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Engineering in Development: Transport

EWB-UK

Andy McLoughlin & Robin Lovelace

engineers without borders uk

First edition published 2014

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To contact the authors about technical aspects of the book or additional case studies please write to andy.mcloughlin@ewb-uk.org or robin.lovelace@ewb-uk.org for issues regarding roads or vehicles respectively. We plan to update this book as an ongoing project so any feedback will be gratefully received.

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A word from EWB-UK

There are many excellent books about technologies that are appropriate for developing country contexts. But this book is unique. It has been written not just by engineers but by engineers without borders; by the new generation of engineers that are supported by the Engineers Without Borders UK organisation and who are part of a global movement for change.

Engineering in Development is also unique because it will never be a finished product. Rather, it is a process. Its content has been created by the people who use it. And as a process, each edition allows for new material to emerge and existing content to be refined. Though any given edition will never be comprehensive – because the work of EWB-UK's volunteers will never cover every type of technology – each edition marks a new iteration, or new milestone, that gathers the best know-how of the EWB-UK community.

In fact, each edition contains just a selection of all the expertise that is gathered and available on www.engineeringindevelopment.org.

Unlike knowledge, 'know-how' is very hard to transcribe. Craftsmanship is tricky to communicate. Skills are difficult to share. Because of this, EWB-UK struggles to get its volunteers to write down the experience they gain from their work around the world. The core purpose of the *Engineering in Development* process is to transform the act of writing down this 'know-how' into a bite-size project.Without shame, it draws on the inspiration and universal admiration of another book called *Engineering in Emergencies* and its contributors aspire to achieve a similar standard of work.

Engineering in Development can be shared freely and openly, removing barriers to access and enabling others to identify how to use technology to determine their own development.

With considered judgement, the humility to listen and learn about context, and a degree of manual competence, the 'know-how' contained in these pages becomes a very powerful force for good indeed.

Andrew Lamb, former CEO, EWB-UK

Foreword

Many people in the world lack access to basic transport facilities. This is especially true in rural areas, which are less likely to be served by good quality transport infrastructure or public transport. Even in wealthy cities, access to suitable vehicles is limited for many people due largely to financial cost. This situation has a huge human impact, harming access to jobs, education, healthcare, trade and above all else, life chances. Poor transport provision also exacts large environmental and social cost, due to air pollution, road traffic accidents - widespread in many parts of the developing world - and other knock-on effects.

Large scale government funded road building programmes backed up by frequent, reliable and safe transport services have long been seen as the solution to transport problems. Yet these are not always implemented and may be unsuitable for sparsely populated areas. It is in this context that smaller scale solutions are developed. Undertaken correctly, these can be more appropriate for local conditions, lower in cost, and capable of being maintained locally.

This book focusses on such solutions, by looking at what is appropriate for the application of engineering under such circumstances. This includes using labour-based techniques of road construction, and choosing the right type of vehicle appropriate for the local context. Examples illustrating good practice in the field are given. An innovative feature of the book is that it tackles vehicles and roads in the same volume. This is important because vehicles and roads are two sides of the same coin, yet there has been a tendency in previous engineering work in this area to focus mainly on road construction, with little attempt to consider or influence the types of vehicle likely to use them.

The book has also been written so that it can be read by anyone with an interest in the transport development sector and no specialist knowledge is required to read it. References are provided at the back of the book for those wishing to find out more.

We hope you will find this book a useful companion regardless of whether you are about to undertake an overseas placement with Engineers Without Border UK, or merely have an interest in the subject matter.

Andy McLoughlin and Robin Lovelace, June 2014.

1 About this book

Basic transport infrastructure such as safe roads and bridges are largely taken for granted in the developed world yet silently play a major role in society. In combination with suitable vehicles, this infrastructure boosts mobility, allows access to essential services and, when designed well, enables healthy and sustainable travel for all. These benefits become clear in areas lacking basic transportation technologies. In many areas in low-income countries moving food, water and people is difficult and dangerous. Poor quality roads mean that motorised transport further damages critical routes and the local environment, making travel hazardous and unpleasant for other road users. In terms of road accidents and access to medical services, poor transport kills.

Engineering in Development: Transport is about how to address some of these issues from an engineering perspective. This book does not prescribe solutions that attempt to emulate the developed world (where the prevalence of motorised transport has caused its own problems) but is about the role of transport in development.

Following the appropriate technology ethic, 'development' here is defined broadly as improved wellbeing and opportunity. The book focuses on small-scale interventions to improve infrastructure, vehicles and optimise travel behaviours. These projects can realistically be set-up during EWB-UK volunteer placements, in collaboration with local organisations. Initiatives are generally intended to be low-cost and harness local resources such as labour, materials, enterprises and the communities themselves.

The overall aim is to provide a cohesive, concise and practical guide to help field practitioners (such as EWB-UK placement volunteers) maximise the positive impact of transport-related projects. To do this, the book:

- summarises the wider context in which transport for development projects take place
- provides an outline of common transport problems in developing countries

- describes solutions to these problems, and evidence about which are most effective
- outlines case studies and further resources to illustrate the issues EWB-UK transport-related placements are likely to face.

2 Transport and poverty

The role of transport in society is often seen as an enabler of economic growth, providing access to jobs, goods, markets and services. Transport also affects lives directly, allowing social links to be maintained over longer distances, reducing the toil of everyday tasks, and, through greater efficiency, reducing transport-related environmental damage.

A lack of access to reliable transport is a problem for many people in the world, meaning that they have trouble in accessing employment, education and health. Poor rural access translates into high unit transport costs and low earnings for, or wastage of, local produce. Limitations to transport can relate to a lack of transport infrastructure such as a road as shown in Figure 2.1, or the absence of a vehicle, be it a bicycle or bus, to make a journey, at an affordable cost. A lack of access to reliable transport is therefore a major barrier to the alleviation of poverty.

Figure 2.1 – This recently completed gravel road in Ghana makes travel to market much easier (photo courtesy: P. H. Bentall).

Throughout this book we will consider both main components of effective transport systems:

- a viable transport network (infrastructure)
- vehicles such as bicycles, trucks, trailers, cars and carts.

Other factors including long-term funding, a regulatory framework and administrative and operational capability are needed for these two engineered aspects of transport systems to work properly. It is worth considering the wider context in which transport infrastructure and vehicles work effectively together before diving into the engineering 'solutions'; if government does not have the resources or capacity to maintain an extensive road network for example, the road design and maintenance plans may have to be adapted accordingly. Engineering solutions can be thought of as the end-product of a wider process that rests on social, political and economic foundations (Figure 2.2). Many underlying political and economic problems are beyond the reach of international NGOs to solve. However, the vehicle stock and transport infrastructure can be directly affected by engineering projects, hence this book's focus on these elements of the wider problem. This is not to say the wider problems should not be tackled by engineers. Appreciation of the operational environment is vital for developing pragmatic solutions (O'Neill et al., 2010) and dialogue and awareness creation with partners can help to bring about positive changes.

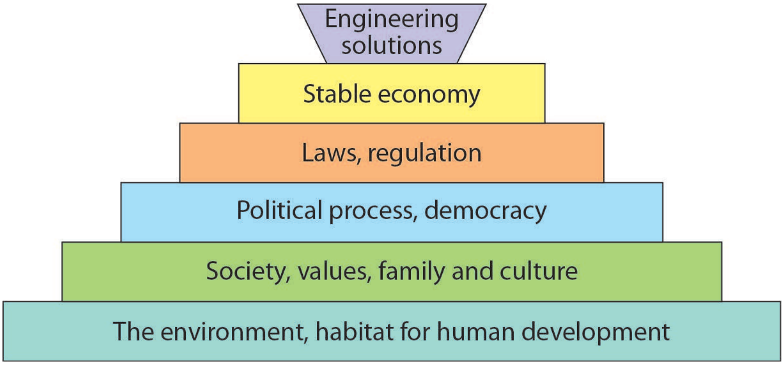


Figure 2.2 – The wider context of engineering solutions for poverty alleviation and development.

Another complexity is that although this book deals with vehicles and infrastructure separately, neither alone is sufficient. It is the interaction between these elements that determines the effectiveness of the transport system. The vehicles used in an area must be compatible with the long-term infrastructure and vice versa. For example, it would be counter-productive to construct a large paved road in an area where car ownership and bus usage is very low. Likewise, it would be unwise to focus on bicycle provision in areas where the terrain and road surfaces make cycling unsafe and inefficient. This should be obvious. However, subtler mismatches between transport infrastructure and vehicles are the cause of many transport problems and the fit between the two elements should be considered early on in EWB-UK project design. Engineers are used to breaking problems up into smaller and smaller manageable chunks – transport can be divided into road construction, road maintenance, vehicle design etc.. However, holistic thinking is needed to provide long-term solutions. In the same way, transport itself should be seen as just one aspect of the development story: what's the point of building a bridge, for example, if there is little demand for crossing it? Perhaps a well sited clinic, market place or school may be a more effective solution than a new or rehabilitated road? Considering cost-benefit and wider knock-on effects is especially important in low-income areas, as every penny must have the best impact. Is the project really necessary? Can it be maintained with local resources after the volunteers have left? Could the money be better spent on something else? As with all projects, these difficult questions must be asked both to the project instigators and, more importantly, the beneficiaries. Critical thinking and strategic planning is especially important regarding infrastructure projects due to the long-term impacts, whereas small vehicles can be replaced relatively quickly.

The recommendations in this book relate to 'affordable' local means of transport and what are normally termed Low Volume Roads (LVR). These can be expected to carry up to 400 motor vehicles (equivalent) per day, and if paving is provided, to be fit to carry a traffic loading of up to 1 million equivalent standard axles (esa).

2.1 EWB-UK's role

EWB-UK's role in a transport context can be split into transport infrastructure and vehicles. Chapters 3 to 7 in this book relate to infrastructure while chapters 8 to 10 are associated with vehicles and communications technology.

3 Infrastructure

There are many different types of transport infrastructure, ranging from roads to railways, from footpaths to cycle tracks, from runways to gravity ropeways and from bridges to culverts. Transport infrastructure also includes the ancillary assets associated with larger scale works such as road signs, traffic signals, street lighting columns, road markings, kerbs and drainage. The list of different elements of transport infrastructure is vast, and easily overlooked by development schemes that are focussed predominantly on improving accessibility.

Typical EWB-UK placements in transport infrastructure involve road building/rehabilitation projects in rural and often remote locations as shown in Figure 3.1.

Figure 3.1 – Remote Dadiyaland in Nigeria is one location where EWB-UK transport infrastructure placements have taken place (photo courtesy: C.Doris and D.Stevenson).

This may include aspects of the design and construction of road structures including small bridges, culverts and retaining walls. An EWB-UK placement volunteer would normally be assisting an NGO that is likely to be funding part if not all of the wider project. EWB-UK placement volunteers typically join such projects at the construction stage. Typical tasks that a volunteer would undertake would be to carry out design checks, to programme the schedule of works for the coming days or weeks, to assist with the physical labour involved in construction, to impart knowledge, skills or experience to local personnel and to work as Acting Task Manager on occasion.

3.1 Accessibility

The greatest economic benefits in terms of transport infrastructure in a development context can be gained from providing basic access (Broch et al., 2004), i.e. reliable all year round access that still functions in the wet season. To provide basic access will normally be the main goal of an EWB-UK transport infrastructure placement.

3.2 Transport infrastructure placements

EWB-UK placements have been run in the past relating to road building and rehabilitation projects in rural areas with low population densities.

3.2.1 Economic analysis

Justification for road building is normally based on economic analysis carried out by governments or their agencies, which are responsible for road development and construction nationally (as described in *Overseas Road Note 5* guidance). As there is rarely enough money available to government to build, rehabilitate and maintain all roads, economic analysis is used to set priorities in order for government to decide which road projects to develop. Priorities are typically developed based on the cost of construction and maintenance over the estimated life of the road versus the economic benefits resulting from the construction of the road. These are normally measured in terms of reduced road user costs (e.g. time savings and reduction in vehicle operating costs). As road user costs are calculated as a function of the number of vehicles using the road, economic analysis tends to favour development schemes that are likely to be used by higher numbers of vehicles. This means that basic access roads in lightly trafficked, remote rural locations are less likely to be prioritised for development by governments since the conventionally measured savings in road user costs may be less than the costs of construction and maintenance.

It is on these type of Low Volume Roads (LVR) that EWB-UK placement volunteers are likely to find themselves working, i.e. those roads that may not be funded for development by government. Efforts are being made to develop analytical tools to better evaluate the wider social, employment and poverty reduction benefits of provision of basic access roads (e.g. *Overseas Road Note 22*).

4 Road design

This chapter outlines the basic design principles likely to be associated with a typical EWB-UK road infrastructure development placement. It explains the purpose of roads as likely to be encountered by EWB-UK placement volunteers and is laid out in the form of key points backed up by appropriate photos and diagrams.

This chapter is not intended to be a comprehensive guide to the design of highway infrastructure, but rather as an overview of the basic knowledge and principles likely to be required by a placement volunteer. References are provided for those seeking additional detail to that provided.

4.1 Introduction

Road access is a component of many development projects, even if not necessarily a project in itself. Often roads are not considered to be an integral part needing proper engineering input compared to other project components and examples of such short-sightedness are commonplace.

Emergency road access works following a natural disaster, for example, often fail to have any lasting benefit, thus wasting time, energy and scarce resources. Roads constructed without due consideration to established engineering principles will not last. Many roads in the world remain in a poor condition and can be impassable, especially in the wet season as shown in Figure 4.1.

Figure 4.1 – Unsurfaced roads can become difficult to use in the wet season (photo courtesy: P. H. Bentall).

4.2 Purpose

Road access may be required for a variety of purposes:

- as part of a national/local road network of varying standards
- as access to rural communities, public facilities; construction sites; agricultural developments; seasonal crop evacuations
- to restore communications after natural disasters
- as temporary links while a more permanent construction is being undertaken.

The purpose of the road is key to its design and construction with respect to user requirements and modes of transport, 'intended working life', standards and specifications to be used, and therefore the costs and resources required.

Figure 4.2 – Overloaded vehicles are often responsible for structural damage to the road structure (photo courtesy: P. H. Bentall).

4.3 Road users

Proper consideration should be given to likely users of the road access, during its design and construction. Potential users may include:

- pedestrians for access to markets often with heavy head loads or panniers
- animal haulage; handcarts; rickshaws (examples of Non-Motorised Transport – NMT)

- bicycles; mopeds; motorcycles; motorised rickshaws
- basic motorised haulage; pickups; saloons
- public transport; light/heavy trucks; 4 wheel drives
- long distance heavy haulage transport.

Potential road users will influence decisions regarding standards of width, gradients, alignments, pavement or surface construction.

As roads must be constructed to withstand the weight and number of vehicles using them, determination of the type and volume of expected road users should be undertaken at the planning stage of any project. Guidance is available in documents such as *Overseas Road Notes 6* and *16*, and national design manuals such as the South Sudan LVR manual.

Provision for mobility impaired and vulnerable road users should be considered where possible (*Overseas Road Note 21*).

4.4 Technology

Design and construction decisions should be based on a choice of engineering technology appropriate to the local situation. For most road works tasks there is a choice of technology to achieve the required standard of construction.

In many areas, abundant labour is an available resource and should be mobilised to the extent possible.

Historically, most of the world's major construction projects were built using labour-based technology and appropriate basic equipment.

It is important to appreciate that the technologies developed for and currently used in the economically developed countries are based on the high cost of labour and relatively low cost and ease of obtaining credit. In developing country situations, labour is relatively low cost and credit is usually expensive and/or difficult to obtain. This suggests that a low capital, local resource based approach is usually appropriate for EWB-UK volunteer assignments; making best use of local labour, local materials, light equipment and hand tools, local enterprises, and minimising imported items.

4.5 Labour

Among the advantages of labour-based technologies are:

- reduction in cost compared to expensive machines
- boost to rural/local economy from labour wages
- reduction in foreign exchange component of construction costs
- creation of a sense of 'ownership' of the project through local consultation/involvement/participation and future maintenance.

Figure 4.3 – Labour based road development projects under construction (photos courtesy: P. H. Bentall).

Some tasks in road construction are more suitable for light/heavy equipment (e.g. soil compaction; long distance haulage and some high standard surfacing). The resources input should be a labour/equipment balance to achieve the specified standards of construction, appropriate to the local circumstances.

4.6 Equipment

It is likely that light or heavy equipment appropriate for rural road construction e.g. tractors, trailers and graders, compacters, concrete mixers etc. can be sourced through local enterprises, government agencies or communities. For the rationale, selection, costing and potential road works applications of agricultural tractors and other intermediate equipment, see the *Handbook of Intermediate Equipment for Road Works in Emerging Economies (2012)*.

Hand tools for use on road works should ideally be of construction rather than agricultural quality. Guidance on specifications is available in the *MoW Tanzania Labour Based Road Works Manual Volume 3*.

4.7 Local participation

Development projects are often specific to a local community. Roads by their nature may serve several communities.

Figure 4.4 – Basic access for communities is needed for vehicle and pedestrian traffic alike (photo courtesy: P. H. Bentall).

All communities/groups/organisations who stand to benefit or who are affected by the road development, should be consulted about the proposal at the earliest possible opportunity. Active participation in the planning, design and ultimate construction should be elicited through whatever local organisation structures exist.

Figure 4.5 – Engagement with local stakeholders is a key factor for ensuring the long-term success of any community focussed road building projects (photos courtesy: P. H. Bentall).

Plans and designs should be adapted to local needs and concerns and other resources to foster a sense of local 'ownership' in the project.

It is important to ensure that all interested stakeholders are fully involved, particularly women and marginalised groups. The consultation process will enable the scope and activities of the project to be discussed and any local cultural or social constraints/ benefits to allocation of particular roles/tasks can be explored.

Figure 4.6 – Ensuring that the needs of women are understood and met is an essential part of stakeholder engagement (photo courtesy P. H. Bentall).

Road development projects can be political, and a common danger is that a local politician tries to commandeer the project for personal political advantage. This aspect needs to be handled sensitively as conversely the politician may be able to mobilise some resources or facilitation.

Communities may be able or asked to contribute some human and/or material resources to the project and any employment opportunities should be carefully allocated. It is preferable to encourage a partnership arrangement than a recipient-without-responsibilities culture.

Particularly in the case of a road, subsequent maintenance is vital for sustainability and local participation is a key factor, in order to give a sense of project ownership to the community and also develop their knowledge of how to maintain the road.

The following case study of a EWB-UK placement demonstrates how effective community engagement can help to make a project successful.

Case study: Pamplona community suspension bridge

Daniel Gallagher, Ecuador, 2009

In 2009, EWB-UK volunteers Daniel Gallagher and Mariam Niknejad travelled to Pamplona, Intag in the Ecuadorean Sierras to re-establish an important community footbridge crossing that had been damaged by floodwater.

The project began with a community consultation, which helped identify the high water mark so that the bridge could be constructed above this level. A bridge inspection then followed which showed the timber deck had rotted beyond repair, but that the stone and concrete foundations were sound. A standard suspension bridge design was then agreed, sourced and adapted to the local context, with design and drawings undertaken back in the office. The bridge was designed with a live load allowance to allow laden cattle to cross.

Construction involved manual excavation for new pad foundations and anchorage blocks, steel fixing of reinforcement cages, batch mixing and pouring of concrete, installation and tensioning of suspension cables, and erosion defence work. Community members worked voluntarily on the project which was completed within ten weeks and before the wet season started.

Figure A – The bridge during construction.

Figure B – Completing the new deck.

A particular success of the project involved using local community knowledge to develop innovative solutions. For example, a zip-line was used to transport materials from the roadside to the inaccessible bridge site. Also, locals knew that cut-off sections of rubber tyre could be used for bearing pads to allow thermal expansion of the bridge deck without overly stressing the foundations. This local knowledge ensures that the bridge can be maintained by the local community.

A particular challenge on site was managing health and safety. Children and families had to continue using the existing bridge during construction and the lack of mobile phone signal and difficult terrain meant that even minor injuries could have had serious consequences. Educating parents and children of the dangers of construction was part of the risk management strategy that ensured the project was completed without incident.

Lessons learned:

Engineers are most effective when acting as a broker of technical advice rather than a provider of solutions. Listening carefully to the community's needs, finding solutions that had worked previously and then validating suggestions with engineering rigour made sure that the decision-making process was effective, participative and that the community had confidence in the solution.

Engineers need to understand risks and be aware that safety is challenging in remote areas. Risks were reduced by minimising excavation and minimising working at height. Residual risks were minimised by making everyone aware of the dangers.

Engineers in developing countries should respect the limits of their knowledge. Development engineers abroad are continually faced with complex challenges that they don't have all the answers to. It was reassuring to have contact with Bridge Engineers I had worked with back in UK to help overcome technical challenges.

Ultimately, the project was successful in constructing a new bridge that restores a key link between two parts of a community. The main impact was to improve primary education levels through higher school attendances. Secondary impacts include longer-term improvements in infrastructure that comes with the community members' increased knowledge of construction methods and health and safety.

About the author: Daniel Gallagher graduated from the University of Glasgow's School of Civil Engineering in 2008 and began working as a Consulting Engineer in the UK, before taking up the placement with EWB-UK. He has since set up a social enterprise and carried out a Master's Degree in Engineering for Sustainable Development at the University of Cambridge. He now works for the World Bank.

5 Materials

5.1 Soils

Roads are built onto existing soils and the rock formations beneath. Around the world, there are many different types of soils such as those shown in Figure 5.1. Those that are most likely to be encountered are described in this chapter. Some of the soils can be used in the construction of pavement layers. Where the properties are deficient for various pavement layer or surfacing requirements, they may sometimes be improved by stabilisation techniques: mechanical (physical blending/mixing), lime, cement, bitumen, emulsion. Specialist advice should be sought.

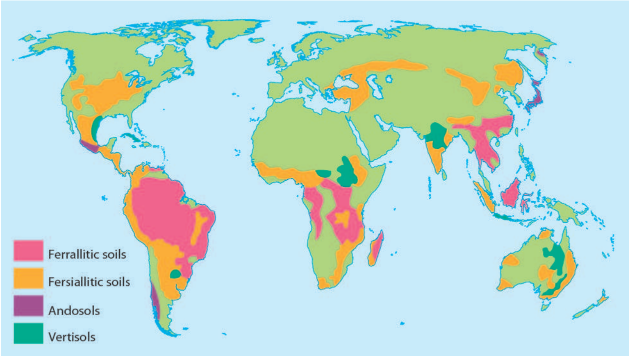


Figure 5.1 – Global distribution of the principal types of tropical residual soils (Millard, 1993).

Laterites

The most widely occurring concretionary tropical soils are the laterites, weathered oxidic iron rock in a sandy/clay matrix. Lateritic gravels as shown in Figure 5.2 are used for un-surfaced roads and as sub-bases and roadbases. They compact easily and harden to concrete-like material on exposure to air. They occur extensively in South America, tropical Africa, and southern Asia as shown in Figure 5.3.

Figure 5.2 – Laterites are easily recognisable by their distinctive colour.

