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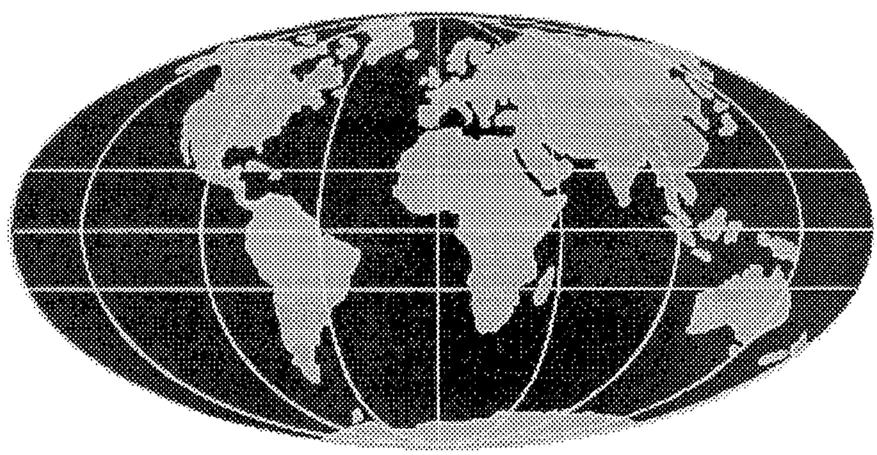
by: D M Brooks and C J Lawrance



Overseas Centre
Transport Research Laboratory
Crowthorne
Berkshire RG45 6AU
United Kingdom

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MAINTENANCE OF ROADS IN HILLY AREAS - EXPERIMENTS ON ROAD CUTTINGS IN NEPAL

D M Brooks and C J Lawrance

1. INTRODUCTION

Nepal is a small land-locked kingdom about the size of England, lying along the northern border of India in the Himalayan mountain range. The Himalayan mountain belt is one of the most difficult terrains in which to build roads: the first motorable road into the mountains connecting the capital, Kathmandu, to the plains in the south, was completed only in 1956.

A number of roads have now been built into the interior and they have all suffered from landsliding to a greater or lesser extent. The development of instability above and below a road results in sterile agricultural land and contributes to the already serious loss of soil from the slopes into the rivers, creating problems of siltation and hydraulic disturbance, often many kilometres downstream.

The problems of highway design and maintenance in mountain regions are by no means restricted to Nepal. Population pressures, deforestation and soil erosion, are common in mountainous countries everywhere.

The aim of the research therefore goes beyond a need to reduce the costs of clearing landslides and delay to vehicles. The methods under investigation are intended to develop low cost engineering solutions to instability that are within the capability of indigenous resources in terms of materials, institutional organisation and manual skills. It is hoped that the research will generate greater empathy between highway engineering and community life in Nepal that could have implications for many other countries.

The British government has funded the construction of two roads in Nepal, a 110km section of the East-West Highway from Butwal to Narayanghat that was opened in 1975, and a 55km road from Dharan to Dhankuta, completed in 1982 (Fig 1). After completion of the two roads, it was evident that the Nepalese Department of Roads, while capable of clearing landslides and repairing the road surface, could not provide the resources necessary for extensive and long term repairs to unstable hillslopes. The Overseas Development Administration accordingly set up a Roads Remedial Works Unit, in conjunction with the Roads Department, under the management of Roughton and Partners, consulting engineers. The duty of the RRWU is to carry out repairs on the two roads other than normal recurrent maintenance, for a period of three years initially. Roughton and Partners hire and supervise local contractors to carry out the work.

The Overseas Unit of TRRL operates independently, in collaboration with the RRWU. Shortly after the establishment of the RRWU in 1984, TRRL visited Nepal to set up the experimental project and select sites for study. TRRL staff visit the sites at least once every year to monitor performance and review the research programme. To date the sites have experienced one monsoon season.

2. ENGINEERING GEOLOGY

2.1 Geology

The development of the Himalayan mountain chain took place some 26 - million years ago, although even today movement has still not ceased. The rate of rise of the land mass was so rapid (in geological terms) and the rate of downcutting by rivers so vigorous, that the mountain slopes were left in a barely-stable state. The present climate of hot monsoon conditions, with both high and intense rainfall, has resulted in deep weathering profiles, on slopes that are near the limit of stability. Landsliding is so common that it can be considered the norm rather than the exception in this landscape. Intense rainfall causes severe soil erosion, aggravated by deforestation and farming of marginal land where population pressures in the hill districts are high.

More than three quarters of Nepal lies within the Himalayan fold mountain chain. The country can be divided into four lithological and structural units, three of which affect the roads under study (Fig 1).

1) Terai. The Terai is an almost level alluvial plain, representing the most northerly extent of the Indo-Gangetic Plain. It is an area of intense agricultural activity, the most productive area of Nepal.

2) Siwalik Hills. Rising sharply from the terai, the Siwalik Hills consist of sedimentary rocks. The hills rise to some 800 m in the vicinity of the Butwal-Narayanghat road.

The Dauney Hills are made up of sediments of the Siwalik group, consisting of alternating sequences of sandstones and mudstones, most of which are micaceous and silty in nature. The rocks vary in thickness from about 0.5 m to several metres, but are usually less than 1 m thick (see Plate 9). In addition there are several beds of sandstone more than 20 m thick (see Plate 3). All the rocks are porous by nature and have been tilted and faulted to produce very fractured rock masses that are highly permeable. Water enters the joints and penetrates to a depth of many metres, creating deep weathering zones and lubricating potential failure planes. It also permeates the body of many rocks, causing them to become internally weak.

3) Mahabharat Lekh, or Lower Himalaya. The metamorphic rocks of the Mahabharat are dissected into ranges of hills increasing in altitude to the north. The Mahabharat rocks of the Dharan - Dhankuta area consist for the most part of metamorphosed phyllites, schists and quartzites. These rocks have been intensely folded and crushed during metamorphism, and now form shattered masses that are very prone to weathering and collapse.

