If there are sharp curves in the road where vehicles can maintain a high speed, invert the camber of the road (see also figure 43). This will reduce the risks of slipping vehicles. Inverting the camber is gradually built up over a 20m section before entering into the curve.

7.4 Graveling

In the past graveling of roads was considered an effective and cost-effective option for surfacing low-volume rural roads. Recent research however shows that gravel roads have serious limitations in many situations. Very often gravel surfaces are not appropriate, affordable or sustainable for rural roads. There are for example serious problems related to the maintenance and sustainability of gravel surfaces (or ordinary earth roads). Although the initial construction costs of gravel roads are low, the maintenance costs are very high.

The suitability of graveling roads depends on a range of factors. These include for example the road gradient, rainfall, material quality, haul distance and maintenance regime. Gravel should NOT be used if any of the following conditions, or a combination of them applies:

- Gravel quality is poor;
- Compaction & thickness cannot be assured;
- Haul distances are longer than 10km;
- Rainfall is very high – Gravel loss is related to rainfall;
- There are dry season dust problems;
- Traffic levels are high, i.e. more than 200 vehicle equivalents per day;
- Road gradients are more than 6% (with < 1,000mm rain per year) or more than 4% (with 1,000 – 2,000mm rain per year);
- If rainfall is more than 2,000mm/year;
- Adequate maintenance cannot be provided;
- Sub-grade is weak or soaked;
- Gravel deposits are limited or environmentally sensitive.
Although natural gravel is not the most cost-effective or appropriate surface in many situations, a description of some key construction considerations is given in this paragraph for reasons of completeness.

When a road is graveled, it is recommended that the full carriage-width and the shoulders are graveled with a layer with thickness of 15-20 centimeter (before compaction). A typical road camber for gravel roads is 8% (this is the equivalent of 10% before compaction). An example of a typical cross-section is shown in figure 46.

The haulage distance from the gravel pit to the site should normally not be more than 5km, otherwise it will be too expensive to construct a gravel surface. Tractors and trailers or light tipper trucks can be used for haulage.

**Figure 46: Typical cross-section of a gravel road**

Good gravel should have a mixture of stones, sand and clay in roughly the following proportions:

- **Stone** (> 2 mm): 50% (range: 35 – 65%)
- **Sand** (0.06 - 2mm): 40% (range: 20 – 40%)
- **Clay & Silt** (<0.06mm): 10% (range 10-25%)

To find out the proportions of the different aggregate fractions in a sample, carry out the settlement test (figure 47). Place a sample in a medicine bottle or a glass jar with straight sides. Fill half the jar with the sample. Then add water till the jar is ¾ full. Shake the jar vigorously and then let it stand to allow the soil to settle. Gravel and coarse sand will settle immediately, while fine sand and coarse silt settle more slowly, taking about 30 seconds. The approximate quantities of each size can be seen as layers in the sample; the finer material usually also has a different colour. The results of these tests only indicative. It may be necessary to have laboratory tests done as well.
To test the quality of the gravel take a sample, moisten it and mould it into a ball. You can feel the sand and stones by the gritty feel of the sample when you squeeze it. When, after drying, the ball retains its shape, you can assume that there is enough clayey binder in the material. Another test is to make a flat thick piece from the moist gravel sample and try to penetrate it with a pencil. If the pencil penetrates easily, the material is not suitable because it contains too much binder or clayey material. You can also take a dry sample of the gravel and crumble it in your hands. About half of the particles should be larger than 2mm in diameter. Try to crumble the large particles in your hand or by tapping LIGHTLY with a hammer. If the particles disintegrate into sand size particles, it will not be suitable for gravelling.

The Work Procedure for the placing of gravel involves four activities: un-loading, spreading, watering and compaction. Before carrying out any graveling works, first check that the earth works have been properly carried out and leveled to the exact and required standards. Before graveling check that all levels are correct and that the camber has not been damaged.
Organize the un-loading in such a way that waiting time for the vehicles is minimized. Based on the availability of labourers, dump trucks and the time required for loading, transport, un-loading and spreading, the supervisor should make a time-efficient plan for loading and un-loading operations. When unloading the gravel, the entire load should be dumped within a clearly marked area. To make spreading easier, instruct the drivers to move slowly forward while dumping so that the gravel is evenly distributed along the length of the rectangular area.

The area to be set out for each load of gravel depends on the required volume of gravel and the average truck load. Take an example where a 15cm of compacted gravel needs to be placed over a road width of 5m. As un-compacted gravel has a volume which is about 1.2 times larger than compacted gravel, a compacted layer of 15cm requires $1.2 \times 15cm = 18cm$ thickness of un-compacted gravel. Per meter road length (running meter) the required volume is $18 \times 5 \times 1 = 0.9$ m$^3$. If you have decided to dump gravel every 2 meters along the road (i.e. per dump $2 \times 0.9$ m$^3 = 1.8$ m$^3$) and if the loading capacity of a truck is 9 m$^3$, this means that one full truck has to dump its gravel load over $9 / 1.8 = 5$ equal heaps of gravel every two meters.

Always try to start graveling from the point where the quarry access joins the road (see figure 49). This will reduce the haulage times (and thus costs) and it will also improve the quality of compaction because the movement of the trucks will help in compaction. It will also allow the delivery of gravel to the finished road section without disturbing clearing, leveling and formation work. Another advantage is that graveling can continue, even during the rainy season. Always try to start graveling as soon as possible after the completion of the road formation works to minimize damage to the formed road.

**Figure 49:** Correct and wrong direction of graveling in relation to quarry location
Spreading starts after the gravel has been unloaded. It is recommended to spread the gravel immediately after it has been dumped to make use of the natural moisture content of the material. If the gravel is stock-piled along the road for a period of days before leveling and compaction is carried out, it will dry out and will then require more water when compacted.

Workers should use special spreading rakes, as shown at the right, or hoes to spread the material evenly onto the road base. Work from the center line towards the shoulder, and spread one side of the center line at a time. Remove or crush oversize pieces of rock.

Watering and compaction is done after the spreading. Compaction of the gravel layer is very important. Compaction should be done when the gravel is at the optimum moisture content.

In particular when the gravel is too dry, it will not be possible to achieve good compaction.

Check the moisture content before compaction making holes through the wet loose gravel layer to check whether the water has soaked through the whole layer. You can also carry out a hand squeeze test at test points.
Most commonly used compaction equipment in labour-based construction works are smooth-wheeled vibratory rollers (picture 12). The pedestrian roller and the sit-on 0.8 – 1.7 ton rollers are preferred. When very coarse or very plastic gravels have to be compacted, light smooth-wheeled rollers usually ‘walk’ on top of the layers without achieving much compaction. In such cases, sheep’s foot roller (for very plastic material like clays) and grid rollers for very coarse materials) should be used.

After compaction, use profile boards along the center line and the road shoulders, in combination with temporary travelers, to check that the compacted surface is at the desired levels and smooth, and that the required camber slope has been achieved throughout the road line.

7.5 Compaction

To produce a good quality road, it is important that all soils are properly compacted. **Without good compaction a road will erode very quickly.** Compaction should be carried out along the road line starting at the shoulder of the road and gradually working towards the center line. Ensure that the overlap when passing back and forth is at least 100mm. When the road is compacted make sure that the camber of the road is always maintained at the prescribed gradient for both the base layers as well as the surface layer.

**Figure 50:** Direction of compaction: from shoulders to center
An optimum quantity of water (usually between 8 to 20%, depending on the soil type) is needed when a soil is being compacted. If the soil is too dry or wet it cannot be compacted well. To check the moisture content, take some of the material and squeeze it into a ball. If you cannot form a ball, the material is too dry. When you can form a ball that packs well together, also under pressure, and does not show visible sign of free water on the surface, it is at the right moisture content. If the ball sticks to your hand and water comes out of it, the material is too wet. If soil is taken from the ditches or a side borrow, and spread and compacted immediately, the natural moisture content is usually sufficient for good compaction.

There are four methods of compaction: natural compaction, manual compaction, compaction using deadweight rollers and compaction using vibrating compaction equipment.

Natural Compaction is achieved by leaving soil to settle naturally. This is a slow process that takes at least 6 months. It is normally only used on very low fills, and is effective if the fill material is very moist and must dry out. Given sufficient time, roads compacted by natural consolidation can achieve similar densities as roads compacted by equipment. A main disadvantage of natural compaction is that while the soil is not consolidated, it erodes easily.

Manual compaction is done with hand rammers. They consist of a long wooden handle with a cast iron or concrete weight at the end. The weight is usually 6 to 8 kilograms. The hand rammer is lifted and dropped on the surface repeatedly to produce compaction. Hand rammers do not achieve good and even compaction over large areas. They are only useful in small and confined areas such as around culverts, potholes and other places where it is not possible to use mechanical compaction equipment.

Deadweight Rollers are for example single or double steel drums, towed or self-propelled, or with a load container to hold the deadweight. If deadweight rollers are not available locally, you have to find out if they can be transported to the work site (against a reasonable cost). Depending on the site conditions, it is not always easy to operate and maneuver deadweight roller, for example in mountainous terrain.
**Vibrating Rollers** Pedestrian vibrating rollers are more suitable for use for compaction of rural roads than hand rammers and vibrating plate compactors. A one ton twin-drum pedestrian vibrating roller is usually recommended for labour-based road construction. These can compact soil layers 10-15cm thick. They can compact to a greater depth than deadweight rollers due to the effect of the vibration. They also require a lower moisture content than deadweight rollers.

However, it is important to maintain an even speed to achieve even compaction (with deadweight rollers this is less important).

The first passes, should be done without vibration, to avoid that the roller gets “bogged down” into the soil. The speed should be around 3 km/hr or slow walking speed. With vibration, the average speed to maintain is around 1 km/hr. Small smooth-wheeled vibratory rollers are commonly used in labour-based road projects. When the first pass is completed, carry out the second pass, also starting from the edge to the center. Repeat the procedure until the specified number passes has been completed. In mountainous terrain it is often difficult to operate and control a pedestrian vibrating roller on steep grades. There it is better to use a riding vibrating roller.

It is very important to know how many passes with specific compaction equipment are required for the compaction of a sub-grade. You can do this in the follow way:

1.  Select a representative trial section about 10 meter long and 3 meter wide and hammer steel pegs on either side of the section, mid-way of the width, and make sure that the tops of the pegs are at the same level;

2.  Pull a string over the top of the pegs and mark on the string the position of the pegs and 5 intermediate points between the two peg marks at equal intervals. With the string in position, measure and record the height of the string at each point from the top of the sub-grade layer;

3.  Remove the string and apply one pass of the available roller. Stretch the string over the steel pegs, and measure and record the heights of the points on the string from the sub-grade layer. Repeat this procedure until 12 passes of the roller have been made;
4. Calculate the average height after each pass and plot the difference in height (Hi) in millimeters against passes, where Hi is the average change in height as a result of pass number Ni;

5. Read from the graph the value of N when H has reached 1mm. Add 2 more passes to that number and this gives the number of required passes. The example of table 9 shows that at pass 9 the compaction is 1mm. Thus 9 + 2 = 11 passes are required to achieve good quality compaction.

<table>
<thead>
<tr>
<th>Table 9: Example of calculating the number of passes for compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height from string to the top of sub-base (in mm)</strong></td>
</tr>
<tr>
<td>Point</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>No pass</td>
</tr>
<tr>
<td>Pass 1</td>
</tr>
<tr>
<td>Pass 2</td>
</tr>
<tr>
<td>Pass 3</td>
</tr>
<tr>
<td>Pass 4</td>
</tr>
<tr>
<td>Pass 5</td>
</tr>
<tr>
<td>Pass 6</td>
</tr>
<tr>
<td>Pass 7</td>
</tr>
<tr>
<td>Pass 8</td>
</tr>
<tr>
<td>Pass 9</td>
</tr>
<tr>
<td>Pass 10</td>
</tr>
<tr>
<td>Pass 11</td>
</tr>
<tr>
<td>Pass 12</td>
</tr>
</tbody>
</table>

Table 10 provides indicative information about the number of passes that is required for different types of compaction equipment for earthwork and gravel.

<table>
<thead>
<tr>
<th>Table 10: Number of passes required for compaction for different compaction equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of compaction equipment</strong></td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Vibrating roller (smooth wheeled)</td>
</tr>
<tr>
<td>Dead weight roller</td>
</tr>
</tbody>
</table>

A simple way to check if the compaction has been done to standard is to use a loaded vehicle. Drive it over the compacted section a few times and see if it leaves any wheel-ruts in the pavement. If ruts are left then more compaction is needed. After compaction, it is important to check with profile boards and a traveler that all levels are correct and that the surface is smooth and does not contain any uneven spots.
7.6 Drainage Works

Water is the main enemy of a road. Water can damage the road in two ways:

- Washing away the soil (erosion or scouring);
- Making the road body less strong (lowering the road bearing capacity).

A good drainage system is extremely important! It should include:

- **Road surface drainage** to enable the water to flow off the road surface,
- **Side drains and mitre drains** to collect and lead water away from the road,
- **Catchwater** drains which catches surface water before it reaches the road,
- **Scour checks** to prevent erosion in ditches by slowing down the water flow,
- **Culverts** to lead water from side drains under the road to the lower side,
- **Small bridges** and drifts to let the road cross small rivers and streams.

Figure 51 shows the typical elements of a drainage system for a road. **Remember that the best way to solve problems caused by the flow of water is normally to remove the water from the road before it causes a damage.**

![Figure 51: Typical elements of a drainage system for a road](image)

7.6.1 Road Surface Drainage

Stagnant water on the road surface will quickly cause erosion of the road surface. Surface water will also penetrate into the road, thereby reducing the strength of the road body. To prevent this happening, a camber is made to let the surface water run off to the side drains (figure 52). A camber is a slope from the center line towards the road shoulders. The camber’s gradient varies, depending on the type of surface materials. For earth and gravel roads, it is usually in the range of 7 to 10%. 

Water is the biggest enemy of a road

A drainage system for a road includes various types of drains

A camber is constructed to enable surface water to runoff to the side drains
7.6.2 Side Drains

Side drains collect and dispose of rainwater from the road and can be constructed as V-shaped, rectangular or trapezoid. The V-shape is usually constructed by a motor-grader. It can be easily maintained by heavy equipment but has a low capacity. The rectangular shape requires little space but needs to be lined to maintain its shape. A trapezoid side drain is often constructed in labour-based operations. It carries much water and, by carefully selecting gradients of its side slopes, it will resist erosion.
To provide side access to schools, clinics, go-downs, community roads, side tracks, etc. it is often required to construct side access drifts, cattle crossings, slope protection and aprons across side drains. If it is not possible to construct access culverts because of drainage problems, the only option is to build an access drift and “pave” part of the side drain to provide reliable access. If light traffic has to pass over these side accesses, they can be built with stone pitching or with concrete (which is more expensive).

7.6.3 Off-Road Drainage

Mitre drains (figure 54) are constructed to empty the side drain at regular intervals before the volume of water builds up and causes erosion of the side drain. The location of mitre drains should be determined while setting out the road alignment. Sufficient numbers of mitre drains are required. Wherever possible, provide a mitre drain for every 100m or less. When the road gradient is very small, provide mitre drains at every 50m along the side drain.

**Figure 54:** Mitre drain

**Figure 55:** Ensure strong block-offs in side drains

**Design considerations for mitre drains:**

- Make a strong block-off in the side drain (figure 55), and make it easy for the water to flow along and out of the mitre drain. The best way to provide a strong block-off is to leave 3 - 8m of natural ground on the drain line not excavated.

- Make sure that the mitre drain is big enough to carry the water from the side drain. In situations where the side drains carry more water than usual or where the side drain slope is much greater than the mitre drain slope, make the mitre drain wider than the side drain so that it can carry more water. Try to link mitre drains to natural run-off channels and agree on their location with local farmers, in order not to damage their land.

- Mitre drains should be as short as possible. Long mitre drains are expensive, silt up easily or get blocked off, and are difficult to maintain. Recommended slopes for mitre drains are 2-5%. Larger gradients may cause erosion. In mountainous terrain steeper gradients may be unavoidable. In that case take appropriate soil erosion control measures.

- The angle between the mitre drain and the side drain should never be greater than 45 degrees. An angle of 30 degrees is ideal (figure 56). To set out the angle between the mitre and side drain, construct a triangle as shown in figure 57 to set out the mitre drain. If you can avoid a larger angle, make two or more bends, each with an angle less than 45o (see also figure 56).
For different types of soil, different cross sections are recommended. Figure 58 shows typical recommended cross sections for different soil types.

Scour checks (figure 59) are used to control erosion in hilly terrain where it is not possible to place enough mitre drains. Scour checks or check dams are constructed in side drains to slow down the water flow.

Scour checks allow side drains to silt up behind the check. The interval for placing checks depends on the gradient of the drain and the quality of the soil. Sandy and silty soils are easy erodible and require shorter spacing of scour checks than less erodible soils. Scour checks are required when the gradient of the side drain is more than 4%.
Scour checks can be made of materials like wooden or bamboo stakes, loose packed stones or stone masonry. When trees are scarce it is not recommended to use stakes. Stakes can also be damaged by termites. If loose packed stones are used the stones must be tightly packed and grass turfs must be placed around the stones to prevent disintegration of the stones by people or cattle walking over them. The foundation of the scour check should be sufficiently deep into bottom, fore- and back slope of the side drain to avoid undermining by the water flow.

The distance between scour checks depends on the road gradient and the type of soil in which it is constructed. This relation is shown in table 11.

An apron is required downstream of the check to prevent erosion by water (figure 60). Aprons can for example be made of stones. Sods of grass should be placed against the upstream face of the scour check wall to prevent water seeping through it and to encourage silting to commence on the upstream side.

### Table 11: Spacing of scour checks for different slopes and soil types

<table>
<thead>
<tr>
<th>Gradien of Road</th>
<th>Scour Check Spacing According to Soil Conditions</th>
<th>Gradien of Road</th>
<th>Scour Check Spacing According to Soil Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>2%</td>
<td>None</td>
<td>None</td>
<td>8%</td>
</tr>
<tr>
<td>3%</td>
<td>None</td>
<td>20m</td>
<td>9%</td>
</tr>
<tr>
<td>4%</td>
<td>None</td>
<td>15m</td>
<td>10%</td>
</tr>
<tr>
<td>5%</td>
<td>20m</td>
<td>10m</td>
<td>12%</td>
</tr>
<tr>
<td>6%</td>
<td>15m</td>
<td>7.5m</td>
<td>15%</td>
</tr>
<tr>
<td>7%</td>
<td>10m</td>
<td>5m</td>
<td></td>
</tr>
</tbody>
</table>

### Figure 60: Cross-section of typical scour check made of local materials

Cut-off or interception drains are sometime useful to prevent surface water from reaching the road or to direct water to where it can cross the road safely at water crossings such as culverts, bridges, drifts, etc. Cut-off drains are also used to channel away water from the high side of the road in side sloping terrain.
In most cases, it is cheaper and safer to direct water away from the road through cut-off drains than providing erosion control measures in the side drains. However, there are certain dangers with cut-off drains that must be considered.

**Take into account the following points in building cut-off drains:**

- If cut-off drains are not properly built they can silt up quickly. To reduce this risk make sure that there is a continuous down hill gradient and that there is a clear outlet at the end of the cut-off drain;
- Cut-off drains are located off the road and often get less maintenance. Make cut-off drains therefore in such a way that they don’t require much maintenance, for example by making them wide with sloped sides;
- When cut-off drains fail, water will break through and will cause damage. Reduce this risk by making the drains strong enough;
- People using the land can plough up or block the cut-off drains. It is therefore important to locate the drains carefully, after discussion with local people. Where people have to cross the drain, provide easy side slopes so that people will not fill the drain;
- Cut-off drains need to be discharged at least every 200 – 300m by a cross drain to avoid that the accumulated water volume becomes too much. The gradient of cut-off drains should be 2-4%. Use scour checks if the gradient is steeper. Minimum dimensions for the cross-section are 0.60m wide x 0.40m deep. Side back slopes should be 3:1. Water should be able to flow freely into a cross drain;
- Cut-off drains should not be constructed too close to the cut face, where it may increase the danger of a land slip. The material excavated to form the drain should be placed on the downhill side to form a bund. Vegetation should cover the sloping sides of the drain and bund to prevent erosion.

In considering construction of cut-off drains, a number of factors need to be taken into account.

*Figure 61: Example of right and wrong construction of cut-off drain*

Don’t construct cut-off drains too close to the cut face.
7.6.4 Culverts

Cross drainage structures made of concrete culvert pipes are the most commonly used drainage structures on rural roads. Depending on the terrain, an average of 3-5 culvert lines per kilometer is normal. Culverts allow water to cross underneath the road to a place where it can be safely discharged. The selection of the location of culverts should be done during the initial setting out of the road alignment. If an existing road is improved, most culvert sites will be obvious. Look for places where (small) gullies have formed because water has been flowing across the road, where sand has deposited on the road because of standing water, or where drains have been badly damaged because they have been carrying too much water.

Water discharged through a culvert may produce serious soil erosion in the surrounding areas if the culvert is not located properly. When water needs to be discharged on to farm land, discuss this with local farmers to avoid damage or disrupt the farming activities. Sometimes farmers can use the water discharged from culverts.

