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Cawangan Jalan

Bulletin on Lessons Learnt in: Drainage

Theme of the month:

Road Surface Drainage & Culvert Design

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1.0 ROAD DRAINAGE

1.1 INTRODUCTION

The primary purpose of a road drainage system is to remove excess water brought about by rainfall. The road drainage system consists of two parts which are dewatering and drainage. "Dewatering" means the removal of rainwater from the surface of the road. "Drainage" on the other hand covers all the different infrastructural elements to keep the road structure dry.

Culvert is a structure that allows water to flow under a road or similar obstruction from one side to the other side. Typically embedded so as to be surrounded by soil, a culvert may be made from a pipe, reinforced concrete or other material.

Culverts are commonly used both as cross-drains for ditch relief and to pass water under a road at natural drainage and stream crossings. A culvert may be a bridge-like structure designed to allow vehicle or pedestrian traffic to cross over the waterway while allowing adequate passage for the water. Culverts come in many sizes and shapes including round, elliptical, flat-bottomed, pear-shaped, and box-like constructions. The culvert type and shape selection is based on a number of factors including requirements for hydraulic performance, limitation on upstream water surface elevation, and roadway embankment height.

Selection of Culvert location is an integral part of the total design. The main purpose of a culvert is to convey drainage water across the roadway section expeditiously and effectively. The designer should identify all live stream crossings, springs, low areas, gullies, and impoundment areas created by the new roadway embankment for possible culvert locations. Culverts should be located on existing stream alignments and aligned to give the stream a direct entrance and a direct exit. Abrupt changes in direction at either end may retard the flow and make a larger structure necessary. If necessary, a direct inlet and outlet may be obtained by means of a channel change, skewing the culvert, or a combination of these. The choice of alignment should be based on economics, environmental concerns, hydraulic performance, and/or maintenance considerations.

1.2 TYPES AND FUNCTION OF SURFACE DRAINAGE

The types, location and functions of surface drainage are as follows:

Interceptor Drain Interceptor drains are located along the uppermost edge of cut slopes where the cutting begins, and along the edge of the cut slope descending towards the lowest point of the natural watercourse to collect water from upstream of interceptor and from bench drain.

Bench Drain Bench drains are placed longitudinally along the bench of a cut section to catch rainwater falling on the cut slope immediately above.

Roadside Drain Roadside drains are used along the road edge to collect water that has fallen on the carriageway and the batters of cuttings to direct to the edge of the formation.

Sub Soil Drain The function of subsoil drain is to drain away subsurface water in order to mitigate surface water ponding and waterlogging of soils by lowering watertables and alleviate ground water pressures to avoid damage to pavement.

Median Drain The function of median drain is to collect surface water which runs towards the central median and are generally of small section and gentle gradient.To collect surface water which runs towards the central road median.

Shoulder Drain The function of shoulder drain is to collect water that has fallen on the carriageway and the batters of embankments to direct to the edge of the formation.

Cascade Drain	The function of cascade drain is to cater for water flowing along the roadside and shoulder drains and natural drainage path that are cut off on top of a cut or fill section.
Berm Drain	Berm drains are located on the berm of a fill section to intersect water running down the slope. The function of berm drain is to catch rainwater falling on the fill slope immediately above.
Toe Drain	The function of toe drain is to collect water that has fallen on the carriageway and the batters of embankments to direct to the edge of the formation or stream.
Scupper Drain	A scupper is an opening in the side walls of an open-air structure such as a road-curb, for purposes of draining water. They are usually placed at or near ground level, and allow rain or liquids to flow off the side of the road -curb.

Figure 1.1 : Types of Surface Drainage

2.0 IDENTIFYING FLOW DIRECTION OF SURFACE DRAINAGE

Provision for adequate drainage is of paramount importance in road design and cannot be overemphasized. The presence of surface water within the road water catchment will adversely affect the engineering properties of the materials with which it was constructed. Cut or fill failures, road surface erosion, and weakened subgrades followed by a mass failure are all products of inadequate or poorly designed drainage. As has been stated previously, many road erosion failures can be avoided if the surface water is well design.

Road drainage is process of removing and controlling surface and sub-soil water within the right of way. The surface water from the carriageway and shoulder should effectively be drained off without allowing it to percolate to sub grade and also water from adjoining land should be prevented from entering the roadway. The road should be adequately sloped to drain the water away from the travel lanes and shoulders and then directed to drainage channels in the system, such as shoulder drain, roadside drain, natural earth drain, and concrete gutters, for discharge to an adjacent body of water. To determined flow direction of every surface drainage it must be referred to the horizontal alignment, vertical profile and cross section which include elevation of the contour lines and from the survey data. **Figure 2.1** shows a Plan & Longitudinal Profile that needs to be referenced into to identify flow direction of surface drainage.

2.1 Plan And Longitudinal Profile

To identify which direction water flow in surface drainage is to determine which is cut and fill section. In the fill section, tadpole shape is pointing away from the alignment whilst, the cut section is determined by tadpole pointing towards the alignment as shown in **Figure 2.1**. From the figure, if the cut section is spread widest along design alignment, it shows the highest point in cut section. Whereas in fill section, the widest spread of the fill section represent the lowest point.

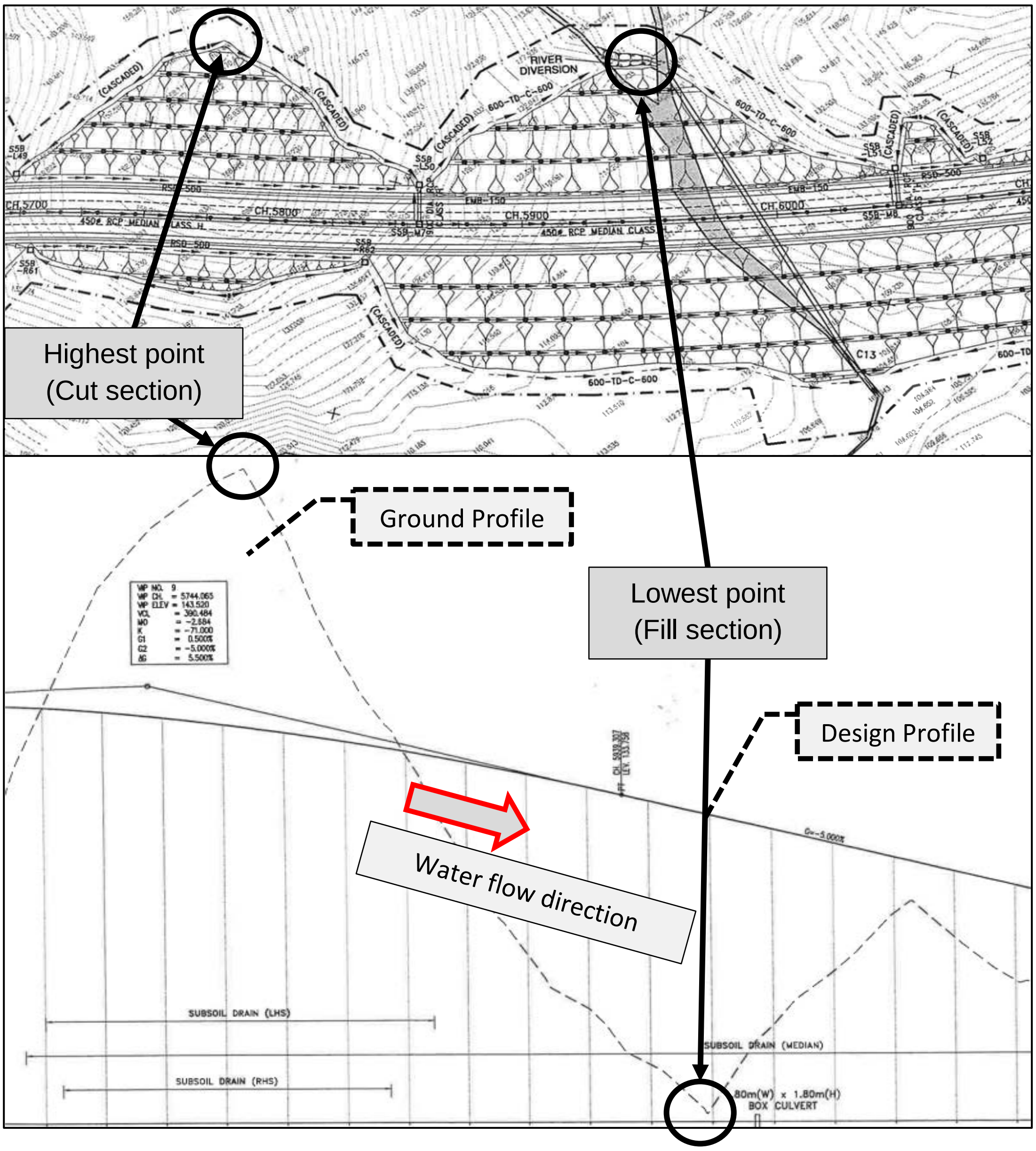

Figure 2.1: Plan and Longitudinal Profile

2.2 Interceptor and Toe Drain

Interceptor and toe drain flow direction are determined by examining the gradient direction of the ground profile. It starts from the maximum point of the cut section and flows towards the lowest point of the fill section where it is discharged to the nearest stream shows in **Figure 2.2**.

