**ADDIS ABABA UNIVERSITY**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

# COMPARISION OF PRECAST AND CAST-IN-SITU CONSTRUCTION APPROACH FOR BURIED CULVERTS

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A Project
Submitted in Partial Fulfillment of the Requirements for the Masters Degree in Structural Engineering

The undersigned have examined the project entitled **'Comparison of Precast and Cast-in-Situ Construction Approach for Buried Culverts'** presented by **Samuel G/Selassie**, a candidate for the **Masters Degree in Structural Engineering** and hereby certify that it is worthy of acceptance.

| | | |
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| Chair Person | Signature | Date |

**UNDERTAKING**

I certify that project work titled "Comparison of Precast and Cast-in-Situ Construction Approach for Buried Culverts" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

Samuel G/Selassie

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**ABSTRACT**

Cast-in-situ is the conventional method of culvert construction which is frequently used in Ethiopia. It encompass a series of construction activities that includes site preparation works, building falsework and formwork in the shape of the member being built, placing reinforcement bar, concrete batching, mixing, transporting, placing and compacting, and curing. All these interdependent activities are time demanding, challenging to conduct quality control measurement and testing, labor intensive, prone to mistakes, reworks, unplanned situations, and material wastages. This study aims to compare this construction approach with precast method based on time performance, quality performance, cost performance, and safety criterion.

To clarify the difference and similarity of these two construction approaches, the design and construction methodologies of precast and cast-in-situ box and slab culverts are discussed briefly. Factors that influences the performance of both methods with respect to construction time, quality of structures, cost of construction and safety are discussed and comparisons are made.

This comparison shows that precast construction method have superior time performance, provides high quality product, reduce the construction cost and have high health and safety record.

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## NOTATIONS

| | | |
|---|---|---|
| $a$ | : | depth of the compression block (mm) |
| $A_g$ | : | gross area of section ($mm^2$), |
| $A_s$ | : | area of reinforcing steel in the design width ($mm^2$) |
| $b$ | : | design width (mm) |
| $B_c$ | : | outside width of culvert(mm), |
| $b_v$ | : | effective web width (mm), |
| CSF | : | Critical Success Factors |
| $d$ | : | distance from the extreme compression fiber to the centroid of extreme tension steel element (mm), |
| DBB | : | Design Bid and Built Type of Contract |
| DC | : | Dead load of structural components and non structural attachments |
| $d_c$ | : | thickness of concrete cover measured from extreme tension fiber to center of flexural reinforcement located closest thereto (mm), |
| $d_e$ | : | effective depth from extreme compression fiber to the centroid of the tensile force in the tensile reinforcement (mm) |
| $D_E$ | : | the minimum depth of earth cover above the structure (mm) |
| $d_v$ | : | effective shear depth(mm) |
| DW | : | Dead load of wearing surface and utilities |
| $E$ | : | equivalent distribution width perpendicular to span(mm) |
| $E_c$ | : | Modulus of elasticity of concrete (MPa) |
| EH | : | Earth pressure load |
| ERA | : | Ethiopian Roads Authority |
| $E_s$ | : | modulus of elasticity reinforcement bar (MPa) |
| $E_{span}$ | : | equivalent distribution width parallel to span (mm) |
| ES | : | Earth surcharge load |
| EV | : | Dead load of earth fill |
| $f'_c$ | : | compressive strength of concrete (MPa) |
| $F_e$ | : | soil-structure factor for embankment installation, |
| $f_y$ | : | yield strength of reinforcement (MPa), |
| $f_{ss}$ | : | tensile stress in steel reinforcement at the service limit state (MPa), |
| $g$ | : | acceleration of gravity ($m/s^2$), |
| $h$ | : | overall thickness or depth of the component (mm), |
| $H$ | : | depth of fill from top of culvert to top of pavement (mm) |
| $h_{eq}$ | : | equivalent height of soil for vehicular load (mm) |

IM : dynamic load allowance

k : coefficient of lateral earth pressure

$k_o$ : at-rest lateral earth pressure coefficient,

LL : design vehicular live load

$L_T$ : length of tyre contact area parallel to span,(250mm)

$L_1$ : modified span length taken equal to the lesser of the actual span or 18000(mm)

LS : live load surcharge

$M_n$ : nominal flexural resistance (N-mm)

$M_r$ : moment capacity (N-mm)

$M_u$ : moment from factored loads (N-mm)

$P_n$ : nominal axial resistance of the concrete(N),

$P_r$ : axial capacity(N)

$P_u$ : axial load from factored loads(N).

$Q_i$ : force effects,

$R_n$ : nominal resistance,

RSDP : Road Sector Development Program

s : clear span(m)

$V_c$ : nominal shear resistance of the concrete(N),

$V_n$ : nominal shear resistance(N)

$V_u$ : shear from factored loads (N)

$V_r$ : shear capacity(N)

$V_s$ : shear resistance provided by shear reinforcement(N),

$W_T$ : Width of tyre contact area perpendicular to the span(mm)

$W_1$ : modified edge-to-edge width of culvert taken to be equal to the lesser of the actual width or 9000

$\beta$ : factor indicating ability of diagonally cracked concrete to transmit tension

$\gamma_i$ : load factor,

$\gamma_s$ : density of backfill (Kg/m$^3$),

$\gamma_e$ : exposure factor

$\gamma_s$ : total unit weight of soil (Kg/m$^3$)

$\Delta_p$ : Constant horizontal earth pressure due to live load surcharge (MPa)

$\Delta_{max}$ : maximum horizontal earth pressure (MPa)

$\Delta_{min}$ : minimum horizontal earth pressure (MPa)

$\delta$= : friction angle between fill and wall

$\eta_i$ : load modifier,

| | | |
|---|---|---|
| $\eta_D$ | : | load modifier factor relating to ductility, |
| $\eta_R$ | : | load modifier factor relating to redundancy, and |
| $\eta_I$ | : | load modifier factor relating to operational importance |
| $\phi$ | : | resistance factor, |
| $\phi_m$ | : | resistance factor for moment, |
| $\phi_v$ | : | resistance factor for shear, |
| $\phi_p$ | : | resistance factor for thrust, |

# 1. INTRODUCTION TO THE STUDY

## 1.1. Introduction

The main objective set by Ethiopian Roads Authority (ERA) under the fourth Road Sector Development Program (RSDP IV), includes enhancing size and quality of road network, improving efficiency and building up of institutional capacity.

Accordingly, to achieve the same goals, construction methodologies being exercised for different road construction activities shall be modernized in such a way that it can enhance the Critical Success Factors (CSFs) such as timely delivery, ensuring optimization of resources, reducing reworks, minimizing idle resources, avoiding waste of usable materials, reducing the number of defective works, ensuring high standard health and safety level at the project sites, and improving the quality of environmental and social issues.

In regards to major culverts(i.e. Box and Slab Culverts) construction, the conventional method, which is cast-in-place technique, requires longer construction time, have unsuitable working environment for quality controlling, prone to weather conditions, and compromises health and safety of road uses.

When precast culvert construction method is adopted, it will significantly reduce the construction time and related costs, increases the productivity, provides better settings for measurement and quality testing, reduce labor costs, eliminate drawbacks imposed by weather and site conditions, minimize material wastages, and omits costly process of cast-in-place construction method.

In due consideration of the same, in this study design and construction methodologies of both cast in situ and precast major culverts are discussed. Moreover, comparison of performance of culvert structures with regards to time, quality, cost, and health and safety for road construction projects are discussed.

## 1.2. Statement of the Problem

The traditional major culvert construction(cast-in-situ) process includes structural excavation, reinforcement bar work, formwork and falsework preparations, concrete casting, concrete curing, and backfilling.

This construction methodology does not allow task overlapping, obliged to follow time demanding technical requirements, can be lingered by weather conditions, prone to unplanned situations, subjected to construction imperfections that might be difficult to rectify (e.g. honey combs, form failures, dimensional errors and finishing defects), difficult for measurement and quality testing, vulnerable to shortcomings of premature drying out of the concrete, allows unexpected construction costs, have high cost variance, diverts or narrows traffic lanes and let traffic flow become slower and highly vulnerable to accidents, has higher environmental impact on the construction site, and has more construction waste.

In spite of all the above negative aspects, the detail design drawings of major culverts furnished within ERA's 2013 Standard Detailed Drawings for Road Works is only to cast-in-place construction methods. As a result, when Contractors on DBB Contract type projects demands to adopt precast construction approach in place of cast-in-situ method, it takes them a number of months to get an approval from the supervision Consultant and/or Client.

## 1.3. Hypothesis

This study deems "Precast concrete construction of major culverts offers more advantages with respect to time, quality, costs, and health and safety" in due consideration of complexity of the project, scale and scope of the project, project site conditions, culvert opening sizes, and number of cells.

## 1.4. Objectives

The main objectives of this study are to:

- review literatures and discuss about design concept and methodology of cast-in-situ and precast major culverts,
- discuss and evaluate the two construction techniques; cast-in-situ and precast concrete construction,
- compare time performance, quality performance, cost performance, safety and health, and clients' satisfaction of these two construction options,
- make conclusion and recommendations based on the study findings.

## 1.5. Chapter Synthesis

Following this introductory section, relevant literatures in regards to construction method of box and slab culverts are addressed in Chapter 2. Chapter 3 discusses about design standard, engineering properties of construction materials, design concept and methodologies that is adopted in our country for the design of precast and cast-in-situ box culverts and slabs. Methods and procedures of construction, including types of construction material and equipments, required for box and slab culverts using both precast and cast-in-situ techniques respectively are discussed within Chapter 4. Chapter 5 compares of two construction methods with regards to time, quality, cost and health and safety performances. Conclusion and recommendation of the study is discussed under Chapter 6.

# 2. LITERATURES REVIEW

## 2.1. Introduction

Culverts are a small-span road cross drainage structures, which are used to allow passage of small streams, livestock, vehicles, and pedestrians through highway embankments [1]. Moreover it is classified as structures with a maximum total clear opening of 6.0m.[2], [3]

## 2.2. Types of Culverts

Culverts can be classified as arch culvert, pipe culvert, slab culvert and box culvert with due consideration of their discharge capacity and structural form.

I. **Arch Culvert:** have an arched superstructure part and their abutment and pier are constructed in such a way that they have sufficient strength to withstand lateral forces from arches. These culverts are mostly constructed using stone masonry, plain concrete, and reinforced concrete. [3],[4]

Figure 2-1: Masonry Arch Culvert

II. **Pipe Culvert:** this type of culvert have circular, elliptical and pipe arch shapes and can be constructed using steel or reinforced concrete. It is preferable only for crossing sections with very small flow of water. Circular reinforced concrete pipe culvert is the major pipe culvert type that is being used in our country under different construction project. [4],[13]

Figure 2-2: RC Pipe Culvert

III. **Slab Culvert:** are composed of simply supported reinforced concrete slab placed over masonry abutments and piers. This type of culvert is suitable where firm foundation material with good bearing capacity is encountered. [2], [4]

Figure 2-3: Slab Culvert

IV. **Box Culverts:** this type of culverts are mainly constructed using reinforced concrete and have a shape of rectangle or square. Its top and bottom slabs are monolithically casted with either side walls. Box culverts are recommended for crossing locations, where black clay and light brown clay soil foundation material; which is expected to be expansive and weak, are encountered.[2], [6]

Figure 2-4: RC Box Culvert;

*Out of the above listed culvert types, this study mainly focuses on design and construction methods of reinforced concrete box and slab culvert.*

## 2.3. Construction of RC Box and Slab Culverts

### 2.3.1. Construction Materials

In Ethiopia, the dominant construction material being used for box culverts and superstructure part of slab culverts is reinforced concrete. This is because of the fact that ingredient of reinforced concrete; which are gravel, crushed rock, sand, water, cement, and reinforcement bar, are relatively widely available, skills required for the construction of reinforced concrete is relatively simpler, and construction using reinforced concrete is relatively more economical than other forms of constructions. [7]

### 2.3.2. Structural Properties of Construction Materials

In reinforced concrete structures, the concrete carries compression and the steel reinforcement carries tension. Figure 2-5 below shows the structural action of a simple reinforced concrete beam. The applied load induces tension in the lower part of the beam, and the concrete cracks, but, the steel in the cracked region carries the tensile force, in a way that the steel tensile force (T) and the concrete compressive force (C) form a couple to resist the moment (M). The function of the reinforcing steel is actually two-fold: to resist the internal tensile force in the member, and to prevent the tensile cracks in the concrete from becoming too wide. [8]