4) High Himalaya. The great mountains of the Himalayan range.

2.2 Mechanisms of slope failure

A mechanism of slope failure is the process that causes one component of a slope to move downhill in relation to another. A common misconception is that "the landslide" consists only of the mixture of soil and rock debris that lies in the slide path and on the road. But the debris is only part of a much larger phenomenon, and it is necessary to consider the slope failure as a whole if the slide is to be permanently stabilised.

The occurrence of a landslide event marks the start of a period of activity that may last at least several years, during which time the landslide grows. The duration of instability depends upon the rock type and structure, but sliding eventually diminishes as the landslide approaches a stable angle, or stable rock planes are exposed. One large debris slide, which was voluminous and blocked the road in the 1981 monsoon, is dwindling now that relatively stable rock planes are exposed in the head area.

To stabilise a landslide the source of supply must be identified and detachment from the hillside should be prevented wherever possible. A landslide can be envisaged as consisting of three components (Fig 2). Some typical mechanisms are illustrated in Plates 1 - 3. It is important to note that all the landslides contain more than one mechanism of failure. At the experimental sites great care has been taken to identify which mechanism predominates in each part of a slide, its likely cause, and to decide which kind of remedial measure is most economically appropriate at that point.

3. ORIGINAL ENGINEERING MEASURES

It is the practice in Nepal to protect the road pavement and side drains by the provision of toe walls and cut-off drains.

3.1 Toe Walls

Two types are generally used. Where there has been a clear need to retain a soil or rock mass gabion walls have been constructed. These are of conventional design and construction, and rely on their deadweight to resist sliding or overturning. Gabions are especially appropriate for Nepal because the nature of the design permits considerable distortion to occur whilst still retaining material. However there are many instances where the wall has been overtopped, or where buckling has been sufficient for individual wires to fail (Plate 4).

Where erosion at the toe of the exposed cut face was expected revetment walls have been employed. These have been constructed of dressed dry stone masonry blocks, strengthened by mortared masonry "frames" (Plate 5). These walls fail where ground movement creates forces behind the wall.

3.2 Cut-off drains

These drains have been provided in numerous locations and have been constructed of bound masonry with a trapezoidal cross-section.

Cut-off drains so constructed have two major shortcomings. Because they are necessarily remote from the road clearing of debris is often forgotten. Also the drain can fracture due to slight ground movement or impact from a boulder. The inherent inflexibility of the bound masonry construction makes this more likely.

Clogging or fracturing can result in severe concentrated erosion which may be worse than that which would have occurred if the drain had not been built.

It is evident that the potential threat to new roads from instabiity was recognised by the original designers. Well understood techniques were employed to retain the small slides encountered. Structural failure has mostly been due to subsequent changes in site conditions that were unforseen at the time of construction. It is not always possible to predict such changes but a clearer understanding of the mechanisms creating the instability may assist the engineer to make adequate provision for them. Performance has also been affected by subsequent lack of maintenance. For this reason, experimental designs are suggested which, as far as possible, require little or no maintenance.

4. EXPERIMENTAL TECHNIQUES

Nepal, like most developing countries, has very limited foreign exchange resources and a severe shortage of qualified engineers and technicians. This situation has limited the techniques to be tested to those which:-

(a) utilise materials readily available in Nepal.
(b) require no knowledge of specialist techniques.
(c) do not require specialised plant and equipment.
(d) require minimal recurrent maintenance.

These requirements have not been satisfied in every case. However, it is believed that the techniques, if successful, can be modified to suit the requirements of Nepal and similar developing countries.

4.1 Support structures

These structures may be required either (a) to retain a soil mass which would otherwise endanger the road pavement or (b) arrest the movement of surface material downslope which would otherwise damage vegetation, promote erosion or pose a threat to the road pavement or side drains.

4.1.1 Earth retaining structures

Earth retaining structures have generally not been recommended as a solution to landsliding because they do not tackle the problem of stabilising the source zone and halting the supply of material to the debris slide. But there are occasions when a heavy retaining structure at the toe is unavoidable. An alternative design to a conventional gabion wall is being tried which it is hoped will provide equally effective restraint at less cost. Cost reduction should be achieved by faster construction and the use of unprocessed fill rather than the broken stone required for conventional gabions. There is also a considerable reduction in the quantity of gabion wire required for a given height and length of wall although this will be partially offset by the need for other materials.

The construction proposed is illustrated in Fig 3. The wall comprises cylindrical columns abutting one another to form a continuous structure. Each column is formed by eight vertical steel bars wrapped in gabion wire and 'Lotrak' fabric. This fabric is being used because a quantity is available on site although geotextile fabrics are not made in Nepal. If the design is successful an alternative to geotextile will be sought for further structures. The cylinders are filled with sand or gravel and capped with concrete. The design of the cylinders provides a structure which:-

(a) resists sliding due to its deadweight and the base being lower then the surrounding ground.

(b) has a very high resistance to overturning.

(c) has a high resistance to deformation. Internal stresses are transmitted to the skin which is cylindrical and taut. The concrete cap resists vertical displacement of the fill.

(d) facilitates the escape of drainage water, through the narrow gap between cylinders.

4.1.2 Surface material restraint

A simple modification to the design of the mortared frame revetment has been introduced at a site where differential vertical displacement may occur. To accommodate this, while retaining the integrity of the wall, joints between the mortared columns were left unbonded (Plate 6).