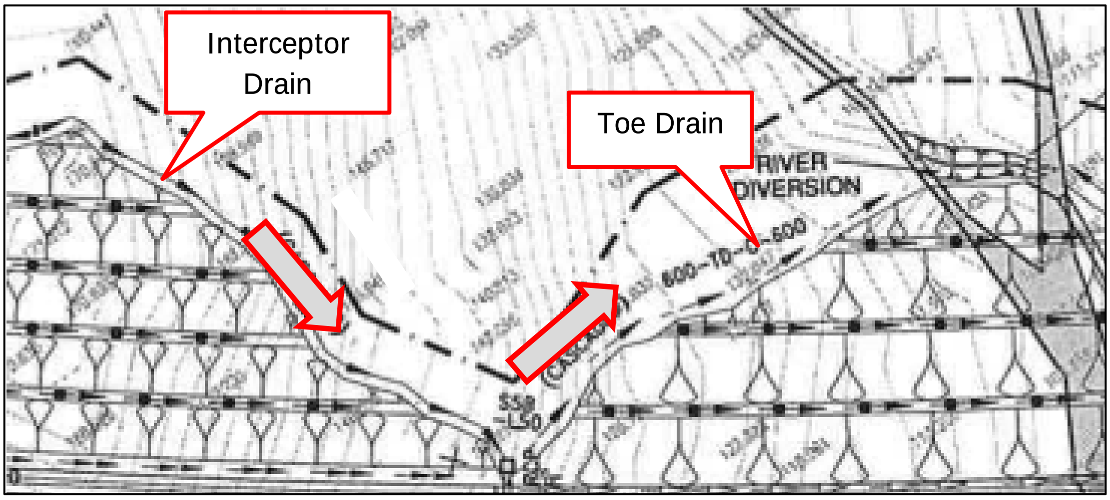

Figure 2.2: Water flow for both cut section and fill section on ground profile.

2.3 Berm Drain

Berm drain flow direction are determined by examining the gradient direction of the berm design profile. It starts from maximum point along the berm of fill section and flows towards to the toe drains. **Figure 2.3** shows all berm drains outlet are discharged to toe drain.

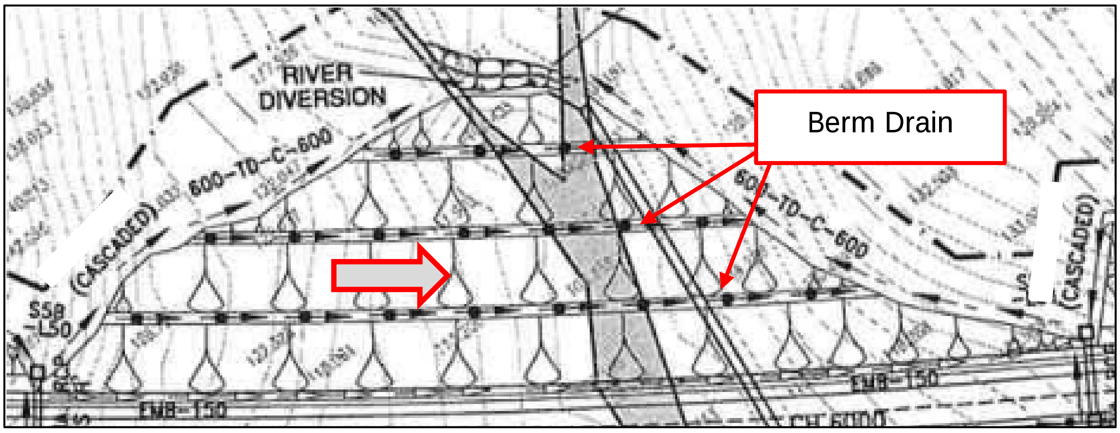

Figure 2.3: Berm drain for fill section. Direction water flows from maximum point in design profile.

2.4 Bench drain

Bench drain flow direction are determined by examining the gradient direction of design profile. It starts from maximum point along the bench of cut section and flows towards to the interceptor drains. **Figure 2.4** shows all bench drains outlet are discharge to interceptor drain.

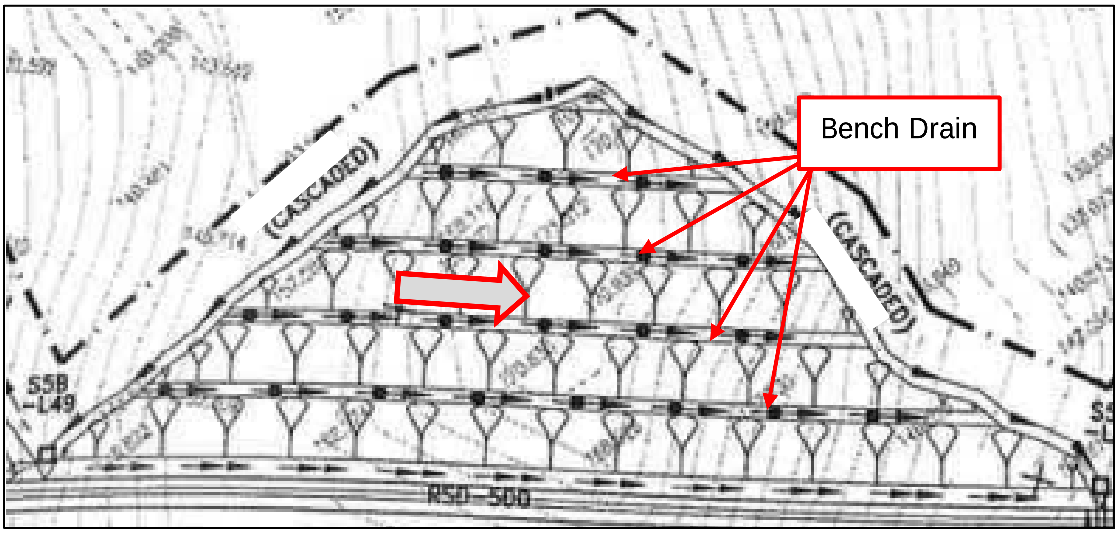

Figure 2.4: Bench drain for cut section. Direction water flows from maximum point in design profile.

2.5 Roadside drain

Roadside drain flows direction are determined by examining the gradient direction of design profile. It starts from maximum crest point of roadside drain and flow towards the lowest sag point along cut section and discharge to the nearest sump. **Figure 2.5** shows roadside drain located along cut section.

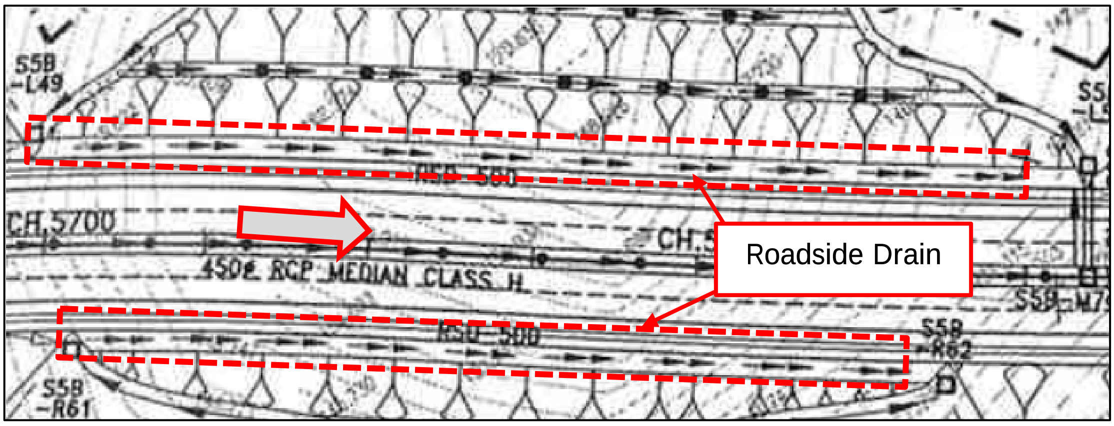

Figure 2.5: Roadside drain

2.6 Shoulder drain

Shoulder drain flows direction are determined by examining the gradient direction of design profile. It starts from maximum crest point of shoulder drain and flow towards the lowest sag point along fill section and discharge to the nearest sump. **Figure 2.6** shows shoulder drain located along fill section.

