STABILIZATION OF A LEGENDARY HANGING CLIFF

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ABSTRACT

Pyramid Hill in southern Taiwan has two monkey face like rocks on its western slope. Local folks consider the rocks as a scenic landmark. There are also lengends about these rocks. During the construction of a highway passing under these rocks, the slope below these rocks was excavated and replaced with a retaining wall. However, in a heavy storm, the retaining wall collapsed and the Monkey Rocks slid almost two meters downslope causing fractures in the rocks. A study was made to determine the feasibility of stabilizing the slope and to preserve these natural scenic rocks. During the investigation stage; boring, rock mapping and stereonets were utilized to provide maximum information of the subsurface condition and state of rock fractures. Finally, rock anchors,rock bolts, grouting, dental grouting and erosion protection were selected to stabilize the slope and the rocks. Since the stabilization was done, the slope has weathered through many storms and no further movement was observed.

INTRODUCTION

1. Pyramid Hill is located in southern part of the Taiwan Island. Passing by the western slope of the hill is the scenic seashore freeway (Highway 24). The hill was formed by pyroclastic and basaltic lava flow which produced a pyramid shape hill. On the western slope of the hill lie two monkey face like rocks, therefore, the local folks name it "Monkey Rocks". In 1982, the slope below these rocks was excavated and replaced with a retaining wall (Figure 1) to widen the original two lane highway to four lanes. Immediately after the construction of the retaining wall, tilting of the wall was observed. Although it was subsequently repaired, the retaining wall collapsed in a heavy storm in the following summer. During the rush repair of the retaining wall, the constructor was unaware of the danger of inducing further movement of the slope and had removed the foundation of the old retaining wall completely. The removal of the old foundation undercut the already unstable slope and aggravated the sliding. This paper describes an investigation to determine the cause and extent of the landslide and the remedial measures to stabilize the slopes and rocks and to restore them to their natural look.

SLIDE AND BLOCK INSTABILITY

2. Geotechnical and geological investigations were conducted at the hill site to study the subsurface geotechnical conditions. Four boreholes were drilled. Two of the boreholes were purposely arranged at an angle to investigate the feasibility of installing anchors to reinforce the retaining wall. The subsurface condition was found to be as shown in Figure 2. Some drilling

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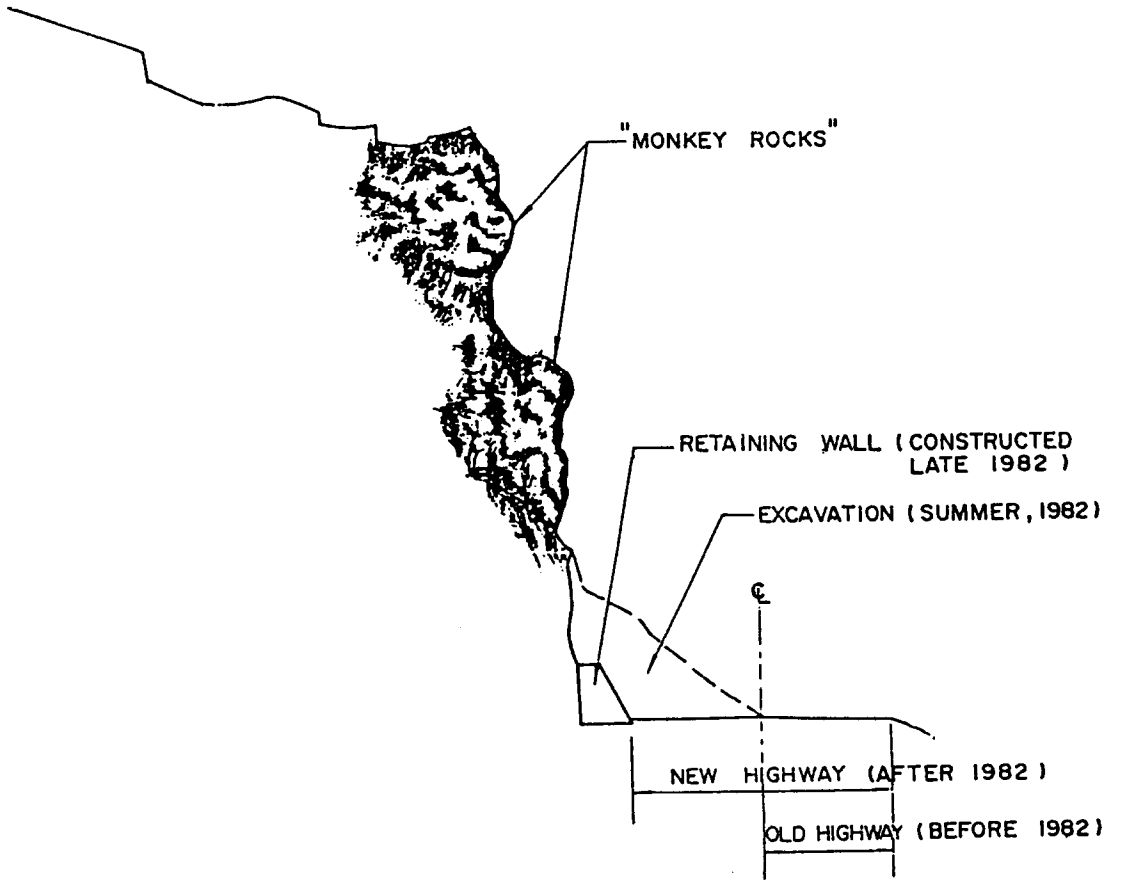

