7.1 Overview

Water is the main contributor to the wear and damage of low-volume rural roads. The water can be in the form of ground water, surface water (streams and rivers) or rain and it can damage the road in several ways:

- by washing away the soil (erosion and scouring),
- by making the road body less resistant to traffic (i.e. weakening the load bearing capacity),
- by depositing soils (siling) which may obstruct the passage of water, or
- by washing away entire sections of the road or its structures.

Damage and wear to the road can be reduced if the flow of water is controlled. Minor damages can easily be repaired as part of the regular maintenance provided to the road and its structures. If the flow of water is not properly managed, the deterioration of the road will be more serious and occur more rapidly. This will lead to higher
maintenance demands and in the worst cases result in serious damage which may obstruct the passage of traffic.

Various drainage measures are applied to effectively deal with the water arriving at the road. Surface water arrives directly on the road as rain, as runoff from the surrounding areas, or in streams and rivers. In flat terrain, the entire area around the road may be inundated with water during the rainy season. In addition, water also travels underground which can have an impact on the quality of the road.

An efficient drainage system is therefore essential to allow water to flow off and away from the road as quickly as possible. This is achieved by a system consisting of the following components:

- road surface drainage which enables the water to flow off the road surface,
- side drains and mitre drains which collect and lead the water away from the road,
- road embankments in flood prone terrain, lifting the road surface well above the highest flood levels,
- catch-water drains which catch surface water before it reaches the road,
- scour checks, preventing erosion in the ditches by slowing down the flow of the water,
- culverts which lead the water from the side drains under the road to the other (lower) side,
- bridges and drifts which allows the road to cross rivers and streams in a controlled manner throughout the seasons.

In addition, different arrangements may be required for drainage of high water tables to lower the levels of underground water.

All these components need to work well together. If one component of the drainage system breaks down, it will not only compromise the drainage in that specific location, but may lead to
overloading other drainage components which in the next turn may lead to more damage.

As the water can cause a serious impact on both the road access and its strength, an efficient drainage system is the most important part of rural road construction and maintenance works. Good drainage needs to be taken into consideration at the early design stages in order to secure a long life for the road. With a well-designed drainage system, future rehabilitation and maintenance works can be considerably reduced and thus limit the costs of keeping the road in a good condition.

Ensuring good drainage begins when selecting the road alignment. A centre line that avoids poorly drained areas, large runoffs and unnecessary stream crossings will greatly reduce the drainage problems. By following ridges and other high points in the terrain, it is possible to benefit from the natural drainage in such locations.

In hilly or mountainous terrain, it is important to select road alignments which do not require steep road gradients. Roads with steep gradients are often troubled with excessive erosion of the road surface and drains. By reducing the road gradients, the water can be drained away from the road more efficiently and at lower speeds, thereby reducing the erosion caused by the water.

In most cases, common drainage problems can be avoided if due consideration is given to these issues during the design stage. The time and costs spent trying to address problems during the construction stage will normally be less than the costs of mitigating efforts after the works have been completed.

When rehabilitating an existing road it is useful to assess the quality and effectiveness of the existing drainage system. The reason for the failure of a road section can often be attributed to damages caused by water. Rehabilitation works offer a good opportunity to assess the various components of the drainage system. Well-designed drainage will clearly prove its worth, while less effective components will show signs of its shortcomings through excessive scouring, accumulation of silt or entire washouts.
Before carrying out drainage improvements, it is important that the reasons for the damages are fully understood. When surveying the works, try to establish the exact cause and effect of the drainage failures. On this basis, more effective improvements can be made to the road drainage and hopefully reduce future maintenance demands, and increase the lifetime of the road.

Obviously, the design of proper drainage relies on careful studies at site. Equally important, the drainage patterns and requirements should be observed during rainy periods, in order to obtain a realistic impression of the how, and how much, water is moving in the vicinity of the road.

Finally, it is also worth mentioning that the drainage system of a road may have an impact on the environment in the vicinity of the road. Water collected through a road drainage system needs to be carefully discharged from the road, avoiding any damages to the adjacent land. Equally, the drainage system of a road needs to be carefully adjusted so it does not conflict with the drainage systems on adjacent farmlands.

7.2 Road Surface Drainage

Drainage of the road surface is provided by shaping the carriageway with a camber or a cross slope. The combination of stagnant water on the road surface and traffic can quickly cause erosion of the road surface. Secondly, if surface water penetrates into the road body, it reduces the load bearing capacity of the pavement, which may cause further damage to the road. To avoid these problems, it is important to secure adequate drainage of the road surface.

On most roads, the camber is roof-shaped with the highest point at the road centre line, with a descending gradient towards the road shoulders. On narrower local roads, the camber may be constructed as a continuous slope from one side of the road to the other. This is referred to as a cross-slope.

Cross-slopes are also used to achieve good driving dynamics. To counter the centrifugal forces exerted on a vehicle manoeuvring a curve, a cross-slope is installed with a downward slope towards the centre of the curve. When roads have a grade towards the cut side of a slope, the surface water needs to be
led away to a side drain and eventually through some form of crossroad drainage arrangement such as culverts or splashes.

On roads in mountainous terrain, some design specifications require the cross-slope to face the hillside of the road for safety reasons. This is often referred to as an inwards cross-slope. With this design, there is a need to install a full drainage system as mentioned above.

For low-cost roads, the cross-slope is sometimes designed to drain the water away from the hillside of the road. The advantage of this design is that the side drains can then be omitted and the road carriageway can be moved closer to the side slope.

In mountainous terrain, this solution can be effective when providing the initial access into an area as it requires less earthworks since the area normally required for installing side drains can be used as part of the carriageway. The major drawback with this design is that "out-sloped" roads with clayey soils may become slippery during rains and become a safety hazard. Also, for this design to be effective, there is a demand for limiting the amount of water from the slope above the road. Cut-off drains may address this problem.

When designing the road with an inward slope, the advantage is that all surface water can be properly managed and the discharge of water can be arranged in a controlled manner. A well-designed system of side drains and culverts, installed with safe measures for leading water away from the road, limits the damage water causes to the road and its surrounding areas.

The camber is the slope from either side of the centre line towards the road shoulders. The optimal gradient of this slope varies depending on the type of surface materials. For earth and gravel roads, it is recommended that the camber is installed with a slope in the range of 7 to 10 percent. On earth roads where the surface gets slippery
when wet, it may be necessary to reduce the camber slope.

For roads with an asphalt surface, the camber is normally not more than 2 to 3 percent, because water will easily flow off a hard, waterproof surface. On earth and gravel roads, the camber needs to be steeper because the water will flow more slowly and the surface is often uneven. Gravel and earth surfaces also absorb some of the surface water unless it is quickly drained away from the road.

Eventually, traffic will erode the road surface, creating wheel ruts and causing more erosion at the centre of the road. It is therefore recommended that the road camber of a gravel road is constructed at 7 to 10 percent. This will prolong the lifetime of the road and allow a longer period of time and use before reshaping of the camber is required.

Cross Slopes
On sharp curves, the camber is often substituted with a super-elevation which leads the water to the inside of the curve. The super-elevation is installed with a gradual change of the road cross section from a camber shape to a road surface shaped with a cross slope. At the same time the super-elevation provides a certain resistance to a vehicle from skidding off the road due to the centrifugal force.

The centrifugal force is dependent on the speed of the vehicle. Since access roads are generally not designed for high speeds (usually less than 30 km/h), super-elevation on this type of road is only necessary in curves with a radius of less than 30m.
To avoid stagnant water at the sections where the camber is being converted to a cross slope, it is useful to design the road with a longitudinal gradient. In any case, the section with a limited cross slope should be made as short as possible on gravel roads.

A full cross-slope is also applied in other circumstances. When the road width is reduced (i.e. in mountainous terrain or on low-volume village access roads), it is common practice to construct a cross-slope towards only one side of the road.

Constructing the Camber

The camber should be formed already before the surface layer is provided. It is created from surplus soils from side drain excavation. The soil is first heaped along the centre-line during the ditching and sloping process and then spread towards both sides of the road. If necessary, use soils from the back slope or widen the drains to provide sufficient materials for the camber.

The quantity of soil along the centre-line should be sufficient to form the camber with the correct angle. In order to secure the prescribed cross-slopes on the completed surface, it is common practice to increase the slope on the loose soils before compaction (7 to 10 percent before compaction, equivalent to approximately 5 to 7 percent when compacted).

The correct shape of the camber can be secured by setting out the levels of the shoulders and the centre line with profile boards and a line level (ref. chapter on Surveying and Setting Out). These levels are then transferred to pegs placed at 5 metre intervals.

By stretching strings between the pegs, the exact level of any point along the road can be accurately determined. The string provides useful guidance to the workers carrying out the levelling.

Once the soil for the camber has been spread, the camber needs to be properly compacted. To secure an optimal moisture content during compaction, the soils may need to be watered.

After compaction, check that the final levels of the road camber is exact and to the prescribed standard and quality. This can be done by setting out the profile boards again, and controlling the levels between the profiles with a traveller. A quicker method, though less accurate, is to use string lines to check the level of the completed surface.
If the levels are inaccurate, the irregularities should be removed or filled in. If further filling is required, make sure that this patching work is also properly compacted. Finally, repeat once again the checking of the levels to ensure that the earthworks are completed to the prescribed quality.