Catch fences are a successful method of preventing erosion in loose materials, and encouraging the growth of vegetation. Two types have been developed, to suit the particle size of the debris. Where fine grained material predominates woven wattle catch fences have been installed (Plate 7). The fences must be placed horizontally to minimise concentration of water flow. The soil platforms form an ideal environment for plant growth. It will be apparent that the fences have very little strength and can be easily breached or damaged by scree or boulders. Where coarse material predominates a wire fence, similar in principle to the wattle fence, has been introduced, illustrated in Plate 8. The wire fences have a much greater resistance to damage, and can survive even when seriously distorted by large volumes of material.

4.2 Surface coverings

To arrest the erosion or weathering of relatively soft material with a steep exposed face where vegetation would be impossible to introduce a range of surface treatments has been devised utilising locally available materials. All the techniques, except perhaps bitumen, are well-proven, but the principal objective is to determine which technique is the most cost-effective. Plate 9 shows a site where they have been tried simultaneously as individual surfacings.

4.2.1 Bricks and masonry facing

One section of the site in Plate 9 has been covered with bricks, laid flat without further keying. Another has been covered with a dressed dry stone revetment. These surfacings are appropriate because brick is very widely used as a building material in northern India where natural aggregate is scarce, and dressed stone masonry is a local skill in Nepal, much exploited in the construction of walls and gabions.

4.2.2 Chunam and Ferro-cement

Chunam is a rendering composed of Portland cement, lime and clayey weathered aggregate (1:3:20). It is applied in two equal layers 20 mm thick and keyed to the previously cleaned face by bamboo dowels projecting from the surface. Weepholes are left to drain any ground water from the protected rock as it is intended to provide an impermeable surface. Ferro-cement is an alternative rendering placed in one layer composed of Portland cement and coarse, sharp sand (1:2). Adhesion to the previously cleaned face is achieved by fixing "Weldmesh" reinforcement or similar, overlain with 10 mm aperture wire mesh prior to application of the mortar. Weepholes are provided as before.

4.2.3 Bitumen

Bitumen has been successfully used in the past to hold seeds in place long enough to allow germination to take place. In that case the bitumen is required to adhere to the surface for only a relatively short time. To resist erosion the material must bond successfully for many years. Observation of the technique in other parts of Nepal suggested that this would be difficult to achieve, particularly where moisture is present. Two applications of a cut-back bitumen have been applied using a hand lance connected to a pump and tank. A very low viscosity cut-back was used (MC30 or less) to ensure penetration of the first coat into the rock surface. This comprised 60% 80/100 pen. bitumen and 40% cutting agent made from kerosene and diesel oil blended 3:1 respectively. Weepholes were built in to remove as much as possible of any moisture in the rock.

4.3 Surface seals

With prolonged rainfall during the monsoon, water percolates to several metres into the soil. The effect is greatly exacerbated if slight ground movement should occur, opening up cracks in the surface. An inexpensive measure is to cover the cracks, to mitigate the effect of water running into open fissures, sufficient at least to give time for a full appraisal of the landslide to be made, or for the slide to reconsolidate and stabilise itself.

Cracks may occur singly around the head of a slide, or all over a moving surface. For these bitumenised jute covers are proposed. Cracks also appear behind the head of a slide, for which roofing felt has been tried.

4.3.1 Bitumenised jute

Jute is indigenous to Nepal and is available as a woven fabric. Being a natural substance it detoriates and rots rapidly in the presence of water unless protected in some way. To seal both individual cracks on a slope and large areas of exposed ground, jute fabric has been sprayed with cut-back bitumen and laid directly on the previously cleared surface. The same design principle is used for both single cracks and multiple cracks: the jute is secured on the upslope side only to allow further ground movement to take place without disturbing the covering (Fig 4). The covering is protected from animal hooves and sunlight by a layer of loose stone rubble.

For area coverage the covering is laid as a series of overlapping 'tiles' (Fig 5).

4.3.2 Roofing felt

Cracking occurs around the head of slide scars by collapse of the unsupported vertical face, causing the head to retreat rapidly. A method has been proposed of covering the 'brow' of the scar with roofing felt to keep the brow area dry (Plate 10). The felt is resistant to sunlight and weathering. Strips are lapped to keep water out, and secured at the rear edge only to allow for some loss of material at the edge without disruption of the cover. The front edge of the cover is weighted to prevent wind damage, and the whole protected with stone rubble as before. This technique has met with success in preventing the headward retreat of a landslide. The head scar now forms an overhang where material has continued to fall away at the base of the scar, presenting a further problem to be solved before the head area can be considered stable.

4.4 Drainage measures

The measures introduced are designed to improve the performance of standard surface and sub-surface drainage methods. The main problems associated with cut-off drains are blockage by debris from higher up the slope, and cracking due to movement or impact. To reduce these effects a simple steel mesh cover has been proposed which is hinged on one edge to allow access for clearance (Fig 6). A fully flexible design was not considered to be feasible but, where cracking of the structure is a danger, channels have been lined with short overlapping lengths of roofing felt, laid transverse to the direction of flow. Minor cracking will not then effect its operation.

French drains are another well-tried technique, but they are generally installed in ground that is not expected to move. Experimental drains have been laid in debris masses, wrapped in 'Lotrak' and wire mesh so that they retain their integrity even after considerable distortion has occurred. Such drains can be laid in a landslide track when further falls of debris are inevitable. The drain would then be buried, but continue to be effective in conveying ground water away from the debris mass.

4.5 Vegetation

The effectiveness of vegetation in combating certain types of instability is recognised. In relatively wet, tropical areas, natural vegetation will usually be reestablished very rapidly, but this may still leave substantial areas of ground exposed to erosion. Also, species which naturally establish themselves most quickly may not be the most effective or desirable for improving stability or for future exploitation for agriculture or forestry.

Local inhabitants make extensive use of vegetation as sources of firewood, animal fodder and building material. In many areas supply is barely able to keep pace with depletion. It is hoped that if vegetation can be established on landslides and a management system introduced, surplus produce could supplement local supply, leaving sufficient vegetation to continue to provide erosion protection.

