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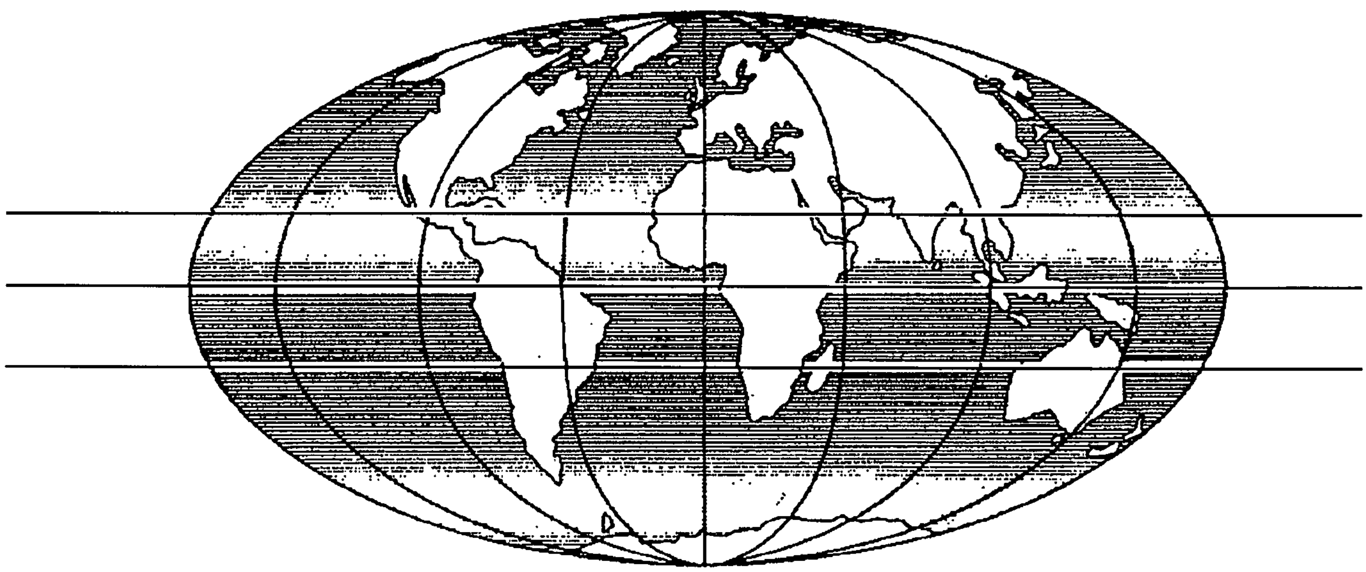

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COMPARISON BETWEEN AERIAL AND GROUND-BASED ASSESSMENTS OF ROAD EARTHWORKS FAILURES IN NEPAL

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ABSTRACT: A method of carrying out earthworks condition assessments on mountain roads, funded by the Overseas Development Administration (ODA), has been developed at TRL using rapid aerial reconnaissance and a relational database system. The advantages of carrying out this technique are compared with those of a conventional ground-based approach on an 84km road in Nepal. Close correspondence has been found in those areas where the database and interpretation developed by the two surveys overlap, and it is concluded that the TRL method has the potential to provide a cost-effective Maintenance Management System over long lengths of alignment, but it cannot replace the conventional method of engineering assessment at the site scale. A combination of the two approaches offers considerable benefits.

1. INTRODUCTION.

Heavy rainfall, steep slopes and highly weathered materials make the construction of roads in Asia's hilly and mountainous regions difficult and costly. Many of the problems relate to erosion and slope instability and dealing with earthworks problems takes up a major part of any engineering effort. In addition, design life can become shortened as heavy rains, floods, landslides and earthquakes take their toll. Consequently, roads are generally expensive to construct and often have a short life before a major programme of earthworks rehabilitation becomes essential.

Problems, which during design and construction may be difficult to predict, often become readily apparent during maintenance. The larger failures, that frequently result in recurrent road blockage or loss of formation, usually require slope redesign and capital investment in stabilisation, while smaller failures and erosion problems can be solved by recourse to relatively inexpensive measures, especially if these methods are employed on a pro-active basis. An evaluation of risk and the use of timely intervention within a programme of maintenance management is essential if maintenance budgets are to be used effectively to reduce repair costs. To achieve this, earthworks condition assessments are needed in order to plan the maintenance requirements. However, conventional engineering geological methods of walkover surveys, if carried out thoroughly, can be time consuming and costly. Also they tend to provide information about specific sites rather than a complete maintenance overview of a road. It is the contention here, therefore, that engineering geological surveys are most valuable in the assessment of specific sites, while aerial reconnaissance provides a more rapid means of recording and classifying maintenance requirements along the entire length of road alignments.