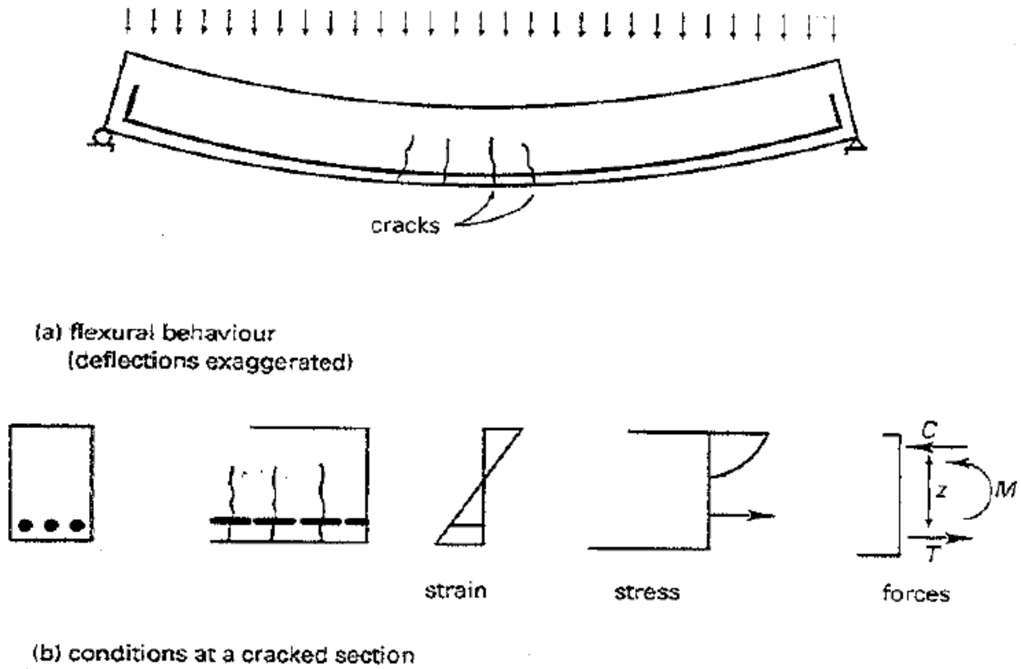



Figure 2-5: The structural action of a simple reinforced concrete beam

Although steel reinforcement is used primarily to carry the internal tensile forces produced by external loading, it also has other uses. As steel is much stronger than concrete in compression, it can be used to boost the resistance of zones of compression in beams and columns when the dimensions of the member are restricted. [8]

In compression members, longitudinal steel are placed to assist in carrying the axial compression and to provide a means of carrying the tensile stresses which can occur as a result of bending. Transverse ties are also provided to maintain the longitudinal steel in position during casting of the concrete and later to prevent its outward bulking when the member is subjected to axial load. [8]

Light secondary reinforcement is usually provided throughout any large concrete region to control cracking of concrete due to temperature changes and restrained shrinkage of the concrete. [8]

### 2.3.3. Construction Methods

The construction of reinforced concrete box culverts and superstructure part of slab culverts can be done using either cast-in-place or precast construction technique.

Cast-in-place concrete is defined as the process of casting the concrete in its final or permanent location. [9] Traditionally, in-situ construction has been used for reinforced concrete structures. For this construction method, the formwork for each elements is first assembled in the required location, the reinforcement is placed in the formwork, and the concrete is placed and allowed to set and harden. After the required curing period, the formwork are removed. [8]

Cast-in-place construction technique takes a longer construction process as it involves a number of operations before raw materials are converted into a finished product. These includes site preparation works, building falsework and formwork in the shape of the member being built, placing reinforcement bar, concrete batching, mixing, transporting, placing and compacting, and curing. All these activities are subjected to the level of accountability and skills exercised by the people involved. Site conditions in terms of accessibility and weather can be highly critical to the work, requiring extreme measure in some situations to control all the stages in the production process.[10]

The form to be used for cast-in-place method is required to be strong enough not only to support the weight and hydrostatic pressure of the wet concrete, but also any forces applied to it by workers, concrete casting equipment, and so on. [7]

On the other hand, precast concrete is defined as casting the concrete at a location different than its final placement, usually in plants or sites close to the final site. Precast concrete element has a finite size and must therefore be joined to other elements to form a complete structure. [9]

The concept of ‘pre-casting’ concrete for major structural purposes is not a new idea and it began in the late nineteenth century, when its most obvious application to span over areas with difficult access began with the use of flooring joists. François Hennebique (1842–1921) first introduced precast concrete into a cast-in situ flour mill in France, where the self-weight of the prefabricated units was limited to the lifting capacity of two strong men.[12]

Changes to the way in which the construction industry must design projects for ease of construction, making maximum use of standard components and processes, and should operate in a ‘zero-waste and zero defects’ environment. The precast concrete industry is ideally placed to accommodate these higher demands by using experienced design teams and skilled labor in a quality-controlled environment to produce high-specification components. [12]

The use of precast construction has considerable advantages to be gained from the factory production of complete elements with their assembly or erection on site. With carefully controlled, repeated operation in factory conditions, it is possible not only to achieve significant cost reductions, but also much better quality control....Pre-casting finds a wide range of uses especially where standardized units can be produced in large quantities. Pre-casting of smaller sized units can very effectively be undertaken in centralized factories, with the units transported to site. [8]

Repetitive production of modular standardized elements associated with precast concrete construction reduces the costs through the use of permanent moulds. Production of precast concrete elements is conveniently done at ground level and thus eliminating the use of scaffolding.[14] Furthermore, precast production assures better quality control of concrete elements, can minimize time for construction and save time related cost as compared to that of in-situ concrete.[11]

The requirement for off-site fabrication will continue to increase as the rapid growth in management contracting, with its desire for reduced on-site processes and high-quality workmanship, will favor controlled prefabrication methods.[12]

# 3. DESIGN CONCEPT AND METHODOLOGY OF CAST-IN-SITU AND PRECAST CONCRETE MAJOUR CULVERTS

## 3.1. Design Standard

Bridge Design Manual specifies that the detail engineering design of all structures throughout the country within ERA are required to adopt the respective manual of ERA's 2013 BDM. The Load and Resistance Factor Design (LRFD) can also be used as a supplement manual (AASHTO 2012).

## 3.2. Design Method

Major culverts are required to be designed in a way that the resistance of their components and connection be greater than effects of loads and combination thereof using LRFD method specified within ERA BDM 2013. Equation that shall be used as a basis for LRFD method is:

$$\Sigma \ \eta_i \gamma_i Q_i \ \leq \ \phi R_n \qquad \text{.... Equation 3-1}$$

where: $R_n$ = nominal resistance,

$\phi$ = resistance factor,

$Q_i$ = force effects,

$\gamma_i$ = load factor,

$\eta_i$ = load modifier,

The resistance factor ($\phi$) for buried structures are listed in Table 3-1 below for both cast-in-place and precast concrete structures. This statistically based resistance factor accounts for uncertainties in material properties, equation that predict strength, workmanship, quality control, and consequence of failure. On the other hand, the load factor ($\gamma$) takes in to account the uncertainties in magnitudes, arrangement, and possible combination of loads. Statistically based load factors for Strength I and Service I Limit State load combinations are listed in Table 3.3 below. [2]

Ductility, redundancy, and operational importance of the structure shall be considered using load modifier factor ($\eta$). This factor is given;

for loads for which a maximum value of $\gamma i$ is appropriate:

$$\eta_i \ = \ \eta_D \eta_R \eta_I \ \geq \ 0.95 \qquad \text{... Equation 3-2}$$

for loads for which a minimum value of $\gamma_i$ is appropriate:

$$\eta_i = \frac{1}{\eta_D \eta_R \eta_I} \leq 1.0 \qquad \text{... Equation 3-3}$$

where $\eta_D$ is a factor relating to ductility, $\eta_R$ is a factor relating to redundancy, and $\eta_I$ is a factor relating to operational importance. Accordingly, considering different cases of ductility , redundancy and operational importance specified within article 1.3.3, 1.3.4 and 1.3.5 of Part 1, ERA BDM 2013, values of $\eta_D$, $\eta_R$, and $\eta_I$ are specified to be 1.

Table 3-1:Resistance Factors

| Construction Method | Load Effects | Resistance factor (ϕ) | |
|---|---|---|---|
| | | Strength Limit State | Other Limit States |
| Cast-in-Place | Flexure | 0.90 | 1.00 |
| | Shear | 0.85 | 1.00 |
| | Axial Thrust | 0.70 | 1.00 |
| Precast | Flexure | 1.00 | 1.00 |
| | Shear | 0.90 | 1.00 |
| | Axial Thrust | 0.70 | 1.00 |

## 3.3. Materials

Reinforced concrete is the prominent material type that is being used for the design and construction of major culverts on every ERA projects. Accordingly, concrete with minimum cylindrical compressive strength of 20MPa with nominal aggregate sizes of 20mm and deformed reinforcing bar with minimum yield strength of 420MPa for bars with diameter of 20mm and above and 300MPa for bars with lesser diameter shall be used.[2]

Modulus of elasticity of concrete, $E_c$, shall be computed using equation 7.3.2.4-1 of Part 1 ERA BDM-2013 and its modulus of rupture shall be determined using the provisions of article 7.3.2.6 of the same manual. As per article 7.4.2 of the above referenced manual, modulus of elasticity reinforcement bar, Es, shall be assumed to be 200GPa. [2]

## 3.4. Precast Box Culvert Design Steps and Method

### 3.4.1. Preliminary Dimensions Design

In accordance to Table 2.3.5-1 of ERA bridge design manual, slab thickness of box is required to be greater than or equal to 175mm. The minimum wall thickness is dependent on clear opening height of the box. [10] The same relation is tabulated as below;

Table 3-2: Wall height Vs thickness

| Clear Height(m) | Minimum Wall Thickness (mm) |
|---|---|
| h≤ 1.8 | 200 |
| 1.8< h≤ 3 | 225 |
| H > 3 | 250 |

Furthermore, the thickness of slabs and walls shall be fixed with due consideration of the requirements set for moment, shear and thrust. Provided thickness shall be sufficient enough to carry the factored shear stress without shear reinforcement.

### 3.4.2. Loads

All loads that are likely to be applied during service life of precast box culverts must be considered as per loading requirements given under ERA BDM 2013.These loads are divided as permanent and transient loads.

#### I. Permanent Loads

Permanent loads are those that remain on the structure for an extended period of time, perhaps for the entire service life. These loads consists of:

- Dead load of structural components and non structural attachments (DC)
- Dead load of wearing surface and utilities (DW)
- Dead load of earth fill (EV)
- Earth pressure load (EH)
- Earth surcharge load (ES)

##### a) Dead Loads (DC and DW)

In the absence of actual information about the unit weight of concrete, fill material and/or wearing course, Table 3.5.1-1 of Part 1 ERA BDM 2013 shall be used as a reference to compute dead loads.

DC of the top slab shall be uniformly applied on top slab and that of top slab, wall and all haunches shall uniformly be applied on the bottom slab as an upward reaction from the soil. Dead load of bottom slab shall not be considered as it is directly balanced by the soil.

**b) Dead Load of Earth Fill (EV)**

The vertical earth pressure on top of the culvert is due to the weight of fill. The fill height shall be measured from the top surface of top slab to the pavement top surface. Conservatively, it shall be assumed that precast box culverts be installed in embankment condition so that vertical earth load (EV) could be increased by arching effects of overburden soil. This arching effect shall be approximated using soil-structure interaction factor ($F_e$), which is recommended not exceed 1.15 and shall be computed using equation 3-4b below. Then, the vertical earth load shall be adjusted according to Equation 3-4a below. [6]

$$EV(\text{in N/mm}) = F_e\, g\, \gamma_s H * 10^{-9} \qquad \text{... Equation 3-4a}$$

$$\text{in which: } F_e = 1+0.2H / B_c \qquad \text{... Equation 3-4b}$$

where: $g$ = acceleration of gravity (m/s$^2$),

$F_e$ = soil-structure factor for embankment installation,

$B_c$ = outside width of culvert(mm),

$H$ = depth of fill(mm),

$\gamma_s$ = density of backfill (Kg/m$^3$),

**c) Earth Pressure Loads (EH)**

At-rest lateral earth pressure coefficient, $k_o$, shall be used for the determination of EH as walls of box culvert can tolerate little or no movement away from backfill. Then, EH shall be computed using Equation 3.5a below and it shall be assumed to be linearly proportional to the depth of fill. [2]

$$EH = k_0 \gamma H \qquad \text{... Equation 3-5a}$$

$$\text{in which } k_0 = 1 - \sin\delta \qquad \text{... Equation 3-5b}$$

where: $\delta$= friction angle between fill and wall taken as specified in Table 3.11.5.3-1 of Part 1, ERA BDM 2013

**II. Transient Loads**

Transient loads are those whose magnitude changes with time and also their direction and/or location of application varies. Accordingly, design vehicular live load(LL) modeled as HL-93 (Highway Load, developed in 1993) and surcharge load due to the same must be the transient load that shall be used for the design of roadway crossing structures.