Before the road is gravelled, ensure that the road base is properly compacted and has the correct camber. Compaction and levelling of the road base is as equally important as the final surface layers and needs to be carried out to the same level of accuracy and quality in order to secure a lasting and smooth surface.

**Road Gradients**
Providing the vertical alignment of the road with a gentle longitudinal gradient improves the road surface drainage. This gradient facilitates the discharge of water from sections of the road surface with limited cross-slope. As the levels of side drains are often set out relative to the level of the road shoulder, the road gradient is replicated in the side drains.

Steep road gradients cause surface water to move rapidly and make surface drainage difficult to control. These problems start when the longitudinal road gradient exceeds 8 percent. Due to the steep grade, it becomes more difficult to evacuate water from the carriageway. Instead, the water has a tendency of finding a passage parallel to the road alignment, commonly following wheel ruts. In a very short time, this will result in accelerated wear of the road surface.

Steep road sections are almost always a problem when dealing with road maintenance. In the long run, the most effective counter measure is to realign the road section to reduce the gradient. Such measures are costly, and should preferably be carried out when the road is first constructed. However, due to the high maintenance costs incurred on such roads, realignments should also be considered as part of the rehabilitation works.

The increased erosion of the road surface and side drains can also cause problems in terms of silt deposits building up in downstream drainage systems, resulting in blocked drains and culverts. Equally, the eroded materials
can damage surrounding farmlands and other property.

Short sections with steep gradients are normally not prone to the same level of erosion as longer sections as long as the drainage is properly designed. Longer sections, however, will always be maintenance intensive. If the steep gradients cannot be avoided by realigning the road, an alternative is to provide an erosion resistant surface to this section, such as stone pavement, asphalt or concrete. Equally, the side drains need to be protected in a similar fashion.

When selecting the final alignment for a rural road, it is more important to choose a design which is resistant to the envisaged exposure to rainfall, rather than insisting on using the shortest distance between two points. The most important feature with a rural road is to maintain its service levels, basically allowing all weather access at all times.
The actual travel distance and time is a secondary concern. It is therefore more important to secure an alignment which is easy to maintain and which does not run the risk of becoming impassable during subsequent rainy seasons after it has been rehabilitated.

Road Pavement
The pavement constitutes an essential part of the drainage of the road. A dense and strong surface, together with the cross-slope on the carriageway ensures that rainwater does not enter the foundation of the road, but instead is lead off to the side of the road.

The sub-grade and base of a rural road normally consists of locally available soils. If compacted properly these materials are able to withstand the loads exerted by the traffic. The use of local soils as the main road building material, however, requires that the material is well protected from surface water. This is achieved by (i) reducing the permeability of the pavement by ensuring that the soils are well compacted and (ii) using a surface material which prevents water from entering the road body.

When local soils are utilized for road building purposes, it is important to know how they react to water. Well-graded materials with an appropriate distribution of fines and larger particles, such as natural gravels, can provide a firm surface, resistant to the wear caused by traffic and water. Clay, silt and sand with a uniform grading easily absorbs water if left unprotected to traffic and water. When water penetrates into these soils, the bearing capacity of the road rapidly deteriorates. Furthermore, when these soils are wet, they are very vulnerable to the abrasive effect of traffic.

Potholes provide a good example of the destructive effects of water and traffic. When the surface pavement has been worn down to the extent that potholes penetrate the surface, allowing water to enter into the layers underneath, the deterioration of the road will accelerate. Unless patching is carried out as soon
as possible, the hole in the surface layer continues expanding, also eroding the soils underneath.

It is therefore important that the base course and sub-grade materials are protected from exposure to water. This involves not only protecting the road carriageway, but also the road shoulders and the surface of fills. For the road surface, the most common approach is to provide a surface layer of compacted gravel, however, when traffic levels are high, other more durable surface treatments should be considered (i.e. concrete or asphalt based mixtures).

If the road shoulders are susceptible to erosion, some form of protective measure should be provided to these surfaces. This is usually achieved by extending the surface layer to cover the shoulders. If the soils on the shoulders consist of well-graded materials, they will normally stand up to the water draining from the road carriageway.

Equally, the surface of side fills needs to be designed with a sufficiently gentle slope to avoid water causing erosion. As a final measure, covering the side slopes with grass turf further protects the fill.
7.3 Side Drains

The function of the side drains (or ditches) is to collect water from the carriageway and surrounding areas and lead it to an exit point where it can be safely discharged.

The side drains need to have sufficient capacity to collect all rainwater from the road carriageway and dispose of it quickly and in a controlled manner to minimise damage. Sides drains can be constructed in three forms: V-shaped, rectangular or as a trapezoid.

The V-shape is the standard shape for ditches constructed by a motor-grader. It can be easily maintained by heavy equipment. However, it carries a lower capacity than other cross-section shapes.

The rectangular shape requires less space but needs to be lined with rock or concrete to maintain its shape. This shape is often used in urban areas where there is limited space for the drainage.
When using labour-based work methods, it is possible to construct a trapezoid shaped side drain. This shape carries a high flow capacity and by carefully selecting the right gradients for its side slopes, will resist erosion.

The exact dimensions of the side drains are dependent on the expected amount of rainwater and the distance to the next exit point where the water can be diverted away from the road. The construction of side drains is also a source of materials for constructing the road formation and camber. In flat or rolling terrain, it is common practice to maintain a balance between the volume of soils excavated to create side drains, and the need for soils to build the road camber. By increasing the dimensions of the side drains, it is possible to raise the level of the carriageway.

In flat or slightly undulating terrain one would aim to achieve a longitudinal gradient between 2 and 5 percent (1:50 and 1:20) in the drains. With gradients less than 2 per cent, silting occurs easily while with gradients steeper than 5 percent the ditches will easily erode.

**Excavating Side Drains**

The excavation of the side drains should only commence after all levelling works have been completed. When relying on manual labour, side drain excavation is done in two stages. First, a rectangular ditch is excavated, then the side slopes of the ditch are excavated. Normally, one or two days are given between each stage to allow sufficient working space for the workers. The excavation work is set out using string line and pegs, and controlled by using ditch templates. The soils from the ditches are placed in the middle of the road.

The reason for excavating the ditch in this manner and shape is that it is easier to measure and control than excavating it in one operation. The correct width and depth can be controlled with a stick with the correct length or using a template. Each worker assigned to
water in the drains, emptying them at sufficient intervals to avoid that the volume of water builds up and starts eroding the ditches.

Soil Erosion
The main challenge in terms of maintaining good quality side drains is to control erosion and silting. Erosion is caused by large quantities of water travelling at high speeds. Soil erosion can be reduced by various design measures such as widening the side drains, installing scour checks, lining the side drains or by leading the water away from the road before it builds up a significant flow and speed.

The best way to control erosion is by reducing the amount of water flowing through the drain. This can be done by installing sufficient numbers of mitre drains, cut-off drains and culverts. These structures limit the amount of water in the drains, emptying them at sufficient intervals to avoid that the volume of water builds up and starts eroding the ditches.

Silting is caused by sand and silt settling out of the water. This only occurs with slow flowing or stationary water. It takes time for the particles to settle, so the further the water travels in the drain, the more time there is for the silting to take place. A good solution is therefore to empty the side drains frequently by means of installing mitre drains and culverts at regular intervals.

Lining Side Drains
In urban areas, side drains are normally shaped with a rectangular cross-section and a cover. This method is chosen to utilize the space next to the road more efficiently. In rural areas, there is normally sufficient space within the road reserve to choose less costly design solutions. With a V-shaped or trapezoidal cross-section with stable
side slope gradients, existing soils and vegetation will in most cases provide a solid enough surface. When soil erosion occurs in the drains, this can be dealt with using scour checks, mitre drains, cut-off drains and culverts.

In mountainous terrain, however, where road gradients reach 8 to 10 percent, it may be necessary to consider lining the side drains in the steep sections. Drain lining can be made from concrete, stone or bricks. Rock, if available in the vicinity of the road, is the preferred building material and can be laid as dry or wet masonry. The size of the stone should be a minimum 200 mm to avoid the rock being washed away by water. The masonry work needs to be well laid to ensure that water does not enter underneath the lining allowing it to become unstable and eventually wash away.
7.4 Mitre Drains

The mitre drains (or off-shoot drains) lead water away from the side ditches to lower areas. By installing mitre drains at frequent intervals, it is possible to reduce the risk of both soil erosion and silting. Mitre drains are also used for diverting water away from the abutments on crossroad drainage structures such as bridges and drifts.

The location of mitre drains should be determined during the initial stages when setting out the road alignment, thereby ensuring that the road receives good off road drainage. It is important that sufficient numbers of mitre drains are located before side drain excavation starts.

The optimal spacing between the mitre drains depends on a number of issues such as gradient, intensity of water flow, soil type, and most important, the terrain conditions. Mitre drains can only be constructed in terrain with a downward gradient. In principle the more mitre drains provided, the better. Where possible they should be placed at intervals as shown in the table below. At the same time, the gradient of the drains should be at a minimum of 2 percent. To avoid silting in the mitre drains, the ideal situation is to maintain the same gradient in the mitre drains as in the side drains.