With this in mind, TRL have developed a new technique based predominantly on the computer analysis of specially commissioned vertical and oblique aerial photographs to provide a broad view of the interrelationships between individual sites and their surroundings (Figure 1). The flying and analysis, including the classification of earthworks slopes, can be carried out quickly and at relatively low cost.The photographs provide an instantly recognisable record of locations that can be used even by non-specialists. The system is capable of identifying factors controlling earthworks stability outside the immediate road corridor and it offers the opportunity for maintenance monitoring by reference to a computer database. Assessment and maintenance data are analysed and stored within an earthworks management system. The Earthwork Condition Assessment Technique (ECAT), and the means of applying the information to a maintenance strategy (the Earthwork Project Management System (EPMS)), are described in Heath and McKinnon (1994).

In 1993, storm damage to a road in Nepal provided an opportunity to compare the advantages offered by the new TRL technique with those of a conventional survey. Two surveys were commissioned to asses the extent of the damage and how best to deal with it; one, a conventional land-based survey carried out by a consultant, the other, TRL's ECAT system, carried out under ODA's research programme. This paper presents the results of the comparison. The ground-based method was undertaken by Scott Wilson Kirkpatrick (SWK) with the specific brief of recording flood-related damage and producing a preliminary design and cost estimate for prioritised road repair and protection works. The brief for the TRL study was to prepare a computer-based inventory of road earthworks problems for longer-term road maintenance prioritisation arising from all causes and not exclusively those that were related to the flood damage.Therefore, the comparison made in this paper is limited to the areas of overlap between the two surveys, namely the assessment of flood damage and required repair works.

2. STUDY DETAILS

The 84km study road follows a river valley alignment between Naubise and Mugling, forming part of the Prithvi Highway from Kathmandu to Pokhara, in Nepal. The road was originally constructed between 1967 and 1973. It was upgraded and widened to a 6.5m carriageway with 1m shoulders between 1989 and 1992 under SWK supervision. Because of the steep and, frequently, only marginally stable terrain, the widening method adopted was to extend the formation outwards on the valley side, where possible, rather than to cut further into the hillside. The majority of the upgrade was therefore achieved by the replacement and addition of gabion and masonry walls. Culvert extensions, longitudinal drainage and bio-engineering programmes also formed part of the improvements.

In 1993 unprecedented rainfall created exceptional flooding and caused considerable damage to the road where it had been built in vulnerable localities. Pavement damage or complete loss occurred along approximately 2% of the alignment length, but many slopes below the road were rendered unstable and therefore potentially dangerous. Three of the original bridges were washed away due to high floods and sediment loads in tributary rivers. The major causes of road failure included loss of wall foundation by river scour on soil slopes, slope failure from below due to toe erosion, and deep-seated failure through or beneath the road formation.

3. SURVEY COMPARISON

3.1 Cost and logistics

Both surveys were undertaken at approximately the same cost (£12-15K, excluding mobilisation and living expenses) and over the same duration (4-5 weeks), although SWK's brief included the preparation of a provisional cost estimate for repair within 2 weeks of mobilisation. The SWK survey, design and cost estimate required a total of 50 mandays. In addition, local technician mantime, amounting to slightly under 2 man-months, was used in the production of a site photographic record, a spreadsheet database and damage inventory drawings. The TRL survey was completed in 45 mandays. The cost of helicopter hire and photography amounted to only 15% of the total survey cost, thus illustrating the potential for low-cost applications of the technique if much of the expatriate mantime can be replaced by local staff.

As far as survey logistics are concerned, the SWK method suffers from the inevitable problems of site access in steep and often densely vegetated terrain. The TRL method depends entirely upon the availability of air transport for its photographic database, and if this is not available then the system cannot be used.

3.3 Problem identification and prioritisation

Determining which earthworks are in need of immediate attention is normally based on qualitative judgement. The method adopted by SWK followed the normal Department of Transport procedure used in Britain (DoT 1993). It was based on grading earthworks into three levels, but was modified according to the brief to suit the particular site conditions. The following levels of prioritisation were identified:

