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Road Problems in Slip Affected Areas

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SYNOPSIS

This paper discusses various problems faced by Highway Engineers in restoring traffic and construction of roads in slip affected areas. It also discusses in detail various causes of landslide and remedial measures which shall be adopted to solve this problem. An account has also been given of various field investigations to be carried out to find out the exact causes of landslides and methods adopted in handling a major slide in Mile 36 and 39 of Rawalpindi-Murree-Kashmir Road.

From the experience gained in case of slides in Mile 36 and 39 it is concluded that areas which are prone to slides shall be thoroughly surveyed, efficient drainage system provided, hill-side slopes stabilized and small movements within the slide areas checked to avoid deterioration of equilibrium of hill-side slopes. In case of areas affected by slides, detailed field investigations shall be carried out to establish causes of landslide and then suitable remedial measures adopted.

This problem is of extensive nature and is faced by Highway Engineers in various countries of the world. It is hoped that lines of action suggested in controlling slips can be of interest to Highway Engineers confronted with similar problems and can be applied in areas having similar geology to that of Murree Hills.

The area around Murree Hills has typical geology, which has not been explored in complete details. It seems that this comprises of alternating beds of shale and sandstone which are dissected by narrow, seasonal stream valleys. Overburden in this area appears to be detritus. Also sound rock intermingled with weathered ones (boulders) and clay shale type residual soil are predominant. Such residual soils derived from shale are often plastic and difficult to handle, if they have bentonite seams. This is very detrimental to slope stability.

Many landslides take place in Murree Hills which affect the roads. As a result of this there is reduction in alignment standards, loss to property and suspension of traffic. Highway Engineer, confronted with these problems, has to

solve them. He is expected to immediately restore the traffic and put the road in original shape. Such problems are often faced in case of roads around Murree Hills. This paper has been prepared with reference to a particular slide in Miles 36 *and* 39 *of Rawalpindi-Murree-Kashmid road which took place in April,* 1965. *As a result of this major slide the road formation settled and moved downwards resulting in cutting of road and suspension of traffic. With the effect of this slide an area starting from upside of Mile* 39 *to the bed of Nullah downward of Mile* 36 *became unstable. The area affected was so slushy that it was not even possible to stand in it. This was due to excessive water which oozed out from the affected mass. Efforts were therefore made by the Building and Roads Department for temporary restoration of the traffic and then a planned programme was made to handle this major slide with a view to evolve certain ways and means for controlling the slips in Hills with a view to avoid suspension of traffic, inconvenience to public and loss to property.*

This paper discusses in detail various methods adopted in controlling the slips and areas similarly affected by slips/slides in Hills. It also describes various causes of land slides such as (i) deep weathering (ii) frost action (iii) previous small movements within affected areas (iv) saturation of soil (v) poor drainage of area (vi) deterioration of equilibrium of hill side (vii) deforestation. An account has also been given about various field investigation, which shall be carried out by Highway Engineer to solve the problems of landslides. These field investigations can help in giving information about topography of the area, nature of soil, land forms, drainage pattern, longitudinal and cross-sections of erosion channels, type of vegetation over the soil, rock characteristics, ground water seepage, rock stratification and beeding planes, dip and continuation of layers etc. Further investigation about nature of soils, ground water table, and rainfall data can help in selecting any or a group of various remedial measures suggested in this paper. These remedial measures can be in the shape of constructing surface and sub-surface drains, retaining of breast wall or stabilization or mechanical stabilization or forestation etc.

All such measures which have been adopted by the authors in slip affected areas are discussed. Certain other measures proposed to be adopted for controlling slip are also discussed in this paper.

It is hoped that if suggested line of action is adopted in exploring the area, in finding the cause of landslide and then adopting suitable remedial measures, this problem can be solved to a fairly good extent and possibility of frequent suspension of traffic can be decreased.

ROAD PROBLEMS IN SLIP AFFECTED AREAS

Introduction

As a result of the great increases of traffic volume in recent years, requirements for shorter routes, wider pavements and improved grades have become necessary. The Engineer is thus faced with deeper cuts, higher fills, and alignments which must overcome rather than avoid obstacles. One of such obstacles to be dealt with is the problem of landslides. This problem has become fairly acute in Murree Hills, where a number of land slides take place. These slides create problem for people whose land is affected, for forest people, for Telephone and Telegraph Departments, Soil Conservation Department and above all, for Road Engineers, who have to keep roads worthy of taking traffic. This is very urgently required in cases where strategic roads like Rawalpindi-Murree-Kohala Road is affected. It is, therefore, very necessary to first find causes of landslides, then ways and means to protect landslides so that roads are not affected and communication system not disturbed and lastly, to suggest guide lines for Highway Engineer to handle actual landslides, so far as his interest is concerned. This is the subject of this paper and is being dealt with reference to a particular major slide which took place in Miles 36 and 39 of R.M.K. road.