The most common type of culvert is a single line of concrete pipes. The diameter should not be less than 0.6m because smaller diameters are difficult to maintain and are easily blocked. If a pipe with a diameter of 0.6m is not enough you can select a pipe with a larger diameter of use two or more rows with a diameter of 0.6m. The advantage is that this will avoid a high fill over the rings (called overfill).

The culvert bed has to be stable and at the correct level, preferably at the levels of the surrounding terrain. Remove stones which may damage the pipes. If the natural material is not suitable, prepare a gravel bed under the pipes. The bed should be constructed with a slope between 3 and 5%.

To calculate the required difference in level between the centerline of the road and the top of the foundation of the inlet apron, take the example of figure 62 and assume the following dimensions:

- Thickness of compacted gravel surface: 0.15m
- Camber: 8%
- Width of carriage way including shoulders: 7m
Calculate the required difference in level between the centerline of the road and the top of the foundation of the inlet apron as follows:

1. Assume the level of the top of the foundation of the inlet apron is at 0.0m
2. Add: Overfill at the end of the pipe near inlet apron = \( \frac{3}{4} \times 0.6 \text{m} = 0.45 \text{m} \)
3. Add 2 x thickness of pipe = 0.14m
4. Add: Pipe diameter 0.6m = 0.60m
5. Add: Height difference of level of road surface between center line and edge of carriageway near the inlet apron = 8% x (7m/2) = 8% x 3.5m = 0.28m
6. Add: thickness of compacted gravel = 0.15m
7. Level at centre line is: 0.0m + 0.45m + 0.14m + 0.60m + 0.28m + 0.15m = 1.62m above the level of the top of the foundation of the inlet apron.

If the pipe length is 8m and the gradient of the pipe is 4%, the difference in level between the top of the inlet and the outlet apron is 4% x 8m = 0.32m.

Aprons should be constructed at the inlet and outlet to protect the culvert bed and the drain bottom from erosion. Aprons can be made by stones, masonry or concrete. Their length should at least 1.5 times the pipe diameter. Head walls and wing walls are strongly recommended to protect the backfill from water damage. They can be made of stones, masonry or concrete and have to be constructed before backfilling is done. If there is no provision for them, make sure that the side slopes of the backfill is not steeper than 1:2 and that the culvert is long enough to reach the end of the side slopes.

If a 0.6m culvert pipe is used, the width of the trench to be excavated needs to be at least 1m (to provide sufficient working space when placing the culvert). Check the level of the bottom of the trench with a traveler to ensure that it is level and has the desired slope.

During excavation, make sure that any water which may enter the trench can run off. This may require that the outlet drain is excavated first. Make sure that there is a sufficient slope in the outlet drain, downstream of the culvert. If necessary, use a 0.1m layer of compacted gravel to achieve a solid foundation for the culvert.
The next step is to lower the pipes *gently* into the trench using a rope. Use crowbars to place the pipes up tight against each other and make sure that they all are in a straight line. Seal the joints between the pipes inside and outside of the ring.

The backfill around the pipes and the overfill should be placed in 15cm layers of suitable fill material, and needs to be well compacted using hand rammers. Do not to hit and damage the pipes when compacting. **The minimum thickness of the fill above the culvert rings should be at least half the pipe diameter, but preferably at least \( \frac{3}{4} \) of the diameter of the pipe.**

It is sometimes necessary to raise the embankment to achieve sufficient fill on top of the culvert rings (see figure 63). In that case a ramp needs to be constructed (and compacted) on each side of the culvert to avoid a rapid change of the road gradient.

For making pipe culverts, cement, aggregates, sand and water must be clean and stockpiles must be prepared. The casting floor (preferably a concrete floor) must be level and firm. Moulds must have no damages or deformations and should be clean. Deposits of dry concrete in edges and around hinges and lockers will result in deformations of the pipe. The inner mould should be properly centered in the outer mould (figure 64). After casting, pipes should be cured for 28 days before they can be installed. For curing, use sacks which can be frequently dampened with water.

**Figure 63:** Constructing a ramp over a pipe culvert

![Constructing a ramp over a pipe culvert](image)

**Figure 64:** Example of poorly and correctly centered mould

![Example of poorly and correctly centered mould](image)

Culvert rings are normally stored at the road site at the planned location of the culvert. They need to be handled with care, in particular when off-loading to avoid that they break. When culvert rings are ordered, always order a couple of spare rings in case of breakage.
7.6.5 Drifts

Drifts allow water to cross from one side of a road to the other by passing over the surface of the road. The road surface will thus need special protection to stand up to the flow of water. This is usually done through a stone packed or concrete surface where the water will pass. The level of the drift needs to be lower than the road on each side to make sure that water does not spill on the unprotected road surface.

Drifts are normally constructed to pass river streams which are dry during long periods of the year. During rains, most drifts will carry shallow flows of water which vehicles manage to pass through. However, occasionally, deep drifts will be flooded for short periods and the road will be closed for traffic. Figure 65 presents a typical cross-section of a drift.

![Figure 65: Typical X-section of Drift](image)

There are three types of structures that are together known as drifts:

**Splashes** are minor crossings that carry water from a side drain across the road to the lower side. Splashes are located at low points along the road alignment and when the side drain cannot be emptied by mitre drains and the water has to taken across the road.

**Drifts** are crossings at large drainage channels and small rivers. They may have to take strong flows of water.

**River Crossings**: are long crossings over a sand river bed. Usually, the river bed would consist of deep sand and the crossing has to be built with a firm foundation.

For all types of drifts the most important step is to locate a suitable site for the river crossing. If the drift is wrongly placed, it may result in both extra work during construction and maintenance afterwards. An example of the selection of a correct location for a drift is shown in figure 66. The main points to consider in locating a drift are:

- The angle between the road center line and water flow should be about 90° and the site should be on a straight length of the stream bed and a straight length of the road;
- Avoid places where there are signs of scouring or silting and places with steep banks that need much excavation or steep aprons.

After the location of the drift has been decided upon, set out the finished level of the drift at the same level as the level of the river bed. Avoid setting the level of the drift below or above the level of the river bed. In cases where the river is silting up, it is best to lift the drift 20 - 25cm above the natural river bed. This will speed up the water passing over the drift and reduces the danger of silting up of the drift.
The ideal slope for a drift approach is 5%. An example of setting out a slope for a drift approach is presented in figure 67. Profiles are set out to a 5% slope at each side of the crossing. The length of the approach can be found moving a traveler 1m high along the line of the slope profiles until it levels up with the slope profiles when standing on the natural ground. The traveler can also be used to measure the depth of the dig along the proposed approach, and this can be used to estimate the volume of excavation.
There are a number of possibilities for the selection of the surface material for a drift. This could e.g. be gabions with gravel, stone paving, or the construction of a concrete slab. The choice depends on:

- Expected force of the water flow and the strength of the river bed foundation;
- Availability of materials, i.e. gravel, stones, concrete aggregate, sand etc;
- Costs.

For slow flowing water, graveled drifts with gabions or dry pitched stone paving may be adequate. Stone pitching is more suitable for river beds with loose sands and a gentle flow. If it is difficult to decide if a gravel surface will be practical - it may be washed out too often – you can try this solution first and allow a full rainy season before deciding whether it is necessary to upgrade the crossing with a stone pavement or a concrete slab. For fast flowing water it is often necessary to provide a concrete slab or cement bonded stone pavement. An example of a drift constructed with gabion boxes and gravel/ rock is shown in figure 68. The top of the gabion dam is 15–20cm higher than the river bed at the downstream end. A typical cross section of a concrete slab that can be used for a drift is shown in figure 69.

Figures 70 to 72 present possible cross sections of bed-level causeways (also called level causeway or paved ford).
In certain cases vented causeways may be required

In those cases where the river flow is too great for too many days in the year to allow the traffic to cross a drift or bed level causeway a vented causeway may be required (picture 17). Since these structures present a considerable obstacle to the free flow of both an ordinary flood and the design flood, they must be built sufficiently massive to withstand water pressure and debris impact. They must also have scour protection where the bed is erodible and marker posts. The vents are usually concrete or corrugated steel pipes from 0.6m to 1.0m diameter, set in a block of concrete or masonry. Concrete or masonry retaining walls and aprons are needed to channel the flow and prevent scour at both entrance and exit.
To prevent blockage of the stream by debris or silting, the pipes must be set level with the stream bed and at the same slope. No part of the vents should be narrower than the entrances. Wedge-shaped deflector walls may be required on the upstream side to guide large floating debris above the vents. Figure 73 shows a typical section and elevation of a vented causeway.

**Figure 73: Typical section and elevation of vented causeway**

7.6.6 Small Bridges

As the design and the construction of small bridges is relatively complicated, it is recommended that this work is undertaken by the responsible line departments like the Public Works Department, as they have the required expertise and experience. This section gives a short description of key features that need to be considered regarding the location, type, design and construction of small bridges.

![Picture 18: Consider traffic requirements when designing bridge](image)

Bridges are structures that span and provide passage over a gap or a barrier, such as a river. Small bridges are commonly defined as structures with span of not more than 12 meters. When deciding on the location, type, size and capacity of a bridge, the engineer has to take into account the site conditions and the terrain, the expected traffic volumes, the available construction materials and skills, available financial resources, and the preferred life-time of the bridge.
Where a required waterway opening is less than about 15m² and in particular, where a road crosses a stream on a relatively high embankment, it is usually cheaper to provide a culvert than a bridge. The most common forms of culvert construction include pre-cast concrete joined pipes, prefabricated corrugated steel pipes and pre-cast or built in situ concrete box culverts. Concrete pipe culverts are commonly used for small openings up to about 2m² and multiple pipes, with or without common headwalls, are used for larger areas. For areas greater than 2m², reinforced concrete box culverts or sometimes corrugated steel pipe culverts can be used, singly or in multiples.

In the selection of the site it has to be checked whether it is possible to construct the vertical and horizontal members of the bridge, whether the soils are strong enough to ensure the stability of the structure and whether the bridge at a proposed location would not have a damaging effect on the environment (e.g. disturbing the river flow) or could be damaged by it (e.g. risk of landslides).

In selecting the location for a small bridge usually a compromise has to be found between the easiest crossing the shortest road alignment. The choice becomes an economic decision. The cheapest bridge site and the one that has potentially the longest service life is a location that is:

- On a straight reach of the river;
- Is beyond the disturbing influence of larger tributaries;
- Has well defined banks;
- Has reasonably straight approach roads;
- Permits as much as possible a square a crossing;
- Has good foundation conditions.

Once the engineer has identified a likely site for a bridge, he/she needs to obtain field information on the local terrain and river conditions. This also includes information about the minimum and maximum water levels in the river, the expected maximum water flow and the soil conditions. Information about required clearance under the bridge may also be needed if the stream carries during floods debris or when a river is used for navigation.
When a site has been selected, the choice between a permanent bridge with a life time of more than 40 years or a temporary structure depends on the traffic volume and loads and the available resources. If it is expected that a permanent structure will be required in the near future but when currently available resources are not sufficient to construct a permanent structure, an alternative solution is to build permanent abutments and a light deck that can be upgraded or replaced when the development occurs. The choice of the design of the bridge structure also depends on the expected traffic volumes over the expected life-time of the bridge. This is a very important factor as it determines the structural design characteristics, i.e. the strength of the bridge.

The design of the width of a bridge is determined by traffic consideration. If there are less than 200 vehicles per day crossing the bridge, a single lane bridge is sufficient. For bridges carrying more than 200 vehicles per day a two-lane bridge is recommended. As box culverts are usually less visible than small bridges, it is recommended to construct box culverts with a two-lane width.

Short span rural bridges often do not need to be designed for heavy vehicles. Standard designs that are conform the British Standard loading for 40 ton gross weight vehicles (BS.HA.LOAD) and the American AASHTO loading for 20 ton gross weight vehicles (HS 20-44) are usually sufficient to cover the loading requirements of the majority of rural bridges. The design standard to be adopted for a bridge always needs to be determined by the responsible engineer of the concerned technical line ministry.

To design the appropriate foundation for a bridge, it is very important that the nature, depths and locations of the different soil types that occur at the proposed bridge location are being examined. The weight of the traffic, the superstructure, the abutments and the piers all need to be carried by the soils supporting the abutment and pier foundations and soil investigations are therefore of crucial importance. Various soil tests may have to be carried out by the Public Works Department to examine the soil characteristics, including field tests and laboratory tests.

The hydraulic design of a bridge is that part of the design of a bridge that needs to ensure that the design flood water can safely be discharged under the bridges. The bridge should for example not obstruct the flow of water as this may lead to undesirable flooding upstream. On the other hand it may not be costeffective to provide a very wide span that clears the entire width of the river. Bridges are therefore often designed in such a way that they can discharge annual high flows without excessively restricting the flow of water or incurring damage to either the structure or

Considerations in selecting the type of bridge

Information about soils is required for the design of foundations

The hydraulic design is very important in the design of a bridge
the surrounding land. In some cases it may be acceptable that unusually high floods over-top the superstructure and cause temporary disruption. The bridge parts should however be strong enough to withstand high floods. Some examples of the hydraulic design of typical bridge crossings are presented in the figures below.

The simplest situation is shown in figure 74 where the river bed of a relatively narrow river is well contained and can be spanned by a single span bridge without obstructing the river flow. The abutments are built clear of the level of the design flood and there is no restriction of its flow. River training works are unlikely to be required, and no backwater or additional scour is expected as a result of the presence of the bridge.

**Figure 74: Bridge crossing for narrow and well defined river**

An example of a wider flood channel is presented in figure 75. In this example the superstructure is longer and will be very expensive if piers are not used. Both pier and abutment foundations are below DFL and will require protection from scour. The abutment walls and piers will cause some obstruction to the water flow. This is likely to cause some backwater and additional scour of the bed and this must be taken into account in foundation design.

In those cases where a small river has a wide flood plain like in figure 76 the most economical solution may be a relatively small bridge approached by earth embankments. The structure will restrict the flow during the design flood but not during the normal flow. In order to prevent flood water rising too high on the upstream side, relief culverts are installed in the embankments while retaining walls and river training works channel the main flow through the bridge. The abutment foundations are designed to withstand the scour caused by the restriction to flow.

**Figure 75: Use of piers for wider river crossings**
Key considerations related to the hydraulic design of a bridge can be summarized as follows:

- Establish the height of the superstructure (i.e. the clearance above the DFL);
- Establish trial positions for the abutments according to the bed shape at the proposed crossing;
- Make a provisional decision regarding the number of piers that will result in the lowest overall cost of the superstructure, piers and abutments;
- Calculate the general scour and the local scour due to abutments and piers, and draw the worst case profiles on the cross sections;
- Check that the backwater caused by the restriction to flow does not cause damage to surrounding land upstream of the bridge or affect the height set for the superstructure;
- Prepare preliminary designs of abutments and piers;
- Check scour and backwater effects and make adjustments as required, recalculating the effects of any changes to the waterway;
- Calculate the cost of the superstructure once its length is decided, and the costs of substructures, embankments, river training works and relief culverts;
- To obtain the most economical design, or to compare the costs of structures catering for different design floods, it may be necessary to repeat the above procedure on the basis of alternative waterway conditions.

The requirements for piers and abutments depend on the availability and cost of material for the structural members of the superstructure; traffic loading; distance between the abutments; the length of timber or steel beams available; HA or HS20 loading and suspended length. Based on this information a configuration of abutments and piers should be selected and for this configuration the likely scour and backwater effects can be calculated. If these are not acceptable, a different configuration needs to be selected.

It should be stressed that scour, the erosive effect of the water flow on the river bed and its banks, is a very common cause of bridge failure and it is thus very important that the possible effects of scour are correctly calculated. To find out what type of river training works will be required to counterbalance the possible effects of scour, it is necessary to examine the river at the bridge site and existing structures, preferably during and soon after a time of flood.
The protection from scour can include a variety of measures, including rip rap on slopes or river bed, gabion mattress for aprons or revetments, groynes, piled walls and vegetation. With the exception of groynes and some forms of vegetation, the rule is that these protective should not protrude in any way into the design waterway at the crossing as this would obstruct the flow even more. Local experience and inspections at the site during and after floods usually form the best guide as to where river training works are required. It may also be useful to inspect the effectiveness of existing river training works in the vicinity of the proposed site.

Rip rap river bed protection consists of a carpet of loose stones, which prevents the water current from eroding the soft bed material. The stone elements must be heavy enough to resist being washed away by maximum water velocities during a flood, and they should not be installed in a manner which reduces the area of waterway designed to accommodate general scour. The main advantages of rip rap are that it is relatively cheap, is a flexible protection and is easy to install and repair. Graded stone needs to be used in such a way that the ratio between the maximum and average size and between the average and the minimum size is about 2:1.

Gabion boxes and mattresses are also very suitable for protection against erosion. A standard gabion is a rectangular box made of steel wire mesh (Figure 77). Standard sizes are 2m, 3m and 4m long by 1m wide by 0.5m or 1m high. Gabion boxes are strengthened at the corners by heavier wire and by mesh diaphragms which divide the box in 1m compartments. Gabions can be supplied ready made or they can be made locally if skills are available in the locality to make them. The gabion boxes are filled in situ with quarried stone or rounded shingles of sufficient size to prevent the stones passing through the mesh. The gabion structure is more stable, strong and durable if the stones are packed carefully by hand, almost as if building a stone wall. Internal tie wires at about 0.5m intervals help to retain the shape. Sections of gabions are securely wired together in position to form a continuous revetment or wall. Two examples of the design of a gabion wall are presented in figures 78.
Gabion mattresses are a mattress-shaped version of the gabion box. They are used for example in lining banks and the bed of rivers. The standard 6m length of the mattress is divided into six 1m compartments or more, as required. After the assembly on site, the mattresses are wired together and filled to form a continuous blanket or lining.

An example of the use of gabion mattresses to provide river bank and river bed protection, is shown in figure 80. The mattress extends from the top of the river bank up to about 1.5 x depth of the scouring depth on the river bed. This ensures that, when scouring occurs, the river bank remains protected over its entire height, even after scouring has occurred. This type of mattress is called a launching apron.

If the river bank consists of fine, non-cohesive material, you can prevent it being washed away through the voids of rip rap or gabion lining by using a textile filter or by a gravel filter layer.

It is also possible to use driven timber, steel or concrete piles to form a continuous wall that protect against erosion or channel the main flow through the bridge. An example is shown in figure 81. Piled walls are less flexible than gabions or rip rap and may fail under small amounts of movement.
The engineer has to make sure that the piles are driven deep enough to withstand the general and local scour, and still retain sufficient stability to withstand earth pressure on one side when the water level is low on the other. If timber is to be used, local knowledge of durability under wet and dry conditions will help selection.

The shaping of the timber piles shown in Figure 81 contributes to achieving a tight wall. Purpose-made steel piles interlock and so make a stronger wall than lengths of guardrail, used railway sleepers or other improvised sections.

**Figure 81:** Driven piles to form a continuous wall to protect from scouring

Many plant types can be used to protect river banks against erosion. The most successful ones are almost always those found growing naturally along the river being bridged. Protecting the plants from annual floods in the form of gabion groynes may be required.

The purpose of groynes is to divert the river flow away from the river banks to reduce erosion. They can be made from permeable or impermeable walls and may be constructed using piles, gabions, rip rap, local materials or mass concrete. The length, height and location of the groynes depends not only on the required path of the river in flood but also on the river banks, bed material and any other obstructions in the vicinity, including the substructures of the bridge. Groynes should be placed and constructed in such a way that they don’t have a negative effect on the river general scouring regime.

The substructure of a bridge consists of the abutments, piers and their foundations. These support the superstructure, i.e. the road deck. Figure 82 shows some typical shapes of substructures in concrete. Timber abutments or gabion abutments may be used for temporary structures but are not recommended for permanent bridges, even those with timber superstructures. Concrete abutments and piers may be built to support a timber superstructure that will be replaced at a later date with a more permanent material. In this case the final dead weight and width, etc., must be used in the abutment design.
As the most likely cause of substructure failure is scour by the river water, the engineer should pay careful attention to the estimation of general and local scour, and its possible depth of occurrence. Abutments also fail when the soil under the foundation is not strong enough to counter the combined forces from the structure and the embankment. It is therefore recommended that spread foundations be used wherever possible, but if this is impossible because of the low bearing strength of the soils for the foundation, a piled foundation will be required. Piling for permanent bridges is a specialist technique that should be entrusted only to experienced contractors. Where a satisfactorily strong foundation soil is found not too far below the preferred foundation level, caisson support may be considered (see figure 82).

**Figure 82: Typical shapes of substructures in concrete**

The abutments of a bridge should not only support the dead load of the superstructure but must also; i) resist the vertical and horizontal live loads caused by the traffic and weather element; ii) retain the approach embankments and the live loads applied to them; iii) provide a smooth transition from the road surface to the deck running surface. Figure 83 shows the main elements of abutments. Their essential elements are:

- A foundation slab, which transmits the weight of the abutment and a proportion of the superstructure directly to the supporting soil, or which forms a capping slab to a system of loadbearing piles;
- A front wall with bearing shelf that supports the superstructure and usually retains the soil of the embankment;
Wing walls or retaining walls may be separate from the abutments or, if they are short, may be built integrally with them. These walls retain the road embankment or river bank adjacent to the abutment and are usually built so as to bisect the angle between the road and the river bank, though they can be set at any angle to the abutments and may be built parallel to the road or perpendicular to it.