1) sites requiring repair prior to the next (1994) monsoon

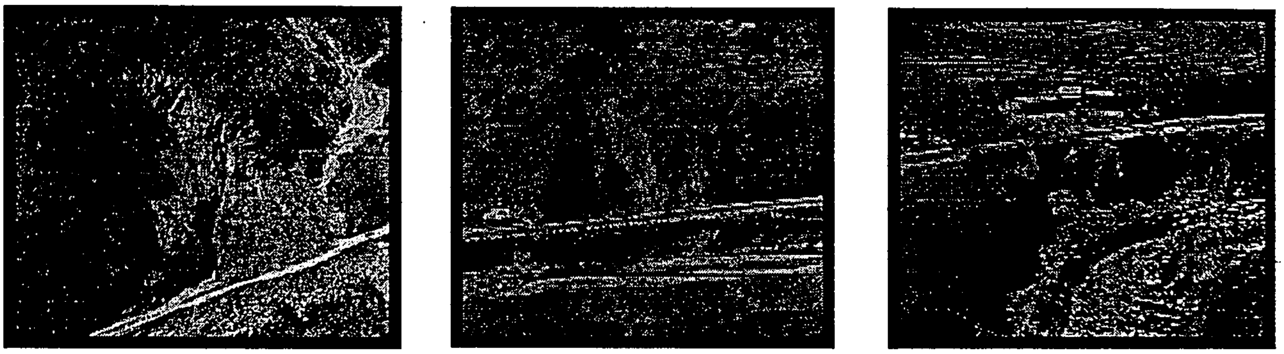


FIGURE 1. Aerial photographs of three types of earthwork problem. a) Major slope failure. b) Cut slope failure. c) Scour of river bank (terrace) below road.

season;

2) those sites for which repair works could be delayed until the following dry season (1994/5), on the expectation that it would not be possible to complete all the works within one dry season;

3) those areas where a potential problem exists but for which no short-term action, other than monitoring, is required.

The TRL grading system, based on the aerial overview backed up by ground verification, makes use of a more systematic form of evaluation applied over a larger area.The method places earthworks sectors (approximately 250m in length in this case) into three categories, A, B and C. However, the method of achieving this relies on a rating derived from the following four factors:

1) the potential danger to life that an earthworks slope presents;

2) the likelihood of a slope collapsing;

3) the effects on traffic and road useability should failure occur;

4) the relative cost of dealing with any failure.

The risk to road users (factor 1) need not be associated with any potential for earthworks failure. For example, runoff from a cut slope could cause a road surface to become slippery, thus representing a hazard to traffic. In determining the risk associated with earthworks failure (factor 2), it is also necessary to consider the implications of such failure with regard to how the use of the road would be affected and what repairs would become necessary, and at what cost (factors 3 and 4).

Each of these four factors is given a score, 1 to 5. This provides a four-dimensional matrix with 625 potential values for each earthworks section. Using look-up tables in the database the total score is simplified into three groups along the lines used by the DoT. Various weightings in terms of cost or risk are assigned to the look-up tables in order to arrive at the final categorisation. These weightings can be adjusted by a highway authority according to the emphasis that it places upon these factors. Thus, the authority can control the manner in which priorities are set by the system, and hence the allocation of funds for repair works.

Out of a total of 70 possible sites that were considered comparable between the two studies,TRL identified only three sites of likely flood damage that had not been recorded by SWK. A similar number had been identified by SWK and not TRL. Therefore, despite the differences in the methods of data collection, on an 84km road with more than 400 earthworks sections, there is very little difference in the results obtained. The overall error between the two methods of assessment is about 2.5%, thus vindicating both methods as complementary approaches.

The correspondence between the studies of flood damage sites that were given top priority for repair is more divergent. SWK identified 59 high priority sites and TRL identified 45, of which 34 were common. This departure is probably due to differences in the definition of the two priority classification systems.

3.4 Cause identification

Determining the cause of any earthworks failure is paramount to the design of its successful remedy. However, this frequently involves the interpretation of a failed condition that is often influenced by a complex range of factors which may not be immediately apparent, either from the air or from the ground alone. Clearly, the SWK survey was required to identify the most likely cause of failure before remedial works could be proposed, whereas cause of failure was not the immediate concern of the TRL survey. Of a total of 58 sites where a cause was diagnosed by both SWK and TRL, 47 instances were in close agreement. The results of this comparison are encouraging given the essentially remote nature of the TRL method.

3.5 Repair recommendation

A direct comparison between repair recommendations is of limited applicability because of the difference of scale between the two surveys. The TRL survey did not have the benefit of a site-by-site examination of failure mechanisms, likely foundation conditions, soil types and slope drainage. Consequently, the TRL recommendations for repair are only indicative and are generally insufficient for preliminary design and cost estimating. Nevertheless, the broad philosophy of repair works recommended by the TRL survey corresponded with those of SWK in 25 out of 29 comparable cases for the high priority sites. Again, this correspondence is encouraging.