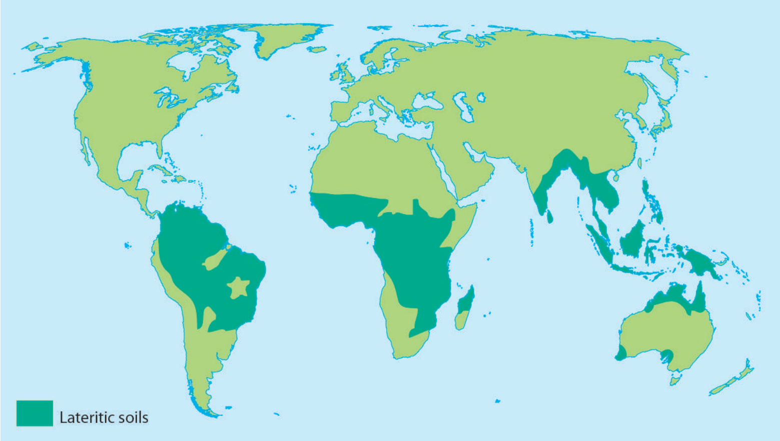


Figure 5.3 – Global distribution of lateritic soils (Millard, 1993).

Calcretes and Silcretes

Calcretes and Silcretes as shown in Figures 5.4 and 5.5 are found in many desert areas. Although softer generally than laterites, water and compaction can produce concrete-like material.

Figure 5.4 – Calcrete soil.

Figure 5.5 – Exposed silcrete formation.

Alluvial gravels

Alluvial gravels as shown in Figure 5.6 occur in the upper reaches of most rivers from where the eroded stone has been carried downstream with silt/sand. They may be suitable for concrete aggregates, but may require to be crushed/screened.

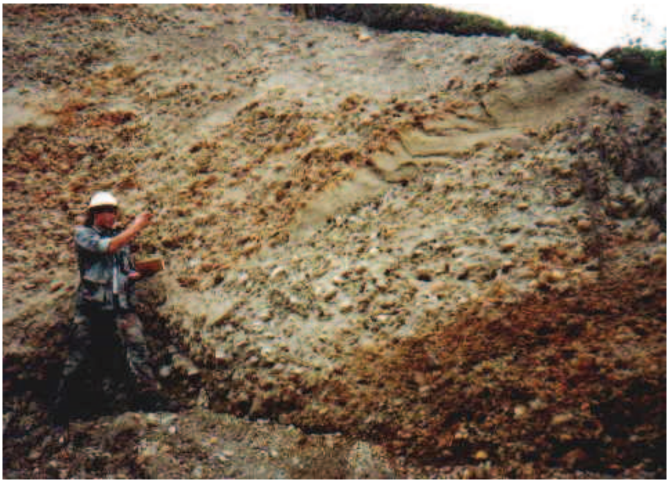


Figure 5.6 – Alluvial gravels.

Quartzitic gravels

Quartzitic gravels as shown in Figure 5.7 derive from the weathering of granite and acidic rocks and where they contain iron oxide leached from above form laterised quartz gravels appropriate for road pavements. They can also usually be crushed/screened to be suitable for concrete.

Figure 5.7 – Quartzitic gravel (photo courtesy P.Stoffer, USGS).

Volcanic soils

Some volcanic soils as shown in Figure 5.8 can be used for lightly trafficked gravel roads. Blast-furnace slag is a stronger alternative where available.

Figure 5.8 – Volcanic soil (photo courtesy: A. McLoughlin.)

Figure 5.9 – Expansive clay.

Expansive clays

Expansive clays (montmorillonite) as shown in Figure 5.9 and black cotton soil occur widely in tropical/sub-tropical regions. They exhibit dramatic changes in character between wet and dry seasons. In the dry, they shrink rapidly causing block pattern fissures, and in the wet they re-expand rapidly and at high moisture content can become almost liquid. They are generally avoided where possible in road construction, but if the moisture content can be controlled around the optimum with suitable protection, they can be used for low embankments.

Specialist advice is recommended where these soils are encountered.

Desert soils

Desert soils as shown in Figure 5.10 are predominantly wind-blown sands, shifting with the prevailing wind along the desert floor. Often they are difficult to traverse even in four-wheel drive vehicles, and too loose to provide a firm road sub-grade without deep compaction involving heavy equipment, or by stabilisation.

Figure 5.10 – Desert soils (photo courtesy: Basin and Range Watch).

Topsoil

The surface layer of soil in which plants and vegetation grow is the topsoil. Topsoil contains organic matter and changes properties significantly with season and moisture content. It is unsuitable for road building and must be removed before construction on top of the sub-grade (the sub-soil) can begin. Due to the high rainfall that can be experienced in tropical zones, the layer of topsoil may be thin or non-existent.

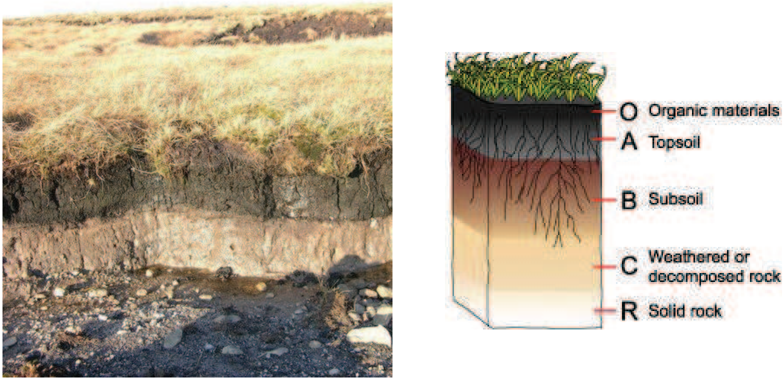


Figure 5.11 – Topsoil and the layers beneath.

5.2 Natural rock

Choosing natural rock for road building purposes, and concrete aggregates will need analysis by a qualified materials engineer as some may change properties or deteriorate on exposure to air or moisture.

Rock may be quarried by hand and shaped for structures and paving units. It may also be hand crushed and screened for concrete aggregates. Masonry structures can be mortar jointed, or where the local skills exist can be dry jointed (thereby saving the need for expensive cement).

In many communities, masonry skills are established for building construction and can be beneficially mobilised in the road works.

Figure 5.12 – Calcrete mining (photo courtesy: M.Holker).

5.3 Bitumen

Bitumen grades (called asphalt in USA) available in-country will have been chosen to suit the local climatic conditions. Different grades are used for different applications from surface dressing to pre-mix macadams to asphalt-concretes. Specialist advice is recommended.

Use of bitumen-based surfacing has a number of advantages including:-

- sealing the road surface to reduce the ingress of water into the road structure
- prevention of vehicle generated dust
- improved skid resistance
- lower maintenance compared to gravel surfaced roads
- reduced road/tyre noise level.

Figure 5.13 – This former gravel road has been recently upgraded to a bituminous standard (photo courtesy: A. McLoughlin).

However, often the bitumen products have to be imported with a high cost implication. Penetration and cutback bitumen grades usually require heating for their application. Bitumen emulsions can be used without heating for many surfacing, paving layer and stabilisation techniques and are more suitable for safe labour-based applications. Pre-mix macadams and asphalt concretes require expensive capital equipment and high levels of testing and quality control. Unless such production facilities are already established in the area, it will be expensive and problematic to mobilise and use these.

5.4 Timber

Local timber is often commonly available and where it is proposed for structural work in bridges/culverts it is important that it is durable and unlikely to be affected by insects such as termites, or fungi, both of which can dramatically shorten the service life of any timber structure. It can also be used for temporary works and formwork. Local treatment practices should be explored.

In some locations, timber applications for piling and matting in soft ground are established. They can provide medium term solutions in difficult conditions.

In many communities, carpentry skills are established for building construction and can be beneficially mobilised in the structures' works.

Figure 5.14 – Timber deck culvert (left) and timber deck bridge (above) nearing completion (photos courtesy: P. H. Bentall).

5.5 Cement and lime

Cement is commonly used for concrete and mortars in structures (bridges, culverts, retaining walls). It can also be used for stabilisation of sands and gravels, and for making surface paving units. Cement can be expensive and sometimes has to be imported. Lime can be used for stabilisation of fine-grained soils (clays).

5.6 Fired clay brick

Figure 5.15 – Beehive or bell shaped kilns for rice husk firing of clay bricks suitable for road paving and structures (photo courtesy: Bach The Dzung).

Clay bricks may be fired with coal, gas, wood and even agricultural waste products such as rice husk. Burning bricks in 'clamps' is a tradition established in many rural areas. However, they are usually only of sufficient quality for use in simple domestic building structures. High strength bricks can be produced from agricultural waste (e.g. rice husk) using simple kilns. Crushing strengths of more than 20 N/mm^2 are achievable. These bricks are suitable for structures and road paving (Dzung and Petts, 2009 includes a design for a small scale kiln). An added advantage is that these bricks are environmentally attractive as the CO^2 produced in brick production firing is only a portion of the CO^2 taken up in the crop growing process.

5.7 Steel

Steel can be used for reinforcing concrete and as structural members. Unfortunately, this is usually imported and of high cost. Gabion baskets and mattresses filled with rock pieces can be used for relatively low cost retaining and anti-erosion structures. The cages can be assembled from imported units or can be woven locally using steel wire.

6 Specific Design Aspects

6.1 Introduction

The first consideration is whether there are established national design standards, specifications or manuals for the category of road that is being considered for the EWB-UK volunteer assignment. Often, these can be non-existent for Low Volume Roads (LVR), deficient, or out of date. If existing, there will be an obligation to use them. However, the recommendations in the following text are based on recent research and accumulated good practice in a number of economically developing regions and can serve as a basis for discussion and agreement regarding achievement of appropriate, affordable and sustainable designs for the assignment road(s). Any designs should be approved by the authority responsible for the road, whether central government, local government, community or private.

In developing countries, substantial proportions of the rural road network are earth or gravel surfaced.

Figure 6.1 – Post-construction gravel-surfaced roads in Ghana (left) and Zimbabwe (above) (photos courtesy: P. H. Bentall).

Earth roads can be constructed from the in-situ soil in many circumstances by shaping into a compacted camber (typically 4%–7% crossfall) and providing a proper drainage system of side drains, turnout drains and cross drainage such as culverts, drifts or bridges.

In-situ soils with a strength of CBR[1] 15 or more are usually suitable for light traffic (up to 50 motor vehicles equivalent per day). Some soils can become too weak or slippery in wet weather. Longitudinal gradients of more than 6% will quickly become eroded in rain. Most earth roads can be very dusty in the dry season causing problems for residents and crops alongside roads. However, a maintained earth road can be an important component of affordable Basic Access.

A route that is predominantly to earth standard can provide year round access at lowest cost if:

- it is maintained (principally camber and drainage)
- limited problem sections, such as weak soils, steep gradients, low lying, etc. are treated with spot improvements of better quality surface or raised embankments.

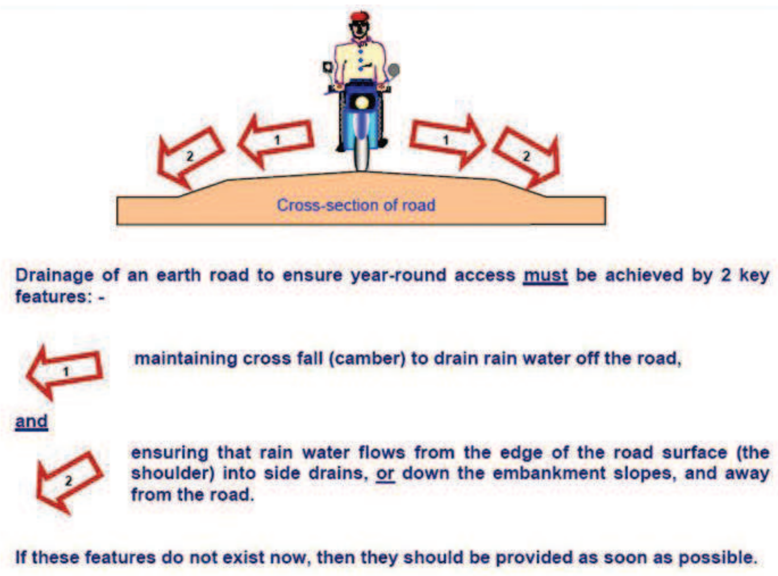


Figure 6.2 – Earth road drainage (image courtesy R. Petts).

1. *California Bearing Ratio. This can be measured in-situ using a low cost Dynamic Cone Penetrometer (DCP)*

A maintained, cambered and drained earth road surface on most soils will normally quickly drain and dry out after a rainstorm, allowing normal traffic to resume safely within hours, without severe damage to the running surface.

If available within reasonable haul distances, natural gravel can be added to the shaped and drained earth formation to provide a basic all-weather road. This surface is suitable for traffic of between 50 and 200 motor vehicles per day (vpd). Unfortunately, gravel surfaces also erode due to the action of traffic and weather and need to be maintained regularly (routine: camber and drainage) and the lost surface materials need to be periodically replaced by re-gravelling. Recent research (Cook and Petts, 2005) has recommended that gravel should not normally be used as a running surface where:

- traffic is more than 200 motor vehicles per day
- annual rainfall is greater than 2,000mm
- gradient of road surface is more than 6%
- through community settlements
- the haul distance from the quarry/pit to the road site is more than 10km
- the road section experiences flooding, or
- the gravel is of poor quality.

There are however many proven alternative surfacing and paving options suitable to provide all-weather access at relatively low cost, using local materials and that can be constructed using local labour with the provision of suitable training and supervision (Cook, Petts & Rolt, 2013). In whole-life cost terms and reduced (more manageable) maintenance requirements, these surfaces can be more attractive than gravel.

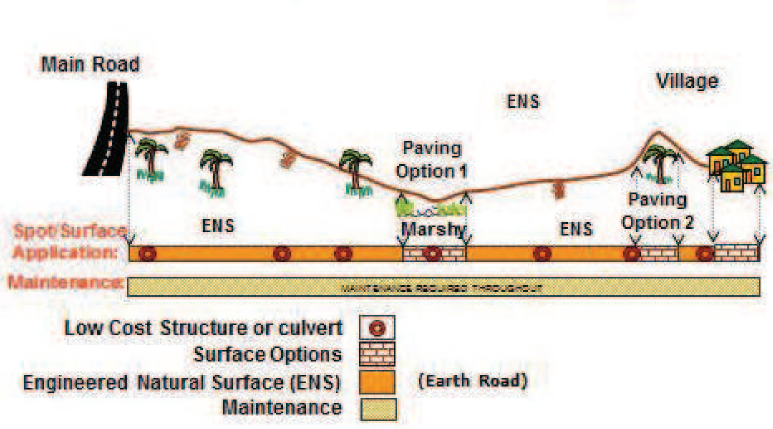


Figure 6.3 – Basic Access concept using Engineered Natural Surface – ENS (earth road) and spot improvements (image courtesy: R. Petts).

The major threat to any road is water. Roads should be designed to prevent ground-water encroachment and actively manage rainwater to minimise damage to the road and adjacent areas. New roads interfere with natural drainage patterns and need special attention to be given to drainage measures. Existing tracks/roads may simply require drainage to be upgraded and/or amplified.

Figure 6.4 – Inadequate drainage (left) and upgraded drainage (right) (photos courtesy: A. McLoughlin).

6.2 Alignments

Road alignment can be thought of as a 3D problem that is broken down into two 2D components. These are:

- horizontal alignments (plan view)
- vertical alignments (profile view).

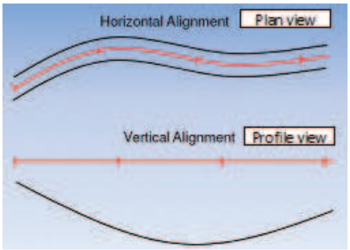


Figure 6.5 – Horizontal and vertical alignments.

The vertical and horizontal layouts of a road form the alignments and these are primarily dictated by the topography and design speed selected.

Construction costs can be minimised by allowing the road alignments to take the form of natural topography where feasible, thus minimising earthworks.

Horizontal alignment

Horizontal alignments are made up of straight sections, arcs, and transition curves between them. The arcs are usually segments of a circle providing a smooth flow of vehicles along the curve. The primary challenge in determining horizontal alignments is to ensure that transitions between different directions are both safe and comfortable for road users. A minimum horizontal radius of 50 metres should be used for a road design speed of 40 km/h. Sharp bends should be smoothed out. Radii have to be relaxed at hairpin bends in severe terrain.

Vertical alignment

Vertical alignments are made up of straight sections known as grades or tangents, connected by vertical curves. The objective of vertical alignment is to determine the appropriate elevation to ensure safety and allow for adequate drainage.

In rural areas, earth and gravel roads are frequently developed along the line of tracks formed by pedestrian traffic. To accommodate vehicles, gradients should ideally be < 6.7% i.e. a 0.2 metre change in rise for every 3 m in the horizontal plane as shown in Figure 6.6.

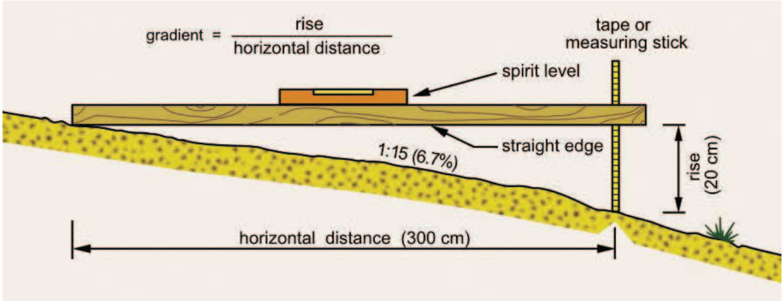


Figure 6.6 – Measuring the gradient using simple equipment (ILO, 2008).

At steeper gradients erosion by surface water is a major concern. Steeper gradients up to about 15% can be accommodated by some surface/paving options. However, these can be unsuitable for animal drawn vehicles and some other Non-Motorised Transport (NMT).

Vertical alignments and curves

Vertical curves provide a smooth and gradual change from one tangent grade to another to ensure that vehicles run smoothly. They are normally parabolic in shape and the vertical curves are based on the principles of a parabola. The two types of vertical curves are:

- crest vertical curves
- sag vertical curves.

Crests occur where the road moves from a positive to a negative gradient, such as at the brow of a hill. Sags occur where the gradient moves from a negative to a positive gradient, such as at the bottom of a valley. Examples of both are shown in Figure 6.7.

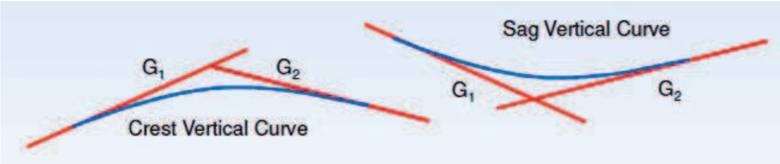


Figure 6.7 – Crest and sag vertical curves.

Determining the transition between two grades to form a vertical curve for a crest or sag is the primary challenge in designing vertical alignments.

Further details relating to selecting a design speed and appropriate horizontal and vertical alignments is available in *Overseas Road Note 6,* and also in the *Ministry of Roads and Bridges Government of South Sudan (2013), South Sudan Low Volume Roads Design Manual.*

Difficult terrain

In mountainous areas steeper grades and sharper bends may be unavoidable as shown in Figures 6.8 and 6.9 and bituminous, concrete or other surfacings over certain lengths may be considered to reduce erosion damage and promote safe passage.

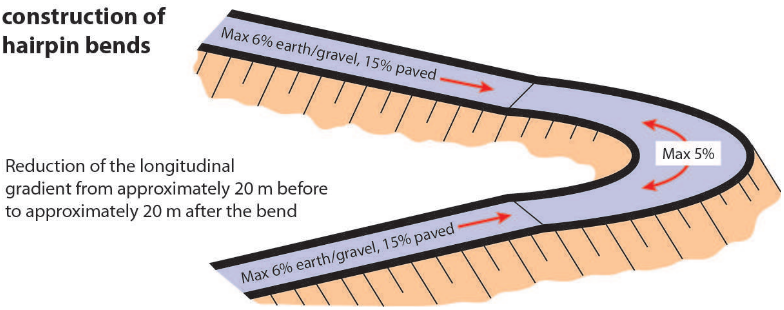


Figure 6.8 – Recommendations for hairpin bends (image courtesy R. Petts).

Figure 6.9 – Constructing a road with bends in mountainous Nepal (photo courtesy: P. H. Bentall).

Vertical gradients can be reduced by forming cuttings through hillsides and embankments over valleys, consistent with the desired design speed for the road.

Long level lengths of road should be avoided to eliminate the risk of water ponding, but if this is unavoidable the vertical alignment should be designed at least 50 cm above existing ground level to mitigate that risk.

Further details relating to principles of low cost road engineering in mountainous regions is available in *Overseas Road Note 16*.

6.3 Sight distances

Stopping sight distance

The minimum stopping sight distance is the distance at which a vehicle can stop after seeing an object in the vehicle's path without hitting the object. It is made up of the time taken for a driver to recognise the need to apply the brake (the perception-reaction time) and the time taken for a vehicle to stop after applying the brake (the stopping distance).

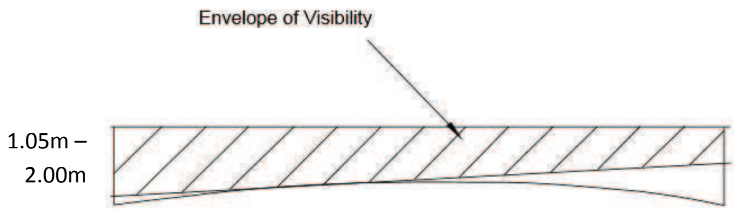


Figure 6.10 – Measurement of stopping sight distance (DMRB, 2002).

The stopping sight distance dictates the minimum length of both horizontal and vertical curves, since minimum visibility distances must be maintained along the route for safety purposes.

Overtaking sight distance

The overtaking sight distance is that required to allow a driver to complete a passing manoeuvre without colliding with an opposing vehicle or cutting off the passing vehicle. It should also allow the driver to abort the passing manoeuvre and return behind the vehicle being passed if required.

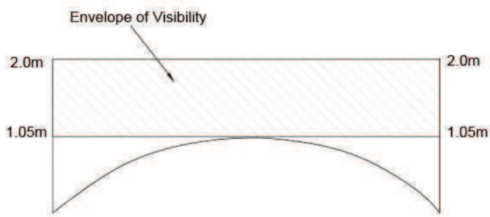


Figure 6.11 – Measurement of overtaking stopping distance (DMRB, 2002).

Further details relating to the principles of stopping sight distances can be found in the *Design Manual for Roads and Bridges, Volume 6, Section 1, Part 1, TD 9/93.*

Note that engineering judgement and local knowledge must be used in conjunction with design guidance, since assumptions over the condition of vehicles and road surfaces in the context of rural environments in developing countries may be different to those from which the design guidance was formulated.

6.4 Earthworks

Earthworks relate to pre-construction site clearance, excavation and the movement of soil and rock. Earthworks should be kept to a minimum and an optimum vertical alignment will ensure that material from cuttings can be placed in adjacent embankments with the minimum of haulage. Due adjustment should be made for the compaction factor cut/fill.