![Figure 83: Main elements of an abutment](image)

Piers also perform a support function. They convey vertical and horizontal loads from the superstructure via the bearing shelf, stem and foundation slab to the supporting soil. In many instances, piers stand on saturated soils for most or all of the year: they do not retain soil embankments but are designed to withstand hydraulic pressures and impact loads. Piers are often more susceptible to scour damage than abutments and need to be orientated carefully with respect to flow direction. Their foundations should be located well below maximum scour depth. Figure 84 shows typical foundation depths for piers in different situations.

When bridges are being constructed, the pressure on the soil caused by the substructure and the superstructure will lead to a certain settlement of the soil on which the abutments and piers rest. The responsible engineers need to calculate as accurately as possible how much settlement can be expected for a selected bridge design. The settlement of the soil should not exceed certain permissible limits, otherwise the risk exists that the bridge may get damaged or, even worse, collapse.

Piers may be built using masonry or mass concrete but reinforced concrete has several advantages, in particular allowing for a more slender stem, thereby causing less disturbance to the water flow regime in the river and thus causing less scour.

In earthquake prone areas the design of bridges, and in particular the design of the piers and abutments, must take into account the additional forces on the abutments and piers that can be caused by earthquakes.
For bridges with spans of up to 12m a solid concrete slab for the bridge deck usual provides an economic and practical solution. It has a number of advantages over the concrete beam-and-slab form, mainly due to its simpler construction. Solid slab decks also show better load distribution qualities than beam and slab forms.

In the construction of a solid concrete slab deck, the simplest form of bearing is by casting the concrete slab onto the abutment bearing shelf, with only a layer of bitumen felt separating the two concrete surfaces.

This may be satisfactory for very short spans, say up to 6m, but for longer spans there is a risk that thermal movement will damage both the supporting structure and the slab. For this reason, simple rubber strip bearings are used. They consist of strips of black natural rubber extending over the full width of the slab at the support point, with a maximum width of about 300mm and a maximum thickness of approximately 25mm.
Construction joints often provide paths for the seepage of water, leading to leaching of lime from the concrete and corrosion of the reinforcement. For this reason, it is recommended to cast a slab in one continuous pour. If the engineer knows that this will not be possible because the batch volume required is too much for one day’s working, it is better for him to mark on the drawings a permissible location for construction joints. If a joint is unavoidable, it should be parallel to the centre line and preferably located at the high point of the transverse camber.

The maximum length of reinforcing bar generally available is 12m. When a longer bar is needed, two bars must be lapped. As a general rule the lap length should be at least 40 times the diameter of the bar. The main bars should not be lapped near the centre of the span, and laps should be staggered so that they do not cause a line of weakness across the slab.

The lapping of bars should be avoided whenever possible so as to ensure good continuity, minimize congestion of reinforcement and so produce better compaction of concrete around the steel. The anchorage and positioning and reinforcement are particularly important where the slab sits on its bearings. Accurate positioning of the reinforcement is essential in order to maintain the minimum cover of 50mm of well compacted concrete, and so avoid moisture and pollutants penetrating the slab and corroding the steel reinforcement.

If the surface (rain) water can freely run off the bridge into the road drainage system, no drains are required on the bridge superstructure (e.g. on a single span bridge where the joints between deck and abutments are sealed). If the bridge is multi-span, or has a flat or sagging profile with a low point on the bridge, drains must be installed on the deck. The simplest way is to provide a 100mm diameter PVC pipe at the kerb line, dishing the concrete around it, and setting a metal gully grating in the surfacing.

Standard concrete slabs are designed to be used with 75mm of asphalt surfacing. If this is not being done and the upper surface of the slab is used as running surface, the minimum cover to the reinforcement in the top of the slab should be increased to 75mm. For bridges serving gravel roads more than 75mm cover will be required to compensate for the abrasive action of stones embedded in vehicle tires on the concrete service.
As an alternative to solid concrete slab deck bridges, bridges constructed from steel beams with a composite concrete deck slab may be considered as permanent bridge (i.e. having a design life time of at least 40-50 years). The composite action of the concrete slab and steel beams is secured by the use of shear connectors welded to the top flanges of the beams and cast into the concrete. Steel/concrete composite deck structures have the following advantages:

- The deck self weight can be less than that of an equivalent all-concrete structure.
- The off-site prefabrication of the main load carrying elements of the bridge substantially reduces the work necessary on site, resulting in more rapid construction.
- No temporary supports are required during of the deck slab, since the shutters can be supported directly from the steel beams. This can be a particular advantage at locations with poor ground conditions, steeply sloping terrain, or with a fast stream.
- Steel is a reliable material which is supplied with guaranteed strength properties, enabling structures of high and consistent reliability to be produced.

The heaviest beams required for a standard bridges with 12m span length weigh less than two tons. They may therefore be erected using a small mobile crane or improvised lifting equipment. Alternatively, the beams may be pushed or pulled out over the gap being bridged using some form of intermediate temporary support and/or a light launching nose attached to the beams. Supporting of the steel beams during deck concreting is unnecessary, since the steel section has been designed to be adequate to support the wet concrete, shutters and construction loading.

The wet concrete loading is a critical design case for steel beams. Wind loading during pouring can add significantly to the stresses in the beams. For this reason it is necessary to ensure that the concrete slab is not poured if there are (or are expected) wind speeds of 60 km/hr or more.

The life time of a Steel/concrete composite deck structure depends on the quality of the works during the construction phase in general, and to the degree of protection of the steelwork in particular. The protection which the steelwork will require depends on the local environment. Particular care will be needed for structures in coastal locations or where there is significant atmospheric pollution.

Types of paint used and surface preparation methods will depend on the local availability of materials and equipment. To ensure a reasonable life-time of the steel beams a multi-coat paint with a total dry thickness of 0.25mm needs to be applied. This needs to be done on a clean surface (i.e. remove loose rust, welding scale, etc.). At least one paint coat should be applied at site after the completion of construction, so that damage to paintwork incurred during transport, steel erection and concreting can be repaired.

A construction of bridge with steel beams and a wooden deck may also be considered. This solution is cheaper but as the life-time of the timber is limited, the deck planks will need to be replaced more often. Another disadvantage is that some parts of the steel beams may not be accessible for painting during maintenance operations and this may reduce the life-time of the steel beams.
For small bridges with relatively low traffic loads, timber bridges may also be considered. They have the following advantages:

- Low material cost for short spans;
- Modest requirements for skilled labour and equipment;
- No need to have a dry river bed for building shuttering during construction;
- Ability to compensate for a certain amount of settlement of substructures without strain.

Timber bridges may also be considered in emergency situations, for example when a permanent bridge has been destroyed and where it is urgently required to replace the bridge.

There are a number of limitations of using timber for the construction of bridges:

- Easy subjected to rotting and insect attack;
- Need for frequent maintenance;
- Heavy duty or long span timber decks require a lot of material, and so may be more expensive than steel or concrete alternatives.

**Log bridges** are common on rural access roads in many countries. Figures 85 and 86 show a longitudinal and cross-section of a standard design for a single lane log bridge (for carrying AASHTO H520-44 loading). Whenever possible seasoned logs should be used. They should be closely matched and positioned the same way, i.e. with the larger diameter ends all at the same end of the deck, so that the decking planks can be fixed in contact with all the logs. It is better to notch the underside of those logs which are high at the abutment than to remove a greater quantity of material along the upper surface of the logs. The maximum span is usually limited by the size of the available trees or by the maximum length that can be transported.

**Figure 85: Longitudinal section of a log bridge**
Sawn beam bridges use rectangular timber beams as the main spanning members for bridges. Construction is easier with such a regular shape, since each member rests on a flat surface and fixing of the decking to the beams is more positive. Cutting allows close examination, so timber can be carefully selected to avoid serious defects.

Considerable time, effort and cost, however, may be incurred in transporting logs to a saw mill, and the sawn section is not as strong as the log from which it was cut. Figure shows the cross-section of a standard designs for a sawn beam bridge for spans up to 12m to carry AASHTO HS 20- 44 loading.

Timber decking using for timber bridges consists of timber planks, usually 100mm thick, set across the top of the wooden beams. To allow water to drain easily and to avoid dirt and moisture being trapped between deck planks, an air gap of 20mm is left between the planks. In practice the logs are rarely uniform enough to fix all decking planks directly to each log. Rather than force a plank down onto a log, hardwood packing pieces should be used to make up the gap, as shown in Figure 86.
To protect the deck timbers and encourage drivers to position their vehicles centrally on the bridge, two strips of longitudinal running boards are fixed to the decking at centers that will accommodate the wheel spacing of conventional motorized vehicles. The strips should also be sufficiently wide and spaced to cater for all common local vehicles, such as bullock carts and rickshaws as well as lorries. It is also recommended to fix transverse threshold boards across the width of the bridge at each end of the running strips. They lessen the impact on the ends of the running strips and reduce the tendency for them to work loose.

Planks for the deck and running strips should be placed with the surface that was nearest to the centre of the tree face-down, so that their edges do not curl upwards on further drying. Nailing is the least successful method of fixing the decking and running boards, since movements of the deck under traffic loads tend to pull the nails loose. Galvanized coach screws or coach bolts and nuts are far more satisfactory. The running strips in particular should be bolted to the deck planks.
An edge beam serves as a kerb and ties the ends of the deck planks together. A pedestrian handrail is provided by extending deck planks at the post positions only, to carry an inclined post brace.

Permanent abutments for timber bridges can be made of masonry or concrete. It is important that the abutment bearing shelf is well drained and that air is able to circulate freely around the ends of the logs. They should sit on a raised bearer, clear of moisture, soil and debris which may collect on the bearing shelf, and they may be secured in position with timber wedges fixed to the bearer.

Temporary abutments made from gabions or logs can also be considered. However, they are highly susceptible to scour and erosion, and should be constructed with great care using ties and anchors where possible because they can be destroyed by a single flood. Figure 88 shows an example of a wooden bridge with temporary timber abutments. In the example of figure 88 the bank seat abutments are made in the form of log grillages.

Figure 88: Wooden bridge with timber abutments

Where water flow is slow, timber piled abutments and piers have proved successful. The use of piers reduces the section of the road bearing beams, and a whole bridge like the one shown in Figure 89 can be built with timber no larger than 325 mm in diameter.

To prolong the life-time of timber bridges, the timber needs to be treated. The most important climatologic factor that affects the life-time of timber is moisture. Wood destroying fungi and insects are the two most important biological factors that undermine the strength of timber. Hardwoods are generally more durable than softwoods, especially against termite attack. A design life ranging from 5 years for untreated softwood to 20 years or more for hardwood heart timber can reasonably be assumed.

Treatment with chemical preservatives to protect the timber against insect attack and fungi decay can extend this design life considerably. The specific treatment depends on the type of timber, the sizes of the timber sections, and the design life required. To be effective in the long term, chemical treatment of timber should take place in a pressurized tank, because protection is short lived unless the preservative penetrates the timber adequately. If boring or shaping of timbers takes place after treatment, the exposed surfaces should be flooded with preservative before final assembly.
The active chemicals are applied diluted in water or in a spirit. Generally speaking, the hard dense heart of hardwoods does not allow the entry of preserving chemicals, nor does it need them, but where the hardwood to he used includes some sapwood, treatment should he applied. All softwoods should be treated. Newly felled timber should be given a preliminary coating of preservative to prevent early contamination by the spores of fungi, and should then be seasoned before pressure treatment.

If pressure impregnation is not available, the hot and cold tank treatment using creosote is a useful alternative. The timber is immersed in a tank of cold preservative which is then heated to about 85-90°C. This temperature is maintained for at least an hour and the preservative is allowed to cool down before the wood is removed. Spray-applied preservative treatments give only slight protection when compared to the methods referred to above and should, where possible, be used only for retreating cut or worked surfaces.

Since there is a risk of corrosion of mild steel or galvanized steel in contact with salt type preservatives, it is important not to apply metal fasteners until the fixation of the preservative within the wood is complete. This usually takes about 7 days.

If the wood is treated with a preservative containing copper, aluminum fixings should not he used. All preservatives are toxic and those which are dissolved in white spirit will be highly inflammable. Therefore workers who handle these chemicals should be very careful and they have to overalls, rubber gloves and eye shields when working with these chemicals.
7.7 Road Wearing Course

The top layer of a road is called the wearing course or road surface. The different layers that constitute a road cross-section are shown in figure 91. In the case of a sealed wearing course or road surface like a bitumen seal or a dressed stone layer we talk about a pavement. Any surface improvement includes one or more of the components as shown in figure 91. Basically, each layer is provided, if necessary, to increase the strength, up through the road surface pavement. This will ensure that the layer below, is not over-stressed and can carry the expected traffic loads.

Factors to be considered in the selection of the most appropriate pavement are summarized in table 12. They relate to the availability of construction materials, the climate, hydrological issues, the terrain, and the condition of the sub-grade, traffic requirements, construction considerations and maintenance factors. Apart from these factors, the lifecycle costs of the investments, i.e. the costs of the initial construction plus the maintenance costs over the life-time of the road, need to be taken into account. Technical line departments can make such a life-cycle cost analysis for different types of pavement.

Commonly used combinations of base course and surfacing options for low volume roads are any of the following combinations presented in table 13.

<table>
<thead>
<tr>
<th>Table 12: Factors to consider in the selection of a pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Construction materials</td>
</tr>
<tr>
<td>Climate</td>
</tr>
<tr>
<td>Hydrology</td>
</tr>
<tr>
<td>Terrain</td>
</tr>
<tr>
<td>Sub-grade conditions</td>
</tr>
<tr>
<td>Traffic regime</td>
</tr>
</tbody>
</table>
The construction regime governs whether the road design is applied in an appropriate manner. Key elements include:

- Appropriate plant use
- Selection of placement materials
- Quality assurance
- Compliance with specifications
- Technical supervision

The maintenance regime ensures that the design life is reached. Achieving this will depend on the maintenance strategies adopted, the timeliness of the interventions, the local capacity and available funding to carry out the necessary work.

Table 13: Some possible options for base course and surfacing combinations

<table>
<thead>
<tr>
<th>BASE COURSE</th>
<th>SURFACING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Bound Macadam (WBM)</td>
<td>Double Bituminous Surface Treatment (DBST)</td>
</tr>
<tr>
<td>Sand Aggregate Road base</td>
<td>Penetration Macadam (Bitumen)</td>
</tr>
<tr>
<td></td>
<td>Bituminous Sand Binding (for binding WBM)</td>
</tr>
<tr>
<td></td>
<td>Otta Seal (Bitumen)</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
</tr>
</tbody>
</table>

When selecting seals that include the use of bitumen it is important that a strong and sound road base is available. The base must be swept clean of all dust, dirt, animal droppings etc. before the seal is applied. Except in the case of an Emulsion Treated Base, a prime is generally recommended. The base must always be dampened with a light spray of water before the tack coat or prime is applied.

Failure to carry out these preparations before sealing will eventually result in failure of the seal caused by insufficient bonding between the base and the bituminous seal. Figure 91 gives an illustrative comparison between various bituminous sealing techniques, i.e. between Sand Seal, Single Chip Seal (or SBST), Double Chip Seal (or DBST), Single Otta Seal and Double Otta Seal.

A bituminous seal consists of aggregate of a specified size (or grading), held in place with a bituminous emulsion binder, penetration grade or cut back bitumen binder. Bitumen is a by-product of the petroleum industry and is the binding material in the binders for bituminous seals or asphalts. The viscosity or stiffness of bitumen (i.e. the resistance to flow at a certain temperature) is given in terms of a penetration. The penetration value of a bitumen is the distance a standard needle will penetrate a sample of the bitumen at a certain standard temperature.
A bituminous emulsion is a liquid mixture of small droplets of bitumen that are suspended in water with the assistance of a so-called emulsifier. An emulsifier is a material that is included in the bitumen water mixture that distributes the bitumen droplets in the water and regulates its stability and breaking time.

There are a variety of bituminous emulsions e.g. anionic or cationic and spray grade or stable grade. The correct emulsion must be used for the correct application. A cutback bitumen is a penetration bitumen which has been softened with a lighter fluid e.g. diesel. There are three types of cutback bitumen: slow curing, medium curing and rapid curing.

The sections below provide short descriptions of different pavement options. More details about these pavement options are given in the annexes.

### 7.7.1 Otta Seal

An Otta seal is a relatively thin hot bituminous application comprising natural graded gravel from river beds or crushed aggregate (containing all sizes) and a cut-back or soft penetration grade bitumen. An Otta seal comprises a layer of binder followed by a layer of aggregate that is rolled into the binder using a pneumatic tyred roller or loaded trucks. It can be applied in a single or double layer. A detailed description of the Otta seal is presented in Annex 6.

Otta seal uses an ‘all in’ graded gravel or crushed aggregate instead of single sized chippings used e.g. in DBST. Its success depends on the binder being squeezed up through the aggregate by the action of extensive rolling. 2 to 3 days or longer of pneumatic-tyred compaction (rollers or traffic) are required to fully coat all the particles.

A Single Otta Seal should, as a minimum, receive a fog spray and a Sand Cover seal for increased durability. This should be applied after about three months under traffic. During these first three months dislodged aggregates must be swept back and patches of excessive bleeding must be blinded off with sand. Materials for a sand cover seal used with Otta Seals can be non-organic crusher dust, river sand or a combination of them. All material should preferably pass the 6.7 mm sieve.
A completed Otta Seal is a dense matrix of graded aggregate held together by a relatively soft bitumen. It performs much like a premix asphalt. It can be used in situations where only lower quality gravel aggregate is locally available. It can save considerable costs over the importation of crushed stone over long distances.

Evidence on the performance of these types of seal constructed by conventional plant methods has shown them satisfactory for over 12 years on roads carrying up to 300 vehicles per day. Otta seals should be considered when: i) a road is to be constructed in a remote area where only natural gravels occur; ii) workmanship is of indifferent quality; iii) flexibility and durability are required to tolerate low quality, low bearing capacity pavements, or: iv) there is a low maintenance capability.

The correct choice of binder for Otta Seals is critical for its performance and a good result requires that both the binder type and application rate are tailored to the aggregate properties. Binders used for Otta Seals should:

- Be soft enough to initially coat the fines in the aggregate and to rapidly move up through the matrix of aggregate voids by the action of rolling and traffic. The should remain soft long enough to continue moving up through the matrix of aggregate voids over 4 to 8 weeks;
- Be able to be applied in a large enough quantity in one spray operation;
- Viscous enough to provide stability after the initial curing of the seal and durable enough to give the expected service life;
- Able to be used with locally available equipment and skills and environmentally friendly to the greatest possible extent; and
- Economical in use.

For Otta seals soft penetration grade bitumen or cutback bitumen can be used. 80/100 penetration grade bitumen, which is normally used with conventional chip seals, does not meet the requirements for Otta Seals and should NEVER be used. The hardest type of bitumen that can be used for Otta Seals is the 150/200 penetration grade. This grade generally performs well for crushed rock aggregate, provided that the bitumen is cut back with 5% power paraffin when used during the cold months of the year. Alternatively, cutback bitumen with MC 3000 and MC 800 viscosity can be used under certain conditions. The recommended bitumen spray rate will vary within the range of 1.7-2.0 l/m², according to the properties of the aggregate.

Advantages and disadvantages related to the use of Otta Seals are:

- By using 19mm graded aggregate, a thick and dense seal (+/- 16mm) is obtained which is more durable than a single chip seal;
- The seal remains flexible over time and is does not crack; as are chip seals where harder bitumen binders are used;
- A wide range of locally available materials can be used, with scope for cost reduction over the use of single sized stones for traditional chip seals;
- Natural gravel deposits can be screened and applied by labourers, thus increasing the labour content of a project;
- Strictly, the use of binders is not required. However, priming may be necessary for the protection of the base until sealing can be done.
Otta Seals require extensive after care for up to three months for sweeping back dislodged aggregates and blinding off patches of extensive bleeding;

- The Otta Seal requires spraying of hot bitumen by a motorized bitumen distributor and this poses a potentially severe health hazard;

- It is difficult to obtain a uniform spreading of the aggregates by labour and a mechanical spreader may be required to even out the aggregates;

- The seal requires rolling, preferably with a heavy pneumatic roller, for at least three days after sealing to knead the bitumen up through the aggregate. This needs to be done to ensure that all particles are well coated and held together. Rolling may be done with loaded trucks but this requires careful monitoring to ensure that the entire surface receives the required compaction.

An adapted form of the Otta Seal is the Modified Otta Seal. The seal retains the main idea of the original Otta Seal using graded aggregate but there are more strict conditions regarding the grading of the aggregate. These are related to the way that the bitumen is being applied.

In the original Otta Seal the soft bitumen tack coat is kneaded up through the aggregate until slight bleeding occurs to ensure that all particles are coated and retained in the seal. The modified Otta Seal, however, is based on penetration of the bitumen emulsion from the top. In order to achieve proper penetration and coating of all particles, the aggregate cannot contain as much fines as for the original Otta Seal. With a high fines content the emulsion will be trapped in the fines and not penetrate the aggregate properly.