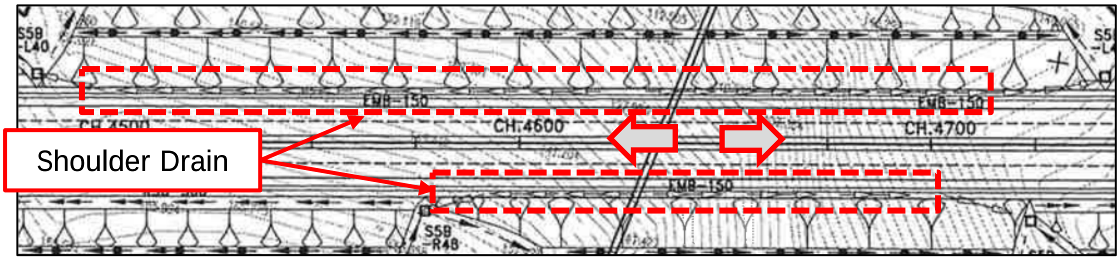

Figure 2.6: Shoulder drain

2.7 Median drain

Median drain flows direction are determined by examining the gradient direction of design profile. Range of median drain are from Tangent to Spiral (TS) point to Spiral to Tangent (ST) point in transition curve. It starts from the maximum point to the lowest point and discharge to the nearest outlet. **Figure 2.7** shows median drain in dual carriageway road design.

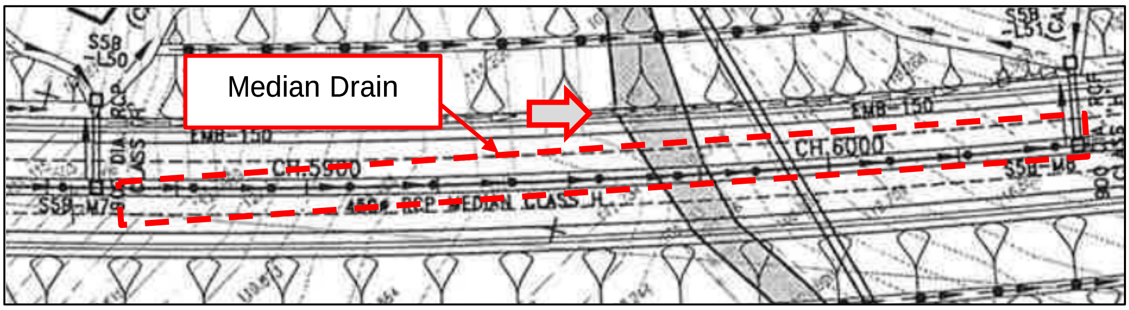

Figure 2.7: Median drain

2.8 Other types of drain

For other types of drain, the flow direction are determined by examining the gradient direction of the design profile. It starts from the maximum crest point of that particular drain type and flow towards the lowest sag point.

3.0 IDENTIFYING LOCATION AND FLOW DIRECTION OF CULVERT

3.1 OVERVIEW

Culvert is a structure that allows water to flow under a road or embankment from one side to the other side. Typically embedded so as to be surrounded by soil, a culvert may be made from a pipe, reinforced concrete or other material.

Culverts are commonly used both as cross-drains for ditch relief and to pass water under a road at natural drainage and stream crossings. A culvert may be a bridge-like structure designed to allow vehicle or pedestrian traffic to cross over the waterway while allowing adequate passage for the water. Culverts come in many sizes and shapes including round, elliptical, flat-bottomed, pear-shaped, and box-like constructions. The culvert type and shape selection is based on a number of factors including requirements for hydraulic performance, limitation on upstream water surface elevation, and roadway embankment height.

Selection of culvert location is an integral part of the total design. The main purpose of a culvert is to convey drainage water across the roadway section expeditiously and effectively. The designer should identify all live stream crossings, springs, low areas (including localised low areas), gullies, and impoundment areas created by the new roadway embankment for possible culvert locations. Culverts should be located on existing stream alignments and aligned to give the stream a direct entrance and a direct exit. Abrupt changes in direction at either end may retard the flow and make a larger structure necessary. If necessary, a direct inlet and outlet may be obtained by means of a channel change, skewing the culvert, or a combination of these. The choice of alignment should be based on economics, environmental concerns, hydraulic performance, and/or maintenance considerations.

3.2 CULVERT TYPE SELECTION

Culvert type selection includes the choice of material, shape, cross section and the number of culvert barrels that will best fit the waterway of the channel or stream.

The following factors should be considered in any culvert type selection:

a) design discharge (Q),
b) site conditions: vertical clearance, blockage due to floating debris from upstream
c) construction period,
d) construction joints,

If the design discharge exceeds 60m^3/s based on a 50 years recurrence interval, consideration should be given to using a bridge structure taking into account the site constraints and economic factors.

3.3 TYPICAL SHAPE AND USES OF CULVERT

These are the typical shape of culvert used widely in construction:

a) round/circular – common uses for small discharge
b) box – common uses, especially where discharge are higher
c) arch – low clearance large waterway opening and aesthetic

3.4 HOW TO DETERMINE LOCATION AND FLOW OF CULVERT

Culvert location refers to the horizontal alignment and vertical profile with respect to both roadway and stream. A proper location is important because it affects hydraulics, the adequacy of the opening, maintenance of the culvert and possible washout of the roadway. The basis to determine culvert location:

Longitudinal Profile

Every local lowest point that occurs within/along a road design profile should be investigated for possible culvert location. Local lowest point can represent the area where water might accumulate or flow.

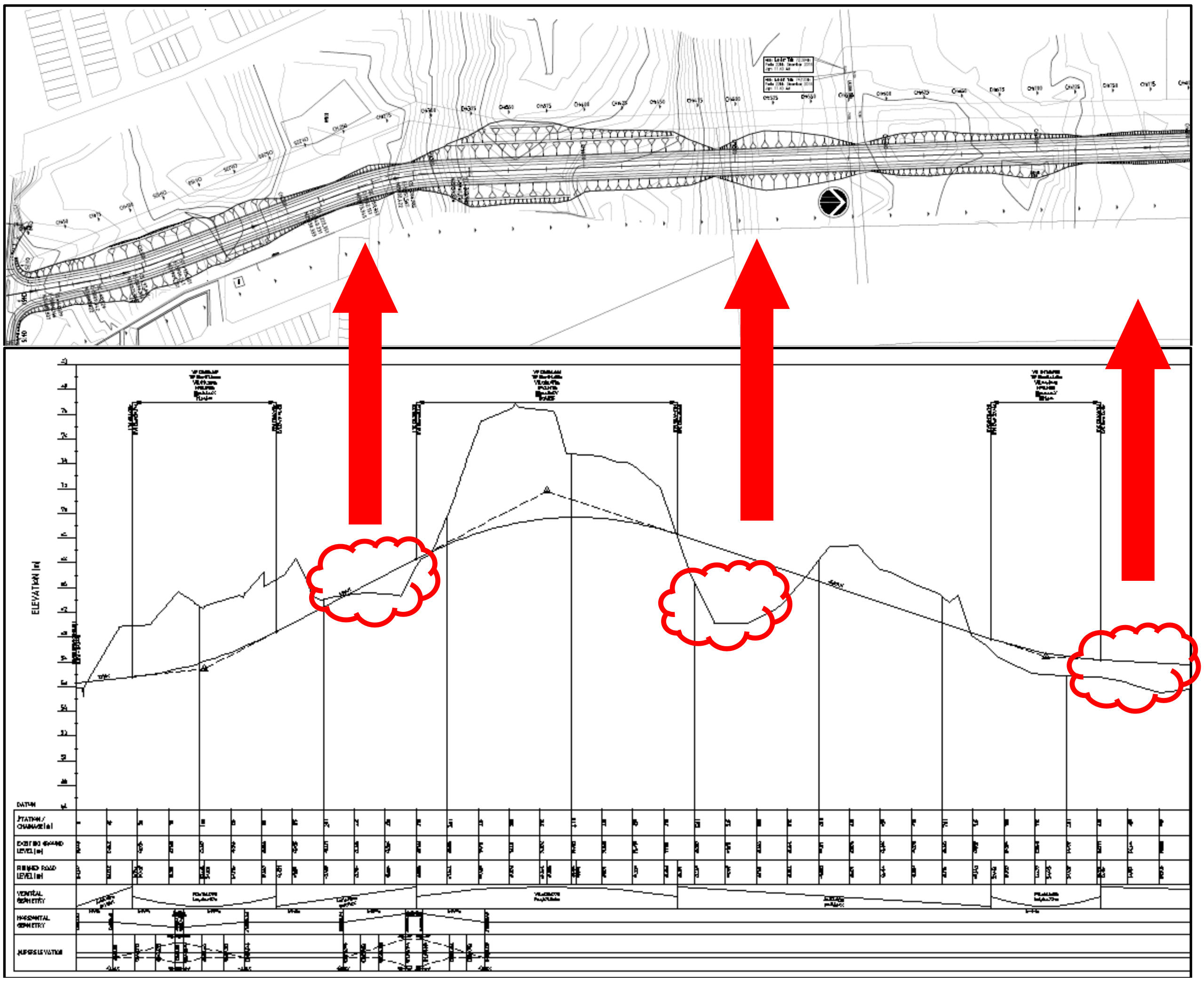

Figure 3.1: Plan and Longitudinal Profile

Plan

While water may possibly accumulate at the local lowest point, designer must take into account that water ponding might not happen as the water can also flow out of that area by taking a path that brings it to the lower area outside. This local lowest point must be checked concurrently with the contour from the plan to confirm whether culvert needs to be located at that particular area.

