STRUCTURAL ANALYSIS AND DESIGN OF BOX CULVERT ALONG ISUANIOCHA/MGBAKWU ROAD USING EURO CODE 2.

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SUBMITTED TO

THE DEPARTMENT OF CIVIL ENGINEERING

FACULTY OF ENGINEERING

NNAMDI AZIKIWE UNIVERSITY AWKA.

IN PARTIAL FUFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE IN CIVIL ENGINEERING

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FEBUARY, 2021

CERTIFICATION

This is to certify that this project topic titled "Structural Analysis and Design of Single and Triple Cell Box Culvert along Mgbakwu/Isuaniocha Road using Euro code 2" was carried out by Okpara Daniel Ifeanyi with registration number (NAU/2016224048) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State.

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APPROVAL PAGE

This research work "Structural Analysis and Design of Single ad Triple Cell Box Culvert along Mgbakwu/Isuaniocha Road using Euro code 2 " has been assessed and approved by department of civil engineering Nnamdi Azikiwe university.

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DEDICATION

This work is dedicated to Almighty God for the gift of life and also for guiding me through school. I also want to dedicate this work to my lovely mother Mrs Okpara Ngozi who served as a real source of inspiration toward my academic pursuit and my dear brother Dr. Muna for his sincere support.

ACKNOWLEDGEMENT

Special thanks go to Almighty God for giving me the strength to complete this work and also for His guidance and protection throughout my stay in Nnamdi Azikiwe University.

Also I will like to express my profound gratitude to my mum; Mrs Okpara Ngozi for her moral support, constant prayers throughout my stay in school, special thanks goes also to my siblings Dr. Muna and Miss Gift for their encouragement during trying times of my academic pursuit.

I want to thank in a very special way, my project supervisor in the person of Prof. C. H. Aginam for his time and guidance in the accomplishment of this project. May the lord rain blessing from heaven for him and his family and may he also protect your family.

Special thanks go to the Head of Department of Civil Engineering in the person of Engr. Dr. C.AEzeagu.He has been more like a father to us all and I appreciate him so much.

I will also like to extend my heartfelt appreciation to all the staff (academic and non-academic) of the Department of Civil Engineering for their invaluable tutorship and professional guidance.

Finally, I will like to appreciate everyone who has in one way or the other contributed to making me a better person, may the Lord Almighty reward you all greatly

ABSTRACT

This study was conducted to evaluate the structural reliability of EC2 in the analysis and design of hydraulic structures. The structural analysis and design of single and triple cell box culvert along Mgbakwu/Isuaniocha road using EC2, focuses essentially on load assemblage and estimation, calculation and analysis of moment using hardy cross method of moment distribution, calculation of shear force, design and provision of area of steel required. From the loading analysis, the ultimate design load for top slab, vertical walls and bottom slab are 78.07KN/m, 41.88KN/m and 140.69KN/m, 122.79KN/m, 48.6KN/m and 159.6KN/m when both culverts is empty and 12.37KN/m, 93KN/m and 99.8KN/m, 10.69KN/m, 76.5KN/m and 41.99KN/m when both culvert is full. The fixed end moment and free end moment generated for the structural members of the single and triple cell box culverts are 27.84KNm, 58.61KNm and 58.61KNm, 76.51KNm, 25.43kNm and 90.08KNm, 189.2kNm, 12.81kNm and 246.2kNm, 283.8kNm, 13.31km and 369.34kNm respectively while the design moment are 48.67KNm, 58.61KNm and 58.61KNm, 154.83kNm, 178.85kNm and 190.49kNm respectively. The maximum shear forces are 53.96KN, 128.69KN and 63.77KN, 63.05KN, 529.3KN and 73.85KN respectively. The design suggest that minimum area of steel of 1200mm^2 was required for all structural members (Top slab, Vertical walls and Bottom slab) of the single cell box culvert and area of steel provided was 1340mm^2 while the triple cell box culvert suggested an area 1600mm^2 as the area of steel required for all structural members, 1800mm^2 as area provided for top slab, 2090mm^2 as area provided for the two vertical walls and bottom slab respectively. The type, size and spacing of reinforcement specified by the design for all structural members are Y16@ 150mmc/c U-bars as main bars and Y12@ 200mmc/c as distribution bars in both faces for the single cell box culvert and Y20@ 150mmc/c U-bars as main bars and Y12@ 150mmc/c as distribution bars in both faces for the triple cell box culvert respectively. The bar bending schedule prepared indicate that seventy-five length of Y16 was required as main bars and forty length of Y12 was required as distribution bars for the single cell box culvert and three hundred and seventy-two length of Y20 was required as main bars and one hundred and fifty-one length of Y12 was required as distribution bars for the triple cell box culvert. The shear design carried out for the critical shear generated (128.69KN and 529.3KN) was satisfactory as the design concrete shear stress exceed the design shear stress in magnitude. The study encourages the use of EC2 in the design of concrete structures as it is logical, organized and structurally reliable, this code is gaining more credence globally and should therefore be adopted by Nigerian Engineers.

TABLE OF CONTENTS

LIST OF TABLES

s

LIST OF FIGURES

LIST OF PLATE

\

LIST OF SYMBOL & ABBREVIATION

A- cross sectional area.

Ac -area of concrete section.

Ac -gross area of concrete at a cross-section.

As- -area of tension reinforcement.

Asc--´ area of compression reinforcement.

As'prov-- area of compression reinforcement.

Asc ---area of compression reinforcement, per unit length of wall.

Asmin - minimum area of steel.

*A*sreq--- area of tension reinforcement required.

BT—bottom

TP--- Top

VT—Vertical

c/c---center to center

Y--- high yield

BF---both face

FF----far face

NF---near face

EC2--- Euro code 2

Gk--- Characteristic dead Load

Qk--- Characteristic Imposed Load

b—breadth of slab

h---- thickness of culvert

M---ultimate design moment

N---shear force or axial pull

ULS------ultimate limit state

SLS----serviceability limit state

Γc--- factor of safety for concrete.

γf ---partial safety factor for load.

γm ---partial safety factor for strength of materials.

Γs--- factor of safety for steel.

P--- Reinforcement ratio for longitudinal reinforcement.

Φ--- diameter of steel.
Ω-- ultimate load.

DCSS---- design concrete shear stress

DSS---- design shear stress

FEM--- finite element model

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

A hydraulic structure is a structure submerged or partially submerged in any body of water, which disrupts the natural flow of water. They can be used to divert, disrupt or completely stop the flow of water. A hydraulic structure can be built in river, sea or any body of water where there is a need for a change in the natural flow of water (Ola, 2018).

Culvert is a hydraulic structure that allows water to flow under a road, railway, trail or similar obstruction from one side to the other side. Typically embedded so as to be surrounded by soil. Culverts can be constructed from a variety of materials including cast-in-place or precast concrete. Precast reinforced concrete (RC) culverts are very common and usually constructed as single or multi-cell culverts. Precast reinforced concrete (RC) culverts offer advantages such as enhanced quality control, use of higher strength concrete, relatively lower cost due to mass production and shorter installation time.

Culverts are commonly used both as cross-drains for ditch relief and to pass water under a road at natural drainage and stream crossing. A culvert may be a bridge-like structure designed to allow vehicle or pedestrian traffic to cross over the waterway while allowing adequate passage for water (Ola, 2018). Culverts come in many sizes and shapes including round, elliptical and box- like construction. The type and shape selection are based on a number of factors including requirements for hydraulic performance, limitation on upstream water, surface elevation and roadway embankment height.

In the 1970s, there was a significant boom in culvert bridge construction in many countries (Alkhrdaji and Nanni, 2014). Most of the culverts, made of corrugated metal or reinforced concrete after approaching 10-15 years of age are deteriorating at a high ratio. This deterioration have been attributed to poor structural analysis and design coupled with aggressive environment (e.g, exposure to high moisture and temperature and heavy traffic load) leading eventually to loss of serviceability. The structural design of culvert involves consideration of load cases (empty box, full and surcharge load e.t.c) and factors like live load, effective width, braking force, dispersal of load through fills, impact factors, coefficient of earth pressure e.t.c. The standard elements are required to be designed so as to withstand maximum bending moment and shear force with relevant code required to be referred.

This study therefore presents the structural analysis and design of single and triple box culverts along Isuaniocha/Mgbakwu road using Euro code 2.

1.2 Statement of Problem

Most of the culverts made of corrugated metal or reinforced concrete after approaching 10-15 years are deteriorating at a high rate. This has been largely attributed to poor structural analysis and design which have consequently resulted to loss of serviceability.

This study therefore tackles the problem associated with the deterioration in the design life of single and triple box culverts along Isuaniocha/Mgbakwu road through accurate structural analysis and design using Euro code 2.

1.3 Aim and Objectives of Study.

The aim of the study is to carry outthe structural analysis and design of single and triple box culverts along Isuaniocha/Mgbakwu road using Euro code 2 and the objectives includes:

1. Determine the total design loads (dead and imposed) acting on the various part of the single and triple box culverts.
2. Generate the internal stresses (maximum bending moment and shear force).
3. Design the single and triple box culvert using Euro code 2.
4. Detail the design structural elements of the culverts.
5. Prepare bar bending schedule of structural elements.

1.4 Scope of Study.

This study is essentially centered at improving the design life condition of single and triple box culverts along Isuaniocha/Mgbakwu road through accurate and efficient structural analysis, design and detailing using Euro code 2. This process involves estimation of load (dead and live load), generation of internal stresses (bending moment and shear force), design and specification of sizes, types, numbers and spacing of reinforcement steel to be employed.

1.5 Significance of Study.

Most of the culverts constructed and installed in Anambra State particularly in Isuaniocha/Mgbakwu road Anambra State have been characterized by deteriorating design life which have resulted to high maintenance cost after construction and installation.

This study will therefore address the problem associated with the decline in design life of single and triple box culverts along Isuaniocha/Mgbakwu road through accurate and efficient structural analysis and design using Euro code 2. This would be extremely beneficial to the host communities through the following:

1. Increase the design life of the culverts thereby reducing post maintenance cost.
2. Reduce the occurrence of accident as a result of poorly designed culverts.
3. Specify materials for construction of culverts with good hydraulic characteristics.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General

Culverts are widely used as cross-drains for ditch relief and to pass water under natural drainage and stream crossings. Culverts are made of concrete or metal (corrugated steel or aluminum), and plastic pipe is occasionally used, as well as wood and masonry. The type of materials used depends on cost and availability of these materials. Generally, concrete and metal pipes are more durable compared with plastic pipes. The culverts are commonly used in different shapes, namely round pipes, arch pipes, structural arch, and box depending on the site, the required span and permissible height of backfill soil (Keller and Sherar, 2003). Culverts need to be properly sized and installed, and protected from erosion and scour. The key factors in culvert selection are that the culvert has adequate flow capacity, fits the site, and that the installation is cost effective (Montana State University, 1992).

Box Culvert is the arrangement made to cross an obstacle in the form of a stream, a river or a road to pass without closing the way beneath (Sagar and Roshan, 2019). A Culvert is defined as standard specifications as any structure whether made up of single and multiple cell construction with a clear span of 6m. Box Culvert which has got its name due to its shape & orientation and looks like a hollow rectangular box with two slab & two vertical walls which connects monolithically. Box culverts are easy to design and easy to construct economically. It is designed to carry all the loads comes from top slab and transferred with help of vertical walls to bottom slab which rest generally where the bearing capacity of soil is low. Box Culverts are economical due to their rigidity and monolithic action no separate foundation is required when bottom slab is rest on hard soil. The structure is designed such as rigid frame adopting moment distribution method for obtaining final distributed moments on the basis of the vertical walls and slabs. Box Culverts are generally found in three locations, the first is at the bottom of depressions where no natural water course exist, second is where natural stream intersect the roadway and third is at locations required for passing surface water carried in the ditches beneath roadways and driveways to adjacent property. There are many general problem occur with box culvert such as serviceability and strength, abrasion and deterioration of concrete. For masonry culverts there will be major cause due to sedimentation and blockage by debris. There are two types of culverts which are rigid culvert for example concrete and flexible culvert for example steel. Rigid culverts are made to bear the bending moments where the flexible culverts are not.

This Eurocode underpins all structural design irrespective of the material of construction. It establishes principles and requirements for safety, serviceability and durability of structures. (Note, the correct title is Eurocode not Eurocode 0.). The Eurocode uses a statistical approach to determine realistic values for actions that occur in combination with each other. The series of European standards commonly known as "Eurocodes", EN 1992 (Eurocode 2, in the following also listed as EC2) deals with the design of reinforced concrete structures – buildings, bridges and other civil engineering works. EC2 allows the calculation of action effects and of resistances of concrete structures submitted to specific actions and contains all the prescriptions and good practices for properly detailing the reinforcement.

EC2 consists of three parts:

1. EN 1992-1 Design of concrete structures - Part 1-1 General rules and rules for buildings, Part 1-2 Structural fire design (CEN, 2002)

2. EN 1992-2 Design of concrete structures - Part 2: Concrete Bridges – Design and Detailing rules (CEN, 2007).

3. EN 1992-3 Design of concrete structures - Part 3: Liquid retaining and containmentstructures (CEN, 2006).

2.2 Culverts and Classification.

Generally, culverts are cast in situ, but it depends on the country you are because some countries they preferred due to economic and low cost with having fast workmanship. There are different types of culvert; it depends on its shape; also, it uses as a small bridge. Culvert spans generally are 6m-10m length so it can control all the water coming from the canals, river, and all the stormwater and floodwater to pass under the road safely. Reinforced concrete box culvert has four sides that monolithically connected. Some box culverts have three sides because there's raft or mat foundation in the bottom and two vertical wells in the sides. There are different types of culvert, and they are,

1. Pipe Culverts
2. Box Culverts

3. RCC Solid Slab Culverts
4. Pipe Arch Culverts
5. Arch Culverts

1. Pipe Culvert

Pipe culvert may be a single or multiple pipes; therefore, if it's used a single culvert, then a large diameter culvert is required if the width of the water channel becomes greater than multiple pipe culvert is going to use in that place. The multiple pipe culvertsare suitable to use for a large water channel. The diameter size of the pipe culverts is between (1m to 6m). Pipe culverts are generally widely used and they look rounded in shape. The shape varies from circular, elliptical and pipe arch. Generally, their shape depends on site conditions and constraints. Some of it advantages includes: ease of construction to any desired strength by proper mix design, thickness and reinforcement, they are economical, the pipes can withhold any tensile stresses and compressive stresses and the crossing of water is under the structure.

Plate 2.0 Multiple Pipe Culvert (Source: metal-culvert.com).

Plate 2.1 Single cell Pipe Culvert with Filter (Source: metal-culvert.com).

2.0 Box Culvert

Box culvert is always in a rectangular shape, and the type of materials used to make the box culvert are (cement, sand, reinforcement, gravel). This type of culvert is used to drain the rainwater, river water, and storm water under the road embankment. Also, box culvert is useful in the dry period because they can help the animals as a passage cross of the railroad or highways. Rectangular cross-section culverts are easily adaptable to a wide range of site conditions including sites that require low profile structures. Due to the flat sides and top, rectangular shapes are not as structurally efficient as other culvert shapes. In addition, box sections have an integral floor. This culvert is made up of concrete and especially Reinforced concrete (RCC). The most challenging part in constructing a box culvert is that the dry surface is needed for installing it. However, due to the strength of the concrete floor, water direction can be changed when a large amount of water is expected. This feature makes box culverts one of the most commonly found types of culverts. Some of the advantages include: simplicity of construction, suitable for non-perennial streams where scrub depth is not significant but the soil is weak, reduces substantial amount of pressure on the soil through it bottom slab, they are economical due to their rigidity and monolithic action and separate foundation are not required.

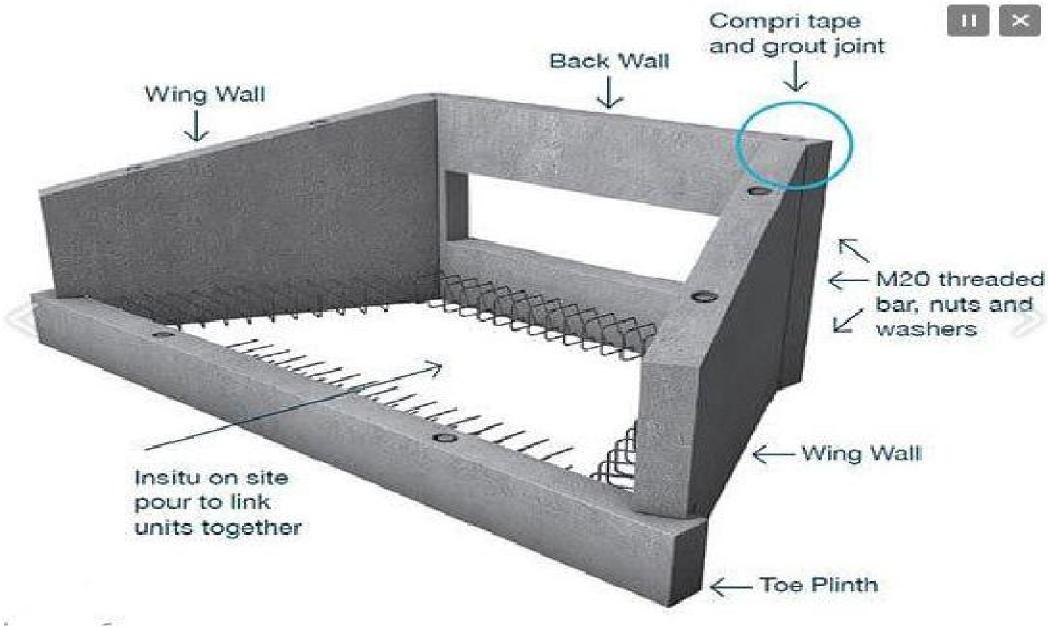


Plate 2.2 Front of Box Culvert (Source: metal-culvert.com).

Plate 2.3 Single Concrete Box Culvert (Source: miller-miller-inc.com).

