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Structural Analysis and Design of Concrete Box Culvert Using in Staad Pro and Effective Width Method

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ABSTRACT

Box culverts are types of bridges used when the discharge in a natural stream crossing a road is small, and where the waterway is on relatively high embankment. They are generally cheaper than bridges, which make them the best solution when the natural streams intersect roadways. This research work discusses the development of structural design of concrete box culverts, and gives advice on the structural design of buried concrete box structures. The standard requirements in the Design Manual for Roads and Bridges were used in the formulation of the structural design of concrete box culverts. A Staad PRO software has been use to solve different types of concrete box culverts. This program has been applied to many practical problems. The results obtained by the STAAD PRO software were compared with manual solutions of the problems, commercially available software solutions (STADD PRO) and solved problems .A very good agreement has been achieved. Based on the results, this program should offer the design engineer a significant saving of both time and effort, without sacrificing accuracy or effectiveness.

INTRODUCTION

Box culverts are types of bridges used when the discharge in a drain or channel crossing a road is small, and when the bearing capacity of the soil is low. Culverts are always cheaper than bridges where the discharge opening is less than $15m^2$ and particularly where the road crosses the waterway on relatively high embankment. Box culverts are constructed of reinforced concrete and are either cast-in-place or precast. Most of them are square dimensions; but if not a square, usually have the span length exceeding the opening height. Box culverts may have multiple or single cell openings. They control water flow and drainage for irrigation and municipal services, control storm water, and perform many other services. All the reasons above represent a good motivation to researchers in culvert design method and construction technique.

Historical Background

Historical records include many references to engineering feats undertaken by ancient civilizations to collect and convey water. Archeological explorations indicate that an understanding of drainage principles existed very early in history. For example, a sewer arch constructed about 3750 B.C. was unearthed in an excavation at Nippur, India. Another excavation in Delhi exposed a sewer constructed in 2600 B.C. Most renowned of this early construction efforts were the aqueducts of Rome .The water carried by these aqueducts was used primarily for drinking. The aqueducts were also used to carry sewage through Rome's main sewer, the Cloaca Maxima .Built in 800 B.C., and constructed mainly of stone masonry and natural cement; the Cloaca Maxima was the first known man-made waterborne method of sewage Disposal. After 2800 years, sections of this concrete sewer are still being utilized.

During the first 5000 years of recorded history, the need for sewers, water supply, and drainage was recognized and practical methods of handling the flow of water were developed. From the remains of the ancient structures, it is apparent that the building materials progressed from relatively simple applications of natural materials to cast concrete. In many applications, permanency was a major requirement and concrete was one of the earliest substitutes for natural stone. While not all stone and concrete structures were able to survive the ravages of time, weather and warfare, concrete has an ancient and noble heritage.

Public health requirements for water and sewage treatment set the beginnings of the concrete pipe industry in the late 19^{th} and early 20^{th} centuries. Plants were established to manufacture pipe for sewers, transportation facilities, irrigation and drainage of agricultural land, and urban storm water drainage. In 1900 Steel reinforcement in pipe wall represents the single most important advance in concrete pipe technology. 1960 Changes to the joint geometry lead to the use of a variety of rubber gaskets for bottle tightjoints that significantly reduce.

Objective

India is a big country with a large area and a lot of natural resources. Recently a great development in construction and building occurred all over the country. This development extended to include design and construction of culverts, and box culverts. More attention and effort for design and construction of box culverts should be made for establishing the basis for preparing standard drawings for concrete box culvert, which will be part of design manual for road and bridges. According to the above, this thesis is carried to cover the following objectives:

a. Structural design for all types of concrete box culverts: single cell , twin cell and multiples.
b. STAAD PRO software to analyze these concrete box culverts.

METHODOLOGY

The methodology of the study was to investigate and compare current methods in analysis of box sructures. This has been done in order to investigate and illuminate actual differences between modelling procedures and how choices made in a modeling stage impact the resulting design of reinforcement in areinforced concrete of box culvert.

