OPTIMUM HYDRAULIC AND STRUCTURAL DESIGN OF MULTI-CELL BOX CULVERT

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DEDICATION

This work is dedicated to the Authors' Family to whom he belongs and his family to be.

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ABSTRACT

The economical design of culvert is a vital engineering decision due to the multiple repetitive requirements in the construction of highway facility. It is therefore important to seek for the cost effective design technique in order to reduce the project cost of highways with high demand of such structures.

The economic design can be achieved through conventional culvert design practice, but the maximum economy can only be achieved by optimizing the design. The optimization procedure shall be applied from the hydrologic design, via the hydraulic design to the structural design in order to yield hydrological, hydraulic, and structurally optimal designed culvert structure.

The hydraulic design determined the size of the culvert and barrel number requirement for the structure to control the passage of storm water flow through it, with risk, economy, property damage, highway overtopping and damage, in mind.

Effective structural design is necessary for the resistance of the structure to various load combination induced from the highway traffic, overfill material, backfill material, hydrostatic thrust, self-weight, and the pressure due to the pipe flow condition.

When site conditions warrant, it is more economical to provide a multi-cell box culvert structure than to embark on the construction of resources consuming bridge structure.

The hydraulic design is according to the method developed by American Association of State Highway and Transportation Officials (AASHTO Methods) and Federal Highway Administration. The structural analysis is done using computer frame analysis software developed by Department of Civil and Structures, Manchester, United Kingdom. The structural design is according to BD/37 "Design of buried concrete structures" and BS8110 "Structural Use of Concrete: Part 1 Code of Practice for Design and Construction".

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CHAPTER 1

INTRODUCTION

1.1 General

Culverts are short conduits sized for the passage of surface drainage under a highway, railroad, canal and other embankment, without overtopping the fill material and eroding the fill at both upstream and downstream side of the structure. They are conventionally measuring up to clear span of 6m. But, they can also be designed up to 8m spans in special cases, as in multi cell box culvert, when the span is more than 6m, then the structure is regarded as bridge.

Culverts also differ from the bridges in that they are usually covered with embankment and surrounded by structural material around the entire perimeter of the surface area. The primary function of culvert is to convey surface water across the highway right of way in addition to the hydraulic function; they may also serve as a support of embankment and roadway for traffic conveyance. Culverts can also be provided for the passage of utilities in order to avoid damage to existing highway pavement, stock and wildlife passage, land access, fish passage, and measurement of discharge through a channel.

The design of culvert involves hydraulic and structural consideration coupled with stability check against effect of buoyancy; scour, piping, and erosion of the embankment fill material. They are usually considered as a minor structure, but they are of great importance to drainage and integrity of highway facility. The most commonly used types of culverts are the pipe and box culverts.

The design of the concrete box culverts in Malaysia is quite different from the method used in many part of the world, in that the roof slab is usually simply supported on a U-shaped formed frame, sometimes grooved bottomed slab is used for the conveyance of dry flow discharge, through the culvert.

1.2 Types of Culverts

Culverts are constructed from variety of structural material, which comes in different shape or which can be constructed in different sizes, shapes and configuration. Therefore, their classification can be according to the following considerations:

a. Structural shape and form
b. Material of construction
c. Longitudinal arrangement
d. End treatment

1.2.1 Structural Shape and Form

The selection of culvert shape is dependent upon the following considerations; construction cost, the potential of clogging debris, roadway profiles, channel characteristics, flood damage evaluation, estimate of service life and public safety. Some of the structural shapes commonly used are:

- Circular (pipe)
- Elliptical
- Box or rectangular
- Arches
- Metal box

1.2.2 Material of Construction

The selection of material for a culvert is dependent upon various considerations such as structural integrity and strength, roughness, water tightness, durability, abrasion and corrosion resistance and finally bedding conditions. Some of the materials used are:

- Concrete (reinforced and non reinforced)
- Steel (smooth and corrugated)
- Corrugated aluminum
- Vitrified clay
- Bituminous fiber
- Cast iron
- Stainless steel
- Wood or timber

1.2.3 longitudinal Arrangement

The culverts are classified in relation to either the direction of stream flow or to the centerline of the roadway, the types are:

- Straight culvert
- Skewed culvert

When the arrangement of culvert center to the centerline of the road way is orthogonal and inclined the culvert is regarded as straight or skewed respectively. Likewise when the arrangement of the inlet and outlet ends of the culvert is orthogonal facing the flow direction it's also regarded as straight culvert. When the angle of inclination between the central axis of the culvert and that of flow direction is less than 25 degrees its also conventionally termed as straight culvert, when greater than 25 degrees is then considered as a skewed culvert.