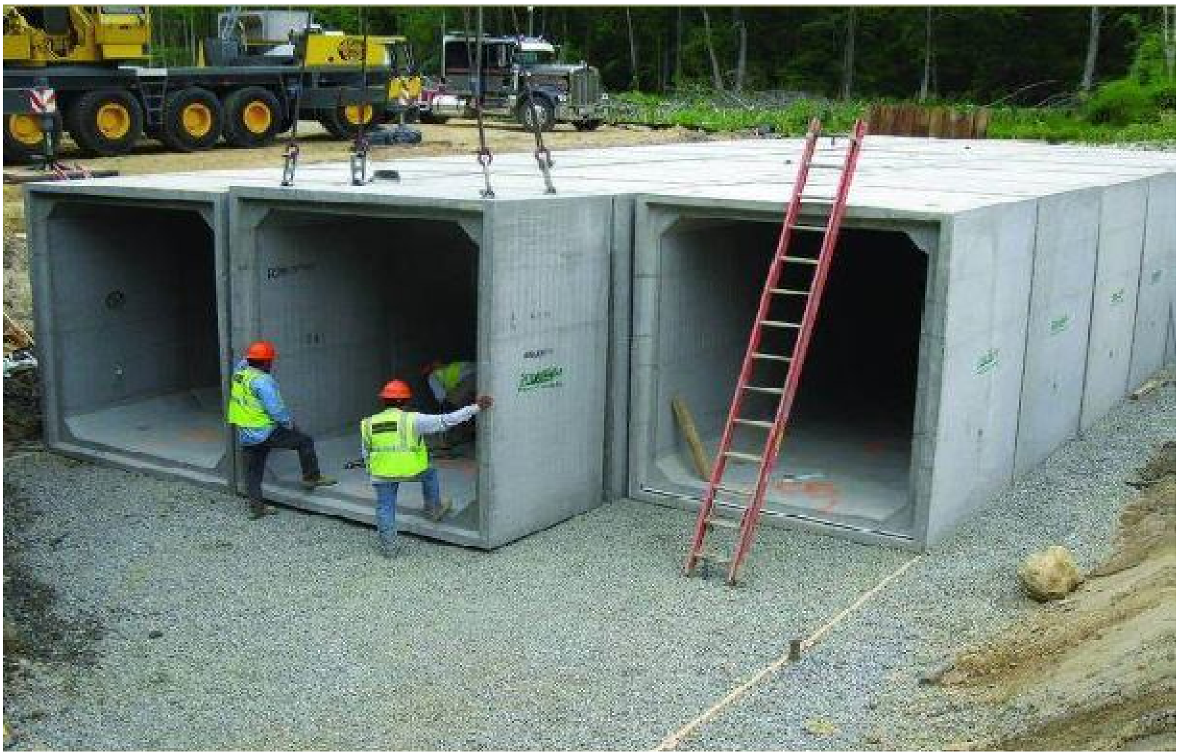


Plate 2.4 Multiple Concrete Box Culvert (Source: miller-miller-inc.com).

3. RCC Solid Slab Culverts

Solid slab culverts are provided where the big canals and the rivers also are used as a small bridge in road vehicles. In these types of culverts, the foundations are laid under the ground surface. A series of box culvert is laid in the ground, then pavement is put on the top surface.

Plate 2.5 RCC Solid Slap Culverts. (Source: http://www.visitgrey.ca).

4. Pipe Arch Culvert.

Pipe Arch Culvert means that they look like a half-circle and half arch culvert. This type of culverts are suitable for the places of the large water flow or waterway opening where fishes can be provided with a greater hydraulic advantage but the flow capacity should be stable. Pipe arch culverts are good for the sewages and fishes because they can use drainage easily without stocking the flow at the bottom. These types of the culvert are very useful so you can see in many places; also, these culverts have a very beautiful appearance. Some of their advantages include: limited headroom condition, improved hydraulic capacity at a low flow, aesthetic shape and appearance, lightweight and ease of installation.

Plate 2.6 Single Concrete Pipe Arch Culverts (Source: http://www.visitgrey.ca).

Plate 2.7 Single Concrete Pipe Arch Culvert with a small Channel (Source: http://www.visitgrey. ca).

5. Arch Culvert.

These types of the culvert are similar to pipe arch culvert, but in this culvert, there is mat provided below the arch. The passage of this culvert is very wide and can transmit a large flow of water. The material made of this culvert is made of concrete or steel.Arch culvert is made up of metal, stone, masonry, concrete. Construction does not take a lot of time unlike box culvert, water diversion is not necessary as it can be installed without disturbing the water current. Thus, it can be termed as low profile culvert. This type of culvert maintains the natural integrity of the wash bed. Some of its advantages include: greater hydraulic efficiency, accelerated construction schedule, cost saving, pleasing aesthetics and design-build advantage.

Plate 2.8 Reinforced Concrete (RCC) Arch Culvert (Source: http://www.visitgrey. ca).

Plate 2.8.1 Steel Arch Culvert (Source: http://www.visitgrey. ca).

2.3 Principle of Culvert Installation

Culvert installation for drainage crossings is quite important process for sustainability of the culvert (Kellar and Sherar, 2003). Important installation details include install culverts at natural stream grade, using quality, well compacted bedding and backfill material, using inlet, outlet, and stream bank protection measures (Normann et al. 1998). However, any soil of low moisture, mud, roots, expansive clay, and boulders can be used. Bedding material beneath the pipe should not have rocks larger than 3.8 cm (Magdi and Zumrawi, 2016). Clay soil can be used if it is carefully compacted at a uniform near optimum moisture content (Montana State University, 1992).

The following guidelines provide specific considerations and details for various conditions in a step-by-step installation sequence according to (NCSPA, 2003), this includes:

1. Check alignment in relation to the plans as well as the actual site conditions.
2. Make certain that the box or pipe length and necessary appurtenances are correct.
3. Excavate to the correct width, line and grade.
4. Provide a uniform, stable foundation—correct site conditions as necessary.
5. Unload, handle and store the box correctly.
6. Assemble the box or pipe properly—check alignment, follow special procedures for the connecting bands, gaskets, and other hardware used.
7. Use a suitable (granular) backfill material as required in the plans and specifications.
8. Maintain proper backfill width.
9. Haunch the box or pipe properly.
10. Place and compact the backfill in 6 to 8 inches (150 to 200 millimeters) of thickness of compacted lifts.
11. Install the necessary end treatment quickly to protect the pipe and your efforts.
12. Protect the structure from heavy construction equipment loads, other heavy loads and hydraulic forces.

2.4 Scouring of Culvert

Eroding of the downstream of a culvert as a result of debris accumulation upstream is referred to as scoring. This occurs when this debris, through crossing hydraulic structures cause the upstream water level and the downstream scour depth to increase, which can lead to failure of the structure. Local scour downstream of culverts involves the removal of granular bed material through the action of hydrodynamic forces. As the maximum scour depth downstream of the culvert increases, the stability of the foundation of the structure may be threatened with a consequent risk of damage and failure (Sarathi, et al 2008). Scour characteristics downstream are affected by many factors, below are previous studies on factors affecting scour characteristics downstream.

2.4.1 Previous Studies on Scour Characteristics Downstream.

Many previous studies have studied the factors affecting the scour hole characteristics downstreamof the culverts. (Abt et al. 1987a: Abt et al. 1987b), experimentally studied the effect of culvert shape on scour hole dimensions.Different culvert sections such as square, arch and rectangular culvert shapes were investigated withuniform graded sand (D50 at 1.86 mm). The results revealed that culvert cross-section shape had alimited effect on outlet scour. (Chen, 1970) and (Ruffet al. 1982) observed that under equivalent dischargeconditions, a square culvert with a height equal to the diameter of a circular culvert would reducescour. (Abt et al. 1985) studied the culvert slope influence on the maximum scour depth, experimental testswere performed on a circular pipe with various slopes (0, 2, 5, 7 and 10%), and uniform graded sand(D50 at 1.86 mm) was used. The results showed that the maximum scour depth increased as the culvertslope increased within the range of the slopes tested.

Doehring and Abt (1994) studied culvert drop height effects on the maximum scour depth.Experimental tests were performed in a 4-inch diameter circular culvert and uniform sand with D50 at 1.86 mm. Drop heights of 0, 1, 2 and 4 times the culvert diameter above the bed were investigated.The results showed that the depth of scour was directly proportional to discharge intensity. As the relative drop height increased, the maximum scour depth increased proportionally, the width of scour increased, the scour length decreased, and scour hole volume increased. Abt et al. (1984) investigated the effects of varying non-cohesive bed material on local scour geometry at circular culvert outlets. Five non-cohesive bed materials were tested downstream of a four-inch diameter circular culvert. The results produced a single expression for estimating the relative scour depth. Aderibigbe and Rajaratnam, (1998) investigated the effects of sediment gradation on scour hole shape deformed by wall jets. Three sediment mixtures were investigated withD50 at 6.75, 1.32 and 1.62 mm, and geometric gradations (∂) of 1.32, 2.02 and 3.13, respectively. The results demonstrated that sediment non-uniformity had a significant effect on the scour hole dimensions deformed by the jets. There is good correlation between the effective sediment size D95 and scour depth at more than D50 for estimation.FdAbidaand Townsend, (1991) investigated experimentally the effects of bed material properties on scour hole patterns downstream of a box culvert. The results showed that the maximum scour in uniform sands was greater than in well-graded mixtures. Sarathi et al. (2008) studied sediment grain size effects on scour hole dimensions in a non-cohesive sand bed.

One of the problems affecting crossing structures such as culverts is debris accumulation upstreamor inside them, which becomes an obstruction in the waterway. Floating or submerged debris causeshigher velocities and vortices, which increase the scour depth downstream of the culvert as well asraising the upstream water level, which increases the possibility of the structure failure during aflood event (Hemdan et al. 2016). Yasser Abdallah et al. (Hemdan et al. 2016: Moussa et al. 2018) studied experimentally the effects of partial blockagepermeability on scour characteristics in front of bridge piers and found that partial blockage occurrencein front of a bridge pier had considerable interest due to its influence on the stream flow and the formedscour around the neighboring bridge supports. (Sorourian et al. 2014: Sorourian, 2015: Sorourian and Keshavarzi, 2016) experimentally investigatedblockage ratio effects on scour characteristics downstream of a square culvert under steady flow,the results showed that blockage had a significant effect on the flow structure and scouring holedimensions at the culvert outlet. The velocity distribution was rapidly increased in the culvertbarrel in blocked condition and the average turbulent intensity was three times greater than thenon-blocked condition.

It may be concluded from the above studies that culvert shape, culvert slope, soil properties,tail-water depth and culvert blockage are the main factors affecting downstream scour deformation.

2.4.2 Minimizing Scour Downstream Characteristics.

Local scour downstream the box culverts outlet may cause a complete failure of the culvert structure. New research is employed to reduce the max scour depth downstream the outlet of the box culvert under a different flow conditions based on an experimental investigation. (Abdel et al. 2019) suggest a sharp edge sill proposed on a rigid bed to dissipate the excess flow energy. Consequently, a great reduction of the scour hole dimensions is obtained by using the sharp edge sill. The experimental study was carried out using a different positions, heights and shapes of the sharp edge sill with different flow rates as well as tail water depths. The results indicate that the sharp edge sill is a promising tool to reduce the scour dimensions. The reduction of the scour depths by using the sharp edge sill are 60%, while the reduction in the scour depths are 64%, on account of using of rigid apron of length 7 times the height of culvert, compared to previous results without rigid bed. (Abt et al. 1984) suggest that Protection against scour at culvert outlets varies from limited riprap placement to complex and expensive energy dissipation devices. At some locations, use of a rougher culvert material may alleviate the need for a special outlet protection device.

2.4.3 Other Causes of Failures on Culvert.

Various reasons of failure on culvert including lack of maintenance, environmental, and installation-related failures, capacity related failures. Those failures causing erosion of the soil around and under the culvert, and structural or material failures that causes culverts to fail due to collapse or corrosion of the materials from which they are made (Architectural Record, 2013).

Capacity related failures of culvert in some cases is accelerated by floating trees that blocks the inlet of culvert in some cases which causes high pressure. Overflow water on the embankment and through the foundation of pipe culvert is the main contributor to the wear and damages of culverts (Magdi and Zumrawi, 2016).

Failures on culverts may occur suddenly. Sudden road collapses are often the result of poorly designed and engineered culvert crossing sites or unexpected changes in the surrounding environment cause design parameters to be exceeded. Water passing through undersized culverts will scour away the surrounding soil over time. This can cause a sudden failure during medium-sized rain events. Accidents from culvert failure can also occur if a culvert has not been adequately sized and flood event overwhelms the culvert or disrupts the road or railway above it.

Ongoing culvert function without failure depends on proper design and engineering considerations being given to load, hydraulic flow, surrounding soil analysis, backfill and bedding compaction, and erosion protection. Improperly designed backfill support around culverts can result in material collapse or failure from inadequate load support (Architectural Record, 2013).

For constructed culverts which have sustainable degradation or loss of structural integrity, rehabilitation using a reline pipe maybe preferred instead of replacement. Sizing of a reline culvert uses the same hydraulic flow design criteria as that of a new culvert, however as the reline culvert is meant to be inserted into an existing constructed culvert, reline installation requires the grouting of the annular space between the host pipe and the surface of reline pipe so as to prevent or reduce seepage and soil movement. Grouting also serves as a means in establishing a structural connection between the liner, host pipe and soil. Depending on the size and annular space to be filled as well as the pipe elevation between the inlet and outlet, grouting maybe required to be performed in multiple stages. As the diameter of the reline pipe will be smaller than the host pipe, the cross-sectional flow area will be smaller.

Failure of pipe culvert may occur due to deformation of pipes which results from load of transportation. Such failure occurs when the soils above pipe culvert are not capable to support transportation loads. Soils above pipe culvert should have suitable strength and compaction and should be of thickness not less than 30cm.

2.5 Efficiency of Culvert Design.

The efficiency of a culvert design is affected by so many factors and according to Flaherty, (1987) different factors are to be considered are as follows:

1. **The depth of water pond:** For a given design, the depth of the pond formed at the entrance is a function of the size and shape of the culverts. Conversely, the manner in which flow takes place in the culvert is affected by the head of water available at the inlet.
2. **Types of entrance:** If the culvert has poorly designed entrance, then considerable turbulence will occur at the inlet and energy will be dissipated which would otherwise be available for moving the water through the culvert.
3. **The roughness of interior walls:** Rough textured culverts which run full will discharge less water than a smooth one also running full, since much of the energy head is used up in overcoming the resistance to flow.
4. **Basic culverts characteristics:** The length of the culvert dictates whether or not the type of entrance and roughness of the interior walls are major or minor feature of the hydraulic design, if the culvert is properly designed, it adequately drain road grades. The structural

and hydraulic design of culverts is substantially different from that of the bridges as are the construction, maintenance, repair and replacement procedures. Culverts are usually designed to operate at peak flows with a submerged inlet to improve hydraulic efficiency. The effects of pounding and flow on appurtenant structures, embankment and abutting properties are important considerations in the design of culverts (Rigby andBarthelmess, 2011). Structural culverts are buried in soil and are designed to support the dead load of soil over the culverts as well as live load of traffic. Either the live load or the dead load may be the most significant load element depending on the type of culvert, type and thickness of the cover and amount of live load. However, live loads on culverts are generally not as significant as dead load unless the cover is shallow.

5. **Maintenance:** Routine maintenance for culverts primarily involves the removal of obstructions and repairs of erosion and scour. Other defects from weathering loads and age will occur and require routine maintenance.
6. **Traffic Safety:** A significant safety of many culverts as compared to bridges is the elimination of construction in the road way. Culvert can economically be extended so that the standard roadway cross section can be carried over the culvert.
7. **Construction:** One of the most significant factors is that culverts are constructed in and through the roadway embankment. The trench width, bedding, composition and amount of fill over the culvert are important factors that influence the ability of the culvert to carry the design load. Thus, the construction techniques and quality control of workmanship are critical to the ultimate serviceability and life expectancy of culvert.
8. **Durability:** Durability of materials is a significant problem in culverts and other drainage structures. In hostile environments, corrosion and abrasion can cause deterioration of all commonly available culvert materials.

2.6 Analysis and Design of Box Culverts.

The structural and hydraulic design of box culvert is different from the bridge design for construction, maintenance, replacement and repair procedure. The basic characteristics of box culverts the first is on hydraulics in which the culvert are designed for highest flood level or peak value with a submerged inlet to improve hydraulic efficiency. Second is load carrying capacity where structural culverts are used to bear all dead load, live load, and load due to pressure, Impact load and braking forces that can safely be resisted by structure and soil. The third one is maintenance; there is a problem with the blockage by debris and sediment, especially when the culvert is subjected to seasonal flow. The fourth one is the construction in which culvert are made to take the vehicle load bycombined strength of box and surrounding embankment. The fifth one is durability of materials which are major problem in box culverts and other drainage structure. Counteractive environment can cause corrosion and abrasion of the available materials. The culvert are divided into categories according to type of materials used in which first is concrete materials which the culvert are made either precast or cast in situ. The selection is depending on the size, type, flexibility etc. Precast concrete are easy to handle and install. Cast in situ culverts are made on site that requires more days for construction. Second is corrugated steel made by factory named as corrugated steel sheet, this culverts are made by steel pipe sections. This is used in steel pipe culverts with steel sheet for greater span. Third is corrugated aluminum, corrugated aluminum culverts are constructed by factory made of corrugated aluminum pipe and this are available as the conventional structure plate for box culvert and long span structure. Fourth is plastic pipe are made from various materials and have a good strength and properties which depend on the base resin made by formulation of chemicals and final resin is used to produce the pipe. According to the shapes of box, the first one is circular pipes and this is the most common shape for pipe culverts. It is structurally and hydraulically efficient under many conditions for smaller opening. Second is pipe arch or elliptical shape which is generally used when distance from channel invert to pavement surface limited to pipe arch and elliptical shape are not structurally efficient as compared to as a circular shape. It is used in the areas with limited vertical clearance. Third is arch culvert which offers less obstruction to the waterway than pipe arches, the structure is also safe for scour design requirements. Fourth is box section or square and rectangular section used generally nowadays due to angular corner of the structure. Fifth one is the multiple cells used where flow channel is wide, span having more length are used to give proper channel to waterways and also where no problem of clogging when the discharge is more.

2.6.1 Previous Studies on Analysis and Design of Box Culverts.

Patil and Galatage (2016) had carried out study on the design and analysis of factors of box culvert done with cushioning and without cushioning the maximum bending moment in each and every loading. The result is that, load combination was found very critical for all aspect ratio, bending moments for different ratio or aspect is varying or constant for with and without cushion. The effect of water ratio 1:1.5 is negligible and for 2:3 is empty. Afzal Hamif Sharif (2016)had done study by using moment distribution method and Staad pro software, compared them and check out all the structural elements for safety of bridge. The results are the advantage of box culvert and their design critical and span length according by ratio of cell and number of cell.

Ajay, Chandreshaand Parikh (2017), had done the analysis and comparison by using design consideration in mind of box coefficient of earth pressure, cushion, width or angle of dispersion and load case for design. The result is without cushion or with cushion and angle of dispersion been zero, there will be maximum live load and greater stresses are created without cushion.

Ayush, et al (2017), had done study of solid slab and R.C.C Box which is evaluated by estimation of quantities, specifications and detailing of each work. The result shows that reinforced box culvert of span up to 9m should be implemented after which the solid slab should be preference for the span range up to 15m.

Sravanthi et al. (2015), had manually design and check all the design factor and coefficients by using codes IRC& IS Codes somewhat using Staad pro software also. Result suggests the advantages of box culvert either single or double depending on the span length and some other factors.

Ketan et al. (2015), had studied the analysis and design of culvert using software hydraulic parameters, graphs, charts, tables showing variations in test result for different ratio which are bending moment, shear force, discharge capacity, loads etc. Result was declared on the basis of the software analysis tables for hydraulic parameter, bending moment for bottom slab, side walls and top slab are shown in tables for different aspect ratio of cell.

Mahesh et al. (2017), had studied the analysis and design of culvert using FEM (ANSYS) Software and IRC guidelines. The internal stresses for the 3m×3m box culvert where the braking force, design moments, total loads all calculated and check for deformation normal stress, principle stress, Von miss stress for without and with cushion conditions. The result obtained was that deformation without cushion is more, maximum principle stress without cushion is more, and also normal stress, shear stress, and equivalent stress are more without cushioning.