Remember that these are maximum distances; the quicker the water is led off the road, the less damage will occur (either from scouring or silting). Wherever possible, the discharged water from the mitre drains should be channelled to streams or land boundaries in order to avoid damage to farmland. The soils from excavating the mitre drains should be deposited on the downhill side of the drain.

There are some important items to bear in mind when designing mitre drains:

- There needs to be a strong block off in the side drain, to make it easy for the water to flow along and out of the mitre drain. Water always flows the easiest way. The water will try to

<table>
<thead>
<tr>
<th>Mitre Drain Intervals</th>
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</thead>
<tbody>
<tr>
<td>Road gradient (%)</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>1-2</td>
</tr>
</tbody>
</table>
continue to flow down the side of the road because it is usually steeper and in a straight line. In order to divert the water into the mitre drain it is vital that the water is effectively channelled into it.

The best way to provide a strong block-off in the side drain is to leave 3 - 8m of natural ground not excavated on the drain line. Forming the block-off with excavated material is not as strong. Block-offs can also act as useful turning points for trucks and other equipment during the gravelling operation. Once the road has been completed, they are a good location for off-loading and storing gravel for future routine maintenance works.

The amount of water entering the mitre drain cannot be greater than the amount flowing out. Otherwise, the drain will fill up and over flow, damaging the block off and causing even greater problems at the next mitre drain. The mitre drain therefore needs to be designed with sufficient capacity to discharge the water from the side drain, also when the slope of the side drain is greater than the mitre drain slope. In such cases, the mitre drain should be made wider than the side drain.

The length of the drain depends on the terrain ground levels and the slope of the drain. Mitre drains should be as short as possible. Long mitre drains are expensive, more likely to silt up or get blocked off, and in general more difficult to maintain.

An effective slope for a mitre drain is 2%. The gradient should definitively not exceed 5%, to avoid erosion in the drain or to the land where the water is discharged. In mountainous terrain, it may be necessary to accept steeper gradients. In such cases, appropriate soil erosion measures should be considered such as ditch lining or scour checks. In flat terrain, a small gradient of 1% or even 0.5% may be necessary to discharge water, or to avoid very long drains. These low gradients should only be used when absolutely necessary. The slope should be continuous with no high or low spots.

In general, the mitre drains should connect to natural run-off channels that take the water clear of the road. If this is not possible, then the next mitre should be set out to catch this water before it enters back into the side drains.

Finally, it is important that the discharged water does not disturb farming or other activities in the surrounding areas. By discussing the location where to discharge water from the road with local residents, it may be possible to find solutions which may improve rather than destroy the water management in the surrounding areas.
Angle of Mitre Drains

The angle between the mitre drain and the side drain should never be greater than 45 degrees. An angle of 30 degrees is ideal.

The angle between the mitre and side drain can be checked by first constructing a 90 degree angle and then using the measurements as shown in the triangles below:

If it is necessary to take water off at an angle greater than 45°, it should be done in two or more bends so that each bend is less than 45°.

Mitre drains are constructed using the same work methods as those used for excavating side drains. String and pegs are used to set out the drains with the exact depth of the mitre drains marked on the pegs. Control of the gradient of the mitre drain can be secured by using profile boards and a traveller.

When excavating the mitre drain, the soils should be disposed of in a manner which avoids that they are washed back into the drainage system when it starts raining.
7.5 Scour Checks

Depending on the prevailing site conditions, soil erosion in the side drains can be countered using a number of different measures:

- as mentioned earlier, by installing frequent mitre drains, the amount of water in the drains can be kept at a minimum,
- by increasing the dimensions of the side drains (i.e. the width), the flow of water can be kept at slow speeds,
- lining the drains using stone masonry, bricks or concrete is a common measure to protect the drains – particularly in mountainous areas with steep road gradients.

Another measure to control erosion is to install scour checks in the drains. These are only used in hilly terrain with steep gradients where it is not possible to remove water using mitre drains. When road gradients are steeper than 4 percent, the drainage water gains higher speeds, which may cause erosion of the side drains. Their function is to slow down the water flow by reducing the natural gradient of the drain by allowing the drain to silt up behind the scour check.

The scour checks hold back the silt carried by the water flow and provide a series of stretches with gentle gradients interrupted by small "waterfalls".

Scour checks are usually constructed in natural stone or from wooden or bamboo stakes. Masonry, or concrete scour checks require less maintenance, but are more expensive to build.
Constructing Scour Checks

The frequency of scour checks is determined on the basis of the longitudinal gradient of the side drains. At the place of each scour check, the ditch is deepened and widened to provide room for securing the boulders or stakes. When stakes are used, they should be driven deep into the ground. The stone is placed downstream of the stakes.

Scour checks are usually constructed in natural stone or with wooden or bamboo sticks. Although more expensive, they can also be built from concrete or brick masonry. By using natural building materials available along the road, they can easily be maintained after the road has been completed. The appropriate distance between scour checks is shown in the following table:

<table>
<thead>
<tr>
<th>Road Gradient (%)</th>
<th>Scour Check Interval [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>not required</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
</tr>
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<td>7</td>
<td>10</td>
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<td>8</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
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<tr>
<td>10</td>
<td>6</td>
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</tbody>
</table>

The basic measurements for constructing a typical scour check are shown in the figure below:

After the basic scour check has been constructed, an apron is built immediately downstream using stones. The apron helps resist the forces of the waterfall created by the scour check. 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. To stabilize them, the long-term goal is to establish a complete layer of grass covering the silted scour checks.
7.6 Catch-water Drains (Cut-off Drains)

Catch water drains are ditches more or less parallel to the road. Their function is to catch and lead away the surface water coming from higher lying areas before it reaches the road or to direct water to where it can safely cross the road at constructed water crossings such as culverts, bridges and drifts. These drains, when properly built, are very effective in reducing the amount of water around the road, thus limiting the damage to the road and consequently reducing maintenance costs.

Wherever possible the catch-water drains should be diverted to a natural watercourse. Catch-water drains usually have a trapezoidal cross-section and the excavated material should always be deposited on the downhill side of the drain. These soils should be properly stabilized so they are not washed away during rains - ending up in the side drains of the road.

In most cases, it is cheaper and safer to direct water away from the road, using cut-off drains, rather than providing erosion control measures in the side drains. However, there are certain dangers with cut-off drains that must be carefully considered:

- surface water usually carries a lot of silt and if not properly built, the drain can silt up quickly,
- as they are off the road they will probably receive less maintenance - especially when they are difficult to reach,
- when they fail, water breaks through in a concentrated flow causing damage, and
- they may be ploughed up or blocked off by people using the land.

These risks can be reduced if they are carefully designed and properly built. The following precautions should be taken:

- The risk of silting can be reduced by making sure there is a continuous downhill gradient and that there is a clear outlet at the end.
- The drains need to be easy to maintain thereby limiting
erosion damage and maintenance needs (wide with sloped sides). Catch-water drains which are not properly maintained and which start pooling water may reduce the stability of the slope and trigger land slides.

- The drain needs to be made strong. This can be done by anticipating the possible weak points where water may break through and strengthen the drain at such locations.
- The drains must be placed at a safe distance from the road, to ensure that it does not weaken the geotechnical stability of any side cuts, and thereby increase the danger of landslips.
- The drains need to be carefully located after discussions with local people. Where people have to cross the drain, easy side slopes should be provided so that nobody falls into the drain.
- These drains may conflict with the current use of the land. Before they are constructed the land needs to be released from its current owners, by the same procedure used when securing the road reserve.
- Finally, it is important to give careful consideration to the design of the exit point of the catch-water drain. It should not cause negative environmental effects to the surrounding areas and the economic activities in such places, i.e. flooding or silting of farmlands, conflicting with existing irrigation systems or causing new drainage problems elsewhere.

The most common purpose of catch water drains is to divert surface water from reaching the road and its side drains. Drains can also be used for diverting minor streams away from the road and collecting it at points where major drainage crossings are being installed. Such interception drains can provide substantial savings in overall construction costs, however, careful attention should be given at the design stage when considering changes to the natural flow patterns of water.
7.7 Culverts

Culverts are the most common cross-drainage structure used on roads. They are built using a variety of materials, in different shapes and sizes, depending on the preferred design and construction practices. Culverts are required in order to (i) allow natural streams to cross the road, and (ii) discharge surface water from drains and the areas adjacent to the road.

Culverts form an essential part of the drainage system on most roads, and most road construction or rehabilitation works include the installation or repair of culverts.

Culverts are constructed using a wide variety of designs. The most common culvert design is based on the use of concrete pipes. This type of culvert is built with 1 - 3 rows of culvert pipes with diameters commonly ranging from 0.6m to 1m.

Chapter 8 provides a detailed description of the use and construction of culverts.

7.8 Drifts

Drifts provide an efficient and economic method of allowing water to cross from one side of a road to the other. In the case of drifts, the water is actually allowed to pass on top of the road surface. As a result, the road surface needs special protection to stand up to the forces from the flow of water. This is usually done by constructing a stone packed or concrete surface where the water will pass. The level of the drift is lower than the road on each side, to make sure that water does not spill over onto the unprotected road surface.