A nursery has been established to raise potentially suitable species for transplanting to the experimental sites. Specialist assistance is being sought to manage this aspect of the research, for which appropriate species and different planting techniques are being investigated.

5. MONITORING OF EXPERIMENTS

Two preliminary site visits were made by TRRL to make a geotechnical appraisal of the mechanisms of failure that appear to be taking place, and to draw up a schedule of remedial measures for each experimental site. It is not possible to be certain about the mode of deterioration of a slide without observing it over a long period, therefore the monitoring techniques are designed to collect permanent records for subsequent analysis.

Ideally, each experiment should be installed and left to withstand several monsoons without interference. But, unavoidably some sites were commissioned before others, and there are cases where modifications had to be made to measures installed before and during the first monsoon. However, it is expected that all 21 experimental sites will be prepared in readiness for the next rains in June 1986.

5.1 Photogrammetric survey

The photogrammetric survey is the principal source of geometric data. TRRL has let a contract with The City University to take terrestrial photogrammetric photographs of each experimental site, from which will be constructed digital terrain surface models. The models will provide site contour plans, elevations and profiles. Models for different epochs, subtracted one from another, will be used to measure for example the distance over which a slope has retreated, or the volume of material lost. Preliminary measurements indicate that points can be plotted to within an accuracy of $\pm$ 10 mm over a distance of 30 m. The photogrammetric survey is repeated every year, ideally shortly before and shortly after each monsoon. Negligible movements of slopes take place during the dry season, therefore two records per year are adequate.

5.2 Periodic photography

The monsoon is the period of landslide activity, when slides can change their configuration almost daily. To follow these changes, colour photographs of the sites were taken about every two weeks throughout the 1985 rains. These photographs have demonstrated that radical changes within short periods are common. A further monitoring technique to be introduced this year is automated photography of a site. A fully automatic 35 mm camera will be installed at a site in a weather-proof box, and triggered by an electronic timer once every 24 hours. Four films will be sufficient to record a site during one entire monsoon season.

5.3 Rainfall measurement

Rain is the motivator of most landslide activity in Nepal, and there is a strong correlation between the intensity and duration of rain, and reactivation of unstable slopes. In 1981 some 227 mm of rain fell overnight in central Nepal, and caused more than one hundred minor landslides on the Dauney Hills sector of the East-West Highway. In 1984, 392 mm of rain falling over a 48 hour period caused more than one million pounds worth of damage to the Dharan road. The amount of rain at the experimental sites is being monitored by rainfall recorders, which give a continuous measure of rainfall intensity as well as volume.

6. ASSESSMENTS OF COSTS

To make rational decisions about the type and extent of remedial measures needed at a particular site it is necessary to understand:-

- (a) the geological processes at work on the landscape.
- (b) the mode of failure which may occur in the future.
- (c) the extent and severity of such failure and
- (d) the likely cost of appropriate remedial measures.

It is important that the costs of remedial work are related to the probability of a future landslide event. The estimation of this probability is extremely difficult to quantify, but to assist engineers in this task, cost information is being collected on all the activities of the maintenance gangs in clearing slides and installing remedial measures. Wherever remedial measures have been implemented, and most sites include several separate techniques, the labour, material and plant costs for each item are being measured separately. Costs are being measured in both financial and non-financial terms. To broaden their applicability such costs will be reported as (a) total labour hours (b) total operating hours for each item of plant and (c) total material quantities. The maintenance engineer will then be in a position to balance the likely cost of the remedial measures against the probability of a future landslide event by applying appropriate local rates to the data and comparing these with the costs of future maintenance computed in a similar manner.

7. ACKNOWLEDGEMENTS

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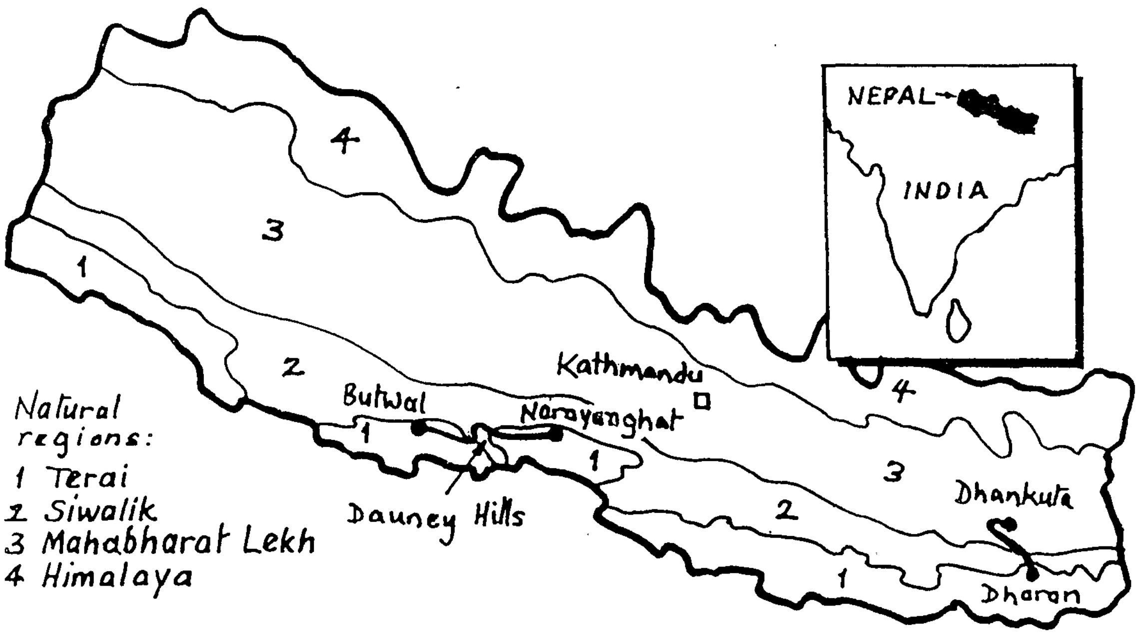