Bilal and Parvez, (2015), conducted hydraulic design of box culvert which include catchment area, maximum HFL, longitudinal area, cross section, velocity observation and estimation of discharge by rational method empirical formula (dickens formula), critical depth and height of jump also decides the area and length of apron. The culvert is designed by manual calculations which give size and shape of box according to discharge and depth of scour

Nehaet al. (2014), had studied the analysis and design of box culvert by using manual calculation and IRC code for bridges and roads taken all the design considerations factors. The findings was that box culvert are economical than the pipe drain and also it have various advantage and design factor may be affected if it is done properly.

Saurav and Pandey (2017), had done comparative analysis study and analysis of conventional method using Staad pro software and FEM using ANSYS Software. The result obtained by using both model conclude that 16.8% FEM through ANSYS Software saves large amount of money and gives the more economical design.

Sujata et al. (2013), had find out the coefficients for moment, shear and thrust of single and two cell box culvert by using Staad Pro software. The result for the design of box culvert includes the information regarding the effect different ratio L/H=1.0, L/H=1.25 etc. Also moments and loads were obtained.

Vaishali, and Ashish (2016), had studied the Berackeven Method / Pay Back period cost, time, labor and material by analytic method. The result obtained by using both methods conclude that cost and time of precast structure is less than the cost in situ structure.

Vasu et al. (2018), had studied the analysis and design of box culvert by using Staad Pro software. The culvert are subjected to certain cases and providing the values in the form of graph and tables in which reduction in displacement and reduction in bending moment are shown. The result obtained using software suggests that the bending moment and displacements decline to minimum value taken in percentage.

Vasu et al. (2018), suggested from study that the stress value increases in the flared portion and shear values decreased on increment of flared portion. Principle stresses decline and give a positive response for structural change. The result obtained from manual design shows the graph and their variations in values with respect to stress by using the flared portion and the stress value were dropped for different cases.

Virendra et al. (2017), provided information regarding the skew box culvert of any angle which shows how reinforcement changes analytical and experimental study of skew bridge model, seismic response, dynamic response and different aspect inspections. The result shows that the longitudinal moment decrease in skew approach as compared to straight approach deflection deck slab, which decrease with increase in skew angle, abutment stiffness and also increases with increase in skew angle which significantly contribute to stiffness of the bridge.

Zengabriel et al. (2018), performed the modeling and analysis of precast reinforcement box culvert with FEM and using ABAQUS and tested the stress, deflections and check the box behaviour by plotting the load deflection graph and loads stress graph. The result obtained from the Modeling and analysis of prefabricated box, knowing the steel requirements, load and deflection curve and load stress curve indicate that there is warning of structure before failure of structure is getting.

Bolden, et al. (2016) stated that the culvert design begins when the structure design unit receives the culvert hydraulic design report. This report shall be used to contain the culvert length, design fill, and other items that lead to the completed culvert plans.

Garg, (2007) reported that box culverts are typically designed similar to bridges, and the new design concepts for bridges are based on the Load and Resistance Factor Design (LRFD) which were developed by AASHTO. Box culvert's four sides are built monolithically and also provide haunch at corners to decrease the water pressure effect. In this type of culvert there is no need of extra foundation since bottom slab act as mat foundation.

2.7 Structural Element of Box Culverts

Kumar and Srinivas (2015) stated that box Culverts consist of top slab, bottom slab and two vertical side walls. Reinforced concrete rigid frame box culverts are used for square or rectangular openings. The top of the box section can be at the road level or can be at a depth below road level with a fill depending on site conditions.

Pencol Engineering Consultants (1983) assumed the thickness of the box culvert and later checked in conventional method. However, this may lead to uneconomical design therefore an attempt is made to evaluate optimum thicknesses for economical design.

2.7.1 Applied Design Loads.

Kumar and Srinivas (2015) classified loads subjected to box culvert to dead load and live load. Dead load comprising of self-weight of top and bottom slab of the culvert and two side walls of the structure which is calculated based on clear dimensions of the culvert and thickness of the culvert. Super imposed dead load depends on the typed road constructed above the culvert and is calculated from standards and specifications code of practice. Live load on culvert is vehicular loading. The vehicular live load consistsof wheel loads moving on top slab of culvert. These loads are distributed through the top slab of the culvert. Earth can exert pressure as active and passive, minimum is active and maximum is passive earth pressure and the median is rest.

Chandrakant and Malgonda (2014) concluded that, since box culvert carries earth embankment which is subjected to same traffic loads as the road carriestherefore; it is required for the box culvert to be designed for such loads. The structural elements are required to be designed to withstand maximum bending moment and shear force. Analysis of box culvert is carried out for various load conditions and structural design is suggested for critical cases.

Kim and Yoo, (2002) conducted an investigation for deeply buried structures, the dead weight of soil itself is the main design load and the effect of live loads is not considered significant. AASHTO LRFD Bridge Design Specifications stipulate the computation of the design load on the top slab of the box culvert based primarily on the effective density of the concrete box culverts can be dependent on the installation method and trench installation.

2.8 Design Fundamental.

The successful completion of any structural design project is dependent on many variables, however, there are a number of fundamental objectives which must be incorporated in any design philosophy to provide a structure which throughout its intended lifespan:

1. Will possess an acceptable margin of safety against collapse whilst in use,

2. is serviceable and perform its intended purpose whilst in use,

3. is sufficiently robust such that damage to an extent disproportionate to the original cause will not occur,

4. is economic to construct, and

5. is economic to maintain

Historically, structural design was carried out on the basis of intuition, trial and error, and experience which enabled empirical design rules, generally relating to structure/member proportions, to be established. These rules were used to minimize structural failures and consequently introduced a margin-of-safety against collapse. In the latter half of the 19th century, the introduction of modern materials and the development of mathematical modeling techniques led to the introduction of a design philosophy which incorporated the concept of factor-of-safety based on known material strength, e.g. ultimate tensile stress; this is known as permissible stress design. During the 20th century two further design philosophies were developed and are referred to as load-factor design and limit state design; each of the three fundamental is discussed separately in Sections below.

2.8.1 Permissible Stress Design

When using permissible stress design, the margin of safety is introduced by considering structural behaviour under working/service load conditions and comparing the stresses under these conditions with permissible values. The permissible values are obtained by dividing the failure stresses by an appropriate factor of safety. The applied stresses are determined using elastic analysis techniques, i.e.

Stress induced by working load $\leq \frac{\text{Failure Stress}}{\text{Factor of Safety}}$

2.8.2 Load Factor Design

When using load factor design, the margin of safety is introduced by considering structural behaviour at collapse load conditions. The ultimate capacities of sections based on yield strength (e.g. axial, bending moment and shear force capacities) are compared with the design effects induced by the ultimate loads. The ultimate loads are determined by multiplying the working/service loads by a factor of safety. Plastic methods of analysis are used to determine section capacities and design load effects. Despite being acceptable, this method has never been widely used.

Ultimate design load effects due to ≤ ultimate capacity based on the failure stress of the material (Working load × factor of safety)

2.8.3 Limit State Design

The limit state design philosophy, which was formulated for reinforced concrete design in Russia during the 1930s, achieves the objectives set out in Section 2.3 by considering two 'types' of limit state under which a structure may become unfit for its intended purpose. They are,

1. The Serviceability Limit State in which a condition, e.g. deflection, vibration or cracking, occurs to an extent, which is unacceptable to the owner, occupier, client etc.

2. The Ultimate Limit State in which the structure, or some part of it, is unsafe for its intended purpose, e.g. compressive, tensile, shear or flexural failure or instability leading to partial or total collapse.

2.9 Eurocode 2

The basis of the approach is statistical and lies in assessing the probability of reaching a given limit state and deciding upon an acceptable level of that probability for design purposes. The method in most codes is based on the use of characteristic values and partial safety factors.

In the Eurocode series of European standards (EN) related to construction, **Eurocode 2: Design of concrete structures** (abbreviated **EN 1992** or, informally, **EC 2**) specifies technical rules for the design of concrete, reinforced concrete and prestressed concrete structures, using the limit state design philosophy. It was approved by the European Committee for Standardization (CEN) on 16 April 2004 to enable designers across Europe to practice in any country that adopts the code.

Concrete is a very strong and economical material that performs exceedingly well under compression. Its weakness lies in its capability to carry tension forces and thus has its limitations. Steel on the other hand is slightly different; it is similarly strong in both compression and tension. Combining these two materials means engineers would be able to work with a composite material that is capable of carrying both tension and compression forces.

Eurocode 2 is intended to be used in conjunction with

1. EN 1990: Eurocode - Basis of structural design;
2. EN 1991: Eurocode 1 - Actions on structures;
3. **hENs**, **ETAGs** and **ETAs**: Construction products relevant for concrete structures;
4. ENV 13670: Execution of concrete structures;
5. EN 1997: Eurocode 7 - Geotechnical design;
6. EN 1998: Eurocode 8 - Design of structures for earthquake resistance, when concrete structures are built in seismic regions.

Eurocode 2 is subdivided into the following parts:

Part 1-1: General rules, and rules for buildings

Part 1-2: Structural fire design

Part 1-3: Precast Concrete Elements and Structures

Part 1-4: Lightweight aggregate concrete with closed structure

Part 1-5: Structures with unbonded and external prestressing tendons

Part 1-6: Plain concrete structures

Part 2: Reinforced and prestressed concrete bridges

Part 3: Liquid retaining and containing structures

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area

The study was conducted in Mgbakwu and Isuaniocha communities in Awka North Local Government Area of Anambra State, Southeast Nigeria. The study communities lies between latitude $6^o\ 26^1$ N/$4^o\ 05^1$N and longitude $7^o\ 03^1$ E/$7^o\ 30^1$E. The area is within the tropical rain forest zone and has marked wet and dry season. The wet season (march-october) is about 8 months while the dry season (October-February) is about 4 months with an average relative humidity of 70%. The length of the road is 16m and the chainage points for both the single and triple box culverts are 0 + 525m and 0 + 725m respectively. The area has a landmass of 1.347km^2 and 1.426km^2 with a population of 5920 and 6450 (2009-2015) respectively. The study area located in Awka North is surrounded by neighboring places like Awba, Ofemili, Ugbene, Ebenebe, Achalla, Urum, Amansea, Amanuke and Ugbenu.

3.2 Hydraulic Design Information

The hydraulic design information for the as-built single and triple box culvert along Mgbaukwu/Isuaniocha road is presented in Table 3.0 below. The measurement of the as-built culvert structure was done with the aid of a measuring tape and recording material. It is however worthy of note that the dimensions of the respective culverts obtained after measurement is relatively different, the findings obtained from the design will be applicable to the respective culverts from different location. Information on chainage was sourced through the structural department situated under ministry of works Awka, Anambra State.

Table 3.0 Hydraulic Design Information for the Proposed Culvert.

Relevant Design Codes	**EN, 1992-1-1, Euro code 2-Part 1-1, Design of Concrete Structure. EN, 1992-1-2, Euro code 2-Part 1-1, Design of Concrete Structure.**
General Loading Condition	**HB Loading Units (30 and 45 units). Specific Density of Concrete = 25KN/m^3 Density of active earth pressure = 18KN/m^3 Water Pressure = 10KN/m^3 Unit Weight of asphalt concrete = 22.5kN/m^3 Characteristic Strength of Concrete = 30Mpa Characteristic Strength of Steel = 500Mpa Effective Pressure for Wheel Load = 1.1N/mm^2 Factor of horizontal active pressure = 0.33 Concrete cover = 50mm**
Factor of Safety	**Dead Load (G_k) = 1.35 Imposed Load (Q_k) = 1.5 Ultimate design load = 1.35 G_k + 1.5 Q_k**
Design Data	**Fixed End Moment = $\frac{wl2}{12}$ Free End Moment = $\frac{wl2}{8}$ Minimum area of steel = 0.4%bh Design parameters for moment and Shear force (Axial Pull) for Top Slab, Vertical walls and Bottom Slab = $\frac{N}{bh}$ and $\frac{M}{bh2}$**
Single Cell Box Culvert Details	**Width of Culverts = 2500mm (2.5m) Depth of Culverts = 2700mm (2.7m) Thickness of Culverts = 300mm (0.3m) Length of Culvert = 7500mm (7.5m) Depth of Earth fill = 140mm (1.4m) Chainage point for the single culvert: 0 + 525m Thickness of foundation = 150mm (0.15m). Wing wall dimension at both ends = 760mm and 120mm respectively.**
Triple Cell Box Culvert Details	**Width of Culvert = 3950mm (3.95m) Depth of Culverts c/c of Top and Bottom Slab = 1600mm (1.6m) Thickness of Earth fill = 1200mm (1.2m) Thickness of Asphalt = 100mm (0.1m) Thickness of all Element = 350mm (0.35m) Chainage Points for Triple Cell Culverts = 0 + 725m Length of Culvert = 1600mm (1.6m) Thickness of Foundation = 150mm (0.15m)**

	Wing wall dimension at both ends = 1000mm and 1200mm respectively.

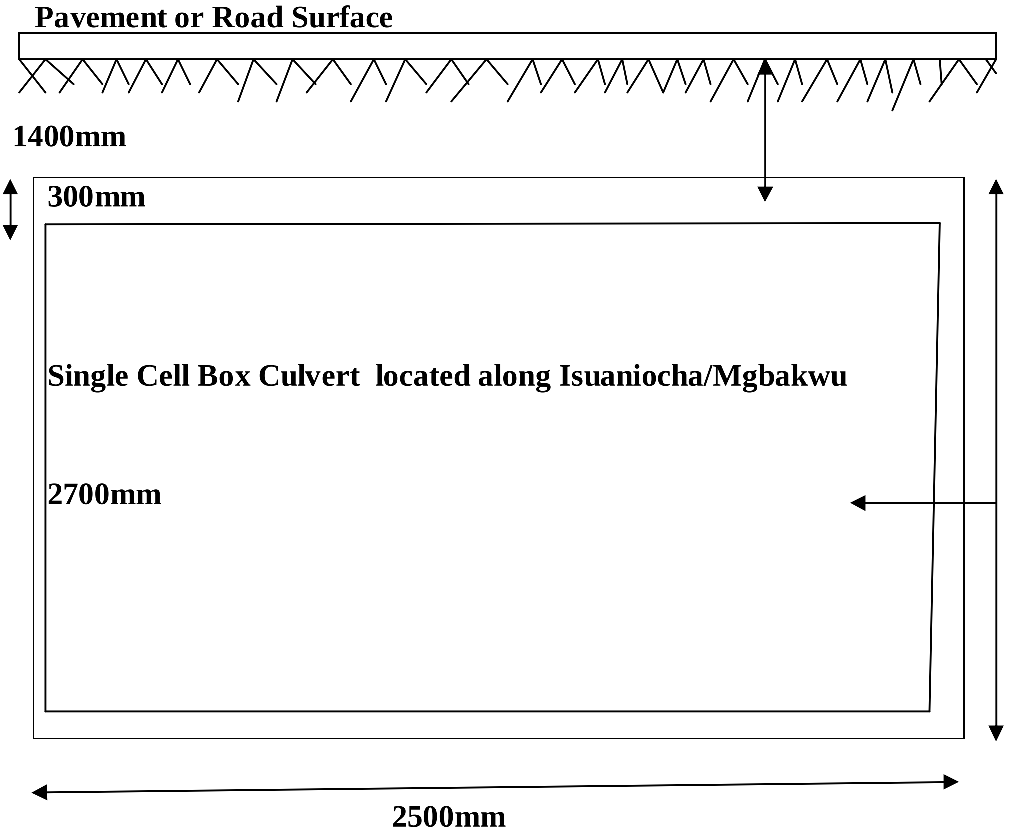


Figure 3.0 Details of Single Cell Box Culvert

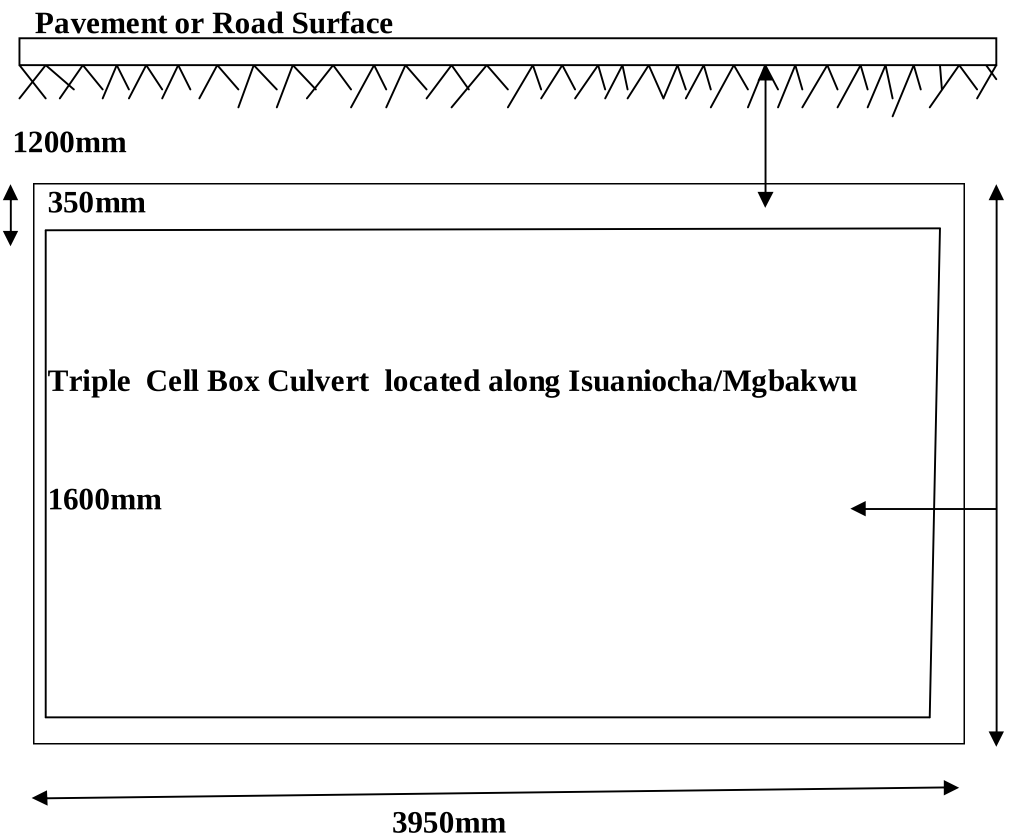


Figure 3.1 Details of Triple Cell Box Culvert.

3.3 Design Consideration for Structural Members

The design is carried out for 7.5m and 16m length of the single box culvert was based on theobtained dimensions from the hydraulic design. The culvert was designed as a hydraulic structure with moment occurring at the four corners. Mainly, the load cases for boxculvert design are: -

1. Box empty, live load surcharge on top slab of box and superimposed surchargeload on earth fill. Active earth pressure, self weight on walls, Top slab and its entire imposed load together with the wall load on bottom slab.
2. Box inside full with water, live load surcharge on top slab and superimposedsurcharge load on earth fill. Water pressure on inside walls and also water pressure and self weight of wall on bottom slab.

3. Box inside full with water, no live load surcharge on top slab and superimposedsurcharge on earth fill. Full water pressure on inside walls and full water pressure and self weight of wall on bottom slab.