Landslide in Miles 36 and 39 of R.M.K. Road

Due to heavy rains of March 1965 (6.02″) and April 1965 (12.96″), a serious landslide occurred on 12th April 1965, in Mile 39 of Murree link road. A length of about 500 feet of road formation settled and started moving downwards. The upside hillock at this site became unstable and was in motion. The traffic in this stretch was thus suspended. The area downward of this stretch of road also became vulnerable, developed big cracks and showed signs of movement. Subsequent rainfall on 13th April 1965 further added to the movement of the landslide and another length of about 750′, in Mile 36 of R.M.K. road, which is down below Mile 39 was affected. The road formation settled and moved downwards resulting in suspension of traffic on 14th April, 1965. As a result of this landslide, an area from upside of Mile 39 of Murree link road to the bed of the Nullah downward of Mile 36 became unstable and was covered with saturated mass of reddish clay soil.

This slide has its scrap in Mile 39 and its length extends well past below Mile 36. On either flank of slide there is a nullah. Hill slopes adjacent to the slide are covered with thick forestation, but within the sliding mass and above the damaged road portions, the vegetation prior to failure was reported to be comparatively less. In the past there have been some unnoticeable movements of soil depriving the area of stabilizing effect of rich vegetation growth.

The length of the slide is more than 2,000 feet; the width ranging from 500 feet to 750 feet. Approximately five million cubic feet of soil was estimated to have been disturbed or moved in the slide. After the slide, it was observed that water was permeating at number of places and slushy conditions prevailed just below the exposed surface. The sliding mass was seen to be plastic, as a result of which it can be said that the soil has low permeability and retains moisture.

The area affected by slide has typical geology, which has not been explored in complete details. It seems that this comprises of alternating beds of shale and sand stone which are dissected by narrow, seasonal stream valleys. Over burden in this area appears to be detritus. Also sound rock intermingled with weathered ones (boulders) and clay shale type residual soils are predominant. such residual soils derived from shale are often plastic and difficult to handle, if they have bentonite seams. This is very detrimental to slope stability.

Causes of landslide

Sedimentary rocks consisting of interbedded layers of shale and sand stone become unstable, when the rock dips down around the cut. Under such conditions the slate layers become ideal sliding planes. Landslides are extremely prevalent in such formation and most difficult to control.

The landslides can take place due to the effect of one or more than one of the following factors :—

1. Deep weathering.
2. Frost action.
3. Previous small movements within slide area.
4. Saturation of soil.
5. Poor drainage of area.
6. Deterioration of equilibrium of hillside.
7. Deforestation.

Studies made on the above lines for landslide in Miles 36 and 39 of RMK road are discussed as follows.

Deep weathering

Due to weathering effects, the area lying between miles 36 and 39 has been constantly losing its stability. There was mass disintegration and heavy rains over the area have constantly been washing the toe of the slope. This also exposed the embedded big stones and layers of rock.

Frost action

When the embedded stones and rocky layers were exposed to open weathering action, frost action took place. As a result of this mass disintegration started. The big stones or rocky layers which were previously capable of retaining earth behind, became incapable of doing so. Therefore, the disintegrated portions of rock or big stones moved down and carried loose mass with them; as a result of this, the stable slope became unstable and amount of overburden increased.

Small movements

Small movements are then expected to have taken place within this area. This contributed to loss of shear strength of weathered overburden soils which in turn increased the slide potential.

Saturation of Soil

Water appearing in different ways is probably the main contributor to a series of failures in hills. The slide under discussion is also associated with heavy winter rain storms and melting of large masses of snow. Excessive precipitation is believed to have caused saturation due to shallow percolation, which had a decisive influence on the amount of the seepage pressure. This is especially true in such cases of interbedded, sedimentary rocks consisting of layers of sand stones and shale, where seepage pressure in sand stone creates currents dragging soil particles along, thereby increasing effective pressures on the same. Although drainage is excellent in sandstone, its flow might be intercepted, if shale layer is continuous, thus creating a lubricated potential slip surface.