LITRETURE REVIEW

The term “culvert” encompasses practically all closed conduits used for drainage with the exception of drains .Culverts must be classed as stock products, in that standard designs are used repeatedly. This is in direct contrast to the situation for bridges that span larger streams, for which special designs are made in almost every case. There are many similarities between bridges and culvert and they perform similar tasks

Culverts, however, usually differentiated from a bridge by virtue of the fact that the top of the culvert does not form a part of the traveled roadway. More frequently culverts are differentiated from bridges on the basis of the span length. On an arbitrary basis, structures having span of 6.0m or less will be called culverts; while those having spans more than 6.0m will be called bridges .This line of division is by means standard (IRC 5:1998), and span lengths of from 2.0 to 6.0m are employed by various organizations as limiting culvert length .Culverts also differ from bridges in that they are usually designed to flow full under certain conditions, while bridges are designed to pass floating debris or vessels. However where the waterway opening is less than about15m² and particularly where the road crosses the waterway on relative high embankment, a culvert will usually be cheaper than a bridge.
Culverts are to be found in three general locations: at the bottom of depressions where no natural watercourse exists; where natural streams intersect the roadway; and at locations required for passing surface drainage carried in side ditches beneath roads and driveways to adjacent property.

Basic Characteristics

The structural and hydraulic design of culverts is substantially different from that of bridges, as are the construction, maintenance, repair, and replacement procedures. A few of the more significant characteristics of water-carrying culverts are:

Hydraulic – Culverts are usually designed to operate at peak flows with a submerged in left to improve hydraulic efficiency. The culvert constricts the flow of the stream and may cause ponding at the upstream or in let end. The resulting rise in elevation of the water surface produces a head at the inlet that increases the hydraulic capacity of the culvert. The effects of ponding and flow on appurtenant

Structures, embankments, and butting properties are important considerations in the design of culverts.

Structural –Culverts are buried in soil and are designed to support the dead load of soil over the culvert as well as live loads 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 cover, and amount of live load. However, live loads on culverts are generally not as significant as the dead load unless the cover is shallow. Box culverts with shallow cover are examples of the type of installation where live loads are important.

In most culvert designs, the soil or embankment material surrounding the culvert plays an important structural role. Lateral soil pressures enhance the culvert’s ability to support vertical loads. The stability of the surrounding soil is important to the structural performance of most culverts.

Maintenance – Because culverts usually constrict flow, there is an increased potential for waterway blockage by debris and sediment, especially for culverts subject to seasonal flow.

Multiple barrel culverts are particularly susceptible to debris accumulation. Scour caused by high outlet velocity or turbulence at the inlet end is of concern. As a result of these factors, routine maintenance for culverts primarily involves.
the removal of obstructions and the repair of erosion and scour. Other defects from weathering, loads, and age will occur and require routine maintenance.

Traffic Safety – A significant safety feature of many culverts, as compared to bridges, is the elimination of a constriction in the roadway. Culverts can economically be extended so that the standard roadway cross section can be carried over the culvert. However, when the ends are located near traffic lanes or adjacent to a shoulder, guide rail may be required to protect the traffic.

Construction – One of the most significant factors is that culverts are constructed in and through the roadway embankment, and vehicle loads are carried by the combined strengths of the culvert and the surrounding embankment. The trench width, bedding, compaction, and amount off ill over the culvert are important factors that influence the ability of the culvert to carry the design loads. Thus, the construction techniques and quality control of workmanship are critical to the ultimate serviceability and life expectancy of culverts.

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. Many types of serviceability problems may occur because of scour ofstreambeds and erosion of embankments adjacent to the culverts.

General Problem with Culvert
There is a wide variety of types of problems that occur with culverts. The problems may be classified by serviceability and strength-related criteria. Listed below are general types of culvert problems: Serviceability-related problems:

- Scour and erosion of stream bed and embankments
- Inadequate flow capacity
- Sedimentation and blockage by debris
- Strength-related problems:
- Cracking of rigid culverts
- Undermining and loss of structural support
- Loss of the invert of culverts due to corrosion or abrasion
- Over-deflection and shape deformation of flexible culverts
- Stress

Culvert Type
Culverts are cross drainage works with clear span less than six meters. In any highway or railway project, the majority of cross drainage works fall under this category. Hence these structures collectively are important in any project, though the costs of the structures are small. Culverts may be classified according to function as highway or railway culvert. The loadings and structural details of the super structure would be different for these two classes. Based on the construction of the structure, they can be of the following types.

Box Culverts: Box Culverts are ideally suitable monolithic structures across a highway or railway embankment to balance the flood water on both sides. It consists of top slab, bottom slab and two vertical side walls. Reinforced concrete rigid frame box culverts are used for square or rectangular openings with span up to 6m. 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.

MATERIAL USE IN CULVERT

General
Culverts are primarily made with reinforced concrete, corrugated metal, and more recently, solid wall, Profile wall. The strength and physical characteristics of the materials depend upon their chemistry and the interrelationship between the constituent materials. Metals and plastic are homogeneous isotropic materials whereas concrete and masonry is a mixture or combination of materials.