### 7.7.2 Cold Mix Emulsion Based Applications

To overcome some of the problems encountered with the use of hot bitumen on labour-based projects, emulsion based seals can be considered. A detailed description of cold mix emulsion based applications is given in Annex 7. A cold mix emulsion application is a so called cold-mix ‘seal-as-you-go’ technique. It has a number of advantages over hot bitumen applications:

**Picture 23: Cold-mix sealed road section**
Advantages of emulsion based seals (also called ‘cold mix’)

- The seal can be laid in short sections soon after the base is completed. The base is thus protected before any damage can occur;
- For stabilized base layers the seal will also function as a curing membrane. Adequate curing of stabilized base layers has proven to be a huge logistical problem. If the base is primed and/or sealed shortly after construction and approval, this problem is to a large extent solved;
- The sealing operations are easier to organize and manage and there are far less problems if something somehow goes wrong in the chain of events;
- Heavy pneumatic rollers are not required. The pedestrian vibratory rollers are perfectly adequate for compaction of the seals;
- No heating is required which is preferable over using heated bitumen for which scarce natural resources are required and that expose the involved workers to toxic fumes.

7.7.3 Stone and Concrete Block Pavements

For the pavement of roads with (dressed) stones or concrete blocks only minimal compaction is required. Only the sub grade material and sand cushion beneath the stones require compaction. The placed stones and blocks themselves require minimum compaction. A detailed description of the application of stone or concrete block pavements is presented in Annex 8. Stone and concrete block pavements may be considered under the following conditions:

- Abundance of good quality stones/concrete blocks and a hauling distance of less than 20km;
- The road is exposed to prolonged heavy traffic;
- Other pavement types degrade quickly due to loss of material to bind the road-base together;
- Maintenance capacity is low and maintenance is unlikely to be done;
- The life-cycle costs are competitive with the costs of other pavement types.
Stone/concrete block pavements are constructed for their robustness, and durability, low maintenance requirements, long life-time and the possibility to make optimum use of local construction materials.

### 7.7.4 Concrete Pavements

Compared to flexible bituminous pavements, concrete pavements have a number of advantages. Concrete pavements are relatively easy to construct and they have a much longer life-time (up to 50 years) than bituminous pavements. Maintenance requirements for concrete roads are also much less than for bituminous sealed roads.

Depending on the condition of the sub-grade soil and the traffic bearing requirements, the thickness of the concrete pavement should be between 15 to 20cm. To prevent the concrete from cracking, the length of individual slabs is usually limited to 5 meters and joints are made between the slabs by inserting plastic strips into the fresh concrete. The concrete can be laid in several ways, ranging from labor-intensive methods to techniques that require specific equipment.

Although the initial investment costs of concrete pavements are usually higher than the costs of bituminous seals, it appears that concrete pavements are cost-competitive when life-cycle costing is done over the entire life-time of the road.
7.7.5 Telford Pavement

Telford can be used as a pavement or as a base for a pavement. It can be applied when the sub-grade is weak and where it is necessary to raise and place a firm base. Telford consists of a bottom layer of large (15-25 cm) stones that are being placed tightly and vertically on a sand bed. The voids between the stones are filled with smaller stones of 5-7 cm and the remaining voids are then filled with 2-3 cm aggregate. Compaction is normally done with a 6-8 ton vibrating steel wheel roller or equivalent.

A Telford construction is a low-cost solution that can provide a strong base suitable for low-volume rural roads. An advantage is that it can be easily constructed with locally available skills and construction materials. To ensure a reasonably smooth riding surface it is important that the Telford base is constructed as per specifications and that the stones are tightly packed and well compacted. A detailed description of how to construct a Telford base is given in Annex 9.

7.7.6 Single and Double Bitumen Surface Treatment

Single Bituminous Surface Treatment (SBST) is usually applied as a maintenance operation to an existing bituminous road surface. SBST can fulfill the functions
required of maintenance re-seal, namely waterproofing the road surface, arresting deterioration, and restoring skid resistance. A detailed description of the application of SBST and DBST is given in Annex 10.

**Double Bituminous Surface Treatments (DBST) is used when:**

- A new road base is surfaced;
- Extra ‘cover’ is required on an existing bituminous road surface because of its condition (e.g. when the surface is more badly cracked or patched);
- Available chippings are particularly poorly shaped or are particularly weak, and crush or grind down quickly.

### 7.7.7 Bituminous Penetration Macadam

Penetration Macadam consists of a course of large, uniform graded aggregate that, after compacting and keying, is bound and filled with alternate applications of a heavy bituminous material and smaller aggregate. The thickness of one course varies from 35 to 65mm. These surfaces are stable and withstand considerable tearing action of traffic. A description of the application of Penetration Macadam is presented in Annex 11.

After trafficking, Penetration Macadam is effectively similar to asphalt concrete. The basic form is constructed using a layer of coarse aggregate spread and compacted well in dry state, followed by a second layer of smaller coarse aggregate and a third layer of still smaller aggregate bound together by the interlocking of the layers after rolling. Hot bituminous binder of relatively high viscosity is sprayed in fairly large quantities at the top.

Penetration Macadam is very strong. This is why it is likely to be the best solution for sites where road geometry such as tight bends and gradients cause severe traffic loading on the surface.
7.7.8 Water Bound and Dry Bound Macadam

Water Bound Macadam (WBM) comprises two components; a layer of coarse broken stone (37.5mm to 75mm size) into which graded fine aggregate or crusher dust (<5mm size) is slurried or washed. This forms a tightly bound, strong and semi-impermeable matrix. It can be used as an unpaved surface or as a base material for roads with bituminous seals. In areas where water is scarce or expensive to obtain, it is possible to construct a dry bound macadam (DBM) surface. The only difference in approach is that dry fines are vibrated into the voids between the stones, rather than being washed in with water. Compaction is likely to take longer than when water is used.

WBM is suitable in areas where the terrain is steep and motorized vehicles travel slowly uphill. WBM provides traction, protects the subsoil and prevents erosion and pulverization. WBM is well suited to be constructed by labour, utilizes local materials and minimizes the use of mechanical equipment. WBM can produce a low capital cost surface, if stone and fines are locally available (within 10km). Maintenance is low cost, and labour friendly with only occasional blinding and pothole filling being required. WBM is appropriate as an improved base for subsequent bituminous sealing. A description of the application of Water Bound Macadam and Dry Bound Macadam is given in Annex 12.

7.7.9 Sand Seal Surfacing and Latasir

A sand seal surface dressing may be used to strengthen an existing bituminous surface that is in good condition. It can be an economical solution for very lightly trafficked roads where only sand as a natural aggregate is available. It can also be used as an intermediate seal until another sealing option is applied. A Single Sand Seal is very thin and therefore not very durable, but it is easy to apply a second layer and thereby increase the thickness and durability. If a third seal is applied as part of maintenance activities, the thickness of the seal increases and the durability of the seal thus increase over time.

In many cases locally available sources (e.g. river sand, leached sand graded of the road) can be used successfully, but sand containing a high proportion of dust should be washed before use. The aggregate spread rate should be about 0.007 m³/m². The aggregate must be placed along the road and is spread with shovels once the emulsion has started to break (turning from brown to black in colour).

A cationic spray grade emulsion, for example, Cat 65, is used. At an application rate of 1.6 l/m² there will be approx. 1.0 l/m² residual bitumen in the seal once the water has evaporated. The binder should be heated to around 50°C before spraying with a motorized hand sprayer.

Latasir or Asphalt Sand Sheet is a wearing course of an asphalt mixture of graded natural sand and asphalt. The sand sheet mixture can be produced in an asphalt mixing plant or manually. The application involves the separate heating of the sand and the bitumen, mixing of the components (7-11% bitumen and the remaining being sand), and the spreading and compaction of the asphalt mixture at a minimum temperature of 120°C. For the compaction pneumatic rollers can be used. A more detailed description of Latasir is given in Annex 13.
7.8 Erosion Control

7.8.1 Vegetative Erosion Control Measures

Newly formed slopes on fills and embankments can be easily damaged (by runoff surface water, cattle, etc.). It is therefore necessary to protect slopes as soon as they have been constructed. Commonly used erosion protection measures include planting grass or other types of deep rooted vegetation. Grass can provide very effective protection against erosion if the right method of planting and the right type of grass is used. Planting can be done by planting grass runners, or by covering the slopes with turf. A more expensive but fast and effective method is to use stones for protection.

Grass which has been removed by the grubbing gang can often be used if it is dug out properly and kept moist. It should be protected from direct sun. These so called grass runners are cut in pieces of about 20cm in length and planted in rows in 10cm deep holes with a distance of not more than 30cm. To get the best results, the rows should be skewed so that a zigzag pattern is achieved. The soil should be compacted around the runners by hand.

Grass runners or turf can be used very effectively in providing protection from erosion.
Covering the slopes with whole turfs is even more effective but is more time consuming. Turfs can be collected during the grubbing activity. For easy handling, the turfs should be approximately 20 x 20cm. Care must be taken when cutting the turf so that the roots are not cut off. Turfs need to be kept damp and away from the sun when stored. Before placing the turf, the soil should be watered if it is dry. The newly planted grass needs to be protected from cattle by a layer of thorny bushes, twigs, branches, etc. and watered when necessary.

7.8.2 Retaining Walls

Newly formed slopes on fills and embankments are easily damaged by runoff surface water and animals. It may also be necessary to stabilize road embankments. It is necessary to protect slopes and embankments as soon as they have been constructed. The erosion protection can be of different types. Depending on the local conditions, vegetative protection may not be sufficient and more durable and stronger protection needs to be provided.
Retaining walls are commonly used to protect and stabilize road embankments and side slopes. Retaining walls can be constructed using different materials and techniques. Dry stone walls, masonry walls and gabion box retaining walls are often used to protect and stabilize slopes. Pictures 32-34 show examples of different types of retaining walls.

Dry stone retaining walls can be used in situations where the height of the wall does not exceed 4 meter. For higher retaining walls, gabion boxes are recommended. Regardless of the type of wall, retaining walls should be backfilled with granular materials that permit sufficient drainage to keep water pressure from pushing the structure outward. Depending on the construction type, drainage devices such as weep holes need to be included in the construction, to prevent water from getting trapped behind the structure. To enhance their stability many retaining walls are constructed with what is called “batter”. This is where the base of the wall is wider than the top and a slight slope so that the wall ‘leans’ into the hillside. Retaining walls of more than a meter high need to be structurally well designed and this will require the involvement of a civil engineer.
Annex 14 provides some guidelines regarding best practices in masonry works. This annex also provides a table with typical mix proportions for cement, depending on its application.
8.1 Introduction

The yearly cost of maintaining a road is only a small fraction of the initial investment cost, usually some 2-3% for a major paved road and 5-6% for an unpaved rural road. As the maintenance of a road is the most cost-effective way of preserving its value and ensuring its continued operation, a high priority should be given to the maintenance of maintainable key roads in the road network.

The purpose of maintenance is to ensure that the road remains serviceable until the end of its design life. Maintenance is important because it prolongs the life of the road (by reducing the rate of deterioration, thereby safeguarding previous investments in construction and rehabilitation), lowers the cost of operating vehicles on the road (by providing a smooth running surface) and keeps the road open on a continuous basis by preventing it from becoming impassable.

The lack of equipment or working equipment is often a major constraint when carrying out maintenance. Equipment is expensive, consumes fuel and lubricants, and require spare parts which all have to be imported. Equipment also requires skilled operators, skilled mechanics and workshop facilities. If any of these items are not available, the equipment stands idle and road maintenance is not carried out.

A good alternative to the use of equipment-intensive approaches for maintenance, is the use of labour-based methods, in particular for routine maintenance and simple periodic maintenance activities. Labour is practically always readily available and can be employed at a low cost. Labour-based maintenance can be very effective if the work is well planned and supervised. Table 14 gives an indication of maintenance activities that can be carried out using labour-based methods and for which activities it is better to use equipment.
### Table 14: Potential of using equipment and labour for selected maintenance activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Equipment</th>
<th>Labour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ditch clearing and reshaping</td>
<td>good (V-shaped ditch)</td>
<td>good</td>
</tr>
<tr>
<td>Minor bridge and culvert repair</td>
<td>poor</td>
<td>good</td>
</tr>
<tr>
<td>Building scour checks</td>
<td>poor</td>
<td>good</td>
</tr>
<tr>
<td>Repair of structures</td>
<td>poor</td>
<td>good</td>
</tr>
<tr>
<td>Grading of unpaved surfaces</td>
<td>poor</td>
<td>good</td>
</tr>
<tr>
<td>Patching or sealing bituminous surfaces</td>
<td>poor</td>
<td>good</td>
</tr>
<tr>
<td>Filling unpaved surfaces and slopes</td>
<td>poor</td>
<td>good</td>
</tr>
<tr>
<td>Grass cutting</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Re-graveling</td>
<td>good</td>
<td>fair</td>
</tr>
</tbody>
</table>

In most cases, the choice between labour and machines is not an either/or choice. It is also possible to find a cost-effective combination of the two approaches. Three main types of maintenance activities can be distinguished:

**Routine maintenance** includes the activities that are listed in table 15. These activities are very well suited for manual labour and only require limited inputs. The amount of work needed for routine maintenance depends on the condition of the road and the type of surface, the terrain and its vegetation, the type and amount of traffic, and the climate. Under average conditions, one full-time worker should be able to cover the annual off-carriage way routine maintenance requirements for a length of 1-2 km of a low-volume rural road.

**Periodic Maintenance** works involve activities such as reshaping of the road surface, filling potholes, re-graveling, repair or reconstruction of damaged drainage structures, and re-sealing of the wearing course. Such works need to be organized in the same way as rehabilitation and new construction works where labour-based methods are used.

**Emergency Maintenance** can obviously not be planned. Most likely it will be mainly required during, and just after the rainy season. Emergency works involve activities such as the repair of sections of roads washed away by floods or heavy rainfall, removal of landslides and fallen trees and the repair of culverts, drifts and bridges. By using local labour, emergency works can be quickly mobilized and urgent repair works can be completed early, thereby limiting the damages caused by rainfall, landslides, etc.

Table 16 provides a checklist for determining maintenance requirements of the elements of a road.
Table 16: Elements of structures to be inspected to determine maintenance requirements

<table>
<thead>
<tr>
<th>Element</th>
<th>Defect</th>
<th>Element</th>
<th>Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundations</td>
<td>• Cracks</td>
<td>Beams</td>
<td>• Cracks</td>
</tr>
<tr>
<td></td>
<td>• Erosion alongside and underneath</td>
<td></td>
<td>• Bends</td>
</tr>
<tr>
<td>Head and wing walls</td>
<td>• Cracks</td>
<td>Waterways</td>
<td>• Corrosion</td>
</tr>
<tr>
<td></td>
<td>• Erosion behind walls</td>
<td></td>
<td>• Rotting</td>
</tr>
<tr>
<td>Abutments and piers</td>
<td>• Cracks</td>
<td>Road furniture</td>
<td>• Vegetation growths</td>
</tr>
<tr>
<td></td>
<td>• Erosion behind abutment</td>
<td></td>
<td>• Deposits of sand, silt organic</td>
</tr>
<tr>
<td></td>
<td>• Blocked weep holes</td>
<td></td>
<td>materials</td>
</tr>
<tr>
<td>Culverts</td>
<td>• Blocked or silted</td>
<td>Road banks</td>
<td>• Damaged</td>
</tr>
<tr>
<td></td>
<td>• Cracks</td>
<td></td>
<td>• Missing</td>
</tr>
<tr>
<td></td>
<td>• Cracks</td>
<td></td>
<td>• Faded paint</td>
</tr>
<tr>
<td></td>
<td>• Uneven settlement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road decks</td>
<td>• Cracks</td>
<td>Approaches</td>
<td>• Drainage</td>
</tr>
<tr>
<td></td>
<td>• Deflection</td>
<td></td>
<td>• Visibility</td>
</tr>
<tr>
<td></td>
<td>• Cleanliness</td>
<td></td>
<td>• Settlement</td>
</tr>
<tr>
<td></td>
<td>• Drainage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cleanliness</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Drainage</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If there are not sufficient resources available, maintenance priorities have to be set. This needs to be done for routine, periodic and emergency maintenance. In general the first priority is given to maintenance activities that ensure that the road remains passable and those that limit the chance of the road getting damaged. A critical element in this respect includes the drainage system, such as culverts and drains. First priority should be given to the removal of obstacles which block the water passage away from the road. Small erosion channels must be repaired before the next rains can deepen and widen them.

Table 17 provides a list of priorities for routine maintenance according to the climatic seasons. The table shows that keeping the drainage system in good running condition is the most important task. This will require regular – daily - inspection, in particular during the rainy season.

Setting maintenance priorities

Table 17: Routine maintenance priorities according to climatic seasons

<table>
<thead>
<tr>
<th>Season</th>
<th>Priority</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before rains</td>
<td>1</td>
<td>• Clean culverts and drifts</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>• Clean mitre drains</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>• Clean side drains</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>• Repair side drain erosion and scour checks</td>
</tr>
<tr>
<td>During rains</td>
<td>1</td>
<td>• Inspect and remove obstacles</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>• Clean culverts and drifts</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>• Clean mitre drains</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>• Clean side drains</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>• Repair side drain erosion and scour checks</td>
</tr>
<tr>
<td>End of rains</td>
<td>1</td>
<td>• Repair erosion on shoulders, back slopes and drain</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>• Reinstate scour checks</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>• Reshape carriage way</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>• Fill potholes and ruts in carriage way</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>• Cut grass</td>
</tr>
<tr>
<td>Dry season</td>
<td>1</td>
<td>• Repair structures</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>• Reshape carriage way</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>• Clear bushes</td>
</tr>
</tbody>
</table>

Technical Guidelines for Supervisors
Emergency maintenance work always requires immediate action. Priority should be given to activities which make the road (even partially) passable. For example, a broken culvert may disrupt the whole road while a landslide only covers part of the carriageway, allowing the traffic still to pass the affected section.

8.2 Labour Requirements for Maintenance

When maintenance activities have to be carried out, it is useful to know how much labour will be required. Although, as a general rule of thumb, it can be assumed that 1 to 2 labourers will be required to carry out the routine maintenance on a section of 1 kilometer, there may be situations where it is useful to know more precisely how much labour is needed to carry out the maintenance work. This section gives an indication of the work load for different maintenance activities.

Cleaning culverts

Table 18 gives an overview of the labour input requirements for cleaning single, double and triple pipe culverts with a diameter of 0.6 and 1.0 meter and a length of 6 meter. If for example silt has accumulated for more than ¼ of the depth in a double pipe culvert with a diameter of the pipes of 1 meter (1000 mm), table 18 indicates that 2 x 5 wd = 10 work-days of labour will be required to clean the pipes.

If the culvert pipe is longer than 6 meters, new tasks should be calculated using the above rates for 6 meter pipes as the basis for the calculations. Similarly, if other diameter pipes are used, new rates need to be calculated based on the new internal area of the culvert pipe.

<table>
<thead>
<tr>
<th>Table 18: Labour requirements for cleaning culverts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task Difficulty - Silt depth in culvert</strong></td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>600 mm</td>
</tr>
<tr>
<td>1000 mm</td>
</tr>
<tr>
<td>Tasks cover culverts with up to 6 rings (total pipe length = 6m)</td>
</tr>
</tbody>
</table>

Clearing debris from bridges

The work consists of clearing of all silt, debris and other foreign matter from the structure, its abutments and piers and for a minimum distance of 25 meters, both upstream and downstream, thereby allowing water to flow freely and unhindered. All debris and other materials needs to be removed well clear of the river and the drainage system to prevent it from being washed back and once again obstructing the river flow.
Table 19 gives an indication of the labour requirements for clearing debris from bridges. If for example 4.5 m$^3$ of debris and 4 m$^3$ of silt needs to be removed from a bridge, this will require $(4.5 / 0.5) + (4 / 2) = 9 + 2 = 11$ work-days of labour input.

<table>
<thead>
<tr>
<th>Table 19:</th>
<th>Labour requirements for clearing debris from bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removing loose debris such as boulders, branches, etc.</td>
<td>0.5 m$^3$/wd</td>
</tr>
<tr>
<td>Excavating and removing silt</td>
<td>2.0 m$^3$/wd</td>
</tr>
</tbody>
</table>

Clearing of mitre drains

For the cleaning of mitre drains the indicative labour requirements are given in table 20. To prevent the mitre drain from eroding at its start, it is useful to reinforce this section with stones, as shown in figure 93. If for example 3 m$^3$ of hard and dry soil needs to be removed from a mitre drain, this will require $3 / 1.5 = 2$ labour-days of input.

<table>
<thead>
<tr>
<th>Table 20:</th>
<th>Labour requirements for clearing mitre drains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Difficulty - tasks relate to drained ditches without any standing water</td>
<td></td>
</tr>
<tr>
<td>moist and loose soils</td>
<td>average soil conditions</td>
</tr>
<tr>
<td>2.5 m$^3$/wd</td>
<td>2.0 m$^3$/wd</td>
</tr>
</tbody>
</table>

Cleaning side drains

For side drains with a cross section as shown in figure 94 the labour input requirements can be estimated using table 21. If for example 30 m$^3$ of soft silt needs to be removed, table 21 indicates that this will require $30 / 2 = 15$ labour-days of input.

<table>
<thead>
<tr>
<th>Table 21:</th>
<th>Labour requirements for clearing side drains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Difficulty - tasks relate to drained ditches without any standing water</td>
<td></td>
</tr>
<tr>
<td>moist and loose soils</td>
<td>average soil conditions</td>
</tr>
<tr>
<td>2.5 m$^3$/wd</td>
<td>2.0 m$^3$/wd</td>
</tr>
</tbody>
</table>
Labour requirements for clearing side drains with x-section of figure 95

Table 21: Labour requirements for clearing mitre drains

<table>
<thead>
<tr>
<th>Task Difficulty</th>
<th>moist and loose soils</th>
<th>average soil conditions</th>
<th>hard and dry soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 m$^3$/wd</td>
<td>2.0 m$^3$/wd</td>
<td>1.5 m$^3$/wd</td>
<td></td>
</tr>
<tr>
<td>tasks relate to drained ditches without any standing water</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For a section as shown in figure 95, labour inputs requirements can be estimated using the information of table 22.