Drifts are normally constructed to pass river streams which are dry during long periods of the year. If the waterway has a continuous flow of water throughout the year, the use of other cross-drainage solutions such as culverts, vented fords or bridges should be considered.

During rains, most drifts carry shallow flows of water through which vehicles can pass. Occasionally, deep drifts are flooded for short periods and the road will be closed for traffic.

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

(i) Splashes are minor crossings that carry water from a side drain across the road to the lower side. As an inexpensive alternative to culverts, splashes are located at low points along the road alignment when the side drain cannot be emptied by
mitre drains and the water has to be lead across the road.

(ii) **Drifts** are crossings at large drainage channels and small rivers. Although the flow of water is normally seasonal, they may have to take strong flows of water.

(iii) **River Crossings** are longer crossings of riverbeds. In order to allow traffic to cross the riverbed, it would usually consist of deep sand or rock. When improving a river crossing, the running surface is improved by building a firm foundation. With seasonal flows of water, a concrete slab would be sufficient, however, with all-year-round flow of water, it would normally be more appropriate to design a vented ford, or a combination of a vented ford and a drift slab.

Choosing drifts as the preferred cross-drainage structure has a number of
advantages. Most importantly, the drift is a low-cost structure which carries a good capacity. In places with only seasonal flows of water, but with large and intense flows during parts of the year, the drift provides an economic and technically feasible approach to dealing with water crossings.

Floodwater often carries excessive amounts of debris and silt which can easily create blockages. While such debris often poses a danger to culverts and bridges, drifts do not face such problems. Drifts require limited maintenance compared to other structures and the most common maintenance tasks for drifts are far less complicated.

**Drift Warning**

Adequate sign posting to warn traffic of the location of a drift or river crossing should be placed on the side of the road. Traffic can then reduce speed and proceed safely down the approach and across the drift.

Additional guidance can be given in the form of marker stones painted white and placed along both sides of the drift slab.

**Site Location**

As with all cross-drainage structures, part of the design work is to identify the optimal location for the river crossing. If the drift is wrongly placed, it may result in extra work during construction as well as afterwards during maintenance. The main points to consider are:

- The angle between the centre line of the road and the flow of the water should be close to 90 degrees.
- The site should be on a straight length of the stream.
- Places where there are signs of scouring or silting should be avoided. Such locations run the risk of generating excessive
maintenance problems.

- If possible, avoid places with steep riverbanks. A crossing with gentle side slopes is the optimal. This reduces the excavation work required for building the approach roads at a reasonable gradient.
- Preferably, the site should be on a straight length of road.

Once the site has been established, the finished level of the drift is set out at the same level as the present level of the riverbed. The level of the drift should not be set below or above the level of the riverbed. Any disturbance of the natural flow of water may cause scouring at or next to the drift.

In cases where the river is suffering from silting up, it is best to lift the drift 20 - 25cm above the natural riverbed. This will speed up the water passing over the drift and reduce the danger of the drift becoming silted up.

The actual river crossing should be at least the same width as before the drift was constructed. No attempt should be made to constrain the width of the river by reducing the length of the actual drift. This may seem feasible during the dry season, however, during high flood periods this may lead to scouring and eventually wash-outs of parts of the river crossing structure.

**Drift Approaches**

The ideal slope for a drift approach is 5%. Steeper approach slopes may cause problems for the traffic. All drift approaches should have the same gradients, so that drivers can establish a good estimate of safe speeds to travel across the drifts.

The road connecting to the drift approaches should have a standard cross-section shape with a camber. At the bottom of the approach, the drift is flat (i.e. without a camber). The cross-section of the drift approach will therefore need to be designed so that there is a gradual change from a camber at the top, to a flat surface at the bottom of the approach.

When planning the construction of a drift, the approaches are set out first to assess how much excavation is required. Sometimes, it may be possible to reduce the excavation works by moving the location of the drift.

First, the end points of the drift bed are located. Two profiles are set out with a 5% slope at each side of the crossing. The length of the approach can be found by means of a traveller moved along the line of the slope profiles until it levels up with the slope profiles.

The traveller 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 required. If the initial setting out results in excessive excavation works, consideration should be given to moving the drift to an alternative location.

**Surface Materials**

It is important to select the appropriate surface material for the drift, which will support the traffic as well as stand up to the expected water flow in the rainy season.

There are a number of possible solutions ranging from gabions with gravel, stone paving or constructing a concrete slab. The choice depends on the following issues:

- the expected force of the water flow,
- the availability of materials, such as gravel, stone, aggregate and sand,
- the quality and strength of the existing river bed foundation, and
- costs of labour and materials.

For slower flowing water, gravelled drifts with gabions or dry pitched stone paving is adequate. Stone pitching is more suitable for riverbeds with loose sands and a gentle flow.

At some crossings, it may be difficult to decide if a gravel surface is practical - it may be washed out too often. In these cases, the cheaper solution using gabions with gravel should be adopted first, and then allow a full rainy season before deciding whether it is necessary to upgrade the crossing with a stone
pavement or a concrete slab.

The figure above shows an example of a drift consisting of a porous dam which retains the gravel/rock from being carried away by the water flow. The top of the gabion dam is between 15 and 20cm higher than the riverbed at the downstream end.

This construction provides a simple and economic solution. A one-metre wide trench is excavated along the downstream edge of the future road. The gabions are then placed in position, filled with rock and bound together with binding wire. Gravel is then placed upstream from the gabion to form the road surface. An apron on the downstream side of the gabion to resist scouring should also be put in place.

Strong flows of water will erode and wash away gravel surfaces and dislodge dry pitched stones, resulting in high maintenance costs to keep them repaired and in good condition. Where large volumes of strong flowing water are expected, a concrete slab or cement bound stone paving with a solid base will provide the only long-lasting solution.

Stone masonry can also be used for the drift aprons and foundations. However, the use of such building materials requires good availability of quality stone and skilled masons. A very good alternative to pitched stone works is the use of gabions for the same components of the drift.

Gabions have the advantage that:

- they are easier and faster to build,
- stone of lesser quality and size can be utilised, which are easier to find locally,
- gabions are more resistant to erosion and
- they do not require skilled masons.

A typical cross section of a concrete slab is shown below. If the foundation is made of gabions, the concrete is laid on an adjustment layer of gravel/sand which is placed on the top of the gabion mattresses. The gravel needs to be levelled to provide a uniform and well-compacted surface on which the concrete deck is constructed.

Once the concrete has been placed, it should be kept damp and allowed to cure for 7 to 10 days. An adequate supply of water must be available on site
during the curing period, and a worker should be assigned to keep the concrete surface moist during this period. The traffic needs to be diverted away from the drift during the curing period.

If the length of the slab is less than 12m there is no need for an expansion joint. On longer river crossings, expansion joints are required for approximately every 10 to 15 metres.

Splashes
A splash is a low-cost solution to crossroad drainage and provides an inexpensive alternative to culverts. This drainage structure is normally only applied to rural roads with very limited traffic volumes.

The splash is basically a simplified version of the drift, however, while drifts are used to cross natural streams and rivers, the splash is mainly used to lead road surface water across and away from the road.

As with culverts, the main purpose of the splash is to lead water from the hillside drain across the roadway to be discharged on the downstream side of the road. The main design element when building a splash is therefore to secure a surface on which the water can flow without creating any erosion or reducing the bearing capacity of the road. In exceptional cases, where there is a limited flow of water, good natural soils and little traffic, the splash can be built using gravel. However, in most cases it is necessary to install a more durable surface made from materials such as stone or concrete.

Similar to drifts, the splash is designed at a lower level than the road with descending approaches on both sides. The splash needs to be deep enough to cater for the highest flow of water, without reaching the unprotected road sections on each side of the water crossing.

As with all drainage structures, the frequency and capacity of the splashes need to be assessed in relation to the overall drainage system of the road. However, providing frequent possibilities for water to be discharged from the side drains will minimize the chances of erosion and silting.

Downstream from the splash, it is often necessary to protect the area where the water is discharged. Packed stone or gabions can provide a solid but inexpensive surface for this purpose.
7.9 Vented Fords

Vented fords, also referred to as causeways, can provide a cost-effective alternative to culverts and bridges. While drifts are appropriate for streams which dry out during periods of the year, vented fords are commonly used for crossing rivers and streams which carry a minimal flow of water through the dry season.

The advantage of the ford is that it is a relatively inexpensive structure appropriate for both narrow and wide river crossings. Vented fords use a combination of culvert pipes to discharge water under the road during low water flows, and a drift slab allowing water to overtop the structure during high water flows. This arrangement keeps traffic out of the water most of the year when the flow of water is limited. With a solid running surface made from stone masonry or concrete, the entire structure is submerged during high water flows, but still allows traffic to pass.

Similar to drifts and culverts, the installation of vented fords needs to be carefully designed, taking into consideration the topography, the features of the river or stream and the water flow. The ideal location of a vented ford is at a shallow stream location, away from river bends. The riverbed should be firm and stable, preferably with bedrock or coarse soils so that there is limited scouring or sedimentation.
The key design parameters for a vented ford are to establish (i) the appropriate drainage required through the culvert pipes during low flows, and (ii) provide a sufficiently solid structure with adequate capacity to cater for the highest water flows. Important factors for the design of a vented ford are low and high water levels, design and protection of approach roads and protecting the structure and its surroundings against scouring.