FIG. 1 PROFILE OF THE "MONKEY ROCKS"

difficulties were encountered when inclined drillings were advanced through fractured zones, otherwise boreholes were kept open for a period of time without collapse. After completion of drilling, piezometers were installed in the boreholes to determine the subsurface groundwater conditions.

3. From the field investigation, it was found that Pyramid Hill mainly consists of basaltic lava flow and tuffaceous breccia. The "Monkey Rocks" are the extrusions of pillow basaltic lava flow which stick out from the surrounding tuffaceous breccia and become an outstanding feature. Due to the successive slides, there were four progressive sliding planes developed behind the slope. Through the field exploration program, it was found that these sliding planes were rather shallow and that they passed under the foundation level of the retaining wall, as shown in Figure 2.

4. The Monkey Rocks were fractured into 13 blocks during the sliding (Figure 3). The fractures were mainly along the weak planes and fissure cracks pre-existing in the rocks. The attitudes of each fracture plane were surveyed and plotted on the stereonet. They were predominately of 4 orientations (Figure 3 and Figure 4), and the blocks were therefore mostly enveloped by these fracture planes. Stereonets were utilized to determine the possible directions of movement for each block and were also utilized to determine the potential keyblocks. For instance, three contact fracture planes and two free surfaces of Block #2 were surveyed and presented in Figure 5 and plotted in stereonet in Figure 5. The contact slide planes are ④, ⑦ and ⑪. Planes ⑤ and ⑥ are the free surfaces of Block #2. Block #2 is only possible to slide along Plane ⑦ which is dipping outward or to topple perpendicular to Plane ⑥. Sliding along Plane ⑪ is not possible for Block #2, because it is restrained by Block #5 below. Block #1 is enveloped by Planes ①, ②, ③ and ④. From Figure 2, one can see that Block #1 is restrained to slide along any of these planes. In other word, it is not a keyblock. After examining all blocks, Block #2, #5, #6 and #7 were determined to be the potential keyblocks. Blocks #6 and #7 are the foundation keyblocks of all the other blocks, while Blocks #2 and #5 are keyblocks which the other blocks abut against. Therefore if all four potential keyblocks are restrained, the other blocks will not be allowed to move significantly. Otherwise, if these keyblocks move, they will create a space into which the other blocks previously restrained by the keyblocks may then advance. Thus a serious failure may occur retrogressively.