If for example the drain bed has been silted up with a layer of 20 cm silt and the silt is moist and loose, you can estimate that for cleaning a side drain with a length of 100 meter the labour inputs that will be required are $100 / 25 = 4$ work days of input.

Figure 95: Typical cross-section B of side drain

Table 22: Labour input requirements for clearing side drains type B

<table>
<thead>
<tr>
<th>silt depth</th>
<th>moist and loose soils</th>
<th>average soil conditions</th>
<th>hard and dry soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 cm</td>
<td>50 m/WD</td>
<td>40 m/WD</td>
<td>30 m/WD</td>
</tr>
<tr>
<td>15 cm</td>
<td>33 m/WD</td>
<td>27 m/WD</td>
<td>20 m/WD</td>
</tr>
<tr>
<td>20 cm</td>
<td>25 m/WD</td>
<td>20 m/WD</td>
<td>15 m/WD</td>
</tr>
</tbody>
</table>

Side slope repair

This activity includes the excavation of soils to establish a proper bench on to which new soils are added. Soils are then excavated from nearby borrow pits and placed in layers not thicker than 0.10 meters and compacted with hand rammers at its optimal moisture content. After final shaping of the slope, it is covered by grass to prevent future soil erosion.

Figure 96 illustrates the excavation of soils using benching. For this activity, labour input requirements can be estimated using table 23. If 30 m$^3$ of soil in average condition needs to be excavated, using the benching technique, table 23 indicates that this will require $30 / 1.5 = 15$ days of labour input.

Figure 96: Benching in earthworks
**Table 23: Labour input requirements for benching**

<table>
<thead>
<tr>
<th>Task Difficulty</th>
<th>moist and loose soils</th>
<th>average soil conditions</th>
<th>hard and dry soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m³/wd</td>
<td>1.5 m³/wd</td>
<td>1.0 m³/wd</td>
<td></td>
</tr>
</tbody>
</table>

**Shoulder Repair and Grass Planting**

The work includes the filling and compaction of erosion gullies formed by water running over the edge of the carriageway and the road shoulders. Erosion gullies on the side slope can be repaired using soils borrowed from the adjacent areas next to the road. Although no vegetation shall be allowed on the carriageway, grass should be established on the sloping shoulders to protect against erosion. After repairing shoulders, it is important that the repaired slide slope is immediately covered with grass turfing.

Table 24 gives an indication of labour input requirements for this activity. Take the example where 30 m³ of erosion gullies have to be filled in hard soil. Table 24 indicates that in this case 30 /1.5 = 20 labour-days of input would be required to carry out this work.

**Table 24: Labour requirements for filling erosion gullies**

<table>
<thead>
<tr>
<th>Task Difficulty</th>
<th>moist and loose soils</th>
<th>average soil conditions</th>
<th>hard and dry soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m³/wd</td>
<td>1.5 m³/wd</td>
<td>1.0 m³/wd</td>
<td></td>
</tr>
</tbody>
</table>

**Patching potholes in the road carriageway**

Potholes collect rainwater on the road surface and restrict it from draining off to the side of the road. Combined with traffic, this stagnant water accelerates the wear of the road surface and finally if this water penetrates the road surface layer, it reduces the bearing strength of the road base.

Patching potholes in earthen or gravel roads starts with the excavation of the pothole with squared off edges to a minimum depth equal to the lowest point of the pot hole or until firm and compacted materials are reached. The excavated material and other approved filling material is mixed together, watered and placed back into the excavated hole and compacted using hand rammers. Make sure there is no water in the pothole when it is filled.
If the pothole is deep the materials should be filled and compacted in layers not thicker than 5 cm. Compaction is done with hand rammers. The surface level of the filled hole after compaction should be at least 2 cm higher than the adjacent pavement surface level.

Table 25 provides an indication of the labour requirements for filling potholes. If for example 6 m³ of potholes have to be filled and the haulage distance to bring the fill material is 200 meter, table 25 indicates that in this case 6 / 1.2 = 5 labour-days of input will be required.

<table>
<thead>
<tr>
<th>Task Difficulty - Hauling Distance to Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 100 m</td>
</tr>
<tr>
<td>1.5 m³/wd</td>
</tr>
<tr>
<td>100 m - 300 m</td>
</tr>
<tr>
<td>1.2 m³/wd</td>
</tr>
<tr>
<td>more than 300 m</td>
</tr>
<tr>
<td>1.0 m³/wd</td>
</tr>
</tbody>
</table>

**Filling ruts in carriageway**

Ruts are caused by vehicles that keep on passing in the same tracks made by vehicles before them. The weight of the vehicles and their speed push surface material to the sides of the road. This process eventually deforms the cross section and the camber of the road surface. The ruts obstruct the water from exiting the surface. The stagnant water accelerates the wear of the surface when subject to passing traffic.

Filling ruts normally comprise of raking excess materials from the road shoulder back on to the carriageway where ruts have been formed. In cases of more severe rutting, it may be necessary to bring in additional laterite gravel or earth to compensate for the gravel loss. In such cases the ruts should be treated using the same work methods as when filling potholes. The ruts should then be excavated to form vertical edges and the fill materials need to be placed, watered and compacted in layers. When using hand rammers for compaction, the thickness of each layer should not exceed 5 centimeter.

Table 26 gives an indication of the labour inputs that are required for filling ruts. If for example ruts have to be repaired over a length of 300 meters using 50% material from the shoulders and 50% laterite from a pit at 100 meters distance from the site, it can be calculated that the labour input requirements are 0.5 x (300 / 30) + 0.5 x (300 / 1.5) = 5 + 20 = 25 labour days.
Grubbing the edge of the carriageway

Grass growing on the edge of the carriageway can prevent rainwater from draining off the road surface. It can also start growing into the carriageway. Grass and roots should be removed from the carriageway. A string line showing the exact position of the start of the side slope provides a good guidance when removing grass and grubbing the shoulders. Debris should be removed well away from the road to avoid the removed material being washed back into the drainage system.

Reshaping the carriageway of earthen and gravel roads

Over time, the camber of the carriageway is reduced due to the action of traffic and weather and needs to be reshaped. The camber is rebuilt by redistributing material from the edge of the carriageway to the crown of the road. To achieve the correct levels, it is required that the works are set out using pegs and strings and re-establishing the correct camber using line levels. Light reshaping of the carriageway is normally carried out relying entirely on excess materials from the road side. After placing the materials, they are compacted at optimal moisture content.

Labour input requirements for light reshaping of the carriageway can be estimated on the basis of the information provided in table 28. If for example a section of 1.5 kilometer of road needs to be reshaped for hard and dry soil, table 28 indicates that this would require $1,500 / 15 = 100$ labour-days of input.

Grass cutting and bush Clearing

Clearing consists of the removal of grass, bushes, other vegetation, rubbish and all other superfluous material including the disposal of all material resulting from the
works. The work comprises of cutting (not scarifying) all grass and bush on both sides of the roadway and for the entire width between the pavement edge and the top of the back-slope at the outer side of the side drain.

The vegetation should be cut to a height not exceeding five centimeter. Where roadside drainage exists on only one side of the roadway, grass and bush cutting on the fill slope should extend for a minimum distance of 2.5 meters from the pavement edge adjacent to the embankment slope. Where no road side drains exist, i.e. on road embankments, clearing should extend from the pavement edge to the foot of the embankment or to the paddy water level on both sides of the roadway.

All bush and branches hanging over the road, shoulders, side drains, mitre drains and traffic signs should be cut down and disposed of safely. When tree seedlings have recently been planted, it is important that they are not damaged when clearing grass and bush around the seedlings.

Furthermore, when the seedlings are young, vegetation close to the trees should be removed to allow the trees good growing conditions. Finally, trimming of planted trees should be included in this activity on a regular basis to ensure that they develop into healthy shapes and which do not interfere with the road traffic.

The labour input requirements for clearing can be estimated using table 29. If for example heavy vegetation needs to be cleared covering bush cutting and grass cutting for an area of 2,000 m², table 29 indicates that in this case (2,000 / 200) + (2,000 / 100) = 10 + 20 = 30 work-days of labour would be required.

Table 29: Labour input requirements for clearing

<table>
<thead>
<tr>
<th>Task</th>
<th>Density</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bush cutting m²/wd</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Cutting grass m²/wd</td>
<td>100</td>
<td>150</td>
</tr>
</tbody>
</table>

Grass Planting

This work consists of furnishing turf and sods as required and planting them to give a healthy stable covering of grass which maintains its growth in any weather and prevents erosion of the material in which it is planted. Grass should be of native species harmless to persons and animals and not of a kind recognized as a nuisance to agriculture. It should be free of disease and noxious weeds, deep rooted and sufficiently rapid growing and spreading to give a complete cover over the planted area.

The term "grass" embraces turf and sods and, if the Maintenance Supervisor permits, may include plants of other types capable of giving effective erosion protection. Sodding or turfing should be done by planting sods or turf to give continuous cover over the whole area. Turfs should be planted with their root system substantially undamaged, well buried in firm material, and packed around with moist earth in which they have grown.
Grass should be planted at such a time and done in such a way that at the time of the final inspection all areas to be grassed are substantially covered with healthy, well established, firmly rooted grass and the planted area is free from erosion channels. Surfaces to be planted should be trimmed in such a way that the ground surface after planting should be as shown on the standard drawings.

Labour input requirements are indicated in Table 30. If an area of 3,000 m² needs to be planted, with a hauling distance of the grass to the site 100 meters, it can be calculated that the labour input requirements are 3,000 / 100 = 30 labour-days.

<table>
<thead>
<tr>
<th>Task Difficulty - Hauling Distance to grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 10 m</td>
</tr>
<tr>
<td>20 m²/ld</td>
</tr>
</tbody>
</table>

### 8.3 Planning and Organization of Maintenance Activities

For the implementation of maintenance activities by local communities, funds will be required and an organization needs to be set up to organize, manage and supervise the planning and implementation of the maintenance works.

For the maintenance of simple routine and periodic maintenance of low volume local community roads, the establishment of community-based maintenance organizations may be considered. A community-based Operation and Maintenance (O & M) Committee can be established (members can be selected through the musyawarah system) that will be responsible for mobilizing and managing the necessary financial and labour resources that are required for the identified maintenance works.

Although labour constitutes the main input requirement for labour-based routine and periodic maintenance of low-volume rural roads, financial resources will be required as well to procure or rent equipment and tools and for purchasing construction materials. Depending on the local situation, there may be different ways of mobilizing the required financial and labour resources.

One option would be the submission of requests for maintenance funds from the community development committee or local governments. Another option would be to levy road toll to the users. A combination of the two possible sources of funding can also be considered. If there is an effective gotong royong system of self-help in the locality, it would be possible to consider tapping into resources available through this system.

The planning of maintenance activities, includes the preparation of long term and short term plans for general routine maintenance and periodic maintenance activities. Normally long term plans are prepared by the Public Works Department and are based on the annual maintenance requirements and the available resources. Apart from long term plans, short term plans are usually also prepared for routine maintenance works. Such plans have to be prepared before the execution of specific works. The basis for these plans is a detailed inspection of the road condition and covers usually a period of 2-4 weeks.
These plans outline what needs to be done and how many labourers are required for the road sections covered under the plan. Tables 31 and 32 give an example of how a work plan for routine maintenance activities can be prepared. The assumed period for the implementation of the plan is 4 weeks. In table 31 the input requirements have been estimated (using productivity norms given in paragraph 8.2). In the example of 31 a total of 280 labour-days of inputs is required. In addition Rupiah 2,400,000 is required for the procurement of cement.

**Table 31: Illustrative example of input requirements for maintenance activities**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Unit</th>
<th>Qty</th>
<th>Productivity per work-day</th>
<th>Labour-days needed</th>
<th>Materials requirements</th>
<th>Unit cost (Rp)</th>
<th>Material cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense bush cutting</td>
<td>M²</td>
<td>2,000</td>
<td>200</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benching</td>
<td>M²</td>
<td>100</td>
<td>1</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning side drains</td>
<td>M²</td>
<td>50</td>
<td>2</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning mitre drains</td>
<td>M²</td>
<td>30</td>
<td>2</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder repair</td>
<td>M²</td>
<td>75</td>
<td>1.5</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass planting</td>
<td>M²</td>
<td>1,500</td>
<td>15</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reshape carriageway</td>
<td>M²</td>
<td>300</td>
<td>15</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repairing ruts</td>
<td>M²</td>
<td>300</td>
<td>30</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filling potholes</td>
<td>M³</td>
<td>15</td>
<td>1.5</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repairing 3 bridges</td>
<td></td>
<td>30</td>
<td>40 b.cement</td>
<td>60,000</td>
<td></td>
<td>2,400,000</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>280</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,400,000</td>
</tr>
</tbody>
</table>

As the plan is to complete these activities in 4 weeks, it means that per week 70 labour-days of input are required. If we assume that local labour is mobilized through the gotong royong system whereby the community members contribute one day per week, it means that 70 labourers have to be mobilized per week.

Based on this information, a work plan can be made, as shown in table 32. The work plan reflects the availability of labour, the logical sequence of activities and the preference of organizing the work in labour gangs, with individual labour-gangs responsible for specific activities. In the example it has been assumed that one gang consists of about 10-15 labourers.

**Table 32: Example of 4-week maintenance plan, based on info from table 31**

<table>
<thead>
<tr>
<th>Labour input (number of labourers; 1 day of work per week)</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Total</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense bush cutting</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>40</td>
<td>1 gang</td>
</tr>
<tr>
<td>Benching</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>10</td>
<td>100</td>
<td>1-4 gangs</td>
</tr>
<tr>
<td>Cleaning side drains</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td></td>
<td>75</td>
<td>2 gangs</td>
</tr>
<tr>
<td>Clean mitre drains</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td></td>
<td>45</td>
<td>1 gang</td>
</tr>
<tr>
<td>Shoulder repair</td>
<td>30</td>
<td>20</td>
<td>50</td>
<td></td>
<td>100</td>
<td>3-2 gangs</td>
</tr>
<tr>
<td>Grass planting</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>1 gang</td>
</tr>
<tr>
<td>Reshape carriageway</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>2 gangs</td>
</tr>
<tr>
<td>Repairing ruts</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>1 gang</td>
</tr>
<tr>
<td>Filling potholes</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>1 gang</td>
</tr>
<tr>
<td>Repairing 3 bridges</td>
<td>30</td>
<td>30</td>
<td></td>
<td></td>
<td>60</td>
<td>3 gangs</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>280</td>
<td></td>
</tr>
</tbody>
</table>
For the implementation of labour-based routine maintenance, basically two different organizational methods can be considered:

- **Individual length-men system:** A worker is assigned to carry out all routine maintenance activities over a specific length of the road and throughout the year. He/she is solely responsible for his/her section and carries out all work as instructed.

- **Group-wise length-men system:** A number of workers carry out all activities as a group, covering a longer road section. They are together responsible for the road section and are guided by a headmen or gang-leader.

A variation to the above systems is the situation where the workers or group of workers work only once or twice a year (for example before and after the rainy season) to carry out all necessary activities in one go. An example of this organization is shown in the illustrative work plan that is presented in table 32.

Usually a group-wise length-men system is preferred as this will provide the best assurance that maintenance requirements are timely identified and taken care of.
The central objective of a maintenance reporting system is to provide the responsible government authorities information about the progress against the approved plan. Progress reports usually need to contain information on:

- Description of road,
- Chainage of road section,
- Activities carried out, and the period that the work was done;
- Targets for each activity,
- Task rates used,
- Workdays spent on each activity,
- Materials used,
- Information about completed road works

The responsible government authorities need this information as they are accountable to higher level authorities regarding the progress and the expenditures. They also need the information to update their road condition inventories and for future planning.

An illustrative example of a simple monthly reporting form with some fictitious information is presented in Table 33 below. In this example a monthly frequency has been assumed for reporting. As required by the concerned government authorities this frequency may be changed, for example to 2-weekly or 3-monthly.

The example of Table 33 also includes information about the budget for the particular works and the targets set regarding the progress for the different activities. This information is useful for both the Village Development Committee and the Government authorities to find out whether the work is progressing per plan, whether the contributions of the involved parties materialize and whether there are any factors that hinder the progress. This information will enable the involved parties to take corrective action, as required.

To be able to produce a progress report it is thus necessary that adequate and accurate records are being kept on the site regarding the number of labour-days of work done, the number of labourers involved, the materials received and used and the status of the use of the equipment. The responsibility of this information is primarily with the supervisor. If a store keeper is available he/she may assist the
supervisor in keeping records of the store. Gang-leaders may likewise be involved in keeping records of the attendance and work done by the labourers. However, it is the supervisor who is ultimately responsible to ensure that the information provided to the higher authorities is accurate and complete.

The information provided in a progress report like the one shown in table 33 is very useful for the authorities and the planners as it gives them the status of progress. In the particular case of the example of table 33 it appears that works have been delayed and that there may be a need for re-scheduling.

To know the total progress, all one has to do is to add the progress figures of all the monthly progress report. It is also possible to add a few columns to the above progress report to have an instant overview of the overall progress, as shown below.
Annex 1: Reference Documentation

- Increased Application of Labour-Based Methods through Appropriate Engineering Standards, TRL, DFID and ILO, 2006
- Bituminous surfacing options for low volume roads constructed by labour-based methods, Jon Hongve, Senior Technical Adviser, ILO, 2006
- Guidelines for Labour Based Tertiary Road Rehabilitation Methods Implemented by Community Organizations in Balakot and Muzaffarabad Tehsils, ILO, Project Office for Earthquake Response Mansehra, Pakistan - October 2007
- Technical Manual Labour-Based Construction Methods prepared for the ILO by Bjorn Johannessen, August 1997
- Labour-based Road Construction and Maintenance Technology, Course Notes 1, Bjorn Johannessen, ILO, National Polytechnic Institute and School of Communication and Transport
- Manual for Supervision of Labour-based Road Rehabilitation Works, Prepared for ILO ASIST by Simon Tembo & Frans Blokhuis
- Labour-based Work Technology, Surveying and Setting Out, ILO-ASIST
- Local Resource Based Road Construction Approach, Practical Implementation Field Guide, ILO/UNDP Rural Roads and Capacity Building Project in Selected Districts in Aceh and Nias, ILO.
- Local Resource-based Road Works, Work Method Guidelines, ILO/UNDP Rural Roads and Capacity Building Project in Selected Districts in Aceh and Nias, ILO.
- Guidelines to the design of plain concrete pavement, Road Engineering Association of Malaysia,
- Concrete roads in developing countries, TRL and DFID, 1985
- Overseas Road Note 9, The Design of Small Bridges, TRL and DFID, 1992.


• Concrete Mixes Guideline Draft, Engineers without Borders, USA, 2005.

• A design manual for small bridges, TRL and ODA, 1993.

• Building Rural Roads, Bjorn Johannessen, ILO ASIST, 2008

• Low Cost Road Construction in Indonesia, Labour-Based Road Projects in Manggarai District, Volume I and II, Beusch, Hartmann, Petts and Winkelmann, Intercooperation and SDC, 1997.

• Pictures from the Community Access Project (CAP) implemented by UNOPS in Ampara District in Sri Lanka within the framework of the Ampara Partnership Programme, financed by the EU, 2009.

• Technical guidelines from the ILO TIM-Works Project in Timor Leste. This labour-based rural roads development project is implemented by the ILO and is financed by the EC and the Governments of Timor Leste, Ireland and Norway.
Annex 2:

Format For Proposals under Community – Government Partnership

# Partnership Program for Rural Road Development

- Village: ............
- Hammlet: ..........
- RT/RW: ............
- Village: ............
- Sub-District: ...  
- District: Malang

## The Outline Proposal

**Proposed Activities for Fiscal Year XXXX**

- Village/Kelurahan: 
- Sub-district:  
- District:  

1. Activity  
2. Implementer  
3. Location (RT/RW/Hamlets)  
4. Description of Activities  
   a. Background:  
   b. Objectives:  
   c. Volume:  
5. Time Estimation  
6. Cost Estimation  
   a. Grant  
   b. Societies fund  
   c. Total Cost

---

**Applicant**

**Chief of Committee**
The Result of Community Meeting (Musyawarah)

Rural Planning and Development

Year: xxxx
Village/Kelurahan:
Sub-district:
District:

1. Activity
2. Implementer
3. Location (RT/RW/Hamlet)
4. Description of Activities
   a. Background:
   b. Objectives:
   c. Volume:
5. Tentative Schedule
6. Community Contribution
   a. Cash
   b. In-Kind (material)

Malang,
Kepala Desa/Kelurahan

……………………………………………………………………………………………………………………………

……………………………………………………………………………………………………………………………

Camat Veri

……………………………………………………………………………………………………………………………

……………………………………………………………………………………………………………………………

Camat
COST ESTIMATES

Activities:
Volume:
Village/Kelurahan:
Sub-district:
Year:

<table>
<thead>
<tr>
<th>No</th>
<th>Items</th>
<th>Unit Cost</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Cost

Total (in word) ........................................................................................................................................
.................................................................................................................................................................