Poor drainage of area

The seriousness of problem due to water is further aggravated if the area is poorly drained. Water starts percolating within the mass and its weight steadily increases. As a result the gravitational force increases and frictional resistance simultaneously decreases due to constant lubrication. This then becomes another factor contributing towards an unstable condition.

Moreover, under-currents start within saturated mass and the water starts emerging near the toe of the slide, where it starts cutting the soil. Similar action took place in case of slide in Miles 36 and 39 of R.M.K. road.

Deterioration of equilibrium of hillside

The existing equilibrium of the hillsides in Miles 36 and 39 of R.M.K. road steadily deteriorated long before the first slide in this area in August, 1963.

Ultimate failure can be attributed not only to under-cutting of the toe of slope but also to a combination of other circumstances having an adverse effect on stability conditions. Some of these factors have been discussed above.

Deforestation

Vegetation and forestation reinforces the stability of slope. When this is removed, not only the original stability is lost but also with the removal of roots, the upper surface gets loosened, and is washed away with heavy rains. Also with the removal of vegetation, the surface is exposed and water starts percolating within the mass. This ultimately reduces frictional resistance of soil and thus deforestation becomes a detrimental factor to slope stability. Deforestation was reported on slopes between miles 36 and 39, before the slide took place.

Field Investigations

As the slide trouble in Murree Hills has taken a proportion, therefore it requires extensive efforts to keep the road in motorable condition throughout the year. In order to do so, the problem of land slides is to be tackled rationally.

This can be done by first carrying out the following field investigations and then adopting the suggested remedical measures.

The Murree hill areas can be split in three categories :—

(*a*) Areas which are presently under active slides.

(*b*) Areas which are prone to sliding.

(*c*) Areas which are stable and no slide problem is likely to be experienced in foreseeable future.

The geological and hydrological conditions of areas which come under category (*a*) seem to indicate that failure will not occur necessarily along a slip circle. It might move along a plane of weakness existing between the sandstone and shale as discussed above. Therefore, in order to handle problem of landslides, some proper method of investigations, together with a carefully executed and supervised sub-surface exploration programme and combined with certain continuous observations on the following lines should be followed.

1. **Maps.** The Topographical maps of the area, along with cross-sections and profiles be prepared.

2. **Aerial Survey.** Aerial survey of the area shall be carried out which will supply information about topography of the area and nature of the soil. This study would also reveal land forms, drainage patterns, longitudinal and

cross-section of erosion channels, the type of vegetation over the soil and rock characteristics, ground water seepage etc. Identification of soil and rock types, buried as well as exposed ones, can be made with surprising accuracy from a pair of overlapping photography in stere.

3. Geophysical Investigations. The measurements to determine the depth of rock or other layers beneath the ground surface are recommended to be carried out. Geophysical investigations can define dip and continuity of layers. Moreover, determination of water table is also possible.

4. Geological Investigation. Information about rocks shall be collected which will be helpful in determination of their strength, stratification, beeding planes and action of weather on them and fissures etc.

5. Soil Classifications. Investigations for the determination of plasticity of soils, grain size distribution shall be done. Inference can be drawn from these tests about drainage properties of soil.

6. Rainfall data. Information about the frequency, duration and intensity of rainfall be tabulated. This information can be helpful in splitting the areas in three categories mentioned above, when correlated with damages experienced in the past.

7. Boring. Boring operations should be carried out on a limited scale only due to errotic sub-surface conditions. Samples obtained should be analysed for the type of clay present. Rock cores should be taken to identify condition and type of rock.

8. Pore-Pressure Observations. Observations of excessive pore-pressure in areas which come under category (*b*) should be made. This can be done by installing a system of peizometers at predetermined locations and depths. This will help in analysing the cause of slide in accordance with well-established methods.

9. Surface Movements. The surface movements can be measured by setting up number of bench marks on firm ground and some offset stacks within the affected area, at desired intervals. If cracks appear above the top of the slide, daily measurements should be taken, between two stacks driven into the ground.

10. Records. All the data collected from observations should be recorded and plotted in a proper manner and preserved. Dates of observations be recorded distinctly on each sheet. Name and designation of person making observations should also be written.