**a) Live Load(LL)**

HL-93 model consists of three distinctly different live loads named as design truck, design tandem and design lane load. [2]

The design truck load looks a like the typical semitrailer truck and have a total load of 325kN that is distributed between 3 axles. The front axle load is 35kN and both the middle and rear axle load is 145kN. The relative spacing of the three axles is illustrated in Figure 3-1 below. [2]

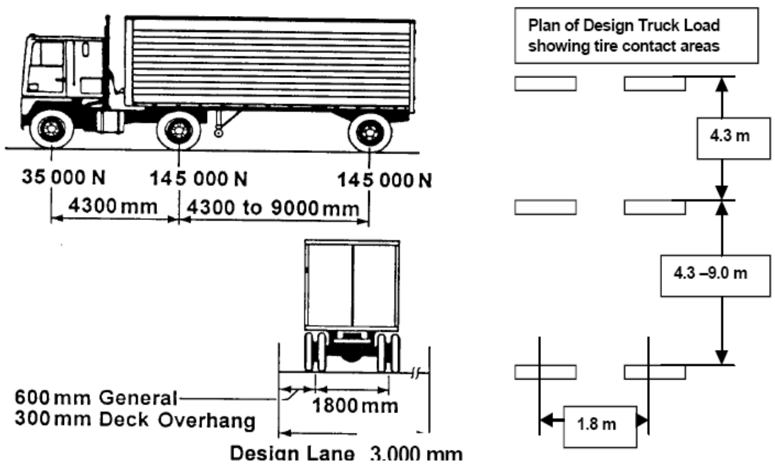



Figure 3-1: Design Truck Wheel Configuration

The design tandem load comprises a pair of 110kN axles spaced at 1.2m. Each axle comprises two wheels spaced at 1.8m transversely. Figure 3-2 below illustrates the relative position of both axle and wheel of design tandem.

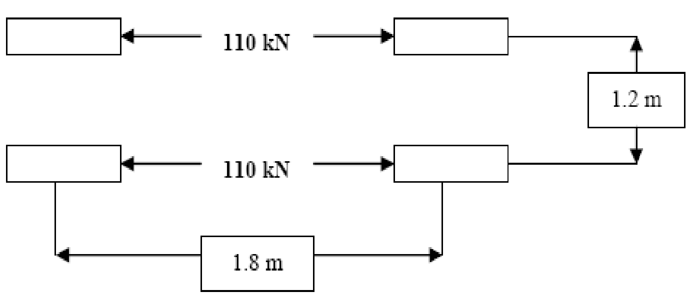



Figure 3-2: Design Tandem Load Wheel Configuration

The design lane load consists of uniformly distributed load of 9.3 kN/m and it is assumed to occupy a 3.0m width in the transverse direction.

Only axle load of design truck and tandem shall be considered for box culverts design. Single loaded lane with the single lane multiple presence factor of 1.2 shall be applied to the live loads considering recommendation given under article 12.11.2.1 of AASHTO LRFD Bridge Design Specification -2012.

The dynamic load allowance (IM), which is a factor that is used to increase static effects of design truck and design tandem, shall be reduced based on the depth of fill over the culvert using Equation 3.6 below. [2]

$$\mathrm{IM} = 33(1.0 - 4.1 \times 10^{-4} \mathrm{D_E}) \geq 0\% \qquad \text{.... Equation 3-6}$$

where: $D_E$ = the minimum depth of earth cover above the structure (mm)

A single rectangular area, with width and length of 510mm and 250mm respectively, shall be used as the tyre contact area of a wheel consisting of one or two tyres. It shall be assumed that the tyre contact pressure shall have uniform distribution over this rectangular contact area. [2]

For culverts that spans in the longitudinal direction and with the depth of fill less than 0.6m, axle load shall be distributed through fill using Equation 3-7 and 3-8 below. However, this distribution width perpendicular to the span shall not exceed precast segment length. [13] Accordingly;

Distribution width perpendicular to the span: $\mathrm{E} = 2440 + 120\mathrm{S}$ ... Equation 3-7

Distribution width parallel to the span: $\mathrm{E_{span}} = \mathrm{L_T} + 1.15(\mathrm{H})$ ... Equation 3-8

where: E = equivalent distribution width perpendicular to span (mm)

S= clear span (m),

$E_{span}$ = equivalent distribution width parallel to span (mm),

$L_T$ = length of tyre contact area parallel to span, (250mm),

H = depth of fill from top of culvert to top of pavement (mm),

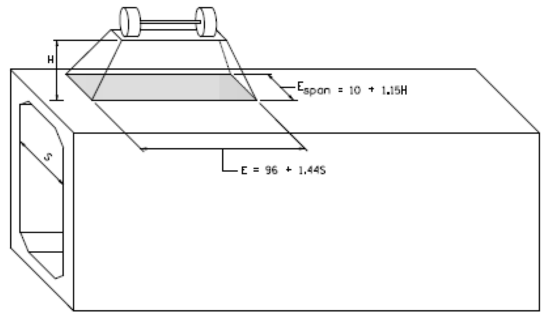



Figure 3-3: Axel Load Distribution Through Fill
(for less than 0.6m fill)

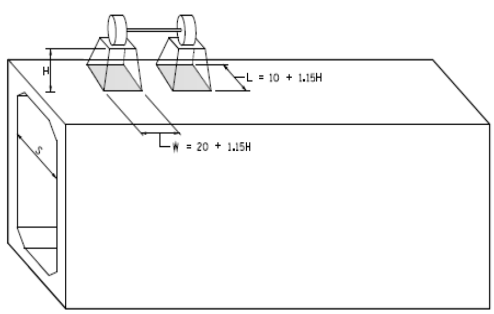
When the depth of fill is greater than 0.6m, wheel loads shall be considered to be uniformly distributed over a rectangular area with sides equal to the dimension of the tyre contact area and increased by 1.15 times the depth of fill. Where such areas from several wheels overlap, the total loads shall be uniformly distributed over the area. [2]

Accordingly;

Distribution width perpendicular to the span: $E = W_T + 1.15(H)$ ... Equation 3-9

Distribution width parallel to the span: $E_{span} = L_T + 1.15(H)$ ... Equation 3-10

where: $W_T$ = width of tyre contact area perpendicular to span,(510mm)



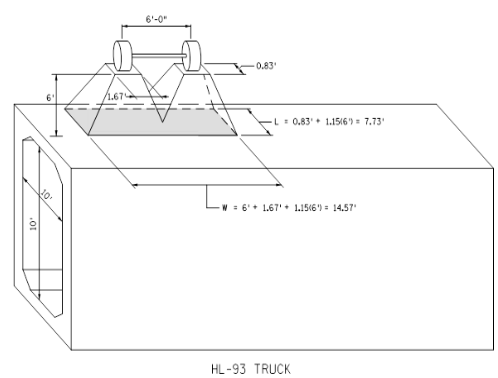




Figure 3-4**:** Wheel Load Distribution Through Fill (for 0.6 of fill or greater)

Figure 3-5**:** Wheel Load Distribution Overlap (for 0.6 of fill or greater)

Shear transfer across precast culvert joints need not be provided when span-to-thickness ratio(s/t) is less than or equals to 18 and segment length is greater than or equal to 1.2m in length. On the other hand, a means of shear transfer like soil fill, pavement, physical connection between adjacent joints shall be provided for precast culverts that does not satisfy the same requirements. However, these dimensional requirements set for precast culverts is not considered for buried culverts as fill above culverts will provide sufficient shear transfer to distribute live load to adjacent box section without shear keys and avoid higher stresses due to edge loading. [13]

**b) Live Load Surcharge**

The live load surcharge (LS) shall be applied on the back face of wall where vehicular load is expected to act on the surface of the backfill within a distance equal to one-half the wall height behind the back face of the wall. A trapezoidal pressure distribution shall be assumed with the maximum pressure $\Delta_{max}$ at the top and the minimum pressure $\Delta_{min}$ at the bottom of the box culvert. At rest coefficient of lateral earth pressure shall be used. [2]

$$\Delta_p = k\gamma_s g h_{eq} * 10^{-9} \quad \text{... Equation 3-11}$$

where: $\Delta_p$ = Constant horizontal earth pressure due to live load surcharge (MPa)

$\gamma_s$ = total unit weight of soil (kg/m$^3$)

k= coefficient of lateral earth pressure

$h_{eq}$ = equivalent height of soil for vehicular load (mm); taken from Table 3.11.6.4-1 of Part 1, ERA BDM -2013,

g = gravitational acceleration (m/sec$^2$)

To determine $\Delta_{max}$, $h_{eq}$ shall be determined based on the distance from the top of the top slab to the top of pavement and likewise for $\Delta_{min}$ the distance from the bottom of the bottom slab to the top of pavement shall be used. [2]

### 3.4.3. Load Factors and Load Combinations

Buried structures are required to be designed using Strength I and Service I Limit State. Accordingly, the Strength I limit state shall be used to design for flexure, shear, and thrust while Limit state I shall be used for checking reinforcement for crack control criteria. [2]

Table 3-3*: Load Factors*

| Load Type | Strength I Load Factor | | Service Load Factor |
|---|---|---|---|
| | Max. | Min. | |
| Dead Load of Components (DC) | 1.25 | 0.9 | 1 |
| Dead Load of Wearing Surface (DW) | 1.5 | 0.65 | 1 |
| Vertical Earth Pressure (EV) | 1.3 | 0.9 | 1 |

| Load Type | Strength I Load Factor | | Service Load Factor |
|---|---|---|---|
| | Max. | Min. | |
| Horizontal Earth Pressure (EH) | 1.35 | 0.9 | 1 |
| Live Load (LL) | 1.75 | 1.75 | 1 |
| Live Load Surcharge (LS) | 1.75 | 1.75 | 1 |

Strength Limit states;

Ia. Maximum vertical load and maximum horizontal load:

1.25DC+1.5DW+1.3EV+1.75(LL+IM)+1.35EH+1.75LS

Ib. Maximum vertical load and minimum horizontal load:

1.25DC+1.5DW+1.3EV+1.75(LL+IM)+0.9EH

Ic. Minimum vertical load and maximum horizontal load:

0.9DC+0.65DW+0.9EV+1.35EH+1.75LS

Service Limit states;

Ia. Maximum vertical load and maximum horizontal load:

1.00DC+1.00EV+1.00(LL+IM)+1.00EH+1.00LS

Ib. Maximum vertical load and minimum horizontal load:

1.00DC+1.00EV+1.00(LL+IM)+1.00EH

Ic. Minimum vertical load and maximum horizontal load:

1.00DC+1.00EV+1.00EH+1.00LS

### 3.4.4. Structural Analysis

Precast box culverts shall be analyzed using a two-dimensional (2D) plane frame model that is assumed to have an element spanning center to center of box members. It shall be assumed that this fame is externally supported by a pinned support on one bottom corner and roller support on the other bottom corner. The model shall be assumed to be in equilibrium so that external reactions to loads applied to the structure shall be assumed to act equal and opposite.