Once the location for the river crossing has been selected, the ford can be set out using the same methods as when building a drift. This includes establishing the exact location of the end points of the ford bed and designing the approach roads with a gentle and uniform slope. With the highest flood levels established, it is possible to determine the appropriate length of the sections of the approach roads that need to be protected with a reinforced surface. Allow between 0.3 and 0.5 metres in elevation between the top of the reinforced roadbed and the highest level of the floodwater.

Similar to culverts and drifts, the introduction of a structure in the stream
needs to be constructed with a more solid foundation.

During flood periods, the water flow will be diverted from its uniform flow to pass through the culvert pipes. This will cause strong currents close to pipe inlets.

To avoid the water from scouring the soils close to the inlet and thereby undermine the foundation of the ford, it is useful to install a cut-off wall upstream and strengthen the riverbed next to the inlets. Gabion mattresses provide low-cost and effective protection for this purpose.

Equally, the sides of the approach roads need to be protected from scouring during high flood levels.
Construction

Obviously, the construction of fords should take place during the dry season when water levels are at its lowest. Equipment and construction materials need to be assembled in advance, so work is ready to start when the stream is at its lowest. Before any construction can take place, the existing stream needs to be temporarily diverted away from the work site.

As with culverts, the first step is to excavate the trenches for the cut-off walls. A suitable culvert bed is then levelled and compacted between the cut-off walls. It is recommended that a concrete bedding is provided on which the pipes are placed. The bedding should be indented to accommodate the shape of the culverts and its joints. The bedding must be set out at the correct level, thus ensuring that the culvert pipes are flush with the riverbed.

After laying the culvert pipes, the headwalls are constructed up to the road level. Headwalls are normally built from cement bound masonry. The space between the pipes is backfilled with a well-graded stony material. Lean concrete with rock may also be used as a backfilling material, although this choice will increase the costs of the structure.

For the road surface, it is recommended to install a 10 cm reinforced concrete layer with a 3 percent cross-fall. The surface slab needs to be strong enough to protect the culvert pipes from the
expected traffic loads. The connection between the approaches and the horizontal stretch should be rounded to provide a smooth riding surface. The concrete slab must be kept moist for at least 10 days during curing. Traffic should be kept off the slab for two weeks.

Aprons can be constructed from stone masonry, concrete or gabions. On the downstream side they should be at least two times the height of the causeway.

Marker stones can be placed along both sides of the road surface slab to provide traffic with proper guidance when the ford is immersed in water.
8.1 Introduction

Culvert works constitute a significant part of both rural road construction and maintenance. Road construction may obstruct the natural flow of water unless the crossroad drainage is properly designed. As a crucial part of the drainage system, the culverts are also essential for basic access along a road section.

Culverts allow water to cross underneath the road. Their function is to lead water from the uphill side of the road to the lower side where it can be safely discharged. The water may be from natural streams or run-off surface water from the road structure or areas close to the road. There are basically
two types of culverts, depending on their function:

- stream culverts, allowing water from streams and canals to cross beneath the road, and
- relief culverts, which divert water from the high side to the lower side of the road, relieving the side drains of water which cannot be discharged by mitre drains.

Culvert works should be planned at an early stage of any road improvement project so that when all the culverts are in place, good access is provided to all sections of the road and the remaining works activities. Culvert works are sensitive to local weather patterns. During the rainy season, it may be difficult to carry out culvert installation or improvement works.

Culverts can be built using a variety of materials, including brick and stone masonry, corrugated steel, timber and concrete. Culverts are also constructed in a wide range of shapes and sizes.

They can be manufactured on site or purchased from suppliers of pre-fabricated building materials. Smaller diameter culverts are commonly manufactured in advance, while larger culverts are built to specifications on site.

The pipes can have cross-section with a circular or rectangular shape or built as an arch. The most common type of culvert is fitted with one or several rows of circular pipes made of concrete.

Rectangular shaped culverts – referred to as box culverts - are commonly used to cater for larger crossings.

The most common is the pipe with a diameter of 60 cm. Any smaller diameter should be avoided as they tend to get blocked more easily and are difficult to keep clean. Larger diameters requiring a high fill over the rings (the overfill) can be replaced with two or more rows of a smaller dimension. If large flows of water are expected, multiple rows of culverts are placed in appropriate locations.

Culverts are placed at each low point in the vertical alignment of the
specialized manufacturers. The standard one metre pipes have the advantage of being easier to handle, especially during loading and unloading. These pipes can be laid relying entirely on manual labour.

Culvert Bed
The pipes are laid on a stable bedding, properly aligned and at correct levels, preferably at the levels of the surrounding terrain. If the natural soils are of good quality, the culvert can be installed using in-situ materials. Stones should be removed from the culvert bed as they may damage the pipes. If the natural materials are not suitable, a
bed of gravel or sand can be used as a foundation for the pipes. If the ground is swampy or muddy, it may be useful to construct a bed made from stone packing, lean concrete or selected soils such as sand or gravel.

It is important to install the culvert at the correct position, level and gradient, preferably with a slope of 2 – 5%. The inlet and outlet level and gradient of the culvert should to the extent possible follow the existing natural water channels and ground levels.

If the culvert inlet is lower than the surrounding terrain, sediments will start to deposit at the inlet side of the pipe and eventually reduce the flow capacity of the culvert. This may in turn lead to overflowing and possible damages to the road body above the culvert.

Equally, it is important to align the culvert with the existing terrain at the outlet side. If the outlet is higher than the surrounding terrain, the water exiting the culvert may erode the side slope and the terrain below the culvert outlet.

### Aprons

Aprons are constructed at the inlets and outlets to protect the culvert bed and the connecting ditches from erosion and scouring. At the outer end of the aprons, it is common practice to construct a toe wall to prevent water from eroding the soils underneath the apron. Aprons and toe walls can be made of stone, brick, concrete or gabions.

The length of aprons should be equivalent to at least one and a half
times the diameter of the pipes. In addition, there may be a demand for further soil stabilisation measures downstream of the apron.

Headwalls and Wing Walls
The purpose of headwalls and wing walls is to protect the backfill and the side slope of the road embankment from water damage. Headwalls are built parallel to the centre line of the road (preferably even when the culvert is located in a skewed position) in order to take the pressure from the traffic evenly. They can be built using hand packed stone, mortar bound masonry or concrete.

If the headwalls and wing walls are omitted, the side slopes of the backfill should not be steeper than 1:2. However with well-graded and cohesive natural soils, the gradient of the side slopes can be increased. The culvert should be long enough to reach the end of the side slopes on each side of the road.

With good natural soils, the culvert can be installed using the existing sub-grade as the culvert bed. By omitting aprons, headwalls, wing walls and culvert beds of imported materials, it is possible to reduce the cost of culvert installations by approximately 30 percent.

Drop Inlets
In mountainous terrain, there may not be sufficient space for a headwall at the inlet side. In such situations a wing wall is only installed at the outlet of the culvert. Instead, a drop inlet is constructed on the high side of the culvert.

In populated areas, the inlet can be fitted with a grill to avoid people and debris falling into it.
8.2 Culvert Location

Before fixing the position and frequency of culverts, it is necessary to carry out a survey of the surrounding terrain to establish the exact patterns of water flow and on this basis the exact need for crossroad drainage. Roads will obstruct the natural flow of water. Crossroad drainage is therefore essential in terms of discharging the water surrounding the road. The frequency and location of culverts forms an important part of the water management surrounding the road.

If an existing road is being improved, the locations of most culvert sites are obvious, as large quantities of water will leave their mark on the existing road structures. Insufficient cross drainage would lead to the road being damaged in some way. In such situations, look for places where:

- small gullies have formed because water has been flowing across the road,
- sand has deposited on the road because of standing water, or
- drains have been badly damaged because they have been carrying too much water.

Insufficient cross-drainage may lead to washouts of entire road sections. In such instances, it is important to carry out a thorough reassessment of the drainage situation before starting the repair works. An investigation should be carried out as to why the washout occurred and how to avoid it happening again.

Careful consideration should be given to how and where the water is discharged. Water collected along the road and discharged through a culvert may cause serious soil erosion and damage to the surrounding areas.

Appropriate measures dealing with how the water is dispersed downstream of the culvert is an integral part of the culvert design. When water is discharged on to farmland, the water management needs to be discussed with local farmers, thereby avoiding damage to and disrupting farming activities. In some instances, the farmers may be able to make use of the water.
8.3 Setting Out

The culverts form an essential part of the overall drainage system of the road. This implies that their frequency and locations need to be carefully assessed in relation to the location, function and capacity of other drainage elements such as bridges, drifts, cut-off drains and mitre drains.

A well functioning drainage system is dependant on the efficient operation of all the elements of the system. If one component in this system fails, such as a blocked culvert, the water will exert more pressure on the remaining parts of the drainage system.

Determining the exact location of culverts is carried out during the initial setting out of the road alignment. The location and direction of rivers and streams have an important impact on the optimal positioning of the road alignment. Floodwater from rivers and streams can cause serious damage to the road structure so the crossings need to be designed so that they minimize the chances of any future damage.