The course of action suggested above is very ambitious and might take fairly long time to make observations and then to devise ways and means for handling this problem of landslides on permanent basis. But at places where such problem arises, certain immediate steps need to be taken as remedial measures, which may be for the temporary restoration only in case of major slides. But where the magnitude of slide is not much, the following measures suggested (as well as adopted by the authors at various places) can be applied as permanent solution of the problem.

Remedial Measures

In order to handle the problem of major slides in Miles 36 and 39 of RMK road, the following lines of action were followed :

1. Kutcha drains with adequate slopes were immediately made for surface drainage in the affected area with the help of manual labour. This helped in draining moisture from the sliding mass near the surface and also in drainage of surface water from subsequent precipitation. These drains were discharged in side nullahs. This also helped in drying up of the slided mass.

2. Loose mass which was in a state of slush was removed with the help of bulldozers.

3. Temporary diversions on the up hillside of the original alignments were then cut with the help of bulldozers.

4. Stone boulders were then dumped in layers on the newly cut diversions and embedded in their beds with the help of machines. Traffic was restored on the diversions.

5. More layers of stone boulders were spread as soon as the previous ones settled due to the movement of traffic.

6. Beds of kutcha drains were then lined with dry stone pitching in order to decrease percolation of water and to increase flow of surface water.

7. Kutcha check dams were constructed at points where there was sharp fall in levels. This was done with a view to avoid big falls of rainwater and subsequently erosion from the toe of the slide. This also helped in checking the small movements within the slided mass.

8. As soon as the area above and below the newly cut diversions was stable, breast walls and retaining walls were constructed.

9. Road portions were then black topped both in Mile 36 and 39 to avoid percolations of surface water and creation of hydraulic pressure at the back of retaining walls.

10. All sources of water emerging within the slide area has been trapped and water drained to side nullahs through kutcha drains.

11. Pucca drains within the slide area, on firm foundations and having adequate slopes, are under construction. These are for getting the surface water from kutcha drains and then discharging the same into side nullahs.

12. Experimental walls with empty tar drums (which could not be reused) have been constructed in two ways and the area lying in between these walls has been terraced.

13. A proper drainage system in the areas affected by landslide on the following lines is suggested. This drainage system has several components and might consist of one or a combination of the following recommendations. It should also be kept in view that design changes in such cases are not unusual. Therefore, if warranted by subsequent developments, the designs should be changed.

(*a*) Bench the hill-sides. Vertical back slopes can be retained by a retaining wall (various types of retaining walls and breast walls constructed in such areas are discussed in subsequent paras).

(*b*) The terraces should be stabilized either by vegetation growth or by using chemical stabilizers such as calcium chloride, lime and cement or by mechanical stabilization using local stones etc.

(*c*) A paved waterway to collect run-off should be provided at the top of the retaining walls.

(*d*) Install deep interceptor drains covered with impermeable soil and paved with local stones at top. The stone layers can be further sealed by grouting with cement sand slurry.

(*e*) Construct "Y" type French drains along the hillside.

(*f*) Improve or pave channels of existing nullahs along and above the slide area.

(*g*) Design reversed filters around deep holes. Provide for collection of emerging water in paved ditches.

(*h*) Construct a continuous system of back drains along the full length of retaining walls with outlets located beyond the end of the walls.

Various Types of Walls

Walls are constructed to handle the problems of over-slips and underslips. Over-slips result when loose mass from the up hillside of road slides and covers the roadway. In such cases a breast wall may be needed to reinstate the highway after removing the slided mass with the help of machines of manual labour. The problem of over-slips is not as complicated as that of under-slips.

In case of underslips, the highway alignment may be altered, as, due to their effect, the road formation is usually damaged and cut, and this entails a reduction in alignment standards. The highway in such cases can be reinstated either by realignment or by construction of retaining walls. Realignment is thought of when either no solid foundation for retaining walls is available or the height is 20 feet or more.

In certain cases, walls over 20 feet are also constructed to restore the roadway when the availability of land on new alignment becomes a problem.

The following few types of breast and retaining walls have been constructed by the authors in slip areas in Murree Hills. Few more types constructed in other parts of the world are also discussed which are proposed to be constructed and their stability judged. But whatever types of wall is constructed, it should meet the following requirements :—

(*i*) Walls should be constructed with single units. This has been the obvious advantage of easy supply and storage.

(*ii*) Each unit should be such that it is easily carried by one man to facilitate re-erection in difficult positions.