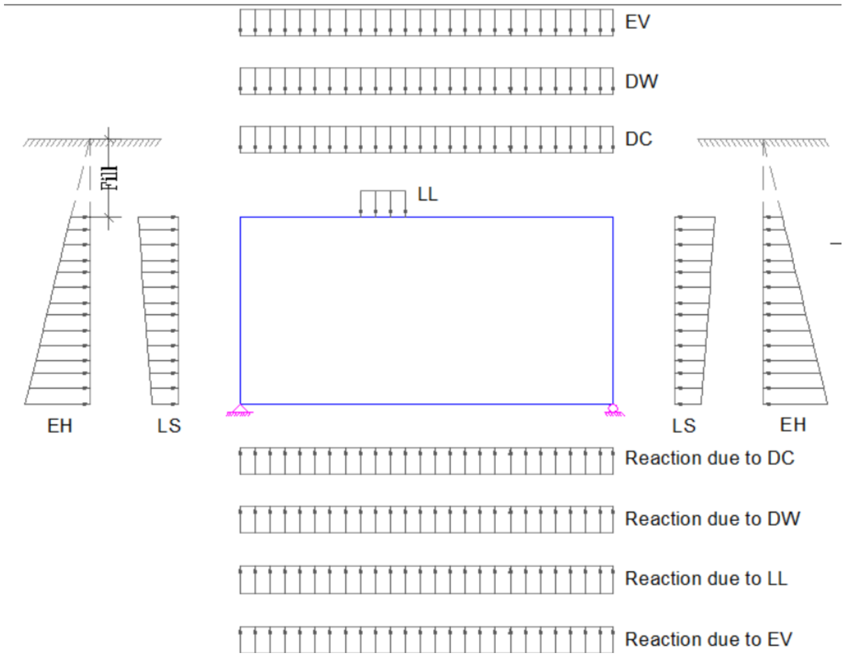



Figure 3-6: Sample Load Case Diagram of Box Culverts

### 3.4.5. Design for Flexure

As per LRFD method, slabs and walls of precast box shall be designed for flexure in a way that their factored flexural resistance ($M_r$) be greater than moment from factored loads ($M_u$). [2],[13]

$$M_r = \phi_m M_n \geq M_u \qquad \text{... Equation 3-12a}$$

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) \qquad \text{... Equation 3-12b}$$

where: $M_r$ = factored flexural resistance (N-mm),

$M_n$ = nominal flexural resistance (N-mm),

$M_u$ = moment from factored loads (N-mm),

$\phi_m$ = resistance factor for moment = 1.00,

$A_s$ = area of reinforcing steel($mm^2$)

$f_y$ = yield strength of reinforcement bar (MPa)

d = distance from the extreme compression fiber to the centroid of extreme tension steel element (mm),

a = depth of the compression block (mm),

in which "a" equals:

$$a = \frac{A_s f_y}{0.85 f'_c b} \qquad \text{... Equation 3-13}$$

where : b = design width (mm)

Critical section for negative moments shall be at the intersection of the haunch and uniform depth of member. [13]

Area of tensile reinforcement required to be provided at all sections shall be checked in a way that the ratio of primary reinforcement in the direction of the span to gross concrete area be not less than 0.002. [6]

To control flexural cracking, the spacing of reinforcement bar over the region of maximum tensile stress shall be limited not to be greater than the spacing obtained using Equation 3-14a below.

$$s \leq \frac{123000\gamma_e}{\beta_s f_{ss}} - 2d_c \qquad \text{... Equation 3-14a}$$

$$\beta_s = 1 + \frac{d_c}{0.7(h-d_c)} \qquad \text{... Equation 3-14b}$$

where: $\gamma_e$ = exposure factor =0.75 for class 2 exposure condition,

$d_c$ = thickness of concrete cover measured from extreme tension fiber to center of flexural reinforcement located closest thereto (mm),

$f_{ss}$ = tensile stress in steel reinforcement at the service limit state (MPa),

h = overall thickness or depth of the component (mm),

d = distance from the extreme compression fiber to the centroid of extreme tension steel element (mm),

For culverts with depth of fill less than 0.6m, it is required to place a transverse distribution reinforcement in the bottom of top slab to distribute wheel loads in the longitudinal direction of culvert to the primary reinforcement in the transverse direction. [6]

$$\text{Percentage} = \frac{1750}{\sqrt{S}} \leq 50\% \qquad \text{... Equation 3-15}$$

where: s = effective span length (mm)

The minimum spacing of reinforcement bars shall not be less than the minimum of the nominal diameter of the bars, 1.33 times the maximum course aggregate, and 25mm. The maximum spacing of reinforcement bars shall also be checked not to be greater than 1.5times the thickness of the member or 450mm. [13]

Shrinkage and temperature reinforcement shall not be applied for precast box culverts. [13]

### 3.4.6. Design for Shear

As to LRFD method provisions, slabs and walls of precast box have to be designed for shear in a way that their shear capacity ($V_r$) be greater than shear from factored loads ($V_u$). The factored shear resistance of concrete ($V_r$) shall be determined as follows: [2] which defines that $V_r$ is the product of nominal shear resistance ($V_n$) and resistance factor as specified in Table 3-1 above. [6]

$$V_r = \phi_v V_n \geq V_u \qquad \text{... Equation 3-16a}$$

$$V_n = \min\begin{cases} V_c + V_s \\ 0.25f'_c b_v d_v \end{cases} \qquad \text{... Equation 3-16b}$$

where: $V_r$ = factored shear resistance (N),

$V_n$ = nominal shear resistance (N),

$V_u$ = shear from factored loads (N),

$\phi_v$ = resistance factor for shear = 0.90,

$V_c$ = nominal shear resistance of the concrete (N),

$V_s$ = shear resistance provided by shear reinforcement(N),

$b_v$ = effective web width(mm),

$d_v$ = effective shear depth(mm), = max(0.72h,0.9d,d-a/2)

$f'_c$ = compressive strength of concrete (MPa)

As reinforcement for shear is not be provided in culvert slabs and walls, the value of $V_s$ is equals to zero. Then, $V_n$ within Equation 3-16 above became directly equals to $V_c$.

For slabs of box culverts with fill height less than 0.6m and box walls, $V_c$ shall be determined as: [6]

$$V_c = 0.083\beta\sqrt{f'_c}\,b_v d_v \qquad \text{... Equation 3-16c}$$

where : $\beta$ =2= factor indicating ability of diagonally cracked concrete to transmit tension as specified in article 5.8.3.4.1 of AASHTO LRFD 2012,

For slabs of box culverts with fill height of 0.6m and above, $V_c$ shall be computed using the following equations: [13]

$$V_c = \left(0.178\sqrt{f'_c} + 32\frac{A_s}{bd_e}\frac{V_u d_e}{M_U}\right) bd_e \leq 0.332\sqrt{f'_c}\,bd_e \qquad \text{... Equation 3-16d}$$

$\frac{V_u d_e}{M_u} \leq 1$ and

$V_c \geq 0.25\sqrt{f'_c}bd_e$ .... for single cell box culverts with slabs monolithic with walls ... Equation 3-16f

where: $A_s$ = area of reinforcing steel in the design width($mm^2$)

$d_e$ = effective depth from extreme compression fiber to the centroid of the tensile force in the tensile reinforcement (mm)

$V_u$ = shear from factored loads (N)

$M_u$ = moment from factored loads(N-mm)

b = design width (mm)

Critical Section for shear shall be determined at a distance $d_v$ from the end of the haunch. [6]

### 3.4.7. Check for Axial Thrust

The axial capacity of members shall be checked in a way that their factored axial resistance ($P_r$) be greater than axial load from factored loads ($P_u$). Checking axial thrust for side walls is enough as they have the largest thrust value and least amount of thickness. The factored axial resistance ($P_r$) shall be determined using Equation 3-17 below. [13]

$$P_r = \phi_p P_n \geq P_u \quad \text{... Equation 3-17a}$$

$$P_n = 0.1f'_c A_g \quad \text{... Equation 3-17b}$$

where: $P_r$ = factored axial resistance (N),

$P_n$ = nominal axial resistance of the concrete (N),

$P_u$ = axial load from factored loads (N),

$\phi_p$ = resistance factor for thrust ,

$A_g$ =gross area of section ($mm^2$),

$f'_c$ = compressive strength of concrete (MPa)

The benefit of applied axial force shall not be considered for the strength limit state. [13]

### 3.4.8. Check for Fatigue

Fatigue check is not required for the design of buried structures. [2]

## 3.5. Cast-in-Situ Box Culvert Design Steps and Methods

### 3.5.1. Preliminary Dimensions Design

Dimension design requirements discussed above for precast box culvert design, under section 3.4.1 above, shall also be applied here for cast-in-situ box culverts.

### 3.5.2. Loads

Other than the limitation set for the distribution width of live loads for culverts under less than 600mm fill when it exceed precast segment length, provisions of section 3.4.2 shall also be applied to cast-in-situ method.

### 3.5.3. Load Factors and Load Combinations

Load factors and load combinations tabulated and discussed under section 3.4.3 above for precast box culvert design shall also be applied here for cast-in-situ box culverts.

### 3.5.4. Structural Analysis

Refer section 3.4.4 above for related information,

### 3.5.5. Design for Flexure

Design provisions and equations addressed above under section 3.4.5 shall also be applied here for cast-in-situ box culverts in due consideration of the under discussed exceptions:

As tabulated above under Table 3-1, resistance factor for moment of cast-in-situ box culvert shall be 0.9.

Area of tensile reinforcement is required to be sufficient enough to develop at least equal to the lesser of 1.33 times moment due to factored design loads ($1.33M_u$) and 1.2 times cracking Moment ($1.2M_{cr}$). [2]

Shrinkage and temperature reinforcement shall be provided using equation 3-20 below: [2]

$$A_s \geq \frac{0.75bh}{2(b+h)f_y} \qquad \text{... Equation 3-18}$$

$$0.233 \leq A_s \leq 1.27$$

where: $A_s$ = area of shrinkage and Temp. reinforcement in each direction and each face ($mm^2/mm$)

$b$ = least width of component section (mm)

$h$ = least thickness of component section (mm)

$f_y$ = yield strength of reinforcement bars (MPa)

The minimum spacing of reinforcement shall be checked not to be less than the minimum of 1.5 times the nominal diameter of the bars, 1.5 times the maximum size of course aggregate and 38mm. [2]

#### 3.5.6. Design for Shear

Refer section 3.4.6 and Table 3-1 above for related information and use $\phi_v = 0.85$,

#### 3.5.7. Check for Axial Thrust

Please refer section 3.4.7 above for related information,

#### 3.5.8. Check for Fatigue

Fatigue check is not required for the design of buried structures,

### 3.6. Precast Slab Design Steps and Methods

#### 3.6.1. Preliminary Dimensions Design

The thickness of slabs, excluding any provision for grinding, grooving and sacrificial surface, shall not be less than 175mm. Furthermore, the minimum depth of simply supported slabs with main reinforcement parallel to the traffic shall be computed using the following equation; [13]

$$h = \frac{1.2(S+3000)}{30} \quad \text{... Equation 3-19}$$

where: S = slab length in mm, and
h = slab thickness in mm

This thickness is required to be sufficient enough to carry the factored shear stress without shear reinforcement.

#### 3.6.2. Loads

**I. Dead Loads (DC and DW)**

Refer section 3.4.2 (I)(a) above for related information:

**II. Dead Load of Earth Fill (EV)**

Refer section 3.4.2 (I)(b) above for related information:

**III. Live Load(LL)**

Only axle load of design truck and tandem shall be considered for design of slabs with span up to 4.6m (as slab of targeted culvert spans primarily in the longitudinal direction). For slab having span exceeding 4.6m, all types of LL shall be considered and the load effects of design truck and tandem loads shall be superimposed with that of design lane load. [2]

The single lane multiple presence factor of 1.2 shall be applied to the design truck and tandem loads for slabs with span less than or equal to 4.6m. But for those with span greater than 4.6m, multiple presence effect is included within equivalent strip width equation and the factor shall not be applied for design live loads.

Refer section 3.4.2.(II), (a) above for the dynamic load allowance (IM) and tyre contact area.

For slab culverts under less than 600mm fill, live load distribution width computation shall consider the provision of table 4.6.2.1 and article 4.6.2.3 of AASHTO LRFD Bridge Design Specification -2012.The distribution width perpendicular to the span shall not exceed the precast segment length. Accordingly, for precast slab;

Distribution width perpendicular to the span:

$\mathrm{E} = 660 + 0.55S$ .......for spans less than or equal to 4.6m ... Equation 3-20a

$\mathrm{E} = 250 + 0.42\sqrt{\mathrm{L_1 W_1}}$ .......for spans greater than 4.6m ... Equation 3-20b

Distribution width parallel to the span:

$\mathrm{E_{span}} = \mathrm{L_T} + 1.15(\mathrm{H})$ ... Equation 3-20c

where: E = equivalent distribution width perpendicular to span(mm)

S= clear span(mm)

$E_{span}$ = equivalent distribution width parallel to span (mm)

$L_T$ = length of tyre contact area parallel to span,(250mm)

H = depth of fill from top of culvert to top of pavement (mm)

$L_1$ = modified span length taken equal to the lesser of the actual span or 18000(mm)

$W_1$ = modified edge-to-edge width of culvert taken to be equal to the lesser of the actual width or 9000 (mm)

When the depth of fill is greater than 0.6m, wheel loads shall be distributed through fill using the provisions discussed above under section 3.4.2 (II) (a) for precast box culvert design. [2]

### 3.6.3. Load Factors and Load Combinations

The Strength I limit state shall be used to design for flexure and shear, while Limit state I shall be used for checking reinforcement for crack control criteria.