Relief culverts manage surface water from the road and its side cuts. They are normally built at right angles to the centre line of the road. Stream culverts are built following the direction of the

Road realigned to achieve a 90 degree stream crossing
streambed so that the culvert does not interfere with the natural flow of water in the stream.

Depending on the direction of the road at the stream crossing, these culverts may be at an angle or "skewed" to the centre line of the road. Skewed culverts require more pipes as they do not follow the shortest distance across the road. To avoid skewing the culvert, the best approach is to realign the road so that the road crosses the stream at a 90-degree angle.

8.4 Setting Out Procedures

Step 1: Culvert Position
The first step of positioning a culvert is to establish the exact location of the culvert pipe. If the culvert is required for a stream, it should follow the alignment of the existing channel - skewed if required. If it is a relief culvert, it should be set out perpendicular to the road centre line.

Wooden pegs are placed close to the inlet and outlet positions of the culvert pipe to mark the centre line of the culvert pipe. In most cases these pegs will be located on the road shoulders or side slopes. In addition, it is therefore useful to place reference pegs well outside the work area of the culvert works.

Setting Out Tools:
- 2 ranging rods
- 2 profile boards
- 1 line level or hose pipe
- 50 m string line
- 20 pegs - 40 cm long
- 2 pegs - 1 to 1.5 m long
- 1 hammer
- 1 permanent markers pens
- 1 measuring tape 20 m
- 1 measuring tape 5 m

Step 2: Length of Culvert
The total length of the culvert pipe is established by calculating the distance between the two pegs at the inlet and outlet. Pipes are manufactured at a fixed length, determined by the dimensions of the culvert mould, commonly with
a length of one metre. Culvert pipes are therefore installed at a total length consisting of multiples of the individual length of the pipe segments.

For example, if the total road width, including side slopes is 4.4 metres, one would choose to build a culvert with a total length of 5 metres using 1 metre long culvert pipes. The total length of the culvert pipe also needs to accommodate the thickness of the headwall in addition to the road width.

If the culvert crosses a tall embankment, the length of the culvert is extended to cater for the width at the base of the road fill.

Step 3: Width of Culvert Trench
The trench should be wide enough to allow workers to comfortably carry out the pipe installation and backfilling around the pipes. A clearance of at least 40 cm on each side of the pipes is therefore recommended.

When installing two or more pipe rows, it is important to provide sufficient space between the pipes to allow for proper compaction of the fill material between the pipes.

The total width of a trench for a single pipe culvert with a 60cm pipe can be calculated as follows:

With a pipe thickness of 6cm, the outside diameter of the culvert pipe is then 60cm + (6cm x 2) = 72cm.

\[ \text{WIDTH of trench to be excavated} = 72\, \text{cm} + (40\,\text{cm} \times 2) = 152\,\text{cm} \]
The purpose of adding an extra width of 40 cm on each side of the pipe is to secure sufficient space to:

- easily place the pipes in the trench and make the final adjustments to achieve a straight row,
- easily adjust the position of the pipes to secure tight joints,
- provide sufficient space for compacting the fill material with hand rammers or plate compactors. This activity should be carried out in layers with thickness of not more than 10 cm.

Step 4: Trench Depth at Inlet
The level at which the culvert is built needs careful consideration when preparing the detailed design. If possible, the culvert inlet should be built at the same level as the bed of the stream or the level of the surrounding ground. If the culvert inlet is higher than the existing ground levels, this may cause scouring of the soils around the inlet. If the level of the pipe is lower than the surrounding terrain, this may lead to silt deposits inside the culvert.

Setting out the depth of the trench needs to start at the inlet of the culvert to ensure that adequate cover is secured. The thickness of the backfill should be 3/4 of the inside diameter of the pipes. When installing a 60cm pipe, the backfill should be at least:

\[ 60\text{cm} \times \frac{3}{4} = 45\text{cm} \]

The trench depth is based on the outer diameter of the culvert pipe. With a pipe thickness of 6cm, the outer diameter would then be:

\[ 60\text{cm} + 2 \times 6\text{cm} = 72\text{cm} \]

Finally, with a 10 cm trench bed of imported materials, the calculation would be as follows:

Depth of trench =

\[ 45\text{cm} + 72\text{cm} + 10\text{cm} = 127\text{cm} \]

The pipes are placed on a well-compacted foundation thereby avoiding any future settlements. Imported materials for the culvert bed usually consist of gravel or lean concrete (1:3:6) if the soil in the
trench is too soft. Stone can also be used to create a sufficiently strong foundation.

Step 5: Level of the Outlet
The preferred gradient in a culvert pipe is 3 percent. With lower gradients there is a risk of sediments being deposited in the culvert pipe. At 3% or higher gradients the flow of water will keep the culvert free of deposits and thereby reduce future maintenance requirements.

When determining the level of the culvert, also ensure that there is a sufficient slope in the outlet drain, downstream of the culvert.

Having already established the level at the inlet, the depth of the trench at the outlet can be determined. With a gradient of 3% on a 5 m long pipe culvert, the level at the outlet can be calculated as follows:

\[
\text{Length of culvert } \times \text{gradient} = \text{level difference}
\]

With a 5m long culvert, the difference in levels at the inlet and the outlet is:

\[
\frac{5.0 \times 3\%}{100\%} = 0.15\text{m} = 15\text{cm}
\]

The level of the outlet is the level of the inlet plus the level difference caused by the gradient. In this case:

\[
127\text{cm} + 15\text{cm} = 142\text{ cm}
\]

Setting out the slope of the culvert is usually done after the trench has been excavated to the correct level at the inlet side.

The above example describes the ideal situation, in which it is possible to set the gradient at the desired grade. In flat terrain, it is often not possible to obtain this gradient. In such cases, the culvert grade needs to be determined by the levels of the surrounding terrain at the inlet and the outlet of the culvert.

In some cases, the flow of water changes to the opposite direction at certain times of the year. In such cases, the slope of the culvert is set out at zero percent (no gradient).
Step 6: Maintaining the Correct Gradient

Once the levels of the inlet and outlet are established, it is possible to prepare a smooth culvert bed with the desired gradient. With a line level and profile boards, this can be achieved following the process described below:

(i) Place ranging rods at the exact locations of the inlet and outlet of the culvert.
(ii) Measure up one metre from the level of the inlet and mark this level with a profile board attached to the ranging rod.
(iii) Use the line level to transfer this level from the inlet to a ranging rod placed at the outlet.
(iv) On the ranging rod placed at the outlet, measure 15 cm down from the level transferred from the inlet and place a profile board at this level. This should mark the level one metre above the level of the outlet, when applying a 3% gradient for a 5m long culvert.
(v) To establish the correct level of the trench between the inlet and the outlet, place a one metre high traveller in the trench and sight from the profile boards at either side to control the depth.
(vi) The correct depth is achieved when the top of the traveller is level with the sight line between the profile boards. If the traveller
is above the sight line, it means that more excavation is required. If it is lower, this means that the trench is too deep.

Step 7: Setting Out Headwalls
Headwalls around the culvert inlet and outlet serves to protect the surrounding road body next to the culvert pipe. Together with the wing walls the head walls also acts as collectors, directing the water to the pipes.

As the foundation of the headwall is located under the outer rings of the culvert pipes, this activity needs to be carried out at the same time as when the levels of the culvert pipes are established. The headwalls are normally built parallel to the road centre line.

(i) Re-establish the road centre line (20m to both sides of the culvert) and set out straight lines parallel to road centre line at both ends of the culvert.
(ii) Set out the width of the headwalls (start from the centre line of the culvert, measuring out to both sides) and mark the outer corners of the walls with pegs. This width is normally equivalent to the outer diameter
of the culvert pipe when laying a single pipe culvert. With multiple pipe culverts, the headwalls normally extend to the outer edges of the pipes.

(iii) Set out the thickness of the headwalls. Mark the inner corners with pegs and mark the height of the headwalls on the pegs. Finally, set out the depth of the headwall foundations. Remember that the headwall foundations need to be constructed before laying the pipes.

The top of the headwalls on each side should be constructed to the same level. To achieve this, the height of the headwall at the culvert outlet, measured from the top of the pipe, will be higher than at the inlet side. This difference in height between the two headwalls is equivalent to the height difference resulting from the gradient of the pipe(s).

**Step 8: Setting Out Wing Walls**

Wing walls serve the purpose of stabilising the side slopes adjacent to the headwall. They are constructed at the same time as the headwall, at an angle of 30° or 45° to the culvert centre line. On skewed culverts, the angles of the wing walls at each side are not necessarily the same. In such cases, the angle depends on the angle between the road centre line and centre line of the culverts.

(i) Set out the desired angle between the culvert pipe and the wing wall,

(ii) Set out the correct length of the wing walls and mark the outer corners with pegs,

(iii) Mark the height of the wing walls on the pegs (at the headwall side and outer ends),

(iv) Set out the thickness of the wing walls,

(v) Set out the depth of the wing wall foundations.
Step 9: Aprons and Toe Walls

Aprons and toe walls are constructed to avoid scouring of the soils close to the culvert inlet and outlet. The depth of the toe walls is normally the same as the depth of the headwall foundations.