Oyenuga (2001) proven that the first load case gives the higher value of moments,because when the box culvert inside full with water, the resultant force ofhydrostatic water pressure on the inside and resultant of superimposed surchargeload on the outside, the sum of the two resultants yields a lesser resultant forceacting on the culvert wall. But however, the analysis and design will be done with due consideration to both cases with the higher value of internal stresses developed used for the final design.

3.4 Analysis and Design of Structural Elements using Euro code2

3.4.1 Top Slab

The method adopted for analysis and design of top slab include:

1. Load assemblage and estimation
2. Calculation of Fixed and Free end moment from ultimate design load calculated in 1.
3. Analysis of fixed end moment using hardy cross method of moment distribution.
4. Generation of final design moment through the principle of superimposition of free end moment with consideration of higher value.
5. Calculation of shear force (Axial pull) from design load.
6. Selection of final shear force to be used for design.
7. Design proper.
8. Provision of reinforcement size, type and spacing.
9. Preparation of bar bending schedule.

3.4.2 Vertical Walls

The method adopted for analysis and design of vertical walls include:

1. Load assemblage and estimation
2. Calculation of Fixed and Free end moment from ultimate design load calculated in 1.
3. Analysis of fixed end moment using hardy cross method of moment distribution.
4. Generation of final design moment through the principle of superimposition of free end moment with consideration of higher value.

5. Calculation of shear force (Axial pull) from design load.
6. Selection of final shear force to be used for design.
7. Design proper.
8. Provision of reinforcement size, type and spacing.
9. Preparation of bar bending schedule.

3.4.3 Bottom Slab

The method adopted for analysis and design of bottom slab include:

1. Load assemblage and estimation
2. Calculation of Fixed and Free end moment from ultimate design load calculated in 1.
3. Analysis of fixed end moment using hardy cross method of moment distribution.
4. Generation of final design moment through the principle of superimposition of free end moment with consideration of higher value.
5. Calculation of shear force (Axial pull) from design load.
6. Selection of final shear force to be used for design.
7. Design proper.
8. Provision of reinforcement size, type and spacing.
9. Preparation of bar bending schedule.

CHAPTER FOUR

4.0 RESULT AND DISCUSSION

4.1 Results

During the course of the research, certain analysis were conducted which would be of immense importance in the design of the proposed culverts. The results of the analysis are summarized in Table 4.1 below:

Table 4.1 Summary of Result obtained through analysis of Single Cell Box Culverts along Mgbakwu/Isuaniocha road.

STRUCTURAL MEMBERS	PARAMETERS	EURO CODE 2(EC2)
Top Slab	Load Assemblage (KN/m) When Culvert is empty.	
	Slab own load	10.13
	Wheel load on Slab	30.14
	Earth Load on Slab	37.8
	Ultimate design load	78.07
	Load Assemblage (KN/m) When Culvert is full.	
	Water load	22.5
	Slab own load	-10.13
	Ultimate design load	12.37
	Internal Stresses	
	Moment (KNm)	
	Fixed End Moment	27.84
	Free End Moment	76.51
	Design Moment	48.67
	Shear Force (KN)	53.96
	Area of Steel (mm^2)	
	Area of Steel required	1200
	Area of Steel Provided	1340
	Reinforcement	Y16@150mmc/cT&B
Vertical Walls	Load Assemblage (KN/m) When Culvert is empty.	
	Wall own load	10.13
	Earth fill on wall (W1)	12.47
	Earth fill on wall (W2)	41.88
	Design load	64.48
	Load Assemblage (KN/m) When Culvert is full.	

	Water pressure at Top Slab	**22.5**
	Water pressure at Bottom Slab	**70.5**
	Total load	**93**
	Internal Stresses	
	Moment (KNm)	
	Fixed End Moment	**58.61**
	Free End Moment	**30.51**
	Design Moment	**58.61**
	Shear Force (KN)	**128.69**
	Area of Steel (mm^2)	
	Area of Steel Required	**1200**
	Area of Steel Provided	**1340**
	Reinforcement Provided	**Y16@ 150mmc/c (BF)**
Bottom Slab	**Load Assemblage (KN/m) When Culverts is empty**	
	Top Slab load	**218.60**
	Load from vertical walls	**175.34**
	Unit design load	**140.69**
	Load Assemblage (KN/m) When Culverts is full	
	Load due to Top Slab and Walls	**-38.35**
	Water pressure on walls	**306.9**
	Wall own load	**60.78**
	Unit design load	**99.8**
	Internal Stresses	
	Moment (KNm)	
	Fixed End Moment	**58.61**
	Free End Moment	**90.08**
	Design Moment	**58.61**
	Axial Pull (KN)	**63.77**
	Area of Steel (mm^2)	
	Area of Steel required	**1200**
	Area of Steel provided	**1340**
	Reinforcement provided	**Y16@150mmc/c (BF)**

Table 4.1.1 Summary of Result obtained through analysis of Triple Cell Box Culverts along Mgbakwu/Isuaniocha road.

STRUCTURAL MEMBERS	PARAMETERS	EURO CODE 2(EC2)
Top Slab	Load Assemblage (KN/m) When Culvert is empty.	
	Slab own load	11.81
	Wheel load on Slab	75.54
	Earth Load on Slab	32.4
	Ultimate design load	122.79
	Load Assemblage (KN/m) When Culvert is full.	
	Water load	22.5
	Slab own load	-11.81
	Ultimate design load	10.69
	Internal Stresses	
	Moment (KNm)	
	Fixed End Moment	189.2
	Free End Moment	283.8
	Design Moment	154.83
	Shear Force (KN)	63.05
	Area of Steel (mm^2)	
	Area of Steel required	1600
	Area of Steel Provided	1800
	Reinforcement	Y20 @150mmc/cT&B
Vertical Walls	Load Assemblage (KN/m) When Culvert is empty.	
	Wall own load	11.81
	Earth fill on wall (W1)	16.2
	Earth fill on wall (W2)	48.6
	Design load	76.61
	Load Assemblage (KN/m) When Culvert is full.	
	Water pressure at Top Slab	22.5
	Water pressure at Bottom Slab	54
	Total load	76.5
	Internal Stresses	
	Moment (KNm)	
	Fixed End Moment	12.81
	Free End Moment	13.31
	Design Moment	178.85
	Shear Force (KN)	529.3

	Area of Steel (mm^2)	
	Area of Steel Required	**1600**
	Area of Steel Provided	**2090**
	Reinforcement Provided	**Y20@ 150mmc/c (BF)**
Bottom Slab	**Load Assemblage (KN/m) When Culverts is empty**	
	Top Slab load	**528**
	Load from vertical walls	**159.16**
	Unit design load	**159.8**
	Load Assemblage (KN/m) When Culverts is full	
	Load due to Top Slab and Walls	**-49.71**
	Water pressure on walls	**175.95**
	Wall own load	**54.33**
	Unit design load	**41.99**
	Internal Stresses	
	Moment (KNm)	
	Fixed End Moment	**246.2**
	Free End Moment	**369.34**
	Design Moment	**190.49**
	Axial Pull (KN)	**73.85**
	Area of Steel (mm^2)	
	Area of Steel required	**1600**
	Area of Steel provided	**2090**
	Reinforcement provided	**Y20@150mmc/c (BF)**

4.2 Discussion on Result obtained.

4.2.1 Culverts Loading

The results obtained from the load analysis of structural members of the single and triple cell box culverts using Euro code2 at their respective ultimate limit state indicate that the design loads of the single cell culvert for the top slab, two vertical side walls and bottom slab when the culvert is empty are 78.07, 12.47, 41.88 and 140.69 while when the culvert is full are 12.37, 93 and 99.8 respectively while that of the triple cell box culvert suggest that for the top slab, two vertical side walls and bottom slabs when the culvert is empty are 122.79, 16.2, 48.6 and 159.8 while when the culvert is full are 10.6, 76.5 and 41.99 respectively. The aforementioned results, implies that the bottom slab produces comparatively higher loading than the top slab and walls for both the single and triple cell box culvert respectively, this is evident from the fact that both the load from the top slab and walls is borne by the bottom slab. Comparative deduction with respect to the load estimation of both the single and triple cell box suggest that the triple cell box culvert generate relatively higher magnitude of load when the culvert is considered than when it is considered full.

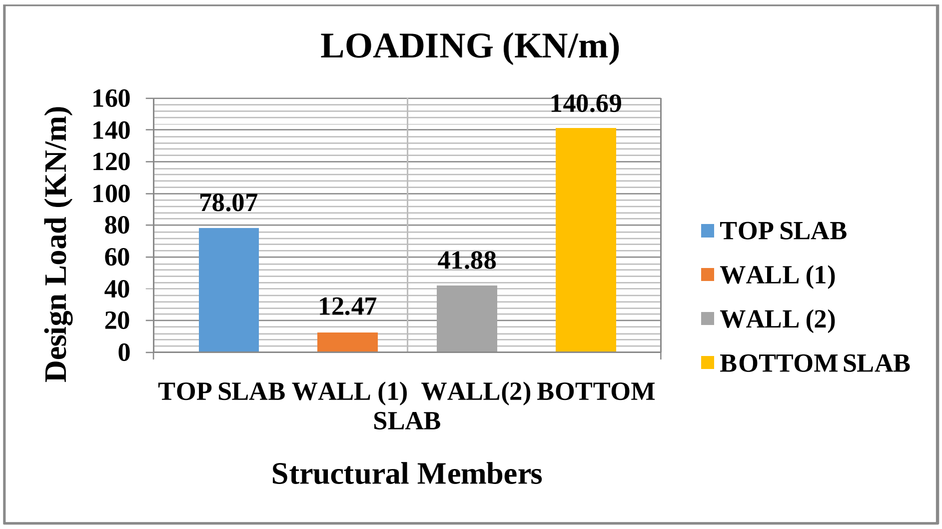


Figure 4.0a: Loadingon Structural Members of Single Cell Box Culvert when Culvert is Empty.

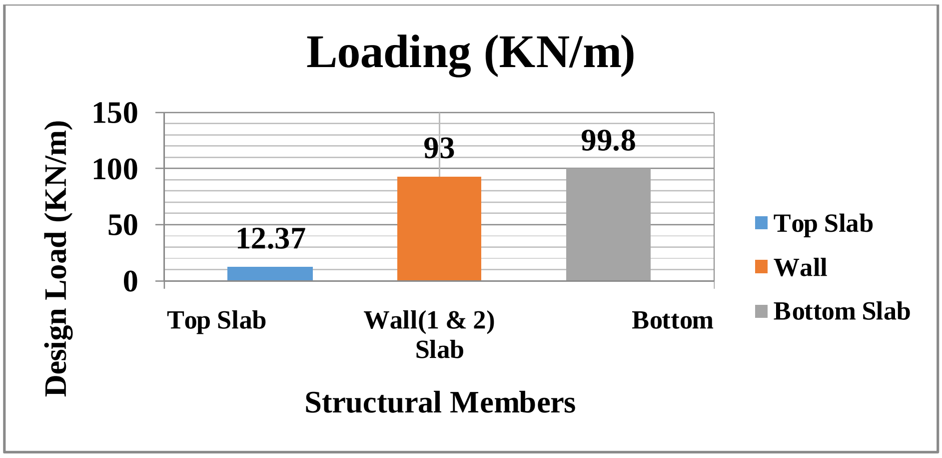


Figure 4.0b: Loading on Structural Members of Single Cell Box Culvert when Culvert is full.

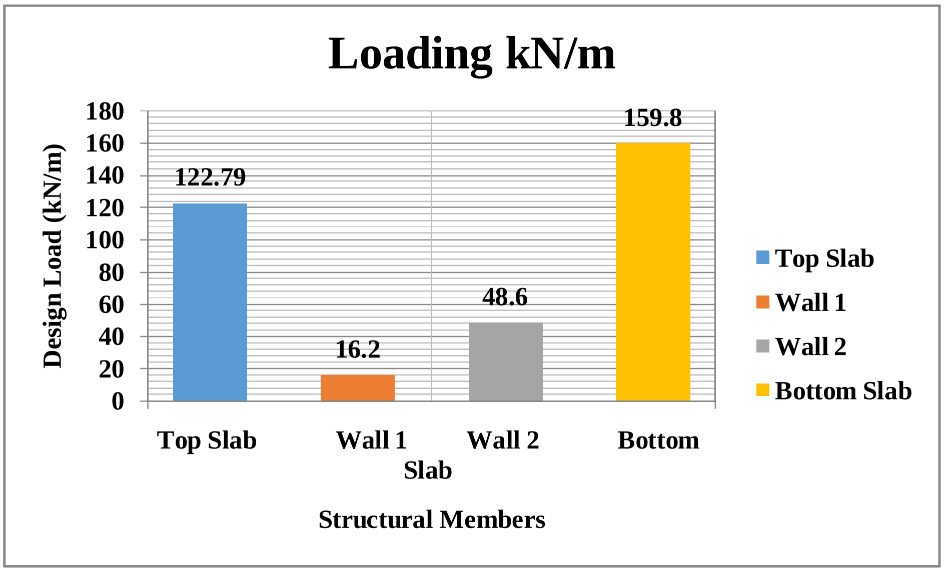


Figure 4.0c: Loading on Structural Members of Triple Cell Box Culvert when Culvert is Empty.

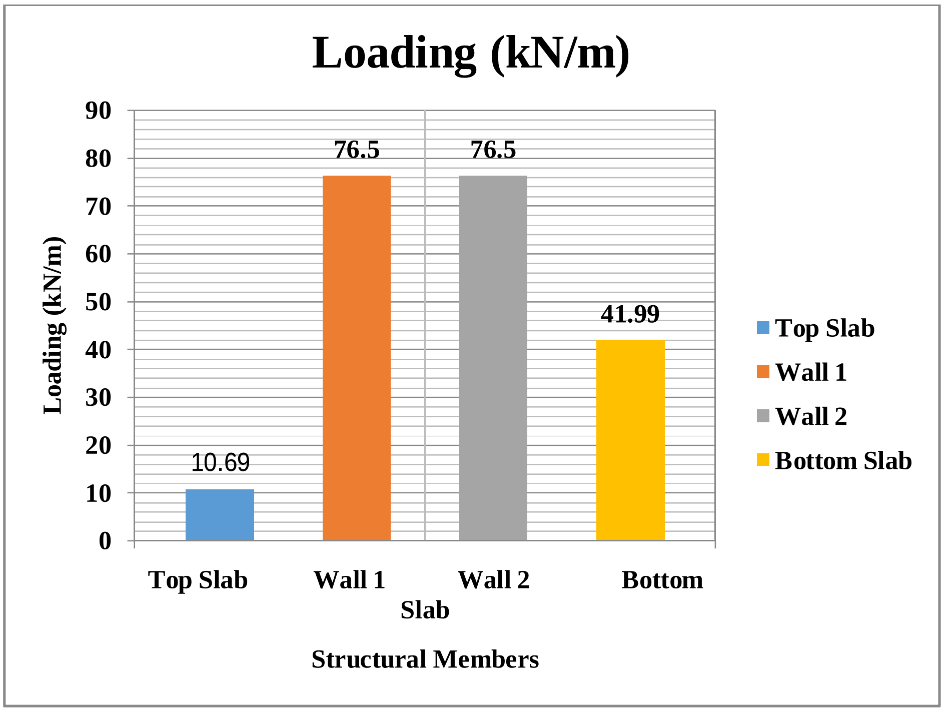


Figure 4.0d: Loading on Structural Members of Triple Cell Box Culvert when Culvert is full.

4.2.2 Fixed and Free End Moment

The fixed and free end moment obtained from the structural analysis of the single and triple cell box culverts members (top slab, walls and bottom slab) using Euro code2 shows thatfor the single cell box culvert, the fixed end moment are 27.84, 58.61, 58.61 and 58.61 while the free end moment are 76.51, 5.48, 25.43 and 90.08 respectively while for the triple cell box culvert, the fixed end moment are 189.2, 11.06, 12.81 and 246.2 while the free end moment are 283.8, 5.66, 13.31 and 369.34 respectively The above results indicate that the fixed end moment of the two vertical side walls and bottom slab are the same for the single cell box culvert with the top slab producing comparatively lower value of fixed end moment while for the free end moment, the bottom slab produces higher value followed by the top slab and the vertical walls. Comparison between the value of both fixed and free end moment generated by both the single and triple cell box culvert suggest that the triple cell box culvert produces comparatively higher value of fixed and free end moment for both the top and bottom slab and this can be attributed to the higher geometry of the triple cell box culvert compared to the single cell box culvert.

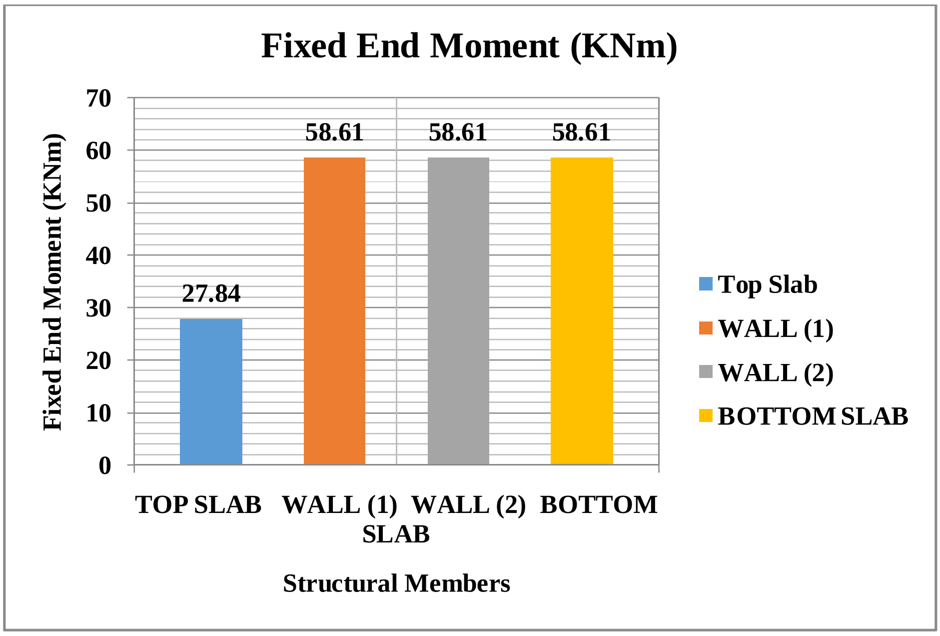


Figure 4.1a: Fixed End Moment for Structural Members of Single Cell Box Culvert.