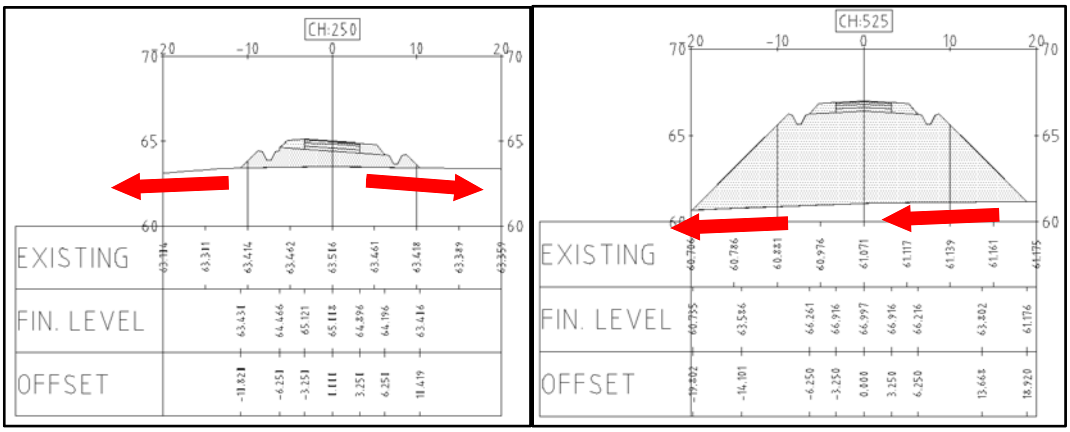

Figure 3.2: Cross Section

Cross-section

The use of cross-section can also help to verify whether a culvert needs to be placed or not. It also helps to determine the elevation of the culvert inlet and outlet and the direction of the flow. Take CH250 as an example (**Figure 3.2** left); when view from the plan (**Figure 3.1**), it shows that water is likely to accumulate in the localized lowest point. However, view from the cross-section and ground profile show a concave shape profile where water will moves away from the embankment; summarizing that there is no need to place a culvert.

In **Figure 3.2** right, it can be seen that water flows from the right side to the left. When a culvert is to be located here, this direction of flow must be followed through to prevent water stagnation on the right side.

Horizontal Alignment

Culvert should be aligned with the existing flow where it gives the stream a direct entrance and a direct exit (**Figure 3.3** left). Pertaining to the plan profile, largest width of fill slope should be taken as a location to place the culvert (**Figure 3.3** right).

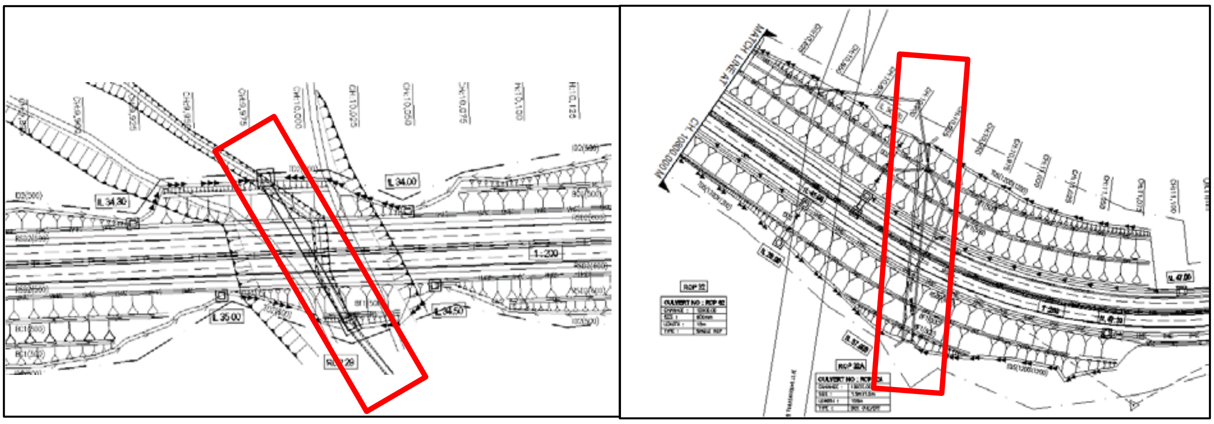

Figure 3.3: Horizontal alignment

Modification/realignment of a river alignment is needed when:

a) Natural channel requires longer culvert
   - When the road alignment crosses natural stream on acute angle, it requires a longer culvert to channel the existing flow.
   - This will increase the cost, reduce the efficiency and make the maintenance more complicated.
   - One way to overcome is by reducing skewness and shortens the culvert.
   - This also requires stream realignment. It should be designed properly so as to avoid erosion on the concave side of the channel and siltation on the inner side of the bend.

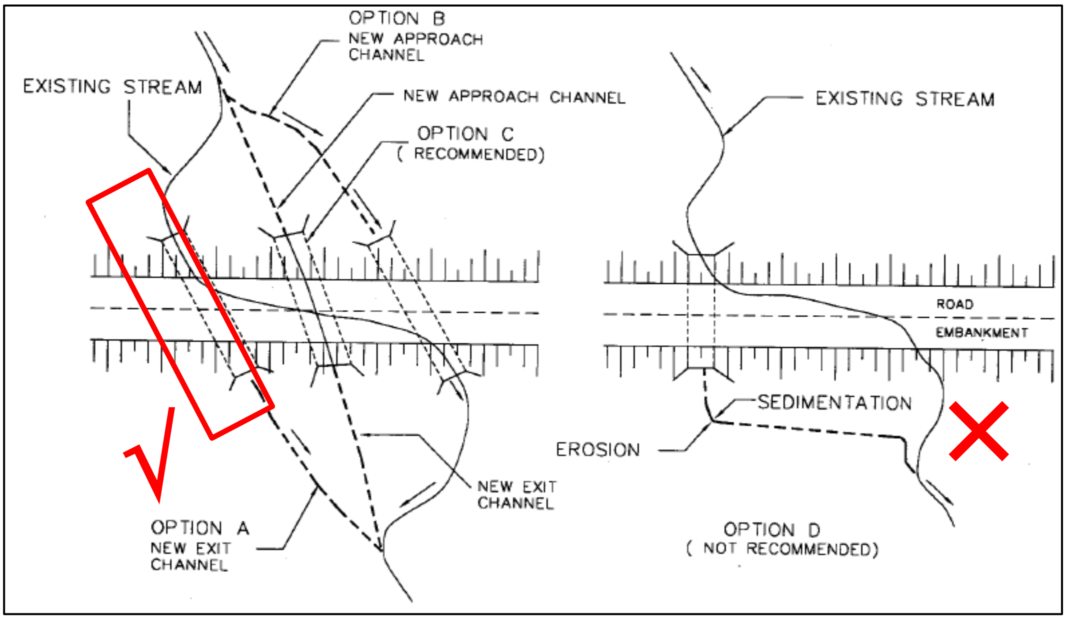

Figure 3.4: Stream Alignment

b) Culvert gradient too steep or too shallow
   - Steep gradient may expose the streambed to degradation or scouring while shallow gradient will cause siltation inside the culvert.
   - Changing the culvert gradient accordingly can improve hydraulic performance of the culvert, prevent stream degradation or minimise sedimentation. It will also reduce structural requirement needed for a culvert with high embankment.