(i) Set out the thickness of the aprons. The aprons should be constructed at the same gradient and level as the culvert pipe.
(ii) The gradient of aprons can be set out using string line levels and profile boards.
(iii) Set out the depth of the toe walls at the outer edge of the aprons.

Step 10: Soil Erosion Measures

Culverts are designed to collect water from a large area and discharge it on the lower side of the road. In doing so, the surface water is concentrated to a limited area at the culvert outlet – which may cause soil erosion downstream from the culvert. This may have a detrimental effect on the stability of the culvert, as well as cause damage to the land areas below the culvert. In areas with a risk of such damage, it is important to install appropriate protection measures to avoid soil erosion.

In mountainous terrain, the water from culverts is often discharged onto large side slopes. If the water is left to run down the side of the slope, it may cause considerable erosion and eventually make the side fill unstable. If this continues for
a period of time, the road carriageway may eventually be at risk of collapsing.

A common solution for strengthening the soils and surface below culvert outlets is to install gabion mattresses below the outlet. These mattresses will then act as a cushion on which the falling water can land. On high slopes, gabions are installed starting at the foot of the slope, covering the entire surface up to the outlet apron.

Similar arrangements need to be considered where the slopes are not necessarily very steep, but where the soils are incohesive and prone to erosion. The installation of a culvert may trigger soil erosion in areas which at the outset appeared to be stable.

**Step 11: Drop Inlets**

In mountainous or rolling terrain, the road is often constructed as a side cut into sloping terrain. In such terrain, most culverts would need head walls and wing walls on one side only. At the inner side, i.e. close to the side slope, it would be more appropriate to construct a drop inlet.

The function of drop inlets is to collect water from the side drains and feed it through the pipe culvert dispersing the water on the lower side below the road. Drop inlets are usually made of the same materials as the headwalls and wing walls, such as concrete or stone or brick masonry.

The drop inlet is constructed in a square shape with its inside dimensions equivalent to the outside diameter of the culvert pipe. The thickness of the walls of the drop inlet should follow the thickness of the headwalls and wing walls. The height should be minimum 40cm higher than the outside diameter of the pipes and its bed level should be flush with the culvert pipe.

The level of the inlet of the collectors should be at the same level as the side drains, and its size and shape should follow the size and shape of the side drains.
Step 12: Securing Sufficient Backfill

Depending on the type and design of the culvert pipes, the thickness of the backfill may constitute a vital part of the design of the culvert. A sufficiently thick backfill above the pipe will protect the pipe from the forces exerted by the traffic. A rule of thumb is to ensure that the backfill is at least _ of the pipe diameter. This often implies that the road levels need to be lifted in order to accommodate this requirement. Once again, this design consideration stresses the importance of assessing the need for culverts and their locations and levels already when carrying out the initial design of the road alignment.

Sufficient backfill is also required during the construction period to avoid any damages to the pipes. Although the road may still not have been completed to its final levels, it is important to secure sufficient cover on top of the culvert pipes to cater for traffic during the construction period.

When building box culverts, backfill is normally not required, as the top slab of the box is normally designed to carry the expected traffic loads. In areas where it is difficult to secure the necessary backfill over culvert pipes, the alternative is to introduce the use of box culverts.
8.5 Construction Operations

Detours

Before starting the excavation of the culvert trench, traffic needs to be diverted away from the work site. When excavating the trench and laying the pipes, the road is blocked and traffic will not be able to pass. If it is not possible to build a detour outside the culvert site, the alternative is to build one half of the culvert while allowing traffic to pass on the other half of the roadway. The diversion should be properly organised to cater for existing levels and type of traffic, and equipped with adequate sign posting to avoid any accidents caused by the diversion.

In order to keep the work site dry and free from water, it may be necessary to build temporary waterways. With efficient management of surface water, the culvert works can also be carried out during the rainy season.

Excavation Works

Once the position and depth of the trench have been set out, the excavation can commence. By digging the trench starting from the outlet side towards the inlet, it is possible to keep the trench free of water. The trench should be marked with pegs and string lines, to ensure that it is excavated at the correct location and to the correct width. With the use of profile boards and a traveller, the foundation bed is excavated to the correct level and slope.

The trench should not be excavated deeper than to the intended levels. The natural soils are normally well compacted, and if left alone, they will in most cases provide a sufficiently firm foundation for the culvert. If the trench is dug too deep, it is necessary to refill the trench to its intended levels and provide the fill with proper compaction at optimal moisture content.

Ensure that any water which may enter the trench can exit. This not only implies that excavation should start at the outlet side of the drain. It is also essential that the water is properly drained away from the culvert outlet.
Keeping the work site dry and free of water will contribute to securing the correct dimensions and levels as shown on the drawings.

When excavating deep trenches it is important to show some caution in regards to the safety of the workers operating inside the trench. Unprotected trench walls may collapse when the water content in the soils increases and may cause serious harm to workers. When excavating deep trenches during periods of the year when rains occur, it may be necessary to support the trench walls with temporary retaining walls.

**Bedding and Foundations**
The foundations for the headwalls should be completed up to bed level on both sides before starting the construction of the culvert bed. The exact position of the foundation for the headwalls should be carefully measured from the centre line of the road.

Before commencing any concrete or stone masonry works, it is important to ensure that mud or any unsuitable materials are removed and replaced by selected materials, correctly levelled and compacted.

The bedding surface should be well compacted, providing a firm foundation throughout the length of the culvert. If the existing soil in the trench is of poor quality, it is replaced with a layer of imported materials such as sand or gravel. The fill material is watered and compacted in 10 cm layers. The supervising engineer will normally insist on inspecting the quality of the culvert bed before laying pipes and backfilling commence.

Before pouring concrete, make sure that the compacted ground under the formwork has been properly watered to prevent any water being absorbed from the concrete. If the concrete surface is kept continuously damp, adequate curing for a concrete bed would take 4 days following the placing of concrete.

**Placing the Pipes**
Pipe joints come in different forms. The most common is the bell and spigot joint, however larger pipe diameters often have flush joints—without the bell shape but still with a socket and spigot.

When laying the pipes on the prepared foundation, start from the outlet and
proceed towards the inlet. The pipes should be oriented so that the bell or socket is facing the inlet. If the pipes are fitted with a bell and spigot, a void should be excavated to fit the bell joints snugly into the trench bed, ensuring that the full length of the pipe is resting on the bed.

The culvert pipes should be gently lowered into the trench using a rope. Avoid the pipes falling onto each other as this may damage the pipes. The surface of the joints should be cleaned from dirt and soil before they are fitted together. Using crowbars, the pipes are eased up tight against each other, ensuring that they are in a straight line and properly joined. The pipes must be placed in the right position forming a straight line along the culvert pipe axis. Any pipe found defective or damaged during laying should be replaced.

After laying the complete run, the joints are sealed with cement mortar. When sealing the joints, the mortar must be flush with the inner surface of the pipe, thus securing a smooth inner surface, easy to maintain and keep clean of debris and silt.

Before commencing the backfill, it is common practice that the supervising engineer inspects and approves the laying of the culvert pipes and the mortar work at the joints. The contractor should not commence any backfilling of the pipes before he receives an explicit go-ahead from the engineer.
8.6 Constructing Headwalls, Wing Walls and Aprons

Culvert headwalls, wing walls and aprons can be constructed in concrete, stone or brick masonry. The work should be carried out by skilled workers with good experience in masonry works. Besides providing important protection to the areas surrounding the culvert inlets and outlets, the headwalls and wing walls act as facades to the structure and therefore require a neat and clean finish to the surfaces.

The choice of materials for this purpose depends on their availability in the area where the structures are located. Equally, the choice of materials depends on the aesthetic preferences of the agency in charge of the construction works.

Stone Masonry

Stone masonry is commonly applied to wing walls and aprons on culverts and small bridges. It can also be used for the foundation work on such structures. Stone is also used for providing a surface texture and therefore needs to be hard, clean and compact and should be carefully selected to ensure roughly flat sides.

Although these structures can be built in dry masonry, it is more common to
set the stones in mortar. When using mortar for the joints, the stone needs to be wet before laying in order to prevent any absorption of water from the mortar. Equally, the bed of each layer (course) of stones should be clean and also wetted before applying the next layer of mortar. The stones should be fully surrounded by mortar covering both the bed and the vertical joints. When laying the stones, they should be carefully settled in place and a wooden mallet used immediately after so that they are firmly embedded before the mortar sets.

Clean chips can be used as wedges in the mortar joints where necessary to support the stones in the required positions and to avoid thick beds of mortar joints. Use of chips, however, should be limited to the extent possible by carefully choosing stones that fit neatly together.

No dry or hollow space should be left anywhere in the masonry. Each stone must have all the embedded faces completely covered with mortar. A smooth face should be maintained where the joints are not more than 2 cm thick.

Whenever foundation masonry is laid directly on rock, the face stones of the first course should be dressed to fit snugly into the rock when pressed down in the mortar bedding on top of the rock.

In general, the length of the stone should not exceed 3 times of its height. The breadth of the stone at its base should not exceed three fourths of the thickness of the wall, nor less than 15cm.