Load Combinations that shall be used are:

Strength Limit states: 1.25DC+1.5DW+1.3EV+1.75(LL+IM)

Service Limit states: 1.00DC+1.00EV+1.00(LL+IM)

### 3.6.4. Structural Analysis

The slab culverts shall modeled and analyzed as simply supported one way slab as it is supported on two opposite edges and deflects in one direction only. Microsoft excel spread sheet or design software can be used for the analysis.

### 3.6.5. Design for Flexure

Refer section 3.4.5 above and adopt all the design provisions and equations addressed within the same section;

### 3.6.6. Design for Shear

Design provisions and equations addressed above under section 3.4.6 shall also be applied here for precast slab culverts in due consideration of the under discussed exceptions:

For simply supported single cell slabs, $V_c$ need not be taken to be less than:

$$V_c \geq 0.207\sqrt{f'_c}bd \qquad \text{... Equation 3-21}$$

Critical Section for shear shall be taken at $d_v$ from the internal face of the support. [13]

## 3.7. Cast-in-Situ Slab Design Steps and Methods

### 3.7.1. Preliminary Dimensions Design

Dimension design requirements discussed above for precast slab design, under section 3.6.1 above shall also be applied here for cast-in-situ slab.

### 3.7.2. Loads

Other than the limitation set for the distribution width of live loads for culverts under less than 600mm fill when it exceed precast segment length, provisions of section 3.6.2 shall also be applied to cast-in-situ method

### 3.7.3. Load Factors and Load Combinations

Load factors and load combination discussed under section 3.6.3 above for precast slabs design shall also be applied here for cast-in-situ slabs.

#### 3.7.4. Structural Analysis

Refer section 3.6.4 above for related information,

#### 3.7.5. Design for Flexure

Refer section 3.5.5 above for related design provisions and equations,

#### 3.7.6. Design for Shear

Use $\phi_v$=0.85 and adopt procedures discussed above under section 3.6.6,

# 4. CONSTRUCTION METHOD OF CAST-IN-SITU AND PRECAST CONCRETE CULVERT

## 4.1. Introduction

Cast-in-place construction is the major construction method that is being exercised though out Ethiopia for reinforced concrete box culverts and concrete part of slab culverts constructions. Now a day's, a very few projects are adopting precast construction technique in due consideration of its varies advantages.

This section of the study discusses about construction materials, equipments, construction procedures and methods of constructions that are required for construction both precast and cast-in-situ box and slab culverts.

## 4.2. Construction Methodology of Precast Box Culvert

Precast box culverts construction consists of production of precast RC box units, structural excavation, bedding preparation, transportation of precast box, installation and backfilling activities.

### 4.2.1. Required Major Construction Materials

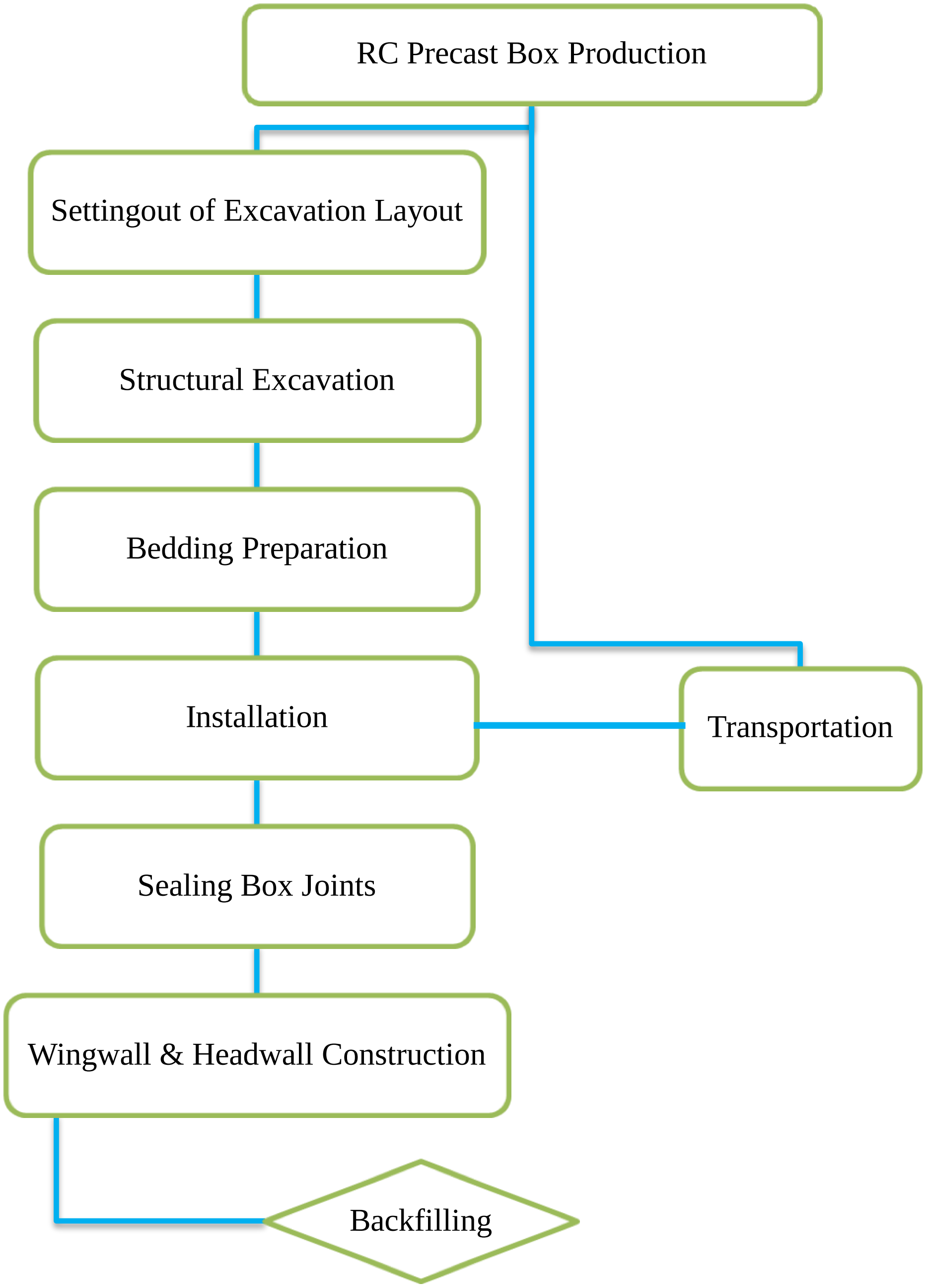
The major construction materials of precast box culverts includes but not limited :

- Concrete - Class 24/20,
- Reinforcement bar - Grade 40 and Grade 60,
- Steel Formwork,
- Lifting cable seven wire strand,
- Structural Backfill Materials,

### 4.2.2. Required Major Construction Equipment

Excavator, dump trucks, rammer/plate compactor, roller, concrete mixer, vibrators, water tank, crane, truck trailer, and other minor tools are the major equipments required for the construction of precast box culvert.

### 4.2.3. Construction Procedures




### 4.2.4. Construction Method

#### 4.2.4.1. Precast RC Box Production

For the production of precast box culvert, fabrication yard provided with shed and leveled floor, and curing and storage area with soft stone base shall be prepared first. Soft stone base is to avoids damage to the product. Precast box culvert production methods discussed as below shall be adopted,

I. **Clearing the Formwork**: both inner and outer form shall be cleared from any foreign material so that the form and product performance could be improved,

II. **Inner Core Formwork Assembly**: the cleared inner form is assembled carefully with due attention to the given detail drawing. Then the female joint is placed around the bottom of inner core.

III. **Applying Form Release Agent**: a thin layer of form release agent shall be applied on the inner core form so as to insure the proper release of concrete from the form during stripping,

IV. **Reinforcement Bar Preparation**: this activity includes bar cutting, bending and rebar cage arrangement around inner core form as to the requirements of the approved shop drawings.

V. **Lift hole Installation**: lift hole shall be installed both on the inside and outside form so as to enable proper lifting of the product. Lifting points shall be selected in a way that the flexural reinforcements provided in service are, as far as possible, fully utilized in lifting. The lifting points shall also be chosen to minimize deflections.

VI. **Pre-pour Inspection**: in order to insure the correct finished product, assembled inner formwork, detail of reinforcement bar arrangement and provided concrete cover shall be inspected prior to outer form assembly,

VII. **Outer Formwork Assembly**: following pre-pour inspection approval, the outer form shall be assembled properly by maintaining the required wall thickness,

VIII. **Concrete Pouring**: before commencing this activity, the availability of adequate quantity of materials such as cement, sand, aggregate and water and also adequacy in number and efficiency of equipment (such as vibrator, concrete mixer, etc) shall be checked. Once all materials and machineries are ready, concreting shall commence. The required care shall be taken so as to avoid segregation of concrete while placing and vibrating. Workability of concrete mix shall be checked by the means of slump test and cube samples shall taken for strength checking.

IX. **Formwork Removal:** after 24hour of concrete casting, both the inner and outer formwork shall be removed. The product shall be transported to the curing and storage area after seven days.

X. **Curing**: curing shall begin immediately after the forms are removed and it shall be applied at least for the following 28days.

#### 4.2.4.2. Excavation

This activity shall be carried out using excavator and will be performed within the approved limits of excavation. Jackhammer might be used where hard rock is found above the design level.

#### 4.2.4.3. Bedding Preparation

Bedding under the box culvert must be able to support the full load of the installed box culvert, its contents, and the loading above the box culvert. Hence, the sub-grade shall be proof rolled first after the appropriate excavation is performed and then bedding material, which is made up of granular material, shall be installed and compacted to provide uniform support for the full length and width of each box culvert section. A minimum 5cm thick leveling course of fine granular base material shall be used as required to achieve a level bedding surface.

#### 4.2.4.4. Transportation

Precast box, which is casted and cured in the production yard shall be transported to the site using truck trailer which shall have the capacity to carry the product. Loading and unloading of precast unit shall be done carefully using truck crane. To avoid damage on the precast unit during transportation, rubber band(used tire) shall be placed in between precast unit and loading bed of trailer truck.

#### 4.2.4.5. Installation

Crane with appropriate load carrying capacity shall be assigned. This activity shall start at the downstream side and proceeds to the upstream with male joint aligned towards the outlet side and female joint on the inlet side. The joint shall be sealed using wet cement mortar. Where box culvert are required to be laid side-by side in multi cell installations, they shall be placed with a gap up to 10cm which shall be grouted with cement mortar.

#### 4.2.4.6. Wing Wall and Head Wall Construction

Wing wall and Head wall of box culverts can be cast on site in due consideration of design drawing requirements. Precast unit to be placed at the inlet and outlet side shall be partly/fully casted on site so that reinforcement bar assembly for head wall and wing wall shall have appropriate lapping with the barrel section of culvert.

#### 4.2.4.7. Backfilling

Backfilling can commence right after the box culvert installation is completed. The trench shall be filled to the level of the top of the culvert, filling evenly on each side of box as backfilling progresses. Special care shall be given not to disturb the box culvert alignment. The backfill material, percent of compaction, depth of layers,..etc, shall follow the project specifications requirement.

Sample pictures from Humbo - Arba Minch Road Project are tabulated as follow to further clarify precast box culvert construction activities,

Figure 4-1:Steel Formwork Prepared before Concrete Casting

Figure 4-2: Reinforcement bar within assembled Mould


Figure 4-3: Box on Production Yard before

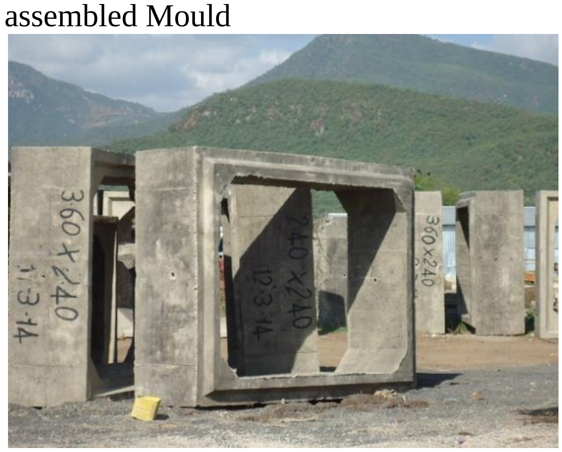



Figure 4-4: Precast Box on Storage and

Transported to Storage Area

Figure 4-5: Installation process of precast Box

Curing Area

Figure 4-6: Backfilling activity which begin immediately after installation

## 4.3. Construction Methodology of Cast-in-Situ Box Culvert

Major construction activities of box culverts using cast-in-situ method are structural excavation, bedding preparation, formwork & falsework assembly, placing reinforcement bar, concrete batching, mixing, transporting, placing and compacting, curing and backfilling.