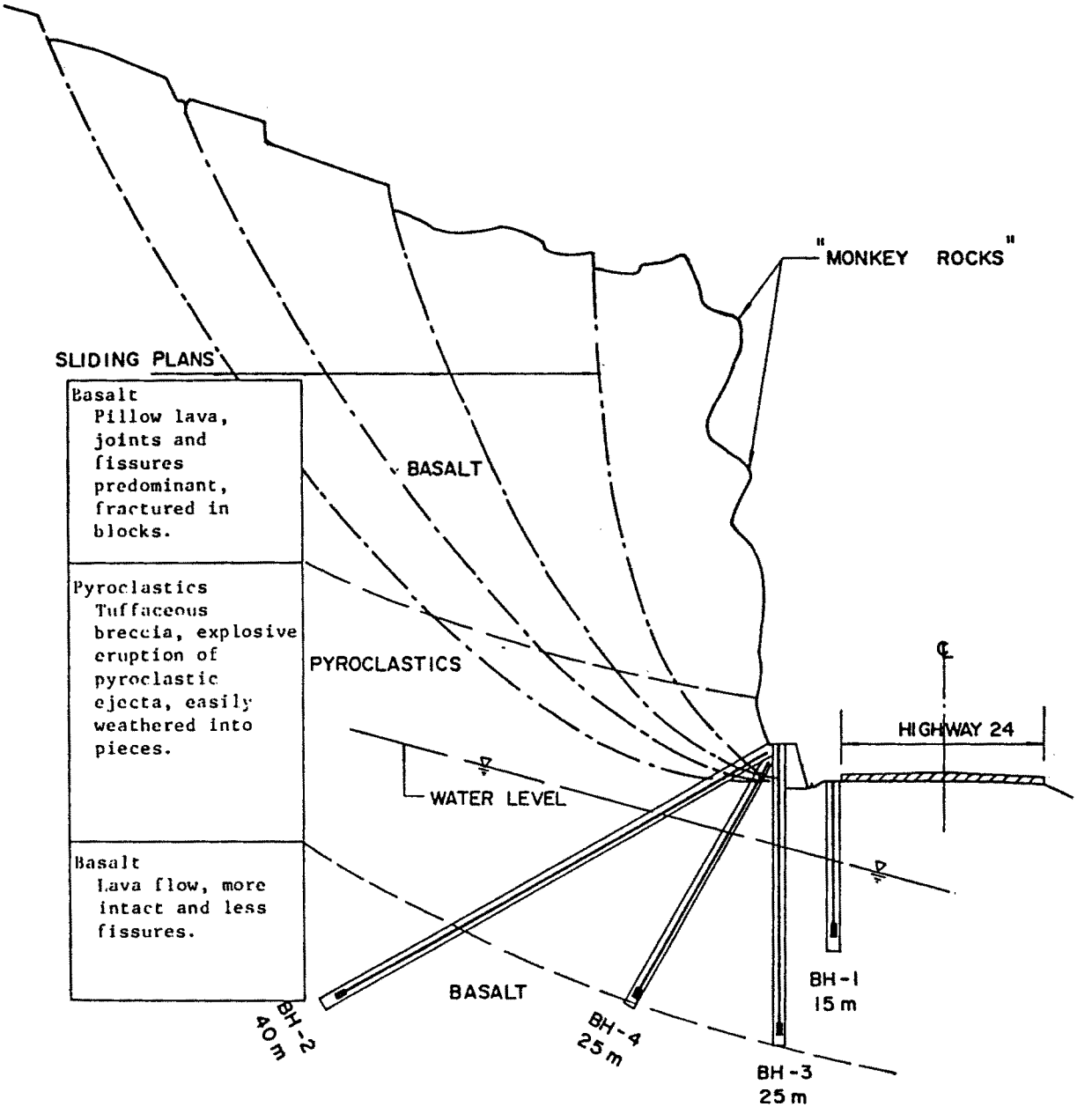

FIG. 2 SUBSURFACE GEOTECHNICAL CONDITIONS

5. Stereonet as Figure 5 can also be utilized to determine the direction of rock bolts, if rock bolts are to be used to restrain the keyblocks. For instance, Block #2 can only slide along Plane (7) and topple perpendicular to Plane (6). It was therefore purposed to restrain Block #2 with one rock bolt perpendicular to Plane (6) and two rock bolts perpendicular to Plane (7). They were geometrically located to provide most resistance to sliding and toppling. These rock bolts were proposed to be 10 m long to reach far behind the blocks forming the Monkey Rocks.

REMEDIAL MEASURES

6. From the field investigation and stability analysis, it was revealed that in order to stabilize the Monkey Rocks, keyblocks #2 and #5, their foundation blocks #6 and #7 must be stable. In order to provide stable foundation for Blocks #6 and #7, the slides has to be stabilized. By this reasoning, a sequential construction procedure should be followed. The sequence of remedial measure was proposed and excuted as follows:

Step 1: Stabilization of the landslide by restoration and strengthening of the original retaining wall

The first step to stabilize the landslide was by restoration of the original retaining wall. During the restoration of the old retaining wall, care was exercised so that not to further aggravate the landslide.

