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GOVERNMENT OF PAKISTAN
PLANNING COMMISSION
NATIONAL TRANSPORT RESEARCH CENTRE

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CHEMICAL STABILIZATION OF LANDSLIDE KOHALA - MUZAFFARABAD ROAD (Preliminary Report)

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NTRC-152

November, 1991

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EXECUTIVE SUMMARY

Stability of slopes plays a very important role in the construction of transportation infrastructure facilities such as highways, rail, roads, airports and inland water ways. Failures of slopes in these applications are very common and is generally caused by fractured strata, shaly clay materials in loose state and movements within the slope. Investigation for the safety of slopes and taking corrective measures are the primary responsibilities of the transportation engineers.

Unstable and creeping slopes along highways has recently gained much attention through out the world. Unfortunately in Pakistan due to the lack of expertise and timely attention large portions of many important highways are badly damaged or completely destroyed due to slope failures. One such example is the Kohala - Muzaffarabad road in AJ&K which is being subjected to very extensive landslides at various locations. The continuing problem has caused severe destruction to the road as large sections get washed away each year. Except for routine maintenance work for the affected area, so far no efforts have been made to solve this problem.

NTRC on the request of C&W Department of AJ&K carried out a detailed literature review alongwith the field and laboratory investigation of the landslide materials in the first instance. The literature search revealed valuable information on the use of chemicals for stabilizing instable slopes. Two

chemicals which show promise are cement and lime as both the materials have been found to be effective in increasing the strength and stability of soil. Three techniques were also identified for the placing of chemicals in the soil in a well mixed condition. They are the following:

- Jet Grouting
- Deep Chemical Mixing
- Impulse Injection.

After thorough field investigation, a test site of 3000 sq.meter was selected at Dulai. Samples of the materials were obtained for laboratory analyses and some of them were added various percentage of lime and cement. The following laboratory tests were conducted on both treated and un-treated samples:

- Original moisture content
- Atterberg Limits
- Moisture-density
- Potential for volume change
- Water resistance
- Resistance to weathering.

Laboratory test results indicates that:

i) Physical and performance characteristics of the test site material is that of an expanding clay.

ii) Adding 9% lime by weight to the test site soil significantly decreased the plasticity index thus reducing the possibility of elastic deformation within the material.

iii) Soil treated with 7% portland cement showed higher density. It also lowered the plasticity index to within acceptable limit.

iv) Specimens made with natural soil subjected to ASTM standard wetting/drying cycles test collapsed in less than a cycle.

v) The specimens of the same soil after treating with 9% lime and 7% cement showed remarkably positive results.

Due to non-availability of drilling and mixing equipments, field implementation of the laboratory test results is not possible at this time. The Centre is making efforts to acquire the needed equipment under UK Technical Assistance. In case it does not bear fruitful, then AJ&K C&W Department would be approached to arrange the equipment from their own resources. The interim report therefore deals with the first phase of the project based on the finding from literature search and field and laboratory investigation of the materials obtained from the test site.

Chapter - I

INTRODUCTION

There are numerous landslides in Azad Jammu and Kashmir (AJ&K) and Department of Works spends millions of rupees each year cleaning and maintaining the Kohala - Muzaffarabad highway after winter and monsoon rainfall. Adequate preventive measures have not so far been applied by the Government of AJ&K for want of experties, suitable technologies and related facilities. Therefore, the Communications and Works Department of AJ&K and the National Transport Research Centre (NTRC) decided to carry out research for stabilization of the slopes along Kohala - Muzaffarabad road at Dulai. A typical slope area of 3000 sq.meters was selected that has experienced severe landslides and a thorough field and laboratory investigations of the existing landslide materials were carried out on the basis of which a comprehensive proposal was prepared for the stabilization of that very area on experimental basis using cement and lime as the stabilizing agents.

This report is intended to provide a brief literature review, identification of chemicals and methods of application that could be utilized. It also gives findings of the laboratory tests carried out on the materials that were picked-up from the test site at Dulai on Mile 14.0 at Sta. 47+00.

The application of the laboratory test results, and physical implementation of the project would be reported in the second phase when chemicals will be placed in the soil at the already selected test site that has experienced long-term creep resulting into the problem of landslide. A comparison of the treated (test section) and untreated (control section) will be made by installing inclinometers and monitor it periodically for 36 months.

Statement of Problem

Unstable and creeping slopes along Kohala - Muzaffarabad road is a continuing problem in highway maintenance for the Public Works Department of AJ&K. Several landslides have taken place along the road. The problem of landslide between Kohala - Muzaffarabad has caused enormous destruction to the road. Except for regular maintenance for the road affected by landslides, so far no efforts to solve this problem have been made.

National Transport Research Centre were contacted to help sort out this problem as the C&W Department of AJ&K does lack technical expertise in this specialized area.