### 4.3.1. Materials

The major construction materials required for the construction of cast-in-place box culverts are Eucalyptus log/tubular steel frame scaffolding/metal posts with lateral bracings, job built/timber or prefabricated steel form, concrete(Class 24/20), reinforcement bar (Grade 40 and Grade 60), and structural backfill materials.

### 4.3.2. Equipment

Excavator, dump trucks, rammer/plate compactor, roller, concrete mixer, vibrators, water tank, and other minor tools are the major equipments required for the construction of cast-in-situ box culvert.

### 4.3.3. Construction Procedures

The procedures of precast box culvert construction are depicted as below, Settingout of Excavation Layout

↓

Structural Excavation

↓

Bedding Preparation

↓

Bottom Slab Formwork & Reforcement Bar Preparation

↓

First Pre-pour Inspection for Bottom Slab

↓

Bottom Slab Concrete Casting

↓

Side Walls Reinforcement Bar & Formwork Preparation

↓

Second Pre-pour Inspection for Side Walls

↓

Side Walls Concrete Casting

↓

Walls & Bottom Slab Form Stripping & Concrete Curing

↓

Top Slabs Falsework, Formwork & Reinforcement Preparation

↓

Third Pre-pour Inspection

↓

Top Slab Concrete Casting

↓

Falsework & Formwork Stripping & Curing

↓

Backfilling

### 4.3.4. Construction Method

#### 4.3.4.1. Excavation

Please refer section 4.2.4.2 above for related information.

#### 4.3.4.2. Bedding Preparation

Construction methodology adopted for similar activity of precast box culvert shall also be followed here with the exception of the provision of 5cm thick blinding lean concrete that shall be used in place of a 5cm thick granular base material leveling course to prevent direct contact of the bottom slab concrete with the soil and also to provide uniform surface to the bottom of box culvert,

#### 4.3.4.3. Bottom Slab Formwork and Reinforcement Bar Preparation

Prefabricated steel form or timber shall be cleared from any foreign material first, and then closely arranged following the outer profile of bottom slab and wing walls.

A thin layer of form release agent shall be applied on the form so as to insure the proper release of concrete from the form during stripping.

Bottom and side walls reinforcement bar shall be arranged as to the approved shop drawing requirements. Formwork, details of reinforcement bar arrangement and provided concrete cover shall be inspected prior to bottom slab concrete casting,

#### 4.3.4.4. First Pre-pour Inspection

Formwork, detail of reinforcement bar arrangement and provided concrete cover shall be inspected prior to bottom slab concrete casting,

#### 4.3.4.5. Bottom Slab Concrete Casting

Please refer Section 4.2.4.1(VIII) for related information,

#### 4.3.4.6. Side Walls Reinforcement Bar and Formwork Preparation

Side walls reinforcement bar shall be arranged as to the approved shop drawing requirements. Cleared Forms shall be shall be arranged close to each other and well supported in a way that they can resist the lateral pressures generated by fresh concretes and maintain the design thickness of the walls. Accordingly, the forms, which might be prefabricated steel form or plywood sheathing, shall be supported by and attached to studs, which is a beam like element and made of wood or steel. Then Wales, which is also a beam like element and made of wood or steel, shall be used to support the studs.

A thin layer of form release agent shall be applied on the form so as to insure the proper release of concrete from the form during stripping.

#### 4.3.4.7. Second Pre-pour Inspection

Formwork, detail of reinforcement bar arrangement and provided concrete cover shall be inspected prior to side walls concrete casting,

#### 4.3.4.8. Side Walls Concrete Casting

Please refer Section 4.2.4.1(VIII) for related information,

#### 4.3.4.9. Side Formwork Removal & Concrete Curing

Side walls formwork shall be removed after 24hour of concrete casting and then curing activity shall commence and be applied for the following 28days,

#### 4.3.4.10. Top Slab Flasework, Formwork and Reinforcement Bar Preparation

Falsework shall be constructed using either eucalyptus log, metal posts or tubular steel frame scaffolding. Likewise, prefabricated steel form or timber shall be used for the construction of formwork. Both falsework and formwork shall be designed in a way that their whole system shall have sufficient strength to support self weight, weight of concrete, reinforcement and the weight of any operatives or plant engaged in the work.

Metal posts, scaffold-type frame or wood posts shall be arranged with due consideration of formwork design outputs, (e.g. material properties, dimensions, center to center spacing,..etc). Similarly, these vertical member shall be braced to each other so that their unsupported length can be reduced and their load carrying capacity be increased.

With due consideration of finishing level of top slab, horizontal members which are stingers(ledgers) and joists, shall be placed subsequently on top of vertical members so that they can support deck forms. It is a stringers that supports the joists and rest on vertical members, while the joists support the form.

Following the same, bottom and side forms that are cleared from any foreign material shall be arranged very close to each other in such a way that gaps in between could be avoided. Foam or other fillers shall be used to fill the narrow gap between forms.

A thin layer of form release agent shall be applied on the form so as to insure the proper release of concrete from the form during stripping,

Top slab reinforcement bar shall be arranged as to the requirements of the approved shop drawings,

#### 4.3.4.11. Third Pre-pour Inspection:

In order to insure the correct finished product, assembled falsework and formwork, detail of reinforcement bar arrangement and provided concrete cover shall be inspected prior to concrete casting,

#### 4.3.4.12. Top Slab Concrete Casting:

Please refer section 4.2.4.1(VIII) for associated information,

#### 4.3.4.13. Formwork & Falsework Removal & Concrete Curing

Side formwork shall be removed after 24hour of concrete casting while the bottom form and falsework shall be removed after fourteen (14) days of the last pouring date of concrete.

Curing shall begin after the 24 hours and be applied for the following 28days.

#### 4.3.4.14. Backfilling

Backfilling shall commence after 14 days of the last concrete pouring or till the concrete attain sufficient strength to withstand pressures created by the backfilling activity or the backfill load itself. The backfill material shall be in parallel, as far as it is possible, to the same elevation on both sides of the box till its top. The backfill material, percent of compaction, depth of layers,..etc, shall follow the project specifications requirement.

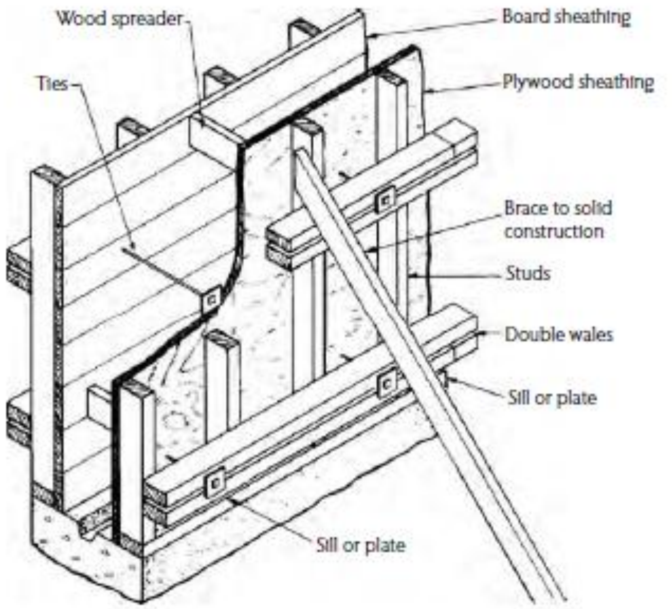



Figure 4-1: Typical Wall Form Components

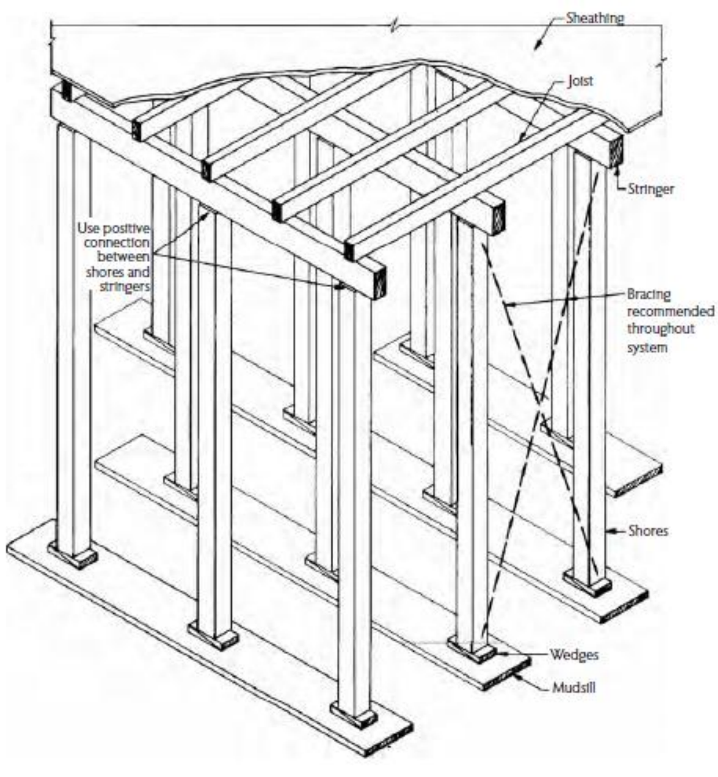



Figure 4-2: Typical Elevated Formwork and Falsework

Sample pictures from different Road Project are tabulated as follow to further clarify cast-in-place box culvert construction activities,

Figure 4-3: Falsework preparation activity for top slab of box culvert

Figure 4-4: Falsework, formwork and reinforcement work completed and ready for concrete casting

Figure 4-5: Bottom slab and wall reinforcement bar preparation work

Figure 4-6:Machineries and materials prepared for top slab concrete casting

Figure 4-7: Concrete casting process for top slab of box

Figure 4-8: Concrete casting process for top slab of box

## 4.4. Construction Methodology of Precast Slab Culvert

Production of precast RC slabs, transportation of precast units, and installation are the major construction activities that are required for the production and construction of precast slab culverts.

### 4.4.1. Materials

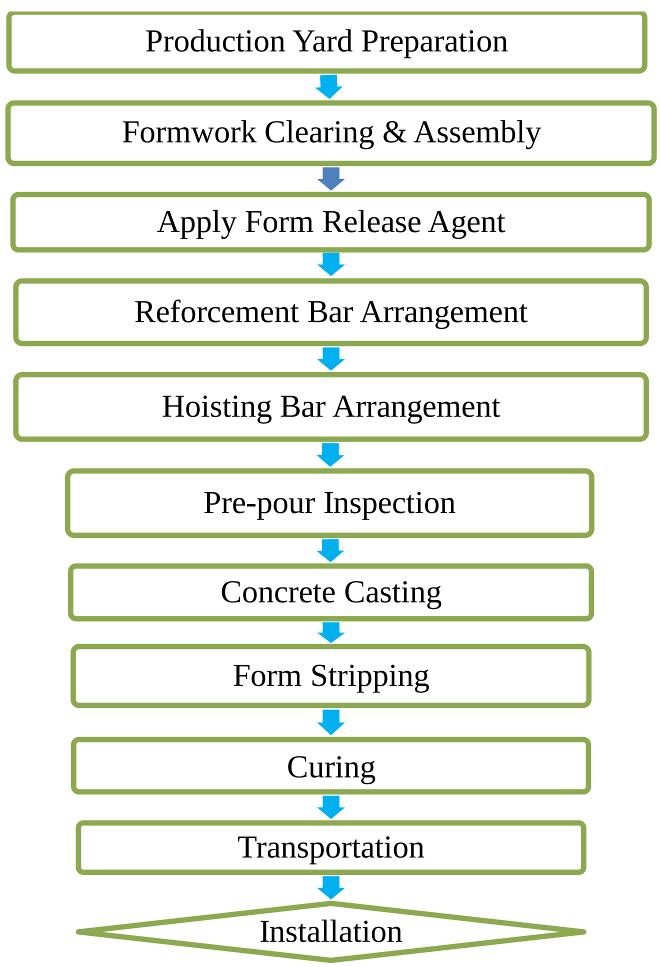
The major construction materials required for the production and construction of precast slabs are (Class 24/20), reinforcement (Grade 40 and Grade 60), steel/timber formwork, and lifting cable with seven wire strand.