(*iii*) It should have at least 20 years life.

(*iv*) The units with which walls are constructed should be robust and able to withstand considerable handling shocks.

(*v*) Should be economical.

(*a*) **Stone walls.** The stone walls are usually built to check both over-slips and under-slips. In case of under-slips, the height is about 8 to 10 feet maximum. Such walls are usually constructed in a thickness of one to two stones only, using undressed stones of approx. 9″×9″×6″ size. These walls can be constructed dry or with mud mortar or by grouting each layer with cement concrete. In case of two stones thickness wall, big stones of double the width are usually used at every 5 feet in each layer to act as bond stones. When concrete is used for grouting, no boxing is required. Such a wall constructed dry is shown in Photo No. 2.

(*b*) **Vertical Drum Wall.** Walls with empty useless drums can be constructed by placing the drums vertically on end in a row. These drums are filled with local material and embedded in ground. Such a wall is good to check over-slips and under-slips of 2 to 3 feet height only. Such walls can also be constructed within slip areas at frequent intervals to make terraces and benches. These are also useful in checking the minor movement of mass within the areas which are prone to slides. A wall constructed with such specification is shown in Photo No. 3

(*c*) **Horizontal Drum Wall.** Walls with empty, useless drums can be constructed by placing the drums horizontally in a row. Where such a wall is constructed, a foundation is dug, and empty drums filled with local materials are laid horizontally. Successive layers are then constructed over these by similarly placing the drums. But every layer is given a horizontal step, which is good for the stability of the wall. The gaps formed due to circumference of drums act as deep holes. Such walls are useful both for checking over-slip and underslips of 8 to 10 feet height maximum.

A similar wall constructed in slide area lying below mile 36 is shown in Photo No. 4

Dry Stone Masonry Walls

Walls up to a height of 12 feet can be constructed in dry stone masonry with hammer dressed stones, both as breast walls and retaining walls by keeping top width at 2 feet and having a slope of 1 in 4. The back of the wall is kept vertical and the front portion is given the above-mentioned slope. Such walls have been very useful had have had a life of over twenty years. Bond stones at every 5 feet should be provided in each layer which should have length equal to the width of wall in that layer. Such walls constructed in slip area around Murree hills are shown in Photos Nos. 5 and 6.

Masonry Walls

Other types of walls, which can be constructed with local stones on similar principles, are :—

(*i*) Dry stone walls with bands of C. R. Masonry in 1 : 6 cement mortor at every 4 feet having a thickness of 2 feet across the full width of wall. Such a wall is shown in Photo No. 7.
The foundation is to be made in 1 : 6 cement mortar.

(*ii*) Dry stone walls with 1 : 3 : 6 cement concrete bands at every 4 feet having a thickness of 6″ across the full width of wall. Such a wall is shown in Photo No. 8.

(*iii*) Walls constructed with local hammer dressed stones in 1 : 6 cement mortar. Such walls are desired where height is abnormal or the pressure at back is excessive.

Various other types of walls which have been constructed in certain other parts of the world are :—

(*i*) **Gasket Type Unit Wall.** Such unit is shown in Photo No. 9.

Walls built in such unit have the advantage that the same unit could be used for a wall 3 feet thick or 1 foot 8″ thick. In a wall 8 to 10 ft. high ,the lower 4′ could be built with the units facing onto the bank and the upper 4 to 6 feet with the units running with the line of the wall to give a 1 foot 8″ thickness to the wall. The holes ¾″ dia in the back face of the unit could be threaded with twisted No. 8. galvanized wire to tie the back face from the bottom. A wall constructed with such units is shown in Photo No. 10.

Unit Cell Type Wall

The units cells used for the construction of R/Wall are shown together with a wall in Photo No. 11.

Such units were developed because of the fact that gasket type were not very robust. A wall constructed with such units made of precast cement concrete 1 : 2 : 4 is also shown in Photo No. 12.

Wall with precast rectangular units.

Precast RCC units 5″×3″×3′—6″ having holes in corner when placed and tied together in a shape shown in Photo No. 13.

From a box type wall. The cavity so formed by these members can be filled with broken rock or shingle rammed inside the wall. The back fill should also be compacted very properly.

Conclusions

Form the experience in case of slip in Mile 36 and 39 of RMK road and a similar other slips, it is concluded that proper drainage of areas which are prone to slides is absolutely necessary. The areas under slide shall be benched as suggested above.