Fig. 1 Map of Nepal showing project roads

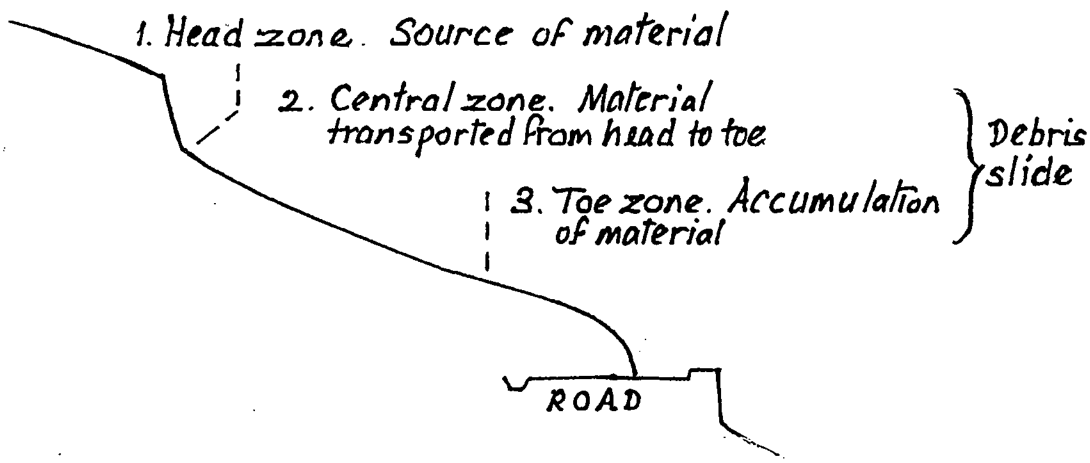

Fig. 2 Division of a landslide profile into zones

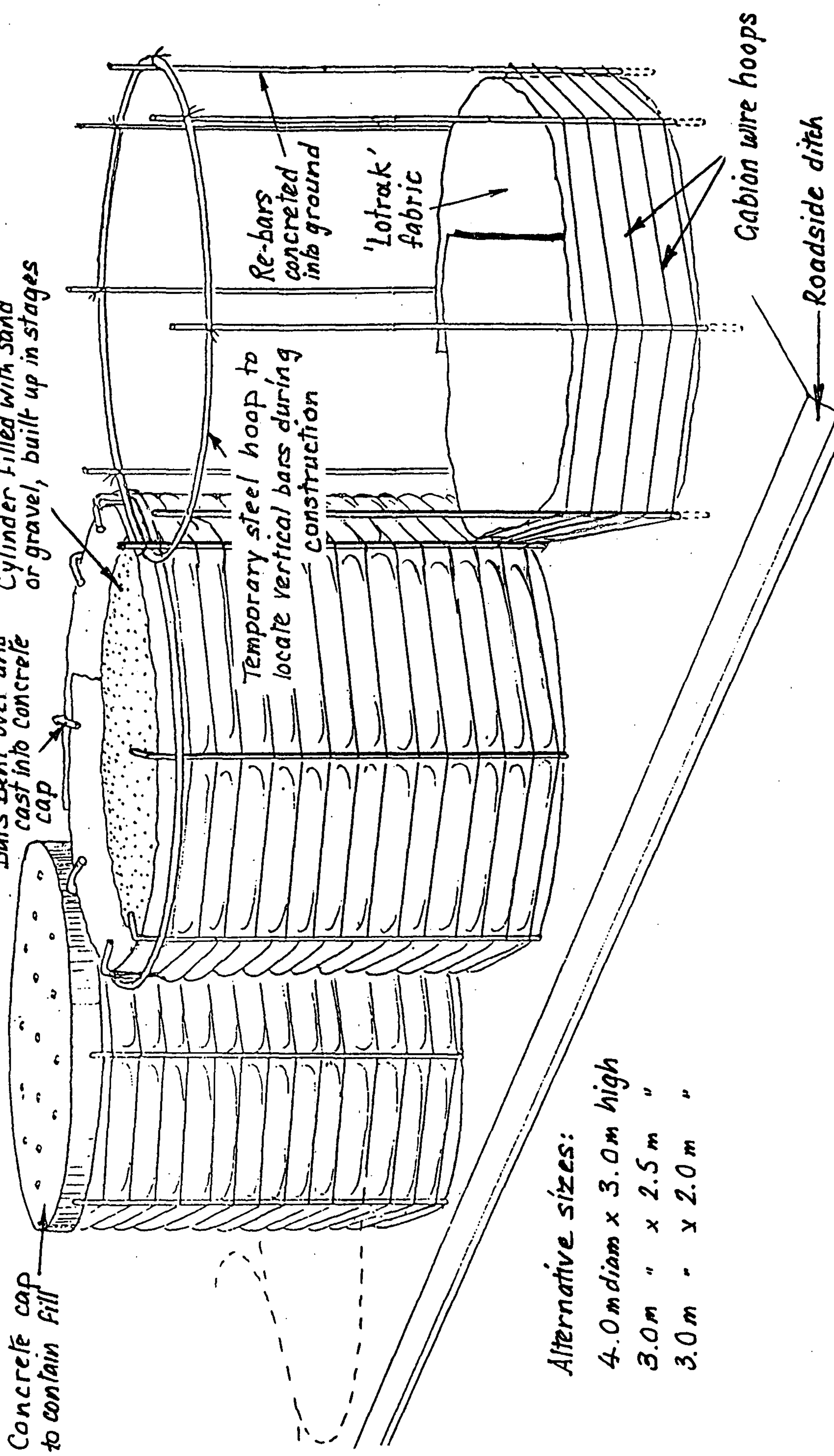