1.2.4 End Treatment

Culverts are usually facilitated with end structures, which may be built as a pre cast segments or constructed in situ, in order to reduce erosion, inhibit seepage or piping, retain fill material, improve aesthetics and hydraulic performance. Some types of end treatment are as follows:

a. Mitered Culvert End

This type of culvert end is formed when the barrel is tapered or cut to conform with the sloping plane of the embankment. The treatment is used mainly for large metal culverts for the improvement of their end appearance. It has to be well anchored in order to resist hydraulic, earth, and impact loads. It is found to have approximately equal hydraulic performance with a thin edged projecting inlet discussed earlier.

b. Projecting Culvert End

A culvert is referred to as projecting end when the barrel extends beyond the face of the roadway embankment. It is an economical, but unpleasant looking method of end treatment, it is therefore recommended on site with less aesthetic consideration such as bush, off sight locations

c. Pipe End Section

Which is also called flared or terminal end section, in this type of culvert metal or pre cast concrete section are placed on the ends of the culverts. The section function in the retention of embankment material and improvement of aesthetics, but are structurally in significant. They are also not very efficient to the hydraulic performance of the culvert when compared to end treatment like the headwall.

d. Headwalls and Wing walls

They are cast in place concrete structures commonly built on the ends of culvert barrels, which are mainly monolithically connected, to serve the following purposes:

- Improve hydraulic performance
- Increase the weight of the structure, hence preventing buoyancy
- Inhibit piping
- Retain fill material
- Reduce erosion of the embankment.

1.3 Improved Inlets

Culvert capacity is based on either culvert entrance conditions (inlet control) or barrel resistance (outlet control). For inlet control, the culvert's capacity is based only on entrance configuration and headwater depth, in which case the culvert barrel could handle more flow than the inlet. Therefore, for culverts operating in inlet control the use of improved inlets would maximize the barrel capacity.

Culverts in inlet control usually lie on steep slopes and flow only partly full. Entrance improvements can result in a reduction in barrel size and a proportional reduction in project cost. The amount of reduction depends on site conditions and engineering judgment regarding the dependability of flood estimates and limiting headwater elevations to avoid damages. Improved inlets may be constructed on existing culverts with inadequate capacity.

This may avoid the replacement of the entire structure or the addition of a new parallel culvert. Three types of inlet improvements should be considered, these are:

- Bevel – edged inlet,
- Side – tapered inlet,
- Slope – tapered inlet.

Side tapered inlets have an enlarged face area with tapering sidewalls to transition to the culvert barrel. They can provide as much as 40 percent increases in flow capacity over that with conventional inlets. Slope-tapered inlets provide a depression or fall in conjunction with a taper at the inlet In some cases they can provide over 100 percent greater capacity than a conventional inlet. Cost of excavation and sediment potential are prime considerations for these designs.

1.4 Energy Dissipater

The failure of many highway culverts can be traced to unchecked erosion. Erosive forces, which are at work in natural drainage networks, are often increased by the construction of a highway. Constriction of natural waterways inevitably leads to increased erosion potential. To protect the highway and adjacent areas it is sometimes necessary to employ energy dissipating devices. Energy dissipaters should be considered a part of a larger design system, which includes the culvert, improved inlets, channel protection (both up and downstream), and debris control structures.

The use of improved inlets many times is complemented by the use of an energy dissipater. There are several types of energy dissipaters available. The Federal Highways Administration's publication Hydraulic Design of Energy Dissipaters for Culverts and

Channels (Hydraulic Engineering Circular 14) should be consulted in the design of these Structures. It is hydraulic design policy to design energy dissipaters for the 25-year frequency peak discharge or for a lesser frequency if the headwater design is based on a lesser frequency. The headwater design should still meet the requirements of Hydraulic Design Frequency Criteria.

