International Recovery Forum 2009

"Building Back Better and Greener"

26 - 27 January 2009, Kobe, Japan

South East Asia Community Access Programme - SEACAP

Applications of selected research outputs for the

Mitigation and Management of Crisis and Recovery Operations

Abstract

SEACAP is a poverty-targeted rural transport initiative. It is aimed at improving the sustainable access of poor people in rural communities to health, education, employment and trade opportunities, with projects currently in Vietnam, Cambodia and Laos PDR. SEACAP provides funding for applied research to solve rural access problems, disseminating information about the research outcomes to stakeholders, and supporting the mainstreaming of the solutions. SEACAP research is not specifically directed towards crisis and recovery operations. However, the principles of a local resource approach readily span both development and crisis engineering applications. This paper draws together four short technical notes. The technical notes are derived from the outputs of SEACAP and the UNOPS Community Access Programme in Sri Lanka. These outputs have direct application for mitigating and managing crisis and recovery operations. The subjects covered herein include:

i. Experience and techniques for risk and hazard assessment for managing mountain slope instability;

ii. Bio-engineering for road embankment and mountain slope erosion protection and stabilisation;

iii. The use of tsunami debris as material for constructing rural roads; and,

iv. The development of standards and specifications that allow engineers to construct roads with available materials.

Key words: Risk; Hazard; Slope Stability; Bio-engineering; Local materials; Standards and Specifications.

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- Slope Stability Hazard and Risk Assessment, SEACAP 21, Laos PDR,

  Hearn, Dr. G.J. and Hunt,T. (Scott Wilson Ltd) and Howell, J. (Living Resources Ltd);

- Bio-engineering for embankment and slope erosion protection and stabilisation, SEACAP 19 and SEACAP 21,

  Howell, J. (Living Resources Ltd)

- Use of tsunami debris for reconstruction in Sri Lanka, UNOPS/CAP,

  Gleeson, F.; and,

- The Development of Standards and Specifications that Allow Engineers to Construct Roads with Available Materials, SEACAP 3,

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Introduction

Sustainable and affordable rural access is a necessary precondition for expanding social and economic opportunities for rural people, thereby enhancing pro-poor growth and poverty alleviation efforts. SEACAP[1] is a poverty-targeted transport initiative within the global Transport Knowledge Partnership[2] (gTKP) framework. It is aimed at improving the sustainable access of poor people in rural communities to health, education, employment and trade opportunities, with projects currently in Vietnam, Cambodia and Laos PDR.

SEACAP funds **applied research** to solve rural access problems, **disseminates** information about the solutions, and supports their **mainstreaming**. SEACAP supports the uptake of low cost, proven solutions for rural access. Focused on the needs of the poor, it aims to maximise the use of **local** resources, including labour, materials, enterprise and most importantly ingenuity.

SEACAP is primarily funded by United Kingdom's Department for International Development (DFID) and enjoys close links with governments, World Bank (WB), Asian Development Bank (ADB), the European Union (EU), and the United Nations Agencies (UN).

SEACAP work is not targeted to crisis and recovery situations. However, the principle of adapting engineering designs to use local materials does have potential application for the management and mitigation of crisis and for recovery operations. This paper looks at four areas of SEACAP and related work carried out by UNOPS. The areas are hazard and risk assessment, bio-engineering, use of available materials and enabling standards and specifications. A common theme is working with local and available resources to cost effectively solve engineering problems.

Assessing potential hazards and consequent risks is a logical first step towards managing and mitigating any potential problem. SEACAP has developed this approach as the basis for managing unstable slopes in the mountains of Laos PDR. This approach enables scarce resources to be rationally focused on the most serious problems in the most cost effective manner.

Erosion often is the trigger to mountain slope and road embankment instability and failure. Bio-engineering is a cost effective approach for preventing erosion and thus stabilizing slopes and embankments. In mountains, the local environment can be highly variable. Plant species that are suitable in one place may not be so in another nearby location. It is necessary to identify species and planting systems with soil stabilizing properties specific to local conditions. SEACAP research projects in Laos and Cambodia have found effective bio-engineering methods to control erosion and increase stability. Bio-engineering also has other benefits such as improving the local environment as well as employment generation and livelihoods potential when using plants that have economic value.

In Sri Lanka, the year-2004 tsunami left considerable debris in its wake from the destroyed buildings and structures. This debris can hamper access and is a potential source of pollution. At a minimum it must be cleared and safely disposed. The debris often includes a variable component of brick, concrete and stone. These materials can be processed for use in bases for access roads. The UNOPS[3] Community Access Program in Sri Lanka has demonstrated the effectiveness of this approach. Benefits include improved local access while reducing the costs of road construction and debris clearing, as well as employment generated from processing the materials and construction.

Engineers are required to follow official standards when designing infrastructure. Standards should assure two requirements. One requirement is that the asset is built to a “fit for purpose”

[1] http://www.seacap-info.org/

[2] http://www.gtkp.com/

[3] http://www.unops.org/SiteCollectionDocuments/Factsheets/English/MEO/OC/MEO_OCFS_LKOC_EN_88.pdf

quality. The other, is that the life cost of the asset is minimized. Using available rather than imported materials can provide reduced costs for both construction and maintenance. Therefore standards and the accompanying specifications need to enable the use local resources and available materials. SEACAP has developed comprehensive standards that achieve this for Low Volume Rural Roads (LVRRs).