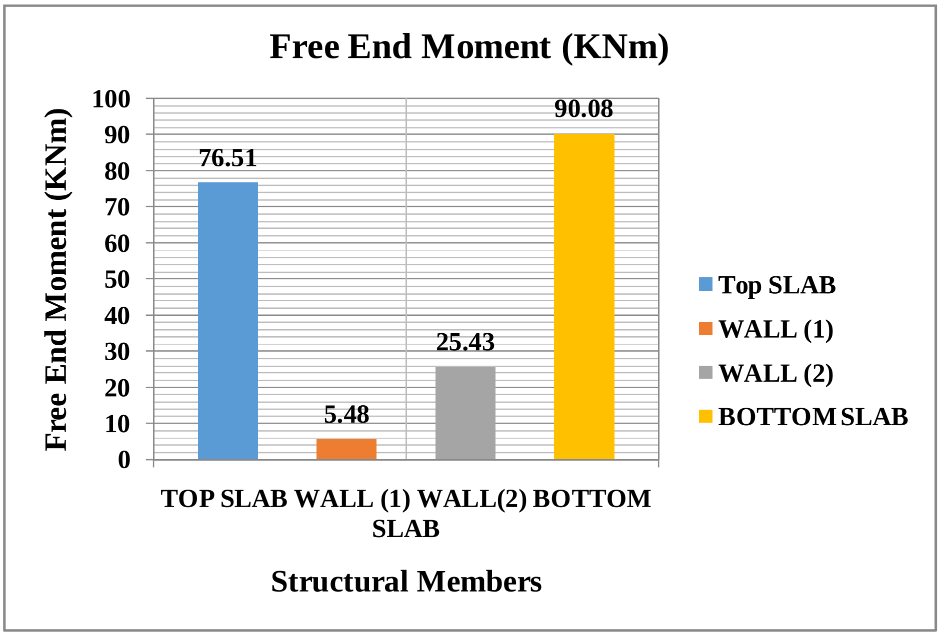


Figure 4.1b: Free End Moment for Structural Members of Single Cell Box Culvert.

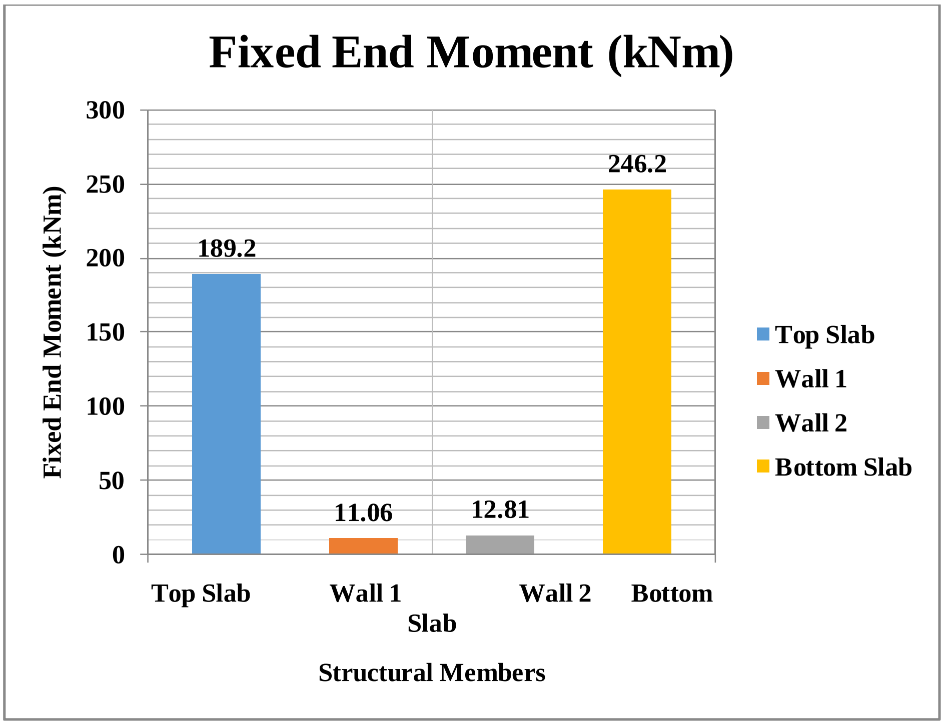


Figure 4.1c: Fixed End Moment for Structural Members of Triple Cell Box Culvert.

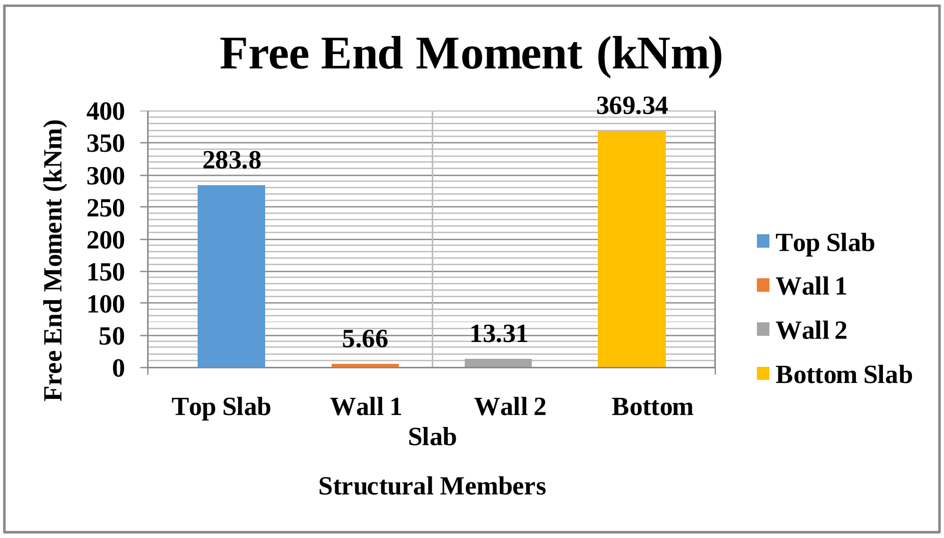


Figure 4.1d: Free End Moment for Structural Members of Triple Cell Box Culvert.

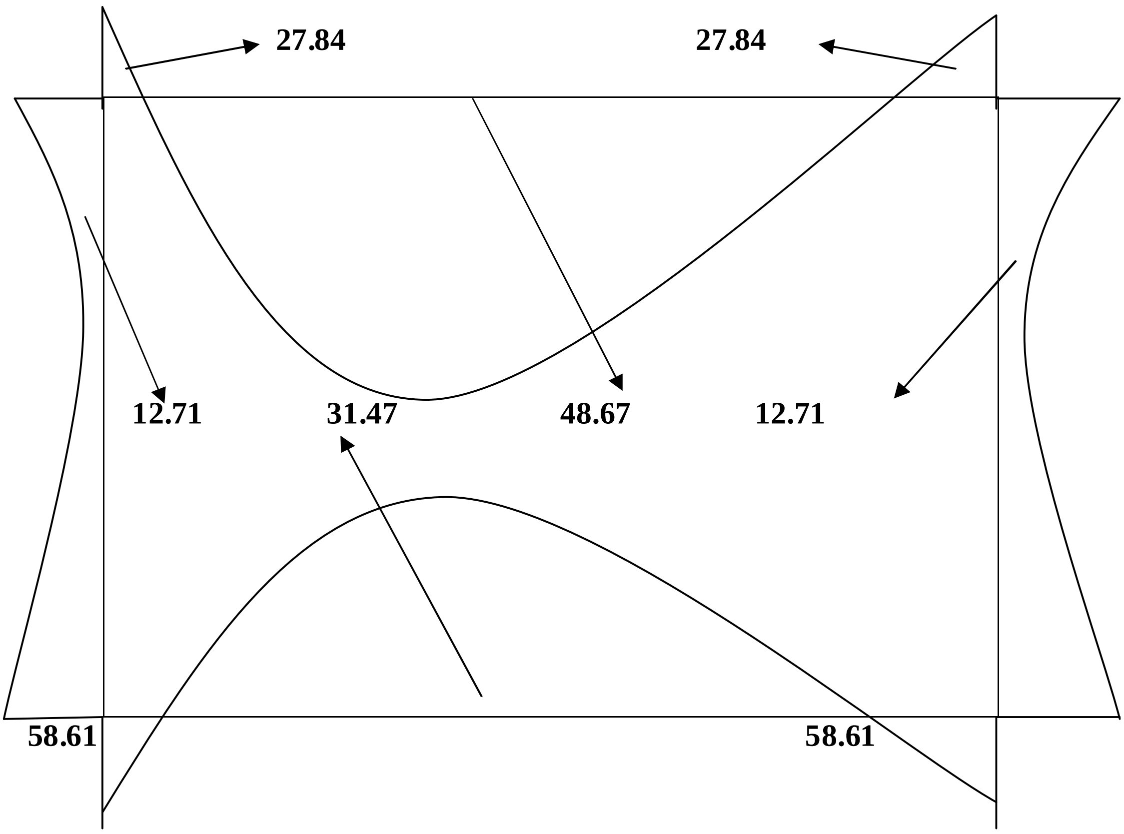
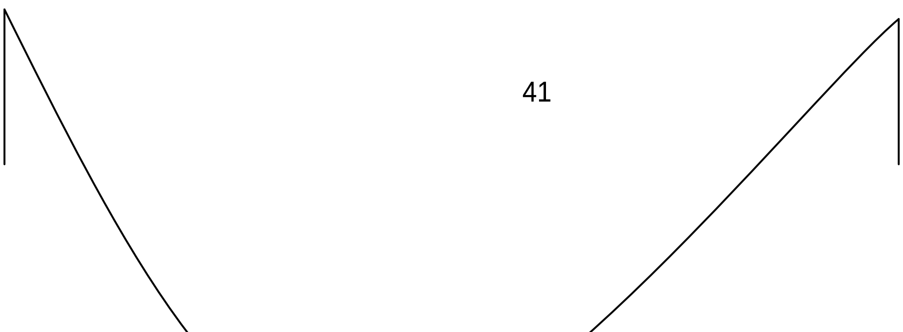


Figure 4.1e Bending Moment Diagram for Structural Members of Single Cell Box Culvert.



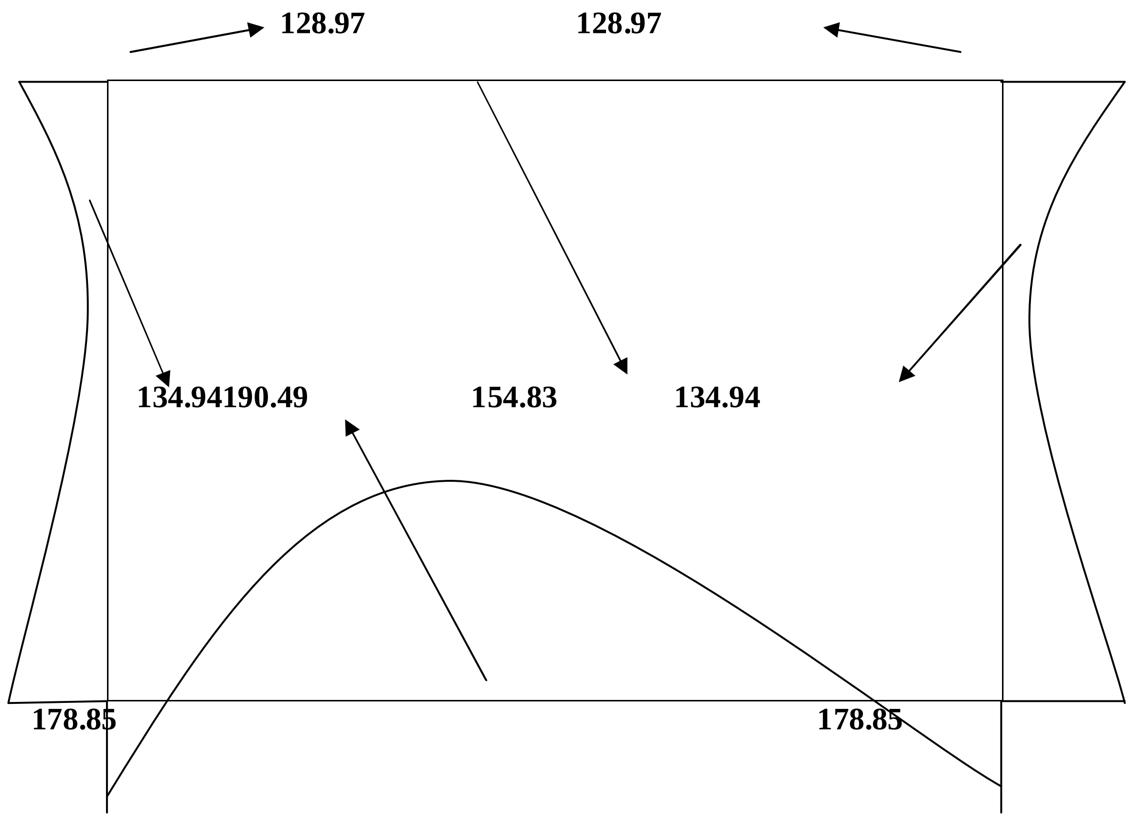


Figure 4.1f: Bending Moment Diagram for Structural Members of Triple Cell Box Culvert

4.2.3 Design Moment

The design moment was obtained after superimposing the free end moment for the respective structural members and considering the highest value of moment as the design moment. The result obtained indicate that the design moment of the two vertical side walls and bottom slab are the same for the single cell box culvert with the top slab producing comparatively lower value of fixed end moment. Comparative inference extracted from both culverts shows that the triple cell box culvert produces relatively larger magnitude of design moment for all structural members with the bottom slab producing the highest value, this can be attributed to the culvert geometry and also due to the fact the a larger magnitude of the load from the top slab and two vertical side walls is borne by the bottom slab which transfers this load safely to the underlying soil.

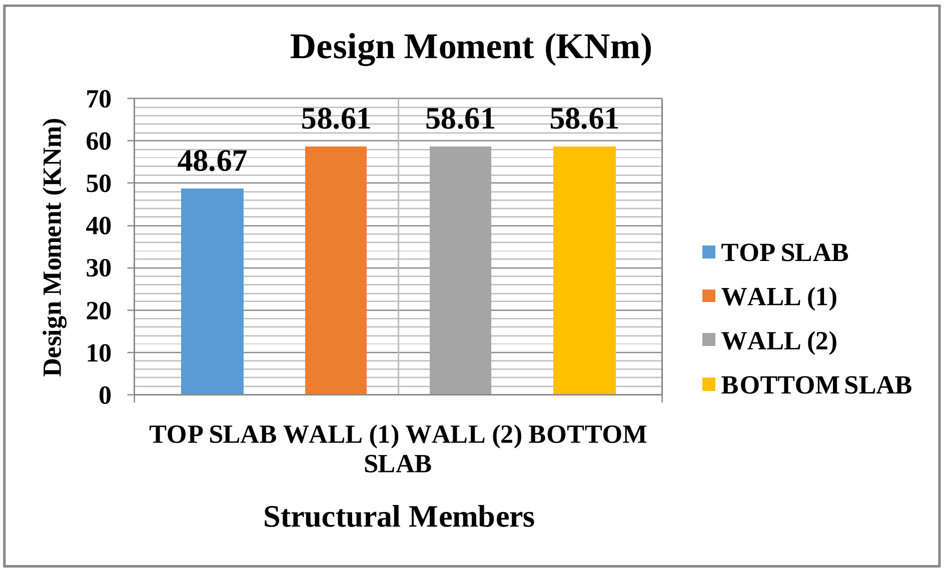


Fig 4.2a: Design Moment for Structural Members of Single Cell Box Culvert.

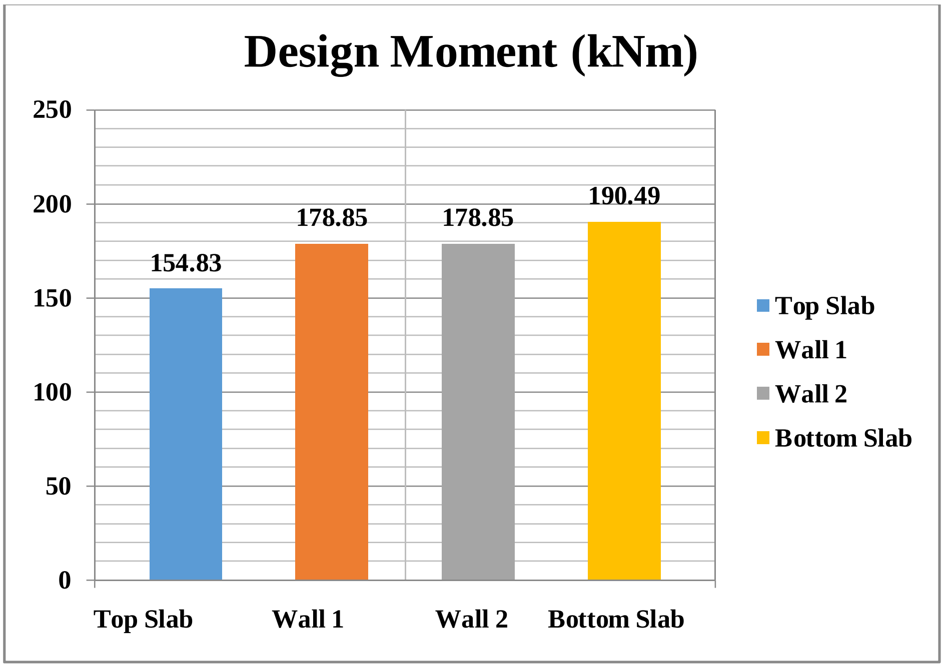


Fig 4.2b: Design Moment for Structural Members of Triple Cell Box Culvert.

4.2.4 Shear Force (Axial Pull).

The shear force generated for the structural members (top slab, vertical walls and bottom slab) of both the single and triple cell box culverts are 53.96, 128.69 and 63.77, 63.05, 529.3 and 73.85 respectively. This result implies that the highest shear generated for the walls of both the single and triple box culverts would be considered for design purpose because of it relatively higher value.

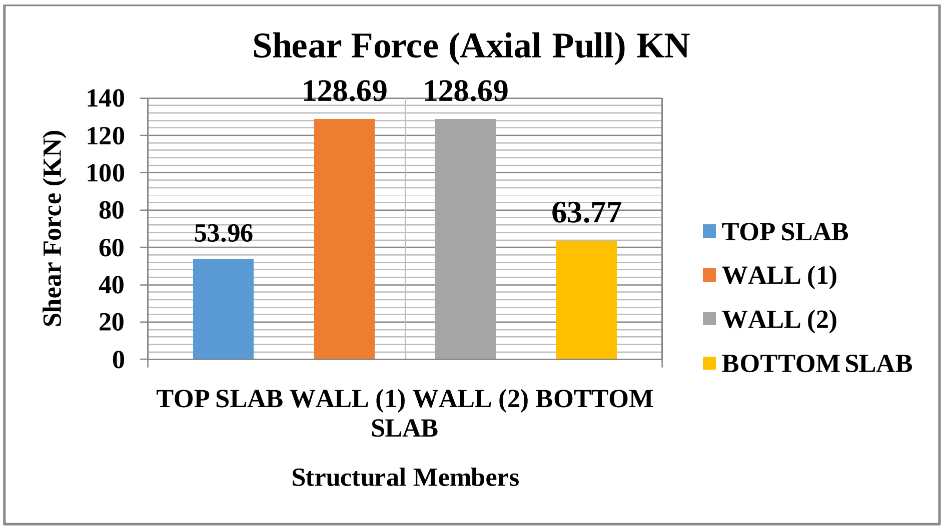


Fig 4.3a: Shear Force Value for Structural Members of Single Cell Box Culverts.

