Engineering with the Environment, working with the environment to improve access

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1. Introduction

SEACAP

The South East Asia Community Access Programme – SEACAP, is a DFID (Department of International Development – UK based), funded programme the goals of which are

a. To help and support developing countries make the optimal decisions on providing rural access to remote poor communities

b. To improve sustainability and affordability of rural access to poor countries

c. Create opportunities for pro-poor growth and poverty alleviation.

The objectives of the Programme are to improve livelihoods of poor and vulnerable people in SE Asia and include empowering local ownership of their access. This includes initiatives that improve community access by ensuring that roads and spot improvements are constructed and maintained in a sustainable way by maximizing the appropriate use of local resources including: materials, labour, enterprise and ingenuity. More affordable in capital and recurrent costs, these local road solutions have become the spine of local government policy and this programme is designed to expand the successes of the initial research work.

SEACAP advocates three simple approaches for achieving sustainable community access:

1. Maximize the use of local resource based technologies.
2. Maximize the use of spot improvements to remove priority obstacles to access.
3. Select the appropriate solution to access problems based upon minimizing full life cycle costs.

The SEACAP research work carried out provides sound evidence for stakeholders on the technical, financial and economic viability of the premises.

Rural Access

Studies carried out in SE Asia find a strong correlation between access to basic infrastructure services and the incidence of poverty. For example, in Lao PDR the very poor (estimated to some 17 per cent of the population) live in remote areas where infrastructure is especially scarce. Villages in the Northern region are particularly isolated; some have no access to social services even during dry season.

A Poverty Impact Study of rural roads constructed under the Lao Swedish Road Sector Project indicated that all villages, having been provided with road access, to a greater or lesser extent were now producing more in general, than before. Expenditures had increased more than threefold; there was evidence of positive impact on education, health, commerce, agriculture, land use and reduced gender inequalities and decreased transport costs. These finding reflect the general benefits of providing access to rural communities.

Poor people often rely on non-motorised transport, motorcycles and simple trucks for their transport needs. On many soils, an engineered earth road is sufficient to provide basic access for these vehicle types, provided that specific, limited location constraints, such as watercourse crossings and steep gradients are adequately engineered with spot improvements. The camber and drainage must of course be maintained using appropriate, low cost techniques.

Low cost construction and maintenance techniques using local labour and simple equipment have an important role to play. These techniques are particularly suitable for implementation by small enterprises or communities. They use the locally available labour and have negligible capital requirements. Engineered Natural Surfaces can be provided for less than US$2,000 per km in many situations, including the necessary low cost drainage measures.

However in some circumstances the in-situ soils are just too weak to support any traffic in the wet, and must be covered. For these situations, there is a range of alternative surfacing and paving options already proven in various countries that could provide appropriate, economical and sustainable alternatives to natural gravel in developing countries. Suitability will depend on local circumstances. These alternatives, involving the appropriate use of locally available materials, may be cheaper in whole-life-cost terms. Many can be carried out by small and medium enterprises using low-capital, labour based and light equipment methods.

Even so, with limited funding available to rural communities and roads authorities, there is often insufficient funding to rehabilitate all the rural roads. Approaches must therefore be sought which can maximise the use of these funds. The use of spot repairs to make roads accessible and the exploitation of local gravel sources can increase the available access to rural communities while at the same time reducing the dependence on increasingly scarce natural resources.

Environmental Issues

Providing access to these communities can have adverse environmental consequences. Rural access roads require large quantities of gravel, which is often produced in large quarries and transported over long distances on roads not designed for heavy traffic and through villages, with corresponding environmental and road safety impacts. Large scale quarry operations themselves have associated environmental impacts, more so when poorly managed which is often the case in remote areas where strict controls are difficult to enforce.

The roads can also have serious effects on the environment such as erosion on steep grades, which often cause similar damage to the adjacent land, and landslides caused by cutting or widening the road bench in mountainous regions. These issues are not always addressed when providing basic access to rural communities due to the cost implications and ways must be sought to mitigate these adverse effects with low cost local resource based solutions.

Communities themselves could use some of the techniques discussed in this paper to improve their own access. The alternative surfaces have lower (and more manageable) maintenance requirements than gravel, not only in terms of cost but also by reducing the need for heavy equipment to transport and compact. Their environmental impact is potentially substantially less. Furthermore, the use of bioengineering techniques for slope stabilization is also within the capability of communities while providing environmentally friendly solutions to these problems.

SEACAP Approach

Through the SEACAP and other initiatives, DfID is exploring solutions to these issues. The research carried out in Vietnam on the loss of gravel from road surfaces has provided important data relating to the sustainability of unpaved surfaces. The results of this research have reinforced the need for more sustainable pavement materials and approaches to pavement construction and road design strategies, which have been explored under SEACAP projects in Cambodia, Vietnam, Lao PDR, and Sri Lanka. Further research is ongoing into the use of bioengineering techniques for slope stabilisation in Lao PDR.