Material can be hand-cast up to a few metres, or wheel-barrowed, head-loaded, stretchered or panniered up to about 100 metres. Carts or equipment haulage are usually required for longer haulage distances. Significant earthworks will add substantially to the works' costs.

Figure 6.12 – Labour based earthworks (photo courtesy: P. H Bentall).

Embankments should be specified to be constructed in layers appropriate to the compaction equipment to be used, the standard of compaction required (e.g. 95%–98%) and the optimum moisture content (OMC) for the material.

Figure 6.13 – Applying water to the road formation to achieve the OMC before compaction (photos courtesy: P. H Bentall).

In-situ compaction testing is possible if appropriate apparatus is available. An alternative is a method-specification based on the type of equipment and local knowledge of the behaviour of the material, otherwise compaction until no observed movement under the roller will suffice for some materials.

6.5 Drainage

Well-designed drainage is essential to ensure that damage to the road surface and structure is minimised, and to avoid problems at points of discharge to the adjacent land. Prevention of damage to the sub-grade should be a major priority since structural damage to the road will require extensive works to rectify.

Road surface

Rainfall should be drained away from the road surface as shown in Figure 6.14.

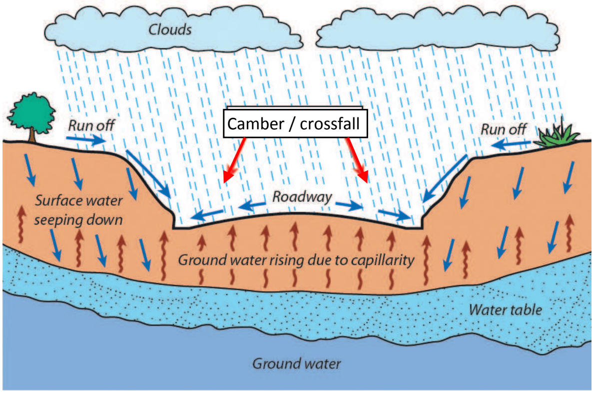


Figure 6.14 – The relationship between roads and the water cycle (ILO, 1990).

Road surface drainage is affected by constructing the carriageway with a camber or crossfall. Initially this should be 6% or 7% for an earth or gravel surface, which will reduce gradually under traffic action and weathering. The camber should be maintained between 3% and 7%. For paved roads, less crossfall is required and this is typically specified as 2.5%–3%.

Roadside drainage

Side drains carry water away from the road and prevent surface water from the surrounding ground from reaching the road as shown in Figure 6.15.

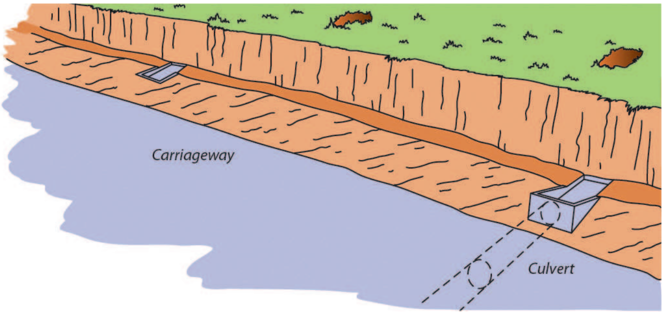


Figure 6.15 – Side drains collect surface water from the road and embankments to be discharged at suitable locations or through culverts (ILO, 1990).

Ditches constructed by grading equipment are usually V-profile. However, using labour-based techniques it is easier to construct ditches of trapezoidal section. This is also preferable to a V-section for better flow and erosion characteristics.

Minimum ditch gradients should be 2% to minimise silting and on steep sections if > 4% then scour checks are required to minimise erosion as shown in Figures 6.16 and 6.17. Spacing of these decreases from 20 m to 5 m with gradients of 4%–10%.

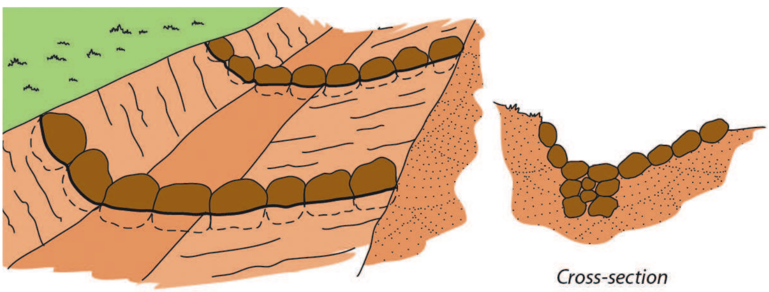


Figure 6.16 – (above) scour checks in a ditch using stones (ILO, 1990).

Figure 6.17 – (right) scour checks installed on site (photo courtesy: P. H. Bentall).

Catchwater (intercepting) drains of trapezoidal section may be required above the road on sidelong ground and in cuttings to prevent overground water reaching the road as shown in Figure 6.18. However, these can promote slip circles in the cutting face. An alternative technique is to construct a bund back from the top of the cut face to intercept runoff water and direct it to a safe discharge point.

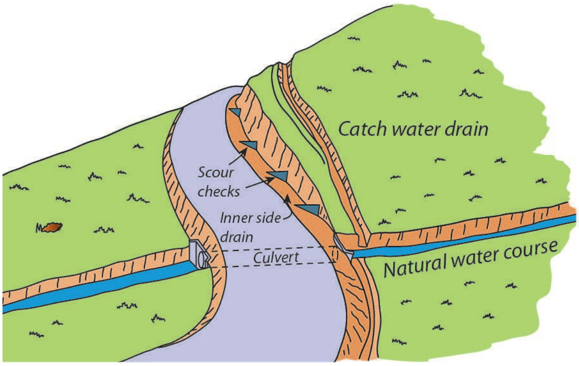


Figure 6.18 – Catchwater drain situated above the cutting (ILO, 1990).

Turnout drains are specified to lead water from the side drains to adjacent land at convenient points where no erosion damage will result as shown in Figure 6.19. Where possible, these should be constructed at 20 metre intervals on the basis that 'little and often' will minimise erosion risks or siltation on adjacent land, and the risk of land users blocking them off.

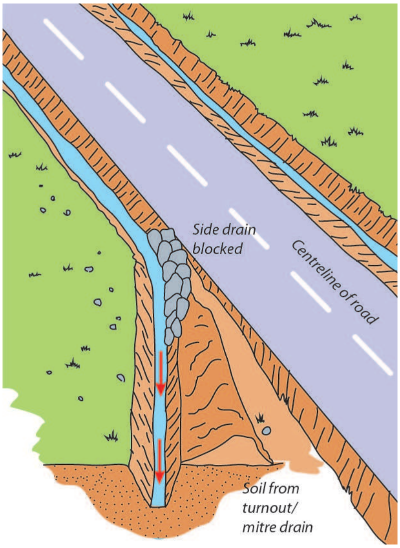


Figure 6.19 – Turnout drain (ILO, 1990).

Cross drains are required to accommodate existing water courses and where water in side drains needs to be transferred as shown in Figure 6.20. Pipe sizes and culvert openings are designed on normal hydraulic principles, with minimum pipe diameter/openings of 60 cm to allow easier maintenance.

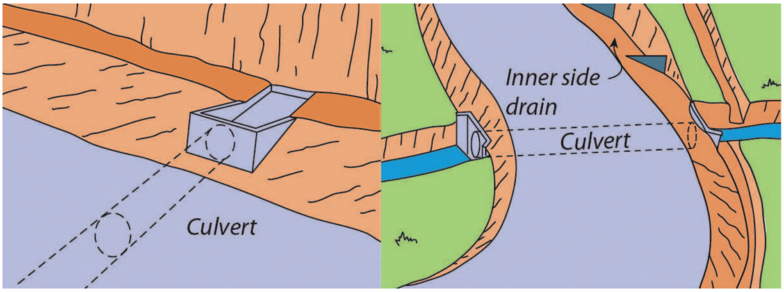


Figure 6.20 – Cross drainage (ILO, 1990).

Culverts may be of pre-cast pipe concrete, cast in-situ concrete, stone masonry, treated timber or fired clay brick. Drifts can be used to discharge water across LVR where there is insufficient depth for a culvert and adequate cover under the road surface, or on bedrock. Standard designs and specifications exist for pipe and box culverts; inlets and outlets; short-span bridges; and they should be consulted e.g. the *Small Structures for Rural Roads Guideline* and *Overseas Road Note 9*.

Small bridges for rural roads can be concrete, stone masonry, fired clay brick or timber; single or multi-span depending upon the water flow and traffic volume. An example of a single span bridge structure is shown in Figure 6.21.

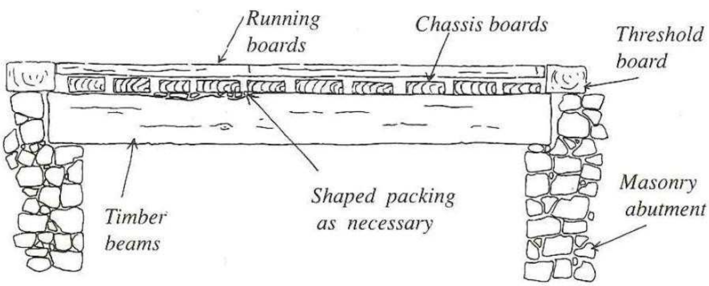


Figure 6.21 – An example of a timber decked bridge structure (ILO, 1990).

Larger structures in steel or reinforced concrete should be subject to a full rigorous design process by qualified engineers to reduce the risk of structure failure as shown in Figure 6.22.

Figure 6.22 – The failure of this steel reinforced concrete bridge illustrates the need for appropriate design and construction (photo courtesy: A. McLoughlin).

6.6 Pavements

Basic principles

In road engineering, the term 'pavement' refers to the road surface and its underlying structure. The pavement is constructed on the subgrade or road (earthworks) formation. One or more of the pavement layers shown in Figure 6.23 may be required to satisfactorily spread the traffic loading stresses so that the subgrade can accommodate them. In some situations an 'improved subgrade' may be adopted to improve the properties of the in-situ material (e.g. by stabilisation).

The basic principle of pavement engineering is to distribute vehicle loads over a larger area than the area the vehicle is in contact with as shown in Figure 6.24.

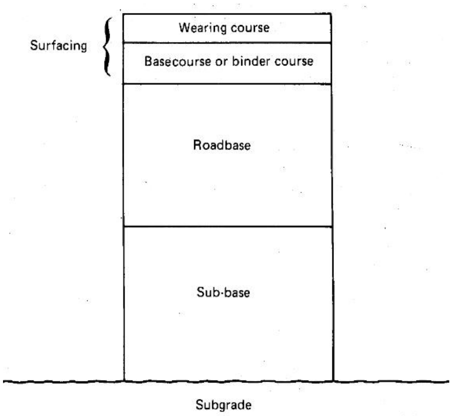


Figure 6.23 – Typical structure of a road pavement (TRL, 1993).

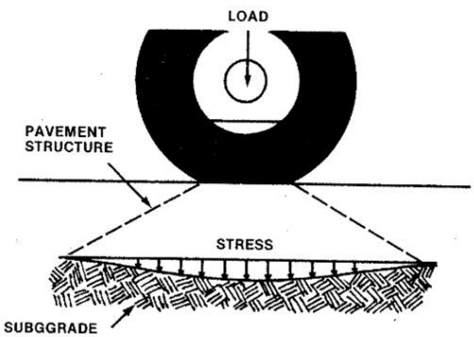


Figure 6.24 – Road pavements work by spreading loads over a wider area.

In general, the thicker and/or stiffer the pavement, the heavier and the higher number of vehicles it can support without failing.

At its most basic, selecting the appropriate thickness and stiffness for the layers of the pavement is a function of the load bearing capacity of the soil under the road (usually measured by its California Bearing Ratio or CBR), the weight and number of vehicles expected to use the road, and the loading time of the vehicles expected to use the road; i.e. stationary and slow moving vehicles have the potential to cause more damage to the road pavement as they have longer loading times.

Pavement Structure

Road pavements are usually said to be either flexible (e.g. bituminous) or rigid (e.g. concrete) in nature and examples of both are shown in Figure 6.25.

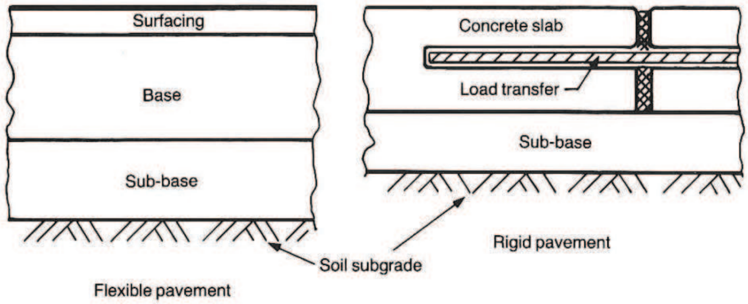


Figure 6.25 – Typical structures of flexible and rigid pavements (Millard, 1993).

Incremental paving such as stone setts or concrete/brick pavers are usually characterised as rigid.

In developing countries, paved rural roads are predominantly flexible with a thin bituminous seal surfacing. They usually have base and sub-base layers consisting of the best locally available material to minimise the haulage costs associated with carrying construction materials to site.

Standard road design criteria are recommended by *Overseas Road Note 31*. Recent national LVR manuals, such as South Sudan, incorporate good practice and recent research that can be considered for adaption to local circumstances if no local guidance exists.

Engineered Natural Surface – ENS (Earth Roads)

These are the lowest cost type of roads and do not have a 'pavement'. Engineered Natural Surface (ENS) roads utilise existing or immediately adjacent materials along an alignment to form a shaped and drained low-cost basic rural access road. The nature of these natural materials can vary from clayey/sandy soil to weathered rock. The suitability of this option must be assessed in the light of the likely impact of the Road Environment factors. The option involves the shaping and compaction of existing in-situ or immediately adjacent material to form a basic surface for traffic with a cross-fall of 3% to 7% away from the road centre line to disperse rainwater into side drainage. Alternatively the surface may be raised above surrounding ground on embankment. Soils with an insitu CBR of 15 or more can provide good ENS. Longitudinal gradient should not be more than 6% due to weather related erosion factors. Problem sections of the route should be considered for selective upgrading or spot improvement to other surface/paving types.

Soils that are predominantly sand will not hold a camber shape and should be left with a flat cross section as they will normally be free draining. Some sandy soils can be difficult to pass over with vehicles. They can be possible to stabilise by mechanically mixing in fine material (clay) to improve performance.

Gravel

Gravels are commonly used as a surfacing material for rural roads in developing countries. Gravel is normally the next cheapest alternative to ENS in terms of initial costs. However, the need for regular re-gravelling to replace lost surface material can make gravel surfaces more expensive than some paving options in whole life cost terms.

The gravel is transported to the road site and placed on a previously shaped and compacted in-situ earth subgrade. The gravel is shaped, watered and compacted to the required finished profile. Gravels are derived from a number of natural processes and usually occur in limited deposits of usable particle grading. The gravel should be laid to the same crossfall with a constant thickness. Maximum particle size is 40 mm for good performance and to avoid high material loss and surface roughness problems. Oversized materials can be screened or hand-picked out. The overall constructed gravel thickness is typically 15 cm–30 cm. Individual gravel layer thickness is usually up to 15 cm (compacted) maximum. Deficient natural gravel can be blended with selected soil/sand to improve quality.

Gravel as a running surface is a wasting resource under the action of traffic and weather. In dry conditions, finer particles disappear as dust and coarser particles are displaced into the ditches. In wet weather, surface material is eroded. With surface gravel losing typically 30 mm–50 mm per year, a re-gravelling operation should be expected every 3–6 years. Excessive clay may render the road impassable in the wet season, but too little and the surface becomes loose and a driving hazard.

Paving options

A wide range of other surfacing and paving options are proven and many can make good use of local labour and materials resources. Synthesis of research and good practice are contained in the *Low Volume Rural Road Surfacing and Pavements Guideline* (Cook et al., 2013). For a road intended to include a surfacing layer, attention needs to be paid to the sub-base and roadbase layers to ensure sufficient strength for the anticipated traffic loads. These layer options may be:

- crushed stone for dry-bound/wet-bound macadams
- natural gravels (lateritic/quartzitic)
- cement/lime stabilised in-situ or imported material (specialised design)
- bitumen stabilised in-situ or imported material (specialised design)
- cement-bound granular
- lean concrete
- hand packed stone.

Such pavements will need the full design process by a qualified road engineer.

Bituminous surfacings

Bituminous surfacings are another specialist area and can be:

- asphaltic concrete (continuously graded aggregate/bitumen mix)
- rolled asphalt (gap-graded aggregate/bitumen mix)
- mastic asphalt, which is often used on bridges (fine aggregate/bitumen mix).

However, the above bituminous surfacing are normally too expensive for LVR application. The following are usually more applicable:

- in-situ mixes (Otta Seal, bitumen spray on graded aggregate layers, penetration macadam)
- surface dressing (bitumen spray and chippings, 1 or 2 layers)
- sand or gravel seals
- combination chip and sand seals (e.g. Cape Seal).

Road surfacings will need a full engineering design. The advantage of a surfacing, even a single surface dressing, is the protection of the base layer from deterioration by traffic and weather, but regular maintenance is essential to prevent potholes forming.

Further details relating to selecting bituminous surface materials are available in the *Manual For The Labour-Based Construction Of Bituminous Surfacings On Low-Volume Roads (2003).*

Concrete pavements

Concrete (rigid) pavements are not used extensively in the tropics, although some well designed and constructed examples have given excellent service for many years.

Lack of consistent standards of concrete and thermal strains induced by variations in temperature are the main problems. However, with good design, supervision and quality control a local building contractor can produce concrete of adequate quality for road works.

For rural roads the use of concrete is usually confined to spot improvements and drifts across stream beds as shown in Figure 6.26. Concrete strength of 20 N/mm^2 at 28 days laid at a minimum thickness of 125 mm is recommended for drifts. Edge, cut-off and anti-erosion detailing are important design issues. In areas subject to frost occurrence, the required strength should be increased to $25N/mm^2$. Drift mesh reinforcement to limit thermal cracking should be laid at around half slab depth.

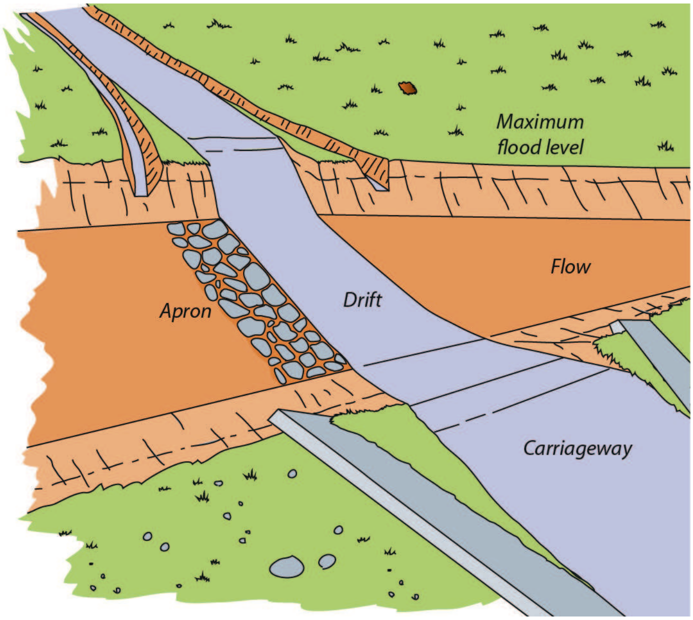


Figure 6.26 – Drift across a dry stream bed (ILO, 1990).

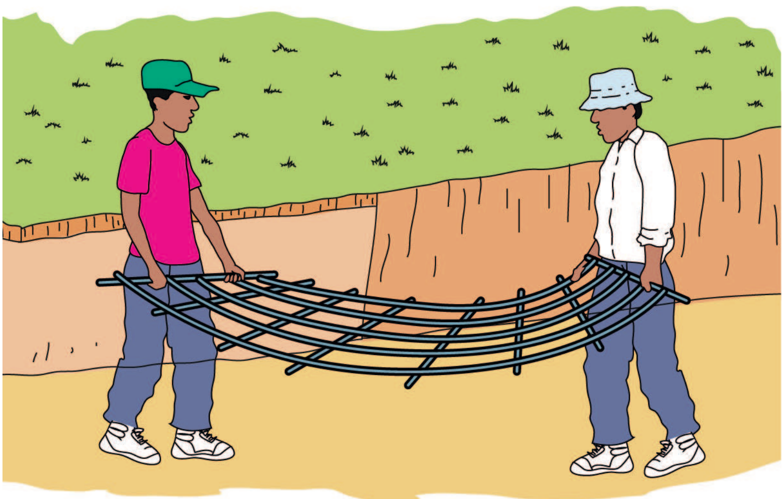


Figure 6.27 – Laying of steel reinforcement mesh (ILO, 1990).

Expansion joints for thermal movement and contraction joints for crack inducement are required. Variations on such joints are shown in Figure 6.28.

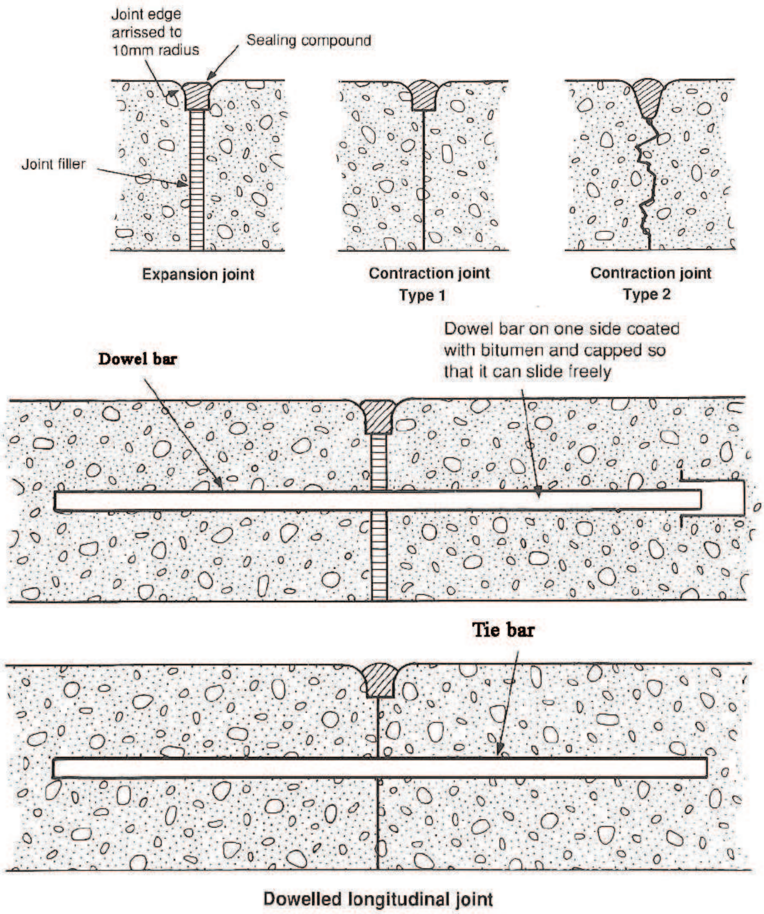


Figure 6.28 – Joints in concrete pavements (adapted from Millard, 1993).