Objective of the Study

The objective of this research project is twofold, first to perform a detailed literature search in order to identify chemicals and processes that may be applied to the problem areas of landslides and also to carry out a detailed field and laboratory investigation on the landslide materials in the Phase-I programme. Second, to stabilize a slope at Dulai area on Mile 14.0 at Sta. 47+00 from Kohala on Kohala - Muzaffarabad road that has experienced landslide by using the in-situ technique of chemical stabilization. This will be the Phase-II of the project.

Scope of the Study

The scope of this study would be limited to stabilize only one area of approximately 3000 square meters (100 x 30m) at Dulai on Mile 14.0 at Sta. 47+00 from Kohala on Kohala - Muzaffarabad highway. The study will be carried out in two phases as follows:

Phase-I:

i) To perform a detailed literature search to identify chemicals that may be used for slope stabilization and methods that could be used for in situ application of the chemicals to stabilize the selected landslide area at Dulai, AJ&K.

ii) To carry out a complete set of the standard laboratory tests on the soil materials obtained from the site that were treated with certain percentage of lime and cement and on untreated materials as well.

Phase-II

To implement the findings of Phase-I by stabilizing an already selected site on Kohala - Muzaffarabad highway that has experienced landslide and long-term creep by placing the chemicals (cement and lime) in the soil with the use of a rotary drill machine and later monitor the treated site for a period of 3 years to determine the effectiveness of the treatments.

Methodology

Phase-I of the study were carried out in the following steps:

i) Literature Review: The literature search were done to identify two specific subject areas. First to identify chemicals that have the potential for stabilizing slopes experiencing landslides and/or long-term creep. Second to identify methods of placing the chemicals in the soil. Relevants reports, articles and papers were reviewed in order to achieve this task.

ii) Site Selection: A site at Dulai on mile 14.0 at RD47+00 from Kohala on Kohala - Muzaffarabad Highway was selected

(Fig. 4) after thorough visual inspection. This area of approximately 3,000 sq.meters (100x30m) has experienced slides in past and is under-going measurable creep and is at a state of failure. Soil samples from this area were picked up for laboratory analyses.

iii) Laboratory Analyses: A complete set of the following laboratory soil tests were carried out on the materials that were picked up from the test site. These tests were conducted on natural material and on the same material treated with a specified level of chemicals.

- Atterberg Limit test,
- Moisture-density relationship,
- Potential for volume change,
- Resistance to weathering.

Phase-II of the study will include the following items:

i) Design of Treatment Programme: Analyses will be made to determine the amount of soil that must be treated. The geometry of the treated zone will be decided. The location and distribution of these treated zones will be selected using appropriate stability analyses so as to give an appropriate factor of safety.

ii) Construction Procedures: The construction procedures for slope stabilization will be defined. Samples of the treated soil shall be taken during construction to verify that the specified properties are being attained.

iii) Instrumentation: The chemically treated sections (test site) of slope will be instrumented with inclinometers or slope indicators for measurement of profiles through the deforming ground. The same instrument will also be installed on an untreated section (control site) for comparison.

iv) Monitoring: The instrumentation will be monitored on a regular basis by NTRC for a period of 3 years for comparison of the long-term creep between the treated and untreated sections. The data will be evaluated as it comes in so as to maintain a real time assessment of the field performance.

v) Evaluation: Comparison of the movements recorded in the treated and untreated test sections will provide an indication of the overall effectiveness of stabilization. Sampling of the treated and untreated soil at the end of the test will provide a basis for final evaluation of soil properties.

Chapter - II

BACKGROUND ON LANDSLIDES

Stability of slopes plays a very important role in the construction of transportation facilities such as highways, rail, roads, airports and canals. Failures of slopes in these applications are very common and caused by the fractured strata, shaly clay materials in loose state and movements within the slope. Investigation for the safety of slopes as well as controlling and taking corrective measures are primary responsibilities of Highway Engineers. Slope failures can be of various type depending on the form of failures, the age, or the stage of developments[1].

According to Schuster and Krizek[2] slope movement can be divided in five main groups in which one of the basic form describes landslide as the rotation of mass under the action of gravity or by fluids in cracks. Generally a landslide can be classified in one of the three categories:

i) Downslope movement of surface deposits,

ii) Landslides of soil along rotational sliding surfaces, movement along composite sliding surfaces.

iii) Rock slides.

Creep Phenomena:

The phenomenon of creep occurs when surface layers of clayey material move downhill as the result of slow plastic deformation. Surface movement rates are usually a few millimeters to a few centimeters per year. No discrete slideplane develops, but rather a broad zone within which small movements occurs is formed, making stabilization difficult. Motion is restricted to a relatively shallow surface layer that may not exceed the depth of seasonal variations in temperature and moisture.