Key aspects of the research, completed, ongoing and planned, include:

- Investigation of naturally occurring unimproved gravel as a suitable pavement material;
- Low cost alternative surfaces and pavements;
- Spot repairs and improvements;
- Exploitation of local gravel sources using mobile crushers;
- Combining bioengineering and geotechnical engineering for slope stability

The following chapters summarise the gravel loss research, alternative sustainable pavements and other approaches to providing sustainable access to rural communities.

2. Gravel loss

The Limitations of Gravel

The word gravel is used within this document to denote any naturally occurring granular material, including laterite gravel, used as a road surfacing material. Gravel is a 'wasting' surface. Material is lost from the surface of the road due to the action of traffic and rainfall Gravel should only be used for rural road surface applications in situations where certain conditions are fulfilled.

Gravel is a natural and finite resource that is found in limited quantities. It tends to occur in relatively thin, generally horizontal layers (1-1.5m), hence the development of borrow areas inevitably carries "green environment" penalties. For example, each kilometer of a 3.5m wide gravel surfaced rural road will require the opening up and excavation of a minimum of 30mx30m borrow area (assuming a 1m thick deposit layer) as well as attendant overburden dumps and access haulage roads. In addition, as deposits are used up, subsequent periodic re-gravelling will involve longer hauls from ever more distant sources and consequently higher maintenance costs.

Under an ILO rural road project in Cambodia, there were concerns regarding the sustainability of gravel/laterite roads in many locations. The ILO Upstream Project reported the experiences of gravel loss and maintenance in Battambang Province, Cambodia. The report highlighted the serious environmental and social consequences of the use of gravel as a surfacing material, the very high overall cost and the lack of sustainability of the approach.

Recent research under SEACAP indicates that gravel may not be appropriate for use where any of the following conditions apply:-

- Gravel quality is poor – Gravel should comply with internationally recognized grading and plasticity requirements, and resistance to break down under traffic, otherwise it will be lost from the surface at a high rate.
- Compaction & thickness cannot be assured – uncompacted surface gravel will be less durable.
- Haul distances are long – if haul distances are longer than 10km, then other surface types may be cheaper in whole life cost terms. Hauling gravel for construction and periodic maintenance often causes damage or further maintenance liabilities to the haulage routes.

- Rainfall is very high – Gravel loss is directly related to rainfall and may be excessive with intense storms or where annual precipitation is greater than 2,000mm.
- There are dry season dust problems – long dry seasons can allow the binding fines to be removed from the surface by traffic or wind. The removal of fines from the road surface accelerates the wearing process and the suspended dust causes environmental and health problems for exposed humans and livestock. This is particularly problematic where communities live beside the road or their crops and property are regularly coated in dust. For example the inhalation of road dust is very unhealthy and there are also visibility-safety issues.
- Traffic levels are high – gravel loss increases with traffic. It is unlikely that a gravel surface will be cost-effective at traffic flows of more than 200 passenger car units per day.
- There are Longitudinal Gradients – Gravel should not be used in low rainfall situations (< 1,000mm/year) on longitudinal road gradients of more than 6%. In medium rainfall areas (1,000 – 2,000 mm/year) gravel loss by erosion will be high on gradients of more than 4%.
- Adequate maintenance cannot be provided – Gravel is a high maintenance surface requiring timely both routine reshaping/grading and expensive periodic re-gravelling to replace surface material losses.
- Sub-grade is weak or soaked (flood risk).
- Gravel deposits are limited/environmentally sensitive – Gravel is a natural and finite resource, usually occurring in limited quantities.

Even in simple combinations of some of the above factors, gravel can be lost from the road surface at rates of more than 3cm per year, leading to the need to re-gravel at very frequent intervals.

Fortunately there is a range of proven alternatives to natural gravel. Some of these have similar initial construction costs to gravel in certain circumstances. Most have higher initial costs but have better whole life cost, attributes and lower maintenance liabilities.

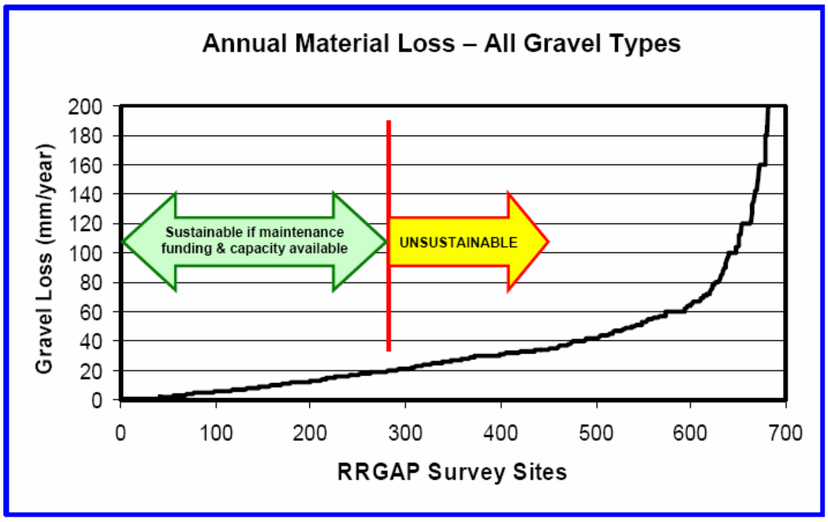
Rural Road Gravel Assessment Programme (RRGAP)