Concrete curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. It is particularly important in tropical temperatures and needs to be specified and well supervised, with coverings kept consistently damp throughout the curing period. Concrete should not be poured when ambient shade temperatures are above 38°C or below 30°C.

Where the formers are available at reasonable cost, concrete geo-cell paving is a viable option for concrete paving and drifts. Incremental paving using concrete bricks is another option suitable for labour based application; units can be factory or locally made by hand using simple equipment. Examples of both are shown in Figure 6.29.

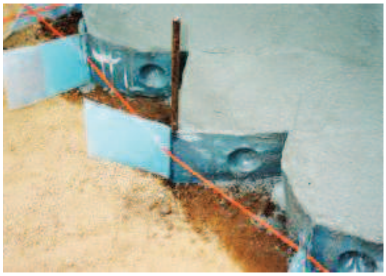


Figure 6.29 – concrete brick and geo-cell paving options (photos courtesy: R. Petts).

Fired clay brick pavements

Fired clay bricks are the product of firing moulded blocks of silty clay and are commonly used in low-cost road pavement construction in areas with a deficiency of natural gravel or rock materials. This surfacing consists of placing a layer of edge-on engineering quality bricks within previously installed edge constraints. The bricks are laid in an approved pattern on a sand bedding. Joints between the bricks may be either in-filled with suitable sand or the bricks may be sand-cement mortared in. A seal may be specified to waterproof the finished surface as a separate operation. Bricks should have a minimum crushing strength of $20N/mm^2$.

Stone paving

There are a number of proven surfacing and paving techniques that use natural stone in various forms. These include:

- stone chippings
- hand packed stone
- irregular cobble stone
- telford paving
- cobble stone
- dressed stone
- stone setts or pavé

Wheel strips

Wheel track paving as shown in Figure 6.30 is a low-cost technique particularly suitable for steep gradients on otherwise unpaved routes and is cheaper than full width paving. It consists of constructing two durable wheel strips designed to support the wheels of the locally used vehicles. The area between the strips and shoulders are constructed of lower quality material. However, this needs to have the appropriate characterics to minimise erosion and maintenance. It should also ensure that occasional passing movements can be accommodated.

Figure 6.30 – Wheel strip paving (photo courtesy: Cook et al., 2013).

6.7 Bio-engineering

In a road development context, bio-engineering solutions can be used to address problems related to erosion and shallow slope failure. Plants may be used to fulfil engineering functions through their hydrological and mechanical influences:

Hydrological influences relate to the ability of plants and vegetation to slow down the rate and volume of water flow across a surface through interception, stem flow, leaf drip evaporation, evapotranspiration and infiltration.

Mechanical influences relate to the ability of plants and vegetation to reduce the likelihood of shallow slope failure by improving soil stability primarily through their root structures.

Both types of influence are shown in Figure 6.31.

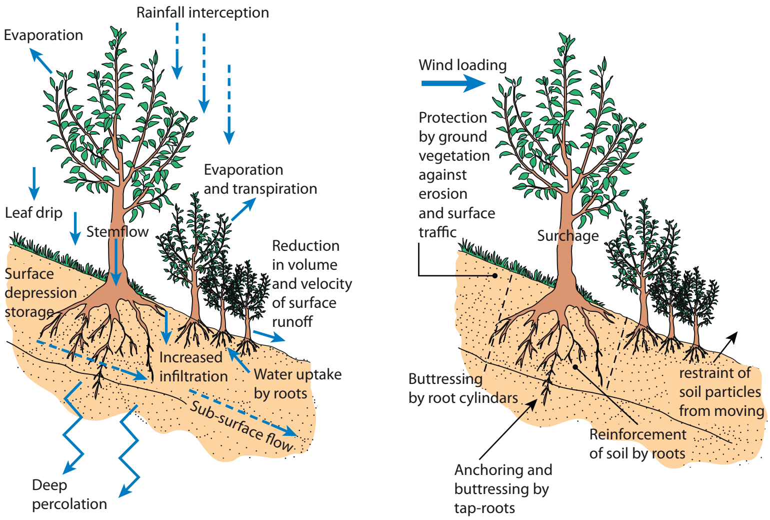


Figure 6.31 – Hydrological (left) and mechanical (right) physical effects of vegetation (Clark and Hellin, 1996).

In many places in the world, tropical storms involve high rates of precipitation and cause serious erosion damage particularly to drainage and the slopes of cuttings and embankments. Scour checks and vegetation planting in appropriate locations will help mitigate these effects.

Knowledge of the properties of local plant species and vegetation is invaluable and should be matched to the engineering solution being sought.

Most vegetation grows quickly in the wet seasons, when the planting should take place.

Six basic bio-engineering techniques which have been useful in the road sector are described below. Further details of these techniques are available from *Bio-engineering for effective road maintenance in the Caribbean (1996).*

Live mini check dam

A live mini check dam as shown in Figure 6.32 is constructed from live plants and locally available materials. The dam is designed to be porous and its main purpose is to decrease the effective gradient in a rill or gully thereby reducing the velocity of water.

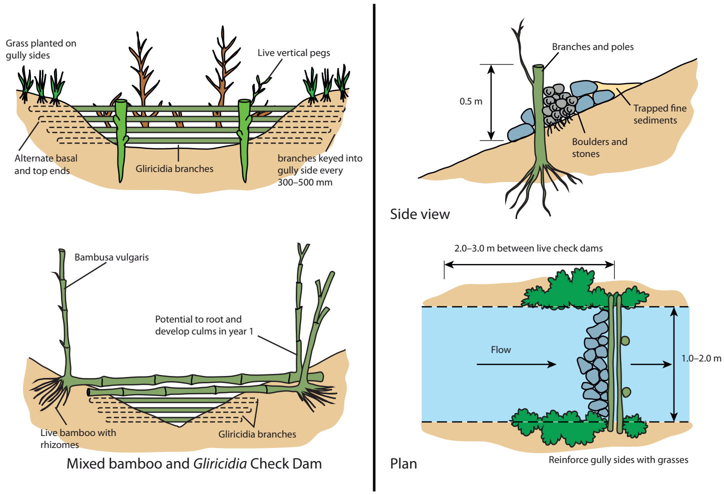


Figure 6.32 – Live mini check dam (Clark and Hellin,1996).

Fascines

A fascine as shown in Figure 6.33 forms a dense hedge which is established on the contour of a slope from material which has the capability to spread from horizontally placed hardwood cuttings. Fascines can withstand small surface slope movements and are strong in tension across the slope.

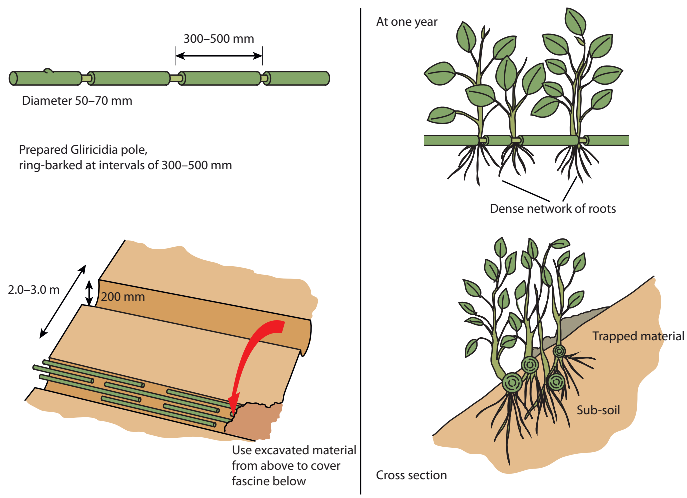


Figure 6.33 – Fascine (Clark and Hellin, 1996).

Stone pitching with vegetation

Stone pitching as shown in Figure 6.34 is a carefully placed layer of stones, cobbles and small boulders that prevent surface erosion and scour. Vegetation can be placed between and over the stones to improve the effectiveness and visual appearance of the pitching.

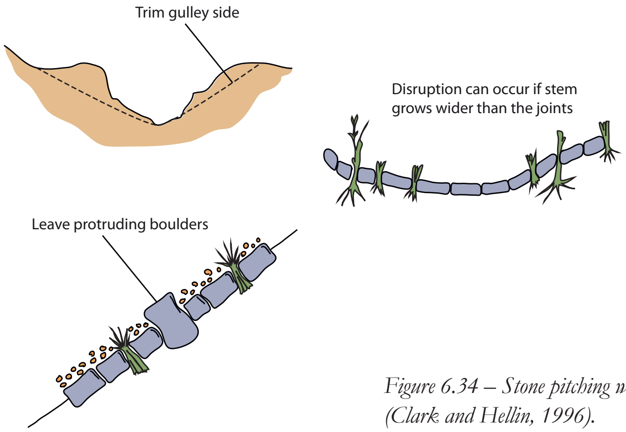


Figure 6.34 – Stone pitching with vegetation (Clark and Hellin, 1996).

Grass barrier silt trap

Grass barrier traps as shown in Figure 6.35 provide an effective way of preventing silt moving downslope and entering a drain or waterway, reducing the potential for drainage to become blocked and waterways to become filled with sediment.

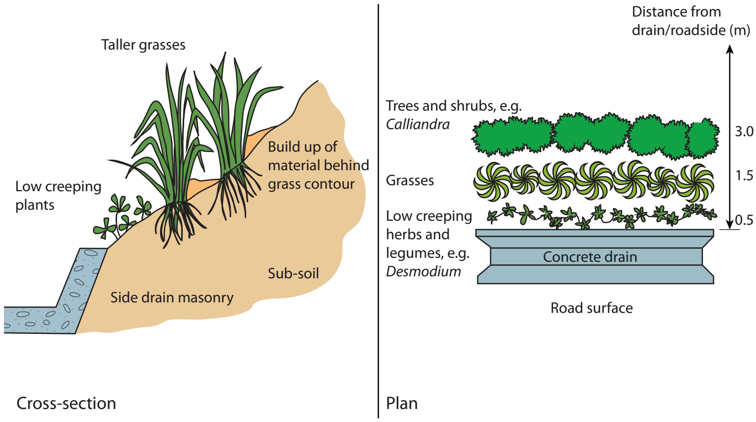


Figure 6.35 – Grass barrier silt trap (Clark and Hellin, 1996).

Surface erosion control with grass

Certain types of grass, when planted densely across a slope, reinforce and protect the slope from surface damage and shallow surface slumping as shown in Figure 6.36.

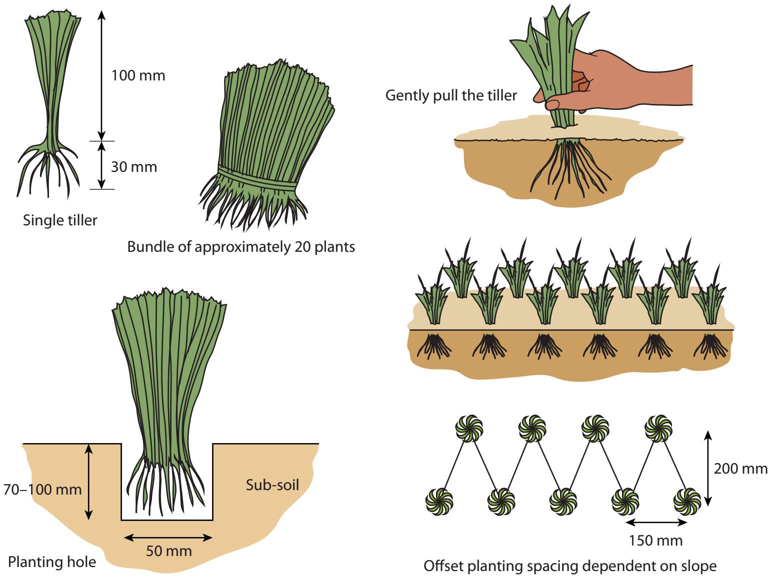


Figure 6.36 – Surface erosion control with grass (Clark and Hellin, 1996).

Dry stone toe wall with vegetation

Dry stone toe walls can be used to strengthen the toe of the slope preventing erosion and undercutting which can lead to retreat of the slope as shown in Figure 6.37; and to create a strong barrier at the base of the slope to trap eroding debris from above entering the inside drain.

Note that variations on these techniques suited to local conditions are to be encouraged, but must be appropriate for the solutions being sought.

Certain areas of the world are more prone to slope failure and soil erosion. Further details may be found in *Overseas Road Note 16*.

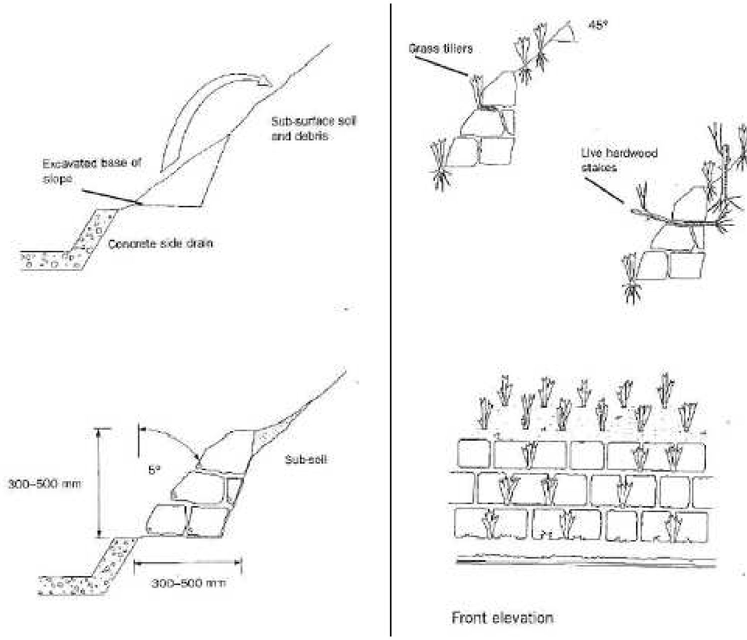


Figure 6.37 – Dry stone toe wall with vegetation (Clark and Hellin, 1996).

6.8 Road safety

Owing to the limited budget associated with typical rural road development projects, road safety is often an afterthought in terms of being designed into projects from the start. Nevertheless, there are some low-cost measures that can be incorporated into schemes from the planning stage that will improve road safety.

The most important point is to provide adequate provision for all road users, including both motorised and non-motorised transport. This includes pedestrians, cyclists, rickshaws and animal powered transport, all of whom are vulnerable to being injured through interaction with motorised vehicles. The best way of achieving such provision is through the separation of different types of road users from one-another. Examples of non-separation and separation of road users are shown in Figures 6.38 and 6.39.

Figure 6.38 – Non-separation of motorised and non-motorised transport.

Figure 6.39 – Low cost separation of motorised and non-motorised transport (Overseas Road Note 21, © TRL, 2004).

Specific road safety measures include:

- provision of adequate crossing facilities for pedestrians (Figure 6.41)
- maintaining minimum sight lines and sight stopping distances based on appropriate design standards
- ensuring horizontal and vertical alignments conform to the appropriate design standards
- use of appropriately located street furniture, such as road signs and barriers
- providing off-street parking and bus stops where required
- providing sensible traffic calming measures in residential areas
- carrying out maintenance, and particularly so with regard to potholes, which can damage vehicles and cause drivers to swerve to avoid them.

Figure 6.40 – Inadequate pedestrian crossing facilities (Watkins, 2010).

On rural roads, the sealing of shoulders can provide a safe travelling surface for pedestrians and NMTs, thus separating and reducing the speed conflicts with motorised vehicles.

All of the engineering methods described above to improve road safety must be backed up by adequate enforcement and education of road users.

Figure 6.41 – Purpose built pedestrian crossing facilities (Watkins, 2010).

7 Road construction

This chapter outlines the construction principles likely to be associated with a typical EWB-UK road infrastructure development placement. It covers the entire construction phase, from setting out on site to completion of construction.

7.1 Introduction

Decisions on the organisation of construction will depend on a careful appraisal of locally available skills and resources.

The direct hiring of labour gangs for the many tasks on the road which can be carried out simultaneously along its length can be effective if experienced gang leaders/foremen/supervisors are available.

In many countries, particularly in Africa, programmes to train small-scale local labour-based contractors have been successful and local participation can be maximised by this method. These methods also have a long tradition in Asia.

Works for LVR roads are often of too small a scale to interest the larger contractors whose higher overhead and mobilisation costs can make them un-economic and less sensitive to local involvement.

The availability of appropriate small-scale equipment e.g. rollers for compaction; tractor/trailers for haulage; trucks for importing materials; will determine the optimum construction technology balance. Examples of such equipment in use are shown in Figure 7.1.

Figure 7.1 – Use of a tractor and trailer for haulage of gravel (photos courtesy: P. H. Bentall).

Personnel with the appropriate experience are essential to ensure that specification standards are met for higher standard roads, e.g. those designed with specialised surfacings and/or high traffic volumes, major earthworks, or concrete drainage structures as shown in Figure 7.2.

Figure 7.2 – Concrete double pipe culvert (left) and box culvert (right) (photos courtesy: P. H. Bentall).

Many countries will have specifications and standard documentation for construction works, but often these will not be appropriate for the smaller-scale works as they are designed with higher traffic volumes in mind. Suitable documents in use elsewhere should be considered such as the *Overseas Road Notes* and the recently developed national LVR guidance found in the *South Sudan Design Manuals*.

The long-term sustainability of a road depends greatly on the standard of construction. Faults even in small areas can render a whole road impassable at a later stage, for example, due to structural failure caused by water ingress or inadequate drainage. Tight supervision of construction is therefore essential. There will invariably be an element of training required for introduction of new techniques.

7.2 Methods and equipment

The main tasks required in constructing a road are planned in sequence and are described as follows.

7.2.1 Surveying

An initial survey will determine the basic alignment of the road and in many cases this will follow an existing path/track. The survey should confirm that the road can be built/rehabilitated to the required alignment standard, and any problem sections or particular challenges should be identified. Deviations and alternative routes should be explored. Local consultation will allow information regarding materials and clean water sources, drainage and flood characteristics to be gained. Although rights of way and road margins may be established, these may need to be confirmed on the ground and any land ownership issues resolved.

Sites of drainage structures need to be identified and sufficient information gathered to be able to size them. Locations of significant earthworks also need to be identified. Key information can be recorded on simple chainage related plots and charts as indicated in *Overseas Road Note 20*.

A materials survey should be carried out to identify possible sources of gravel, rock and aggregates.

More detailed surveys can be carried out for alignment, earthworks and structures as identified by the initial survey.

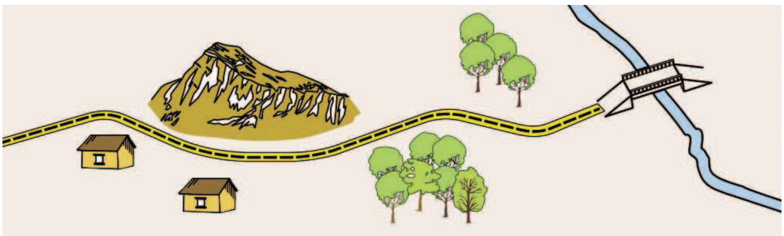


Figure 7.3 – An initial survey to determine the alignment of the road should consider the most appropriate route (ILO, 2008).

7.2.2 Setting out

Setting out is the process by which the alignment of the road is measured and physically marked out on the ground. Even if works are minor and small-scale, high standards of setting out should be maintained. Setting out can be achieved with poles, pegs, string, and basic levels.

Horizontal alignment

The first step is to establish the centre line of the road either with rods and tapes or instruments and pegs as shown in Figure 7.4.

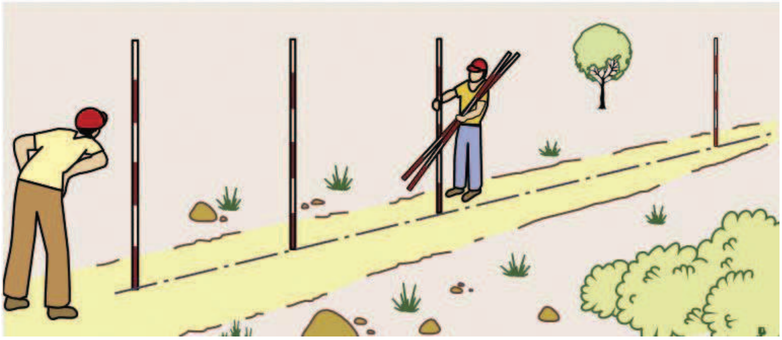


Figure 7.4 – Establish the centre line of the road (ILO, 2008).

The full roadway width is then set out at intervals, from the centre line, with reference pegs as shown in Figure 7.5.

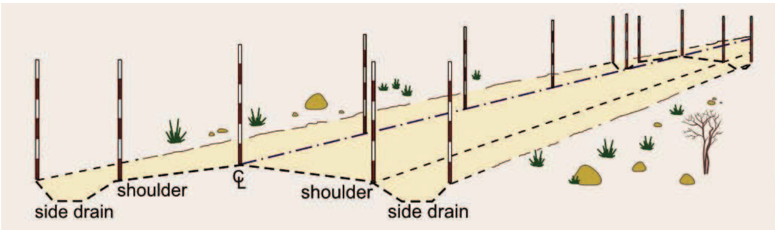


Figure 7.5 – Set out the width of the roadway from the centreline (ILO, 2008).

The line should minimise the need for clearance work and environmental damage.

Horizontal curves can be set out using pegs and string as shown in Figure 7.6.

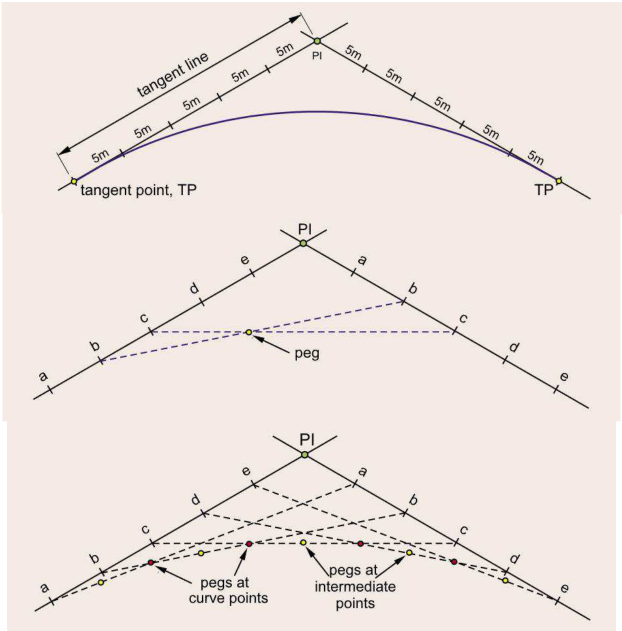


Figure 7.6 – Setting out a horizontal radius using pegs (ILO, 2008).