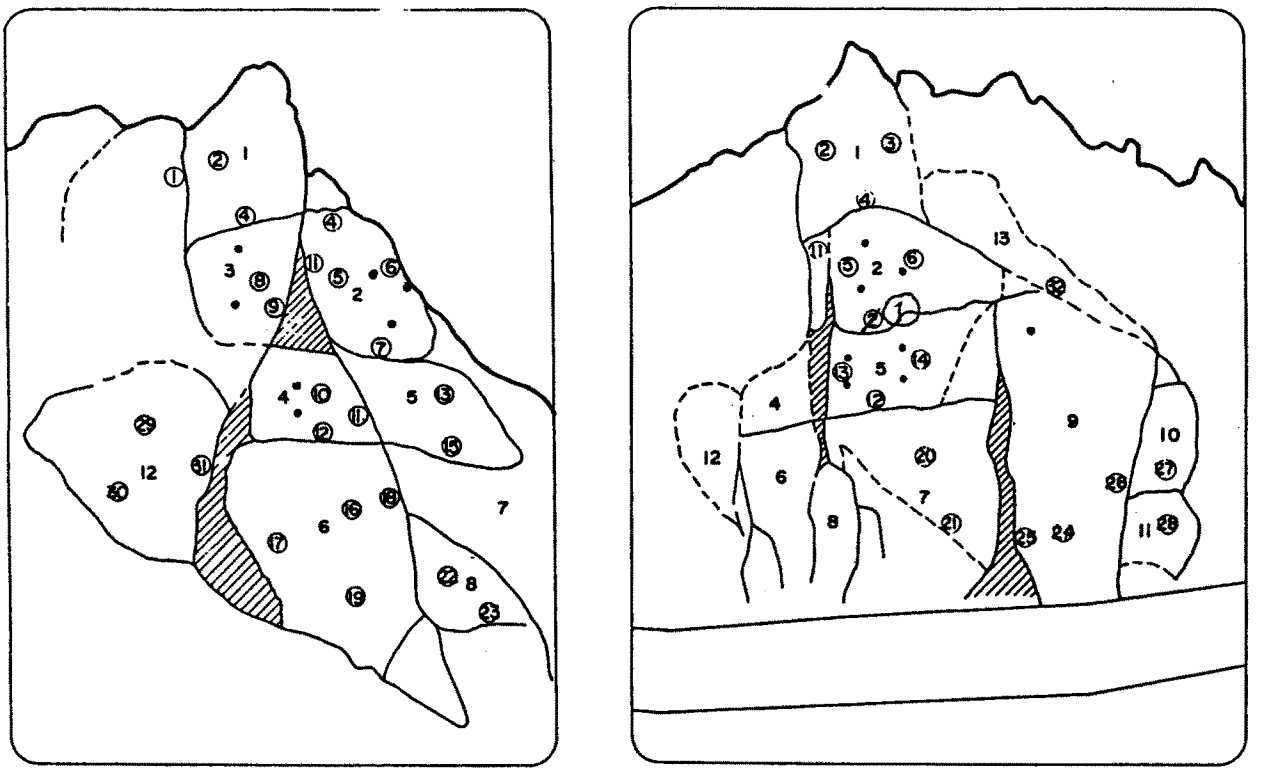

FIG.3 BLOCKS FORMING MONKEY ROCKS

Each time the removal of the old retaining wall was restricted to not more than three meters at a time. Immediately after excavation of the old foundations, precast panels were laid on the slope to replace the removed position of the retaining wall. The new retaining wall was constructed by joining these precasted panels together.

Stability analysis indicates that the retaining wall was not enough to restrain the slide. Anchors of 20 meters length at spacings of 2 meters with design capacity of 60 tons were installed to provide good buttress at the toe of the slides. Since the original backfill of the old retaining wall was in a very loose condition, cement grout with low grout pressure at 200 kPa was utilized to strength the backfill material. The grouting of the backfill material provided good reaction for later anchoring of the original (level 1) retaining wall and also good foundation for level 2 retaining wall, Figure 6.