The Ministry of Transport (MoT) Second Rural Transport Project (RT2) in Vietnam provided basic access roads for communities in 40 provinces of Vietnam (2001–2005). Gravel was traditionally the surface provided for all of the project roads. However, because of increasing recognition that gravel surfacing is not always the best solution for rural roads in all circumstances in Vietnam, studies of alternative surfacing/paving were conducted under the RRGAP.

The RRGAP scoping study revealed that there was little available data and analysis on the engineering performance and deterioration of gravel roads. In the light of increasing speculation as to the long term cost-effectiveness of gravel surfacing in many locations in Vietnam this knowledge gap required urgent attention. This was particularly important in view of the large investments planned for expanding the rural road network for the purpose of rural development.

Key Issues

Material loss was considered to be the principal issue in the RRGAP survey, partly due to its substantial impact on periodic maintenance needs and costs. The RRGAP was designed as a one-off condition survey; hence although material thickness was measured it had to be related to design thickness to gain an estimate of loss rather than by exact measurement. The use of DCP profiles aided in the interpretation of material thickness measurements. Material loss was



Vietnam Rural Road Gravel Assessment Programme (RRGAP) 2004 – ANNUAL RATE OF GRAVEL LOSS FROM ALL SITI

calculated in millimetres of material lost per year.

Erosion was seen as a key cause of road deterioration, causing the formation of surface rills and gullies and increased road roughness conditions. Potholing and rutting were also selected as suitable deterioration indicators.

Material loss trends were evaluated by examining the loss over a large number and range of sites. Gravel loss of 20mm/year was selected as the limiting figure for road sustainability. This level of loss allows for 100mm of gravel to be lost over a 5 year life without re-gravelling and can be considered a maximum loss figure for road management sustainability in an environment where timely periodic maintenance, including re-gravelling, is not the normal practice due to a range of constraints.

Key issues with respect to the RRGAP material loss and erosion data are as follows:

a. Overall material loss figures indicate that around 58% of the surveyed sites were suffering unsustainable deterioration, while 28% were losing material at twice the sustainable rate.

b. . The overall visual assessment data indicated a composite road performance model comprising the differential "spot" deterioration of short critical lengths separated by lengths of road in better condition. This spot deterioration model was indicated for around three quarters of the roads examined. In addition to which the detailed material loss data indicates an overall general deterioration of the entire road length.

Material Characteristics

There is a significant variability in the nature and performance of the materials being used as unsealed road surfaces in Vietnam. The material loss for the RRGAP sites was analysed for each of the seven principal material groups. The key material related issues to arise out of this examination are:

a. The naturally occurring laterite, hill gravel and alluvial gravels have a high number of sites (>60%) with greater than 20mm/yr material loss. The implication is that these materials are not suitable for use as an unsealed road surface within the majority of Vietnam road environments. Similar comments also apply to graded crushed stone as an unsealed surfacing material.

b. Where natural materials have been mixed with additional crushed rock, weathered rock, or alluvial gravel and cobble, the material loss figures show a distinct improvement.

c. Coarse non-graded stone surfacing performs significantly better than other options in terms of material loss. However, it does suffer significantly from surface erosion of fines, leaving a rough surface susceptible to localised deterioration.

d. The natural gravel-stone mixtures also have lower than average material loss, but, as with the non graded stone, they also appear to have a higher than average erosion/roughness potential.

Terrain and Gradient

The impact of terrain indicates that erosion increases significantly between 4% and 6% road gradient. It has been commonly acknowledged that gradients above 6-8% are not usually suitable for gravel surfacing, however the RRGAP data suggest that, for some materials at least, this limiting figure should be lowered to 4% for the high rainfall environments in Vietnam.

Construction

Good drainage is considered a fundamental aspect of road engineering in almost all relevant guidelines and design manuals. In a high rainfall country such as Vietnam this aspect of road construction should have a particularly high priority. The RRGAP survey has, however, indicated that drainage, in the form of side ditches and carriageway run-off capacity has not been given sufficient priority either in construction or in maintenance in the Vietnam rural road network. The effects of poor drainage on road performance are indicated by the impact it has on potholing and erosion.

Maintenance

Maintenance is a key factor for the sustainability of gravel roads. Gravel is a low-cost, but high-maintenance surface. The RRGAP data, indicates that adequate maintenance is not being achieved on the large majority of RT1 & RT2 roads. Gravel roads suffering more than 20mm/yr of material loss without appropriate maintenance are largely non-sustainable beyond 4-5 years and may well deteriorate at a significantly greater rate in some in sections within that timescale.