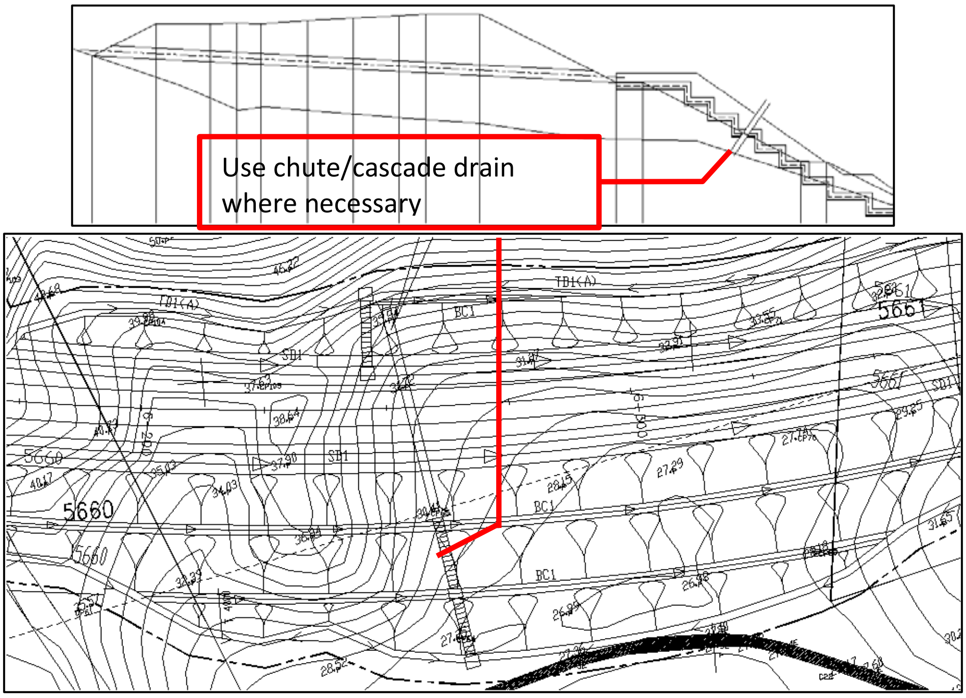

Figure 3.5: Culvert with cascade drain

3.5 CULVERT FOR MEDIAN DRAIN

Special attention need to be given when designing the median drain. Its position in the middle of the road hinder it from connecting directly to the toe/roadside drain. This can lead to water ponding on the center of the road if not being taken care off. Two issues to look at are:

a) On the drainage part: the length of the median drain should stretch from TS to ST point on the superelevation section
b) On the culvert part: the lowest elevation along the stretch of the median drain should be the discharge point. A discharge culvert should connect between this point to the toe/roadside drain.

3.6 BALANCING CULVERT

Where there is an area with a long stretch uniform embankment along the alignment, it may represent a swampy or inundated area. Balancing culvert must be provided to cater for water fluctuation/movement between both sides of the embankment.

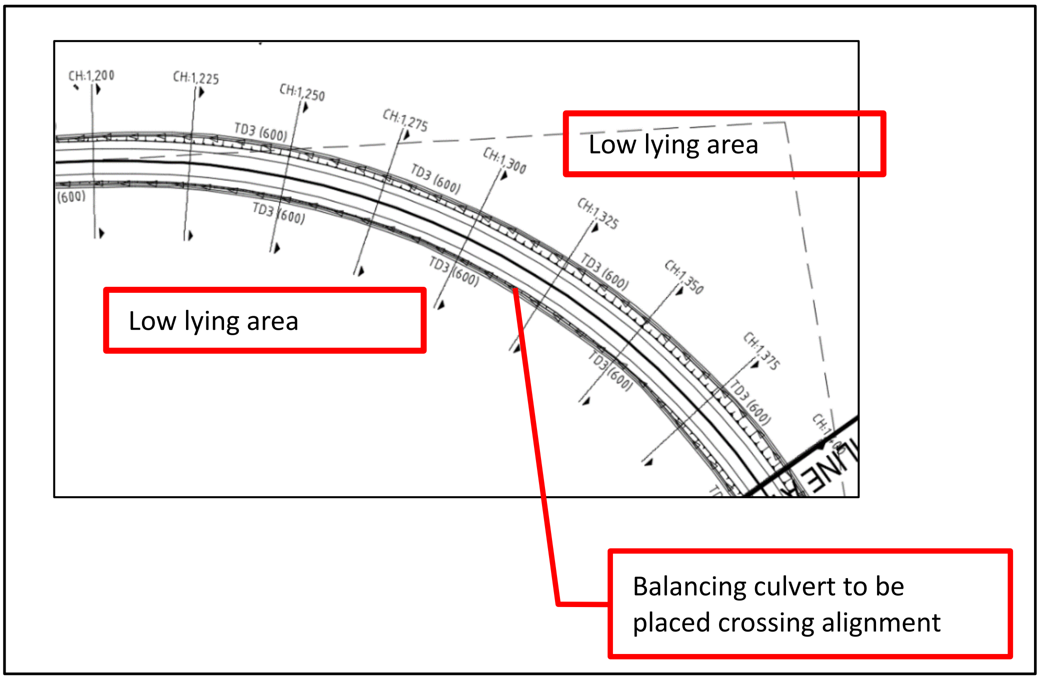

Figure 3.6: Road alignmentstretching in a Low lying area

4.0 LESSON LEARNED ON DESIGN ERROR

4.1 FAILURE TO LOCATE PROPER CULVERT LOCATION

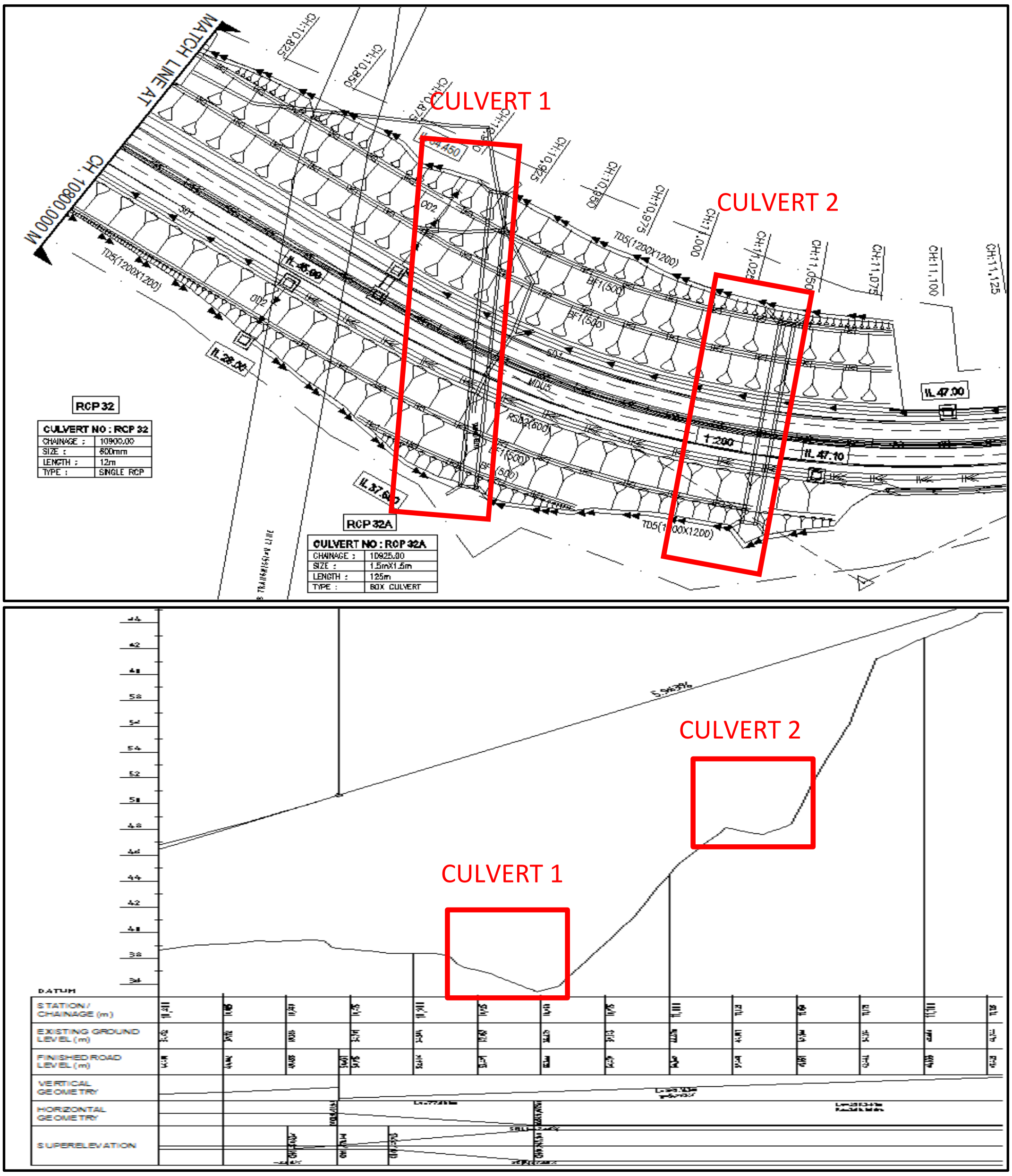

Figure 4.1 : Plan and Longitudinal Profile

As depicted above, there are two culverts being located near to each other. The concepts of locating a culvert by locating the local lowest point seems to be the right thing to do. But in this case, the confirmation with the plan and cross section is not being done simultaneously. A review on the cross-section's elevation shows that the water can move further down without the use of the **culvert 2 - Figure 4.1** (this can be done by trenching the drain deeper to get the desired gradient). While it is not totally wrong, the thorough checking to locate the culvert can save cost to the project.