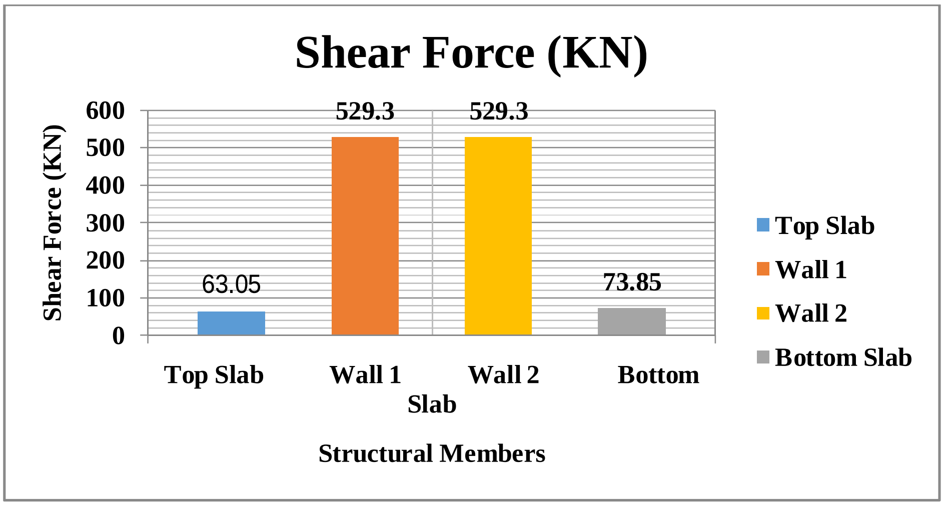


Fig 4.3b: Shear Force Value for Structural Members of Triple Cell Box Culverts.

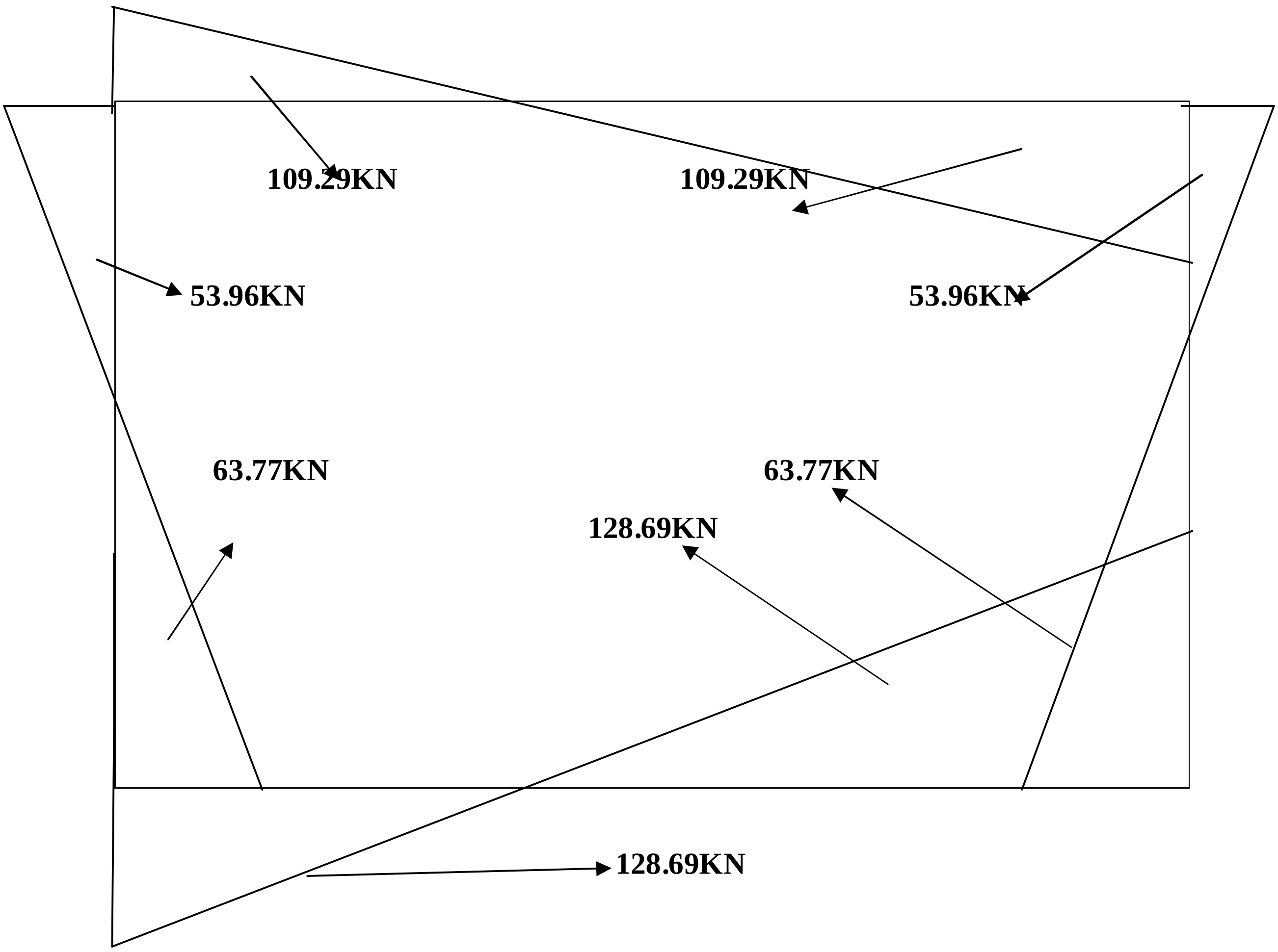
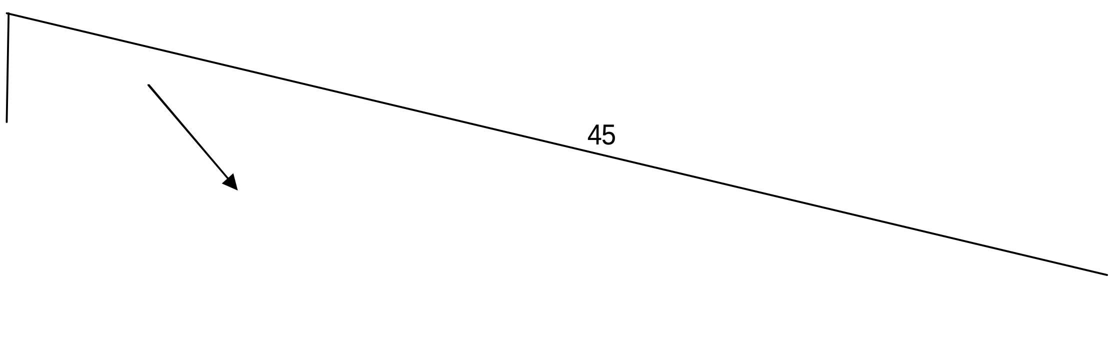


Fig 4.3c: Shear Force diagram for Structural Members of Single Cell Box Culvert.



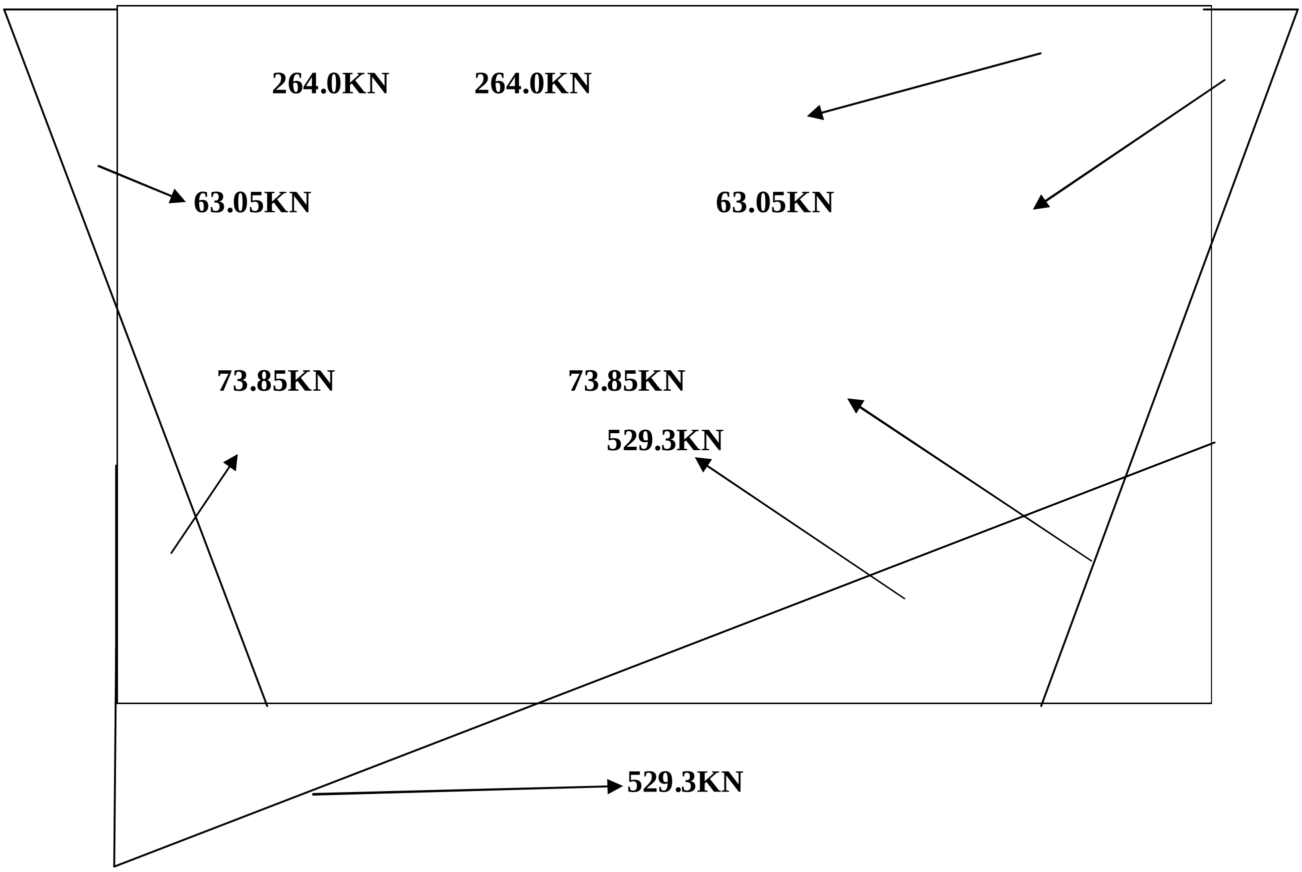


Fig 4.3d: Shear Force diagram of Structural Members for Triple Cell Box Culverts.

4.2.5 Area of Steel

The area of steel required and provided for all structural members (top slab, walls and bottom slab) are the same for the single cell box culvert because the design outcome shows that minimum reinforcement was provided for all members with area of steel required at 1200mm^2 and the area provided at 1340mm^2 respectively. The triple cell box culverts give a required area of 1600mm^2 for all structural members and area provided as 1800mm^2 for top slab and 2090mm^2 for both the two vertical side walls and bottom slab respectively. Comparison between the two culverts suggests that the triple cell box culvert required and provided more area of reinforcement than the single cell box culvert; this can be attributed to the magnitude of moment generated as the triple cell box culvert generated relatively higher magnitude of moment than the single cell box culverts as depicted in the Figure shown below:

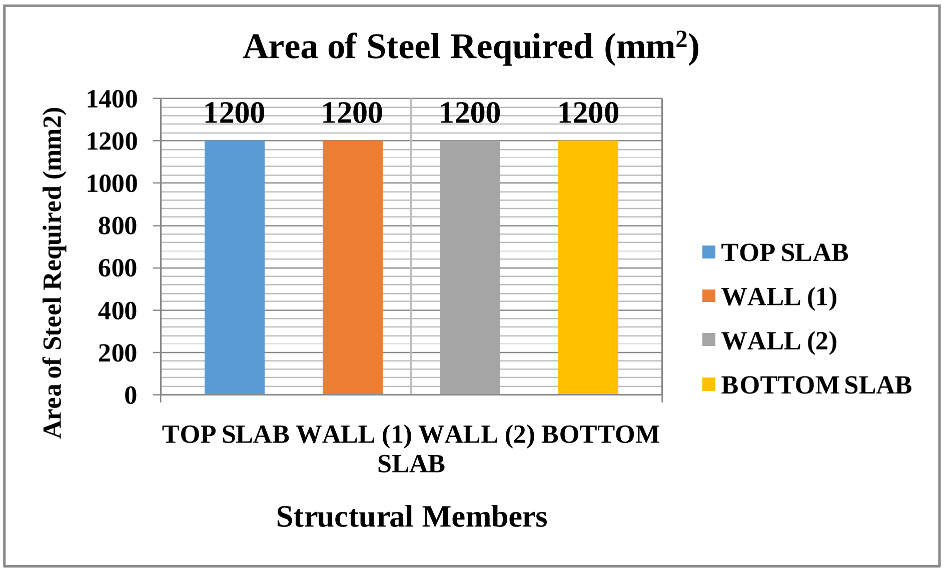


Fig 4.4a: Area of Steel Required for Structural Members of Single Cell Box Culvert.

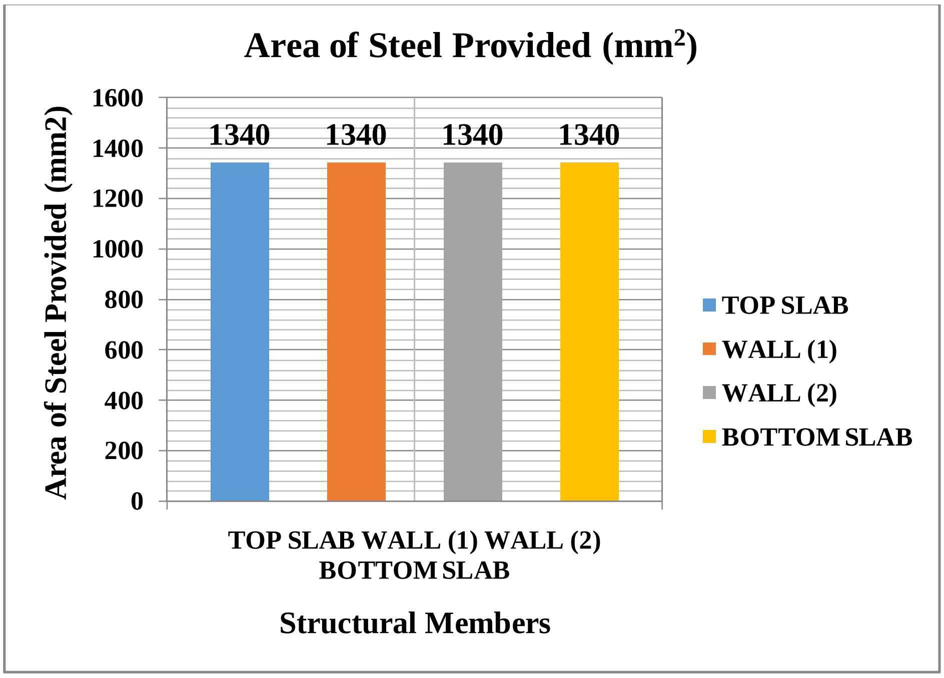


Fig 4.4b: Area of Steel Provided for Structural Members Single Cell Box Culvert.

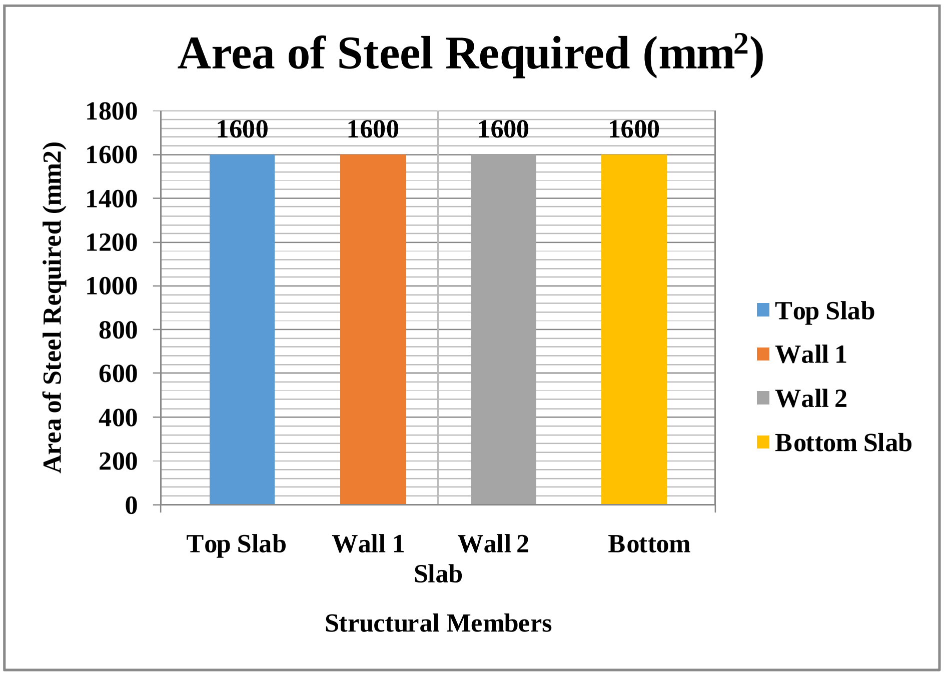


Fig 4.4c Area of Steel Required for Structural Members of Triple Cell Box Culvert.

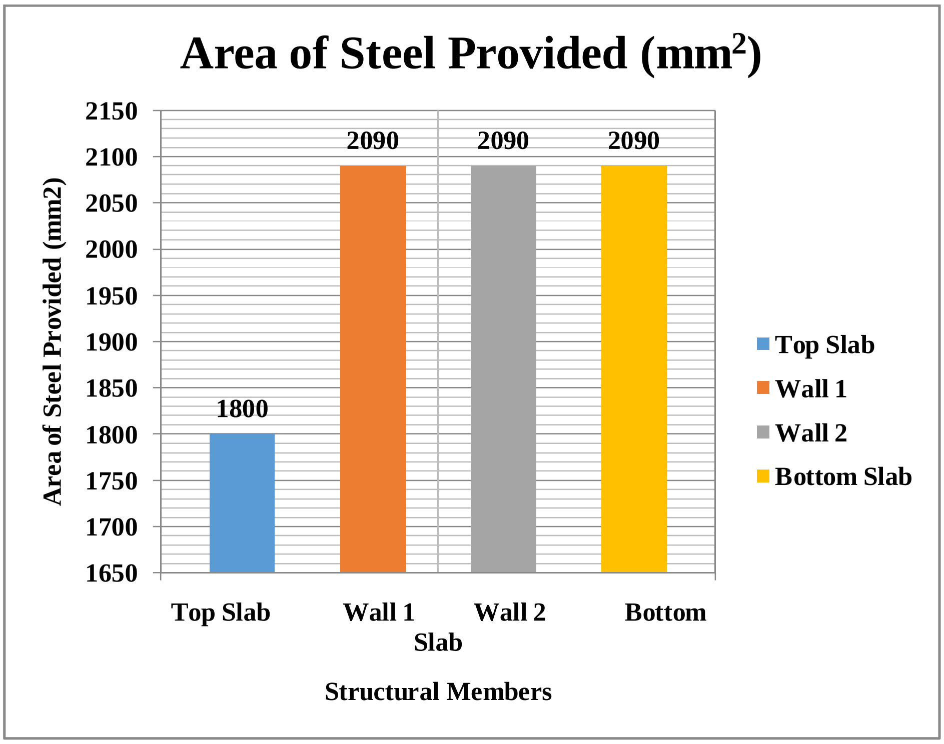


Fig 4.4d Area of Steel Provided for Structural Members of Triple Cell Box Culvert.

