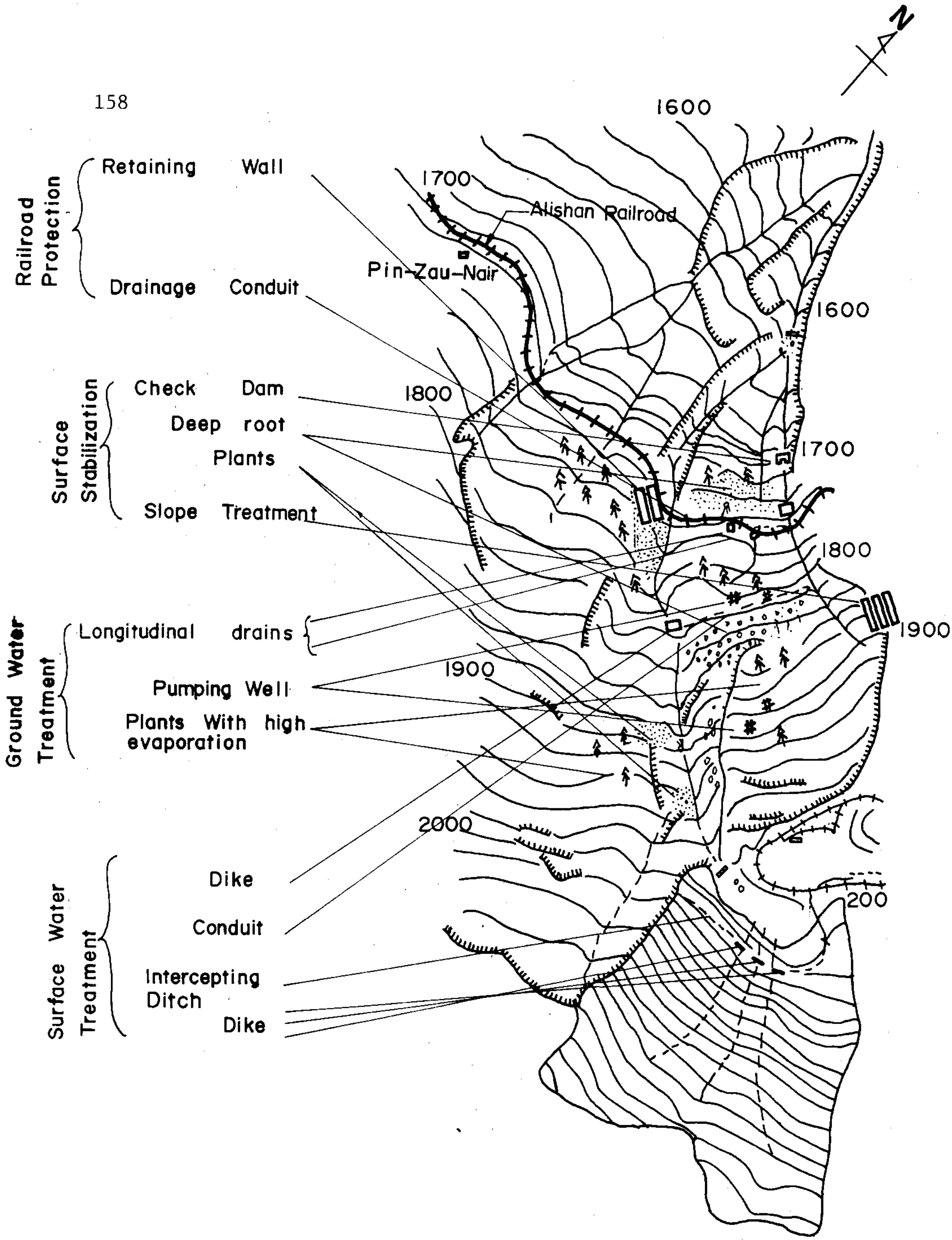


FIG. 13 SITE PLAN SHOWING LOCATIONS OF CONTROL WORKS, PIN-ZAU-NAIR AREA

It became obvious that two of the most important measures which must be undertaken were control of the debris and restoring the plantation covers. From 1972 to 1976, the provincial Forest Bureau, with the support of the Joint Commission for Rural Redevelopment (JCRR), conducted an investigation and completed a system for treatment of the slide and control of the debris movement.

The geology of the area belongs to Wulai Group of the Oligocene consists of mainly black slate and shale, interbedded with quartzite sandstones. The formation had undergone considerable geotechtonic movement and developed many faults. Most of the surface layers of the rock formation are highly fractured and distorted. These materials are easily weathered particularly in subtropical climate with heavy rainfalls. The overburden soils in the area are primarily gravelly, sandy silts and gravelly clays with rock fragments. At many localities, due to the steepness of the slope, the overburden had been eroded and the rock formation was exposed. At the time of the Typhoon Gloria, the heavy rainfall has caused numberous landslides. The flood water of the Tu-Chan Chi carried large volume of debris downstream which in turn caused further erosion of the river banks. The total area affected by the landslides exceeded 33 hectares.

The treatment plan which took place in a 4-year period was essentially a soilwater conservation scheme which involved control of river flow, reducing slope of the river bed, reducing bank erosion, stabilizing river bed and toes of hill slopes, control of landslide and its vegetation coverage. Construction included a series of submerged dams, debris dams, steel dams, and slope protection measures as shown in Fig. 14.

REFERENCES

BUREAU OF FORESTRY (1976), Report on Methods of Landslide Treatment and Debris Control for the Tu-Chan Chi Watershed, Bureau of Forestry, Taiwan Provincial Government (in Chinese).

FRISCH, H., HUNG, J.J. and SIMON, A.B. (1975), Stability Analysis of the Fushan Slope in Shilin, Taipei, Taiwan, Bulletin of the College of Engineering, National Taiwan University, No. 18, pp. 114-124.

CHOU, H. (1973), Studies on the Causes of Landslides and Design of Control Methods at Pin-Zau-Nair in Alishan, Research Report, Dept. of Soil and Water Conservation, National Chung Hsing University (in Chinese).