Landslide Correction:

Correcting landslides involve preventing the movement of the soil mass by construction of barriers able to resist the downslope forces and/or reducing the forces tending to cause the movements. Techniques used to correct the slope instabilities are removing the slide materials, installing a drainage system, construction of retaining walls, installation of pile and sheet pile walls, grouting and chemical treatment. Very little has been done using chemicals for landslide and creeping hillside stabilization.

This interim report deals with the first phase of the project which includes the results of a comprehensive literature review and laboratory investigation of promising chemical additives i.e. cement and lime and methods for in situ application of the chemicals for stabilization of landslides on Kohala - Muzaffarabad road that may help mitigate this problem.

Chapter - III

LITERATURE REVIEW AND DISCUSSION:

In the past the primary additives used for the stabilization of fine-grained soils were lime and Portland Cement. Primary application have been for the treatment of pavement subgrades and base courses. Feroz Akbar and George W. Hollon [3], in their report to Texas Highway Department stated that low cement factor for high plastic soil will be equally good to stabilize as with the higher percentage of lime. Injection of cement and chemical grouts has been used successfully for soil strengthening in a number of cases. Mass Hatano, Bennelt John and Pete Zaniewski [4] in their report uncovered that both lime and portland cement have been used to some extent for stabilization of slopes and the results have been found encouraging.

To stabilize a slope, the chemicals must affect the soils so as to maintain or increase the shear strength, either by cementing the soil particle and/or by giving the soil cohesion. In addition, reduction of the plasticity and an increase in the water resistance of a soil are desirable property changes [3]. In the field of soil stabilization many chemicals have been tried. The chemicals were injected, mixed, or allowed to diffuse through the soil. Of the chemical types that were identified, resins and silicates[4] appear to be applicable to slope stabilization. Both types have been effective in increasing the strength and stability of soil. The potential for effective stabilization of an area appears high if these chemicals are well mixed with the soil.

Resins and slicates are however expensive chemicals and are not readily available in Pakistan, so the option left is to apply cement and lime as chemical agents for stabilizing slopes which are not only easily available but also not very expensive to use.

<u>Methods for In Situ Mixing:</u>

Diffusion rates of chemicals in soils are very slow, therefore, it is not reasonable to expect that a critical mass of soil can be permeated by diffusion alone. James K. Mitchell and Elizabeth Klainer[5] in their report uncovered three techniques for the placement of chemicals in the soil to achieve a well mixed state.

Deep chemical mixing, jet grouting and impulse injection are processes that can be used for the placement of chemicals in the soil in a well mixed state.

Deep chemical mixing is an in situ process whereby an admixture generally lime or portland cement is mixed with the soil to form stabilized columns or walls. A measured amount of stabilizer is placed into the soil through a rotary drill equipped with special auger bits that mix the chemical and soil thoroughly. This method could be used alone or in combination with other stabilization methods to prevent the slope movements.

Jet grouting is a technique that fractures and erodes the soil around a drilled hole by high pressure jets directed horizontally away from the drill rod. The chemical is injected through the drill rod and mixed with the disturbed soil to form columns of stabilized soil. Jet grouting can be used in both cohesive and noncohesive soils. This method can be used vertically or at an angle to stabilize a slope.

Impulse injection is a rapid series of pulsed injections under very high pressure that is used to mix a chemical stabilizer with the soil. The injected material breaks down the soil and mixes with it to form a high strength material. This technique has recently developed and it is not possible to define the levels of improvement as data available regarding the application of this method is not enough. However, the method has been used successfully for strengthening the foundations of towers and poles.

Chapter - IV

TESTING PROCEDURE

Field Investigation:

A detailed survey of the area selected as test site was conducted. Many fissures and crack were found (Fig. 4) on the top of the hill that may be one of the main reason for the failure of the slope materials as surface and undrained water may have percolated into the slippage surface of the soil.

The existing materials of the test site area were over saturated (Fig. 5). The materials itself were found to be of high plasticity with numerous boulder (Fig. 6). The area under investigation was measured (Fig. 7 & 8), a total length of 100 meters and height of 30 meters was designated as test site.

Field Sampling:

The typical soil samples were picked up from the test site area (Fig.9 & 10). Extra care were taken to hold the original moisture of the landslide materials. The landslide materials were air dried and processed in the laboratory before the actual tests were carried out.

Laboratory Tests:

Landslide materials that were picked up from the test site area were used for evaluation of the physical properties of the materials. The following tests were conducted on the test site materials:

1. Determination of water content of soil[6].
2. Determination of Liquid Limit, Plastic Limit and Plasticity Index[7].
3. Standard proctor tests (M/D relationship)[8].
4. Durability test which includes potential for volume change and resistance to weathering[9].

All these tests were conducted on the parent materials and on the materials treated with 9 percent lime and 7 percent cement by weight. The level of treatment i.e. 9% lime and 7% cement were found after running cement and lime series tests on the test site materials.