Malang, .................................
Village Head  Chief of Village Development Committee

______________________________  __________________________

Camat

______________________________
SAMPLE OF MINUTES OF COMMUNITY MEETING

On Monday, February fourteenth, two thousand and five in the village Duwet Kradjan Tumpang Malang District has held the village development meeting. The meeting was held to discuss the issues of the rural road improvement for the partnership program.

The community meeting was attended by the head of the village and the village development committee Duwetkrajan, a group of community leaders. Details of the participants are attached. In the meeting the following was agreed:

To improve the road for which the detailed design and cost estimates are enclosed. The detailed activities are mentioned below:

**Type of civil works:** asphalts pavement road

**Volume:** 2,000 m length x 3 m wide

**Location:** Duwet Krajan

**Expected outcome:** Improved access to economic facilities and services

**Cost:** Rp. xxxxxxxx

**Community Contribution:** Rp. xxxxxxx

**Implementer:** Village

<table>
<thead>
<tr>
<th>Village Head</th>
<th>executive team / committee / LPMD Village</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
List of Participants

VILLAGE.................................................................
SUB DISTRICT.........................................................
DATE.................................................................

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Address</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Malang, __________
Village Head
DESCRIPTION OF THE CURRENT CONDITION OF THE ROAD

VILLAGE……………………………
SUB-DISTRICT…………………………………………………

DESIGN ENGINEERING DRAWINGS

ROAD DEVELOPMENT……………………………
VILLAGE…………………………………………………
SUB DISTRICT…………………………………………
Annex 3:

Calculating Areas, Volumes and Weights

Calculating Areas

<table>
<thead>
<tr>
<th>Shape</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square</td>
<td>$a \times a$</td>
</tr>
<tr>
<td>Rectangle</td>
<td>$a \times b$</td>
</tr>
<tr>
<td>Triangle</td>
<td>$\frac{a \times h}{2}$</td>
</tr>
<tr>
<td>Trapezoid</td>
<td>$\frac{a + b \times h}{2}$</td>
</tr>
<tr>
<td>Rhombus</td>
<td>$a \times h$</td>
</tr>
<tr>
<td>Circle</td>
<td>$\frac{d^2 \times \pi}{4}$</td>
</tr>
<tr>
<td></td>
<td>Circumference: $d \times \pi$</td>
</tr>
</tbody>
</table>

Example: Suppose you have to calculate the area of figure 1A below. The first step is to divide the area in areas that are easy to calculate. Once you have done this take the measurements (figure 1B). After that you can calculate the areas of the individual segments and add them. The table below shows the total area of figure 1A is 450.14 m$^2$.

![Figure 1A](image1.png) ![Figure 1B](image2.png)

<table>
<thead>
<tr>
<th>Calculations:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Area Triangle A: $a \times h / 2$</td>
<td>$17.68m \times 5.75m / 2 = 50.83 m^2$</td>
</tr>
<tr>
<td>Area Rectangle B: $a \times b$</td>
<td>$24.30m \times 12.15m = 295.25 m^2$</td>
</tr>
<tr>
<td>Areas Trapezoid C: $a + b / 2 \times h$</td>
<td>$16.90m + 12.33m / 2 \times 7.12m = 104.06 m^2$</td>
</tr>
<tr>
<td>TOTAL Area of borrow pit</td>
<td>$450.14 m^2$</td>
</tr>
</tbody>
</table>
Calculating Volumes

- **Rectangular Prism:** \( a \times b \times c = v \)
- **Triangular Prism:** \( \frac{a \times b}{2} \times c = v \)
- **Quadrilateral Prism:** \( \frac{a + b}{2} \times h \times c = v \)
- **Cylinder:** \( \frac{\pi d^2}{4} \times h = v \)

Weight of Different Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>kg/m³</th>
<th>kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel and Iron</td>
<td>7800</td>
<td>Stone for masonry work (dense)</td>
</tr>
<tr>
<td>Aluminium</td>
<td>2700</td>
<td>Stone; masonry work (porous)</td>
</tr>
<tr>
<td>Copper</td>
<td>6900</td>
<td>Building Sand (natural moisture)</td>
</tr>
<tr>
<td>Lead</td>
<td>11,340</td>
<td>Building Sand (dry)</td>
</tr>
<tr>
<td>Wood</td>
<td>400-800</td>
<td>Gravel (clean, without fines)</td>
</tr>
<tr>
<td>Hardwood</td>
<td>700-1000</td>
<td>Cohesive Soil</td>
</tr>
<tr>
<td>Asphalt</td>
<td>1600-2000</td>
<td>Heavy Clay</td>
</tr>
<tr>
<td>Bitumen</td>
<td>1100</td>
<td>Cement or Lime Mortar</td>
</tr>
<tr>
<td>Cement Stone Wall (with mortar)</td>
<td>1800-2000</td>
<td>Cement (loose)</td>
</tr>
<tr>
<td>Lime Stone Wall (with mortar)</td>
<td>1800-2000</td>
<td>Lime (loose)</td>
</tr>
<tr>
<td>Brick Wall (with mortar)</td>
<td>1300-1500</td>
<td>Concrete with reinforcement</td>
</tr>
<tr>
<td>Masonry Wall (with mortar)</td>
<td>2000-2200</td>
<td>Water</td>
</tr>
</tbody>
</table>
Annex 4:

Calculating Slopes

A slope shows the steepness of an ascent or descent. Slopes can be expressed as a ratio or in percentage.

**Definition of a Slope (or Gradient)**

![Slope Diagram](image)

The box below shows how slopes can be calculated as a ratio.

**Calculating Slopes as a Ratio**

![Ratio Diagram](image)

Slopes shown as a ratio can be expressed as a percentage by dividing the numerator by the denominator and multiplying the result by 100%. The box below shows how to do this.

**Calculating Slopes as a Percentage**

![Percentage Diagram](image)
Annex 5:

Soil Terminology, Classification and Suitability

**Soil Terminology**

According to practice (Grain) size; the nature of the soil depends largely on the sizes of particles forming the solid part of the soil and are the basis for the identification of different soils.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>Consists of 2 - 60 mm stones (the term gravel is also used in road terminology for a mixture of stones, sand and clay for surface layers)</td>
</tr>
<tr>
<td>Sand</td>
<td>Grains of size 0.06-2mm, coarse to fine gritty soil, firm when damp</td>
</tr>
<tr>
<td>Silt</td>
<td>Fine grain soil of size 0.002 - 0.06 mm, non-plastic. When dry = fine soft powdery silt and does not stain hands when wet</td>
</tr>
<tr>
<td>Clay</td>
<td>Very fine soil of size 0 - 0.002 mm, plastic. When dry = hard lumps cracked surface and stains hands when wet</td>
</tr>
<tr>
<td>Organic Soil</td>
<td>The soil contains remnants of plants, roots etc. and has a distinct smell, dark in colour</td>
</tr>
</tbody>
</table>

The particle sizes, silt, clay, sand and gravel:

- **Coarse grain soils**: The soil consist mainly of sand and gravel, with little or no silt or clay
- **Fine grain soils**: Mainly silt and clay
- **Cohesive**: The soil sticks together, mainly clay
- **Non cohesive**: The soil does not stick together, mainly sand and gravel
- **Well graded**: A wide range of particle sizes which are well distributed (note: a mixture of particle sizes means that the soil will be easier to compact)
- **Poorly graded**: Not all particle sizes are present in the soil; too much of some sizes and too little of others
- **Uniformly graded**: Soil with a limited range of sizes, mainly concentrated in one size category
- **Proportions of soil fractions**: E.g. 10% gravel, 20% sand, 50% silt and 20% clay

- **Plasticity**: The degree to which the soil can be moulded (clay is very plastic)
- **Moulding**: Forming soils in certain shapes (e.g. threads)
- **Stability**: A stable soil is not easily deformed
- **Bearing Capacity**: The ability (strength) of the soil to carry surface loads (measured by the weight that can be loaded on to a specified area without penetration - or the amount of penetration under a certain load on a specified area)
- **Density**: In a dense soil the particles are close together (or well compacted)
- **Optimum moisture cont.**: The water content gives the best effect of soil compaction
- **Compaction**: The process which packs the particles close together (by pressure, tamping or vibration) and consequently increasing the density and bearing capacity
- **Permeability**: The degree to which water can penetrate a particular soil

**Soil Classification**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Grain Soil</td>
<td>Silt and clay are strongly affected by the amount of water present (moisture content). With increasing moisture content the silt and clay will: - first become plastic = can be moulded - then become liquid = begins to flow like water</td>
</tr>
<tr>
<td>Coarse Grain Soil</td>
<td>Sand and gravel are affected to some extent by an increased moisture content, but not extensively</td>
</tr>
<tr>
<td>Combination Soils</td>
<td>Soils by nature are a combination of coarse and fine grain soils. Both the moisture content and the particle distribution affect their behaviour.</td>
</tr>
</tbody>
</table>
### Suitability of Soils for Road Works

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Grading</th>
<th>Compressibility when Compacted</th>
<th>Bearing Capacity</th>
<th>Resistance to Wear And Tear</th>
<th>Suitability as Road Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel with few fines</td>
<td>well graded</td>
<td>almost none</td>
<td>excellent</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td>poorly graded</td>
<td>almost none</td>
<td>fair to good</td>
<td>fair</td>
<td>fair</td>
</tr>
<tr>
<td>Gravel with many fines</td>
<td>well and poorly graded</td>
<td>slight</td>
<td>fair to excellent</td>
<td>fair to good</td>
<td>fair</td>
</tr>
<tr>
<td></td>
<td>poorly graded</td>
<td>almost none</td>
<td>poor</td>
<td>poor</td>
<td>poor</td>
</tr>
<tr>
<td>Sand with few fines</td>
<td>well graded</td>
<td>almost none</td>
<td>poor</td>
<td>poor</td>
<td>poor</td>
</tr>
<tr>
<td></td>
<td>poorly graded</td>
<td>almost none</td>
<td>poor</td>
<td>poor</td>
<td>poor</td>
</tr>
<tr>
<td>Sand with many fines</td>
<td>well and poorly graded</td>
<td>slight to medium</td>
<td>poor to fair</td>
<td>fair</td>
<td>poor to not suitable</td>
</tr>
<tr>
<td>Silt</td>
<td>-</td>
<td>medium</td>
<td>very poor</td>
<td>very poor</td>
<td>not suitable</td>
</tr>
<tr>
<td>Clay</td>
<td>-</td>
<td>high</td>
<td>very poor</td>
<td>poor</td>
<td>not suitable</td>
</tr>
<tr>
<td>Organic</td>
<td>-</td>
<td>very high</td>
<td>very poor</td>
<td>very poor</td>
<td>not suitable</td>
</tr>
</tbody>
</table>
Annex 6:

Otta seal

Description

An Otta seal is a thin bituminous seal, applied as single or double layer, comprising of graded gravel or crushed aggregate containing all sizes and a cut-back or soft penetration grade bitumen. A layer of aggregate is rolled into the binder using a pneumatic tyred roller or loaded trucks. An Otta seal is different to surface dressing in that an ‘all in’ graded gravel or crushed aggregate is used instead of single sized chippings. Otta seals should be considered when only natural gravels are available, workmanship is of mediocre quality, low bearing capacity pavements are allowed and there is a low maintenance capacity.

The success of an Otta seal depends largely how effective the binder can be squeezed up through the aggregate by the action of extensive rolling. Due to the fines in the aggregate, 2-3 days or longer of pneumatic-tyred compaction (rollers or traffic) are required to fully coat all the particles. Evidence shows that Otta seals constructed by conventional plant methods has shown them to be satisfactory for over 12 years on roads carrying up to 300 vehicles per day. Binder and aggregate design is by judgment and must be established through trials. Inadequate trials can give poor results and a loss of confidence in the construction technique. A wide range of aggregate sources and types can be used.

Design Aspects

The grading of the aggregate is based on the expected level of traffic. For roads carrying light traffic (less than 100 vehicles per day), a ‘coarse’ grading should be chosen. A ‘dense’ grading should be applied to roads carrying more than 100 vehicles per day. The amount of fines (<0.075 mm) should not exceed 10%. The recommended aggregate spread rates is given in the table below.

<table>
<thead>
<tr>
<th>Aggregate spread rate m³/m²</th>
<th>Dense grading</th>
<th>Medium grading</th>
<th>Coarse grading</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016-0.020</td>
<td>0.013-0.016</td>
<td>0.013-0.016</td>
<td></td>
</tr>
</tbody>
</table>
The table below shows the recommended binders for Otta seals with different aggregate grading and for different traffic levels.

**Recommended binders for Otta Seals with different aggregate grading and traffic levels**

<table>
<thead>
<tr>
<th>Annual Average Daily Traffic</th>
<th>Aggregate grading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dense</td>
</tr>
<tr>
<td>More than 1000</td>
<td>MC 3000</td>
</tr>
<tr>
<td>100-1000</td>
<td>MC 3000</td>
</tr>
<tr>
<td>Less than 100</td>
<td>MC 800</td>
</tr>
</tbody>
</table>

Spray rates must be chosen through road trials. The range of spray rates for different levels of traffic is roughly as follows:

- Average annual daily traffic <100, then 1.8 - 2.2 l/m²
- Average annual daily traffic 100 – 500, then 1.8 - 2.0 l/m²
- Average annual daily traffic >500, then 1.6 - 1.8 l/m²

The best results are achieved by spraying the bituminous binder with a self propelled or tractor drawn bitumen distributor. However application by hand lance, if skillfully carried out, can achieve satisfactory work on small-scale work.

**Construction Aspects**

Because of the broad range of materials that may be used and the empirical nature of the design of this type of seal that it is very important that pre-construction trials be carried out. An Otta seal will, like any other type of bituminous seal, not add to the structural strength of the road and therefore the surface to be treated must previously have been prepared to withstand the expected traffic levels. Preparation of the road base may include re-gravelling, reshaping and compaction.

Immediately prior to the construction of the Otta seal, the road base must be broom free of sand and excess dust, mud or any other material that might hinder bonding between the seal and road base. Priming of the road base of non-calcareous material is not normally required. Calcareous material does require priming due to its capacity to absorb high amounts of bitumen. MC 30 or MC 70 is normally used for priming and is applied at spray rates between 0.8 and 1.2 l/m².

Stockpiles of aggregates must be inspected to see if screening is needed to remove excess fines or over size particles. If aggregate is to be spread by hand then small stockpiles must be placed in sufficient quantities on either side of the road to be treated at approximately every 10 meters. The aggregate must be placed so as not to interfere with the binder spraying operation.

A spray length of at least 100 meters at full sealing width shall be taken in one lift so that an immediate cover with aggregate and rolling operation can be started within 10 minutes after the bituminous binder is applied. If there are “fatty” spots, these shall be blinded off with more aggregate and rolled. It is recommended to apply a bit more
aggregate than strictly necessary to ensure proper coverage. This excess shall be broomed off about a week after completion. Not all of the loose aggregate shall be broomed off as this aggregate plays an important role in forming the final surfacing.

Immediately following the spreading of aggregate, rolling shall start (preferably within 1-minute after spraying of the binder) with a pneumatic tyred roller to embed the chips in the bituminous binder. Consecutive roller passes shall generally overlap by about one half of the roller's width. When the initial rolling with the pneumatic roller is completed, commercial traffic could be allowed in the surfaced area. The speed of traffic shall be temporarily reduced to 30-40 km/hour for a period of a month to avoid the damage to the aggregate cover materials. The need for extensive rolling by pneumatic rollers for two to three days or longer after construction is an ABSOLUTE MUST. The action of rolling ensures that the binder is forced upwards, coats the aggregate, and thereby initiates the process, (which is continued by subsequent trafficking) of forming a premix like appearance to the surface.

The following activities should be carried out in the Otta sealing construction:

1. Mark areas to be set-out. This will ensure correct placement of binder and no overspray on adjoining areas.
2. Put in place controls to prevent traffic to come within the area of construction.
3. Load the distributor with enough binder to complete the work area and be at the right spraying temperature
4. Place cut-off sheets of paper or other material across the road at the start and end of the section to be sprayed.
5. Check whether the speed with which the distributor will be driven will give the required binder spray rate.
6. Check that the aggregate is placed correctly and the workforce is ready to spread the aggregate
7. Check that the equipment for rolling is in place and ready for rolling.
8. It is recommended that distributor makes a spray run of 100 meters to allow for immediate covering of the binder with aggregate. Rolling will be able to begin within 10 minutes of the binder being applied.
9. Spreading of the aggregate must begin immediately after the spraying has started. The binder must be covered with aggregate as soon as possible.
10. Check that no areas are left uncovered or too little aggregate is spread. Drag broom pulled manually can help ensure an even distribution before rolling starts.
11. Preferably 12 tons pneumatic-tyred rollers are used for rolling. Loaded trucks may also be used as alternative. The section of the treated road may be opened to traffic after 3 passes of the rollers but on the day of construction, the surface treated must receive a minimum total of 15 passes.
12. Traffic must be restricted in speed to 30 km/hr for 2-3 weeks after construction to minimize the risk of loose excess aggregate thrown up in the air.
13. During this initial period, aggregate that has been displaced by the traffic should be broomed back into the wheel paths. After 2-3 weeks the excess aggregate should be swept away and the traffic speed restriction can be lifted.
14. If a second layer is to be constructed to make a double Otta seal, then a minimum of 2-3 months should pass before construction takes place.
Specifications

The work consists of one or two careful applications of bituminous material and cover aggregate on properly cleaned and prepared base course surface. When one application of bituminous material and cover aggregate is placed, the term “Single Otta Seal” shall apply. When two applications of bituminous material and cover aggregate are placed, the term “Double Otta Seal” shall apply.

The bituminous binder for Otta seal shall be a cut back product of 180/200 penetration grade bitumen. Power paraffin and Engine Oil (SAE 30 grade) are blended as cutter by the proportions 10% and 8% respectively as percentages of total volume at blending temperature of the bitumen (minimum 140°C) or with 5% to 8% kerosene as an alternative if approved by the Engineer. The hot binder is applied at a rate of 1.6 to 2.2 liter per square meter, depending on the average daily traffic and grading of the aggregates.

Both natural gravel and crushed gravel or a mixture of both may be used. The maximum size of stone shall be 16-19mm. Screening of aggregate shall be required to remove over size stones as well as excess of fines. The gradation of aggregate is given in the table below.

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>Passing the sieve (% by mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dense Graded</td>
</tr>
<tr>
<td>19</td>
<td>100</td>
</tr>
<tr>
<td>16</td>
<td>79-100</td>
</tr>
<tr>
<td>12</td>
<td>61-100</td>
</tr>
<tr>
<td>9.5</td>
<td>42-100</td>
</tr>
<tr>
<td>4.75</td>
<td>19-68</td>
</tr>
<tr>
<td>2.36</td>
<td>8-51</td>
</tr>
<tr>
<td>1.18</td>
<td>6-40</td>
</tr>
<tr>
<td>0.600</td>
<td>3-30</td>
</tr>
<tr>
<td>0.300</td>
<td>2-21</td>
</tr>
<tr>
<td>0.150</td>
<td>1-16</td>
</tr>
<tr>
<td>75 micron</td>
<td>0-10</td>
</tr>
</tbody>
</table>

For light traffic (less than 100 vehicles per day), gradation should be in the courser side and at finer side is used for conditions of more than 100 vehicles per day. For roads carrying more than 200 vehicles per day, a blend of crushed and uncrushed aggregate at a ratio of 30/70% is preferable.

In the preparation of binder, the first step is to empty the 180/200 penetration bitumen from drums into a bitumen heater. If there is water in the drum this needs to be removed before pouring the bitumen into the bitumen boiler. The bitumen boiler shall be equipped with gas or paraffin/diesel burner and a thermometer to control over-heating of the bitumen. The bitumen level in the distributor shall be maintained at a minimum of 150 mm. The adding of cutter (power paraffin) and engine oil or kerosene at the correct quantity shall follow the same procedure as for the bitumen. The power paraffin shall be added first followed by engine oil.

The maximum temperature of the bitumen (180/200 penetration) during the blending process shall not exceed 140°C. To ensure a homogeneous mix of the component, the blend shall be circulated for a minimum of one hour. The last 15 minutes before
spraying, the blend shall also be circulated through the spray bar. During the circulation time, the binder is heated up to the required spray temperature of a minimum of 150°C and a maximum of 155°C. The binder blend shall not be held at temperatures within the spraying range for a period exceeding 10 (ten) hours.

Prior to starting the sealing, stockpiles of aggregate shall be checked to ensure that they are free from over sizes and excess fines. The spreading of aggregate can be done manually. Stockpiling of aggregate along the road side must be carefully planned in order to have a sufficient volume of aggregate for the sealing operation. Stockpiled aggregate shall be placed in such way that the stockpiles do not interfere with the spraying operation.

Areas to be sprayed shall be set out with a string line. Prior to spraying, all the necessary arrangement for sealing shall be ensured. No priming is needed for Otta Seals. The application rate of the binder shall be 1.6 to 2.2 liter/m2. A light spray of water may be required to develop a good bond between the base and the seal. The spreading of aggregate for an Otta Seal does not require any mechanical equipment. The spreading of aggregate @1.3 to 2.0m3 per 100m2 of road surface shall start immediately after spraying the binder. It is essential that the binder shall be covered with aggregate as quickly as possible. No spraying binder shall be carried out on a wet pavement, when rain is expected or during periods of strong winds.