Fig. 3 Construction of cylindrical retaining wall

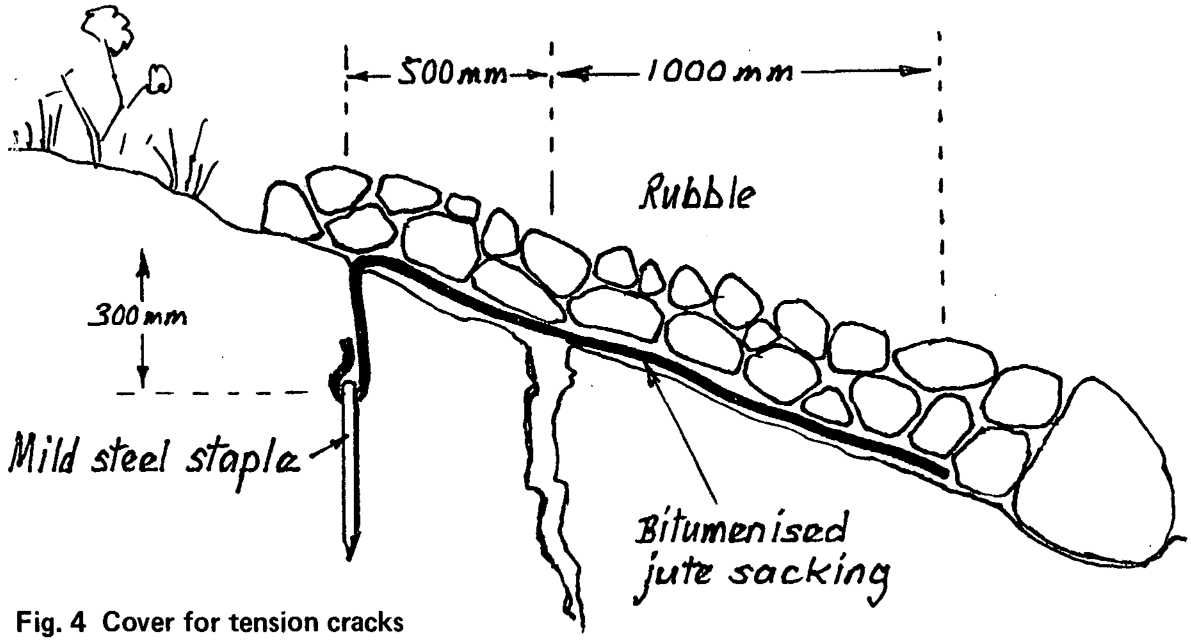

Fig. 4 Cover for tension cracks

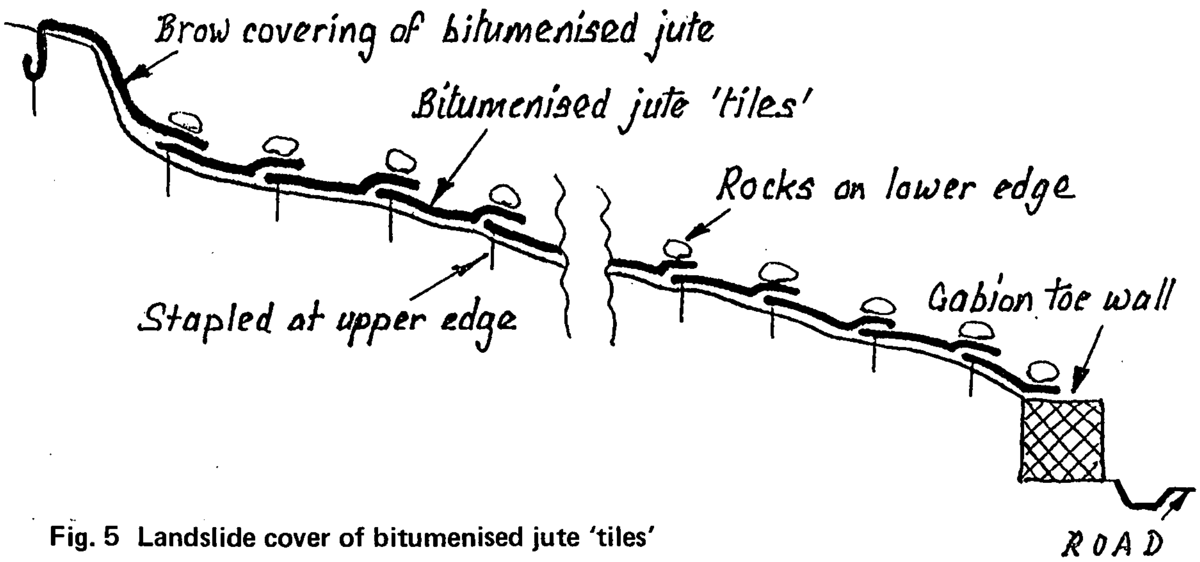

Fig. 5 Landslide cover of bitumenised jute 'tiles'