Climatic Effects

In general terms Vietnam is a high rainfall environment with intense storm concentrations, and hence very high erosion potential. This undoubtedly has an impact on the deterioration of the unsealed rural roads in Vietnam.

Conclusions and Recommendations

The RRGAP data indicate that it is likely that over 50% of the unsealed rural road network is either unsustainable in terms of material loss or contains significantly deteriorating road sections. There are key factors that could be addressed to improve their condition and sustainability. These are:

a. Funding/resourcing and implementation of appropriate routine and periodic maintenance.

b. Construction of additional side ditches to ensure that the road surfaces can effectively shed rainwater from the road and disperse it satisfactorily.

c. Sealing of appropriate road links. In a resource constrained environment, a spot improvement strategy of selectively treating problematic lengths within a road link should be considered, e.g. sections liable to flooding or with steep gradients.

d. Improve the evaluation of the correct usage of local gravel materials in rural road programmes in Vietnam. It is now recognised that a key objective in sustainable road construction is to properly match the available material to its road task and local environment and greater use should be made of adapting local non-standard materials within appropriate designs.

e. Gravel can only be considered as a serious viable surfacing option for Vietnam rural roads on engineering and economic grounds under the following conditions:

   i. Where specified quality material is locally available in sufficient quantities both for construction and maintenance (probably within 10km of the road). A realistic assessment of the likelihood of routine and periodic maintenance being carried out should be included in the whole life costing, including the risks and consequences of inadequate maintenance.

ii. Where road gradients are less than 4% in medium rainfall areas (1,000 – 2,000 mm/year). Gravel will probably be unsustainable at any gradient for higher levels of rainfall

iii. Where adequate drainage (crossfall, side and dispersion) can be guaranteed.

iv. Where adequate quality assurance controls are in place for construction supervision to ensure contract and specification compliance.

v. Where an appropriate maintenance regime can be guaranteed as part of a whole-life construction and maintenance specification.

vi. Where flooding is only a minor local occurrence.

vii. Where traffic is below 200 motor vpd equivalent.

Apart from assessing gravel performance the RRGAP has raised other important issues, such as:

a. The investigations have indicated the effectiveness of unsealed stone macadam in providing a sustainable surface/road-base, albeit with high surface erosion or roughness penalties.

b. Other techniques utilising natural stone, without bitumen or cement binder, could have superior performance to gravel, but with reasonable initial costs and lower maintenance liabilities. These surface options include hand packed stone and cobble stone paving.

c. Composite construction should be considered as a strategy in future rural road programmes. This involves the construction of different surfacing options along a road link in response to differing environment impacts.

d. There is a clear requirement to make local road authorities, contractors and local consultants more aware of the importance of quality control and to place more emphasis on effective and contractually empowered construction supervision of rural road projects.

3. Low Cost surfacing

Many communities are denied road access due to the condition of the road during the rainy season. Poor quality pavement materials and subgrade conditions make it impossible to traverse the road. This usually occurs in low lying swampy areas and on steep gradients, where traction is drastically reduced.

In order to address these specific problems, DfID has funded research into alternative pavements using local resources and materials. These pavements, although more expensive to construct provide year round access and lower long term (life cycle) costs. In environmental terms they also reduce the reliance on increasing scarce gravel deposits by removing the need for frequent re-gravelling of the problem sections and reducing erosion which often affects adjacent land. Research has been conducted in Cambodia, Vietnam and Lao PDR as detailed below.

Cambodia

Pavement trials were conducted in the area of Puok District Market in Siem Reap Province. Previously the access roads to and roads around Puok Market itself had been surfaced using the laterite, which has been applied to many tertiary and sub-tertiary roads in Cambodia. The need for a more durable wearing surface was recognized by the need for continuous maintenance of laterite surfaces and the associated strain on resources. This became more apparent following excessive flood damage during the exceptionally high intensity rainfalls in year 2000.

The higher traffic volume in the area of the market further compounded the need. The suitability of laterite as a wearing course decreases with increase in traffic volume. Laterite loss has been found to increase almost exponentially with increases in traffic volume. Furthermore the economic viability of laterite as a wearing course becomes increasingly dubious with the increase in haulage distance.

A further consideration is the dust problem associated with laterite, especially in an area of high population density such as Puok, there is a need to reduce the amount of dust because of health problems, which may result in the local community. In an area such as Puok market where there are many food vendors and restaurants large volumes of dust represent a serious hygiene problem with foodstuffs being contaminated daily.

Although laterite has a relatively low initial cost, ongoing periodic maintenance requirements are considerable, even more so when the traffic volume exceeds 50 four-wheeled vehicles per day as is the case for Puok. Furthermore, laterite is a finite non-renewable resource. Such were the economic, social and environmental issues, which led to alternative surface options being considered for the rehabilitation of the roads around Puok Market.