Chapter - V

DISCUSSION ON LABORATORY TEST RESULTS

Test results obtained on natural untreated soil indicates high original moisture content in comparision to the optimum moisture (Table 2), thus changing the property of the soil from plastic state to liquid state causing flow and ultimately failures to the stability. Plasticity index of 23 (Table 1) reveals that the soil is basically a high plastic material which has a significant impact from the engineering viewpoint. This would seem to indicate that the physical and performance characteristics of the test site material will be that of an expanding clay.

Clays are characterized by their ability to attract and bind water molecules to the surface of the clay platelet. The water molecules that are bound to the platelet are held there by forces that are much weaker than the forces that are associated with ionization.

The presence of bound water on clays that are contained in soils creates at least two undesirable conditions. First, bound water acts as a lubricant between the clay platelet and gives the soil the physical characteristic of "plasticity". Secondly, the presence of bound water lowers the bulk unit density of a soil since water has a lower specific gravity than soil and takes up a portion of the bulk volume that could otherwise be occupied by the more dense soil particles.

When lime is mixed with clay bearing soils it reacts with the bound water. The bound water on clays is ionized, and as such, is released from the clay and the material behave as a friable material, thus governs the criteria of plasticity. It is also seen from Table 1 that the soil after treatment with 9% lime has significantly reduce down the plasticity index from 23 to 5 percent.

On the other hand when cement is added as an admixture, the strength criteria holds good. The laboratory data indicates that the soil treated with 7 percent portland cement showed higher density (Table 2) (Fig. 1). It is also evident that clayey soils modified with cement has the ability to lower the plasticity index to within an acceptable limit.

Results of the ASTM standard wetting/drying cycles test showed (Tables 3-4) (Fig. 2 & 3) that 9 percent lime and 7 percent cement when added to the soil by weight has remarkable positive effect on the landslide material as the tests were continued all the way upto the eleven cycles, whereas, the specimens of the natural soil without any admixture did not even servive the very first cycle and collapsed while it was soaked for 5 hours in water. This indicates that with the addition of cement and lime of 7 and 9 percent respectively will increase the durability of the soil as well as the strength of the materials.

Chapter - VI

CONCLUSION

The literature search revealed a host of information on the use of chemicals for stabilizing slopes. Most of the information dealt with the stabilization of slopes, road bases, erosion control or the prevention of settlement of structures.

Cement and lime in some cases were found to be effective in increasing the strength and stability of slopes and reducing plasticity of soil. The potential for effective stabilization of an area appears high if cement and lime are well mixed with the soil. Laboratory tests for the evaluation of their effectiveness generally included one or more of the following tests. Atterberg limits, strength test, potential for volume change control, determination of moisture-density relationships, water resistance tests and resistance to weathering. Laboratory analyses shows that the existing landslide material have a tendency to flow at a moisture content little over optimum, however treating it with low cement and lime factor increases the stability and durability and reduces plasticity index which can in turn become an advantage for an expensive soil to be stabilized.

Specialized ASTM wetting/drying tests also indicates the suitability of cement and lime that may be used as an admixture to stabilize the landslide area.

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4. Mas Hatano; Bennet John and Pete Zaniewski, "Chemical Stabilization of Landslides Literature Review and Field Testing", Department of Transportation, States of California".

5. James K. Mitchell and Elizabeth Klainer, "Chemical Stabilization of Landslides", California Department of Transportation, December, 1987.

6. "Determination of Water Content of Soil", ASTM D2216-80, ASTM Standard Specification, Volume 04.08.

7. "Liquid Limit, Plastic Limit and Plasticity Index of Soil", ASTM D4318-84, ASTM Standard Specification, Volume 04.08.

8. "Moisture-density Relation of Soil and Soil-Aggregate", ASTM D698-78, ASTM Standard Specification, Volume 04.08.

9. "Wetting and Drying Compacted Soil-Cement Mixtures", ASTM D559-89, ASTM Standard Specification Vol. 04.08.

Table 1. ATTERBERG'S LIMITS TEST RESULTS

Description	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)
Natural Soil	32.0	9.0	23.0
Soil + 7% Cement	27.0	11.0	16.0
Soil + 9% Lime	27.0	22.0	5.0

Table 2. MOISTURE DENSITY RELATIONSHIPS

Description	Opt.Moisture (%)	Max.Dry Density (lbs/cu.ft.)	Org.Moisture (%)
Natural Soil	8.7	129.0	10.8
Soil + 7% Cement	10.5	132.0	-
Soil + 9% Lime	10.7	122.0	-

Table:3 ASTM Standards Wet/Dry test results (% Weight Loss)