Slope Stability Hazard and Risk Assessment, SEACAP 21[4], Laos PDR

Hearn, GJ and Hunt,T (Scott Wilson Ltd) and Howell, J (Living Resources Ltd)

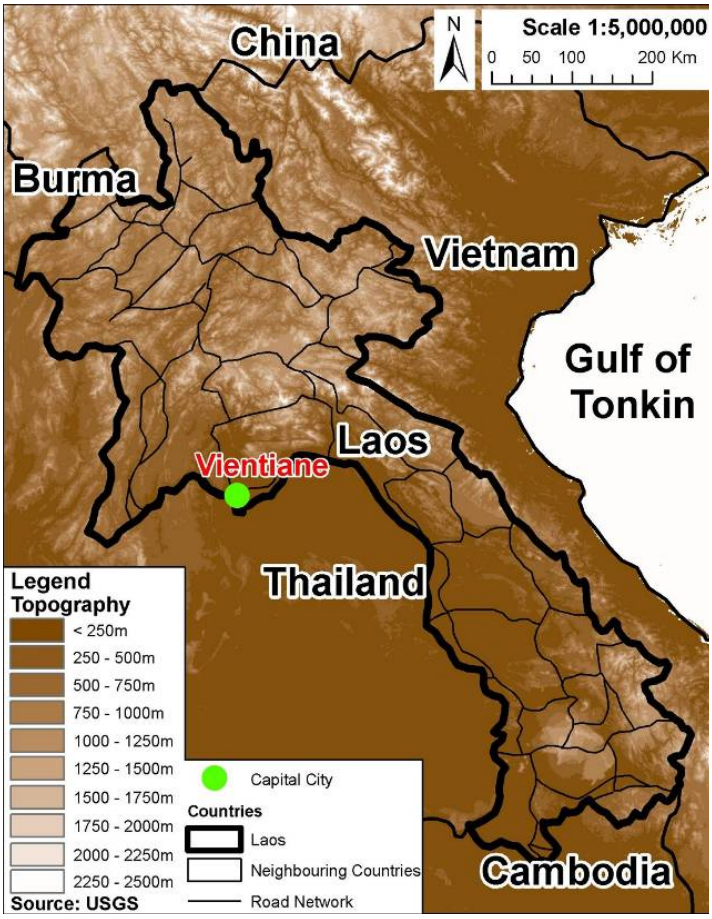
Abstract

The project has involved the conduct of slope stabilisation trials, a feasibility study for a national slope management programme and a series of activities aimed at mainstreaming project outputs. The stabilisation trials focused on locally sustainable technologies and materials, and included bio-engineering measures and geotechnical works. The trials demonstrated that successful slope management interventions at low to moderate landslide risk sites can be achieved even with low construction budgets. An adequate understanding of the nature of the slope hazard, however, is a prerequisite. The feasibility study involved the development of an inventory of landslide hazard and risk along selected sections of the national road network, and this assisted in categorising landslides for prioritisation. The components of a national slope management programme were proposed and designed, and it was concluded that such a programme was technically feasible and economically justified when the costs of traffic delays were taken into account. Mainstreaming of the outputs is in progress.

1. Country setting

Lao PDR (Fig 1) has an area of 236,800 km^2 of which more than 75% is mountainous, with elevations usually varying from 500 to 2000 metres above sea level. The country is roughly 1000 km long with a width varying from 140 to 500 km.

Figure 1: The topography of Lao PDR



The geology of the country is described by Workman (1977) in relation to the region as a whole. In Laos much of the underlying geology is extremely old and comprises metamorphic, intrusive and sedimentary rocks. The outcrop pattern is complex, but some of the more persistent rock types include phyllites and schists (metamorphic), granites (igneous intrusive) and limestones (sedimentary). Rock masses at surface are often intensely folded and faulted, and weathering has given rise to the development of deep weathering profiles and residual soils, especially on the metamorphic rocks.

The climate is dominated by the Asian monsoon. The rainy season is associated with the south-west monsoon between May and October, and can be extended by humid air movements from the south-east at either end of this period.

[4] http://www.seacap-info.org/?mod=home&act=pdesc&pid=22

Rainfall in excess of 100 mm in 24 hours is not uncommon but this depends very much on the location. In high rainfall areas such rainfall may occur several times a year, in drier areas it can be expected on average every three or four years. The mountain areas exert strong physiographic influences on rainfall distributions that are further complicated by the paths of cyclonic storm events. At the southern and northern points of the project study area described below annual totals are 3,900mm and 1,430mm respectively.

2. Slope Stability and the Lao Road Network

Landslides have a frequent impact on the road network of Laos. The majority result in partial or complete temporary blockages to short sections of road. These failures can give rise to several hours of delay to traffic and also require ongoing investment in debris clearance, repairs to walls and roadside drains, and road pavements. Between 50% and 80% of annual expenditure on emergency road repair costs are due to landslides.

The slope failure illustrated in Figure 2 below is common on the mountain road network and poses relatively low risk, in as much as the outcome is only partial blockage to the carriageway and materials can be removed relatively quickly if plant is available to do so.

Figure 3 illustrates the case where part of the carriageway has been lost as a result of movement on the slopes below. This hazard poses significant risk to the operation of the road, as it can be difficult and expensive to rectify and can ultimately result in the loss of access. These failures are less frequent on the road network and they are often associated with the progression of large naturally occurring landslides on steep valley side.

Figures 2 and 3 Typical Slope Failures Above and Below the Road Respectively

3. The SEACAP 21 Slope Stability Project

3.1 Project programming and objectives

First Stage

The SEACAP 21 project was executed in three stages. The first stage ran from October 2006 to September 2008. The principal objective was to implement a series of slope stabilisation trials maximising the use of local materials and technologies along Road 13 North and Road 7, both located in the mountain region to the north of Vientiane. In total 13 sites were selected for implementation works. The selection was based on the preference to include a range of hazard types and risk scenarios, as well as the need to keep within the available construction budget of US$250,000.

Topographic survey, engineering geological mapping, ground investigation, design, procurement and construction supervision were implemented, and the performance of the works was reviewed over two wet seasons. Manuals covering slope management and maintenance were prepared as part of the dissemination strategy.

Second stage

The second stage of the project implementation involved the development of a feasibility study for a national programme to manage slope stability within the road network (Hearn *et al* 2008). This study built on the findings of the first stage work and collected a database of landslide hazard and risk derived principally from a road inventory. It examined the costs of road impacts, both in terms of physical repair costs and traffic delays brought about by road closures. The institutional structure and functionality of the Lao PDR Ministry of Public Works and Transport (MPWT) and other related and relevant bodies were also reviewed and recommendations for strengthening the road sector in relation to the management of slope stability hazards were provided along with a programme for implementation. A landslide hazard and risk index system was developed for the landslide inventory, based on hazard (magnitude and probability), vulnerability and value following international definitions (Crozier and Glade 2005). A simplified system was also developed and presented in the feasibility study report.

Third stage

The third stage of the project involves the mainstreaming of findings and outputs from the first two stages, principally in conjunction with the MPWT and the National University of Lao (NUoL).