The method by which the materials are connected significantly influences whether the strength of the materials may be utilized structurally.

Concrete

Culverts may be made with either precast or cast-in-place reinforced concrete. This selection depends on the size and complexity of the culvert design. Precast sections are uniform in size and shape and are made in sections that can easily be transported, lifted, and installed. Cast-in-place concrete construction is often used when ready-mix concrete is available and when the culvert should be constructed without joints. Precast concrete culverts may be made with high strength concrete, whereas cast-in-place concrete culverts may have special reinforcement at critical locations to resist high loads and stresses

Precast–Precast concrete box is manufactured rectangular or arch-shaped. The rectangular box

Cast-in-place – Reinforced culverts that are cast-in-place are typically either rectangular or arch-shaped. The rectangular or box shape is more common and is usually constructed with multiple cells

Geotechnical

During design, particularly for larger culverts, 0.9m span or greater, the foundation conditions should be investigated to determine such factors as allowable bearing pressure, bedding requirements, and any condition requiring special treatments. In addition, determinations should be made concerning any unusual construction conditions such as groundwater, slope stability, and rock excavation. These factors apply to the end treatments, approaches, and barrel elements. The type, strength, slope, and bedding of soils and rocks all influence the design, construction and maintenance/repair operations.

STRUCTURAL ANALYSIS OF RCC BOX CULVERT

Introduction

Box culvert consists of a reinforced concrete box of a square or rectangular opening with a span usually restricted to 5 m. The top of the box may be at road level or it may be at a depth below the road level if the road is in embankment. If the design discharge is considerable, a single box culvert becomes uneconomical because of the higher thickness of the slab and walls. In such cases, more than one box is cast side- by-side monolithically".

Box culverts are economical for the reasons mentioned below:

- The box is a rigid frame structure and both the horizontal and vertical members are made of a solid slab, which is very simple in construction.
- In case of high embankments, an ordinary bridge will require very heavy abutments that will not only be expensive but also transfer heavy loads to the foundations.
- The dead 1oad and superimposed 1oad are distributed almost uniformly over a wider area as the bottom slab serves as a raft foundation. Thus reducing pressure on soil.

Analysis & Design Method

After the hydraulic design of concrete box culvert the required size of culvert is determined with the proper location that matching road levels. Box culverts are analyzed and designed as rigid frames with equal bending moments at the end supports. The moment distribution method is generally adopted for determination of final moments at joints of the frame.
The culvert is analyzed for critical loading conditions, Limit State principles are adopted for the design of the structural elements and the foundation .Be than Ultimate Limit State and serviceability Limit State are considered.

Modeling

3D shell elements with thicknesses defined 2m x2mRCC box top slab thickness 300mm, bottom slab tackiness 350 mm and outer wall thickness 300mm were used to model the geometry of the bridge,

The material properties was therefore set to M30 concrete with modulus of elasticity 32 GPa, poissons ratio 0.2 and coefficient of thermal expansion 10-5

Limit State Design

The design of concrete structural elements is contained in IRC 112 :2011 as implemented by (Design Manual for Road and Bridges) Limit states are the acceptable limits for the safety and serviceability requirements of the structure before failure occurs. The design of structures by this method will thus ensure that they will not reach limit states and will not become unfit for the use for which they are intended. It is worth mentioning that structures will not just fail or collapse by violating (exceeding) the limit states. Failure, therefore, implies that clearly defined limit states of structural usefulness has been exceeded.

- Limit State of Collapse/Ultimate
- Limit State of Serviceability

Loads

The requirements for Loading are contained in IRC 6 :2017 as implemented by The following loads areused in the design.

Self-weight. The self-weight was applied uniformly as a material parameter on the concrete with aneffect of 25kN/m3.

Due to Self-weight Bending diagram in box culvert using STAAD PRO

Surfacing & Earth Crushion .The surfacing of the road was given a thickness of 65mm and a weight of 22 kN/m3.

Due to Surfacing and Earth Cushions Bending diagram in box culvert using STAAD PRO

Earth pressure: Earth pressure .Earth pressure was applied on frame and wing walls with earth density of 22kN/m3 and frictional angle φ k=45°.