Cycle Number	Percent Weight Loss									
	Sp-L1	Sp-L2	Sp-L3	Sp-L4	Ave(L)	Sp-C1	Sp-C2	Sp-C3	Sp-C4	Ave(C)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	10.55	8.76	10.92	10.99	10.31	7.17	7.05	6.48	6.55	6.81
2	10.97	10.69	11.24	11.09	11.00	7.36	7.20	6.48	6.55	6.90
3	11.81	13.76	13.14	11.98	12.67	7.46	7.29	6.57	6.74	7.01
4	11.81	15.48	13.46	12.18	13.23	7.84	7.43	6.67	6.93	7.22
5	12.03	15.64	13.72	12.39	13.44	7.93	7.77	6.90	7.40	7.50
6	12.87	15.69	14.78	12.65	14.00	8.08	8.05	7.14	7.50	7.69
7	12.87	16.01	14.78	12.65	14.08	8.84	8.52	7.14	8.02	8.13
8	13.08	16.34	15.04	12.91	14.34	8.88	8.62	7.48	8.21	8.30
9	13.61	16.71	16.09	12.96	14.84	8.88	8.71	7.67	8.25	8.38
10	13.66	19.61	18.47	13.43	16.29	9.03	8.71	7.86	8.25	8.46
11	15.61	20.37	18.79	13.43	17.05	9.12	9.09	7.90	8.59	8.68

Sp-L = Specimen made with Soil + 9% Lime
Sp-C = Specimen made with Soil + 7% Cement

Table:4 ASTM Standards Wet/Dry test results (% Volume Change)

Cycle Number	Percent Volume Change									
	Sp-L1	Sp-L2	Sp-L3	Sp-L4	Sp-C1	Sp-C2	Sp-C3	Sp-C4	Ave(L)	Ave(C)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.33	0.22	0.66	0.33	0.53	0.32	0.42	0.84	0.38	0.53
2	0.66	0.77	0.76	0.33	0.53	0.74	0.74	0.84	0.63	0.71
3	0.77	1.99	1.31	0.43	0.53	0.84	0.95	0.95	1.13	0.82
4	0.88	1.99	2.40	0.54	0.63	0.84	0.95	1.05	1.45	0.87
5	0.99	2.10	2.40	0.76	0.74	1.16	1.06	1.16	1.56	1.03
6	1.10	2.21	2.62	0.87	0.95	1.16	1.17	1.37	1.70	1.16
7	1.21	2.43	2.62	0.98	1.06	1.26	1.17	1.48	1.81	1.24
8	1.32	2.65	2.84	1.08	1.06	1.26	1.27	1.58	1.97	1.29
9	1.65	2.77	3.49	1.19	1.16	1.26	1.48	1.69	2.28	1.40
10	1.87	3.10	4.69	1.41	1.16	1.37	1.48	2.00	2.77	1.50
11	2.64	3.21	5.57	1.52	1.48	1.79	2.22	2.00	3.23	1.87

Sp-L = Specimen made with Soil + 9% Lime
Sp-C = Specimen made with Soil + 7% Cement