3.2. Project experience and results

The inventory of roadside slopes indicated that 70% of slope failures affecting the road network takes place above the road, and of these 60% are considered to be low risk with the majority being shallow failures into the roadside drain or adjacent carriageway. These shallow failures predominantly occur in soils and highly weathered rock. In the former case, these involve soils derived from in situ weathering (residual soils) or colluvium (previous landslide) deposits. Those failures taking place in weathered rock were often observed to have occurred along relict structural discontinuities (joints and bedding) within the weathered rock mass. Only 3% of all recorded landslides were judged to have affected the entire road carriageway, i.e. involving complete failure of the hillside. Only 4% of all recorded landslides were judged to have taken place as structurally-controlled deep-seated slope failures within unweathered rock.

The slope instability features selected for trial slope stabilisation works on Roads 7 and 13 North varied between relatively shallow landslides within cut slopes (low risk) through road fill retaining wall failures to areas of entire carriageway failure (high risk). Bio-engineering measures comprised principally the planting of grasses and shrubs, often in conjunction with surface drainage and small-scale retaining and slope protection structures. The geotechnical measures comprised mainly earthworks and gabion and masonry retaining walls. At those high risk sites of deep-seated failure involving movement of the entire carriageway, a combination of local improvements (localised walling and drainage) and slope monitoring was implemented. The slope monitoring was undertaken to detect and record ongoing slope movements, thus assisting in longer-term decision making over higher-cost slope interventions.

The trials on the whole proved successful and allowed several conclusions to be drawn, confirming that experience from elsewhere applies in the context of the Lao road sector.

First, that the use of low-cost measures can be successful in resolving most sites of low to moderate risk, i.e. the majority of landslides along the national road network.

Second, that engineering geological mapping, supplemented with trial pits and carefully selected boreholes, advances the interpretation of the extent, depth and mechanism of the landslide hazard, thus assisting in the development of remediation works.

Third, that it is important to include comprehensive specifications in the construction contract documents and to ensure that the contractor adheres to these.

Fourth, that the site supervision staff should have the competence and authority to vary the works to take account of the variable ground conditions uncovered during construction. The control of drainage is a key element in all trials, as is the safe management and disposal of construction spoil. These items need to be covered sufficiently in both the specification and the bill of quantities.

Fifth, it is important to ensure that the technologies proposed are within the capability of the contractors likely to be bidding for the works. The pre-bid meeting is a key opportunity to discuss designs, specifications and construction methods. In the case of the project stabilisation trials the contractor made maximum usage of local skilled and unskilled labour, and this is an important entry point to engage the local population in works implementation and maximising their participation in longer term land use management, especially with regard to drainage and erosion control.

The feasibility study concluded that the recently revised structure of the MPWT was adequate to engage in an improved slope management programme, though resources would require strengthening, particularly in engineering geology. The technical feasibility of introducing both proactive and reactive slope management improvements is demonstrated by the work undertaken in association with the stabilisation trials and through other road improvement projects and MPWT activities in the country. The economic feasibility in terms of engineering costs associated with pre-emptive works versus anticipated engineering gains through improved slope management appeared marginal. However it was demonstrated that the costs of traffic delays and holdups on the road network due to landslides can be significant, especially for periods in excess of 3 hours, and the overall conclusion of the feasibility study was that the slope management programme should be implemented.

The risk assessment matrix developed for the landslide inventory proved to be difficult to apply in practice due principally to the uncertainties involved in the assessment of likelihood and vulnerability. Likelihood relates to the probability of slope failure or ground movement over a given period of time, and this can be extremely difficult to assess without landslide movement records and monitoring data. Vulnerability, i.e. the potential degree of loss of a given asset, such as the road pavement or a retaining wall for example, will be dictated to an extent by the depth, speed and extent of ground movement, and these factors are also difficult to define on the basis of cursory inspection without more substantial engineering geological information.

Although the list of priority sites for future investment was based on this risk assessment, a simplified classification procedure was included in the reporting, based on a judgement of actual or expected consequence of hazard (Table 1). The assessment of risk is central to the prioritisation of investments in slope improvement and mitigation measures, and it is important to ensure that a reliable and workable system is in place.

Table 1 Actual or anticipated consequence of hazard

Actual (current condition) or expected consequences (without mitigation)	Risk ranking				
	1	2	3	4	5
Road completely lost (including road subsidence greater than 1m)	✓				
Road partially lost		✓			
Road completely blocked		✓			
Road subsidence less that 1m		✓			
Road partially blocked			✓		
Productive agricultural or forest land lost or destroyed			✓		
Walls damaged or slope drainage blocked or damaged				✓	
Roadside drainage damaged or blocked					✓
Continued erosion without destroying vegetation cover					✓

Ranking

1. Top priority, emergency measures required immediately; buildings may need to be evacuated.
2. High priority; realignment may be necessary.
3. Moderate priority, but some temporary remedial measures are required immediately, such as slip debris clearance, emergency road signing etc.
4. Low priority, but some temporary remedial measures are required quickly, such as slip debris clearance.
5. Least priority, but should be tackled as soon as possible under routine maintenance.

3.3 Mainstreaming project outputs and recommendations

Among the key outputs from this work are the two manuals that cover slope management, and roadside slope and maintenance activities. They are Lao-specific though they can be applied, probably with some contextual modification, to neighbouring countries where topography, climate and geology are similar. The third stage of the project demonstrated the use of these manuals in the field with MPWT staff, and this should be regarded as the first step in the mainstreaming process. However, it is considered that the key to mainstreaming of outputs will be in the implementation of the national programme to manage slope stability. It is recommended that this involves the development of a country-wide landslide inventory that takes into consideration landslide hazard and risk, together with the implementation of priority improvements that allow mitigation options to be trialled further, incorporate training and capacity building in landslide management in general, and engineering geological assessment in particular.

4. Conclusions regarding the management of landslides

Several landslides on the Lao road network represent deep-seated and complex failures, and these require engineering geological assessment and ground investigation in order to be able to assess the hazard they pose and devise remedial measures with confidence. This presents a significant knowledge gap in many countries of the SEACAP region due to limited technical and financial resources, and poses a serious potential hazard in times of major national crises (such as those that might result from severe storm events).