4.2.6 Reinforcement Details

The reinforcement details shows that Y16@ 150mmc/c U-bars both face is required as the main bars while Y12@ 200mmc/c both face is required as the distribution bars for the single cell box culvert while Y20@ 150mmc/c U-bars both face is required as the main bars while Y12@ 150 mmc/c both face is required as the distribution bars for the Triple cell box culvert and this applies for all structural members.

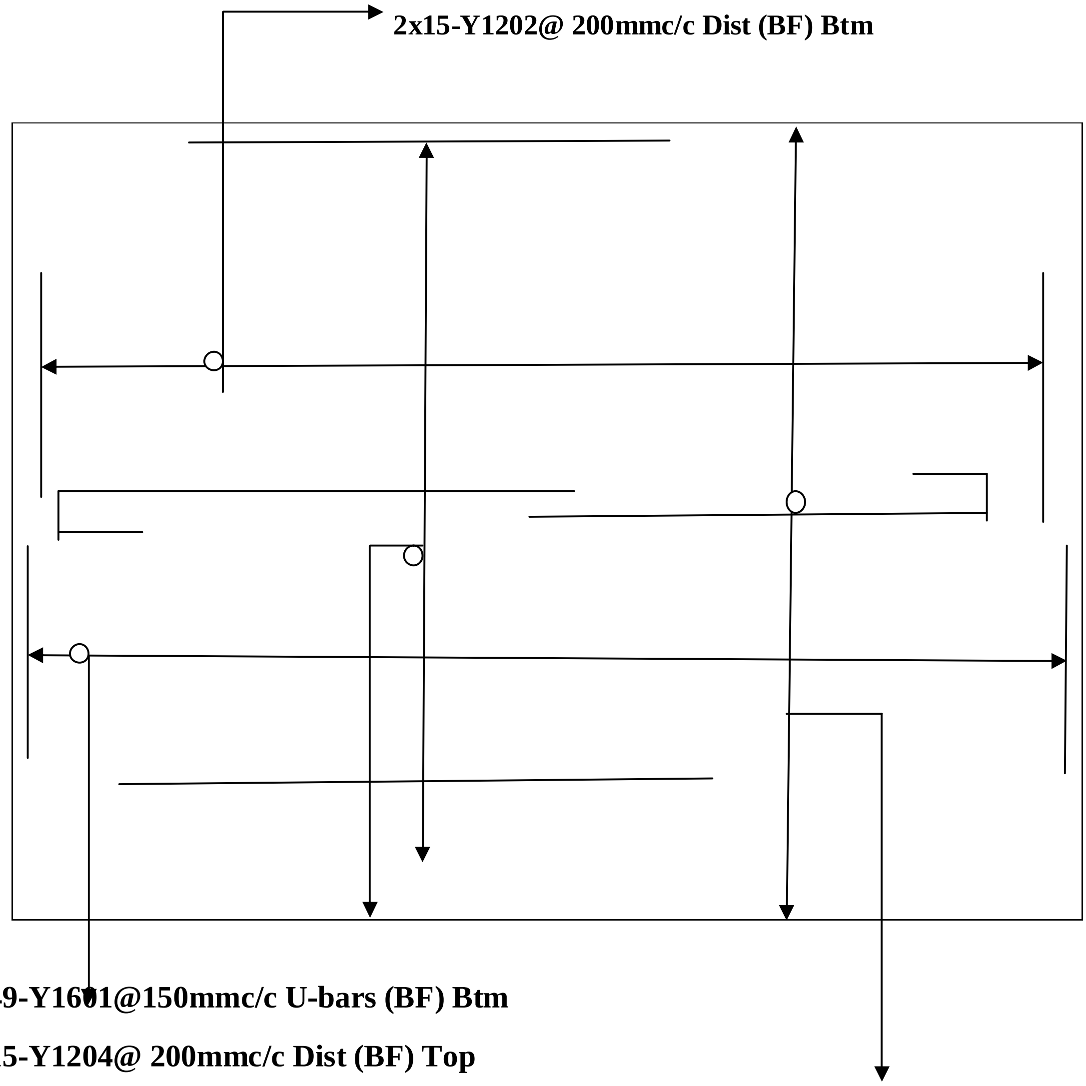
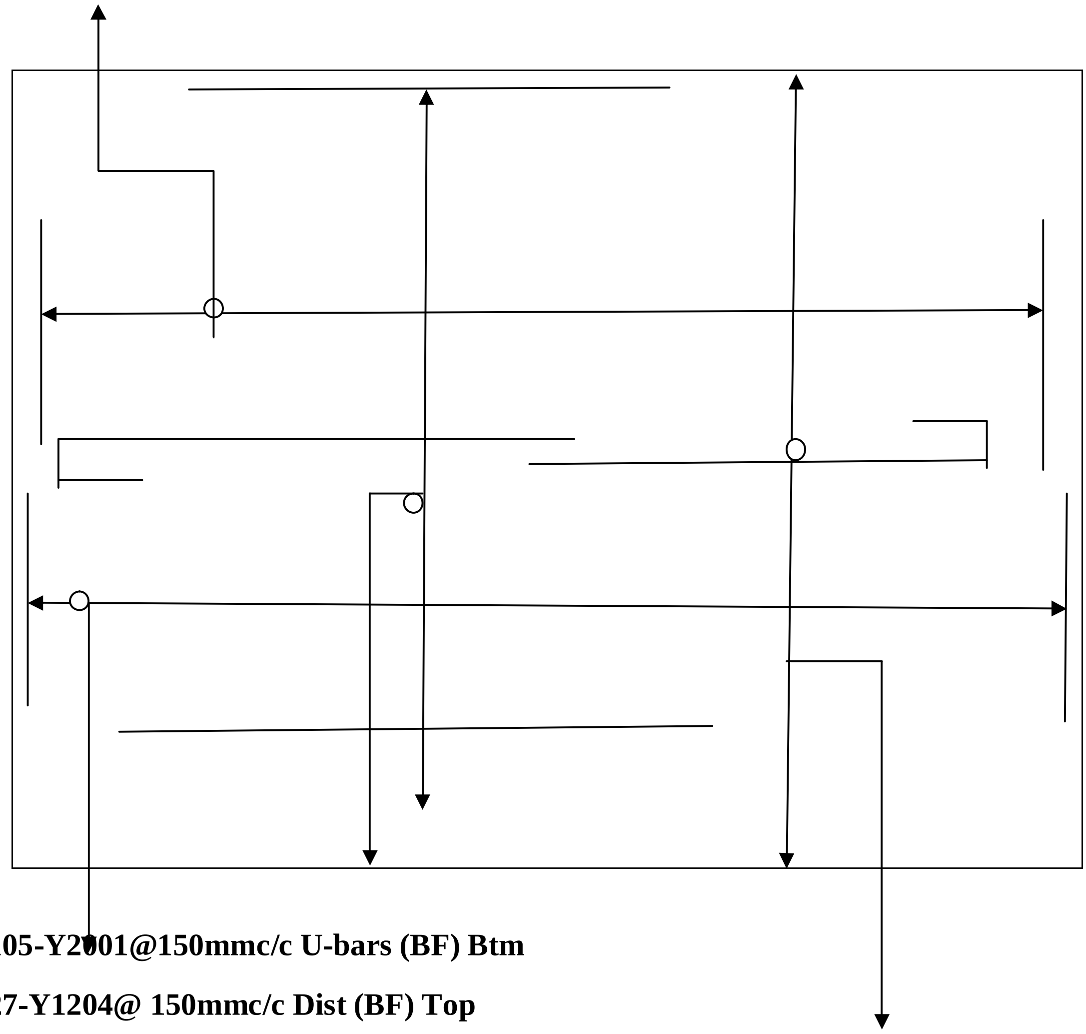


Fig 4.5a: Reinforcement details of Single Cell Box Culverts.

2x27-Y1202@ 150mmc/c Dist (BF) Btm



2x105-Y2001@150mmc/c U-bars (BF) Btm

2x27-Y1204@ 150mmc/c Dist (BF) Top

2x105-Y2003@ 150mmc/c U-bars (BF) Top

Fig 4.5b: Reinforcement details of Triple Cell Box Culverts.

Table A1 Bar Bending Schedule for Structural Members of Single Cell Box Culvert.

SECTION	BAR MARK	SIZE & TYPE	NO OF EACH	NO OF MEMBER	SHAPE CODE	LENGTH OF EACH	TOTAL LENGTH OF

						(mm)	**EACH (mm)**
SLAB/WALL SECTION	**01**	**Y16**	**49**	**2**	**U-Shape**	**4300**	**421,400**
	02	**Y12**	**15**	**2**	———	**7500**	**225,000**
	03	**Y16**	**49**	**2**	**U-Shape**	**4300**	**421,400**
	04	**Y12**	**15**	**2**	———	**7500**	**225,000**

Total Length of Y16 = 421,400 + 421,400 = 842,800

Total Length of Y12 = 225,000 + 225,000 = 450,000

Conversion

Y16

1 Length = 11,500mm

842,800mm

$$= \frac{842,800}{11,500} = 75 \text{ Length}$$

Y12

1 Length = 11,500mm

450,000mm

$$= \frac{450,000}{11,500} = 40 \text{ Length}$$

Table A2 Bar Bending Schedule for Structural Members of Triple Cell Box Culvert.

SECTION	BAR MARK	SIZE & TYPE	NO OF EACH	NO OF MEMBER	SHAPE CODE	LENGTH OF EACH (mm)	TOTAL LENGTH OF EACH (mm)
SLAB/WALL SECTION	**01**	**Y20**	**105**	**2**	**U-Shape**	**10200**	**2,142,000**

	02	**Y12**	**27**	**2**	———	**16000**	**864,000**
	03	**Y20**	**105**	**2**	**U-Shape**	**10200**	**2,142,000**
	04	**Y12**	**27**	**2**	———	**16000**	**864,000**

Total Length of Y20 = 2,142,000 + 2,142,000= 4,284,000

Total Length of Y12 = 864,000 + 864,000 = 1,728,000

Conversion

Y20

1 Length = 11,500mm

4,284,000mm

$$= \frac{4{,}284{,}000}{11{,}500} = 372 \text{ Length}$$

Y12

1 Length = 11,500mm

1,728,000mm

$$= \frac{1{,}728{,}000}{11{,}500} = 151 \text{ Length}$$

4.2.7Bar Bending Schedule

The computation done for the bar bending schedule shows that seventy –five (75) length of Y16 are required as main bars while 40 length of Y12 are required as distribution bars for the single cell box culvert and one three hundred and seventy-two (372) length of Y20 are required as main bars while one hundred and fifty-one (151) length of Y12 are required as distribution bars for the triple cell box culvert.

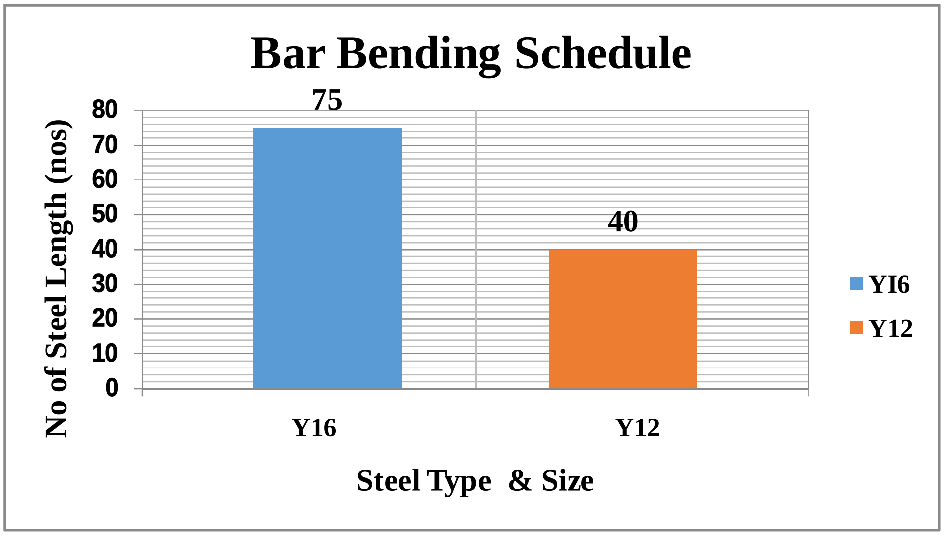


Fig 4.6a: Schedule of Reinforcement for Single Cell Box Culverts.

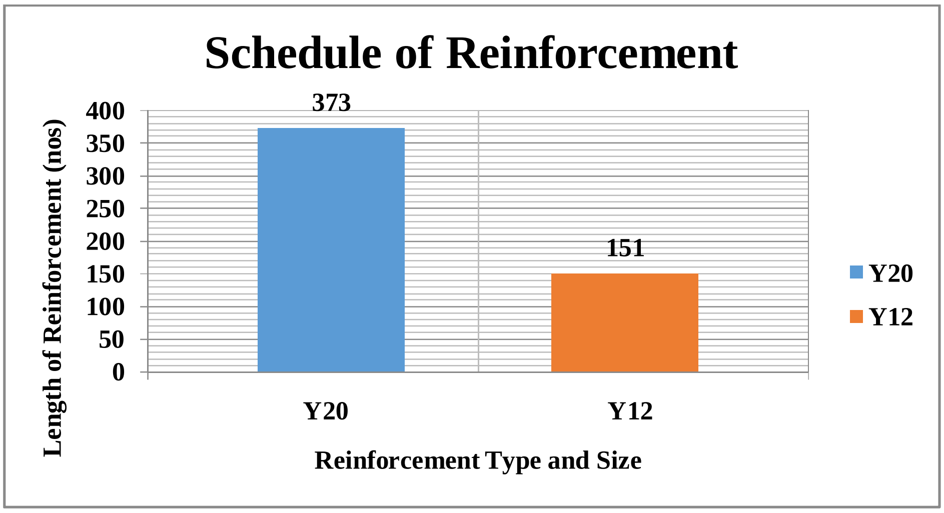


Fig 4.6b: Schedule of Reinforcement for Triple Cell Box Culverts.

4.2.8 Shear Force Design

The shear force design carried out after taking cognizance of the critical shear force (128.69KN) obtained after thorough analysis suggest a design shear stress of 0.536N/mm^2 and a design concrete shear stress of 0.58N/mm^2. From this findings, it can be deduced that the shear design is satisfactory as the design concrete shear stress exceed the design shear stress in value and as a result, the thickness of the as-built culvert satisfies all practical purposes for it construction. This same findings applies for the triple cell box culverts.

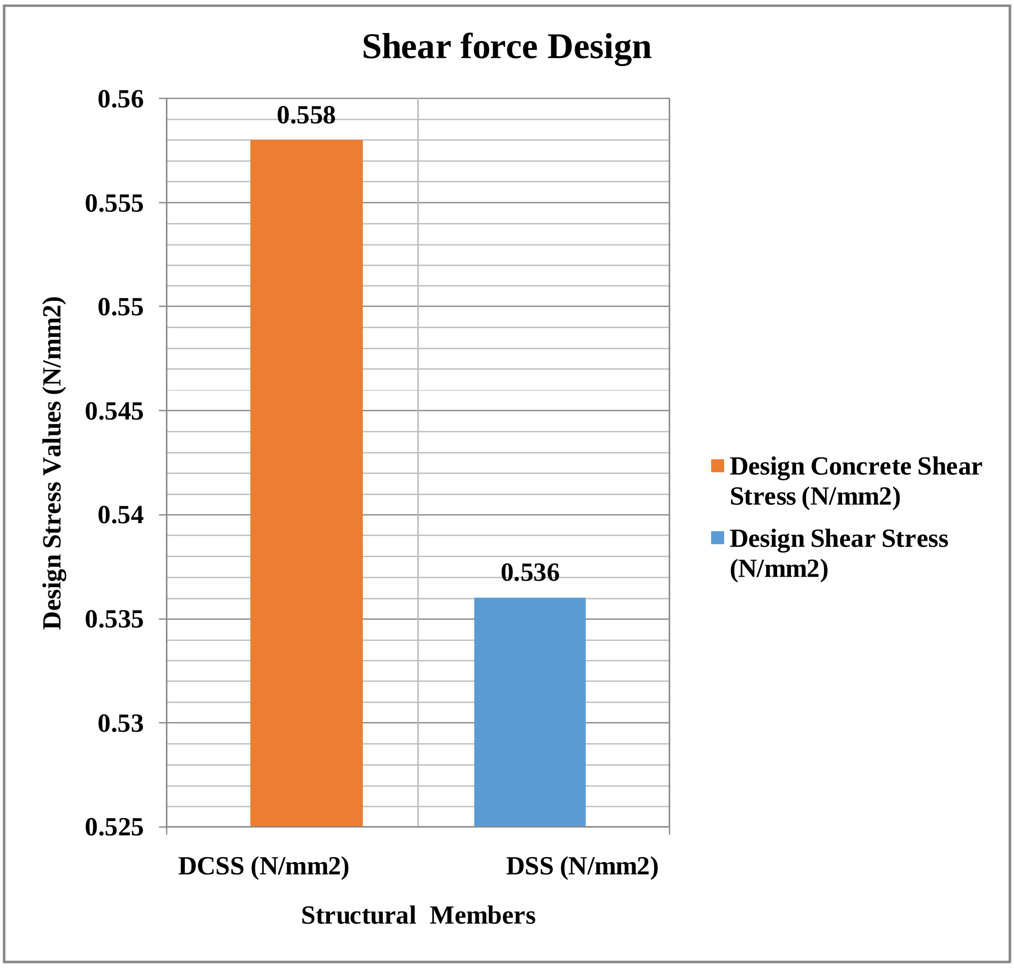


Fig 4.7a: Shear Force Details for the Single Cell Box Culvert.