In order to repair over-slips and underslips walls shall be constructed with local hammer dressed stones by using 1 : 6 cement mortar in foundations and then constructing the wall with dry stone masonry. If the height of wall is more than 12 feet, bands of cement concrete 1 : 3 : 6, 6″ thick or that of 2′ thick C.R. masonry 1 : 6 cement mortar could be provided after every 4 feet.

Stability of all such walls is further strengthened when bond stones at every five feet equal to width of wall is given in each course of masonry. In case bond stones are not available, precast cement concrete units shall be provided to act as bond stone.

Acknowledgement. The authors acknowledge with thanks the help and guidance received from the report of Mr. Horst Barbrakey, Highway Consultant, Lahore on the subject.

A view of slip affected area in mile 39 showing making of Diversion.

Photo No. 2

Photo No. 3

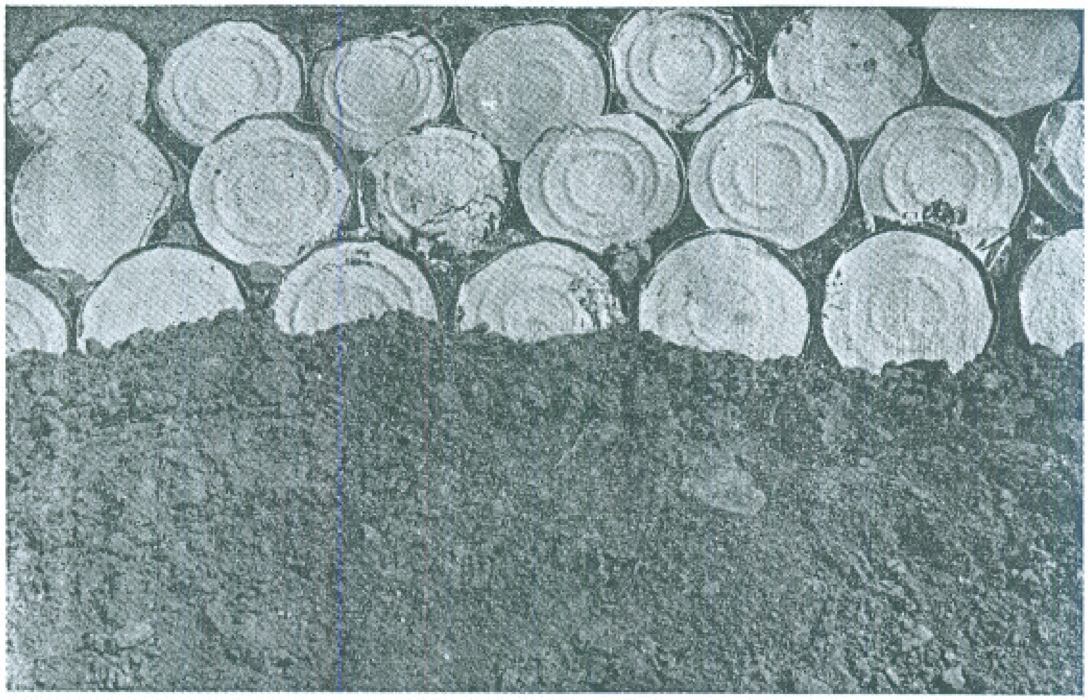

Photo No. 4

Photo No. 5

Photo No. 6

Photo No. 7

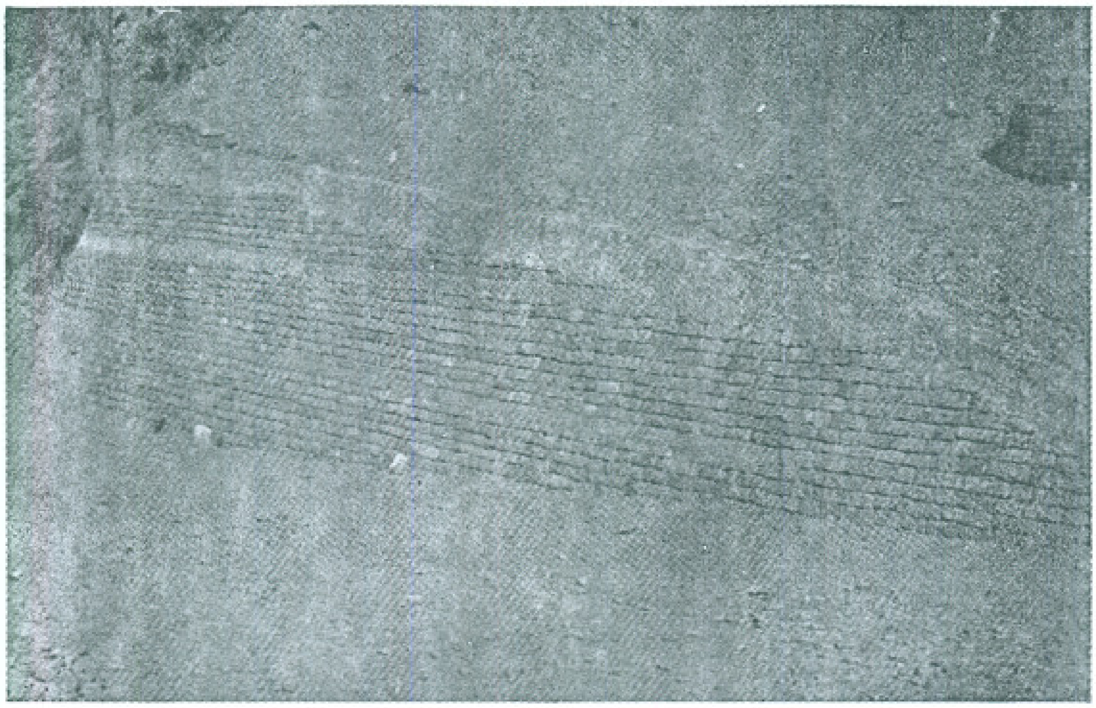

Photo No. 8

Photo No. 9

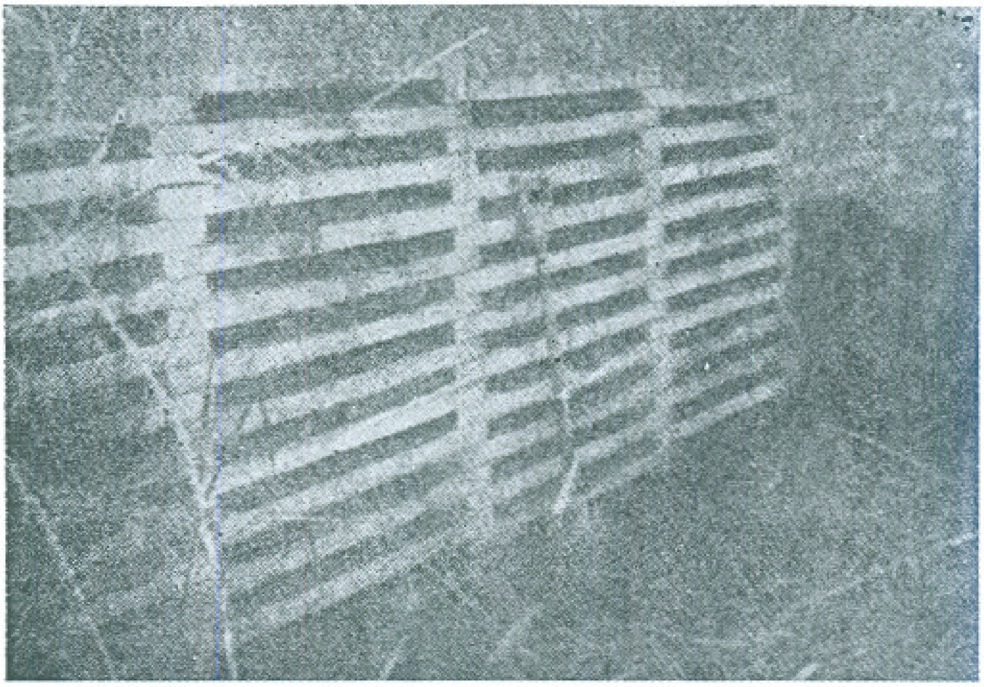

Photo No. 10

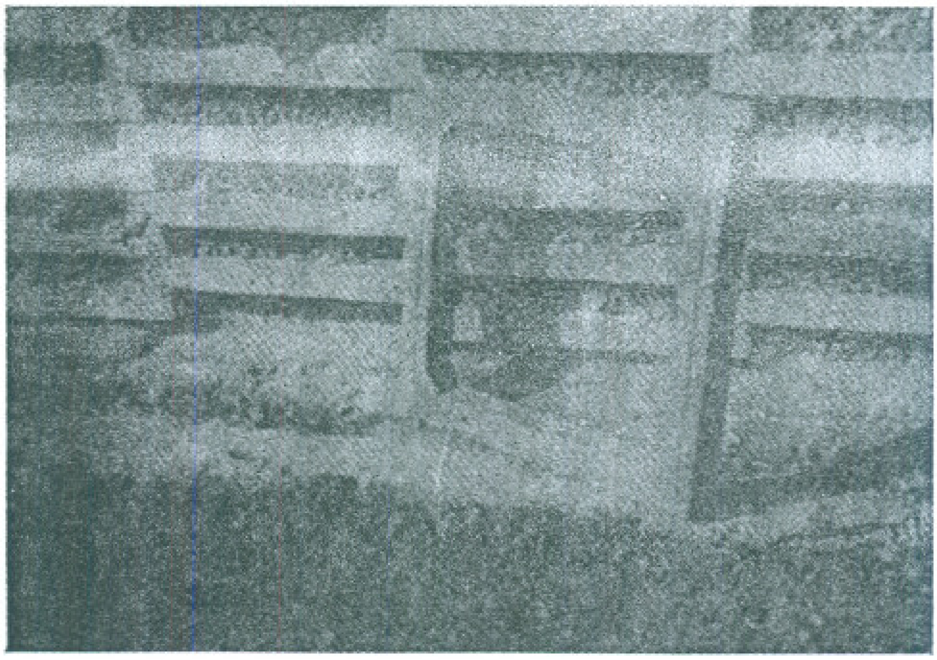

Photo No. 11

Photo No. 12

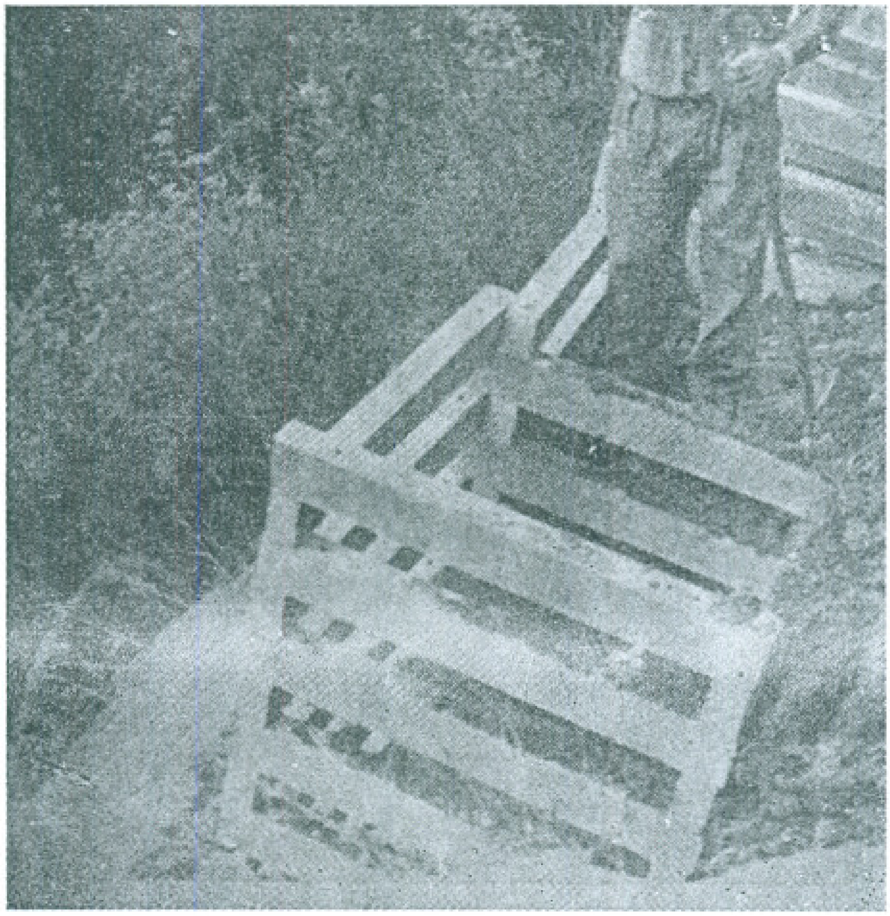

Photo No. 12