Vertical alignment

Setting out the vertical alignment can be achieved using a range of equipment as shown in Figure 7.7.

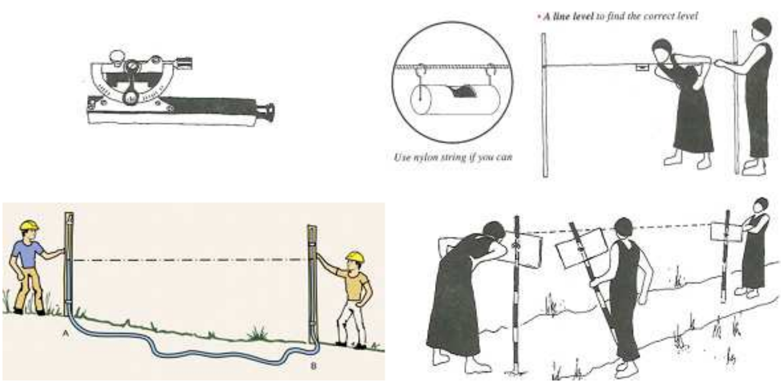


Figure 7.7 – From top left clockwise: use of an Abney, line/spirit, profile boards and water and to determine basic vertical levels (ILO, 1990 and 2008).

Use of profile boards (an adjustable fastening board mounted on a ranging rod) remains one of the simplest yet most effective methods for setting out vertical alignments as shown in Figure 7.8.

Figure 7.8 – (above and below) Setting out the vertical alignment on site using profile boards (photos courtesy: P. H. Bentall).

The vertical alignment at structures is critical. The watercourse alignment should take precedent over road alignment. Natural forces will always act vigorously to enable the water to follow or revert to its 'natural' course (both horizontally and vertically). Culverts need to have sufficient fall and outlet grade to allow them to discharge without siltation or erosion. They will also need sufficient cover from the wheel loads at the road surface. **Incorrect installation of culverts on LVR is a widespread problem due to insufficient attention to these requirements**.

7.2.3 Clearing and grubbing

The first step is to clear the full roadway width of bush/scrub/small trees as shown in Figure 7.9. Only fell larger trees if unavoidable.

Figure 7.9 – Bush clearing and grubbing (photos courtesy: P. H. Bentall.)

Next, any topsoil must be removed from the area of carriageway and ditches as shown in Figure 7.10. This can be stored for re-use on completion.

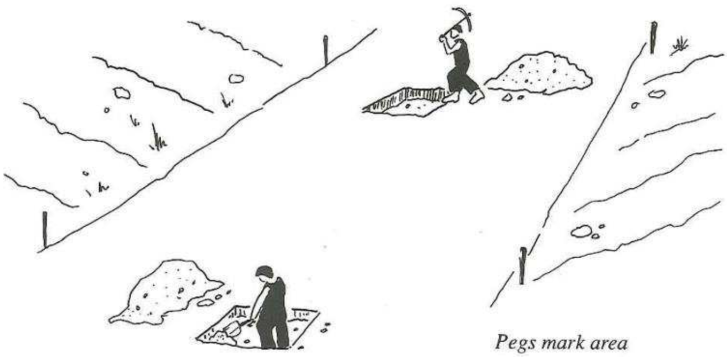


Figure 7.10 – Topsoil removal (ILO, 1990).

Ideally, works should be carried out by hand in order to mitigate unnecessary damage. Only for major road construction may machines be appropriate.

7.2.4 Earthworks and formation

Earthworks include cuttings and embankments designed to produce an appropriate vertical alignment for the road relative to its purpose/users.

The objective is to keep earth moving from cuts to fills to a minimum particularly if labour-based technology is to be used. An example of a project in which material was taken from an embankment to be used as fill is shown in Figure 7.11.

Figure 7.11 – Cutting material from an embankment to be used as fill (photo courtesy: P. H. Bentall).

Embankment fills will require adequate compaction with appropriate equipment (pedestrian rollers; towed rollers; self-propelled rollers). Completed earthworks will provide the road formation on which the carriageway is built. At this point the full road cross-section should be set out in detail.

Cross sections for various circumstances can be found in national manuals such as the *South Sudan LVR Manual*. The breaking up of earthworks and drainage into simple tasks is illustrated in the *Tanzania Labour Based Roadworks Manuals*.

7.2.5 Drainage ditches

In cuttings, and over lengths at or near existing ground level, drainage side ditches are needed to remove water from the roadway area. These evacuate water to existing water courses or storage areas. Usually, the side drain levels will be tied to the standard cross section and road centreline alignment. However, at low points greater attention will be required for vertical and horizontal ditch alignment.

The ditch invert levels are normally determined from the road centre line setting out pegs and then excavated to a pre-determined level differential as shown in Figure 7.12. In this illustrated case, the ditch invert is 0.25 metres below the earthworks 'terrace' before the build-up of the camber. Normally, ditch inverts are established at between 0.25 and 0.5 metres below the level of the edge of the road running surface.

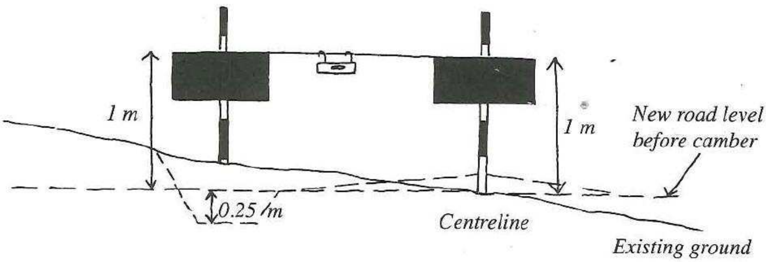


Figure 7.12 – Setting out ditches from the centreline.

Ditches are preferably excavated by hand as shown in Figure 7.13 to a trapezoidal section. The excavated material (unless unsuitable) is deposited on the road carriageway area to form the basis of the road camber.

Figure 7.13 – Forming drainage side ditches by hand (photos courtesy: P. H. Bentall).

This may be achieved by initially excavating a rectangular section trench using a template as a guide as shown in Figure 7.14, then trimming back the side slopes with hand tools.

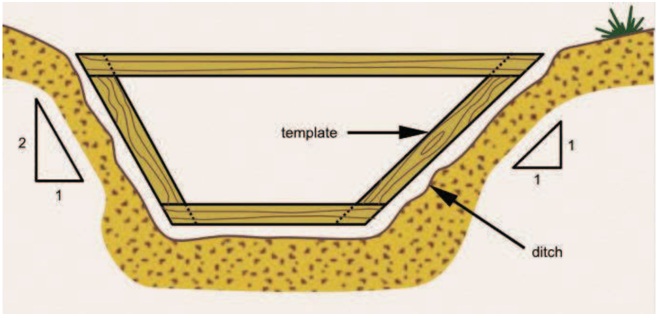


Figure 7.14 – Trapezoidal ditch template according to final required profile, made of timber (ILO, 2008).

Setting out wooden pegs and string lines can be used to help guide the excavation and placement of materials (Figure 7.15), prior to spreading out to form the camber.

Figure 7.15 – Excavating the side ditch by hand in two stages using pegs, string lines and templates for guidance (photo courtesy: R. Petts).

After the material has been spread to form the camber and compacted, a camber board or line level may be used to check the camber on site as shown in Figure 7.16.

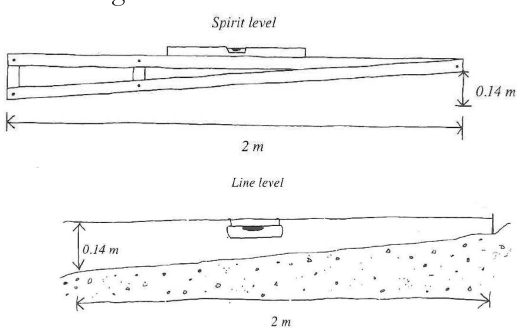


Figure 7.16 – Use of a camber board and line level to measure a 7% crossfall (ILO, 1990).

7.2.6 Structures

At intervals, cross-drainage structures will be required for existing water courses or discharge from ditches, which may be seasonal in flow. The types of structures needed may be:

- vented fords – more regular and flash flows (Figure 7.17)
- drifts – occasional flows (Figure 7.18)
- pipe culverts – concrete, treated timber or metal (Figure 7.19)
- box culverts – concrete, possibly with treated timber deck (Figure 7.20)
- arch culverts – masonry, brick (Figure 7.21)
- small bridges – rivers (Figure 7.22).

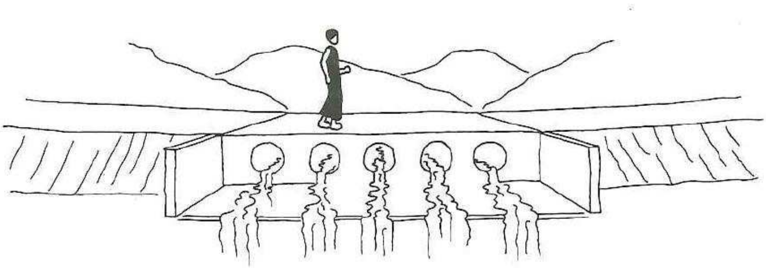


Figure 7.17 – Vented Ford (ILO, 1990).

Figure 7.18 – Drift (ILO, 1990).

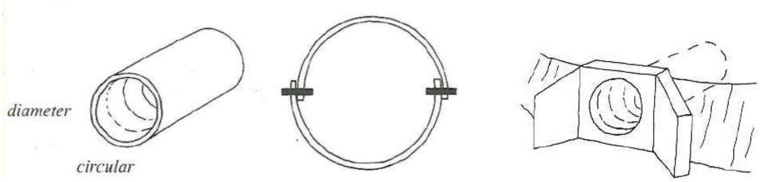
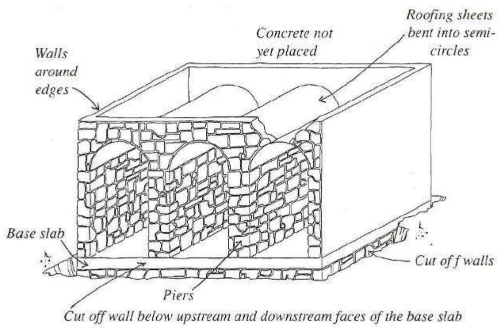


Figure 7.19 – Corrugated steel culverts (ILO, 1990).

Figure 7.20 – Box culvert (photo courtesy: P. H. Bentall).

Figure 7.21 – (right) Drawing of a small arch culvert masonry bridge nearing completion (ILO, 1990) and (below) in practice (photo courtesy: P. H. Bentall).



Structures can be in concrete, with steel reinforcement, requiring particular skills and close supervision to ensure the correct standards. Simpler requirements will be necessary for structures in masonry, gabions, fired clay brick and timber using locally available skills. Further information on structures options is provided in *Small Structures for Rural Roads*.

Figure 7.22 – Masonry arch bridge completed using local carpentry and masonry skills, and without lifting equipment (photo courtesy: R. Petts).

Concrete strength depends on the water/cement ratio which should be as low as possible for adequate workability, but without compromising the concrete strength. Formwork for the structures is another specialist skill for which good supervision is required as shown in Figure 7.23.

Figure 7.23 – Formwork being used to apply concrete to a corrugated steel pipe culvert (photo courtesy: K.Ogutu).

Concrete compaction is ideally attained with a poker vibrator; otherwise hand held rods are effective in working concrete into all areas of the formwork and around the reinforcement.

A case study of a EWB-UK placement involving the construction of several road structures follows.

Case study: Dadiya Road River crossings

Don Stevenson and Christina Doris, Nigeria, 2005 onwards

Dadiyaland is a tribal area located in Gombe State in the northeast of Nigeria and home to the Dadiya people, one of more than 300 tribes in Nigeria. Through local consultation, it was determined that the main concern locally was that during the rainy season (July to September), their land became inaccessible by road as the Dadiya River flooded, and rendered most Dadiyans cut off from access to markets, healthcare, and other communities.

In 2005–2006, EWB-UK volunteers Joe Mulligan and Anna Tompsett started the task of building a permanent bridge to span the Dadiya River. In Spring 2006, EWB-UK volunteers Annette and Benny Lucas began constructing the bridge and the whole community worked together to dig, mould, pour, and build the bridge as shown in Figure A. Unfortunately, months after the bridge was erected there was massive flooding and the bridge collapsed.

Figure A – The Dadiya River crossing pre and post construction.

After the bridge

Consensus in the community since the loss of the bridge, was to continue efforts to improve the road network by focusing on smaller, but similarly important stream crossings. In September 2007, we started work on the construction of smaller stream crossings, together with the partner organisation, following three months of community consultations, surveying and design work.

Culverts

After months of planning and gathering the required materials, the first culvert site was started in mid-December and the second in April. We received engineering advice and assistance from a local engineer from the Gombe State Ministry of Works, hired a group of steel benders to complete the steel reinforcement for the bridge and built the rest of the bridge together with the partner organisation and local community assistance as shown in Figure B.

During April and part of May we worked together with the community to backfill both crossings with the help of a dilapidated local government tipper. This was followed by several days of planting grasses, and digging drainage channels along the culvert approaches. In May, we were able to leverage additional funding to complete a third culvert.

Figure B – Road approaches to a culvert close to completion.

Bridge design

The bridge was built using a simple and economical design with openings along the body of the bridge allowing for water to flow through during times of flooding. Deep trenches, for the feet of the bridge, were dug into the river banks and the base of the bridge rested on the river bed. This design was chosen because it was simple to build and believed that the river bed was stable enough to withstand the structural weight of the bridge during flooding.

Lessons learned

With the heavy rainfall, the sand underneath the structure of the bridge liquefied and the bridge collapsed. After consulting with local engineers and determining that the river bed is composed of many feet of sand with no clay to be found (as far as we could excavate), we now believe the best solution for the crossing would be a span bridge.

The culverts (based on the same design, but much smaller scale), have been a success. According to the last report from the partner organisation, all the culverts are still working, and the community has been diligent with the necessary maintenance.

About the authors: Don Stevenson and Christina Doris lived in Dadiya, Nigeria in 2007–2008 as volunteers with Engineer Without Borders UK. Their projects included building culverts on the through road, taking a census of the Dadiyan population, and assisting with community wide immunisation programmes.

7.2.7 Gravel running surface

Where the gravel running surface option is selected, on the subgrade formed from the excavated ditch material, a layer of stronger gravel material (100 mm–150 mm) can be laid, shaped and compacted to form the running surface as shown in Figure 7.24.

Figure 7.24 – Unloading and spreading gravel for the surface running layer (photos courtesy: P. H. Bentall).

In many areas, this will be a naturally occurring material, locally quarried as shown in Figure 7.25 and brought to site by wheelbarrow/ tractor-trailer/truck depending upon the haulage distance.

Figure 7.25 – Gravel being quarried for spreading as the surface running layer (photos courtesy: P. H. Bentall).

The long term performance of the road will depend upon the specified standards of material grading, plasticity, width, shape, and compaction being attained. Compaction using a typical pedestrian roller is shown in Figure 7.26.

Figure 7.26 – Final compaction of the gravel surface layer (photos courtesy: P. H. Bentall).

7.2.8 Other road surfacings

Pre-mix bituminous road surfacings are expensive and require construction skills not usually available within a locally recruited labour-force.

Surface dressing (spray and chippings) can be carried out by hand using a bitumen spray lance as shown in Figure 7.27.

Figure 7.27 – Bitumen spray-lance in use.

Bitumen emulsions allow the safe application of bitumen at ambient temperatures. Measured capacity containers can be used for dispensing the specified quantity per unit of area as shown in Figure 7.28.

Figure 7.28 – Manual application of bitumen emulsion seal prior to chipping application (photo courtesy: R. Petts).

Unreinforced or reinforced concrete paving can be constructed as shown in Figure 7.29 with skills normally found in a competent local building contractor. Particular care is required in supervising formwork preparation, jointing and dowel arrangements, control of mix proportions and water content, fixing or any reinforcement, compaction and finishing. Cube tests for strength and slump tests for the wet concrete are normal testing requirements. It is also important to cure the concrete after placing by covering with suitable material and keeping it moist, normally for a period of one week.

Figure 7.29 – Constructing reinforced concrete paving (photo courtesy: R. Petts).

There are a number of natural stone paving techniques that avoid the need for expensive (often imported) binders. The following images show irregular cobble stone paving and stone setts or pavé (Figure 7.30) and dressed stone (Figure 7.31). Good quality control is required to achieve a relatively smooth acceptable surface finish.

Figures 7.30 – Irregular cobble stone paving (left) and stone setts/pave (right) (photos courtesy R. Petts).

Clay fired bricks may also be used where appropriate as shown in Figure 7.32. Detailed specifications should be written for each type of surfacing which need to be closely followed and supervised.

Further advice and information on the various options is available from *Overseas Road Note 31* and the *LVR Road Surfacing and Pavements Guideline*.

Figure 7.31 – Dressed stone paving using granite material, hand quarried and dressed (photo courtesy: R. Petts).

Figure 7.32 – Laying fired clay brick paving between previously placed edge restraints/kerbs (photo courtesy: R. Petts).

7.2.9 Productivity

If local productivity norms are available, then they can be used to plan the works and develop task rates for the various activities. Task work systems based on fair rates have been very successful in labour based road works programmes where the work can be broken down into easily set and controlled tasks against payment of a day's wages. These are usually based on the national minimum rural wage rates and are normally attractive in an environment of limited employment opportunities. If no local norms are established, then the task rates contained in the *Tanzania Labour Based Manual* can be used for guidance. These were developed from extensive studies in East Africa and the experience is that able bodied personnel with adequate nutrition can achieve these tasks comfortably within five to seven hours.

7.2.10 Testing and quality assurance

Working in the rural areas of an economically developing region, an EWB-UK volunteer cannot expect to be able to rely on easy access to the level of testing services and supervision widely established in Europe. Testing laboratories, facilities and services may be non-existent, deficient or only available in large urban centres. The contractual, assurance and supervision regime may be weaker than the volunteer has been used to.

In such circumstances, the engineers most useful tools are their eyes, ears and common sense. By visiting and discussing other construction projects in the area, it may be possible to identify materials issues, shortcomings in the testing and supervision regime, or local problems, and to take measures to counter them at the assignment site.

Training, adoption of simple but sound setting out practices, batch controls, simple templates and control mechanisms can help to achieve quality of finished works. Regarding quality of materials and workmanship, visual checks are vital and simple low-cost testing equipment such as the Dynamic Cone Penetrometer – DCP (for measuring in-situ CBR of soils and pavement materials *in the current* *conditions*[1]) can provide instant results on site. The DCP is shown in Figure 7.33.

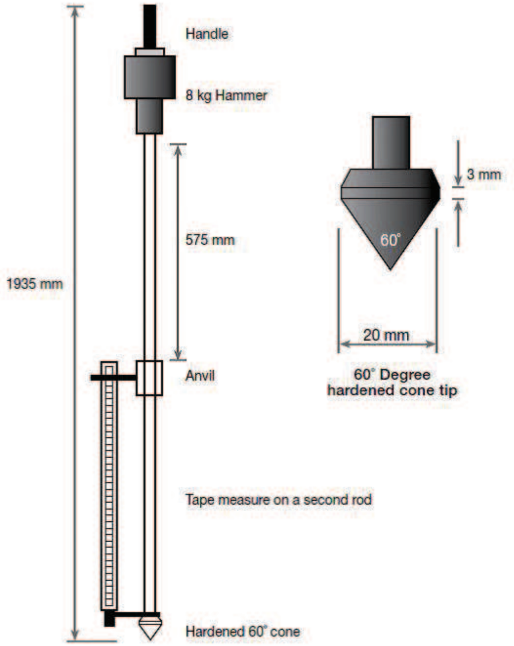


Figure 7.33 – Dynamic Cone Penetrometer.

7.3 Maintenance

Although this chapter of the book has been primarily focussed on development rather than maintenance, the importance of maintenance cannot be overlooked. A misunderstanding of the significance of road maintenance has, in fact, been the major failing of road administrations around the world (Heggie, 1995). This has led to the deterioration in the condition of road networks since the 1970's (Robinson, 2008).

Evidence suggests that for every $1 spent on road maintenance, there is a wider saving of $2 to $3 to the economy (Heggie, 1995).

1. *It is important to appreciate that materials strength can vary significantly with moisture content and any in-situ materials testing should consider possible seasonal and moisture variations.*

At the local level in rural areas, many local languages do not have a word for maintenance and the concept is not readily understood. This can be a particular problem for low volume, low-cost road works where regular deterioration occurs from climate and traffic, and funds and resources can be very limited.

When local communities are fully involved in the construction, the necessary ownership and technical skills are acquired which are key to long-term maintenance. It may be that in a limited resource environment, a cooperative initiative is required to maintain community assets, with mobilisation of any available government funding or resources, together with community labour, and possibly materials, skills or equipment contributions from NGOs, local business or enterprises. It could be necessary for the beneficiary community to take the lead in making such an arrangement work.

A checklist of issues to be tackled to achieve effective maintenance is included in the g*TKP ROADCAP* assessment framework and PIARC's Save your Country's Roads makes a powerful argument for maintenance.

Maintenance is defined by the *PIARC International Road Maintenance Handbook (IRMH)* under three categories:

Routine maintenance

Operations required to be carried out once or more per year on a section of road. These operations are typically small scale or simple, but widely dispersed, and require skilled or unskilled manpower. The need for some of these can be estimated and planned on a regular basis, e.g. vegetation control, de-silting or routine grading.

Periodic maintenance

Operations that are occasionally required on a section of road after a period of a number of years. They are normally large scale and require specialist equipment and skilled resources to implement, and usually necessitate the temporary deployment of those resources on the road section. These operations are costly and involve specific identification and planning for implementation, and often require design. Examples include gravelling and bituminous re-sealing.

Urgent maintenance

Certain unforeseen situations necessitating remedial action to be taken as soon as possible, e.g. flood damage, land slips.

The *IRMH* details all of the defects for paved and unpaved roads and the maintenance tasks required to counter them using labour, intermediate equipment or heavy equipment methods. The *South Sudan LVR manual Volume 3* also provides more detailed guidance on organising unpaved and paved road maintenance.

The level of maintenance input will be dependent upon the road purpose/traffic use/surface type/climate/terrain and the proposed maintenance plan should be an input into the initial design and construction technology. Maintenance costs will be an important influence on the whole life costs for the different road surface options.

Research in East Africa allowed maintenance resource needs estimates and productivity guidelines to be developed for unpaved LVR which are contained in the *MoT Tanzania Labour Based Manuals (Vol 2)* and *Maintenance of Minor Roads Using the Lengthman Contractor System*.

It should also be borne in mind that maintenance needs to be carried out on not only the road itself but also on all associated ancillary assets and structures as shown in Figure 7.34.

In summary, the importance of maintenance cannot be overstated, since well-built roads have the potential to last indefinitely if they receive the appropriate maintenance treatments at the correct time throughout their life. Therefore, if resourcing and organising maintenance is likely to be an extreme challenge, design and construction solutions that minimise the need for maintenance should be sought.