The height of a course depends on the size of locally available stone. The selected stone should produce a course height of not less than 15 cm. Common heights of courses are 16 cm, 18 cm and 20 cm.
Common sizes of face stones for these heights of courses are given in the table below:

<table>
<thead>
<tr>
<th>Height of Course (cm)</th>
<th>Minimum Acceptable Size (cm)</th>
<th>Preferable Size (cm)</th>
<th>Size of Larger Stone (1/3 of Total Face Stones) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>15 x 15 x 20</td>
<td>15 x 18 x 22</td>
<td>15 x 18 x 30</td>
</tr>
<tr>
<td>18</td>
<td>17 x 17 x 21</td>
<td>17 x 21 x 25</td>
<td>17 x 21 x 34</td>
</tr>
<tr>
<td>20</td>
<td>19 x 19 x 22</td>
<td>19 x 22 x 28</td>
<td>19 x 22 x 38</td>
</tr>
</tbody>
</table>

With some effort it should be possible to obtain the size of stones specified above. When measuring the size of stones, the height of course should be fixed by the engineer in charge and insisted upon during the construction. The face work should be brought up evenly. Two lines of nylon string are used to control the surface of each course:

(i) Fix the first string line at the bottom of the course of stones between two ranging rods outside the wall (exposed side),
(ii) Fix a second line between two ranging rods at the top of the course,
(iii) Using a plumb bob to ensure that both ranging rods are in a correct vertical alignment,
(iv) Adjust the stones so that the top and bottom of each stone slightly touch the guidance strings. Chips can be used to support the stone in its correct position and angle before filling the mortar,
(v) Repeat this activity for all courses.

**Brick Masonry**

If stone is not readily available, a good alternative is using brick masonry. Bricks can also be used as façade or they can be plastered, giving a smooth concrete like surface.

When laying bricks, they first need to be soaked in water for a minimum of one hour before being placed. After having been soaked, they are taken out of the water sufficiently in advance so that the skin of the bricks is dry at the time of laying. The soaked bricks are
stacked on a clean place where they will not be soiled by dirt or earth.

Bricks are laid in an appropriate bond ensuring good interlocking between the bricks. A plumb bob and line level should be used to ensure that the work is even and true in both vertical and horizontal directions. Joints should be maintained at a uniform thickness and level. To secure a neat and even outer surface, bricks used on the face should be complete with uniform size and true rectangular face.

Bricks should be laid with frogs up, if any, on a full bed of mortar. When laying, the bricks are pressed slightly into the mortar so that the mortar can get into the surface pores of the bricks to ensure proper adhesion. All joints should be properly flushed and packed with mortar so that no hollow spaces are left. The thickness of joints would normally not exceed 10mm.

When using bricks for the foundation, a 15 mm layer of mortar is placed over the base on which the brick works are evenly laid. The first layer of bricks is laid immediately after spreading the mortar.

**Backfilling**

The backfill should be carried out after the concrete is fully set or the masonry has hardened. It should be carried out in such a manner that it does not cause any thrust or pressure to any part of the structure.

The backfill around the pipes and the overfill should be placed in 10 cm layers of suitable material free from large or sharp stones. Preference should be given to suitable material excavated from the pipe trench or the foundation. If these soils are unsuitable, good quality material should be borrowed from adjacent locations or by importing granular materials such as sand or gravel.

Backfill material should be spread, watered and compacted in layers using hand rammers or plate compactors. It may be necessary to add water to ensure that compaction takes place at optimum moisture content. Care should be taken not to hit and damage the pipes when compacting. The minimum thickness of the backfill above the culvert rings should not be less than three quarters of the pipe diameter.

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**Mortar**

Mortar consists of cement, sand and water and is mixed in the proportion 1:4 (cement : sand). If hand mixing is permitted, the operation should be carried out on a clean watertight platform. In order to obtain a good mix it is useful to:

- first mix dry cement and sand in appropriate portions until a uniform colour is obtained
- mix the mortar for at least 2 minutes after the addition of water.

The mortar will stiffen after a while due to water evaporation. It should then be re-tempered by adding water as frequently as needed to restore the right consistency.
8.7 Culvert Approaches

In flat areas, it is often necessary to lift the road on an embankment in order to achieve sufficient fill height on top of the culvert rings. In such cases, a ramp needs to be constructed on each side of the culvert to avoid a rapid change of the road gradient.

In mountainous terrain, ramp construction should be avoided. Sufficient depth of the trench can then be secured when determining the vertical alignment of the road.

Proper compaction of the approach sections is essential in order to provide a smooth and uniform running surface across the culvert pipe. If the road body is not properly compacted before and after the culvert, it will continue to settle after traffic is allowed on the road. The culvert pipe is a rigid structure so the section above the culvert pipe will be subject to less settlement as compared with the adjoining sections. As a result, the traffic will cause more consolidation of the road body before and after the culvert, and the road section directly above the culvert pipe will appear as a bump in the road surface. However, with proper compaction, this potential defect can be avoided altogether.

8.8 Concrete Pipe Manufacture

Culverts form an essential part of the drainage system of the road, so it is of great importance that the quality of the concrete pipes is good. Technical specifications and drawings will normally prescribe the dimensions and quality of the culvert pipes.

Circular culvert pipes can be manufactured making use of steel culvert moulds of different sizes. Pipes can also be purchased from manufacturers of concrete products or be produced on site.
If a road works project involves the installation of a considerable amount of culverts, the contractor may choose to manufacture culvert pipes on site. For smaller works, it would be more economical to purchase the pipes from a supplier.

When manufacturing culvert pipes on site, it is important that the conditions for proper works procedures are in place and that proper standards as regards to concrete technology are adhered to.

Adequate space is required on which the manufacturing works can be effectively organised and carried out. This includes space for the moulding works, as well as for storage and loading the pipes for transport to the work site.

- **Materials** such as cement, aggregates, sand and water need to be stored in a clean and safe environment. These supplies need to be secured on site well in advance of the pipe manufacturing;
- **A level and firm casting floor needs** to be prepared close to where the materials are stored (preferably a concrete floor);
- **The moulds should be checked** for any damages and deformations, and need to be properly aligned. All joints and hinges should be checked to ensure that they are free from dirt and old concrete;
- **The required hand tools and concrete mixers should be checked that they are in good order** before starting works. A gauge box is used to ensure proper control of the concrete ingredients by volume;
• A shed or a sunshade under which the pipes can be placed during the curing period needs to be erected. In addition arrangements for adequate water supply for the curing process should be put in place.

The mixture for concrete pipes should be 1:2:4 (cement : sand : aggregate). If possible, concrete cover outside the reinforcement bars should be 4cm, else centre aligned.

When pouring the concrete, compact the concrete using a steel bar and by knocking the outside of the mould gently with a hammer.

The mould should be left on the pipes for 24 hours before being reused. 24 hours after pouring the concrete, the rings should be stiff enough to remove the mould.

The rings must be kept damp for another 7 days to ensure proper curing of the pipes. The pipes should be 28 days old before being transported to the work site and installed.

The commonly used 60cm concrete pipe without any reinforcement is normally regarded as sufficiently strong to carry common traffic loads on rural roads, provided that they are placed according to good construction practices (i.e. placed on a sound foundation and with sufficient backfill).

For larger diameters it is often necessary to increase the strength of the culvert rings by adding reinforcement steel.
Reinforcement steel cages are then made in advance and fitted into the culvert mould before pouring the concrete. The figure below illustrates some common dimensions and how the reinforcement is positioned.

The quality of the culvert pipes needs to be carefully controlled before they are installed on site. Arrangements for quality testing of the concrete and the finished pipes need to be agreed upon and established as part of the work organisation. The supervising engineer must ensure that the contractor keeps proper records of the manufacturing and the curing process.

Throughout the production, it is important to control the quality of the moulds. Through extensive usage, the moulds will need to be maintained to ensure that they produce the right shape culvert pipes with a smooth and even surface and uniform thickness. After each use, they should be thoroughly cleaned, ensuring that no deposits of concrete are left from the previous mould. Hinges and lockers need to be properly cleaned so they remain in good condition.

The transport and handling of the pipes should be treated as a delicate exercise, and extra care should be taken to avoid cracking the pipes during off-loading.

On road sections requiring a substantial amount of pipes, the pipes should be manufactured close to the work sites to avoid unnecessary haulage.
8.9 Corrugated Steel Pipes

Culvert pipes are also manufactured from corrugated sheets of galvanised steel. These pipes are available in a variety of lengths and shapes. Some suppliers provide pipes which are ready to be installed in their full length while others are assembled from rounded segments by bolting them together on site.

The most common brand is Armco, who delivers these pipes in a variety of diameters and shapes. Armco pipes are easy to transport and assemble, however, they are usually slightly more expensive to use than concrete pipes.

Their advantage as compared to concrete pipes is that large numbers of pipes can easily be transported to site at the same time so that they are ready to be installed. As compared to pipes made of concrete, they do not need any curing period before they are put to use.

Armco pipes can also be used to produce arch formed culverts. The half circle is then placed on a concrete bedding which acts as the floor inside the arch pipe.

When utilising corrugated steel pipes for culvert works, they are used in the same manner as concrete pipes, fitted with aprons, head and wing walls and installed with a similar backfill.