The findings of the stabilisation trials under SEACAP 21 highlight this issue with regard to the deeper-seated landslides along Road 13 North. This issue also has implications for the development of hazard and risk assessments in such cases. The majority of landslides affecting the road network pose relatively minor levels of hazard and risk, and can be assessed with reasonable confidence. The larger and deeper failures pose significantly higher risk but the current lack of information concerning their depth, mechanism, rate and frequency of movement makes it difficult to assess these hazards fully in terms of potential risk. As landslide data are collected, it is anticipated that this issue will begin to be resolved, but in the meantime a simple approach based on the format in Table 1 is recommended. This approach is judgemental, and strengthening in engineering geological assessment is considered to be a key requirement.

Agencies involved in emergency response following, for example, extreme weather conditions, need to have access to lists of:

- locations of highest landslide risk; and
- emergency works that should be put in place in the event of a landslide.

In Lao PDR it is the MPWT that undertakes emergency responses in relation to landslides that affect the national road network. The MPWT has established mechanisms in place for emergency measures but these could be strengthened through an improved record of landslide sites, together with an indication of locations that could become high risk landslide locations in the future. The manuals prepared by this study provide the basis for developing priority remedial works, either in a pre-emptive capacity at high risk sites or as reactive measures following an emergency event. The expansion of slope monitoring systems in locations of known landslide risk will assist in the identification of accelerating movements, thus providing some opportunity to implement remedial action. However, during emergency events, catastrophic failures can take place with little or no warning. The development of a risk-based landslide inventory might allow some of these locations to be identified in advance, but there will remain significant uncertainty, particularly in areas where geological information is limited.

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Bio-engineering for embankment and slope erosion protection and stabilisation

Howell, J (Living Resources Ltd)

Bio-engineering and what it offers

In the civil engineering context, bio-engineering is the term given to the use of live vegetation in the protection of earth surfaces. This is a well documented approach that has been utilised in many situations on steep slopes (e.g. Schiechtl and Stern, 1996) and in riverine conditions (e.g. Schiechtl and Stern, 1997), and appraised in some depth by both industry (e.g. Coppin and Richards, 1990) and academic assessors (e.g. Morgan and Rickson, 1995). In certain situations the use of plants is augmented with small scale physical structures, such as wattle fencing, particularly for soil conservation. Certain plants have been widely used in slope protection, the best publicised of these being vetiver grass (see www.vetiver.org). In general, however, the use of live vegetation in engineering involves a combination of grasses and higher plants (shrubs and trees), propagated by methods appropriate to both the function for which they are being used and the local ecological conditions.

It is important to understand that live vegetation lacks the predictability that is usually sought in civil engineering materials, and is also weaker than the harder materials that are generally employed (particularly stone, concrete and steel). For these reasons bio-engineering needs to be integrated carefully with other engineering measures, or deployed where it serves its best purpose: the extensive protection of earth slopes against erosion. Plants and their roots protect earth slopes through a combination of armouring the surface and reinforcing the soil. Since erosion is a surface effect (the wearing away of a soil surface), preventing it is often a key part of the stabilisation of natural or man-made slopes. If the surface is protected, undermining does not occur that might lead to the failure of a mass of material or a physical structure. However, landslides in mountainous areas may still occur in certain situations without erosion as an initial factor.

Project experience

Slopes

SEACAP investigated the use of bio-engineering as a protection measure for earth slopes in two different extreme environments in the Mekong river basin of south-east Asia. The first[5] of these was on the stabilisation of steep highway slopes in the mountainous areas of Laos. Extensive road construction in the poorer rural areas of the Lao PDR had led to the identification of a need for effective ways to stabilise and protect slopes over considerable areas. This is true for main highways, low traffic volume feeder roads and access roads to other large infrastructure. Slopes are typically composed of deeply weathered residual soils, subject to possible erosion and occasional mass landslide failures. There are also instances of weak colluvial slopes, often as a shallow covering over steep, semi-competent rock masses. The humid tropical climate gives a long wet season, though with a complex pattern of damaging rainfall events that is not yet fully understood. The SEACAP project working on slope stabilisation in Laos undertook a number of trials of the options available to improve slope protection. These were informed by experience in other mountainous parts of Asia and elsewhere, but particularly from Nepal (best summarised in Howell, 1999).

Embankments

[5] Project SEACAP 21 - http://www.seacap-info.org/?mod=home&act=pdesc&pid=22

The second of the SEACAP project[6] investigations was in connection with the stabilisation of earth embankments in the floodplain areas of Cambodia. It is generally recognised that the banks of major channels require either hard physical measures or extensive areas of riverine forest to act as a buffer zone. These are not conducive to protection using bio-engineering, but other embankment slopes often are, in areas with lower rates of regular water flow. The rural road network, which is the only means of movement on the inhabited and intensively farmed floodplain, can become subject to serious levels of embankment erosion in years of high floods. These do not occur very often – perhaps not more than once a decade on average – but when they do, flood water from the Mekong can inundate very extensive areas. During the weeks that it takes for the floodwaters to subside, strong winds can cause considerable wave damage to the earth road embankments that run across the flooded land. The SEACAP project examined the possibilities of better use of vegetation in averting this damage, as well as in reducing flow velocities where embankments are over-topped.

Project results: mountainous slopes in the Lao PDR

The project remit was to assess the use of low cost techniques to explore the critical limits of slope engineering at low costs. The project adopted minimal designs, which were observed over two wet seasons. Although it was difficult to explain to observers that in experimentation a failure can be as useful as a success, the occurrence of minor partial failures at some sites meant that the project developed a better understanding as to where the limits of low cost methods lie in some of the environments and with some of the materials that were being investigated. An approach using "safer" methods and undertaken using more robust, higher cost structures, would have meant never knowing how far the designs were above the critical limits in both factor of safety and cost.

The project demonstrated that the revegetation of slopes cut in original ground can be achieved in the Lao mountain environment with lines of planted grasses, using locally available species. A number of widely available plant types appeared to perform well, but the trials confirmed a need for them to be selected carefully. It was clear that harsh, stony slopes do not revegetate quickly with sizeable plants, even in the humid tropical environment of Laos that is obviously favourable for plant growth. A greening up may occur through the rapid germination of shallow-rooting herbaceous plants, but this does not have adequate strength to resist erosion in intense rainfall.