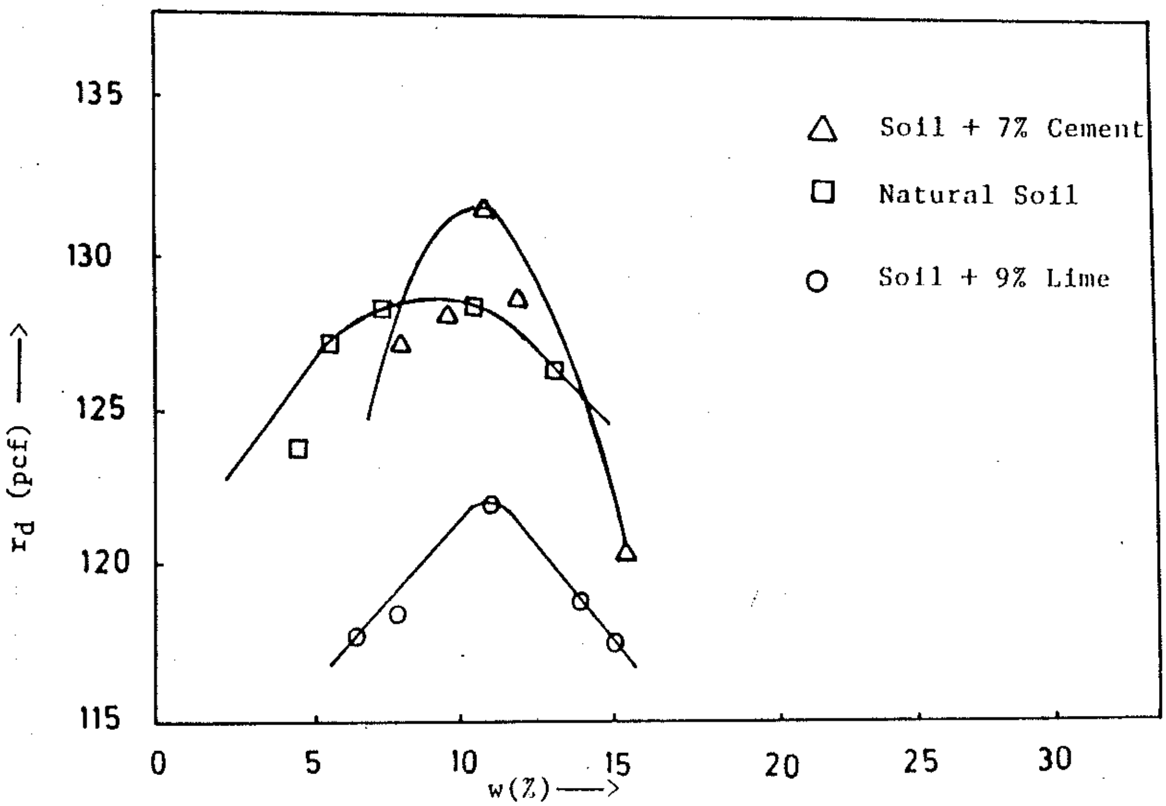

Fig: 1. MOISTURE — DENSITY RELATION

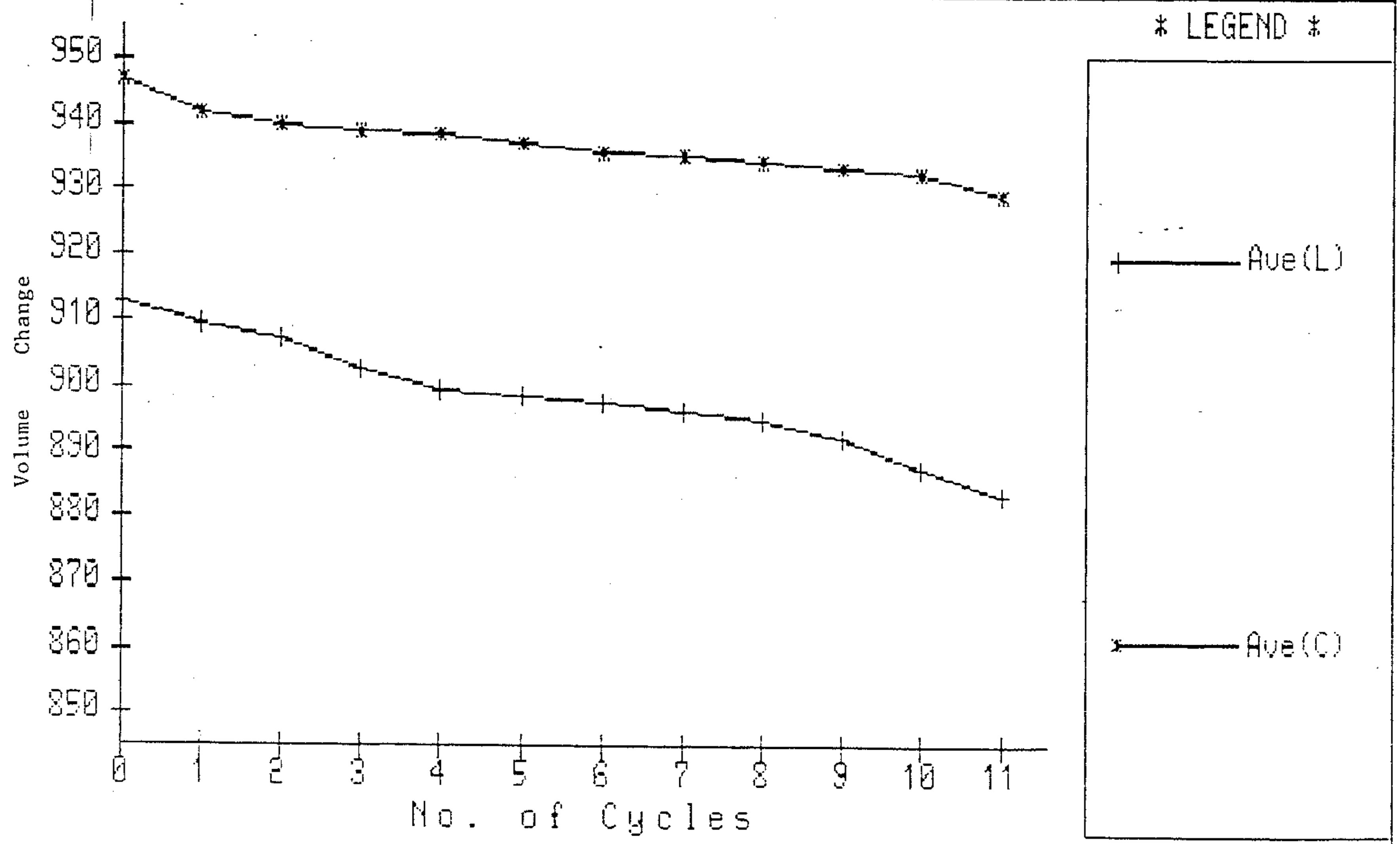

Fig. 3: Percent Volume Change as a result of Wet-Dry Tests of the Specimens made with 9% Lime & 7% Cement.