Even with the benefit of a comparatively detailed site assessment, the SWK survey is not definitive in either its cause recognition or its repair recommendation, primarily due to the uncertainties over the depth below soil to intact rock. The survey recommendations were used extensively in the early stages of detailed design, but excavations for wall foundations frequently revealed unexpected soil and rock conditions. Consequently, in only 75% of cases were the repair recommendations carried from the survey stage through to construction without modification. Furthermore, approximately 10% of final repair locations had not been identified as either priority 1 or 2 by the SWK survey.

3.6 Reporting and database presentation

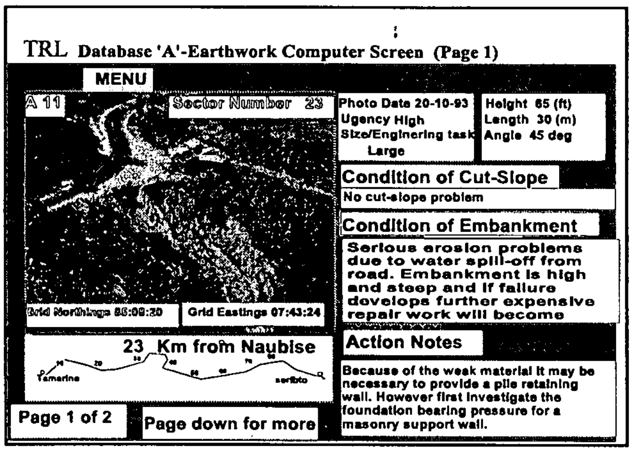
Figure 2 compares the methods of database presentation. That of SWK is orientated towards the preparation of a cost estimate for repair and the presentation of sufficient information to allow funding agreements to be made and detailed design to be pursued.

4. DISCUSSION

Given that the two approaches are entirely different, their correspondence is a promising result for the TRL method. Both methods have their advantages and disadvantages. The conventional method would have benefited from specially flown aerial photography allowing a more detailed inspection of the slopes surrounding the road corridor. The TRL method is of insufficient detail to propose site-specific repair works with accuracy, and would therefore benefit from a greater input of ground verification. As a result of this work the TRL method has been further developed to incorporate a larger element of ground survey and verification in areas of complex topography.

From the above discussion, there is clear advantage in combining features from both methods to form a road Maintenance Management System. The TRL method is a particularly effective means of collecting, archiving and instantly retrieving photographic data on roadside slope condition and provides a broad categorisation of earthworks and problem identification over large areas. The conventional method can then be employed to investigate ground conditions in more detail to confirm the priority categorisation and produce preliminary designs and costs for repair works.

This study has shown that much advantage can be gained from aerial reconnaissance supplementation. As the area of coverage of the enquiry increases, ultimately to that of a regional or national road network, the TRL method becomes more applicable and cost-effective as a means of gathering, analysing and managing slope condition data. The TRL method, therefore, derives more benefit from economy of scale for larger projects than the conventional method, both in terms of cost and duration. The resulting database is readily useable by non-specialists and can be easily updated as remedial or maintenance works are undertaken.



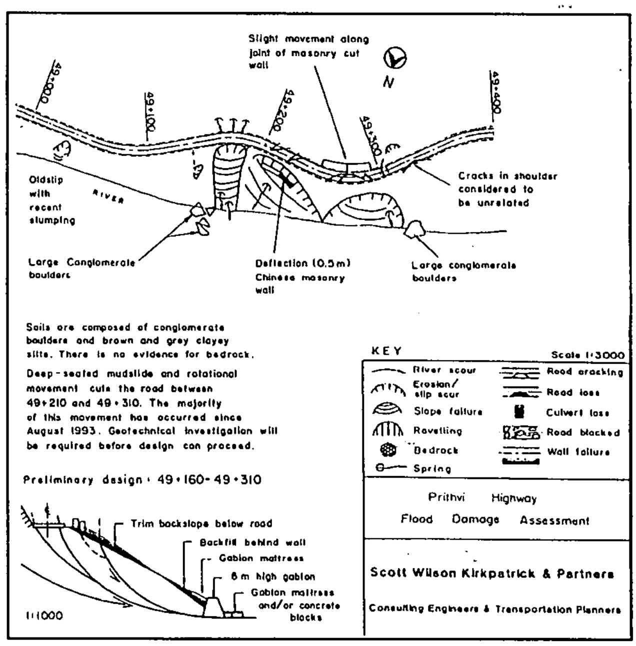


FIGURE 2. An example of data presentation in the TRL computer system (above) and consultant's report (right)

5. REFERENCES

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6. ACKNOWLEDGEMENTS

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