Under the DfID funded Knowledge and Research (KaR) programme and subsequent SEACAP 8 Project, investigations were carried out and guidelines developed on alternative low cost rural road surfaces, which in appropriate circumstances will have lower whole-life-costs than gravel. The alternative surfaces can also have better local resource use attributes; with the effect of injecting more of the road works expenditures into the local community through employment, use the of locally supplied and processed materials and local enterprises.

Ten sections of alternative paving were constructed at Puok Market, under a cooperation initiative between an ILO Project, Ministry of Public Works & Transport and Ministry of Rural Development, Cambodia.. Two local contractors, using the appropriate equipment and the optimum input of local unskilled and skilled labour, constructed the trials in mid year 2002. The aim of the paving trials was to investigate and demonstrate the construction of a range of paving techniques as an alternative to gravel/laterite, suitable for secondary and minor roads using local-resource-based techniques wherever possible. The pavements constructed included four basic road bases (water bound macadam, sand-aggregate, crushed-stone and laterite), three basic surface treatments (double chip seal, single chip seal, sand seal), bamboo reinforced concrete pavement, dressed stone pavement and hand-packed stone.

The principal lessons from the Puok Market trials were:

- Rural road design in Cambodia is particularly challenging and the past simplistic and largely partially informed approach to rural road provision can no longer be tolerated or afforded in a severely resource constrained environment. Factors of traffic and vehicle loading, local materials availability, local resource use technologies, subgrade conditions, maintenance regime must be carefully considered in developing the appropriate construction and maintenance approach.
- Gravel/laterite should be used selectively, as per the recommendations above.
- There is a substantial range of alternative paving options with better whole life cost and social benefits than

gravel/laterite. These can be constructed by small scale contractors with limited equipment resources and using local labour. Some paving types are more suitable for heavy vehicle overloading or a poor maintenance regime.

Vietnam Rural Road Surfacing Trials

The purpose of this programme, was to find out appropriate types of road pavements for each of the variant regions in Vietnam. Apart from the traditional pavements such as brick, hill gravel, laterite, boulder, crushed stone, bitumen sealed macadam, cement concrete, etc. the trial programme also covered other types of surfacing/paving, in consideration of the use of in situ and local materials, simple equipment and local labour, in order to minimize construction costs and routine maintenance requirements, and environmental pollution effects.

The results of these trials were used in the follow up projects, supplement MOT's rural road design and construction related procedures and regulations, in order to utilize investments made by the Government, local governments, local people and international donors in an effective way, contributing to the Government's poverty reduction strategy.

The options used included:

- Dressed Stone - local skills in stone cutting and dressing are established in some communities. Excellent quality stone is available in some locations and suitable for this use. The technique has a very high local labour content so that a large proportion of the construction expenditures is re-cycled in the local community with income benefits.
- Bamboo Reinforced Concrete (BRC) - There are expected to be cost and transport savings over steel reinforced concrete. The technique uses more local resources.
- Steel Reinforced Concrete - To be used as a comparison control for BRC.
- Concrete Bricks - These have good load spreading properties, especially on low strength subgrades. They are re-usable if road base failure occurs. The technique is suitable for small scale local concrete brick production by contractors or communities.
- Bitumen/Emulsion Seals on waterbound or dry bound macadam, or lime/cement/emulsion stabilised soil. These are a more efficient use of bitumen compared to traditional techniques. They represent good protection of investment in roadbase materials and scope for labour-friendly application using bitumen emulsions.
- Fired Clay Brick Paving. Brick technology is well established for house building use and good quality bricks are obtainable from small scale production using rice husk (a commonly available waste product), as well as coal fired kilns. Bricks can have a very high local labour content with most costs recycled in the community. There are very low transport costs and minimal haulage damage to other roads when the kilns are located close by

The RRST-II programme was an important step in the roll out and mainstreaming of sustainable and appropriate rural surfacing solutions. The scientific and engineering objectives may be summarised as follows:

- Trialing of alternative surfacing/pavement options within a range of Vietnam road environments,
- Construction trialing options under longer-length, standard construction conditions,
- Trialing a knowledge-based selection process for rural road designs which included a more detailed weight being

given to road environment factors such as of sub-grade condition, topography and hydrology.

- Integrating appropriate options from into the provincial road authority's selection, design and supervision processes.
- Wider involvement of local consultants and contractors in techniques and practices associated with sustainable rural road design and construction.

During the project, a small number of new options investigated. These were:

- Un-reinforced Concrete
- Cobble Stone Paving
- Quarry-run sub-base and shoulders
- Sealed shoulders

A number of important issues are worth noting in relation to the costing, design and eventual interpretation of the trials. These are listed below.

- The selection and design criteria for the "Local" trial roads were based more on local experience and current standards than on surveyed road environmental factors such as sub-grade strength, traffic and material properties.
- Assessment of the existing, predominantly gravel, surfaces of the trial roads indicated that they were constructed with materials generally below official MoT standard. The costs proposed by the Provincial Road Authorities and Local Consultants for gravel options, whilst in accordance with current norms, are unrealistically low and reflect only the cost of acquiring nearby gravelly material irrespective of its quality, together with subsequent construction under minimal supervision. As the above mentioned research indicates, use of such sub-standard material results in very poor performance of the road surface and high maintenance liabilities, which under the present maintenance environment leads to poor levels of accessibility, high transport unit costs and constraints to rural development.