The proposed solution comes back to the fundamental of how to identify culvert location. Longitudinal profile should be viewed as a whole and not partially. Detailed check should be done together on profile, plan, cross sections and triangulated ground model.

4.2 INSUFFICIENT STRUCTURAL CAPACITY

One of the elements to consider in designing the culvert is the structural capacity of the culvert. Common type of culvert design usually can only hold embankment up to about 2 meters high. Proof load of the culvert that sits on high fill embankment should be calculated to make sure it has an adequate strength. Design with higher over-burdened load must be designed specifically for that load. Negligence to take this into account will lead to the failure of the culvert.

4.3 CASCADE DRAIN IS NOT PARALLEL TO THE CULVERT SKEW.

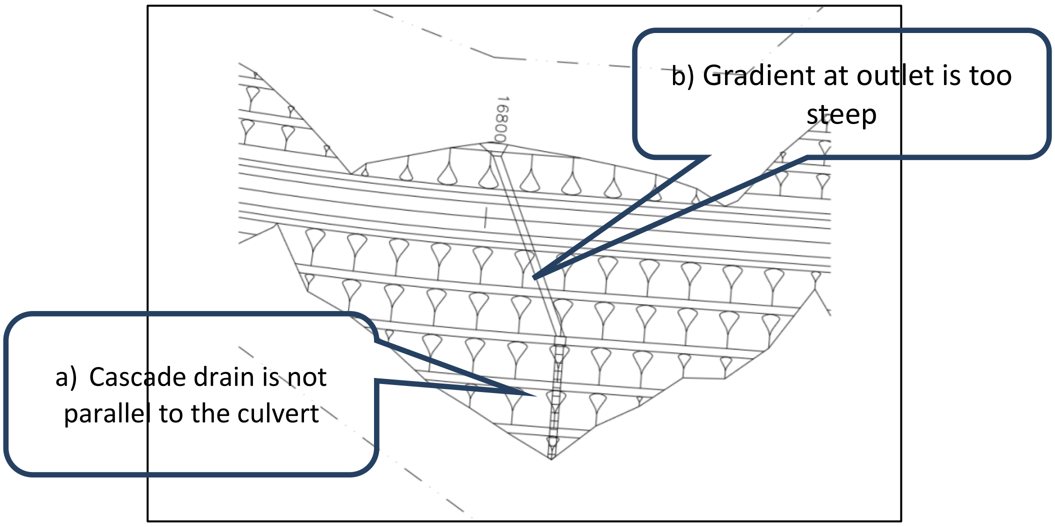

Figure 4.2: Imbalance Embankment

Referring to the Figure 4.2, the cascade drain position at (a) was not parallel to the culvert skew position (b). When the velocity of water was high, the water bounce out as there was a bend between the culvert and the cascade drain.

Effects for this case the slopes were eroded and eventually damaged the slopes and caused slope failure. Besides, it also increased the cost for repairing works.

The solutions for this case are to design the cascade drain parallel to the culvert skewness. Sump should be used in between the culvert outlet and cascade drain. Please refer to the Figure 4.3.

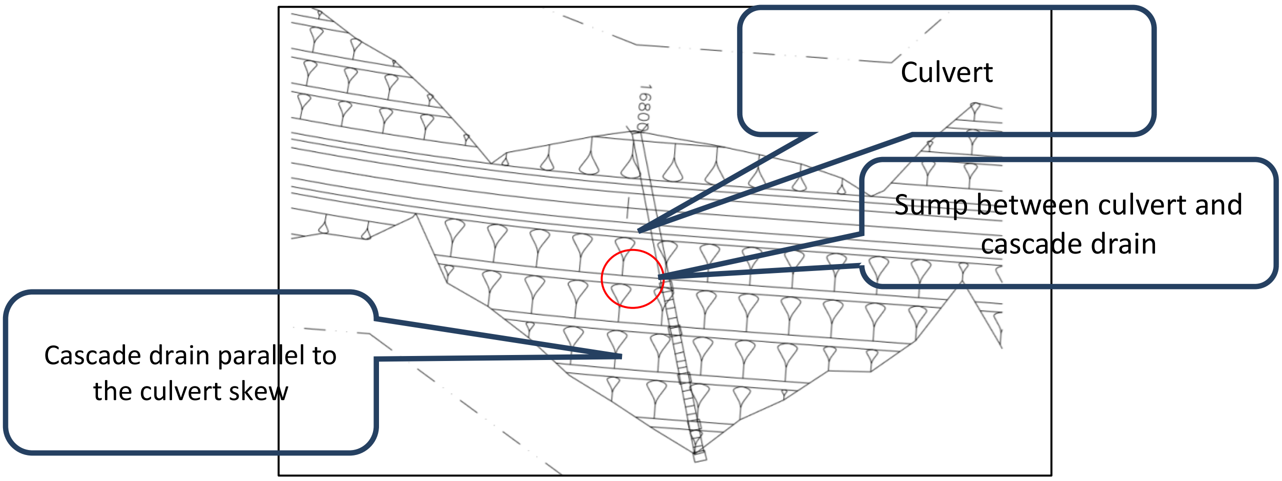

Figure 4.3: Cascade drain parallel to the culvert skewness

4.4 NO CASCADE DRAIN AT IMBALANCE EMBANKMENT LHS AND RHS

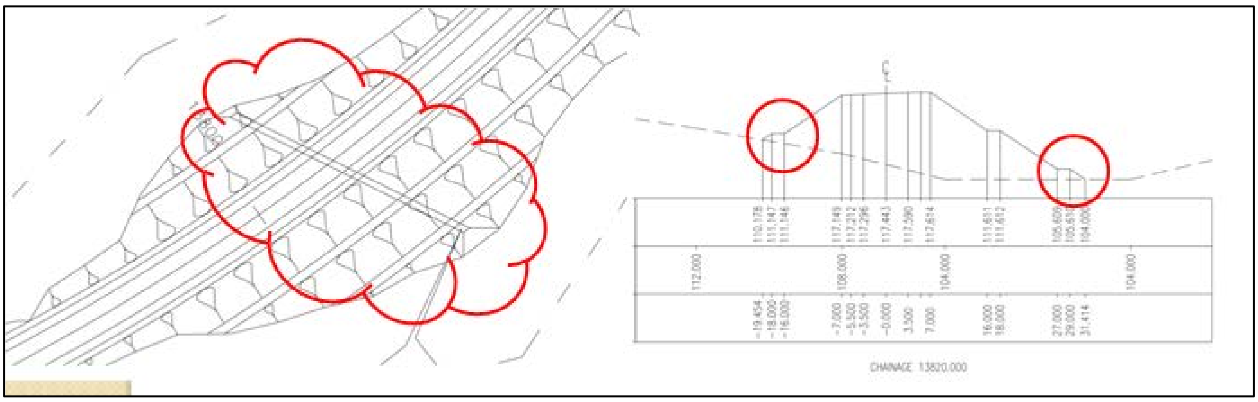

Figure 4.4: Plan and cross-section

Referring to the Figure 4.4 plan and cross-section, it showed that the embankment at LHS and RHS were imbalance (not at the same level) and the gradient between culvert inlet and culvert outlet were too steep. Steep gradient may expose the streambed to degradation due to less resistance and have greater velocity. The increase in velocity can cause excessive erosion or scour of the downstream channel and lead to structural failure of the road embankment / slope and the culvert itself.

The solution to this case is by reduce the culvert gradient accordingly can improve hydraulic performance of the culvert and prevent stream degradation; proposing the sump and cascade drain / chute should be installed at the slope according to the culvert skewness to direct and control the water that flow towards the embankment's toe or water body nearby. Please refer to the Figure 4.5 & 4.6.