Step 2: Restraining foundation Blocks #6 and #7

A second level retaining wall with anchors was constructed on the bench of the level 1 retaining wall. This retaining wall was to prevent tilting of the foundation blocks, #6 and #7 of the "Monkey Rocks" and was to provide further restraining to the slides. Fractures of the "Monkey Rocks" and slides were waterproofed and dental grouted.

Step 3: Stabilization of Keyblocks #2 and #5

Seven rock bolts were installed to stabilize keyblocks #2 and #5. Directions of the rock bolts were selected to be perpendicular to the possible sliding plane or toppling of the blocks. Stereonets representing fracture planes of these blocks as shown in Figure 5 were plotted and direction of the rock bolts was selected based on these stereonets.

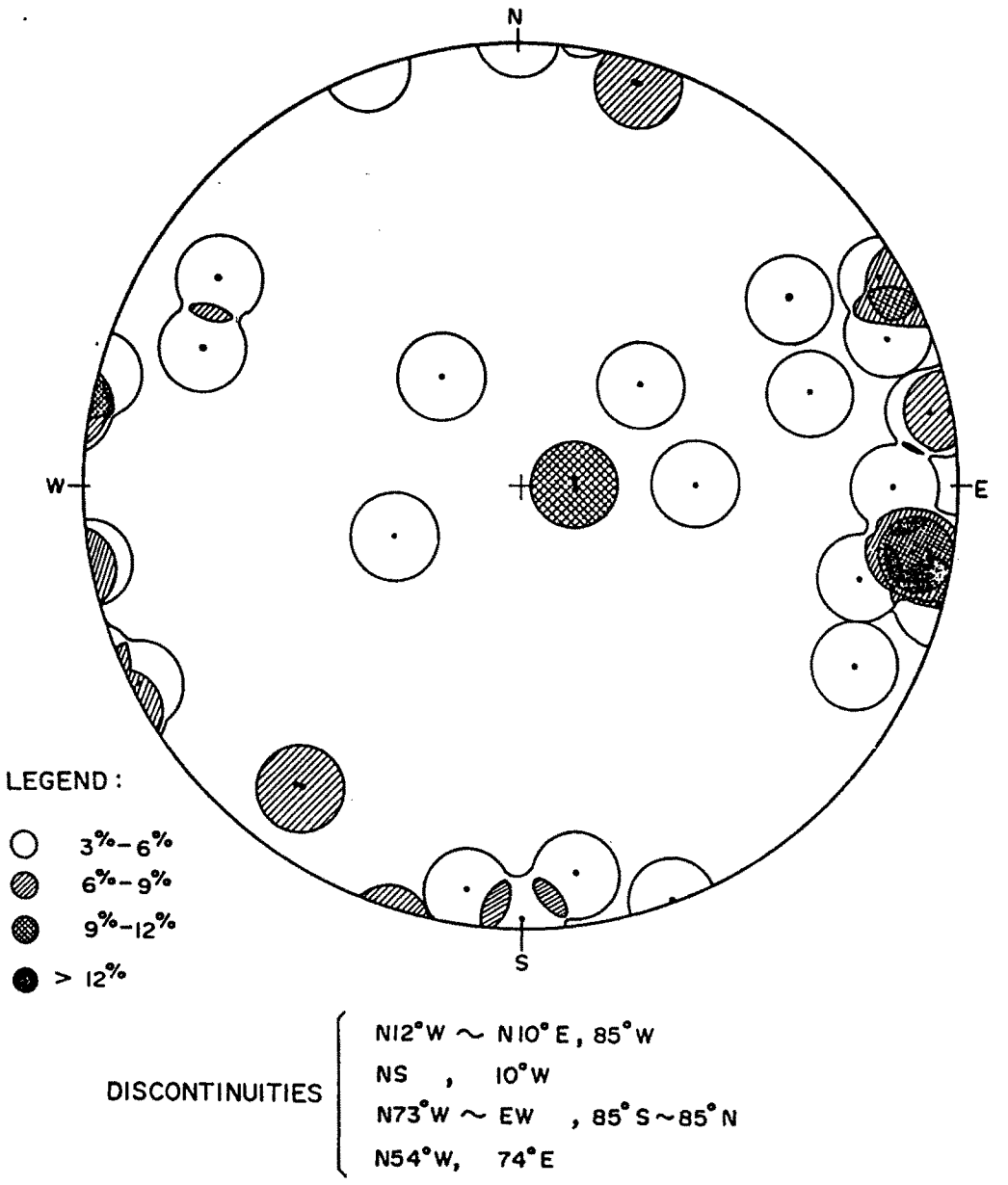

FIG. 4 DISCONTINUITIES OF BLOCKS

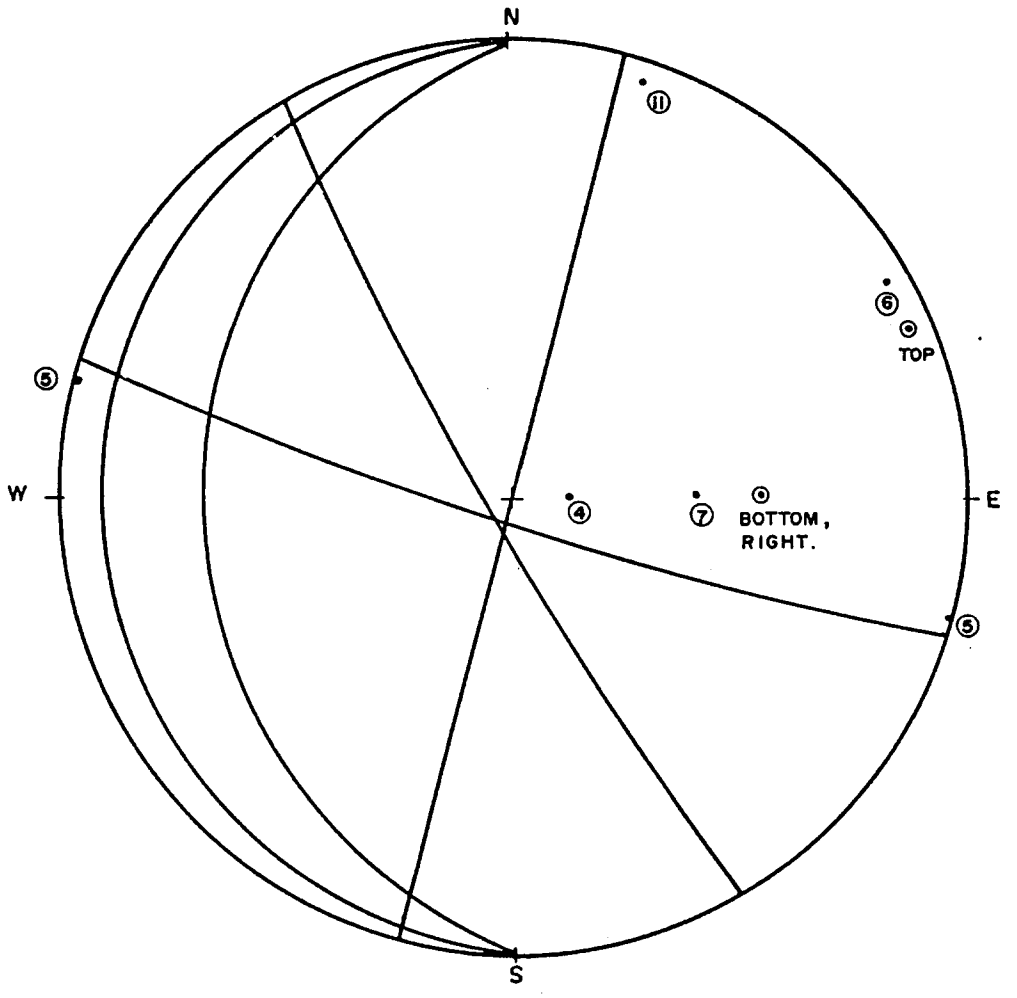

FIG. 5 SLIDING PLANES AND DIRECTION OF ROCK BOLTS

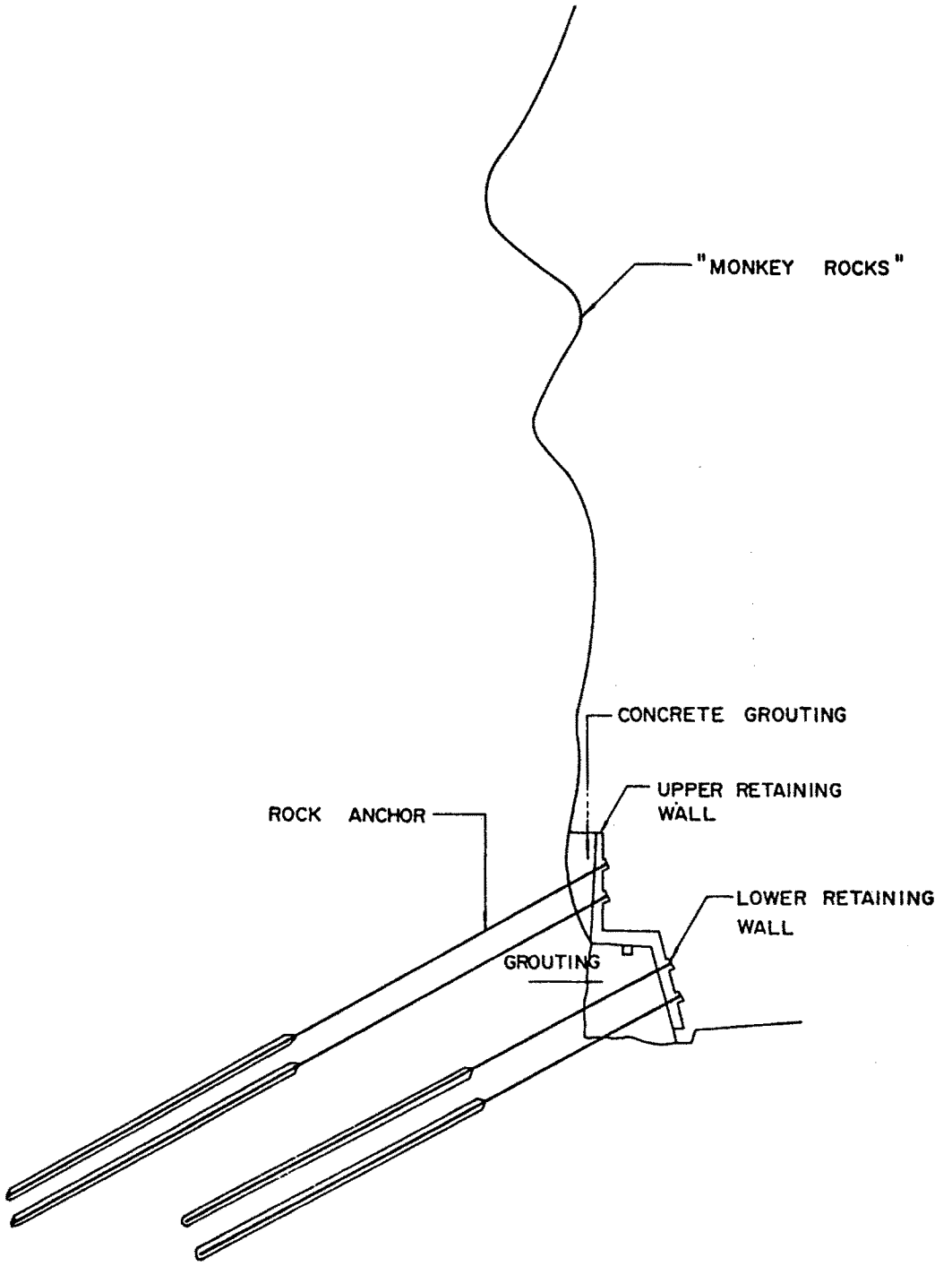

FIG. 6 REMEDIAL MEASURES

Horizontal drains were installed to dissipate groundwater behind the wall after all the grouting was completed.

The remedial measures as described above were executed immediately after the completion of the design work in 1984, and the construction was completed before the beginning of the summer storm.

CONCLUSIONS

7. Since the remedial measure was executed, no further movements of the slope and blocks were observed. The success of the project lies in the execution of the construction in the right sequence. The utilization of the stereonets to assist the determination of the possible direction of block movement and direction of rock bolts also contribute greatly to the success of the project.

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Dr. T.C. Kao received his M.S. and Ph.D. in Geotechnical Engineering from the University of California, Berkeley. Currently, he is the Manager of Geotechnical Department, Moh and Associates, Inc. He oversees project planning, coordination, analysis, design, construction cost estimating, construction scheduling and preparation of construction specifications and technical reports.

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