The monitoring of these trial pavements is still ongoing and the results will be provided in future reports.

Lao PDR

SEACAP 17 Project was implemented to identify cost-effective methods of improving all-year access to the rural poor through low-cost locally resource based improvement of problematic lengths of road leading to sustainable rural access roads. The project has been implemented in conjunction with the ADB Northern Economic Corridor Project (NEC) to carry out research on a group of rural access roads in Houay Xai District of Bo Keo Province. The approach adopted was to replace the standard gravel surfacing with a 'trial pavement' at specific locations along the access roads. The pavement types selected for the trials developed from similar projects in the region and worldwide as follows:

- Bamboo Reinforced Concrete, described above.
- Otta Seal, this surface comprises of a layer of binder followed by a layer of aggregate that is rolled into the binder using a roller or loaded trucks. It is different to surface dressing in that an 'all in' graded gravel or crushed aggregate is used instead of single sized chippings.
- Geocell, manufactured plastic formwork is used to construct in-situ concrete paving. The plastic formwork is sacrificial and remains embedded in the concrete.
- Hand Packed Stone, this surface consists of a layer of large stones into which smaller chips are packed. Remaining voids are filled with sand or gravel to form a strong and semi-impervious matrix.

- Mortared Stone, this surface consists of a layer of large stones, placed closely together to form a tight surface. The voids are filled with mortar to form an impervious layer.
- Concrete Paving Blocks, the blocks are precast in moulds and then laid side by side on the road. Gaps between blocks are filled with fine material to form a strong and semi-impervious layer. A variation of this is to use Fired Clay Bricks where these are available.
- Engineered Natural Surface, this construction is used where the existing subgrade material comprises natural gravel with the same characteristics as the pavement layer.

The work was completed in September 2007. On completion of the trial section monitoring will be continued over the long term and will contribute to the database of knowledge along with the results of similar trials in Cambodia and Vietnam.

4. Spot Repairs and Improvements

What is meant by 'access' for rural communities has to be clearly defined. The rural population needs access to essential services such as health, education, markets and government services. However, it is not always necessary for communities to have 24 hour, 365 day a year access and some short term delays, such as 1 day due to swollen rivers, can be acceptable. Further, the communities do not necessarily need roads designed to carry large volumes of traffic at high speeds.

Often sections of road are trafficable in all weathers and only require minor maintenance works such as side drain cleaning, bush clearing etc, which is well within the capabilities of local communities. A road might also be unusable for the whole or part of the year because of one location blocking access.

It is common practice for projects to re-gravel or rehabilitate the entire length of a road without really considering what is required to provide access. This wastes large portions of the available budget often for works that are not actually required to provide basic access to communities. In many cases good sections of road, which are passable all year round, are 'improved' when they could in fact be left in their existing condition for longer periods of time.

The resulting construction also is wasteful of limited natural resources. There is therefore the need to change the thinking on road improvement and rehabilitation to concentrate on repairing or improving sections that are critically restricting all year access. The spot repair/improvement approach would include treatments such as

- a an appropriate design on steep slopes or soft subgrades,
- spot re-gravelling on short sections,
- culverts/drifts on streams where heavy rain might restrict access for a few hours only.

In SEACAP 17, as discussed above, trial pavements have been constructed on problematic sections of rural access roads. It will demonstrate the use of more robust pavements on steep gradients and soft subgrades to ensure all year access.

In Cambodia, under the KfW funded Tertiary Road Improvement Project, spot repairs and improvements are being carried out under the annual maintenance programme. Roads have been identified which are mostly in reasonable condition, but have short badly damaged sections which prevent access. These include collapsed culverts, minor embankment failures and sections badly damaged by flooding. Adoption of the spot repair approach has resulted in a much larger portion of the rural road network being made accessible than would have been possible through a normal periodic maintenance or rehabilitation programme under the limited budget available. In an area where good quality materials are difficult to obtain, this approach has also minimised the use of these scarce resources.

The following simple strategy can be considered by road agencies for maximising the impact of their budgets and minimising the use of local material resources and engaging with the local communities through each step:

- Identify problem spots.
- Determine user needs, acceptable delays etc.
- Identify local material sources.
- Select appropriate technology for intervention.
- Prepare cost estimates and budget.
- Implement works.

5. Mobile Stone Crushers

Rural road construction and maintenance requires large quantities of gravel. The options available are to use commercial quarries, often with long haul distances, or local 'as dug' materials.

Large scale quarries usually long distance from construction site. Large quarries have associated environmental problems. Long haul distances along local roads increase costs, damage the roads, which were not designed for the heavy axle loads, and cause dust and safety problems through villages. This can result in more money being spent on transport than on the road itself.