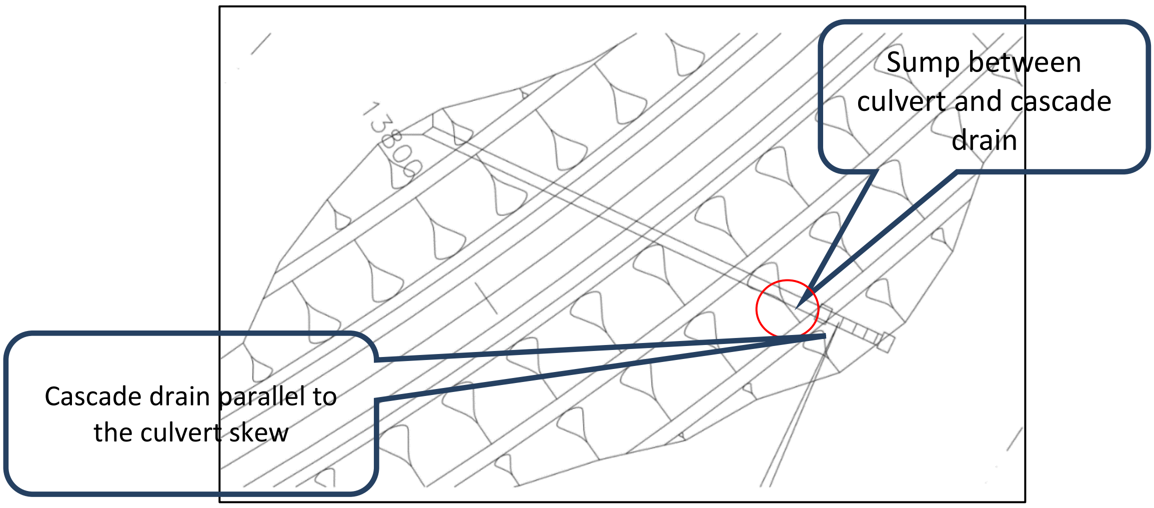

Figure 4.5: Cascade drain at the culvert outlet.

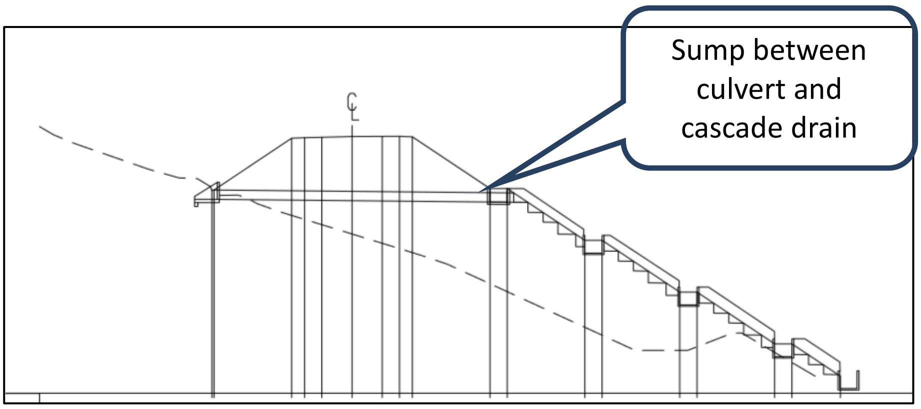

Figure 4.6: Proposed cascade drain at culvert outlet and control the IL.

4.5 WRONG LOCATION OF THE CULVERT AND DRAINAGE FLOW

Referring to Figure 4.7, the culvert outlet was not located at the lowest point and the drainage flow direction was wrong. Ideally, a culvert should be placed in the natural channel or localised lowest point (refer chapter 3.7). Failure to locate the culvert at the lowest point may contribute to the erosion of the slope.

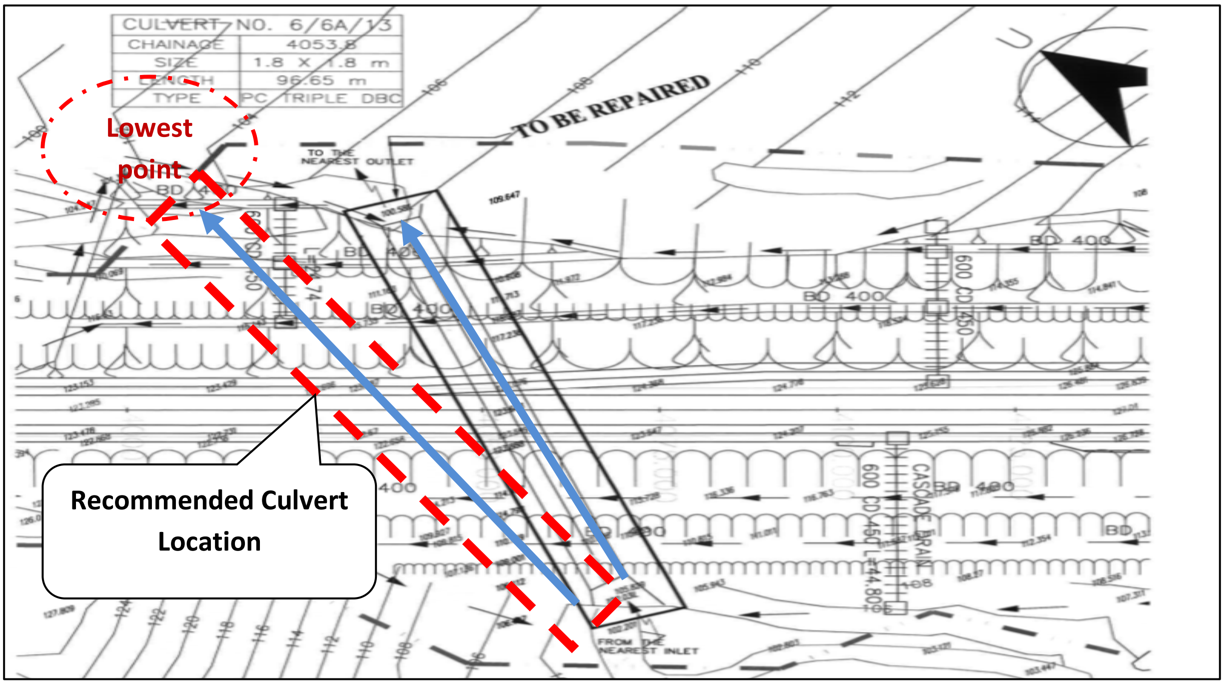

Figure 4.7: Recommended Culvert Location

5.0 LESSON LEARNED ON CULVERT FAILURE

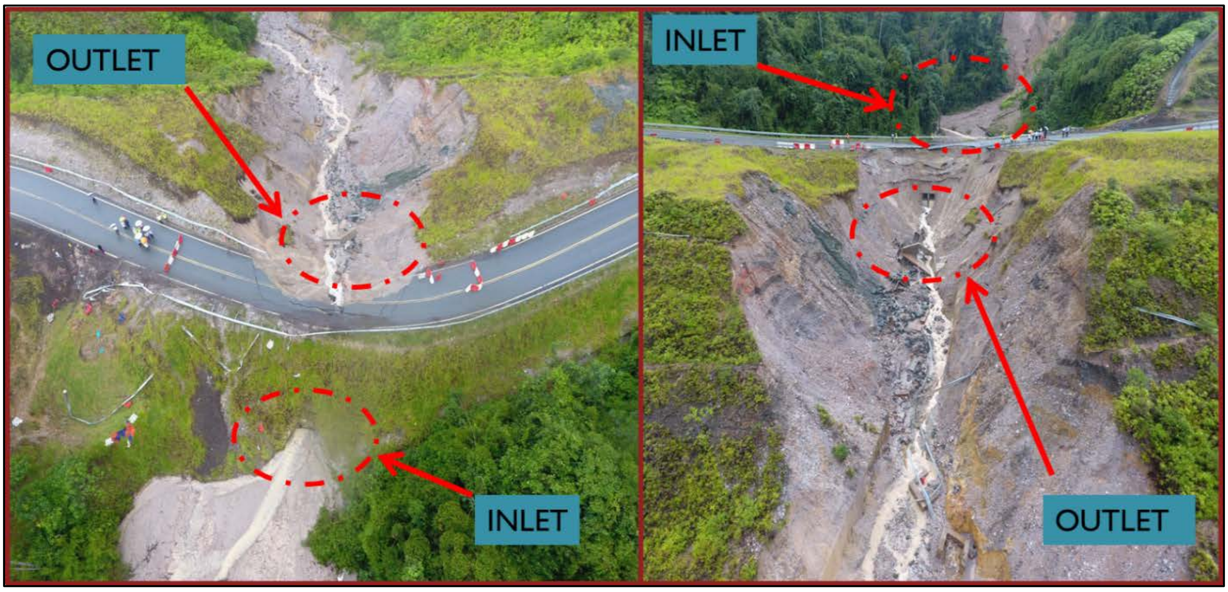

Figure 5.1: Site Observation 1

From Figure 5.1 above, this is a failure on a Federal Road, where several precast culvert segments and headwall and wingwall were seen being washed away together with the slope erosion on the outlet end. On the inlet end severe debris and sand can be seen accumulated on the inlet, possibly from erosion further upstream.