### 4.4.2. Equipment

Concrete mixer, vibrators, water tank, crane, truck trailer, and other minor tools are the major equipments required for the construction of precast slabs.

### 4.4.3. Construction Procedures

The procedures of precast slab culverts construction are depicted as below,



#### 4.4.4. Construction Method

Methods of precast slabs of slab culverts production and Installation are discussed as follow,

I. **Production Yard Preparation:** production yard provided with shed and leveled floor, and curing and storage area with soft stone base shall be prepared first for the production of precast slabs,

II. **Clearing & Assembly of the Formwork**: form shall be cleared from any foreign material so that the product performance could be improved. Then, the cleared form shall be assembled carefully with due attention to the given detail drawing,

III. **Applying Form Release Agent**: please refer Section 4.2.4.1(III) for related information,

IV. **Reinforcement Bar Preparation**: this activity includes bar cutting, bending and arrangement as to the requirement of the approved shop drawings.

V. **Hoisting bar Installation**: hoisting bar shall be arranged so as to enable proper lifting of the product. Lifting points shall be selected in a way that the flexural reinforcements provided in service are, as far as possible, fully utilized in lifting. The lifting points shall also be chosen to minimize deflections.

VI. **Pre-pour Inspection**: in order to insure the correct finished product, assembled formwork, detail of reinforcement bar arrangement and provided concrete cover shall be inspected prior to concrete casting,

VII. **Concrete Pouring**: please refer Section 4.2.4.1(VIII) for related information,

VIII. **Formwork Removal:** formwork shall be removed after 24hour of concrete casting. The product shall be transported to the curing and storage area after seven days.

IX. **Curing**: please refer Section 4.2.4.1(X) for related information,

X. **Installing Precast Concrete Slab:** Precast slab, which is casted and cured in the production yard shall be transported to the site using truck trailer. Loading and unloading of precast unit shall be done carefully using truck crane. To void damage on the precast unit during transportation, rubber band(used tire) shall be placed in between precast unit and loading bed of trailer truck. For installation, crane with appropriate load carrying capacity shall be assigned. On top of abutments/piers, two layers of bituminous paper on one side and 5cm thick mortar on another side shall be placed just before installation.

For further clarification of precast slab production and installation activities, sample pictures from Gambela - Abobo - Pugnido Road Project are tabulated as below,

Figure 4-1: Steel Form Work and Reinforcement bar arrangement


Figure 4-2: Installation process of precast slab

## 4.5. Construction Methodology of Precast Slab Culvert

The major construction activities of cast-in-place slab culverts are building false work and formwork in the shape of slab, placing reinforcement bar, concrete batching, mixing, transporting, placing, compacting, and curing.

### 4.5.1. Materials

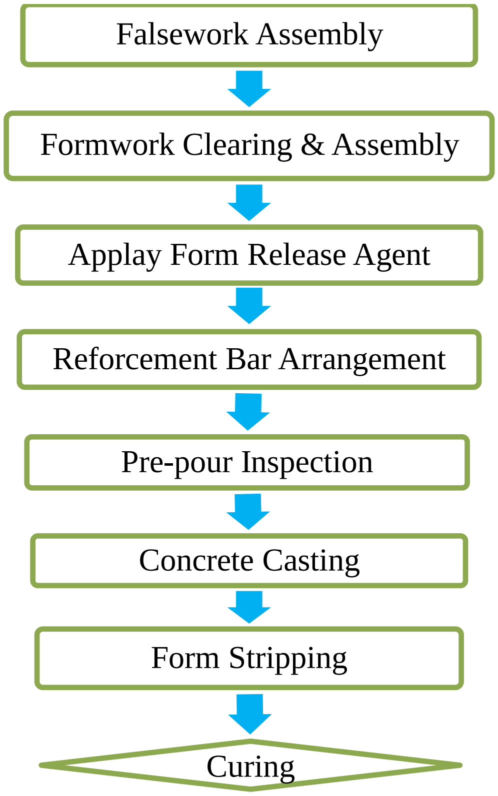
The major construction materials required for the construction of cast-in-place slabs are Eucalyptus log/tubular steel frame scaffolding/metal posts with lateral bracings, job built/timber or prefabricated steel form, concrete (Class 24/20), reinforcement (Grade 40 and Grade 60).

### 4.5.2. Equipment

Concrete mixer, vibrators, water tank, and dump truck other minor tools are the major equipments required for the construction of cast-in-place slab culverts.

### 4.5.3. Construction Procedures

The procedures of cast-in-place slabs culverts construction are depicted as below,




### 4.5.4. Construction Method

The construction method of cast-in-place slabs of slab culverts are discussed as below,

I. **Flasework and Formwork Preparation:** considering crossing site ground condition and actual loads, eucalyptus grade beam or mudsill(temporary footing) shall be arranged first in view of reducing differential settlements between props. The mudsill can be a plank or precast pad.

   Metal posts, scaffold-type frame or wood posts arrangement and formwork preparation shall follow procedures discussed under Section 4.3.4.12 above for the construction of top slab of cast-in-situ box culvert.

II. **Applying Form Release Agent**: please refer Section 4.2.4.1(III) for related information,

III. **Reinforcement Bar Preparation**: this activity includes bar cutting, bending and arrangement as to the requirement of the approved shop drawings.

IV. **Pre-pour Inspection**: please refer Section 4.4.4(VI) for related information,

V. **Concrete Pouring**: please refer Section 4.2.4.1(VIII) for related information,

VI. **Formwork & Falsework Removal:** please refer Section 4.3.4.13 for related information,

VII. **Curing**: please refer Section 4.4.4(IX) for related information,

Sample pictures from different road projects are tabulated as follow to further clarify cast-in-place slab of slab culverts culvert construction activities,

Figure 4-1: Falsework and Form Work Arrangement

Figure 4-2: Concrete Casting Process

# 5. COMPARISION OF CAST-IN-SITU AND PRECAST CONCRETE BOX and SLAB CULVERT CONSTRUCTION

The comparison between precast and cast-in-place box and slab culverts construction method is mainly made based on the performance factors of both methods with regards to construction time, quality and costs. Weighted scoring model is also used to weigh these two construction option based on the under discussed evaluation criteria's.

## 5.1. Comparison with Regards to Construction Time

Construction of box and slab culverts using cast-in-situ method requires longer on site construction processes and have the under listed disadvantages with regards to time when it is compared with that of precast method.

- it does not allow task overlapping,
- its activities are time demanding,
- it is obliged to follow time demanding technical requirements,
- it can be lingered by Weather condition,
- it demands additional time to coordinate logistics and labors,
- it have relatively less contribution to a successful project time performance,

I. **Cast-in-situ method does not allow task overlapping:** almost all major activities of cast-in-situ construction method are required to await the completion of their preceding one so that they can be started. For example, to commence concrete casting for slab of slab culvert or top slab of box culvert, it is required to complete activities like falsework and formwork preparation, and reinforcement bar placing. However, when it comes to precast construction method, precast unit production and transportation can be executed before the commencement of structural excavation and then, installation can proceed immediately after bedding preparation is completed, which is a matter of hours or a day tasks.

II. **Activities of cast-in-situ method are time demanding:** activities of this method, like building falsework and formwork in the shape of the member being built, placing reinforcement bar, concrete batching, mixing, transporting, placing and compacting, and curing, are time intensive, as a result of the same a minimum of a one month or two is required to complete a single major culvert. However, all the above mentioned activities can be performed within two or three days, depends on the actual site condition, using precast method,

III. **Cast-in-situ method is obliged to follow time demanding technical requirements**: cast-in-place method activities like backfilling and form stripping are required to await a minimum of 14 days or till the concrete get sufficient strength to withstand pressures created by the backfilling activity and can support its own weight. As a result of the same, formwork preparation on another culvert location will be lingered until used one shall be stripped and prepared for next use. Conversely, since the precast unit has already attained the required strength during production time, backfilling activity can commence right after precast box culvert installation,

**IV. Weather condition can linger cast-in-situ method:** unexpected rain can halt or damage the construction activity of cast-in-place processes, hence, scheduling of cast-in-place activity needs to avoid rainy seasons. In contrary to this, effect of the same situations to precast construction activities is negligible or almost nil,

V. **Cast-in-situ method demands more time to coordinate logistics and labors**: in contrary to precast method, cast-in-situ method demands additional time of project management team to co-ordinate supply of logistics, like formwork, falsework, concrete ingredients, and to assign on-site skilled labors like carpenter, as it is a process of executing the work on its permanent location and demands more manpower.

VI. **Precast method have significant contribution to a successful project time performance**: it is known that every road construction project under the authority of ERA are being evaluated every months based on their time and quality performance. The performance of the bidders in the immediate previous month is being used as a basis for the evaluation of tenders. To attain the client's satisfaction with regards to time, precast method is more preferable as it can narrows the gap in between scheduled and actual time of major culvert construction since its most activities can be executed ahead of time and in a controlled environment. Furthermore, precast method is less likely prone to unplanned(unforeseen) situations. Therefore, time variance, which is a techniques used to assess time performance of the project and can be obtained based on the difference between scheduled time of work performed and actual time of work performed, of precast method is much lesser than that of cast-in-situ method,

## 5.2. Comparison with Regards to Quality of Construction

It is known that the quality of concrete structure construction depends on many factors like:

- quality of preparation works,
- ingredients batching and mixing precision,
- quality of concrete transportation, placing, and compacting,
- quality of concrete curing, and
- concrete quality controlling.

To control or perform all these points, precast construction of box and slab culverts allow/creates a best environments than that of cast-in-situ method. To be more clear, the above listed points are discussed as below;

I. **Quality of Preparation Works**: it is known that adequate quantity of materials and equipments shall be arranged on site for cast-in-situ method before commencing concrete construction activities. Therefore, cements will be subjected to dampness, reinforcement bars will most likely be placed on the ground and became vulnerable to substance that reduces its adhesion to the concrete, and aggregates can be contaminated with foreign materials. But, all related issues will not be a problem for precast method since well arranged storage area is prepared first during production yard preparation.

   Formwork and falsework, and reinforcement bar works are also the main preparation work for the construction of box and slab culverts, which could affects strength, durability and appearance of structures. Reinforcement bars under precast casting approaches are more securely placed as to the design drawings provisions keeping the required concrete cover, while that of cast-in-situ techniques could be displaced from their design position as they are prone to extra construction loads during concrete pouring. Likewise, quality and precision of mould of precast method gives a better product,

II. **Batching and Mixing**: concrete batching and mixing activity is the process of measuring each ingredient materials as to its mix design requirements, putting the same materials with proper order in to the mixer, and mixing them for the standard mixing time. Accordingly, due to labor inefficiency, all this process are less precise under cast-in-situ approach as it is more labor intensive approach,

III. **Concrete Transportation, Placing, and Compacting**: proper implementation of all these steps in box and slab culvert construction is one of the key factors that helps to obtain a quality product. For instance, concrete segregation can be mitigated using appropriate transportation, placing and compaction means. Furthermore, finishing all this activities in a short time from the start of mixing will prevents formation of poor bond between successive layers of concrete, which is caused by pouring a fresh concrete against concrete that reaches its initial setting time. Therefore, using precast construction method will helps to reduce the same time and also minimizes operational error of the these processes as it is less labor intensive,

IV. **Quality of Concrete Curing**: concrete curing is the process of maintaining proper moisture and temperature condition of concrete by keeping its exposed surface continually wet through sprinkling, ponding or covering with plastic film, etc. This process lets the concrete to gain its strength properly and avoids drawbacks of premature drying out of the concrete. Accordingly, controlled precast units production and curing shed avoids the above mentioned shortcomings. On the contrary, the forms, reinforcement bars and other surfaces that come in contact with fresh concrete including the concrete itself are exposed to external temperature during cat-in-situ approaches, which requires appropriate attention during and after concrete casting to avoid premature drying out of concrete.