Engineering staff often misunderstood the difference between revegetation works designed using engineering principles to add to the strength of the soil, and revegetation purely to turn a bare slope green. It was also shown that there are many appropriate species for the use of "Alpine" bio-engineering techniques such as brush layers, palisades and live check dams (of the type particularly recommended by, for instance, Schiechtl and Stern, 1996). Most of the species that were found to be useful for bio-engineering in Laos also have recognised economic uses, which means that there can be associated livelihoods benefits for rural people in the vicinity of work sites.

The Lao trials were undertaken through a formal contracting arrangement, following strict government procurement rules. Although the works were implemented more or less according to plan, clear problems were identified with regard to the contractors' lack of understanding of the new materials with which they had to work, particularly when they were supervised by engineering staff who were themselves new to the methods being adopted. The fact that the bio-engineering measures tested in the trials were successful under all of these constraints, adds to the conclusion that they offer useful tools for civil engineering in these situations; but it also demonstrates that considerable care and investment are needed in their introduction.

[6] Project SEACAP 19 - http://www.seacap-info.org/uploads/File/SEACAP%2019-001%20Road%20embank%20erosion%20TP-6-Final-F.pdf

Project results: floodplain embankments in Cambodia

The SEACAP project that examined the protection of Cambodian floodplain embankments was an investigation only, and did not involve field trials. It found that the thousands of kilometres of roads on the flood plains have been built to standard designs that have rarely included adequate provision for the dynamic environment in which they lie. There have been limited uses made of vegetation in the protection of earth slopes, or indeed of any protection. Most of what has been done is intended to prevent erosion from rainfall, but it has often not been adequate even for this. Although the government has sets of standards for all types of roads, they tend to have been developed on the basis of designs for less severe situations, and do not include proper specifications for the protection of earth embankments.

Some sections of existing road embankment plantation were examined. These typically consisted of either grass planting using turfs (or “sods”), or a combination of seeding and mulching. It was not possible to tell from field observations outside of an extreme event, as to whether these would be adequate to prevent erosion from wave action under a prolonged period of inundation. Other embankment planting involved a number of species of trees. While these have other benefits, it was clear that they alone would not be enough to stop wave erosion during bad floods, particularly where tree canopies give surface shade and restrict ground cover vegetation.

There was, however, no doubt that the only feasible way forward in terms of affordable embankment protection must lie in an appropriate form of vegetation cover. A very broad estimate suggests that at least 10,000 km of roads are potentially at risk from major Mekong floods. This length increases annually with new construction by a number of agencies. In the severe year-2000 flood, it was estimated that there had been major damage to 1,800 km of national roads and 820 km of secondary and provincial roads, and to 60 percent of the local roads on the flood plains; the total cost of repairs to public infrastructure amounted to around US $ 47 million. The wider implications are more difficult to assess, particularly the consequences of losing road access at a time when it is most needed. In the year-2000 flood, it is estimated that about 3.4 million people were affected in twelve provinces. Since floods of this magnitude occur only about once in ten years, to be feasible a surface protection system must be cheap and applicable over very extensive areas. Only live vegetation fits the criteria.

Recommendations on possible uses

Bio-engineering provides an approach that is intrinsically sound and beneficial to the environment. It is an essential part of civil engineering where there is a need for the protection of slopes and other soil surfaces, on either a routine of occasional basis. The two strands of the SEACAP bio-engineering studies show that these techniques can be used to avert crises in two main ways.

- The control of erosion and enhancement of the stabilisation of steep slopes. This can contribute to a reduction in landslides in mountainous areas, which occur mainly when there are particularly intense rainfall events in areas with weak or disturbed geology. Landslides both damage infrastructure and also cause blockages of roads; blockages can have serious social implications at times of crisis, as well as the more obvious economic disruption. The actual bio-engineering methods used are based on either lines of planted grasses or on structures made from hardwood cuttings.
- The protection of earthen embankment slopes, particularly where they are subject to very occasional but very intense physical forces during major flood events. The judicious use of appropriate, “engineered”, plant cover over extensive lengths of embankments would greatly increase the chances of the embankments remaining intact at a time of crisis, when they are most needed. This would typically involve an arrangement of shrubs or small trees at a wide spacing, interspersed by a dense cover of large grass clumps.

Bio-engineering measures are not an approach to be taken up in a crisis environment, but in the rehabilitation afterwards where the aim is to mitigate the effects of future crises. Live vegetation provides a low cost form of slope protection, and that is why it is used so widely in the control of damage to earth surfaces. However, it takes between two and ten years to achieve full protection of a slope, and in some circumstances regular maintenance may be needed to ensure that the desired benefits are obtained. Bio-engineering has promise, therefore, but only for organisations with a long term vision and that are able to devote a relatively low but sustained level of resources towards the reduction of the effects of sporadic but potentially devastating natural events. In some institutional settings, the relaxation of political will in the long gaps between major disasters can lead to a reduction in resources that might make it difficult for implementing agencies to maintain slope protection to the standard that is necessary when a crisis occurs. In particular, as engineering agencies have limited experience with vegetation management, special provisions of training and capacity development are necessary to ensure adequate understanding of the new materials being used.

Knowledge and application gaps

In the case of the Lao slope stabilisation trials, the project demonstrated that there are complexities in the rainfall patterns that are not fully understood. Rainfall data are not sufficiently comprehensive for hilly areas of the country to give an accurate picture of variability, and following from this the nutrient levels and seasonal fluxes are not well understood on marginal hill soils in Laos. For this reason, more research is required to understand properly how different plants perform in difficult conditions. Two years of intermittent observations was inadequate for a comprehensive picture to be built up of the driving ecological factors, but was extremely valuable in helping to identify the constraints and possible areas for future investigation.

On the institutional aspects, it has become clear through SEACAP's experience that the introduction of new techniques such as bio-engineering needs to be supported by other measures. These should be along the following lines.