Communities and local contractors usually do not have the means of producing good quality materials and often simply make do with what is available 'as dug'. The quality of these materials is often unsuitable for robust pavements and durable surfaces. They often exhibit high plasticity and poor grading, resulting in short life and premature failure of the pavement.

In many circumstances there may be small gravel deposits, either river beds or from hillsides, which if crushed can be improved to an adequate quality material for use in road pavements or concrete works. These deposits are often too small for setting up a permanent quarry site.

In SEACAP 17 Project in Lao PDR the contractor was importing good quality pavement materials for the trial sections from a commercial quarry 50km from the start of the nearest access road. For community based works on limited budgets, this would be prohibitively expensive. A preliminary investigation found six sources of good quality materials in the project area. However, the quantities are relatively small and quality of the uncrushed material is not suitable for use.. Nor is it economical to haul to nearest large crusher and back.

An assessment of the size of the deposits suggests a total quantity of 230,000 cubic metres is available. The pavement dimensions for the access roads are 4.5m wide with 200mm pavement thickness, which requires 900 cu.m of aggregate per kilometer. The identified sources could therefore provide pavement materials for approximately 255km of such access roads, with very short haul distances, if they could be improved.

Mobile crushers are a cheap and easy way to process small local deposits of materials. They are easy to transport and set up and require minimal skills for their operation.

On the UNOPS programme in Afghanistan a mobile crusher was used with a capacity of 4 cubic metres per hour for granite (this rate would be much higher for softer stone) imported from Bangladesh at a cost of about US$6,500 in country. This came with spare jaw plates and the parts are readily available in country and Afghans are able to work with these machines.

While Afghanistan may be a country with a lot of stone, sometimes haul distances did go up fairly high for quarried material but there is almost everywhere river gravel available. In this case this could be extracted, without large scale environmental damage or causing soil erosion since river flood plains are often very large. The cruched material is good for use in road base, sub-base and concrete aggregates.

This appropriate form of intermediate technology can be introduced where materials are abundant but do not meet specification without minor processing. A large cost saving can be affected through establishing this easily transportable equipment is used by small scale contractors.

6. Bio Engineering

Background

Soil bioengineering, in the context of slope stabilization, combines geotechnical, and civil engineering with, biological, and ecological concepts to arrest and prevent shallow slope failures and erosion. Basic approaches to slope protection and erosion control can be divided into two general categories: living and nonliving. Frequently, living and nonliving measures are combined to form a system.

The living approach, which uses live plant materials, can be further divided into two specific categories: vegetative plantings and soil bioengineering. Vegetative plantings are conventional plantings of grasses and shrubs used to prevent surface erosion. Soil bioengineering utilizes live plant parts to provide soil reinforcement and prevent surface erosion.

In soil bioengineering systems, the installation may play the major structural roles immediately or may become the major structural component over time. Live staking, live fascines, brush layers, branch packing, and live gully repair are soil bioengineering techniques that use stems or branch parts of living plants as initial and primary soil reinforcing and stabilizing material. When these vegetative cuttings are placed in the ground, roots develop and foliage sprouts. The resulting vegetation becomes a major structural component of the soil bioengineering system.

Nonliving approaches use rigid constructions, such as surface armoring, gravity retaining walls, and rock buttresses. Vegetation can be used in conjunction with nonliving structures to create vegetated structures. Vegetation enhances the structures and helps reduce surface erosion, but usually does not provide any major reinforcement benefits.

Soil bioengineering uses particular characteristics of vegetative components and integrates specific characteristics of structures with vegetation. The resulting systems and their components have benefits and limitations that need to be considered prior to selecting them for use. Herbaceous vegetation, especially grasses, offers long-term protection against surface (water and wind) erosion on slopes. It provides only minor protection against shallow mass movement. Vegetation helps to prevent surface erosion by:

- Binding and restraining soil particles in place;
- Reducing sediment transport;
- Intercepting raindrops;
- Retarding and controlling velocity of the runoff;
- Enhancing and maintaining infiltration capacity.

Herbaceous species are almost always used in con-junction with soil bioengineering projects to add protection against surface erosion.

More deeply rooted woody vegetation provides greater protection against shallow mass movement by:

- Mechanically reinforcing the soil with roots;
- Depleting soil-water through transpiration and interception;

- Buttressing and soil arching action from embedded stems

Civil engineering structures also play a critical role in the establishment of vegetation on steep slopes or in areas subject to severe erosion. They may make it possible to establish plants on slopes steeper than would normally be possible. Structures stabilize slopes during the critical time for seed germination and root growth. Without this stabilization, vegetative plantings would fail during their most vulnerable time.

Materials Structures can be built from natural or manufactured materials. Natural materials, such as earth, rock, stone, and timber, usually cost less, are environmentally more compatible, and are better suited to vegetative treatment or slight modifications than are manufactured materials. Natural materials may also be available onsite at no cost.