V. **Concrete Quality Controlling**: this is a means to verify that the required design parameters of concrete structures are acceptably achieved or not. These quality controlling are carried out both during and after construction of concrete and they are;

- quality control for material; e.g., chloride content of water for mixing, density of aggregate, water absorption of aggregate and grading of aggregate, density of cement,
- Quality control for manufacturing of concrete, e.g. measurement during batching, mixing time,
- Quality of concrete; e.g. workability of fresh concrete, compressive strength of hardened concrete,

Therefore, as discussed in the previous section, precast construction approach have better settings for measurement and quality testing. As a result, precast construction approach minimizes mistakes, reworks, and material wastages.

**Quality Performance**: as discussed in the previous section, quality performance of each ERA's project is being evaluated at the end of every construction month so as to measure their conformance to the quality standard set within the contract agreement of the projects. Therefore, fulfilling all the above discussed factors for quality of concrete structure construction will helps to avoid nonconformance report or enables the project to be performed as per the given quality standard. Accordingly, precast approaches for box and slab culvert construction guarantees the achievement of great quality performance considering its characteristic presented above.

## 5.3. Comparison with Regards to Construction Cost

Major influencing factors that determines the cost of construction projects are:

- complexity of the project,
- scale and scope of construction,
- method of construction,
- site constraints,
- project location and
- market conditions.

Accordingly, the cost of construction of box and slab culverts are also subjected to all these factors.

Precast construction of box and slab culverts requires high initial investment for the preparation of production yard and assignment/installation of heavy machineries. Furthermore, transportation cost of precast unit from its production site to the construction area using trailers is also another cost issue of the same approach. However, these costs can be cancelled out and the precast construction method became more profitable depending on the above listed cost determination factors. For example;

- **complexity of construction**: this factor includes the amount of overlap and interdependencies in construction stages and unpredictability of site construction. Accordingly, as precast construction allows task overlapping, avoids interdependencies of construction activities, avoids unexpected construction costs, improves time performance, and reduces the cost variance of the project as it is more cost effective than cast-in-place method,

- **scale and scope of construction**: based on the number of major drainage structures and actual site condition of the project, construction of both box and slab culverts using precast method can be more profitable as it can significantly reduce the construction time and its related costs, increases the productivity, increases the quality, and contribute to a smooth and continues construction of subsequent pavement and earth works activities,
- **construction techniques**: the construction method and technology of production of precast box and slab culvert ensures the successful execution of the project and drives down costs. This is because of the fact that precast approach is more profitable as it can significantly reduce the construction time and its related costs and omits costly process of cast-in-place construction method, minimize material wastages, eliminate logistical concerns and let scheduling to become easier and avoid unexpected delay and costs,
- **site constraints**: site condition with regards to topography and weather condition, construction site position in relation to public transport or nearby properties, and access to the construction sites are limitations of the project that determines cost effectiveness of major culverts construction methods.

## 5.4. Comparison with Regards to Health and Safety

Constructions of road crossing structures diverts or narrows traffic lanes, as a result, traffic flow around these locations become slower and highly vulnerable to accidents. Drivers who do not notice the change around construction area or who are not adopted to it are prone to accidents related with the same changes. Likewise, as most detours are not being prepared well to the required standard, they compromises the road users comfort and confuse/frustrate drivers and became a reason for collision/accident.

As discussed above, construction of box and slab culvert using cast-in-situ method takes longer time than precast technique and become highly vulnerable to traffic accidents.

Figure 5-1:Accident on detour that is constructed for culvert construction

Figure 5-2: Poorly provided diversion road around structure construction area

## 5.5.Summary of Comparisons of Precast and Cast-in-Situ Method

The table below summarizes factors used for the comparison of the performance of both construction approaches

Table 5-1: Summary of Comparison of Precast and Cast-in-Situ Construction

| Factor | | Precast Construction Method | Cast-in-situ Construction Method |
|---|---|---|---|
| TIME PERFORMANCE FACTORS | Task interdependency | Allow task overlapping, casting is done ahead of time | Doesn't allow task overlapping |
| | | Subsequent activities can commence right after installation | backfilling and form stripping are required to await a minimum of 14 days, |
| | Time required for construction | Construction of one culvert can be executed within an average of two or three days, | While similar assignment demands a minimum of a one month, as activities are time demanding |
| | Weather condition | Effects of weather condition is negligible or almost nil | unexpected rain will halt or damage the construction activity |
| | Client satisfaction | Helps to attain the client's satisfaction with regards to time | Can became a cause for delays for subsequent project activities |
| | Scheduling | avoid logistical concern and let site scheduling became easier | additional team to co-ordinate supply of logistics is required |

| | Factor | Precast Construction Method | Cast-in-situ Construction Method |
|---|---|---|---|
| | Time performance | narrows the gap in between scheduled and actual time. therefore, have contribution to successful time performance of the project | prone to unplanned(unforeseen) situations |
| QUALITY PERFORMANCE FACTORS | Preparation work | Provided well prepared storage and construction area that guarantee quality of ingredient materials, and similarly, quality and precision of mould and reinforcement bar work assures a quality product | Construction materials stored on site are vulnerable to quality compromising factors e.g., cement to dampness, aggregates to contamination, reinforcement bar to loss of adhesion. Furthermore, formwork and re-bar-work are prone to construction loads that affect quality and strength of work |
| | Quality Measurement and testing | appropriate to implement a tight quality control means for ingredient measurement, mixing time control .. etc<br>have better settings to control quality of ingredient material, manufacturing process, and concrete itself. | Logistics of site casting is challenging for quality measurement and testing and prone to mistakes, reworks, and material wastages |
| | Quality of concrete transportation, placing, and compaction | In addition to manufacturing efficiency, all this activities will be executed in a short time, which will prevents formation of poor bond between successive layers of concrete. | Due to labor inefficiency, this works are prone to operational errors and form concrete segregation, poor bondage between layers of concrete... |

| Factor | | Precast Construction Method | Cast-in-situ Construction Method |
|---|---|---|---|
| | Quality of concrete curing | controlled precast production and curing shed helps to maintain moisture condition of concrete and avoids premature drying out of the concrete | Due attention is required for forms, reinforcement bars and other surfaces that come in contact with fresh concrete including the concrete itself, in relation to external temperature. In addition to this, it is subjected to outside variables like labor incompetency, logistics, humidity and temperature of the day |
| | Quality performance | with due consideration of the above listed quality determining factors, this method guarantees the achievement of great quality performance, | Similarly, in due consideration of the same, this approach provide relatively inferior quality product |
| COST PERFORMANCE FACTORS | Initial cost | requires high initial investment | Low initial investment |
| | | transportation cost of precast unit from its production site to the construction area using trailers is also another cost issue | It is on site construction method |
| | Cost variance | avoids unexpected construction costs or omit cost variance | Prone to unexpected construction cost, or have large cost variance, |
| | Labor cost | omits lengthy and costly process of construction, and reduce the labor(skilled) cost, time related costs | Have high labor cost |

| Factor | | Precast Construction Method | Cast-in-situ Construction Method |
|---|---|---|---|
| | Material efficiency | minimize material wastages | Labor incompetency cause more concrete to be prepared than needed, just in case |
| | Site constraints | cost effective with regards to site constraint like weather condition,.. etc | unexpected weather condition will delay the construction activity, hence avoids rainy season construction |
| | Scale, scope and complexity of the project | more profitable on large scale project as it can increase productivity, significantly reduce the construction time and cost, and facilitate subsequent activities, | Not profitable for large scale and complex project, |
| | Health and safety | Avoids problems related with health and safety | diverts or narrows traffic lanes and let traffic be slower and highly vulnerable to accidents, |

## 5.6. Weighted Scoring

All the above discussed performance criteria's does not have equal significance for major culvert construction. Therefore, an overall comparison of these construction technique is made using weighted scoring model.

Accordingly, evaluation criteria's are "weighted" in comparison of their implication on major culvert construction to each others. Then, prioritization of the same is made based on their "weight" and construction options of both box and slab culverts are scored for respective criteria's.

Findings from consultation made with colleagues and professional experience is used as a bases to 'weight' all criteria's and rate each options.

Table 5-2: Comparison of Precast and Cast-in-Situ Construction Based on Weighted Scoring

| **Purpose**: To Compare the Performance of Precast and Cast-in-Situ Construction Approach for Buried Major Culverts | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Criteria | Weight | Precast-Box | | Precast-Slab | | Cast-In-Situ Box | | Cast-In-Situ Slab | | |
| | | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score | Rating | Weighted Score | |
| Task Interdependency | 20 | 75% | 15 | 100% | 20 | 25% | 5 | 50% | 10 | |
| Required Time for Construction | 20 | 100% | 20 | 100% | 20 | 25% | 5 | 50% | 10 | |
| Quality Performance | 20 | 100% | 20 | 100% | 20 | 75% | 15 | 75% | 15 | |
| Productivity | 20 | 100% | 20 | 100% | 20 | 50% | 10 | 50% | 10 | |
| Time Performance | 15 | 100% | 15 | 100% | 15 | 50% | 7.5 | 75% | 11.25 | |
| Initial Cost | 15 | 0% | 0 | 0% | 0 | 100% | 15 | 100% | 15 | |
| Cost Variance | 15 | 75% | 11.25 | 75% | 11.25 | 50% | 7.5 | 75% | 11.25 | |
| Dependency on Site Constraints (e.g. weather condition, traffic load, working area limitations….) | 10 | 75% | 7.5 | 75% | 7.5 | 25% | 2.5 | 25% | 2.5 | |
| Suitability for Quality Controlling | 10 | 75% | 7.5 | 100% | 10 | 50% | 5 | 50% | 5 | |
| Effectiveness (Material Efficiency, Labor Efficiency..) | 10 | 100% | 10 | 100% | 10 | 50% | 5 | 75% | 7.5 | |
| Health and Safety | 10 | 75% | 7.5 | 75% | 7.5 | 50% | 5 | 50% | 5 | |
| Totals | 165 | | 133.75 | | 141.25 | | 82.5 | | 102.5 | |

**Rating:** Excellent «««««(100%); Good ««««(75%); satisfactory ««« (50%); mediocre «« (25%); poor « (0%)

# 6. CONCLUSION AND RECOMMENDATION

## 6.1. Conclusion

This study aimed to compare the conventional construction methodology (i.e. cast-in-situ approach) of major culverts with that of precast method, based on performance factors of time, quality, cost and safety. Accordingly, the study has shown that precast construction method have better time performance, provides high quality product, reduce the construction cost depending on the project cost determining factors and have high health and safety record.

To briefly describe the structural behavior of construction materials of major culverts and give explanation on both cast-in-situ and precast construction techniques, this study have reviewed literatures. Subsequently, to show the difference and similarity of these construction methodologies with regards to design and construction, the study have briefly discussed the same for each methods independently. Finally, to evaluate and compare these construction approaches, factors that influences the performance of both construction methods with respect to construction time, quality of structures, cost of construction and safety are discussed and evaluated.

This study shows that major culvert construction using precast technique lets casting ahead of time and facilitates task overlapping, avoids delays in construction due to hardening process of concrete, omits long and time demanding cast-in-situ construction process, avoids effects of weather, avoids stoppages due to unplanned situations, omits time variance(improve time performance) and helps to attain the satisfaction of the clients.

Likewise, this study reveals that major culvert construction using precast method guarantees the strength, durability and appearance of structures as it provides well secured preparation work, curing shed to maintain moisture condition of concrete, tight quality control means for ingredient measurement and mixing time control, better setting to control quality of concrete and its manufacturing process, and avoids premature drying out of the concrete.

In addition to the above, this study also explains the fact that major culvert construction using precast construction method is economically preferable depending on factors that determines the cost of constructions; such as complexity of the project, scale and scope of construction, site constraints, project locations...

Finally, by comparing vulnerability of both construction approaches of major culverts to traffic accidents, this study identifies that precast method is less susceptible to construction related accidents.

## 6.2.Recommendation

Based on these conclusions, major culverts construction using precast method shall be adopted for road projects that have considerable number of major drainage structures in order to reduce the construction time and its related costs, increases the productivity, minimize material wastages, avoid unexpected delay, omit unexpected costs, reduce vulnerability to accidents, avoids impacts on environmental and contribute to a smooth and continues construction of subsequent earth works and pavement activities.

Furthermore, precast construction method of major culverts shall also be implemented for road projects that are:

- located in areas that have long rainy season or difficult weather condition to adopt on site construction,
- located within high traffic load routes,
- have limitations of working areas due to nearby properties, and
- limitation of working time,

Bearing this in mind, ERA's design manuals, specifications and standard design drawings shall incorporate more guidelines and standards about precast culvert in way that designers and road builders could easily refer and adopt.

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