Traffic: loads. The traffic Roads used include traffic load model as per IRC 6:2017 libe load traffic is des fine as 70 R wheel and track, CLASS A, SV loading as per most governing case

Horizontal Live Loads: Include live load Surcharge, temperature effects, parapet Earth Pressure

Load Combination

The load combinations are used in the design is as given in IRC 6:2017:. Only combinations Basic, Rare and Quasi permanent are applicable to box culvert design as follows:

- **Combination Basic (ULS)**
- **Combination Rare (SLS)**
- **Combination Quasi Permanent (SLS)**

Load Combinations and Partial Safety Factors for the Design of the Structural Elements

Ultimate Limit State

Design of Box Culert

The problem considered is to analyses and design of concrete box culverts .First the analysis of bending moments per meter length of the culvert was carried out assuming a value for the thickness of the walls and roof. The bending moments were determined by considering the culvert as rigid frame or as a continuous beam of four spans with equal bending moments at the end supports.

The bending moments were calculated by considering the possible incidence of the loads and pressures.

Generally there are three conditions to consider:

- Culvert empty: full load and surcharge on the top slab, the weight of the walls, maximum earth pressure and live load surcharge on the walls.
- Culvert full: full load and surcharge on the top slab, weight of the walls, minimum earth pressure on the walls, maximum horizontal pressure from water in the culvert, and possible upward pressure on the top slab and no lateral pressure due to live load surcharge.
- Culvert full: full load and surcharge on the top slab, the weight of the walls, maximum earth pressure and live load surcharge on the walls, maximum horizontal pressure from water in the culvert, and possible upward pressure on the top slab.
- Durability: Minimum grade of concrete shall be M30 for sever environmental exposure condition.

RESULT AND DISCUSSIONS

STAADPRO software has been developed to solve concrete box culverts problems. one types of culverts were considered in application phase so as to check the adaptation of the STAAD PRO program to different types of box culvert. The results of analysis and design obtained by the STAAD PRO program as output were compared with manual solution and results obtained by the commercially available., to check the accuracy of the calculations. Others applications were carried out to compare results obtained by the STAAD PRO program with results of solved problems in literature to check the accuracy of the STAADPRO program.

Summary

In this thesis modeling procedures for structural analysis in design of concrete RCC Box are studied. The results show that in most cases there are no differences between the models and manually procedures for structural analysis. However, it was identified that when modeling according to some principles in advertent restraint might be introduced to the model if certain care was taken .This might alter the response drastically, while still be difficult to detect when studying envelopes in ULS and SLS.

As the difference between different models is small it is more important to focus on that a model doesn't introduce e errors than it is entirely accurate. In short, one could say that it is more important to avoid errors than it is to model accurately.Thereforeitisimportantthatananalysismodeliseasilyverifiedwith simpler models, since errors otherwise easily arise in 3D modelling.

Culverts were solved by the STAAD PRO software. The results of them were compared with manual solutions and the commercially available software (STAADPRO) for load ULS and load SLS.

The maximum net bearing pressure under the base of the structure under nominal loads shall be checked against the safe bearing pressure of the foundations to ensure that there is an adequate

Factor of safety against bearing failure of the foundation and to prevent excessive settlement and differential settlement

The structure as a whole can fail due to overloading of the soil-structure interface or excessive soil deformations. In order to prevent such failures occurring, two situations shall be investigated prior to carrying out the final structural design, to confirm whether or not the proposed geometry and structural form are suitable.

The culvert is analyzed for critical loading conditions, Limit State principles are adopted for the design of the structural elements and the foundation. Both an Ultimate Limit State and serviceability Limit State are considered.

CONCLUSIONS

RCC box culvert with various type of structure was analyzed for it limit state performance under ultimate and serviceability limit state methods using STAAD ORO software.

The major conclusion derived out of this study is that RCC box culvert performed better than other culvert like pipe minor bridge slab culvert etc in making the roads. However, following are some of specific conclusions drawn from results of the present study:

- Box culvert is used for cross drainage works across high embankments.
- It is easy to add length in the event of widening of the road using STAADPRO.
- The design of box culvert is covered by using three load cases. The values of design moments etc are marginally more than (close to) the values given by manual calculations for the three load cases.
- The study shows that the maximum positive moment develop at the center of top and bottom slab for the condition that the hogging at center and supports aging moment
- The maximum negative moments develop at the support sections of the bottom slab for the condition that the culvert is empty and the top slab carries the dead load and live load.
- The maximum negative moment develop at the center of vertical wall when the culvert is running full and when uniform lateral pressure due to superimposed dead load acts only.
- The maximum shear forces develop at the corners of top and bottom slab when the culvert is running full and the top slab carries the dead and live load.

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