- Contracting systems need to be developed that are flexible. This is partly to allow for variations in construction details as site conditions become better understood during construction. It is also to provide for the involvement of individuals from an appropriate technical background such as forestry or agricultural, not just civil engineering, so that the plants used for bio-engineering are treated properly and perform as they should.
- Further work is also required to ensure that techniques such as bio-engineering are used in locations where expectations are not excessive. This would typically mean developing the critical limits for the integration of bio-engineering with hard civil engineering systems, as relevant for different levels of investment in, for example, national highways, feeder roads and village roads. The implication is that a higher level of risk can be accepted on a lower order of infrastructure, in return for lower investment costs and more limited economic consequences from possible failures in unpredictable circumstances.

For the Cambodian floodplains, research is needed to investigate, test and develop systems of the protection of embankment surfaces that use local Cambodian plants in engineered configurations. This would typically need to be able to establish and maintain in the long term, a cover that combines both robust grasses and large shrubs or trees, to ensure a surfacing of earth slopes robust enough to withstand both runoff and wave erosion. The keys to this approach are already identified through the observations made by SEACAP, but need to be tested in field conditions to assess the optimum solutions for the Cambodian environment. Bio-engineering methodology used successfully in other countries can be adapted and applied, as it has been in the SEACAP slope stabilisation work in Laos.

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Use of tsunami debris for reconstruction in Sri Lanka

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Background

Sri Lanka is a densely populated country of 20M people. A large portion of the population lives along the coastline and engage in fishing, rice farming and other forms of livelihoods. This high population density contributed to the unfortunate high loss of life during the tsunami of year-2004. Large numbers of houses, schools, hospitals etc. were destroyed by the tsunami – resulting in large volumes of destroyed building debris throughout the north east, east and south coasts. Large lengths of local road networks and associated drainage networks were also wiped out.

Shortly after the tsunami a large number of reconstruction projects were implemented throughout affected zones. The vast majority of these projects were constructing community road networks using natural gravel as a wearing course as this had been the practice prior to the tsunami.

Initiation of Trials

UNOPS implemented a number of demonstration projects[7] for local community road reconstruction, initiated six months after the tsunami. These projects were guided by the recognition of a number of important issues:

- Maximum use of local resources – local resources include materials, labour and equipment, would ensure the greatest benefit to the affected communities through the reconstruction activities;
- Construction of durable infrastructure would result in:
  - Benefits to the communities through dependable access to local amenities and reduced transport costs; and,
  - Reduced future maintenance burden to a more manageable level for the local Government offices.

Gravel – laterite

SEACAP had implemented a number of studies on the application of gravel wearing courses in other countries with similar climates and traffic regimes, notably the Rural Road Gravel Assessment Programme implemented in Vietnam. SEACAP implemented trials of varying technology options for rural roads in other countries, again with similar climate and traffic conditions – notably Vietnam and Cambodia. Evidence from the SEACAP projects showed that a laterite gravel wearing course does not perform well under similar conditions to those found in Sri Lanka.

The large-scale use of gravel wearing courses in the Sri Lankan coastal area reconstruction projects resulted in:

- Material cost inflation;
- Gravel haulage damaging the road network due to lack of control of truck axle loads;
- Extraction of the material leads to environmental degradation when borrow pits are not remediated; and,

7 Funded through the International Labour Organisation (ILO) by the Department for International Development (DFID) of the UK and the United Nations Office for Coordination of Humanitarian Affairs (UNOCHA).

- Importantly less of the project funds are directed towards labour wages and therefore local communities.

Therefore a design philosophy was adapted for using this finite natural resource - laterite gravel: It would be used in a more sustainable manner as part of a sealed road pavement where it would not wear away. UNOPS used gravel as sub-base in sealed pavements limiting its wasting.

Appropriate surfacing and paving

UNOPS/CAP applied a number of differing but Low Volume Rural Road (LVRR) appropriate technologies. These ranged from unreinforced concrete pavements to crushed stone road bases with bituminous surface treatments. The existing maintenance capacity, both technical and financial, was accounted for as a design parameter. For example, one of the pavements used:

- a sub-base layer of crushed Tsunami debris blended with sea sand;
- a crushed graded aggregate road base; and,
- a single bituminous surface treatment using bitumen emulsion.

Use of crushed tsunami debris for construction of paved roads

Although much of the tsunami debris was not a health hazard, it was necessary to remove it to clear sites for reconstruction. It was decided to utilize the readily available tsunami debris, after processing, for the sub-base layer.

It should be noted that this is an existing technology. The debris primarily consisted of broken brick from buildings and crushed brick. It was then blended with sand. This is commonly done in Bangladesh due to the lack of crushed stone.

Trials were carried out at the initiation of the project to determine the associated costs of the materials, the most efficient process for crushing and blending the debris and the labour required.

A community contract was initiated with the local Rural Development Society (RDS) in order to determine labour productivity norms for crushing and blending the material. Once the norms were determined through site control sheets[8] another contract was signed with the local RDS for collection and processing of locally collected tsunami debris. Enough material was salvaged and processed for construction of 400m of sub-base. Thus a locally available waste material was reprocessed using a local labour force for an engineered durable road.

At that stage large scale cash-for-work programmes implemented by International Non-Government Organizations (INGO) were underway. Many of these programmes “rehabilitated” roads. These road works involved simply dumping unprocessed tsunami debris along the road alignment as a capping layer over the in-situ sand. Gravel was then placed over this, without adequate, if any, compaction. There was little or no engineering input to the road design. Thus a cheap abundant material was largely wasted.

Without the debris, the road sub-bases were then constructed using specification compliant lateritic gravel. The design for side drains was revised to use pre-cast concrete kerbs raised at the edge of the road to act as gutters.

Dissemination of experience

Training opportunities were offered to NGO staff under the demonstration projects and efforts were made to disseminate road design methods and all lessons learned through the trials.

[8] A site control sheet is used for recording volumes of work done by a known number of representative workers for specific work task under controlled conditions similar to normal site working conditions to determine the labour productivity norm for said work tasks

However the demonstration projects were largely unsuccessful in attracting other staff to the training opportunities.

The road constructed has given more than two years of service now and has been monitored by the UNOPS. To date no adverse effects on the performance of the pavement has been noted.