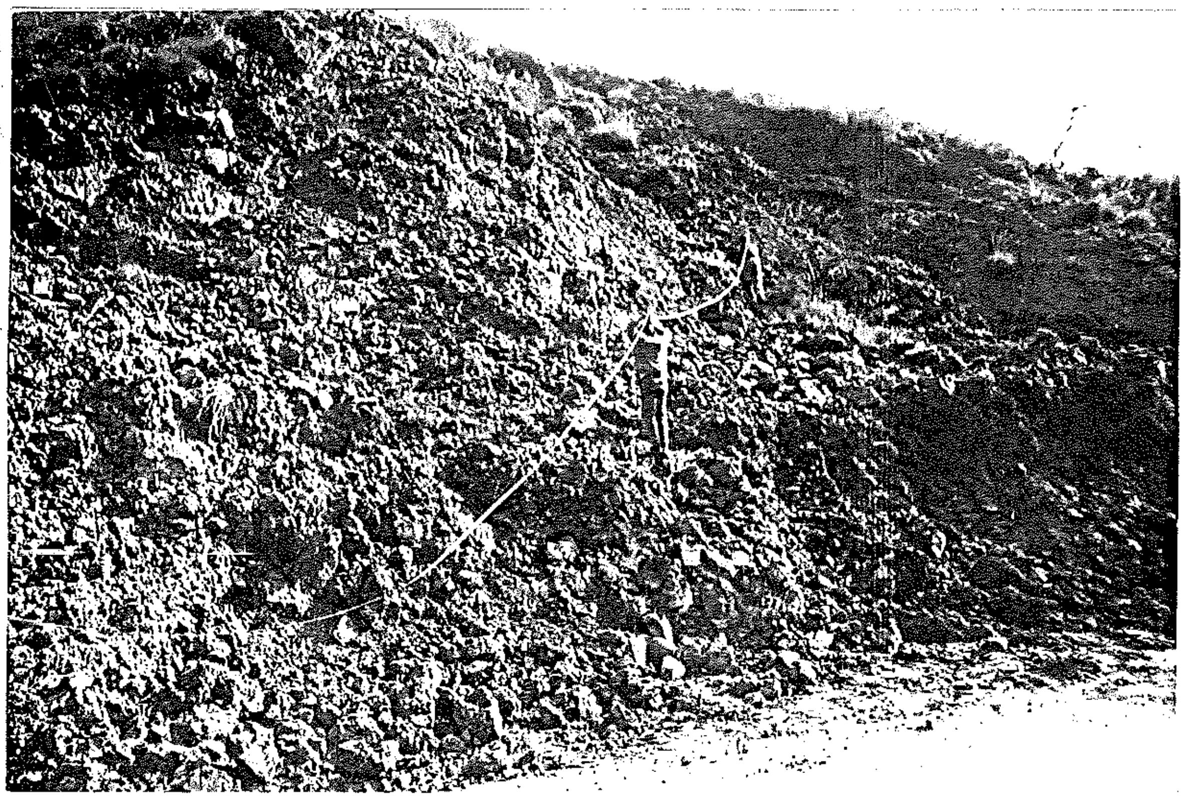

Fig. 4 : Selected Landslide Area (Test Site) 3000 Sq.Meters

Fig. 5 : Cracks and Fissures on top of the hill

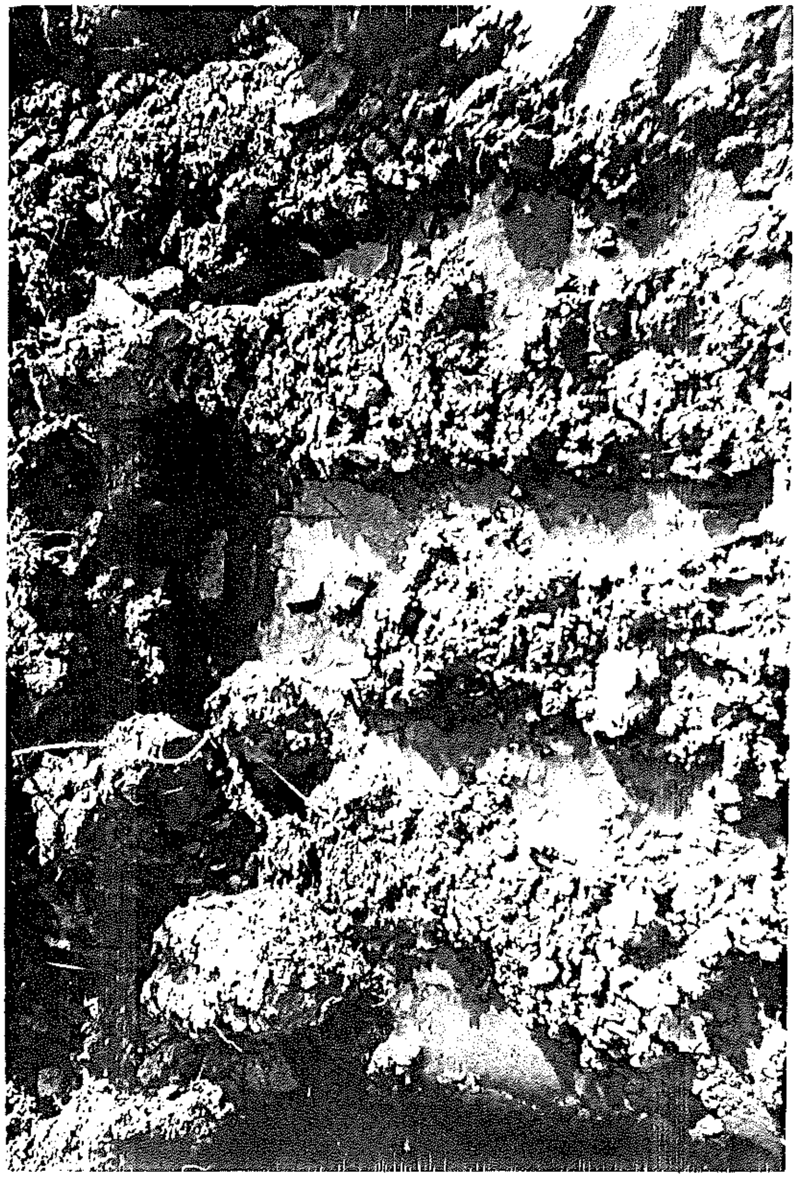

Fig. 6: Over-Saturated Landslide Materials