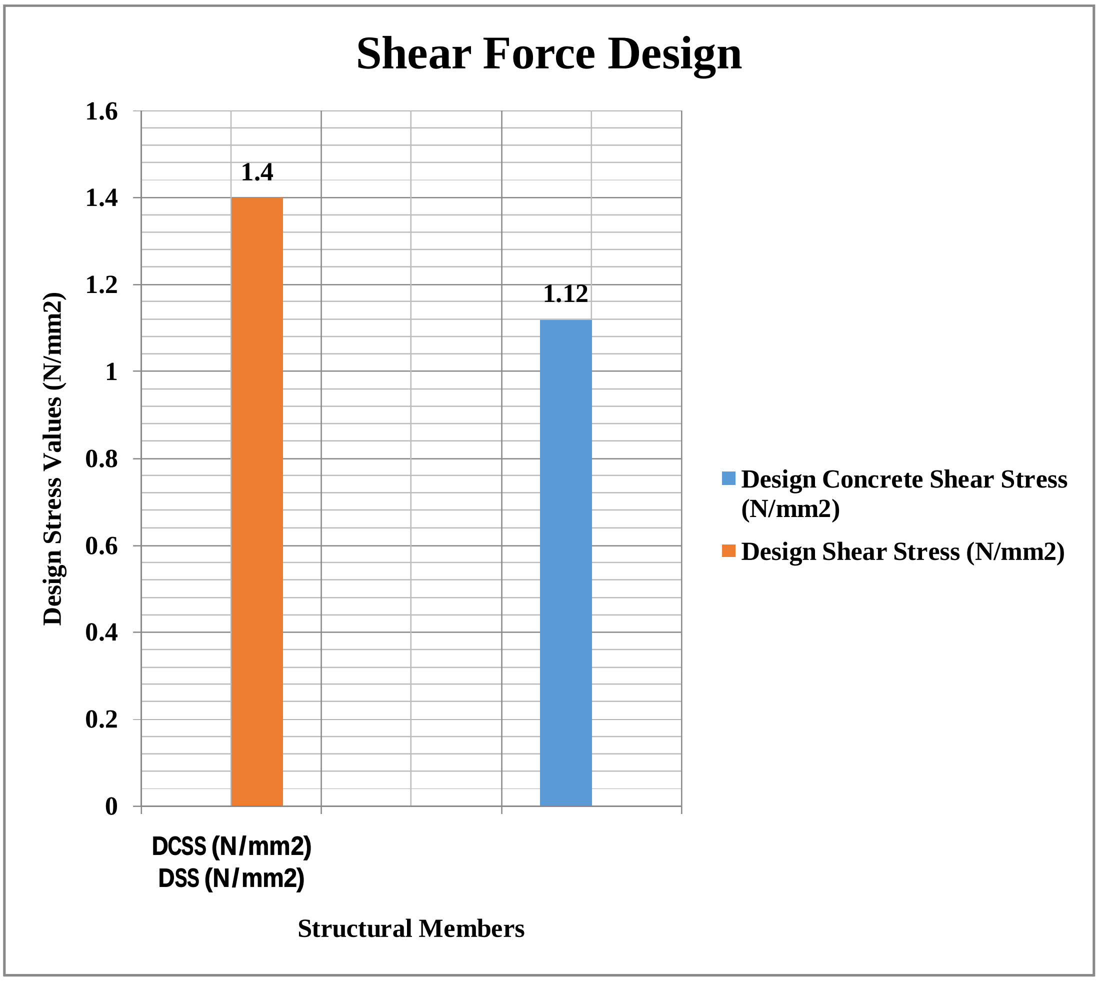


Fig 4.7b: Shear Force Details for the Triple Cell Box Culverts.

STUDY AREA

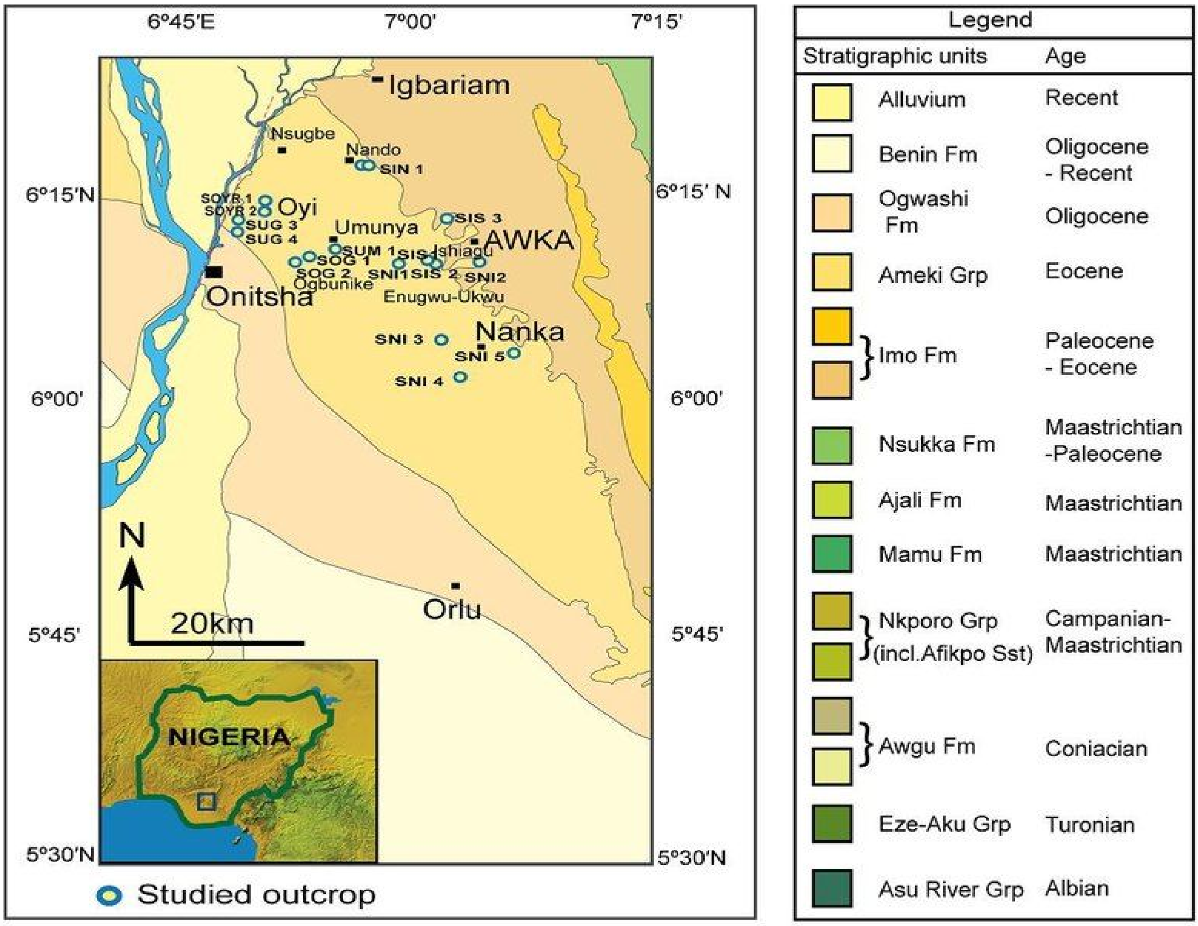


Plate C1 Geologic Map of Study Area.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the structural analysis of members of single and triple box culvert along Isuaniocha/Mgbakwu using Euro code2, the following deduction can be made:

1. The ultimate design load obtained for the bottom slab when the culvert is empty and also when the culvert is full is comparatively higher the other structural members (top slab and vertical walls) for both culverts. This can be attributed to the load from both wall and top slab borne by the bottom slab.
2. The fixed end moment obtained for the bottom slab and vertical walls are the same with that of the top slab been comparatively lower while for the free end moment, the bottom slab is comparatively higher followed by the top slab and walls. Comparison between the fixed and free end moments of both culverts shows that the triple cell box culverts produces relatively higher value of moment than the single cell box culvert.
3. The moment adopted for the design referred to as design moment for both culverts are the same for walls and bottom slab with the top slab producing relatively low value of design moment.
4. The shear force generated for the structural members shows that the walls produces a higher magnitude of shear force (128.69KN) than the other structural members and would be considered for design.
5. The area of steel required for all the structural members are the same with reinforcement comprising of Y16@150mmc/c U-bars used as main bars in both faces and Y12@200mmc/c used as distribution bars in both faces for the single cell box culvert and Y20@150mmc/c U-bars used as main bars in both faces and Y12@150mmc/c used as distribution bars in both faces for the triple cell box culvert
6. The schedule of reinforcement suggest that seventy-five (75) length of Y16 is required as main bars and 40 length of Y12 is to be required as distribution bars for the single cell box culvert and three hundred and seventy-two (372) length of Y16 is required as main bars and one hundred and fifty-one (151) length of Y12 is to be required as distribution bars for the single cell box culvert.

7. The shear force design suggests a satisfactory result as the design concrete shear stress exceed the design shear stress in magnitude.
8. The outcome of the structural analysis and design of members of the culvert suggest that the adopted code for the design (Euro code 2) is structurally reliable for concrete structures and should be given due consideration.

5.2 Recommendation

From the design result obtained using Euro code2 it is recommended that:

1. Design of reinforced concrete structures using Euro code 2 should be given thorough consideration on account of its structural integrity and reliability.
2. More awareness on the use of Euro code 2 should be strongly intensified through its incorporation and use by institution of higher learning and professional bodies (NSE, NIStructE, ACEN) for professional assessment.

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APPENDICES

APPENDIX A

BAR BENDING SCHEDULE

Table A1 Bar Bending Schedule for Structural Members of Single Cell Box Culvert.

SECTION	BAR MARK	SIZE & TYPE	NO OF EACH	NO OF MEMBER	SHAPE CODE	LENGTH OF EACH (mm)	TOTAL LENGTH OF EACH (mm)
SLAB/WALL SECTION	01	Y16	49	2	U-Shape	4300	421,400
	02	Y12	15	2	________	7500	225,000
	03	Y16	49	2	U-Shape	4300	421,400
	04	Y12	15	2	________	7500	225,000

Total Length of Y16 = 421,400 + 421,400 = 842,800

Total Length of Y12 = 225,000 + 225,000 = 450,000

Conversion

Y16

1 Length = 11,500mm

842,800mm

$$= \frac{842{,}800}{11{,}500} = 75 \text{ Length}$$

Y12

1 Length = 11,500mm

450,000mm

$$= \frac{450{,}000}{11{,}500} = 40 \text{ Length}$$

Table A2Bar Bending Schedule for Structural Members of Triple Cell Box Culvert.

SECTION	BAR MARK	SIZE & TYPE	NO OF EACH	NO OF MEMBER	SHAPE CODE	LENGTH OF EACH (mm)	TOTAL LENGTH OF EACH (mm)
SLAB/WALL SECTION	01	Y20	105	2	U-Shape	10200	2,142,000
	02	Y12	27	2	______	16000	864,000
	03	Y20	105	2	U-Shape	10200	2,142,000
	04	Y12	27	2	______	16000	864,000

Total Length of Y20 = 2,142,000 + 2,142,000= 4,284,000

Total Length of Y12 = 864,000 + 864,000 = 1,728,000

Conversion

Y20

1 Length = 11,500mm

4,284,000mm

$= \frac{4,284,000}{11,500}$ **= 372 Length**

Y12

1 Length = 11,500mm

1,728,000mm

$= \frac{1,728,000}{11,500}$ **= 151 Length**

APPENDIX B

INTERNAL STRESSES

Table B1 Summary of Internal Stresses for Structural Members of Single Cell Box Culverts.

ELEMENTS	MOMENT (KNm)	SHEAR FORCE (KN)
TOP SLAB	48.67	53.96
WALLS	58.61	128.69
BOTTOM SLAB	58.61	63.77

Table B2 Summary of Internal Stresses for Structural Members of Triple Cell Box Culvert.

ELEMENTS	MOMENT (KNm)	SHEAR FORCE (KN)
TOP SLAB	154.83	63.05
WALLS	178.75	529.3
BOTTOM SLAB	190.49	73.85

APPENDIX C

Manual Calculation

Design Proper

Top Slab

Standard HB loading width adopted is 1800mm and the standard depth is 1000mm

Slab own load = thickness of culverts x density of concrete x factor of safety = 0.3mx25kN/m^2 x 1.35 = 10.13kN/m^2

Wheel load on slab = calculated wheel load x height of fill x factor of safety = 14.35kN/m^2x 1.4m x 1.5 = 30.14kN/m^2

Earth load on slab = Density of active earth pressure x height of earth fill x factor of safety = 18kN/m^3 x 1.4m x 1.5 = 37.8kN/m^2

Total load on top slab = 10.13kN/m + 30.14kN/m + 37.8kN/m = 78.07kN/m

Fixed End Moment on Top Slab = $wl^2/12$

= $78.07x2.8^2/12$ = 51.01kN/m

Vertical Walls

The wall is divided into two sections, the part of the earth fill referred to as $P_{1.4}$ and the part that span from the earth fill soffit to bottom of slab referred to as $P_{4.7}$ is gotten from (1400mm + 2700mm + 300mm + 300mm).

Wall own load = culvert thickness x density of concrete x factor of safety = 0.3 x 25kN/m^2 x 1.35 = 10.13kN/m

Load for earth fill, $P_{1.4}$ = density of earth pressure x factor of earth pressure (ka) x height of fill x factor of safety = 18kN/m^3 x 0.33x 1.4mx 1.5 = 12.47kN/m^2

Other wall load, $P_{4.7}$ = 18kN/m^3 x 0.33 x 4.7m x 1.5 = 41.88kN/m^2

Total wall load = 10.13 + 12.47+ 41.88 = 64.48kN/m

The wall takes a triangular profile, decomposing the structure we have triangle and rectangle

Triangle value is obtained as follows: 41.88-12.47= 29.41

Rectangular value is obtained as follows: 12.47+ 10.13 = 22.6

Fixed end moment at the two corners of the wall labeled A and D is given as:

$$M_A = \frac{29.41\ x\ 2.35}{2}\ x\ \frac{2.35}{15}\ x\ \frac{22.6\ \ x2.35\ x\ 2.35}{12} = 15.81\text{kNm}$$

$\mathbf{M_D} = \frac{29.41\ x\ 2.35}{2}\ x\ \frac{2.35}{10}\ x\ \frac{22.6\ \ x2.35\ x\ 2.35}{12}$ **= 18.52kNm**

Bottom Slab

The bottom slab is calculated from surcharge from the top slab and two vertical side walls.

Top slab load = load from top slab x width of bottom = 78.07kN/m^2 x 2.8m = 218.60kN/m

Vertical walls = 2 (29.41x 2.35x 0.5+ 22.6x 2.35) = 2 (34.56 + 53.11) = 175.34kN/m

Total bottom slab load = 218.60 + 175.34 = 393.94kN/m

Load per meter (m) = $\frac{393.94}{2.8}$ **= 140.69kN/m^2**

Fixed end moment for bottom slab is given as:

M = $\frac{140.69\ x\ 2.8x\ \ 2.8}{12}$ **= 91.92kNm**

Applying Hardy cross method of moment distribution

Since both corners are fixed – fixed, the stiffness for depth and width of culvert would be shared between 2.8m and 3m = 0.36 + 0.33 = 0.69

Stiffness for wall = $\frac{0.33}{0.69}$ **= 0.48**

Stiffness for bottom slab = $\frac{0.36}{0.69}$ **= 0.52**

AD	AB	BA	BC
0.48	0.52	0.52	0.48
-15.81	51.01	-51.01	15.81
-16.90	-18.30	18.30	16.90
17.62	9.15	-9.15	-17.62
-12.85	-13.92	13.92	12.85
6.61	6.96	-6.96	-6.61
-6.51	-7.06	-7.06	6.51
-27.84	27.84	-27.84	27.84

DA	DC	CD	CB
0.48	0.52	0.52	0.48
18.52	-91.92	91.92	-18.52
35.23	38.17	-38.17	-35.23
-8.45	-19.09	19.09	8.45
13.22	14.32	-14.32	-13.22
-6.43	-7.16	7.16	6.43
6.52	7.07	-7.07	-6.52
58.61	-58.61	58.61	-58.61

Top Slab

M= 0.125x 78.07 x 2.8^2= 76.51kNm

Vertical walls

Rectangular = $\frac{22.6 \, x \, 3x3}{8}$ **= 25.43kNm**

Triangular wall = $\frac{2 \, x \, 1.7 \, x \, 29.41 \, x \, 1.7}{2 \, x \, 9x \, \sqrt{3}}$ **= 30.51kNm**

Bottom Slab = $\frac{91.92 \, x \, 2.8 \, x \, 2.8}{8}$ **= 90.08kNm**

Superimposing the mid span moment we have:

$M_{A\text{-}B}$ = 76.51kNm – $\frac{(27.84+27.84)}{2}$ **= 48.67kNm**

$M_{B\text{-}C}$ = 30.51kNm – $\frac{(27.84+58.61)}{2}$ **= 12.72kNm**

$M_{C\text{-}D}$ = 90.08kNm – $\frac{(58.61+58.61)}{2}$ **= 31.47kNm**

Case Two

Assuming culvert is full of water and flooded to a maximum depth of 1.5m

Top Slab

Water load = height of water x water pressure x factor of safety = 1.5m x 10kN/m^{2}x 1.5 = 22.5kN/m

Slab own load = 0.3m x 25kN/m^{3}x 1.35 = 10.13kNm

N.B: water pressure less than slab load will be acting on the slab, therefore slab load is considered negative.

Total slab load = 22.5kN/m – 10.13kN/m = 12.37kN/m

Wall Load

At top of slab = 1.5mx 10kN/m x 1.5 = 22.5kN/m

At bottom of bottom slab = 4.7x 10x 1.5 = 70.5kN/m

Total load = 22.5kN/m + 70.5kN/m = 93kN/m

Bottom Slab

Due to top slab and wall

Top slab = -12.37x3.1 = -38.35kN/m

Water on walls = 2(22.5+ 70.5) x 0.5x 3.3 = 306.9kN/m

Wall own load = 2x10.13x 3 = 60.78kN/m

Total load = -38.35 + 306.9 + 60.78 = 329.33kN/m

Unit Load = $\frac{329.33kN/m}{3.3m}$ **= 99.8kN/m^2**

These loads are less than that obtained for bottom slab load for case 1, therefore, the case 1 load when the culvert is empty will be adopted for design purpose.

Shear Force Calculation

Top Slab

$V_{AB} = \frac{78.07x2.8}{2} = 109.298kN = V_{BA}$

Walls

$V_{DA} = V_{CB} = \frac{22.6x3}{2} + \frac{2}{2}x29.41 + \frac{(58.61-27.84)}{3} = 63.77kN$

$V_{AD} = V_{BC} = \frac{22.6x3}{2} + \frac{1}{3}x29.41 + \frac{(58.61-27.84)}{3} = 53.96kN$

Bottom Slab

$V_{CD} = V_{DC} = \frac{91.92x2.8}{2} = 128.69kN$

The values obtained for the internal stresses are shown in Table C1 below:

Table C1 Summary of Internal Stresses for Structural Members of Single Cell Box Culverts.

ELEMENTS	MOMENT (KNm)	SHEAR FORCE (KN)

TOP SLAB	**48.67**	**53.96**
WALLS	**58.61**	**128.69**
BOTTOM SLAB	**58.61**	**63.77**

Reinforcement Design

Top Slab

$$N/bh = \frac{53.96\ x\ 10x10x10}{1000x30} = 0.18$$

$$M/bh^2 = \frac{48.67\ x\ 1000000}{1000x300x300} = 0.541$$

NB: breadth of slab was taken as 1000mm

As = 0.4%bh

$$As = \frac{0.4x1000x300}{100} = 1200mm^2$$

Provide Y16@150mmc/c each face (1340mm^2)

Vertical walls

$$N/bh = \frac{128.69\ x\ 10x10x10}{1000x30} = 0.43$$

$$M/bh^2 = \frac{58.61\ x\ 1000000}{1000x300x300} = 0.65$$

As = 0.4%bh

$$As = \frac{0.4x1000x300}{100} = 1200mm^2$$

Provide Y16@150mmc/c each face (1340mm^2)

Bottom Slab

$$N/bh = \frac{63.77\ x\ 10x10x10}{1000x30} = 0.21$$

$$M/bh^2 = \frac{58.61\ x\ 1000000}{1000x300x300} = 0.65$$

As = 0.4%bh

$$As = \frac{0.4x1000x300}{100} = 1200mm^2$$

Provide Y16@150mmc/c each face (1340mm^2)

Same procedure was employed for design of Triple Cell Box Culvert.