Lessons

A number of valuable lessons were learned through the trial:

- The cost of processing the debris material resulted in a much higher proportion of the overall budget of the sub-base layer being allocated for labour wages rather than material purchase and haulage;
- Cost comparison of the crushed tsunami material showed the unit cost to be slightly less than the USD4.50 / cubic metre unit cost at that particular site at the time.
- A large number of projects were implemented very rapidly after the tsunami – driven by urgent need, but also, in part by project administrative timeframes. The time pressures to deliver led to a lack of interest by the NGOs in something “new” or “different”;
- In a situation where no national standards[9] for rural roads existed a large number of NGOs resorted to an acceptance of what they may be familiar with or at least the easiest option for implementation;
- Defining good practice and making it accessible through manuals and training could have helped all involved make better use of the opportunities to use the debris materials; and,
- A database of previously applications of the technology applied and its benefits would be of great benefit in advocating on the ground to the Local Government offices, donors and NGOs.

Photo 1: Dumping of unprocessed tsunami debris for road construction – a wasteful process.

Photo 2: Compacting crushed and blended tsunami debris for sub-base layers.

[9] National standards exist within the Road Development Authority of the Ministry of Highways for class A and B roads and to some extent for class C and D. No standards existed for the local Government roads – class E, which make up the majority of the 65,000Km road network.

The demonstration projects did however get large scale buy-in from local government offices. They recognized the value of the methods that lead to more durable roads and consequently to reduced maintenance burdens. The demonstration projects were also used to advocate these approaches to donors.

The European Union is funding an extension to the UNOPS implemented CAP for Euro 30M. The support of Local Government and the access to demonstration projects was critical in attracting this funding. CAP is currently constructing 400Km of rural roads throughout the tsunami affected District of Ampara on the East Coast of Sri Lanka. CAP is applying the same principals as the demonstration projects. Tsunami rubble was not used under the programme as it was no longer available in sufficient quantities – having been buried already under gravel roads. Gravel roads which are rapidly failing. CAP only constructs paved roads, thereby ensuring a minimum of gravel usage and wastage.

The EU also funded the Environmental Remediation Programme (ERP), implemented by UNOPS in the same District. ERP cooperates closely with CAP, by design, to remediate gravel borrow pits used to source materials, which is likely to be the first such example of environmentally conscientious use of the material on the East coast of Sri Lanka.

Photo 3: Placing base course using strings, pegs & line levels for layer thickness & camber control

Photo 4: Completed road section

1. SEACAP 1: *Research, Rural Road Surfacing Research.* http://www.seacap-info.org/?mod=home&act=pdesc&pid=4

2. SEACAP 3: Mainstreaming Appropriate Local Road Standards and Specifications and Developing a Strategy for the MPWT Research Capacity, http://www.seacap-info.org/?mod=home&act=pdesc&pid=6

3. SEACAP 4: *Research, Rural Road Gravel Assessment Project.* http://www.seacap-info.org/?mod=home&act=pdesc&pid=7

The Development of Standards and Specifications that Allow Engineers to Construct Roads with Available Materials

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The SEACAP Legacy

Since 2003 the DfID-funded SEACAP initiative has delivered a number of low volume rural road research reports, procedures and guidelines[1,2,3]. The main emphasis in these initiatives has been on sustainable options for pavement and surfacings; other important aspects such as earthworks, drainage and structures have also been covered but not in as great a detail. Many of the principles and concepts behind this SEACAP work can be adapted and related to the construction of disaster-recovery roads using locally available materials. In particular, this section of the paper will focus on the requirement to develop appropriate design and construction frameworks that should aim to be:

- *Practical*; capable of delivering roads that are fit for there designated purpose
- *Useable*; can easily be applied within the available construction resources
- *Controllable*; allow effective and appropriate levels of quality assurance to be applied

The Requirement for a Framework of Standards and Specifications

Engineering risks are required to be taken in adopting novel or non-standard solutions to road construction and appropriate Standards and Specifications not only provide guidance and a protective umbrella but also promote general confidence in the their adoption and application. They are essential to provide the context and control framework within which resource-based pavement options may be assessed and selected for use.

The SEACAP 3 project in Lao has developed a simple framework of Standards and Specifications specifically aimed at the Low Volume Rural Road (LVRR) sector[4,5]. This output was arrived at by working through a logical series of key steps which are also applicable in the disaster recovery sector:

1. Define road tasks.
2. Define geometric standards.
3. Identify available construction materials.
4. Identify suitable standard road designs.
5. Draft construction specifications

Road Tasks

There is a need to clearly define what roads are intended to do by classifying their functions in terms of traffic type, traffic volume and vehicle size within any key restraints of topography and climate. For example, a crisis-recovery road required to carry heavily loaded trucks over a short period of time has a very different function from one which may be essentially a pedestrian and two wheeled vehicle basic access route. It is essential that road function is clearly identified at an early stage.

The road task assessment should also take into account the required design life of the road, which for crisis-recovery may differ from the normal 10-20 years used in conventional road building.

Geometric standards

The objective is to define a matrix of aspects such as carriageway widths, shoulder widths, passing places and minimum curves to fit the range of roads classified above. The definition of the typical "design vehicle" is crucial in this regard. For example in Lao one key "design vehicle" was identified as a small pick-up truck and this lead to important decisions on single lane with carriageway widths of 3.0m to 3.5m. Roads requiring larger vehicles would require wider carriageways and roads with a high percentage of mixed truck and pedestrian traffic would normally require additional wider shoulders on safety grounds.

Available Construction Materials

It is important to characterise the general nature of the available materials in terms of their potential ability to perform defined engineering tasks within in a road[6]. This knowledge is an important early feedback into the approach to the road design.

Road construction materials requirements are traditionally focussed on the higher quality needs of the pavement layers and for concrete structures. There is, however, a complete range of tasks that may be required, particularly for completely new roads, whose general road material requirements may be summarised as follows;

- Common and selected fill
- Filter and drainage aggregate
- Concrete aggregate
- Pavement sub-base and base material
- Unsealed surfacing wearing course
- Surfacing aggregate

Many of the construction materials likely to be considered in a crisis recovery situation will have very variable non-standard behaviour characteristics and many of the standard assumptions and empirical relationships that govern their use may not hold true. It is important, therefore to have available a basic framework and field procedure for characterising materials and for understanding the likely impact of any non-standard characteristics in an engineering context. Non-standard materials[7] may well have what would normally be perceived to be inherent "defects", such as:

- High Plasticity;
- Poorly Grading characteristics;
- Poorly Shape;
- Low Particle Strength;
- Low Durability; and,
- Volume change susceptibility to moisture.