Figure 7.34 – Unrepaired street lighting columns and make-shift water crossings are only two examples of inadequate maintenance (photos courtesy: A. McLoughlin and P. H. Bentall).

7.4 Project management

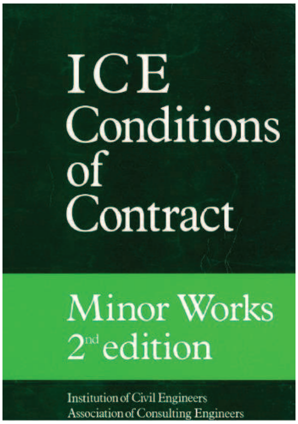
EWB-UK placement volunteers are likely to have to undertake some tasks associated with project management as part of their placement. Given the labour based nature of the road projects likely to be worked on, placement volunteers should familiarise themselves with the basics of:-

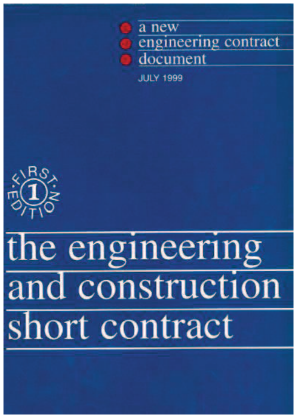
- management and organisation of work on site
- knowing how to calculate the amount of work, materials and labour likely to be required for typical road building activities
- how to plan work so that activities are coordinated
- how to organise workers on site with daily activities
- cash flow, logistics, planning, estimating, costing, personnel management
- monitoring of progress against the project schedule
- the construction contracts likely to be used
- imparting knowledge, skills or experience to local personnel.

Construction contracts

Note that construction contracts are not always used on many small development projects, meaning that neither client nor contractor know their responsibilities or where they stand if disputes arise. This invariably slows down project progress.

The use of construction contracts is therefore recommended to protect all parties. Some examples of contracts appropriate for small scale projects are available from ICE, NEC and FIDIC as shown in Figure 7.35.





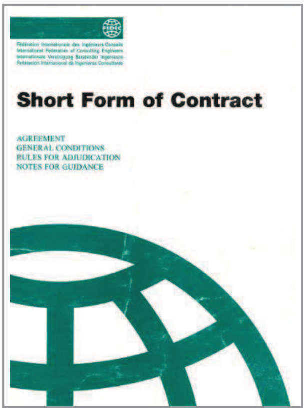


Figure 7.35 – Examples of contracts appropriate for small scale projects.

Note that although it is good practice to use the most recent versions of these contracts which are updated from time-to-time, it is still better to use a superseded version of a good contract as opposed to no contract at all if this is all that is available.

A case study of a EWB-UK placement that involved project management skills in a road construction context follows.

Case study: Nias road rehabilitation project

Charlie Perry, Indonesia, 2009

In 2009, EWB-UK volunteer Charlie Perry undertook a road rehabilitation placement in rural Nias, Indonesia, which involved the reconstruction of 13 km of village access road. The road had become damaged and was impassable in parts due to a combination of natural disasters and a lack of road maintenance.

Upon arrival on site, it was found that 3 km of the planned 13 km of route had already been constructed, making the role of the placement one of planning and implementation, rather than design.

The road design chosen was a Telford road, a durable, if more expensive alternative to dirt roads. Telford roads are built by digging two parallel-running drainage trenches, between which stones are laid as shown in Figure A. These stones are covered with gravel, which is then compacted. The process is then repeated using sand. Such roads are a significant improvement to dirt roads, which can become unmanageable after a period of rain. The road is designed to withstand pedestrians and light motor vehicles in conditions that would previously have left vehicles disabled, due to flooding and damage caused to the road structure by water.

Figure A – 'Telford' road under construction in Nias.

This project's local 'resource-based' approach had wide implications as unemployment in Nias rural areas is very high. By transferring financial resources and skills to the local level, local resource-based methods can have a substantial and immediate poverty-reducing impact.

The main role of the placement involved the daily planning and supervision of road construction.The typical day began with an informal meeting with the Base Manager, the Programme Manager and the Logistics team to assess the existing plans. When activities were agreed upon, the workers and vehicles would head out to the field for the day. Charlie's time was then divided between assisting the supervisors on site and planning work in the office, which involved the scheduling of activities, checking construction method details, assessing material needs and procurement as shown in Figure B. There were two main challenges of the placement. The first of these was related to trying to carry out road rehabilitation during the wet season, which dramatically slowed down the progress of construction due to flooding of the site and prevented vehicles being able to bring tools, materials and labour to the area.

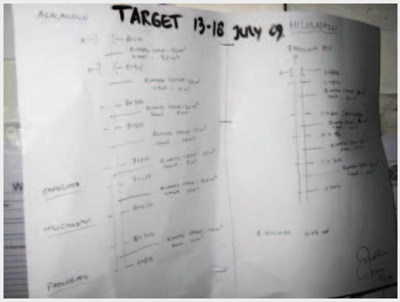


Figure B –Typical weekly scheduling of activities.

The second challenge was political and related to the project being NGO funded, meaning that a 'culture of receiving' had developed. This led to an apparent apathy in the work ethic of the locals who were building the road (that would benefit them) which if constructed too quickly and on budget would have meant the end to NGO funding for local labour in that area. This is a big issue in a rural area with little other employment and little knowledge of when the next project is likely to come along.

Unsurprisingly, the project was not completed on time or on budget. In summary, although the project provided an incredible learning opportunity for the placement volunteer, it left him with questions of whether the approach used for such projects could be improved.

About the author: This case study has been written on behalf of Charlie Perry, a EWB-UK volunteer who carried out the placement in 2009.

7.5 Environmental impact and sustainability

In rural road development projects, sustainability of the road and minimisation of environmental damage can be tackled by using a local approach. This means that local materials should be used in road construction wherever possible to minimise costs, reduce haulage distances and ensure that there are local materials available for which to carry out maintenance.

In many rural road projects, it is essential that the local community have a strong involvement in the project from planning to completion and just as importantly, in the maintenance thereafter. This approach should increase the chances of long-term survival of the road.

In the case of unsurfaced roads, thought must be given to the effect of vehicle generated dust on crops and human health, since it can be produced by every passing vehicle as shown in Figure 7.36.

Figure 7.36 – Vehicle generated dust can be hazardous to crops and human health.

8 Vehicles

The performance of vehicles is closely related to the quality of the road infrastructure and (for example through inappropriate use of small roads by large trucks) vice versa. There are some fundamental differences between the vehicle and infrastructure sides of transport for development, however. These include:

1. The average lifespan of vehicles is much less than that of transport infrastructure, so can be replaced more quickly. The impacts of good (or bad) vehicle projects will often be shorter lived than for infrastructure projects.

2. Vehicle interventions are generally faster to implement, smaller scale and less costly than infrastructure projects, so there has been more experimentation in vehicles – vehicles are often seen as a less risky intervention.

3. Vehicles are by definition mobile, so the impacts of a successful vehicular intervention may extend beyond the local area where a particular project was implemented (the diffusion of bicycle ambulance technology from Bicycle Empowerment Network Namibia is an example of this, described later in this chapter).

4. Road infrastructure is generally government, publicaly or communally owned with insufficient resources allocated for maintenance, whereas means of transport are usually privately owned with direct interest in keeping the transport working to derive an income.

Partly because of these features, there have been many new designs for vehicles to alleviate poverty, from a bamboo rickshaw to an ambulance powered by motorcycle. Because vehicles are relatively small compared with roads, there is greater potential to experiment and try new things. Infrastructure interventions, by contrast, tend to strive towards well-established best practice guides.

A great advantage of vehicle interventions from the perspective of EWB-UK projects, is that a prototype design can often be created and tested in a placement volunteer's home country before implementation overseas. Building some kind of vehicle is also much more feasible as a practical project within EWB-UK branches than constructing a road. Vehicles, if locally assembled, can also generally be more easily maintained and modified than roads, offering substantial educational benefits. As illustrated by the community bicycle trailers case study in section 8.3, some vehicle projects can be equally useful in nations with an advanced motorised transport system as in areas with an emerging motorised transport system. Using technology on a daily basis is an excellent way of pre-departure testing and of providing confidence in the long-term resilience of the design.

Consensus about best practice is less common for vehicles than for roads, due to the factors noted above and the sheer range of vehicular transport solutions (see Table 8.1). This does not excuse poor prior research into past solutions or the perennial attempts to 're-invent the wheel' (e.g. another wooden bicycle design is unlikely to have a major impact on development where previous attempts have failed). This chapter should therefore be seen equally as a source of guidance and further information on the subject (see references).

Many options exist to improve already existing vehicles for development applications. These range from the design of more sustainable bicycles to economical carts and trailers. Interpreting 'vehicle' in the broadest sense, interventions could also include improvements to communications technology, which could reduce the need to travel or make existing travel options more efficient (for example, an application to optimise the use of a minibus to ensure it goes where and when people need it).

In the past, the research and documentation of low-cost rural vehicles and transport services based on their use, have been poorly coordinated and disseminated. This is improving and knowledge and information on recent and current developments can be obtained from websites such as AFCAP, IFRTD and Animal Traction[1].

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1. Research and compilation of good practice continues under various initiatives and programmes on aspects of rural transport services and infrastructure. The practitioner is recommended to check recent developments from established organisations in the field such as AFCAP (Africa Community Access Program), IFRTD (the International Forum on Rural Transport and Development) and DFID (the UK Department for International Development). Each of these has much material about transport online – check the end of the chapter for online resources.

	Indicative characteristics					Requirements			
	Cost ($)	Load (kg)	Speed (km/hr)	Range (km)	Cost ($/Tonne-km)	Foreign exchange	Vetinary services	Mechanics	Good road
Carrying/head load	0	20	5	10	1.5	Low	None	Low	Low
Sledge	10	100	4	3	0.8	Low	High	Low	Low
Wheelbarrow	30	100	4	1	0.4	Low	None	Low	Low
Handcart	60	150	4	5	0.35	Low	None	Low	Medium
Pack donkey	60	80	7	20	0.7	Low	High	Low	Low
Bicycle	100	60	10	20	0.6	Medium	None	Medium	Medium
Cycle rickshaw	170	150	8	15	0.45	Medium	None	Medium	High
Donkeycart	300	400	6	15	0.6	Medium	High	Medium	Medium
Oxcart	500	1000	5	10	0.2	Medium	High	Medium	Medium
Motorcycle	900	100	50	50	1.3	High	None	High	Medium
Pickup	12000	1200	80	200	0.7	High	None	High	High
Truck	60000	12000	80	200	0.5	High	None	High	High

Table 8.1 – Table of various transport vehicle solutions available (source: Starkey, 2001).

8.1 Motorised vehicles

Before the industrial revolution, muscles provided the power source for most transport tasks across the world, except in shipping. It was only with the development of the internal combustion engine that the benefits of motorisation could be applied to personal vehicles. Since then, motorised modes, and especially the car, have come to dominate transport infrastructures worldwide. This fits well with a western concept of development, whereby progress is seen in terms of consumerism (e.g. shopping in an out-of-town supermarket rather than at a local market), comfort and increasing advances in technology.

Due to peak oil, health impacts[1] and climate change, the moment of 'peak car' (and possibly peak travel) seems to have passed in the UK and other OECD countries (Goodwin & Van Dender, 2013; Schipper, 2010). Despite these criticisms, motor vehicles continue to receive the lion's share of funding in transport projects worldwide. This is partly due to the powerful car lobby and the seductive advertising that make cars important status symbols, especially in the most unequal societies. Yet motorised vehicles, used appropriately clearly have a number of practical benefits over 'animate' modes (e.g. walking, cycling, and horse riding). These include:

- Speed: this is typically several times faster for motorised modes.
- Stamina: the range of a car, motorbike or powerboat on a single tank of fuel is much greater than human powered alternatives after a single meal.
- Comfort: given the choice of driving or cycling during extreme weather (heat, cold, rain or snow), for example, most would chose the former. Reduction of toil is an important aspect of development that may favour motorised modes.

1. Road accidents are the number one non-natural cause of death in many nations, and generally affect the poorest in society: road deaths are the second most common cause of death of children and young people aged 5–29 years worldwide and the problem has a disproportionate impact on the world's poor. 96% of all child deaths happen due to road crashes in developing nations, yet relatively little attention or funding is diverted to this 'hidden epidemic in less developed countries' (Hazen et al. 2006). Motorised vehicles are also responsible for another global epidemic: obesity, which is rapidly becoming a problem in developing nations (Caballero 2007).

- Status: the power of a car or truck as a status symbol should not be overlooked at the individual level, although this is in fact a disadvantage for society overall.

The disadvantages of motorised modes include cost (of fuel, vehicles and the infrastructures they demand) and unintended social and environmental impacts. Motor vehicles are instrumental in the breakdown of community spirit and safe public areas (Illich, 1974). They amplify social inequality by providing a clear mobility advantage to the wealthiest community members who can afford the large vehicles that are seen as a symbol of safety and prestige, to the detriment of the poorest in society. These impacts arise largely from the dependence of motor vehicles on finite fossil fuels: their scarcity ensures that motorisation is expensive and causes inequality and their combustion results in environmental impacts. Electric vehicles have provided hope that these negative impacts could be reduced. However, even the much-touted battery-electric vehicles are utterly dependent on finite resources during the materials extraction and manufacture phases of their life-cycle (Majeau-Bettez, 2011). In addition, the electricity needed to charge electric vehicles is often provided by fossil fuels. This additional strain on electricity networks can scarcely be accommodated in wealthy countries (Webster, 1999), let alone in low-income nations where black-outs and rolling 'brown-outs' are a frequent and sometimes deadly feature of everyday life (Iwayemi, 2008).

Due to the high costs of vehicles and fuels, small motor cars, bicycles, goods vehicles and trikes tend to be common in developing nations. For the same reason, vehicle occupancy tends to be higher than in high-income nations, reducing the cost of travel. These positive attributes of developing nation motorisation are present in the following case study of the Motorcycle-ambulance trailer (MAT).

Case study: motorcycle ambulance trailer

Ron Dennis

It is widely accepted that the primary need to achieve Millennium Goals 4 and 5, reducing maternal and new-borne mortality rates, is to increase the number of births with a skilled birth attendant present. This generally means getting expecting mothers to a suitable health facility in good time for the birth. Three main barriers to this have been identified, one of which is access problems due to distance, poor infrastructure and lack of suitable and affordable transport. Because of family pressures, expectant mothers often leave travel until the last minute so that means of transport needs to be comfortable and suitably quick. Moreover, about 15% of births can expect to involve complications which in some cases could lead to death if not treated within 2 hours so effective emergency transport is essential to save lives. Although emergency transport is usually introduced for maternity patients, it is logical that many other lives could be saved if emergency cases reach health-care in time for effective treatment.

Conventional motorised ambulances are costly to buy and run and are generally unaffordable in poor countries. Typically a basic ambulance costs around $80,000 and about $0.60/km to run with fuel consumption around 6 km/litre and average speed 60 km/hr on reasonable roads.

Figure A – The motorcycle ambulance in operation.

Lower-cost versions have therefore been tried. Bicycle ambulances have had some success but require considerable human effort and are limited in speed and range. A significant drawback is that most emergency cases need a carer to travel with the patient. Motorcycle-based ambulances seem very appropriate as an intermediate solution as motorcycles are widely used in developing countries and are reasonably cheap to buy and run.

The MAT shown was first trialled in Mtwara, Tanzania, completing over 10,000 km of service. It was taken over and improved by DT and has been undergoing trials in Zambia with local partner, The Disacare Wheelchair Centre.

Its main features are:

- wheels from a small car with leaf-spring suspension
- removeable lightweight stretcher
- seating for up to two carers
- automatic braking through pivoting hitch pin
- ball and socket hitch directly above rear axle
- rear lights, indicators and brake light powered from motorcycle.

The MAT can be readily towed by an off-road 125 cc motorcycle with high torque at the rear wheel. It can be locally manufactured in a competent workshop for around $1200.

Two MAT are at present on trial in Zambia within the Africa Community Access Programme (AFCAP). They are based at clinics serving catchment populations of about 20,000. Initially it was thought that they would be used mainly to transport referred patients but the main need has been found to collect maternity and emergency patients from villages. Less than 2% of these are then referred on. In six months one MAT has made over 150 trips collecting patients from over 50 villages. All trips have carried a carer.

Review of performance

Motorcycle trailers are common in some Asian countries such as Cambodia but are rare in Africa. However, the MAT has been readily accepted by users who have found it comfortable and convenient. A more convential option, the eRanger sidecar ambulance (Hoffman et al., 2010), is commercially produced in South Africa and has been introduced in a few countries. The cost, $5,500 (without shipping), is about the same as the MAT and motorcycle but the latter involves no shipping cost. The average speed of about 25 km/hr is also the same but the fuel consumption of the MAT with the Honda is about a third less at around 32 km/l. Some of the pros and cons are as follows:

- A sidecar is more stable and easier to control than the MAT, particularly on very sandy roads where it may be difficult to use the MAT.
- A sidecar puts more load on the motorcycle, increasing maintenance costs for wheels and suspension.
- The MAT offers greater flexibility in that the motorcycle is easily unhitched and can be used for other activities.

In sixteen months the MATs have completed 385 emergency trips, covering over 15,000 km and collecting patients from from over 50 villages.

Conclusion

Motorcycle-based ambulances are a viable alternative to conventional ambulances at a fraction of the cost but it will still be a challenge to fund them on a sustainable basis in many poor countries.

About the author: Ron Dennis
After spells as an academic at the University of West Indies, Trinidad, and University of New South Wales, Australia, Ron joined IT Transport Ltd in 1990 as a rural transport consultant, working mainly in sub Sahara Africa. He joined Developing Technologies as co-ordinator in 2004, based intially at Imperial College and then City University, London.
About the organisation: Developing Technologies is a UK-registered charity that aims to improve the lives of people in developing countries, mainly Africa, by developing and introducing appropriate technologies. This is done initially through student projects and then through volunteers working with local partners.

The MAT is still in the development phase and is not yet widespread. In its place, the most common and affordable form of motorised transport for all ages, including the old and infirm (who can be supported by a second passenger who holds them tightly) is the boda-boda. The boda-boda is a two wheeled taxi. Originally it referred to bicycles with some kind of rear seat (generally placed on top of the conventional pannier rack), but now the term has come to mean motorbike taxis, with the influx of cheap motorbikes from China (Dr Gina Porter, personal communication). The advantages of these over cars are clear: low cost, versatility, light weight and speed.

To conclude this section, it is worth considering the long-term. In hindsight, the rapid motorisation of high income nations seems to have been a mistake. This should be seen as an opportunity for the developing world, which could potentially move directly from high use of walking without becoming overly car dependent. There are analogies here in communications (where many nations are going straight from no phones to mobiles, missing-out the intermediary stage of landlines) and energy (where there is hope that developing countries can, to some extent, skip the fossil fuel stage and move directly to renewables). This leads EWB-UK projects to focus primarily on highly efficient or non-motorised options in our vehicles projects.

8.2 Non-motorised personal transport

Non-motorized personal transport includes walking, cycling, bicycle ambulances and wheelchairs. Non-motorised load-carrying vehicles are covered in section 8.3. Their main advantages from a development perspective are low-cost, simplicity and ease of repair. Additional co-benefits include improved air and water quality, social cohesion (as non-motorised transport encourages face-to-face interaction), health and safety. Many of the benefits of non-motorised transport can be attributed to their low energy consumption (Illich, 1974, Figure 8.1).

Disadvantages of non-motorized modes include increased toil, slowness and (on busy motorised roads) risk to the individual user. Because cars are a status symbol in much of the developing world, an additional perceived disadvantage of non-motorised modes is the stigma attached to them[1]. For this reason, social campaigns to promote active transport as a healthy lifestyle may have a particularly large impact. The website and Facebook page of Bicycle Empowerment Network Namibia is a good example of good practice in this area. EWB-UK placement volunteers with internet skills may be well-placed to help in this area, especially with the rapid uptake of the internet in the developing world.

Walking

Walking is often overlooked in transport studies as it is something that happens all the time, is rarely measured and requires no infrastructure or technology. However, it is the most common mode of transport among the world's poorest people, as many cannot afford anything else so deserves attention. Walking for personal travel can be a cheap, healthy and environmentally benign activity. Frequently, however, walking is done to carry heavy loads, typically of around 25 kg or more of everyday necessities such as water and firewood. This carrying is gendered, primarily undertaken by women and children with impacts on health (e.g. back pain, risk of injury), opportunities for participation and well-being (see Porter et al. 2013 for an overview). Walking is rarely targeted directly, yet it can be influenced by other projects, for example roads without adequate pavements can make it dangerous for the poorest people to use. In urban areas, providing pedestrians with a right of way can help create useable public spaces. These can help create a sense of civic pride in a way that does not exclude people due to lack of motorised transport. Because roads in low-income nations lack good pedestrian facilities, many people are forced to walk along the verges. Despite lower rates of motorised transport, the rate of traffic-related fatalities is highest in poor countries, reaching 10 times more than the rate in the UK (3.6 people killed per year per 100,000 inhabitants[2]).

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1. *This is not considered as a real disadvantage: in 1970's London, cyclists were seen as 'either poor or crazy' according to one anecdote. The growth of cycling in the city now suggests that such stigma may only be a temporary and perceived disadvantage in other cities.*

2. *See http://en.wikipedia.org/wiki/List_of_countries_by_traffic-related_death_rate or World Bank statistics.*

Because of the ubiquity of walking but its absence from international development projects, there is large potential for including it as a co-benefit of other EWB-UK projects, although it is unlikely to form the focus of placements in itself.

Bicycles

Bicycles are in many circumstances the most efficient, cheapest, fun and (in congested areas) fastest form of personal travel available. Their low energy use is one of their main attractions in developing areas where liquid fuels are in short supply. Energy savings relative to the car vary depending on a number of assumptions (Lovelace et al., 2011). However, 'under most combinations of assumptions, bicycles can cover a given distance using one-thousandth of the fuel that automobiles use.' (Komanoff 2009, Figure 8.1).

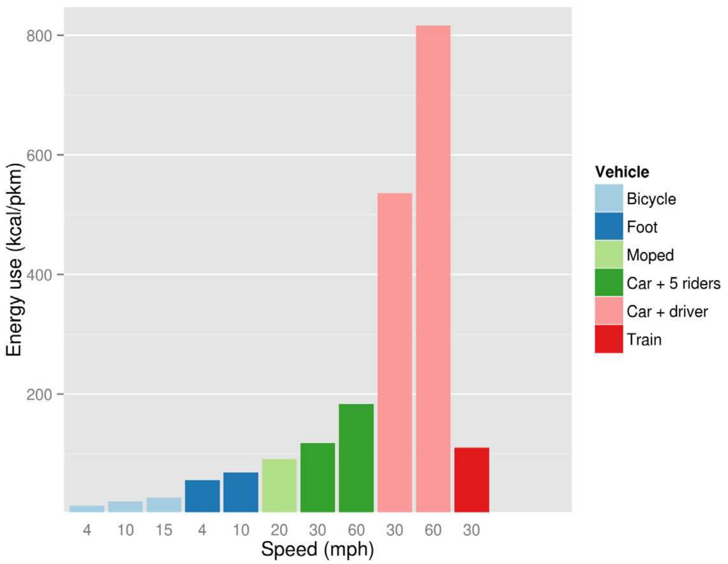


Figure 8.1 – Energy (fuel/food) consumption per passenger kilometre (pkm) and average speed of different modes of personal transport (data from Wilson et al., 2004; graph by Robin Lovelace using ggplot2).