Close supervision is needed during the spreading of aggregate to ensure that there are no areas left out with too little aggregate or no aggregate at all. Any such spot shall be covered with aggregate immediately. The drag-broom shall be pulled manually to distribute the aggregate more evenly before rolling takes place.

Blending of cut back bitumen on site can be a hazardous operation. Appropriate precautions shall be taken to safeguard personnel handling the operation against fire and hot bituminous spray. The personnel shall be protected with overalls, boots, caps, gloves and safety glasses.

Plant and equipment required for the production, transportation, spreading and compaction of the bituminous seal must be in good working order and shall have sufficient capacity to ensure the works are carried out in the required manner. Required plant and equipment includes:

- Motorized or manual pressure bitumen distributor with spray bar.
- Bitumen Heater with temperature control.
- Steel Wheeled rollers and Pneumatic Tyred Rollers’
- Wheelbarrows, brooms, shovels, rakes and lutes

Compaction shall be undertaken with sufficient rollers of adequate size and weight to achieve the required compaction and surface finish. Through a trial the adequacy of the compaction equipment needs to be demonstrated in providing a bituminous seal to the specified requirements.
Quality Control Aspects

Quality control includes pre-construction trials. During these trials the optimum binder content and aggregate spray shall be established. Other quality control tests and checks that need to be done include:

- Inspect the site before bringing Aggregate and bituminous materials and remove any loose materials that may contaminate the aggregate.
- Stockpile the admixture graded aggregates into stockpiles and check that the aggregate are with the given grading specification.
- Check the bitumen drums to determine if the bitumen delivered is the prescribed, approved penetration grade.
- Maintain records at the site of the temperature in all containers used for heating bitumen and record temperatures every 30 minutes.
- Keep records in the site book of the daily consumption of binder and aggregate for the area covered that day.
- Check that the aggregate in the stockpiles is as per specifications.
- Check that the area of road to be treated is clearly marked to ensure correct placement and recording of binder and aggregates.
- The binder distributor should be loaded with sufficient binder to complete the marked up work area and at the correct temperature for spraying.
- Check that the aggregates have been placed correctly at intervals and the workforce are ready to spread the aggregates after the binder distribution.
- Check that the binder is sprayed at the design binder spray rate within the given area and make necessary adjustment together with the spray operator.
- Check that no areas are left uncovered and aggregates are not left in heaps.
- On the first day of construction the treated surface must receive a minimum of 15 passes by a pneumatic roller. Roll the Otta seal until the bitumen can be seen pressing up between the aggregate particles. Restrict the traffic speed to 30 km/hr for 2 weeks after construction.
Annex 7:

Cold mix

Description

Whereas bitumen needs to be heated to a specific temperature when using bitumen in conventional paving grade bitumen (hot mix technology), this is not required when using bitumen emulsions (cold mix technology).

In bitumen emulsion the chemical solvent that is used in hot mix bituminous application, is replaced with water as a solvent. The bitumen is dispersed in the water which, with the help of an emulsifier, produces a binder with a workable viscosity. After it has been applied to a road surface or mixed with aggregate, the water evaporates, leaving behind a film of bitumen at its original viscosity. The use of cold mix has many advantages over hot mix:

- It can be applied under all weather conditions, also when it is raining;
- As no heating is required cold mix is much more environmentally friendly than hot mix as no scarce natural energy resources have to be used for heating;
- The cold mix technology is less complicated than the hot mix technology and lends itself thus much better for the application of labour-based work methods and can generate much more jobs than when a hot mix technology is used;
- Cold mix can be relatively easily be prepared on-site by local labourers;

Picture 35: Cold mix does not require heating of bitumen
The application of cold mix is much preferred from a health point of view as workers are not exposed to poisonous fumes, as is the case when hot mix technology is applied in labour-based operations;

Cold mix is also safer to work with for the labourers as no heating is required;

As cold mix does not require heating, quality control problems related to maintaining the correct temperature, as is the case with hot mix, do not have to be addressed;

Cold mix is reasonably cost-competitive with hot mix and qualitatively comparable with hot mix;

Traffic can be allowed very quickly after sealing with a cold mix. This is not the case with hot mix;

Operations can be set up at the same pace as the completion of the base and thus eliminate the danger of damages to the base before it is sealed;

The batching and laying of cold mix asphalts can be tightly controlled and thus ensure a uniform and high quality of the end product;

Cold mix asphalts give a superior riding surface. Minor irregularities in the base are compensated for with slight variations in the thickness of the asphalt;

The thickness of the asphalt can easily be varied by using different guide rails;

Cold mix can also be applied easily for patching potholes in sealed roads.

**Construction Aspects**

For mixing and laying it is recommended a trial mix be prepared and a trial section constructed to determine the “placeability” of the mix. It is essential that the process of batching, mixing, discharging, transporting, placing and screeding of the asphalt is properly controlled and efficiently executed to ensure that the process is completed before the emulsion breaks. Once the emulsion has broken it will be difficult to place and screed it. For this reason it is recommended that mixes are limited to 100 liters and that the width of a section to be screened should not exceed 1 – 1.5 meters. (Try to arrange the guide rails so that they do not fall in the “wheel paths”).

Steps in the mixing and laying are (following the application of the tack coat; for the tack coat about 0,6-0,7 liter/m² will be required):

1. Measure the required amount of aggregate and load in the mixer. Place the mixer close to the site (within 100-200m) where the mix will be used (mixing needs to be done very fast);

2. Add water. About 1-2% water of the bulk dry density of the aggregate is normally sufficient. Mix thoroughly before emulsion is added. The amount of water can be increased in hot, dry weather and decreased if the aggregate is damp;

3. Pour the right amount of the specified emulsion from the drum into a measuring bucket, then pour it slowly into the mixer while this is rotating slowly. The drum of the mixer should be at an angle of about 45° and should be filled up to 1/3rd. The mixing process is quick and after +/- 2 minutes the mix is ready to
be placed on the road. The engineer should inform which emulsion should be used and which quantity;

4. Pour the mix into wheel barrows (about half full) and transport to the section to be sealed;

5. Place the mix in small quantities at regular interval in front of the screed, then spread with shovels and squeegees to the approximate level and quickly screed off against the guide rails. If the heap in front of the screed is too big, the screeding will be difficult.

Guide rails of 20 mm height will give a finished asphalt thickness of +/- 14mm. The guide rails must have holes for nailing them to the base so they don’t move during the screeding. 20 mm square tubing with welded on lugs may also be used but these tend to be a little too flexible and will follow any unevenness in the base when nailed down. When laying the asphalt on the adjacent strip, a 6 mm flat bar is placed flat on the edge of the previously compacted asphalt to ensure tie-in when the new asphalt is compacted.

When the emulsion has broken and set, the wet asphalt must be compacted. For this a 3-5 vibratory ton roller can be used. Compacting speed should be around 4-5 km/hr. Normally 6-8 passes would be sufficient. The first two passes should be made without vibration, the rest with. The reason for using vibration is to avoid any air to be “sealed in” and thus not obtaining maximum compaction of the asphalt. The drum of the roller must be wetted to avoid that the seal sticks to the drums.

Pictures showing some parts of the construction process of laying cold mix asphalt are shown on the next page.

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1 emulsion bitumen of the type 65% CMS could for example be considered. Usually about 8.5 – 9.5% of the total mix should be the emulsion bitumen.
Picture 37: Compaction of base-course for cold mix sealing

Picture 38: Measuring aggregates for mixing cold mix

Picture 39: Mixing of the cold mix
Picture 40: Spreading and screening cold mix

Picture 41: Compacting cold mix

Picture 42: Completed road section
Annex 8:

Stone and Concrete Block Pavement

Description

Stone or concrete block pavement is suitable for rural access roads with medium loaded vehicles and traffic volumes of less than 500 vehicles per day. It may be considered if other pavement types are likely to erode more easily, are more expensive, or when it is unlikely that maintenance will be carried out. As paving roads with stone or concrete blocks is a very simple technique, it can also be carried out relatively easily, compared to other pavement types. The production of dressed stone and concrete blocks can take place throughout the year and can provide employment to many people.

An important advantage of stone or concrete pavements is that it is almost maintenance free. In addition it is a so-called ‘no-waste’ pavement. This means that the blocks can always be re-laid if necessary and no additional blocks will be required. Block pavement is also practical in urban areas where it will sometimes be necessary to dig trenches across the road for laying pipes and cables. This can easily be done in the case of block pavements.

Construction Method

The road surface and embankment is prepared to sub-grade level (box cutting) with the required camber. Filter drains at both sides of the road are required to ensure drainage of surface water and to prevent saturation of the sub-grade. A sand cushion bedding layer is constructed by spreading coarse and well-draining sand by hand shovels. This layer needs to be watered and compacted by a small pedestrian road roller.

Kerbstones are placed along the edge of the box-cut road alignment. Shaped stone blocks or concrete blocks are placed between the kerbstones and packed together using a wooden (rubber) mallet and properly spaced. The voids between the stones are filled with a mixture of sand soil and gravel. The surface is watered and compacted using either a lighter road roller or plate compacter. The completed pavement is proof rolled with a heavy static road roller to ensure that all stones are thoroughly keyed in place and to provide a smooth riding surface.

If concrete blocks are used, these can be pre-cast interlocking or non-interlocking concrete blocks. They are very popular as they provide a long lasting and low maintenance pavement. Block pavements are being used for light, medium, heavy and even very heavy traffic conditions all around the world.

Concrete blocks can be easily produced locally using a portable semi mechanized stationary machine that provides optimum vibration in the mix, so that the ratio of cement used can be reduced substantially without compromising the strength of the blocks. Such machines also compact and consolidate the mix so that the blocks are uniform in size and achieve the desired physical properties. Blocks have to be cured
for 28 days before use. For vehicle traffic the thickness of the blocks should be around 50-60cm. Blocks need to be placed on a sub-base drainage layer of 20-25cm and a 25cm base-course.

At the top of the sub-grade a layer of coarse sand of 5cm is placed and leveled. This can be done with a screed plank and screed rails placed on either side. The screed rails can be made from steel plumbing pipes and should not be too light or flexible as this will have a negative effect on the quality of the leveling. The sand is placed between the rails and leveled using the screed planks. The rails are removed and the imprints are carefully filled with sand. Walking on the screeded sand surface prior to placing the stone paving blocks must at all cost be prevented, as this will damage the surface and levels so carefully prepared.

To increase the strength (and interlocking) of the (concrete) block pavement, the pavement is laterally confined by the placement of kerbstones (to the height of the finished design level of the pavement). Kerbstones have to be placed before laying the blocks. Blocks are usually placed in a pattern with a joint gap of 2-3 mm to allow for screening materials of sand to be filled in. The block surface is compacted using a plate compactor.

**Specifications Concrete Block Surfacing**

Concrete block surfacing consists of pre-cast concrete blocks on a laying course of 50mm thick sand on a sub-base and sub-grade. The sub-grade shall consist of approved and well compacted granular material. Sub-base material shall be crushed rock or similar hard material or naturally occurring gravel which is clean and free from organic matter, clay balls and other deleterious materials. The materials for the sub-base shall comply with the following grading:

<table>
<thead>
<tr>
<th>sieve size (mm)</th>
<th>Percentage by weight Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>37.5</td>
<td>85-100</td>
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<tr>
<td>10</td>
<td>40-70</td>
</tr>
<tr>
<td>5</td>
<td>25-45</td>
</tr>
<tr>
<td>0.600</td>
<td>8-22</td>
</tr>
<tr>
<td>0.075</td>
<td>0-10</td>
</tr>
</tbody>
</table>

Sub-base material is spread evenly and compacted in layers not exceeding 200 mm compacted thicknesses. Once this is done the kerbstones are placed. The next step is to lay the blocks. The profile of the laying course (blocks) before compaction should be similar to that of the finished surface. The blocks have to be placed to a level which takes into account the compaction which occurs during vibration of the blocks.

Block laying is normally done at angles to the main pavement axis, starting at one end of the area. Interlocking blocks are laid in a herringbone pattern at 45° to the
main pavement axis or other patterns, as approved or directed. Blocks are laid on the sand laying course so that blocks already laid are not distributed. They are placed to fit closely together with a width of the joints between them of 2-3mm. Special edge blocks or cut blocks are used on all edges of the block pavement. In-situ concrete shall not be used to make up to edge restraints.

Blocks are compacted with a plate vibrator (with plate area of 0.2 to 0.3m²) as each area of about 20 m² is laid. The vibrator shall not be used within 1m of an unrestrained edge. Two passes of the plate vibrator shall be made in two directions at 90° to each other. Joints shall be filled by brushing in dry sand with a particle size up to 2mm. Weed killer has to be mixed with residual qualities with the sand used for sealing the joints. After the sand has been brushed in, another pass of the plate vibrator is made in each direction.

Once the work is completed check that the level of any two adjacent blocks differs no more than 2mm and that the actual cross section is in accordance with the design cross-section.

**Maintenance**

Stone paved roads require less maintenance than other pavements. A block paved surface provides a relatively maintenance free overlay if properly designed and constructed. However the joint gaps need routinely filling with fine sand. If service utilities like water pipes and cables are to cross the pavement the block pavements can easily be removed and the same stones replaced.

If localized pavement failure occurs, the blocks and the sand cushion beneath can be removed. Damaged sub-grade soils should be replaced with new material and compacted. The cause leading to the damage, normally water and saturated sub-grade, should be identified and rectified.
Annex 9:

Telford

Telford can be used as a pavement or as a base for a pavement. It can be applied when the sub-grade is weak and where it is necessary to raise and place a firm base. Telford consists of a bottom layer of large (15-25 cm) stones that are being placed tightly and vertically on a sand bed. The voids between the stones are filled with smaller stones of 5-7 cm and the remaining voids are then filled with 2-3 cm aggregate. Compaction is normally done with a 6-8 ton vibrating steel wheel roller or equivalent.

Telford is used for strengthening the sub-base or base in weak sections. It is built as a dense and compact layer consisting of medium size stones placed on a sand layer and interlocked with smaller stones and aggregate. Telford is fully constructed by hand, and creates a strong sub-base ensuring a good surface for the base course layer.

The material used for Telford sub-base are common and can usually be found locally. The different materials should be well arranged when transporting to the site as mixed material supplies will make the placement of the stones very difficult (as it would require sorting on site). When providing the materials to the site, logistical and technical consideration must be taken in consideration to enable a smooth and efficient implementation of the works. In the case of a dead end road for example, a different work organization is required than in the case of a loop road. In the case of a dead-end road work must start from the dead end as delivery trucks can only enter from one direction, thereby giving less production flexibility.

It is also very important that setting out activities are done with strict care, ensuring that the Telford base is given the correct dimensions. A proper camber, as specified, also needs to be maintained during construction. If these matters are neglected,
it will be more difficult to shape the base course and the camber in the required dimensions and this will have a negative effect on quality. Strict setting out needs to be ensured and the placement of the layers of stones and aggregates needs to be closely supervised. In setting out, curb lines shall be set out first, followed by center line and diagonal lines.

The placing activity can start when the preparatory measures are taken. Spread sand between the curb lines in a 10 cm thick layer. Start placing stones in vertical position along the strings marking the road side lines/curbs, center lines, and diagonals between those in order to make the layer as even as possible according to set out profile. Use bigger stones in bottom of layer, and fit smaller stones in voids between those. Interlock them with crushed aggregate of smaller size.

When the layer is finished it has to be properly checked before compaction. The quality control must focus on that all large size stones are properly in place and interlocked with smaller stones and aggregate as this ensures minimal movement in the structure. Evenness of the finished surface is also an important aspect, as uneven spots will be insufficiently compacted as the roller will “ride” on the peak levels and does not have contact with the low surface levels. Unevenness would thus lead to uneven compaction and result in weak spots on the road.

The compaction of the Telford layer should be done using a 6-8 ton vibrating steel wheel roller. The number of passes must be carefully controlled as bad compaction will result in settling of the pavement and subsequent pavement damage. Normally, 8-10 compaction passes are enough.
Annex 10:

Single and Double Bituminous Surface Treatment

Description

Bituminous surface treatment is very effective as a maintenance technique that can greatly extend the life of a structurally sound road pavement. Surface treatment can be applied for example when there are cracks in the road surface, when the condition of the surface is poor because of a loss of aggregates and for surfacing low volume sealed roads.

A surface treatment comprises a thin film of binder sprayed onto a previously primed road-base, or existing road surface. This binder is then covered with a layer of stone chippings. Surface dressing does not contribute to the structural strength of the road structure but can contribute to the performance of a road by preventing the entrance of water.

Surface treatments can be constructed in a number of ways. The common two types are Single Bituminous Surface Treatment (SBST) and Double Bituminous Surface Treatment (DBST). SBTS is normally used as a maintenance operation to an existing bituminous road. DBST is used for surfacing a new road base or for providing extra ‘cover’ on an existing bituminous road surface (e.g. when the surface is cracked or patched);

The quality of a DBST dressing will greatly improve if traffic is allowed to run on the first coat for a minimum of 2-3 weeks (preferably longer) before the second coat is applied. This allows the chippings of the first coat to adopt a stable interlocking mosaic that provides a firm foundation for the second and final treatment.

The correct choice of bitumen for surface treatment work is important. MC3000 grade cutback bitumen (80/100 penetration grade bitumen blended with 12-14% by volume of a 3:1 mixture of kerosene and diesel) or cationic bitumen emulsion (with a bitumen content of 70-75%) is recommended for most surface dressing work. The emulsion bitumen can be applied at a temperature between 70-85 °C.

If a low volume road, carrying less than approximately 100 vehicles per day, is surfaced, the seal should be as durable as possible to minimize the need for subsequent maintenance. On low volume roads it is recommended to increase the binder spray rate above the basic rate of spread of binder. It is important that these increased spray rates are adjusted on the basis of trial sections and local experience.

The success of a surface dressing is very dependent on the binder being applied uniformly at the correct rate of spread. The method adopted for distributing binder must be capable of spreading the binder uniformly and at the predetermined rate of spread and be able to spray a large enough area in a working day to match the required surface dressing site work plan.

Chippings can be spread on the sprayed binder by hand and good results can be obtained by this method when well-trained and sufficient labour is available. In general however better results are obtained when chippings are spread mechanically.
as this will result in a more even distribution and rapid application of the chippings after the binder has been sprayed.

The rolling of a surface treatment is very important to make sure that the chippings are well embedded in the binder. If steel wheeled rollers are used they should not exceed 8 ton in weight and should only be used on chippings which are strong enough, otherwise the chippings will get crushed or crack. In general pneumatic tired rollers are preferred as the kneading action of the tires maneuvers the chippings into a tight mosaic without splitting them and they do not ‘skip’ depressions in the underlying road surface as is often the case with steel wheeled rollers.

**Construction Aspects**

In surface dressing the following main steps are involved:

1. Set out the sections that require surface dressing;
2. Carry out preliminary works such as patching, shoulder and edge repairs, drainage works, reinstatement of service trenches etc. Once this is done allow sufficient time for trafficking before starting with surface dressing;
3. Decide on the type of surface dressing, the binder to be used and chipping sizes;
4. Check the quality of the chippings and stockpile them at convenient points along the road in order to minimize haul distances during construction;
5. Decide on the appropriate binder, taking into account the expected weather;
6. Ensure that all the plant and equipment is in good working order;
7. Instruct the construction team of the details of the work program;
8. Inform the police and other organizations affected by the surface dressing;
9. Set up traffic control and warning signs;
10. Adjusted the binder temperature using the burners; circulate the binder through the spray bar and the jets of the distributor to check whether they work correct;
11. Instruct the distributor crew on the spray rate required, the corresponding road speed and the pump output, where this is necessary;
12. Sweep the road and place cut-off sheets of paper or other material at the start and end of the spray run. Checks that the road is in fit condition for spraying;
13. Extinguish the burners on the distributor and check and record the volume of bitumen in the tank. Position the distributor at the beginning of the spray run;
14. Start the spraying run. The chip spreader, tippers and rollers should follow closely behind the distributor. Spraying should be stopped if chipping is delayed for any reason. A strip of binder 150mm wide is left un-chipped at the edge of the lane to allow for the overlap of the adjacent run of the distributor;
15. A tipper and crew should move slowly over the new dressing, spreading chippings by hand shovels on areas where there is a deficiency of chippings;
16. The operation is then repeated on the adjacent pass (if any) and traffic is allowed to move slowly over the new dressing;

17. The distributor then returns to a level site and the volume of binder remaining is checked. The supervisor records the amount of binder used, and knowing the total area sprayed, calculates the average rate-of-spread;

18. Speed control and other traffic warning signs are left in position along the length of the new surface dressing;

19. At the completion of the day’s work the distributor spray bar is cleaned, all vehicles and plant re-fuelled and lubricated and the supervisor checks that the bitumen heaters are loaded to supply the binder required for the next day.

After-care is an essential part of the surfacing process. It consists of removing excess chippings within 24 - 48 hours of the construction of a dressing. They can be removed by brooming. Care must be taken with brooming to avoid damage to the new dressing and it is usually best to do this work in the early morning when the surface dressing binder is still relatively stiff. It is important to stress that over-chipping can reduce the quality of a dressing, make after-care more time-consuming and also unnecessarily increase the costs.
Annex 11:

Penetration Macadam

Description

Bituminous Penetration Macadam, also referred to as Penmac, is a course of large, uniform graded coarse aggregate that, after dry compacting and keying, is bound and filled with alternate applications of a heavy hot bituminous binder and smaller aggregate. Penmac is stable and withstands considerable tearing action of traffic. It is also used as a base course for asphalt surfacing. Penmac is effectively similar to asphalt concrete and is a good solution for sites where road geometry such as tight bends and gradients cause severe traffic loading on the surface.