It nevertheless may be essential to incorporate these materials into a crisis-road design and the decision process as to how they are assigned particular tasks will be fundamental to developing suitable road designs. In contrast to the more traditional approach of seeking materials to suit a design the crisis-road approach must be to ask what road designs can be found to suit the materials.

The evaluation for use of non-standard materials involves a process of engineering risk assessment based on the required tasks, known properties of the material and the environment in which it is to be used[8]. Outcomes to this assessment could be one or more of the following:

- Use as required in road;

- Downgrade use (i.e. from base to subgrade or fill);
- Use with a modified design;
- Modify the material for use in accordance with specification; and,
- Do not use at all.

Sub-standard or marginal quality materials can be, under appropriate conditions, effectively improved by mixing with another material to produce a blend with better characteristics (mechanical stabilisation) or by treatment with an available additive such as cement, lime or bitumen.

Road Designs

It is an advantage to have readily available a number of suitable standard designs for pavement and surfacing that are compatible with the road task, the available materials and key impacting road environment factors. The SEACAP approach has been to develop matrices of design options utilising a two stage process:

1. Identification of appropriate road style (eg unsealed, sealed flexible, rigid, block); and,
2. Detailed pavement thickness design.

The selection of road style is largely governed by factors such as available materials; maintenance; available technology; road function; climate and topography, whilst the detailed design is a function the more traditional engineering factors such as sub-grade strength and traffic.

Construction Specifications

By necessity, national or international specifications cover a very wide range of standard material types and natural environments, contain significant in-built factors of safety, and are generally not suitable for application in situations where non-standard materials may have to be used within specific road environments. Specifications drawn-up for particular materials for specific environments need not be so conservative in approach and can be drafted to allow the use of previously non-conforming or marginal materials within defined limits.

The role of a set of appropriate specifications is to clearly set out the parameters within which a potential material may be used for a particular road task. Specifications for material for use should be accompanied by clear guidelines laying out the limits within which the approval is valid. In general, the principal problem in specifying the use of non-standard materials is to decide what is the boundary between acceptable and non-acceptable and how best to use what is acceptable. It is important to acknowledge in drafting specifications that the boundaries of acceptability are not fixed, but shift in response to technological innovation or by combinations of external factors such as climate, construction methods and maintenance. Specification of materials cannot, therefore, be rigidly based solely on material character.

It is not realistic to attempt to force contractors to meet inappropriate or unobtainable material standards. Where genuine material problems or shortages exist, it is the responsibility of the road designers to overcome the issue by a combination of:

- Adapting the specification and road design to suit local materials, or
- Adapting or modifying the materials to suit a realistic specification.

The Road Environment

It is important understand all external impacts on a road, and to recognise the influence exerted by these other parameters. In reality the performance of a road depends on a whole range of factors that cumulatively can be described as the “road environment”. Experience has indicated that this range of road environment factors must be taken into account in the designing of appropriate rural roads[9]. It is logical to conclude that a similar, though possibly slightly different set of road environment factors must be accommodated in an effective framework for the design and construction of crisis-recovery roads. These are summarised below, with particular reference to materials.

Climate. Wet climates: All materials need to be resistant to wet working conditions. Exposed materials need to be resistant to erosion. Dry climates: materials in general should be as free from potential dust as possible. Wetting-up of dry materials for compaction purposes may induce shrinkage cracking.

Hydrology. Flooding may mean a requirement for free-draining material or even rock-fill and for slope face protection and erosion resistant pavements. High water table may give rise to poor working conditions and weak foundations requiring flatter embankment slopes and greater amounts of fill material.

Terrain. High relative relief and steep terrain patterns can mean higher embankments**-** more fill**.** Terrain geometry may severely restrict separate haul road development and materials must be selected with construction traffic impacts in mind. Low relief means less constraint on embankment side slopes and hence possible use of weaker fill materials.

Sub-grade Conditions. Weak sub-grades will impact on the pavement thickness and material volume requirements and mitigate against some styles of road – eg unsealed gravel.

Construction regime. The construction regime will govern whether or not a road design can be effectively applied. Key issues are available construction plant and contractor experience.

Maintenance: All roads, however designed and constructed will require maintenance to ensure that the design life is reached. Even within a shortened design life of some crisis recovery roads it may be necessary to assess the maintenance implication of using particular materials within specific road designs.

Natural or man-made hazard Crisis-roads by their definition may well occur in areas of high risk hazard (landslide, earthquake, tsunami) and the extraction, and use of available materials must take this risk into account, and certainly should not add to the hazard by, for example, destabilising already sensitive slopes or slope failures.

Application of Standards and Specification through Environmentally Optimised Design

Recent international and regional research has highlighted the usefulness of applying the principles of Environmentally Optimised Design (EOD) to selection, design and construction of pavement and surfacing options for low volume rural roads[10]. A similar approach may be adopted for crisis-recovery roads.

In essence EOD in this context can be described as utilising the available resources of budget and materials in the most cost-effective manner to counter the sometime variable factors of traffic, terrain, materials and sub-grade that may exist along an alignment. EOD may be considered as spectrum of solutions for improving or creating affordable access – from dealing with individual critical areas on a road link (Spot Improvement) to providing a total whole rural link design (Variable Longitudinal Design).

Variable Longitudinal Design applies the principle of adapting designs to suit variable road environments along an individual road alignment. This results in selecting different pavement/surfacing options in response to different impacting factors along an alignment and hence a more focussed use of limited construction resources.

Spot Improvement involves the appropriate improvement of specifically identified road sections either in actual need of upgrade or deemed to be at high risk of failure, and allows the appropriate application of limited resources to be targeted at key areas on existing earth or gravel road links to improve access throughout the year.

Conclusions

SEACAP and associated research programmes have developed general methodologies for the effective use of local materials in the design and construction of sustainable rural roads. Principles incorporated in this work may be usefully adapted for use in the crisis-road sector where rapidly achieving appropriate access routes using immediately available materials is often a high priority.

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