1.5 Reinforced Concrete Box Culvert

Reinforced concrete box are square or rectangular rigid framed cross section with spans up to 4m.The height of the vent or barrel rarely exceeds 3m.The top of the box section can be at the road level or can be buried below the road level with a convenient fill material depending on the site profile and condition. A box culvert lends itself more readily than other shapes to low allowable headwater situations, since the height may be increased to satisfy the location requirement. It is sometimes equipped with low flow semi circular channel grooved on the bottom slab to cater for such a flow, which could not have passed the flat bed surface of the barrel efficiently.

Sometimes reinforced concrete slab culvert can be misunderstood as box culverts due to the similarity in their cross section. But they are structurally different in that reinforced concrete slab culvert is made up of slab simply supported on the abutments serving as the walls of the culverts.

Meanwhile box culvert slabs and walls are monolithically connected. But in Malaysia the bottom slabs are usually monolithically connected to the walls and the top slab simply placed on the walls to form a box culvert. The advantage and disadvantage of using the different design and construction methods shall be analyzed and the best method, then recommended.

1.5.1 Types of Box Culvert

Box culverts can be classified according to the following considerations, construction method, and number of barrel as described below:

Construction Method:

The method used in the construction of box culvert can be used in classifying them in to the following categories:

a. Cast In situ Box Culvert

The culvert are cast in situ at position on site, it is the first construction method of box culvert developed since 1840s, but it was later found to be uneconomical due to longer construction time, high quality control requirement, and possible damage due to weather condition.

b. Pre cast Box Culvert

The pre cast concrete box culvert was introduced in Ohio, United States in the mid 1970s, they are usually cast in a convenient place and later transported to site for installation. The first known pre cast concrete box culvert were installed in Minnesota in 1974 on T.H 60 with up to 9.75 overfill. Pre cast concrete box culvert can also be classified as describe below;

Four-sided Pre cast Concrete Box Culvert

Four-sided pre cast concrete box culvert was introduced in Ohio in the mid 1970s. Originally designed and built with 3.0 and 3.6m spans and various rises, these where cast in 1.8 to 2.4m segments, shipped to site and set in usually one day. The segments are joining together with a tongue-and –groove joint. The outsides of the joints were waterproofed or in some cases the entire top and sides of the boxes were waterproofed. These box culverts have relatively thick walls (300mm) and are not dependent on the quality of compaction of the backfill for their strength; however proper backfill techniques were necessary to eliminate settlement of the roadway on either side of the culvert.

The four-sided box culverts are now designed and constructed in spans up to 5.485m. These structures have been relatively maintenance free, however joint leakage and lack of adequate concrete cover over the reinforcing steel has been a problem in some cases. Not much preventive maintenance can be accomplished on these structures other than making sure that they are kept cleaned out, and that water is not restricted at the inlet. The inlet and outlet should be checked for scour holes and dump rock added were necessary.

Three-sided Pre cast Box Culvert

The three-sided pre cast concrete box culvert was also introduced in Ohio in1980s a second generation to the four-sided box culvert. By eliminating the bottom slab of the four-sided box culvert, the span could be increased without a significant weight increase for transportation purposes.

There are two types of three-sided box culverts: the flat top and arched top (con span), the three- sided culverts must be placed on cast in place concrete footers, when then the walls are to be placed on the ground, or placed on the sub grade when the slab is to be used as bottomed slab and later a simply supported slab panel is placed on the walls, to serve as a top slab.

The flat top culvert is similar to the four-sided culvert in that it needs no fill and can be driven on, where as the arched top culvert needs a minimum of 600mm of overfill. The arch top culvert is available in a long span up to 12.8m and does not have some dependence on proper backfill for its stability.

This structure should be used in areas of limited fill over top because they cannot support large fills. At least one partial failure of an arched top culvert has been reported due to too much fill and improper placement of reinforcement steel.

Number of Barrel

It is sometimes not possible to use a single cell box culvert due to long span requirement and definitely economic reason. Culverts can be classified according to the number of vent or barrel, namely; single cell, double cell, three cell, and multi cell box culvert, having one, two, three, and many barrels respectively

1.6 Objective of the Project

The main objectives of this study are:

(a) A comparative hydraulic and structural design of reinforced concrete box culvert, including computer structural analysis.

(b) To consider various loading conditions resulting from moving loads, overfill material, backfill material, hydrostatic thrust, and self-weight of the structure.

(c) To compare the effect of number of cells to the hydraulic and structural aspect of the design of reinforced concrete box culvert.

(d) To identify and outline the factors affecting the optimum design of the reinforced concrete box culverts.

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