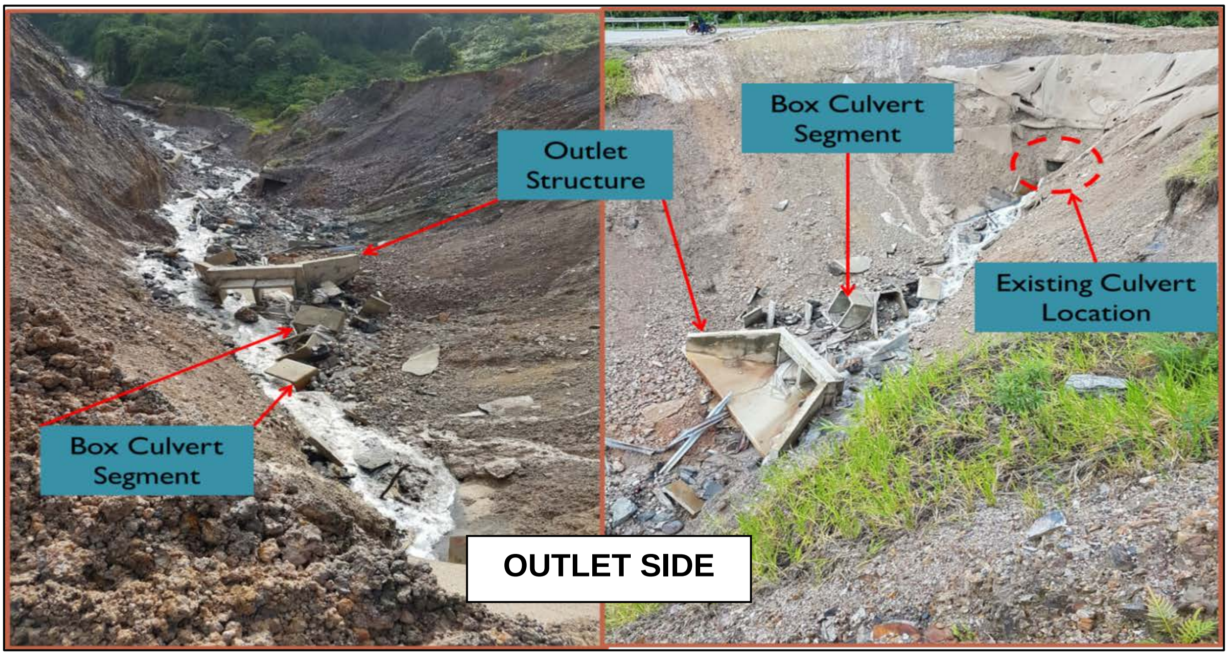

Figure 5.2: Site Observation 2

From Figure 5.2, we can see that a headwall and wingwall structure has been used at outlet location. Several precast box culvert segments can be seen in the pictures above.

5.1 EXISTING CULVERT ARRANGEMENT

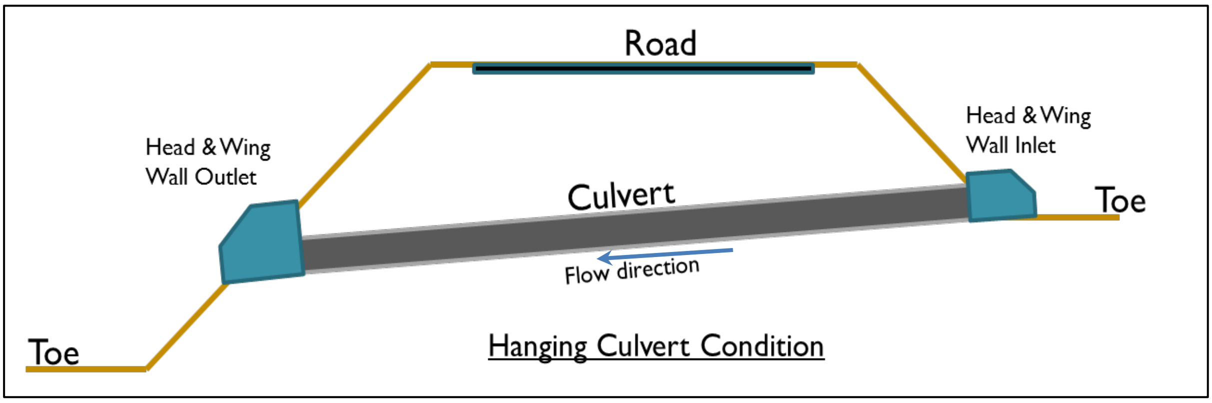

Figure 5.3: Existing Culvert Condition

The existing culvert arrangement was built as per Figure 4.3 above or "hanging culvert condition". This condition happened due to the obvious different to the slope height of the road's embankment. The invert level for inlet need to follow existing toe level to make sure the water from inlet's side can flow crossing road embankment to the outlet's side. The invert level for outlet was control by the design's calculation as it needs to consider others factors such as gradient, culvert length, skew etc. Hence, the outlet for this culvert was located on the slope of the embankment. From the observation, the headwall & wingwall structure were used at this location and no cascade drain was sighted at the site.

5.2 DESIGN WEAKNESS

Based on the observation to the failure conditions, the possibility of under estimation of the flow rate of the culvert might be one of the factors to this failure. This under estimate of flow rate will cause the headwater at inlet to exceed the maximum headwater that been used in design calculation which created more pressure at outlet end.

Other than that, from the existing culvert arrangement, it can be seen that the headwall & wingwall structure were used as the outlet structure for the culvert. For this kind of situation, where the outlet structure stand on a slope ("Hanging Culvert Condition") the used of sump as the outlet structure was crucial instead of headwall & wingwall structure as this cannot control the discharge from culvert and the water to direct the flow towards the toe drain or water body nearby.

A cascade drain should be installed parallel to the culvert to direct and control the water that flow toward the toe drain or water body nearby and it should have enough wall height to prevent the water from spilling out to the slope which can lead to slope erosion and failure of the slope.

Apart from that, there is no sign of foundation being used for the precast culvert such as raft footing, pile, concrete cradle etc. Normal sand bedding cannot prevent the failure from happening when the water seep through the culvert joint and weakened the sand bedding.

5.3 RECOMMENDED CULVERT ARRANGEMENT

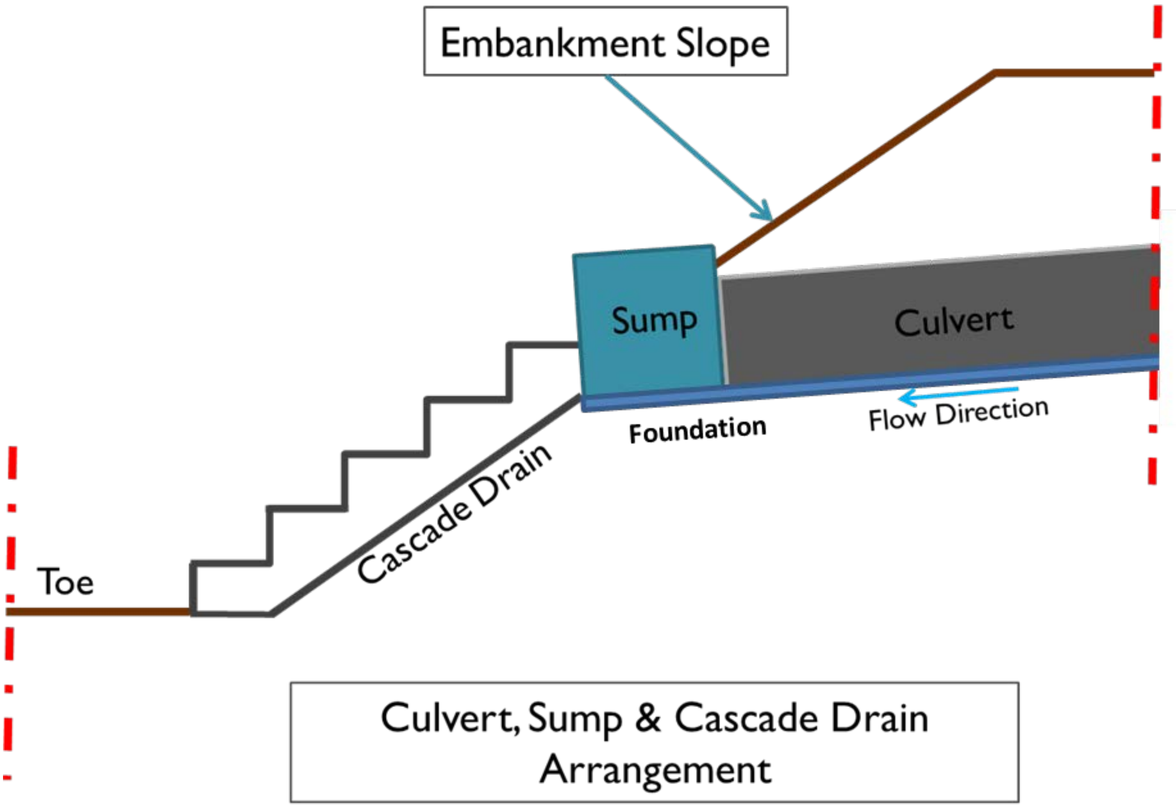

Figure 5.4: Culvert, Sump & Cascade Drain Arrangement

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