A bike allows you to travel roughly 3 times faster (and hence cover an area 9 times greater, in a given time) than walking, and requires no expensive, energy-intensive and high-maintenance roads – although good surfaces improve the cycling experience (Komanoff, 2009) and more expensive bicycles may be needed to deal with the roughest terrain. Cycling does require some infrastructure (pathways, a repair workshop and basic tools such as a pump), but nowhere near as much as a car. This is well illustrated by considering the following: a typical bicycle (~12 kg) is 100 times lighter and less resource hungry than a typical car (~1200 kg). Assuming a body mass of 60 kg, 1/20th of a car's effort actually moves people; for bicycle the ratio is 5:1.

Another major advantage of the bicycle from the perspective of development is its simplicity. It is relatively easy for one person to recognise and understand every part (moving or not) of a bicycle, whereas cars require specialist mechanics and tools to be fixed. As a result of this simplicity and lightness, bicycles have been seen as a pathway to empower the world's poorest people: due to the bicycle's low embodied energy and ease of storage and maintenance, it is feasible for every person on Earth to own one. Bicycles can thus be seen as a transport solution for everyone, not just the wealthy. If the price of oil continues to rise due to increasing demand, bicycles will have an ever-greater economic advantage over the car. This direction of development is encouraged by some transport-development charities such as Re~Cycle and BEN (see case studies on page 99 and 104). With simple modifications such as panniers and bike trailers, bicycles can also carry additional weight in the form of goods or passengers, as illustrated by the Namibian bicycle ambulance.

Case study: Namibian bicycle ambulance

Michael Linke, 2006 onwards

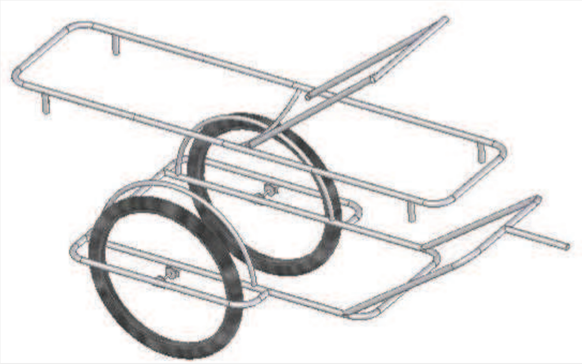
The Bicycling Empowerment Network Namibia (BEN Namibia) is a Namibian non-profit organisation that began in 2005 in response to demand for bicycles from healthcare volunteer networks. After surveying early recipients of bicycles, (in this case volunteers providing outreach services to people living with HIV/AIDS in rural Namibia), it became apparent that volunteers often took responsibility for transporting clients to health facilities, and that the luggage racks of their bicycles were often used for this purpose. Clearly this situation was not ideal, especially given that at this time HIV treatment medication was still not widely available, and many clients were seriously ill and physically weak.

Figure A – Completed bicycle trailer.

BEN Namibia was aware of a bicycle ambulance project in Uganda run by FABIO (First African Bicycle Office) and built a prototype out of scrap steel, mountain bike wheels and shade-cloth. This was demonstrated to a group of volunteers and health professionals in northern Namibia, and the feedback for the concept was positive, though the many shortcomings of the prototype were pointed out.

Design

To advance the project, BEN Namibia contracted a designer, Aaron Wheeler to develop the design. Early research revealed that ambulance projects in Mozambique (Design for Development) and Zambia (Disacare's Zambulance) had developed interesting designs, and these were referenced for BEN Namibia's next set of prototypes. Each of the several design iterations was field tested, with logs and user interviews informing the next iteration. BEN Namibia began production of the final design in its own workshop and soon after distributed the first bicycle ambulances, along with a basic tool kit, training in use and maintenance, and a discussion on management.



Figures B and C – sketch of the BEN bicycle ambulance trailer (above) and photo of hitch (right).

Results

Early feedback showed that the ambulance had the potential to provide effective emergency transportation. It was used for patients with a range of conditions including malaria, domestic violence, scorpion bites and HIV/AIDS. The design proved highly functional and durable, with the exception of a bicycle tube-sprung stretcher, which was replaced with a more durable cord when the tubes began perishing.

Over 100 ambulances were delivered over a two year period, and logs showed that they had been effective in reducing discomfort and saving lives. Unfortunately, many of the bicycle ambulances were not in use beyond two years in the field. The main issues were found to be a lack of resources to maintain them, and a lack of a well defined structure to manage them. As a small non-profit organisation with few field staff, it was impossible to provide the requisite monitoring and support to keep more than 100 ambulances functioning. Of those that still function, there is a committed individual or group in charge of management.

Conclusion

Our conclusion is that bicycle ambulances have potential to fill an emergency medical transport gap in some contexts; however recipients should be well-resourced and have a long-term commitment to managing them. BEN Namibia has begun delivering a smaller, multi-purpose trailer that can carry water, grain and firewood, as well as an adult or child in an emergency. We hypothesize that a device with economic value is more likely to be maintained, and hence be more available for medical emergencies for a longer time.

About the author: Michael Linke is an Australian who founded the Bicycling Empowerment Network Namibia in 2005, and still works as its managing director. His previous roles include editing cycling and sustainable technology magazines and working as a bicycle rickshaw mechanic.

About the organisation: BEN Namibia has conducted a range of bicycle-related projects, from managing a competitive cycling team that promoted HIV/AIDS awareness, to researching the impact of transport on health in rural Namibia. Its network of 32 supported partner bicycle shops is its main project area.

Another major advantage of the bicycle is its ubiquity. Levels of bicycle ownership and use vary considerably however, so it is important to gain understanding of its current role and accessibility to local people before any bicycle-related projects are undertaken. Projects conducted in areas where cycling is to some degree embedded in the culture stand a better chance of succeeding in areas where the bicycle is seen as foreign object. An indication of this variability is provided in Table 8.2.

Country or region	Bicycles	Autos	Bicycle/ auto ratio	Bicycles per 10001	Autos per 1000
China	500,000,000	18,000,000	28	392	14
India	60,000,000	10,000,000	6	59	10
Netherlands	12,000,000	6,000,000	2	750	375
United States	120,000,000	180,000,000	0.7	421	632
Argentina	5,000,000	5,000,000	1	135	135
Africa	40,000,000	20,000,000	2	50	25
World totals	1,200,000,000	600,000,000	2	198	99

Table 8.2 – Data on the variation of bicycle and car ownership, around the year 2000 (Komanoff, 2008).

Bicycles are primarily seen as a means of passenger transport. However, as Figures 8.2 and 8.3 show, they are also highly efficient at carrying loads at low to medium speeds. Many organisations use bicycles for development, such as BEN (see previous case study) and Re~Cycle (see case study Re~Cycle for Africa on page 104). Note that a racing bicycle is used in this graph; for utility bicycles, the power curve would be higher and steeper.

It is important to remember that even a bicycle without any modifications can ease the burden of goods transportation by placing the strain on wheels rather than on humans as shown in these photographs. Innovative solutions can enable bicycles to carry loads far exceeding what they were designed for.

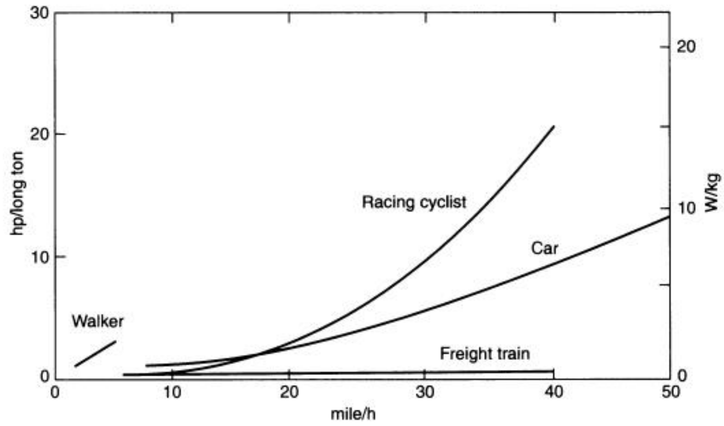


Figure 8.2 – The power requirements of bicycles relative to other modes for carrying loads (Wilson et al., 2004). Note that a racing bicycle is used in this graph; for utility bicycles, the power curve would be higher and steeper.

Figure 8.3 – Bicycles used for people and load carrying in the developing world.

Case study: Re~Cycle for Africa, UK

Merlin Matthews, 2008 onwards

To date, Re~Cycle has donated over 50,000 bicycles to more than a dozen low-income nations including Ghana, South Africa and The Gambia. Unlike many appropriate technology organisations, it emphasises quantity as well as quality in its service, reasoning that the more bikes that get delivered the more people benefit. Another feature of Re~Cycle is that it undertakes development work in both low-income nations and the UK. While it seeks out the most needy recipients in the developing world, it simultaneously works to improve the skills and quality of life of those disadvantaged at home. Under one scheme, Youth Offending Teams (YOTs) in London and in prisons are provided with tools and training to enable them to service and refurbish bicycles. These bicycles are packed into shipping containers (which can take 450–500 bikes each) and arrive in various states of disrepair across Africa. This provides skilled employment and encourages local industry, as bicycle workshops must be employed to service the bicycles ready for use.

Re~Cycle emphasises that its aim is transport for development (unlike schemes such as Maya Pedal, which focus on pedal powered machines). Nurses, midwives and other health workers are therefore some of the targeted beneficiaries – a bicycle can allow them faster access to more people. As the founder of Re~Cycle says, 'in Africa a four-hour daily walk is common – mothers collecting clean water, parents trekking to the farm, factory or market, or children facing a 20 mile walk to school and back.'

About the author: Founder of Re~Cycle, Merlin Matthews studied management before working as a bicycle mechanic which provided the inspiration to set up Re~Cycle. Merlin proudly does not own a car.

About the organisation: Re~Cycle is an international charity based in the UK that operates in more than a dozen African countries. See more at http://www.re-cycle.org/.

The final bicycle design to consider before moving on to load-carrying vehicles is the Xtracycle. This idea, which originated in Nicaragua, involves lengthening existing bicycles by adding additional tubes to the rear triangle. The advantages of this in developing-world contexts are that existing bicycles can become more diverse, for carrying multiple passengers or goods. This is also a good example of technological development flowing from low to high-income nations: the idea of a long-wheelbase bike has caught on in the West. Manufacturers such as Yuba have long wheelbase designs, but the Xtracycle is the original, and is much more appropriate to developing nations as it can be retrofitted to existing bicycles at low cost. The Xtracycle company sells long wheelbase adapter kits, but it should be possible in many contexts to build Xtracycles (based on its plans, which are widely available, see http://www.xtracycle.com/longtailtech) abroad, using the 'cut and shut' techniques showcased in Graham & Mcgowan (2003) and the Atomic Zombie website.

Figure 8.4 – An example of the Xtracycle concept (photo courtesy: Andrew Dressel) © Creative Commons.

8.3 Load-carrying vehicles

This section focuses on ways of moving goods, not people, from A to B using hand-carts, bicycle trailers and rickshaws. Motorised options such as vans, trucks and lorries are inherently large-scale and mass-produced and generally not suitable for EWB-UK placements, so we restrict the description to non-motorised modes. The potential of simple technologies to aid the transportation of small to mid-weight goods (up to ~50 kg for bike trailers and hand carts or ~100 kg for tricycles or quadricycles) is large and often overlooked in the transport in development literature.

Hand carts

Due to their simplicity, ubiquity and cheapness, hand carts are often overlooked as a sustainable transport technology. Yet they reduce daily toil for thousands of people and make possible many transport tasks that would otherwise be impossible for a single person. Often these devices are simply assembled from available materials and hence many designs in operation will be far below the optimum. On the other hand, many purpose-built hand-carts have been manufactured in factories over the past centuries (CSIR, 2011). In 1978, for example, China was producing 10 million hand carts each year (Starkey, 2001). Regardless of the specifics of design and manufacture, Figure 8.5 illustrates the utility of even rudimentary hand carts and wheelbarrows. There is much room for improvement in hand cart design. EWB-UK placements could help make this humble technology even more accessible and useful.

Figure 8.5 shows the very high weights that sturdy hand carts can carry, especially if the load is well-balanced[1].

Figure 8.5 – Hand cart loaded with onions, Mumbai.

Bicycle trailers

Bicycle trailers are essentially the same as hand carts, but can be towed by bicycles as well as by hand, making them potentially faster and more efficient over suitable roads. The co-author can attest to

1. *Credit: http://mumbaidailysnapshot.blogspot.co.uk/2007/09/hand-cart-wallahs-haath-gaadi-wallahs.html*

this utility in the UK, having moved house ~100 kilometers (from York to Sheffield) by bicycle trailer and using a bike trailer for small tasks such as shopping and transporting materials for EWB-UK projects. Bicycle trailers are diverse, in that they can often also double as hand-carts, but require more specific local factors for them to be appropriate. These include:

- the availability of suitable bicycles (sturdy, accessible, with low gears) and cyclists
- smoother roads than would be required both for bicycles and hand carts, due to the added weight and friction of bicycle trailers and the possibility that they can flip in uneven terrain
- local knowledge and incentive to regularly use and maintain bicycle trailers.

As with many appropriate technologies the final point is key. Even if bicycle trailers may seem perfectly suited to an application, in practice there is no guarantee that it will be taken up. A good example of this is the failed attempt to implement bicycle trailers in rural Ghana to reduce the toil of head-carrying by women. Bike trailers' ability to remove stress on neck and knee joints seemed to make them ideal on paper. Ultimately, the solution was deemed to have failed to meet its objectives, 'because it was unaffordable and not entirely relevant to the needs of its intended users,' (Salifu, 1997). The recommendations that stemmed from this sobering realisation were technological and social: that the bicycle trailer should be made cheaper and more sturdy, and that bicycle training should be offered to rural women to enable them to take full advantage of the technology. EWB-UK placement volunteers hoping to use bicycle trailers in any part of their project (such as moving small goods for different projects) are recommended to accustom themselves with the technology before setting-out for their assignment. As illustrated in the next case study, bicycle trailers can have a large benefit in developed nations – a technology that is truly appropriate worldwide and can help level the technological divide between high and low income nations.

Case study: community bicycle trailers, UK

Robin Lovelace, EWB-UK Sheffield, 2011 onwards

My interest in bicycle trailers for development was sparked by three things: seeing small loads being painfully and inefficiently carried in Honduras, concern about the long-term impacts of fossil fuel dependence and the experience of moving house from York to Sheffield by bike trailer.

It only became apparent that there was high local demand for bicycle trailers in 2011. Abundance, a community group that harvests and distributes surplus fruit, built their own bicycle trailer with the help of Ben Milner, an appropriate technology expert from Leeds. Their trailer carried substantial loads (up to 100 kg) around town at low cost, leading to interest from other community groups and local businesses.

Figure A – Abundance bicycle trailers and cargo (photo courtesy: Pete Hodge).

Based on this research, EWB-UK Sheffield applied for a £1,000 grant to build bicycle trailers for other community projects in Sheffield, which we secured. The next stage was to find out which organisations wanted bicycle trailers, and their design criteria. To do this, an article was written in the local magazine asking people to send requests for bicycle trailers (see http://nowthenmagazine.com/issue-42/bike-trailers/). Five new organisations applied, ranging from a bakery who wanted a trailer to deliver bread, to Sustrans, who wanted a trailer for bicycle path maintenance.

The design criteria for each trailer was different, but we opted for a unified approach to construction, centred around the 40 mm aluminium L sections used for the Abundance trailer. A key design challenge was the hitch, which tended to break in previous DIY designs. To overcome this, we used a 3 mm thick stainless steel box section, instead of 0.5 mm sheet aluminium.

The design stage was longer than anticipated: over six months of the planned one year schedule. The use of CAD software was encouraged, for ease of modification and ease of disseminating the designs. In hindsight, this led to some impressive models which may have distracted from more practical tasks (Google Sketchup is a cheaper alternative); hand drawings sufficed for some designs.

The diagram below shows a CAD drawing and specifications of the 'Sustrans Trailer'. This overview was useful during construction.

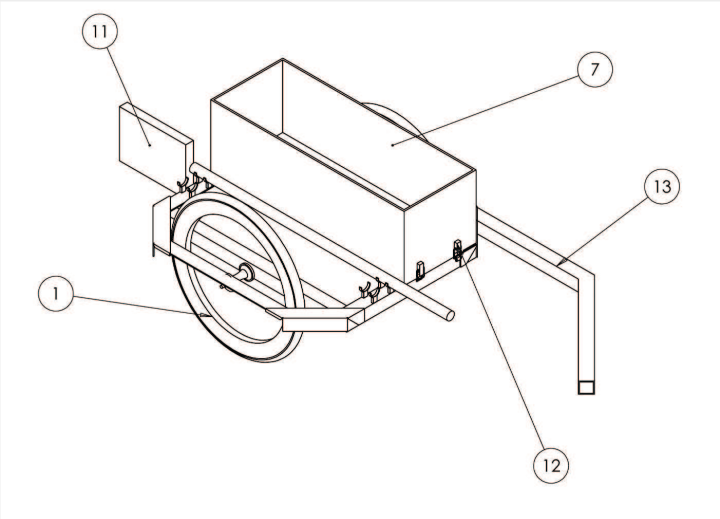


Figure B – CAD drawing of 'Sustrans Trailer', showing specific elements: 20" front bicycle wheel (1), spade/brush (11), removable box (7), left-hand tow bar (13) and tension clips (12). Design: Robin Lovelace, CAD: Jasper Roseland. This overview was useful during construction.

An inventory of all the materials was collated, from which the materials were purchased. Twenty inch wheels were obtained free from Recycle Bikes, Sheffield. Finally, in summer 2012 we began construction. This was a learning experience, as many had not done practical metalwork before. It involved lots of careful measurements and bolting together the struts with dozens of M6 stainless steel bolts and 'nylock' nuts to avoid failure due to vibration.

As of July 2013, three trailers have been completed: 'bread trailer', Sustrans trailer and a large trailer for transporting musical instruments. Setbacks included holidays, exam pressure and poor workshop conditions. The other trailers are nearing completion, the students involved with the project are learning sustainability skills and community groups are soon to be able to transport small goods more quickly. To conclude, the bicycle trailer project has been challenging yet rewarding. The results could be useful in many areas worldwide, rich or poor.

About the author: Robin Lovelace is a researcher at the University of Leeds. His interest is in the energy costs of personal transport. He became involved in EWB-UK when he started Sheffield's Wind Turbine group in 2009. From 2010 until 2013 he coordinated the Pedal Powered Machines group. See robinlovelace.net.

About the organisation: EWB-UK Sheffield is a highly active branch with a strong focus on community involvement.

A step up again from hand carts and bicycle trailers, tricycles and quadricycles are custom build pedal machines specifically designed for carrying weight. The rickshaw is the most common of these worldwide. As the following case study shows, new materials and insights have the potential to update existing designs, although these need to be tested thoroughly before they are accepted as 'better' than existing solutions, which have evolved over many decades.

Case study: a bamboo rickshaw, UK

Miriam Kennedy, 2012-2013

Cycle rickshaws are an important livelihood for many people throughout Asia. In Dhaka, an estimated 400,000 people operate cycle rickshaws daily rendering the city the 'rickshaw capital of the world'. Many of these rickshaw drivers come from the poorest regions of rural Bangladesh looking for a better life. However, pedalling a rickshaw is hard due in part to heavy and cumbersome designs. The hours to earn enough money to live from are long and the dangers from air pollution and other road traffic are rife[1].

In addition to weight, another issue is that rickshaws are made from materials originating from outside Bangladesh, e.g. the main bike frames. These are imported from elsewhere, mainly China, and there is a heavy import tax which makes them relatively expensive. This study identified a need for a rickshaw which can be produced with local skills and materials, not just to reduce costs but also to fund the local economy and to increase the sustainability of the rickshaws.

Under normal conditions, rickshaw pulling is not a difficult job: an averagely fit man or woman should be able to work for several hours. However, with just 10 mph winds or a gradient of 2%, the power required to maintain speed doubles. Rough roads, worn tyres and repeated stopping and starting in busy traffic increase the burden. In addition, rickshaws are expensive for a labourer to own. Approximately 13% of rickshaw drivers own their own rickshaws; the rest rent them on a half-day/daily basis[2].

Based on these problems, a rickshaw made from bamboo and jute (a natural fibre) composite was proposed. An analysis of the literature suggests that this use of materials is new. This could reduce the weight of the rickshaw, make it cheaper to produce locally and take advantage of an abundance of natural resources. Ninety percent of the needs of the rural populace for

1. *Engineers Without Borders research projects: http://www.ewb-uk.org/projects/ideas*
2. *Pulling rickshaws in the city of Dhaka: a way out of poverty? Begum, S.; Sen, B. 2005*

construction, thatching, household articles and fuel are served by bamboo and rattan; Bangladesh is the largest exporter of jute in the world.

A prototype has been built from the design (Figure B) and its main features are:

- Most structural components of the frame are made from bamboo culms.
- All joints are secured using jute and epoxy composite.
- Half drive transmission for easier steering.
- Front fork, bottom bracket and wheels taken from a standard bicycle.
- Highly adaptable design which can accommodate passengers or freight.

Testing is still to be completed, following the addition of the chain and seat post. This prototype was developed as a proof of concept and will need to be further developed and tested in the future. For example, the design of the connection between the rear axle and wheels should be further examined as little consideration was given to it. Fixings to controls such as the front and rear deraileur need to be developed. Also, it may be beneficial to manufacture more parts from bamboo e.g. the forks which could be manufactured using CNC machines from bamboo laminate.

Once a more complete design has been tested, the rickshaw should be tested in Bangladesh for extensive use and market acceptance. In conclusion, bamboo rickshaws may offer a feasible way to reduce both the materials and manufacturing costs typically involved in rickshaw construction. They could provide a lightweight yet strong alternative to traditional frames, with large potential benefits for rickshaw drivers.

Figure C – The bamboo rickshaw prototype.

About the author: Miriam Kennedy is a Mechanical Engineer whose final year project was on rickshaw design.

9 Vehicle operating costs

It is important that owners of transport equipment understand the actual costs of ownership and operation of vehicles, be they individuals, or organisations. There is widespread ignorance of this knowledge and much wishful thinking about how little it will cost to run a vehicle effectively. This leads to many wasted resources worldwide and has particularly severe economic consequences in developing regions where capital and credit is scarce and expensive to obtain. Local credit interest rates are often extremly high in developed countries, meaning that enterprises can become crippled by debt if they invest in the wrong vehicle technology.