Soil bioengineering systems generally require minimal access for equipment and workers and cause relatively minor site disturbance during installation. These are generally priority considerations in environmentally sensitive areas, such as parks, woodlands, riparian areas, and scenic corridors where aesthetic quality, wildlife habitat, and similar values may be critical

Soil bioengineering measures should not be viewed as a panacea or solution for all slope failure and surface erosion problems. Soil bioengineering has unique attributes, but is not appropriate for all sites and situations. In certain cases, a conventional vegetative treatment (e.g., grass seeding and hydro mulching) works satisfactorily at less cost. In other cases, the more appropriate and most effective solution is structural retaining system alone or in combination with soil bioengineering.

Soil bioengineering systems are strong initially and grow stronger with time as vegetation becomes established. In some instances, the primary role of the structural component is to give the vegetation a better chance to become established. It has been shown in slope reconstruction projects that soil bioengineering systems can withstand heavy rainfalls immediately after installation. Even if established vegetation dies, the plant roots and surface residue may continue to play an important protective role during reestablishment.

Once vegetation is well established on a soil bioengineering project, usually within one growing season, it generally becomes self-repairing by regeneration and growth and requires little maintenance. However, newly installed soil bioengineering project will require careful periodic inspections until it is established. Established vegetation is vulnerable to trampling, drought, grazing, nutrient deficiencies, toxins, and pests, and may require special management measures at times.

Bioengineering in Southeast Asia

The use of bio-engineering has been introduced successfully in many situations. Particular success has come from its applications to low-traffic, low-cost hill roads in Nepal. Research in Vietnam has also demonstrated significant potential Other similar areas in South and South-east Asia where bio-engineering has been used successfully are Cambodia, the north-eastern states of India, Kashmir and Bhutan.

With the exception of Cambodia, all of these areas are in an approximately similar eco-climatic band running east-west along the sub-Himalayan zone that straddles the Tropic of Cancer. Combined with broadly similar material and slope characteristics resulting from a shared geological history, this leads to a potential for adopting similar preventative maintenance strategies.

Outside the region, successful applications of bio-engineering have been made particularly in the Caribbean and Central America, and under rather different climatic conditions on the huge networks of forest service roads in the USA and Canada.

Slope stability trials are being conducted in Lao PDR under the SEACAP 21 project. Initial findings during the preparation of SEACAP 21 in Lao PDR have shown that bio-engineering measures alone will not be adequate for the scale of many of the slope stability problems found on the roads. For this reason these require a significant scale of geotechnical engineering structures in order to safeguard roads in particularly unstable sections.

There are two main types of failure from the engineering perspective. The first, and by far the most common (upwards of 200 incidences on the project studied road), is typified by small failures above and below the road. The failure mechanism appears to be due to erosion caused by surface water running down the slope and/or, saturated failure through the poorly drained soil passing its liquid limits on an over-steep artificial cut.

The second type of failure is more serious. It is represented by relatively deep-seated failures along a rotational shear plane, and can result in the loss of the road edge, or displacement of the road itself. Fortunately they appear to be absent in the problems found in the SEACAP project road.

In general the first of these types of failure can be resolved, or even prevented, through the judicious use of slope drainage and surface protection using bio-engineering. An important feature of these interventions is that they tend to involve labour intensive works that yield high employment opportunities for local people.

The second type usually requires complex analysis and may require substantial geotechnical engineering structures, with bio-engineering measures limited to protection of the ancillary earthworks. In some cases these works are possible using relatively low cost measures, as appropriate to the local economy and the likely scale of resources available for future maintenance.

7. Conclusion

Providing and maintaining access to rural communities does not necessarily have to negatively impact on the environment. Careful use of scarce resources and providing environmentally sustainable solutions to access problems can minimise the undesirable effects and contribute to environmental preservation.

As discussed in this paper, gravel, especially good quality laterite in the lower Mekong region, is increasingly difficult to locate resulting in the use of poor quality substandard material in road construction. Rapid deterioration of the gravel pavements results in the need for even more material to rehabilitate the road in order to maintain access. With the constant use of these poor quality materials, the communities and road authorities are locked into an unending cycle of repair with a constant drain on local material resources.

Similarly, the repair of frequent landslides by removing material and cutting back slopes does not solve the problem, which returns year after year with the consequent increasing environmental damage.

Traditional rural road rehabilitation programmes use large quantities of gravel, often of marginal quality, which rapid erodes and requires replacement. Large scale quarry operations to feed these programmes cause environmental problems in their operations and through long haul transport through rural communities. Gravel is an increasingly scarce resource and governments and donors must look at ways of reducing its use while at the same time managing their limited budgets. Similarly, cuttings in mountainous areas must be stabilised as part of the construction and maintenance programmes and included in the scope of projects

These strategies are being investigated and mainstreamed through the DfID SEACAP programme involving bioengineering techniques, spot repairs, the use of robust pavements on problematic sections and the exploitation of small gravel sources can address and help solve these problems.

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