Depending on the quantity of bitumen spread and the extent of penetration, it is called “full-grout” when bitumen penetrates to the full depth of the compacted aggregates and “semi-grout” when it penetrates up to about half of the depth. Full-grout is required in regions of heavy rain fall and semi-grout is adopted in regions of moderate rain fall and traffic.

Design Aspects

Normally clean crushed aggregate is used. The proportions of aggregate of different single sizes used in the basic three layer construction of Penmac are:

- 60% of 40mm single sized stone;
- 30% of 28mm single sized stone;
- 10% of 14 to 20mm single sized stone.

Voids within the three layers will remain after compaction (using a pedestrian roller). Therefore, a supply of 10-14mm single sized blotter course stone, sand or crusher dust is required in combination with further compaction to fill these voids and produce a satisfactory surface.

For the binder, the surfacing you can apply 5.5 to 7 liters/m² of rapid break bitumen emulsion (such as K1-70 or CRS-2). For this heating is not needed and watering cans can be used for application if they are fitted with suitable multi-holed distribution spouts. Hot bitumen with a Penetration Grade of 60/80 or 80/100 is also suitable.

Construction Aspects

The following equipment, tools and materials are required:

- Measuring tape of minimum 10 meter length and string
- Shovels, rakes, brooms, watering cans, wheelbarrows, buckets
Pedestrian roller or Static 8-10 ton Roller
Water.
Mechanized or motorized bitumen distributor
Bitumen Heater and bitumen thermometer

Work Method

<table>
<thead>
<tr>
<th>Step</th>
<th>Activity</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Set out the area of the road to be surfaced that day.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Unload aggregates outside the area of road to be treated. Ensure aggregates are not contaminated with dirt, dust.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Unload aggregates outside the area of road to be treated.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Spread the 40mm aggregate on the road surface. Aggregate is laid by hand.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Spread the 28mm aggregate.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Roll and compact the two layers of aggregate. Begin rolling from edges of the road and work toward the center.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Spread the 14mm-20mm stone.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Roll and compact the aggregate. Continue rolling until no movement of the aggregate is seen.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Dampen the surface of the aggregate with water.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Apply emulsion or Hot Bitumen to the newly rolled surface at a rate of 2 liters per square meter.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Spread 10-14mm aggregate to just fill large voids in the surface.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Roll and compact the surface. Apply with watering cans.</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Apply emulsion or Hot Bitumen to the newly rolled surface at a rate of 1.2 liters per square meter.</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Repeat steps 10 to 12 with the ‘blinding’ of the surface by sand or crusher dust until the surface appears free of voids. The complete construction procedure will typically require 5.5 to 7 liters per square meter of bitumen emulsion to be applied.</td>
<td></td>
</tr>
</tbody>
</table>

Specifications

Coarse clean aggregates needs to be used that meets the following gradation requirements:

<table>
<thead>
<tr>
<th>Sieve Size mm</th>
<th>For 40mm % by weight Passing</th>
<th>For 28 mm % by weight Passing</th>
<th>For 14/20 mm % by weight Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.5</td>
<td>80100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>3570</td>
<td>75100</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
</tr>
<tr>
<td>6.3</td>
<td></td>
<td>0-10</td>
<td></td>
</tr>
</tbody>
</table>

Blotter course of key aggregates shall consist of crushed stone, free from dirt and other objectionable material and shall have the following gradation:

- Passing 14mm sieve 100%
- Passing 9mm sieve, not more than 75%
- Passing No. 10 sieve 10-30%

Bitumen Binder shall be emulsified bitumen or bitumen penetration grades 60/80 or 80/100.

Equipment: Rollers and compactors shall include self-powered three (3) wheeled and tandem steel rollers and self-propelled pneumatic-tired rollers, weighing not less than seven (7) nor more than ten (10) tons, and multiple vibratory compactors of
approved design. Steel-wheeled rollers shall be equipped with scrapers to keep the surface of the wheels clean. All rollers and compactors shall be equipped with devices to wet the wheels, or contact surface, to prevent the material being compacted from sticking to them.

**Construction methods**

When no curb and gutter or side forms are used, well compacted shoulders with vertical face for the full depth of the course or layer shall be prepared in advance of spreading aggregate so as to permit the roller to lap the shoulder and edge of each course or layer of the pavement. The shoulder material shall be kept leveled at the proper elevation to avoid irregularities extending into the macadam. When the subgrade has been adjusted to true line and grade to the satisfaction of the Engineer, a blanket of insulation course material shall be spread on the sub-grade and compacted to a minimum thickness of 25mm.

Aggregates are spread in three separate and compacted courses before the first bitumen application. The first layer of coarse aggregate of 40 mm shall be spread uniformly upon the prepared surface in such quantities that the thickness of compacted layer is “one stone thick”. Spread on the top a layer of the 28mm aggregate. The two layers of aggregates are dry-rolled with a 10 ton static road roller until the aggregates are compacted and interlocked. Then spread the 14mm-20mm stones. Roll and compact the aggregate. Continue rolling until no movement of the aggregate is seen.

![Compacting aggregate](Picture 44: Compacting aggregate)

The surface of the aggregate shall be carefully turned up with templates and level all high or low spots by removing or adding aggregates as may be the case. The irregularities are much easier to correct in loose layer than later. The surface shall not vary more than 12mm from a 3 meter straight edge applied to the surface parallel to the center line of the pavement. Areas of the pavement which show more than the allowable variation shall be loosened and reconstructed in accordance with these specifications.
Over the dry and compacted three layered course, the first coat of bitumen is applied uniformly either with pressure distributor or mechanical hand sprayer. The quantity of heated bitumen required for this purpose is around 1.8 liter/m². If emulsified bitumen is used, dampen the surface of the aggregate with water. Apply emulsion to the newly rolled surface at rate of 2 liters/m². This operation can be applied with watering cans. After the application of bitumen, the key aggregates, 10 to 14 mm, are spread and compacted to fill voids in the surface.

On top of the blinded compacted three layered course, the second coat of bitumen is applied uniformly either with pressure distributor or mechanical hand sprayer. The quantity of bitumen required for this second application is around 1.2 liters/m². After the application of second coat of bitumen, the second and final layer of key aggregates, 10 to 14 mm, are spread and compacted to fill voids in the surface. The blinding of the surface by the blotter course is done until the surface is free of voids and normally requires about 12 kg/m².

The complete construction procedure will typically require 3.0 to 3.7 liters/m² of hot bitumen or 5.5 to 7 liters/m² of bitumen emulsion.

**Quality Control:**

The following quality control checks should be made before, during and after the construction works:

- Inspect the site before bringing aggregate and bituminous materials and remove any loose materials that may contaminate the aggregate.
- Stockpile the aggregates into separate stockpiles for coarse-fine- and filler materials and check that the aggregate is as per specifications.
- Check the bitumen drums to determine if the bitumen delivered is the prescribed, approved penetration grade.
- Records shall be maintained at the site of the temperature in all containers used for heating bitumen. Temperatures shall be recorded every 30 minutes.
- Records shall also be maintained in the site book of the measurements of the thickness of the compacted layer.
- Check that the area of road to be treated is clearly marked to ensure correct placement and recording of binder and aggregates.
- The binder distributor should be loaded with sufficient binder at the correct temperature to complete spraying of the marked work area.
- Check that the aggregates have been placed correctly at intervals and the workforce are ready to spread the aggregates after the binder distribution.
- Check that the binder is sprayed at the design binder spray rate within the given area and make necessary adjustment together with the spray operator.
- Check that no areas are left uncovered and aggregates are not left in heaps.
- On the first day of construction the surface treated must receive a minimum of 15 passes by a pneumatic roller.
- Test the achieved compaction by placing a piece of metal or a one inch stone on the hot mixed asphalt surface and run the roller over it. If no imprint is made on the surface or no embedment results, the compaction may be considered as adequate.
- The finished surface shall be uniform and smooth. The longitudinal profile and cross slope shall be checked using straight edge and camber board. The average thickness shall be equal to or greater than the specified compacted thickness.
- Traffic speed must be limited to 30m/hr for two weeks after construction.

**Maintenance**

Normal periodic and routine maintenance activities are essential to ensure good road performance. Surface maintenance works such as patching and crack sealing can be done using labour-based approaches.
Annex 12:

Water Bound and Dry Macadam

Description

Water Bound Macadam (WBM) consists a layer of coarse broken stone (37.5-75mm) which is first compacted and into which then graded fine aggregate or crusher dust (<5mm size) is washed. Using strong stones, providing edge support and ensuring that voids are filled with fines, produces a durable surface of low to medium roughness. WBM forms a tightly bound, strong and semi-impermeable layer. It can be used as an unpaved surface and is also very suitable as a base material for roads with bituminous seals. If the WBM is sealed with bitumen surfacing, a camber of 3% is acceptable. Where used as an unpaved surface a camber of 5-6% is normal.

WBM is particularly suitable where the terrain is steep and vehicles travel slowly uphill. WBM provides traction, protects the subsoil and prevents erosion and pulverization. WBM can produce a low capital cost surface, if stone and fines are locally available (within 10km). Maintenance is low cost and labour friendly. It only requires occasional blinding and pothole filling.

If water is difficult to obtain dry bound macadam (DBM) is an alternative. The only difference in approach is that dry fines are vibrated into the voids between the stones, rather than being washed in with water. Compaction is likely to take longer than when water is used.

Design Aspects

The stones for the surface should be angular, non-flaky (similar dimensions in all directions) and have preferably a nominal size of around 40 mm. Larger stone (up to 75mm) can also be used. Even larger stone can be used as kerbstones to provide edge support. The compacted thickness of each layer should not exceed twice the nominal maximum particle size of the stone used. Hard burned-clay bricks, broken into chips, are also suitable but in that case the WBM has to be surface sealed.

To test the stones for strength, drop a one-fist sized stone ten times onto a larger rock from a height of 1.5 meters. If the stone is not significantly damaged, it should be strong enough for WBM. The table below shows the required specification of the coarse aggregate to be used.

The fine material should be less than 5mm in size and graded. Fines produced by hand breaking or rudimentary crushing the coarse stone does not usually produce a fine material in the quantity or grading needed. It is therefore usually necessary to seek out supplies of sandy soils (e.g. within or close to river beds). In dry and semiarid areas, sandy soils with quite large proportions of clay can be used, as the clay will give an additional binding action. If the surface is to be sealed with bitumen, lower plasticity materials should be used. In some cases addition of 5-10% cement or lime can be used to strengthen the material or reduce plasticity.
Construction Aspects

WBM should be constructed on a firm foundation. Where sub-soils are weak it may be necessary to let the site “dry out” before shaping and compaction of the formation layer and constructing the surfacing.

First the normal formation for earth roads is constructed to the required camber and width. A berm is constructed along the kerb line by forming a 0.5m wide strip of compacted soil or shoulder material to the required layer thickness. This is then cut to form a vertical face along a trench into which kerbstones are laid. The top of the kerbstones are set at the required final road level. Fine material should be back-filled and compacted around the kerbstones with hand rammers. If the WBM is to be sealed with bitumen, the WBM should be extended into the shoulder area for the full road width.

Work Methods

The following activities need to be carried out for the construction of WBM:

- Construction and shaping of formation (and drainage)
- Construction of shoulder berm and berm drains
- Trenching and placing of kerbstones
- Placing and compaction of coarse stone
- Placement and washing in of fines

Berm drains: To prevent trapping water within the road structure it is necessary to provide drainage. 250mm wide trenches should be cut through the shoulders every 2-3m on both sides of the carriageway, with a gentle downward fall. The trench should be filled with 50-75mm of free draining material (such as a sand/gravel mix) and compacted before bringing it up to the final level with berm soil. This is a particularly important feature if the WBM is to be surfaced with bitumen.

Surface: Firstly the coarse stone is spread over the road area to just above the required final road level. A single pass of a static roller is used to settle and bed the stone in position. The second stage involved spreading the fine material over the stones which is then sprayed with water to form slurry. The slurry is washed into the matrix of the coarse stone. When no more fines will enter the layer, a final compaction static roller or vibratory compaction is carried out. Additional fines are applied to areas showing further settlement on compaction.

Specifications

The preferred mix proportion of the materials shall be 80% crushed stone aggregate and 20% fine materials or clayey soil that shall be confirmed as per grading limits.

The coarse aggregate shall be sharp and angular of approximately cubical in size and shall be hard and durable. It needs to be free from vegetation, soft particles and excess clay. The crushed stones shall comply with the following grading limits:
Screening material generally consists of smaller size aggregate and crusher dust of the same material as the coarse aggregate. The materials shall be well graded and conform to the following grading limits:

<table>
<thead>
<tr>
<th>sieve size</th>
<th>Percentage by weight Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>63mm</td>
<td>100</td>
</tr>
<tr>
<td>50mm</td>
<td>95-100</td>
</tr>
<tr>
<td>38mm</td>
<td>35-70</td>
</tr>
<tr>
<td>20mm</td>
<td>0-10</td>
</tr>
<tr>
<td>10mm</td>
<td>0-5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>sieve size</th>
<th>Percentage by weight Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mm</td>
<td>100</td>
</tr>
<tr>
<td>4.75mm</td>
<td>85-100</td>
</tr>
<tr>
<td>150 micron</td>
<td>10-30</td>
</tr>
</tbody>
</table>

The sub grade to receive the WBM course shall be prepared to the required grade and camber and cleaned of all dust, dirt and other extraneous matter. Weak places shall be strengthened, corrugation removed, depressions and pot holes made good with suitable materials before spreading the WBM aggregate.

Necessary arrangement shall be made for the lateral confinement of aggregate. There are two options for doing this:

- Construct side shoulders in advance to a thickness corresponding to the compacted layer of the WBM. After the shoulders are ready, their inside edges shall be trimmed vertical;

- Complete the earthwork up to finished level of WBM and make a trench up to sub grade level to the required depth, like a box cutting.

The broken aggregate shall be spread uniformly upon the prepared sub grade in such quantities that the thickness of the compacted layer is 75mm. This usually requires the placement of two or more layers.

The surface of the aggregate shall be carefully checked with templates for irregularities and high or low spots need to be corrected by removing or adding aggregates.

Following the spreading of coarse aggregate, it is rolled dry with an 8-10 tons roller. Rolling shall continue until the road metal is thoroughly keyed and stone creeping ahead of the roller in no longer visible. Slightly sprinkling of water may be done during rolling, if required. Rolling should not be done if the sub grade is soft. The rolled surface shall be checked transversely and longitudinally with templates and if the irregularities exceed 12 mm, the surface should be loosened and aggregate added or removed before rolling again.

After the 1st layer of coarse aggregate has been rolled, dry screening material is applied to fill the voids between the coarse aggregate. Dry rolling shall be done while
screenings are being spread so that vibration of the roller causes them to settle into
the voids of the coarse aggregate. The screenings shall be spread slowly and uniformly
in three or more successive thin layers. Screening applications shall continue until no
more screenings can be forced into the voids of the coarse aggregate.

After the screening material has been applied, the surface shall be well sprinkled with
water, swept and rolled. Hand brooms shall be used to sweep the wet screenings into
voids and distribute them evenly. The sprinkling, sweeping, and rolling operations
shall be continued, with additional screenings applied if necessary, until the coarse
aggregate has been thoroughly keyed, well bonded and firmly set in its full depth and
a grout of screening and water is seen squeezing out ahead of the roller. Make sure
that the base or sub grade does not get damaged due to the addition of excessive
water during construction.

A second layer of aggregate can now be spread and all the stages of dry and wet
rolling should be repeated. It is recommended that a smaller size of aggregate is used
for the second layer. The lower layer should be dry before the top one is put. When
the top layer is completed, the surface is finally checked to see irregularities and
deviations and is corrected to proper camber and longitudinal slopes.

After final compaction of WBM, the road shall be allowed to dry overnight. The next
morning “hungry spots” shall be filled with screening materials, lightly sprinkled
with water if necessary and rolled. No traffic shall be allowed on the road until the
Macadam has set.

Quality Control includes the following activities before, during and after the
construction activities:

- Check that the right construction materials, in particular aggregate, sand and
  mixed materials are being used;

- Test the level of achieved compaction. By placing a piece of metal or a one inch
  stone on the WBM surface and run the roller over it. If no imprints are made
  on the surface or no embedment results, the compaction may be considered
  as adequate.

**Maintenance**

The top layer of fine material, if not stabilized with cement, or bituminous sand sealed,
will gradually erode due to traffic. It may be necessary to apply more fines as these
are lost to rain or traffic. If not properly maintained, the additional fine material can
be lost, resulting ultimately in loosening of the stone and destruction of the surface.
Soft spots can be dealt with by removing the fines and stones over the affected area,
leveling (possibly with replacement of weak material with improved soil), re-laying
the stones, and refilling with fresh fines.

Water bound macadam is liable to collapse if unsupported at the side. The berm or
kerbstones should be checked for signs of damage and reformed and compacted
or re-laid as necessary. If the WBM is showing signs of saturation, the berm drains
should be checked for blockages. It should be noted that WBM surfaces cannot be
maintained by grader.
Annex 13:

Latasir

Description

LATASIR— or sand sheet asphalt is a mix of sand and bitumen that are mixed during heating together on site using simple equipment. Mixing and heating is done using a thin steel plate put on top of empty oil drums. Under the mixing platform heating is provided by wooden fire.

The correct proportions of ingredients in the mix are imperative for the product quality, and equally important is that the ingredients are heated separately before mixed. It is also of greatest importance that correct mixing temperature is carefully controlled to ensure a good quality mix.

Before putting the asphalt mix the road base must be primed in order to ensure good adhesion between the pavement and the base course through binding dust particles.

The prime coat material is heated bitumen mixed with kerosene in 35-40 % ratio. The prime coat mix must be sprayed carefully controlling the application ratio. After spraying, the road must be closed for traffic to allow the prime coat to dry and function correctly.
When the prime coat has dried and the asphalt is ready mixed it is time for the spreading operation. The mix must be covered with canvas during transportation to the site to keep it in good quality, not to loose temperature and to prevent it from contamination.

It is also important that the container is in good order so minimum spill is achieved. Spreading shall start on the road furthest away from the mixing point.

Wooden guiding rails are very useful for keeping a correct and uniform thickness, and should be put in pavement edge lines and in the road center line. Spreading shall be done on half the carriageway at one time. Imperative for a good quality end result is that the temperature of the mix spread is carefully controlled.

Compaction activity shall start immediately after spreading, and best result is achieved using a 6-8 ton pneumatic double steel drum roller. Ensure sufficient passings and keep pavement soaked with water during the activity. The pavement will remain soft immediately after the activity, and should not be subjected to traffic within the coming 1-2 hours in order to avoid local pressure dents.
Annex 14:

Typical Concrete Mixes and Stone Masonry Guidelines

<table>
<thead>
<tr>
<th>Mix Ratio (Volume) (Cement:Sand:Gravel:Water)</th>
<th>Use</th>
<th>Aggregate Volume, liters (cf) per 50-kg bag of cement</th>
<th>Approximate Yield, m³ (cf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : 3 : 6 : 1.6</td>
<td>Large Aggregate, Mass Foundations, Kick block anchors</td>
<td>Sand 130 (4.6) Gravel 180 (6.4) Water 70 (2.4)</td>
<td>0.24 (10)</td>
</tr>
<tr>
<td>1 : 2.5 : 5 : 1.6</td>
<td>Foundations on poor soil</td>
<td>Sand 110 (3.9) Gravel 160 (5.7) Water 70 (2.4)</td>
<td>0.21 (9.5)</td>
</tr>
<tr>
<td>1 : 2 : 4 : 1.6</td>
<td>Medium Aggregate Floors, nonstructural Walls</td>
<td>Sand 80 (2.8) Gravel 130 (4.6) Water 70 (2.4)</td>
<td>0.17 (8.0)</td>
</tr>
<tr>
<td>1 : 2.5 : 3.5 : 1.6</td>
<td>Small Aggregate</td>
<td>Sand 110 (3.9) Gravel 115 (4.0) Water 70 (2.4)</td>
<td>(8.0)</td>
</tr>
</tbody>
</table>

...HIGHER...

| The Strength of Stone Masonry is...
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>...with rectangular stones.</td>
<td>Form or Shape</td>
</tr>
<tr>
<td>...the less stones are used.</td>
<td>Number</td>
</tr>
<tr>
<td>...when the vertical joints are staggered.</td>
<td>Position of joints</td>
</tr>
<tr>
<td>...the rougher the joints are.</td>
<td>Roughness of joints</td>
</tr>
<tr>
<td>...the smaller the beds are.</td>
<td>Bed</td>
</tr>
<tr>
<td>...the wider the stones are.</td>
<td>Height &amp; Width</td>
</tr>
<tr>
<td>...the deeper the bond inside is.</td>
<td>Bond Across (in top view)</td>
</tr>
<tr>
<td>...the lower the amount of water in the mortar.</td>
<td>Strength of Mortar</td>
</tr>
</tbody>
</table>

...LOWER...

| ...with irregular shaped stones. |
| ...the more stones are used. |
| ...when the vertical joints are in line with the joint above. |
| ...the smoother the joints are. |
| ...the bigger the beds are. |
| ...the slimmer the stones are. |
| ...the worse the bond inside is. |
| ...the higher the amount of water in the mortar. |