It is important that any investment in transport equipment is highly utilized so that it can pay back its owner/investor as quickly as possible. Many vehicle/equipment investments have been unsuccessful in the past because of lack of understanding of the economics of the ownership and operation and inadequate utilization of the asset.

EWB-UK assignees can have an important role in creating awareness in owners and users of the real costs of transport ownership and operation. Aspects of availability and utilization assessment, expected vehicle life span, knowledge of maintenance requirements, availability and costs of spares and repair skills, flexibility of application/task, knowledge of the market for services, residual or resale value and good record keeping, are all factors that an owner should understand to enable realistic pricing and a reasonable return on the investment. Carbon footprinting of transport options is likely to be an increasingly important issue for owners, the public and policy makers in the future, and considerable work is required in researching these aspects for both the transport infrastructure and means of transport.

This short chapter outlines the main vehicle operating costs – financial, labour, food and fuel, maintenance and wider social and environmental impacts – before highlighting the issues with a case study from Ghana. This extended case study, which forms a section in its own right, is valuable because it demonstrates how the daily realities of transport decision making are often much more complex than abstract reasoning from afar.

9.1 Outline of vehicle operating costs

Although the initial outlay for a new vehicle is the most visible cost, it is only one part of the overall 'life cycle' cost. This is well illustrated by considering a car, the total cost of which to the owner depends on much more than the initial outlay (Figure 9.1).

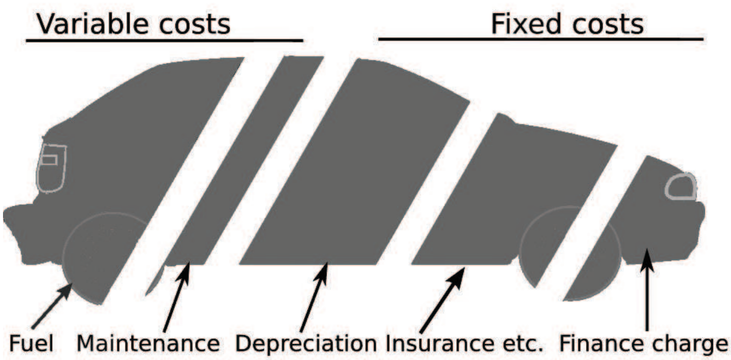


Figure 9.1 – Fixed and variable costs of a motor vehicle (not to scale) (credit: Robin Lovelace after Vaclav Smil).

Clearly, the proportions spent on each aspect of the total cost will vary for different modes (for example fuel costs will be zero for human powered transport) and places (fuel prices vary significantly internationally and are set to increase over time) but the concept applies throughout. Vehicle costs not included in the diagram include impacts on the local and global environment and society at large. For example, a large pickup truck will have impacts on each of these, perhaps leading to potholes in local roads, reduction in the frequency of walking in the local community due to fear of being run over or, on the other hand, increased access for elderly people to services via lift sharing. These wider knock-on impacts are not conducive to quantification, but deserve consideration.

In developed countries there is a strong second-hand market for cars, bicycles and other vehicles. Yet the difficulties associated with acquiring a vehicle in the first place should not be overlooked: the new and second-hand markets for vehicles will be less mature than in the West (where a quick search on Ebay can generally find you what you are looking for). Although there are probably enough bicycles worldwide for everyone to aspire to ownership at some stage, for example see Table 8.2, distribution is a major issue, as illustrated in Figure 9.2.

Figure 9.2 – A mass of bicycles delivered by container ship to an African port needing distribution.

The example of 'Bikes for Africa' type schemes underline the importance of distribution and associated costs. The organisational, logistical, energetic and financial costs of fairly distributing thousands of new and uniform vehicles over millions of square kilometres is not to be underestimated. And the problem is made all the more complex when one considers that second-hand bicycles will be in a variety of different conditions depending on their origin.

These issues provide an urgent challenge for development engineers interested in computing, mapping and logistics, which have all too often been overlooked in favour of purely local and low-tech solutions.

9.2 Labour, food and fuel

One of the first savings that one can expect from a new vehicle is a reduction in the toil and time taken for transport. Replacing animal carts with a small tractor, for example, will lead to savings in labour, food (for the animals) and time, although these could easily be offset by the price of liquid fuels. To take another example, carrying heavy items on one's head or shoulders is still a common way of transporting small goods in many areas. Replacing this by bicycle trailer can lead to savings all round.

Assessing the magnitude of these costs is an important stage in identifying scenarios in which a particular vehicle technology is likely to be effective. It is true that a wide range of factors will ultimately decide the choice of transport for a given application and that many of these cannot be quantified (as we shall see in the next section). Yet it is still worth estimating the magnitude of costs and savings that can be measured. To take the example of bicycle trailers for food distribution described in section 8.3, this would involve comparing the fuel savings of a switch to trailers from cars, against the additional costs, in terms of capital outlay and (if the trailers are to be used for long trips) time. To include both fixed and ongoing costs (see Figure 9.1) in the same comparison, the one-off payments should be converted into a per trip value. If, for example, the trailer is expected to cost £100 and make 100 trips over its lifetime, this would correspond to a capital cost of £1 per trip. Representing the cost like this is useful, as it allows direct comparisons with running costs of a car which could be, for example, £3 per trip.

This is not to say that non-quantifiable costs such as the risk to the user or the benefit of increased outdoor exercise, should be ignored from the analysis, simply that labour, food and fuel costs and savings of new vehicles should be considered in a systematic and (to the extent possible) objective way.

9.3 Maintenance and wider costs

An important cost that is often overlooked when acquiring a new vehicle is maintenance costs. The cost can be much higher than expected, not only because of the price of new components and labour to fix broken parts, but also because when a vehicle is broken the wider costs of undelivered goods or people can be high. All well-used machines will inevitably break at some point so it is vital to take maintenance considerations into account at an early stage in any vehicles-based project.

As a hypothetical example, let us look at bicycle provision in an urban settlement. Bicycles improve quality of life in the area by reducing the time spent travelling, enabling more people to attend school and find employment, encouraging the use of public space and making roads more accessible to those who cannot use cars. However the entire project could rapidly be ruined due to lack of a simple and cheap set of tools: bicycle tyre levers, repair kits and track pumps.

Continuing with this example, many of the roads are unpaved, making the rate of wear much faster than would be expected for the same bicycles in developed countries. We have seen in previous sections the tendency to use bicycles for passenger and load carrying. This will further accelerate the rate of degradation. There are additional issues of cyclist knowledge and skill. If the new users have not had proper training about how to cycle safely in a way that maximises the bicycle lifespan, there is no reason to expect the bikes to be ridden with care. Finally, there are no bicycle shops or trained bicycle mechanics in the local area. All of these factors conspire to make maintenance a much graver concern in developing world contexts than in the west and this also applies to other forms of transport. The example of the bicycle is particularly apt, not only because it is a plausible and probably common scenario. The bicycle is also an easily understood technology that can, if adequate systems are put in place early on, be maintained to a high standard over many decades.

So what systems need to be put in place to ensure the bicycle in the example are maintained? The answer is multi-faceted, encapsulating both mechanical and social aspects. The development engineer should consider implementation of, at a minimum, the following:

- Tools appropriate to the task of fixing foreseeable problems with the new vehicles.
- Provision of a workshop in which the the repairs can take place. This could also act as a hub for repairs and expertise in the area - the question of who owns it and how to keep the services affordable to the people who most need it needs to be considered.
- Expert training in vehicle repair (possibly involving certification of someone to take on the role as a job) and maintenance for the community at large.
- Education about best practice in the use of the vehicle. In the example of bicycles, this would involve instruction on the basic checks that need to be undertaken to diagnose the need for servicing. It would also involve cycle training – how to use the gears, brakes and racks correctly and how to cycle in a way that is both safe and ensures the longevity of the bicycle.

The above points demonstrate that maintenance is not something to be taken lightly. It can be critical to the success or failure of a project over time and needs to be taken seriously for any vehicle, especially those with many moving parts being deployed in areas with little experience in the technology in question. As the next section shows, it is one thing to make these plans on paper, but quite another to implement them successfully in the complex realities of transport systems in the developing world.

9.4 Realities of transport decision making

So far, the costs underlying transport decision making have been presented in abstract terms. Yet in the field, this thinking must be translated into an understanding of why certain decisions have been made. Often what can seem like an unusual or even backward way of moving things or people around is the result of decades of trial and error and careful planning. This section illustrates the options available and range of factors influencing the transport systems used for transporting agricultural materials and (to a lesser extent) people in Northern Ghana. This extended case study deserves a section in its own right because it is so detailed and pulls together many of the ideas of the preceding chapters into a coherent whole. Clearly, each region of the world will use a different combination of options. Yet everywhere there are parallels with the decision making processes described below. Consideration of the options should help development engineers arriving from abroad to appreciate the careful planning that has probably gone into a certain transport arrangement. The evidence presented below warns against assuming that transport decisions have been made haphazardly by the individuals involved and the usually mistaken impression that 'they are doing it wrong. Often, as we shall see, the realistic options available for change, are fewer than one would have initially imagined.

9.4.1 Transporting agricultural inputs in Northern Ghana

Agricultural inputs are bulky, and farmers need robust vehicles to transport them effectively. Animal traction (moving goods with animals) provides a low-cost, low-risk option compared to mechanized vehicles such as tractors. However, animal traction is still relatively expensive compared to human labour, especially when the latter derives from the family and is therefore un-costed. This is the case in much of sub-Saharan Africa, and Northern Ghana is no exception. This section illustrates how farmers can innovate to use animals as an appropriate transport mode, and was written by Imogen Bellwood-Howard[1]. Although the section is context-specific, the innovative combination of many transport modes and careful planning to minimise labour and monetary costs is a feature of goods transit systems that apply in developing rural areas worldwide.

Manure transportation is a critical issue in many rural farms. Tractors and carts are expensive and it is very labour intensive to have to transport a tonne or so of compost using only headpans (containers carried by people). Recognizing their limited access to funds and abundant labour force, the farmers of Ypilgu and Zaazi

1 *Imogen Bellwood-Howard is a researcher interested in agroecology, with a particular expertise in West African Savanna agricultural systems. This work was carried out whilst she was a PhD student at King's College London.*

worked out ways to combine animal traction and human labour, in order to transport such agricultural inputs in the most convenient way.

Researchers in Northern Ghana provided a donkey cart that could carry approximately half a cubic metre of manure. Farmers established a system to maximise its effectiveness. One way they did this was by having an adult farmer, almost always a man, help load the cart with manure and then use an older child to drive it to the farm at around three miles per hour. While that took place, the adult filled another 50 litre sack with compost. He tied it to the pannier rack of a bicycle, rode ahead, overtook the donkey cart, and dumped the sack of manure on the field. By the time he finished spreading it, the cart had arrived with more compost, and the adult could then use his superior strength to shovel it off again. Buckets and head-pans can be used for shoveling, if a more expensive shovel or spade is not available. In this way the adult can make good use of his labour time.

Figure 9.3 – A Donkey cart typical of West Africa (credit: Imogen Bellwood-Howard).

This process can also take place with bullock carts, which carry about four times the load of a donkey cart, and are pulled by two animals. Teamwork is much more efficient in these systems. When several people are shoveling muck onto a cart the relative effort is more concentrated; they can rest and recover for the next circuit as the cart travels to its destination.

Figure 9.4 – A metal Bullock cart. Wooden models are also available (credit: Imogen Bellwood-Howard).

9.4.2. Alternatives to animal traction and carts

As for the actual vehicles involved, there are technical reasons why animal carts are preferred for this type of work. Another option would be to use a Motokia (Figure 9.5). However, the harness connection between an animal and the cart is more flexible than on these motorized vehicles. Therefore animal traction is better able to deal with uneven road surfaces and tight corners.

Figure 9.5 – Motokia. Most are made in China (credit: Imogen Bellwood-Howard).

Donkeys and bullocks also each have their own particular advantages. Donkeys have more stamina and can work until midday, and even again in the evening between 4 pm and 6 pm. Cattle, on the other hand, must be released to graze with the herd around 9 am. In their favour they can pull a larger sized cart.

There are two main types of bicycle in use in Northern Ghana. The Phoenix model is generally favoured for farm work as it is characterised as 'stronger'. However, people often use reinforced pannier racks to avoid the prefabricated ones on the 'Fifi' bicycle bending, and so this smaller model can also be used for compost transportation.

Figure 9.6 – Two common bicycle models used in West Africa: The Fifi (above) and the Phoenix (below) (credit: Imogen Bellwood-Howard).

Of course, not everyone has access to animal carts, because of their scarcity in rural areas as well as a lack of cash to hire those that are available. Also, although family labour is common, it is not always available. Farmers therefore combine cart use, cycling and head carriage as far as possible, playing labour requirements off against cash.

People may gain access to animal drawn vehicles in a number of ways. Straightforward hiring is becoming more common as carts become available in rural areas. However, once a household in a given community is in possession of a cart, borrowing and sharing also become part of the picture.

9.4.3 Maintenance issues

Problems with the donkey carts in use here are mostly related to the wheels. The carts used in the study were obtained from a nearby factory in 2010, and at that time the axles and bearings used for that model were difficult to obtain in Ghana, being one of the few items that were imported from Burkina Faso. A better solution has since arisen: models are now being produced by local blacksmiths that use old car tyres. Although these are less robust, they are easier to replace from disused vehicles in the event of damage.

Air also escapes from the tyres of the cart, because no inner tubes are used. However, farmers have found ingenious way to deal with this: smearing cooking oil or maize porridge around the rim of the tyre seals it to the metal rim in an elastic fashion. This deals well with temperature fluctuations and thus prevents air escaping in hot weather.

9.5 Chapter summary

This chapter has moved beyond the technological focus of chapter 6 to explore how vehicles are financed, maintained and used in practice. The key message of this chapter is that technology is only one aspect of vehicle-based solutions to transport challenges: in many cases the greater and more difficult transport problems to solve are to do with running costs, finances, maintenance and behaviour. The hypothetical example of bicycle deployment in a settlement that has previously had little access to this technology – which will be new and alien to many of the inhabitants – demonstrates that considering these wider issues is vital for the long-term success of the project. The study of animal traction illustrates that it is not always the technology itself, but more the innovative way in which it is used, that can maximise effectiveness of the transport system in a given situation. In the penultimate chapter we turn our attention to information communications technologies (ICT), which are already dramatically altering transport patterns in many parts of the world. All that has been said before should thus be considered in the context of these digitally-driven changes, which are only set to accelerate in the future.

10 Mobile phones and the impacts of ICT on transport patterns

Mobile phones are not a mode of transport in themselves but they deserve a section of their own, due to their large impact on transport habits and the potential to vastly improve the utility of trips that are made. In the early 2000s mobile phone ownership in most developing areas was rare, network coverage was poor and usage in daily life was limited. Now, in the early 2010s, mobile phones have become ubiquitous in many areas, and mobile phone operators have extended coverage to most settlements. The booming second-hand market in mobile phones and increased production worldwide has made the mobile phone an accessory that is available to most people. 'It is nothing' to own a mobile phone now, even for a low income teenager, according to a recent talk on the subject. Elderly people, a group often overlooked in development studies, increasingly make use of mobile phones, for example as a means of staying in contact with children who have left the home and for organising visits to a doctor or a hospital in times of need.

A case study from Ghana supports these more general observations. It was found that mobile phones are increasingly well-integrated into the transport decisions of everyday life, acting as a trigger for travel in some cases (e.g. receiving an invite by mobile phone) and a way of re-scheduling long-distance trips in others (e.g. if the price is very low for products at the market one day, or if a river is flooded)[1].

Returning to the wider social and environmental context of engineering solutions described in chapter 1, the ongoing 'digital revolution' has great potential to empower people. While car ownership is something to which most people cannot realistically aspire, a mobile phone is within reach of the majority of the world's population,even those with very low incomes. If current trends continue, even 'smartphones' with internet connection will become increasingly available to people in the developing world.

Given that one of the main functions of transportation is to facilitate communication, the potential impacts of this development

1 *A talk on the subject can be found here: http://youtu.be/6QwhkjLy-Uc*

are vast. Using video-conferencing technology such as Skype and Google Hangouts, for example, people could 'travel' to faraway places and cultures to conduct their business. Clearly, this will never be a substitute for travelling to the market (although smartphones certainly could help decide whether or not it's worth travelling to market on a particular day) yet the potential for mobile communications to change and to some extent reduce the need for travel remains vast.

Because this book is primarily targeted at potential placement volunteers, our final comment regarding the impact of ICT is for engineers working in the development sector. One of the major inequalities in the world today is the ability to travel freely between borders. This is limited to a tiny subset of the world's population, perhaps only ~1% due to financial, legal, social and family barriers for the majority. Development engineers are generally in this privileged 'high mobility' 1% group and we should use this privilege with care. In some cases, the act of travelling to a developing country, and then leaving again, can in itself increase this 'mobility inequality' by making the limited travel options of local communities clear in comparison with the jet-setting volunteers. This is not to say that international travel for engineering projects should be discouraged: physical presence in a country can lead to exchange of skills, knowledge and culture that nothing else can replace. However, an enlightened view of development is one in which outside support is only temporary; in place while local capacity grows. As one experienced development volunteer put it in a highly recommended article, 'I think we're finally doing aid right, and I'm not there.'[2]

What is meant by this, is that building local capacity should be the priority and that, for the author, the best indication of success is that the developing community is no longer dependent on outside support. Returning to ICT, perhaps this interpretation of development has implications not only for how developing communities use communications, but for how placement volunteers use it. It opens up new opportunities for exploring the host community via reading local news stories, mapping and even live communications such as Skype calls before travelling out there. If

2 *https://medium.com/race-class/b84d4011d17e*

knowledge is the ultimate resource, then perhaps the engineer's positive impact on an area can begin (and continue) when he or she is not physically there. In many cases it is not a deficiency of motivation or skill, but a lack of information, and this is something that can, in the hands of a conscientious engineer, be at least partly overcome using ICT to share knowledge.

In addition, this insight may help to overcome one of the tensions in development engineering overall: while sustainability is at the core of appropriate solutions to poverty alleviation it is somewhat of a contradiction that being a placement volunteer in most cases depends on that most unsustainable and unequally distributed form of transport – flying. By harnessing ICT technologies and enabling developing communities to use computing solutions for empowering their own development, engineers can reconcile this contradiction. That is not to say that international trips are no longer necessary – they undoubtedly are for many projects – simply that the frequency of trips can be reduced. More importantly, ICT has the potential to spread the positive impacts of a project far beyond the limited duration and spatial extent of a placement. An example of this is 'Map Tandale', a project whereby local knowledge was harnessed to improve the open-access Open Street Map (OSM) data for the area (Iliffe et al., 2013)[3]. This project is now continuing without further input from development engineers, achieving one of the ultimate goals of development work. The insights gained from the project have the potential to spread to other places worldwide as most of the engineering is in the form of computer code which is a low cost but highly labour-intensive building resource. Arguably, the hundreds of pounds spent on international travel could, in such cases, be better spent in the local communities rather than being transferred to multinational airline companies who are unfortunately one of the main financial beneficiaries from international development engineering.

To summarise this chapter, the digital revolution is happening in the developing world at an extraordinary rate. This is due primarily to the proliferation of low cost (new and second-hand) mobile phones,

3 *The impacts of this project can be seen clearly on OSM here: http://www.openstreetmap.org/node/279283638#map=16/-6.7932/39.2444*

an increasing proportion of which allow internet access. There is evidence that this phenomenon is dramatically changing travel patterns, making them more efficient and, in some cases reducing the need for travel. These changes are set to accelerate and intensify over the coming years as mobile phone operators deploy "4G" base stations worldwide. ICT developments also have implications for development engineers, enabling them to gain insight and communications with communities before and after placements. ICT has vast potential to amplify the impacts of seemingly small interventions beyond the initial scope of the project. This benefit of harnessing ICT in development work is well illustrated by a case study of community mapping in Tanzania, as well as the diffusion of the practices of Bicycle Empowerment Network Namibia (BEN) described in chapter 8. ICT technologies used intelligently by development engineers can also have potentially large financial and environmental benefits by reducing the need for expensive flights.

11 Conclusion

In this book we have looked at both well-established and recent practice and thought about engineering interventions in transport systems for development. The range of options covered was wide, from bicycle trailers to culverts, ambulances to bridges. Yet, it is important to remember that the projects we have highlighted represent only a fraction of international experience in the area. EWB-UK is a relatively small player in the big game of development, so trying to cover everything in a single book would not be feasible. Moreover, transport for development is a quickly evolving field in some respects. For example, the current rate of change is particularly rapid in the area of communications technology. Chapter 10 demonstrated how mobile devices are already influencing transport behaviours worldwide; a trend that is accelerating the transformation of certain travel patterns, mediated by digital technologies.

Furthermore, as the example of community mapping in Tandale illustrated, it is often difficult to predict the direction in which innovation will happen. Decades ago, such community involvement in redrawing the plans used by local government would have been unthinkable, yet technological progress has made this possible. What other empowering possibilities will be opened up by technological change? Here is not the place to speculate. Suffice to say that the innovative thinking and design displayed in the case studies throughout the book demonstrate that development engineering requires a combination of skills, including adaptability. Understanding of previous experience and physical processes form the foundation on which every small-scale transport intervention should be built. Empathy, communication skills and, at times, creativity are also vital to discover which problems to prioritise and how they can best be tackled in the local context.

Throughout, we have seen how complexities 'on the ground' mean that a single solution is unlikely to work in all areas. Understanding local conditions and their implications for the project is critical to its success.

The interventions we have covered all fall within the concept of appropriate technology: EWB-UK deliberately focuses on solutions that are accessible to as many people as possible. One danger with very large projects of any kind is that accountability can be lacking. By seeking local solutions to local problems, the available resources can be used in the most effective way and tailored to the needs of people in the local area.

That is not to say that development engineering will always be undertaken on a small scale. As emphasised in chapter 4, rehabilitating a rural road should not be taken lightly. Appropriate does not mean simple or easy. Placement volunteers will often not see the long-term outcomes of their projects – although with improved ICT links, this barrier can increasingly be overcome – let alone rely on the transport solutions on a daily basis. This means that transparency, documentation of work and following best practice are more important than ever. Likewise it is vital to consider maintenance in developing world contexts, perhaps more so than in almost any other area of engineering.

Finally, seemingly small placement projects can help provide a stepping stone to allow EWB-UK volunteers to pursue an alternative type of engineering, beyond the typical career path, which can be quite restrictive. This could involve a full-time career in the development sector, voluntary work outside working hours (some engineering firms actively encourage their employees to undertake work for social benefit), pushing for change within one's work or even setting up one's own enterprise, as illustrated by the example of Re~Cycle. In every case, the practical field experience gained during a placement will be of great use.

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12.1 Online resources

The internet is awash with information on transport in development; it is important to be selective. The following should provide a good starting point for high quality on-line resources on the topic:

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DFID Research for Development: http://r4d.dfid.gov.uk/Default.aspx
IFRTD: http://www.ifrtd.org/en/

ITTransport: http://www.ittransport.co.uk/ SSATP: http://www.ssatp.org/
Transport Services and Animal traction: http://www.animaltraction.com/index.html

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