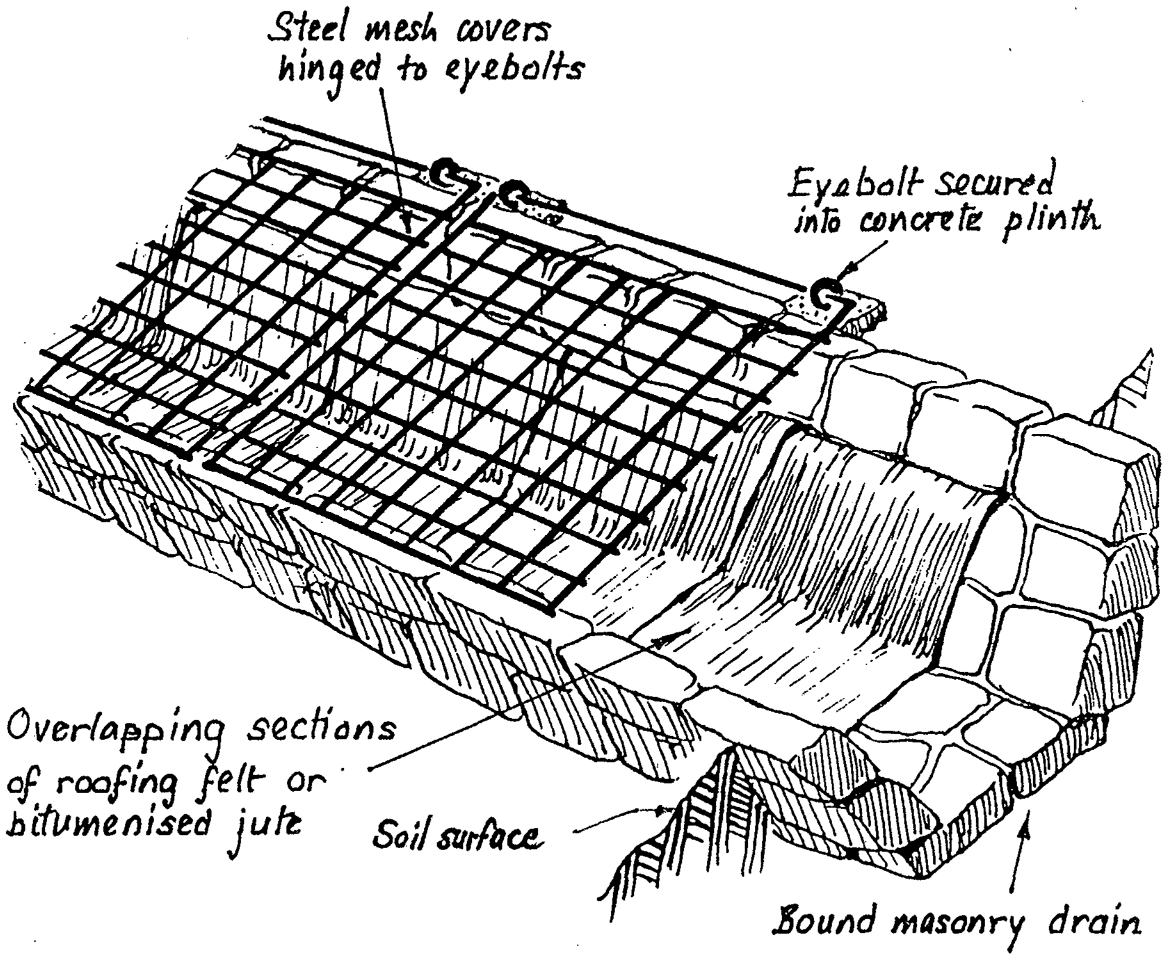

Fig. 6 Diagram of covered, lined cut-off drain

Plate 1 Modes of failure I

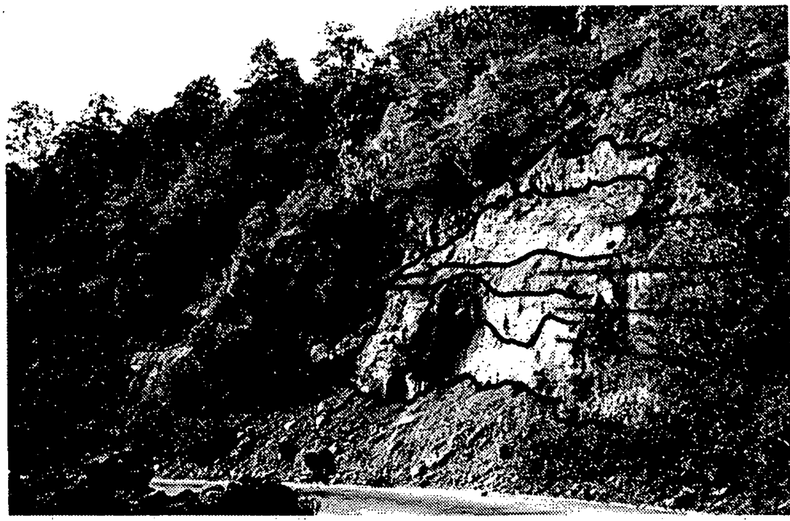

Plate 2 Modes of failure II

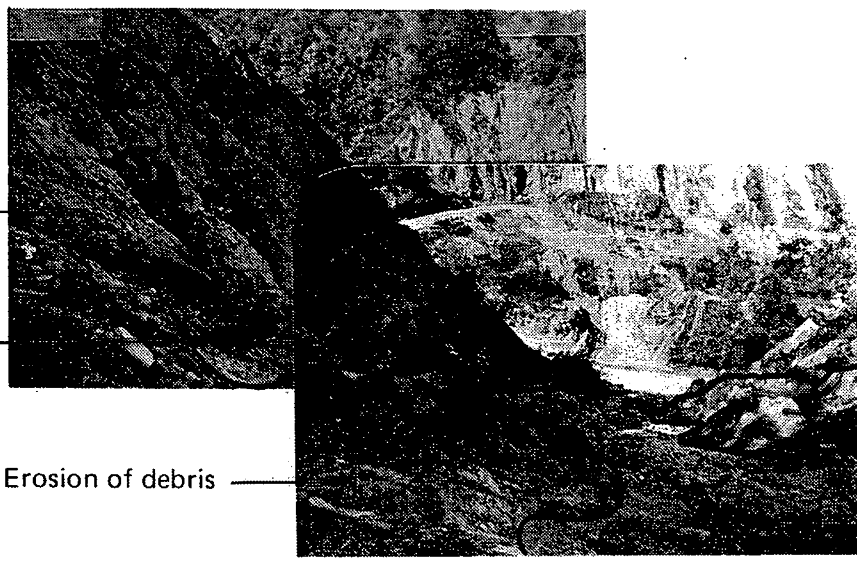

Plate 3 Modes of failure III

Plate 4 Failure of gabion under wet debris slide

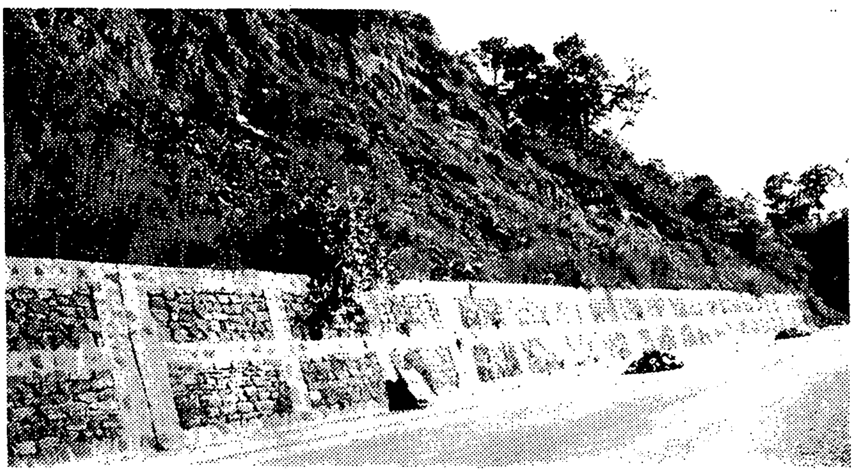

Plate 5 Mortared-framed masonry wall, performing successfully