Fig. 7 : High Plastic Materials with Numerous Boulders

Fig. 8 : Measurement of Length of the Test Site

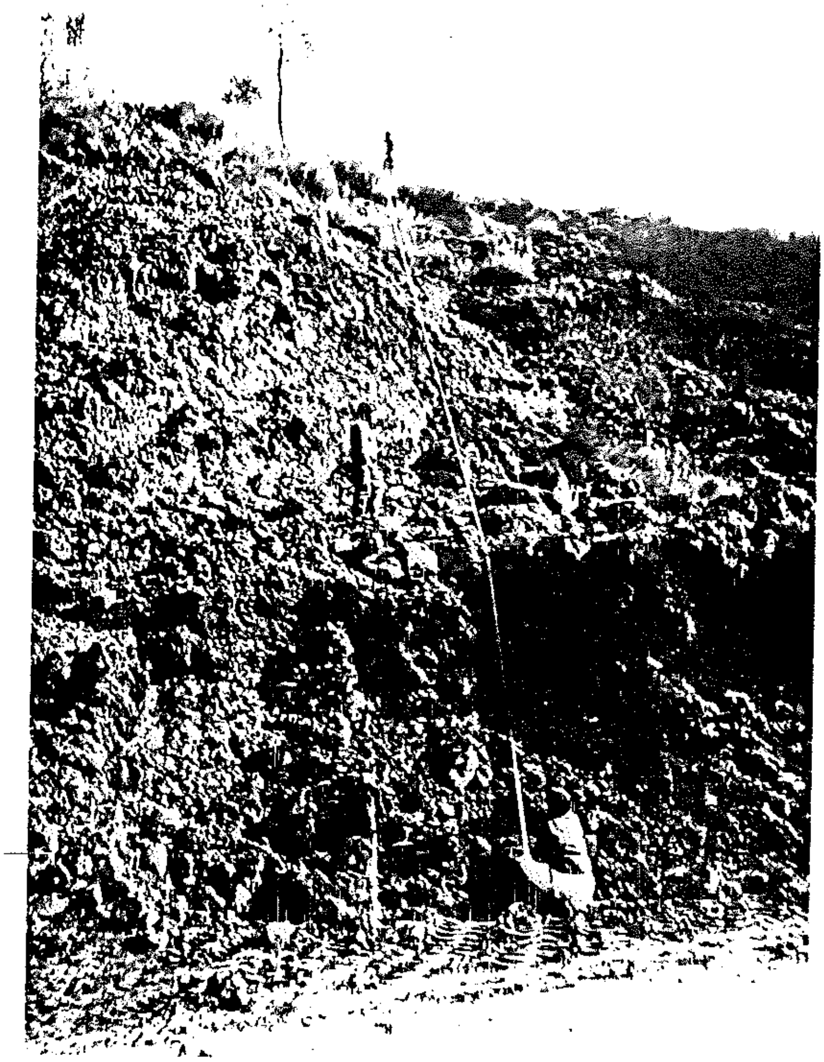

Fig. 9 : Measurement of Height of the Test Site

Fig. 10 & 11 : Sampling of Landslide Materials