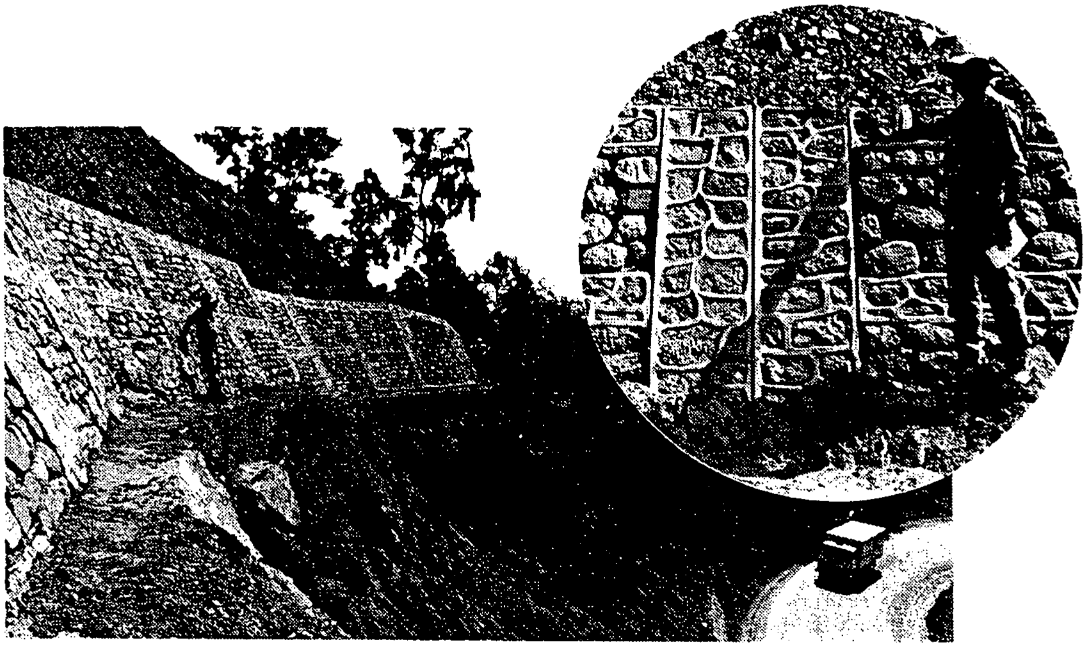

Plate 6 Mortared-framed masonry revetment, with experimental joints

Plate 7 Woven bamboo wattle fences, installed to stabilise soil slope and to establish vegetation

Plate 8 Wire fences, installed to stabilise wet, bouldery debris

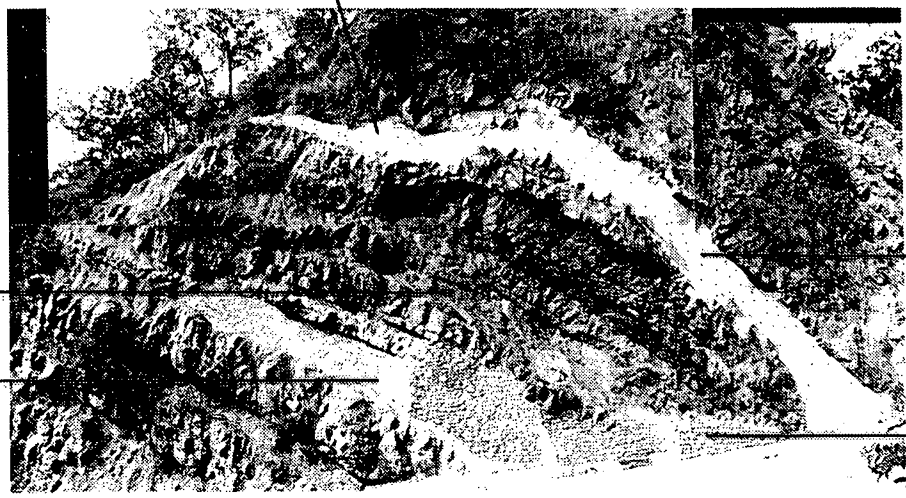

Plate 9 Multiple revetment experiment in a sandstone/mudstone sequence of rocks

Plate 10 Roofing felt cover at head of landslide