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ANALYSIS AND DESIGN OF BOX CULVERT BY USING COMPUTATIONAL METHODS

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ABSTRACT

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. It is most economical due to monolithic action and no separate foundation required since bottom slab serves as a mat foundation.Inthis paper we present a complete study of box culvert by using computational methods such as Grillage analysis and Finite element method. Grillage analysis is versatile in nature and can be applied to verity of bridge decks having both simple and complex configurations with ease and confidence. Grillage analysis has done by most commonly using software STAAD Pro. Finite Element analysis is a discretized solution to a continuum problem using Finite element method. Finite element method is a numerical procedure for solving differential equations associated with field problems, with an accuracy acceptable to engineers. It gives more accuracy to the Engineers. Finite element method has done by most accurate and emerging software SAP 2000. In FEM we model the structure by using shell element. In this paper we find out stresses such as bending moment and Shear force of the structure under railway loading and these stresses were computed by computational methods and also compared with conventional method. Design parameters are also computed based on Indian Railway Standards. In this paper we also study about design of box culvert and comparative study of reinforcement details. Vent size of the culvert is fixed based on flood discharge from upstream side.Clear dimensions of the box culvert is 3mX3m. Thickness of slab is 400mm.Grade of concrete is M30, grade of steel is Fe415 and angle of repose is 30^0.

Keywords: Box culverts, Railway, Computational methods, Grillage Analysis, Finite Element Method, SAP 2000.

1. INTRODUCTION

Culverts

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 cost 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.

Types of Culverts

- Slab Culverts
- Pipe Culverts
- Box Culverts

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.

In box culverts four sides of the structure 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. When discharge flood is small then we prefer single cell box culverts. In case of under passages we provide only three sides and those are built monolithically.

When discharge of flood is high then we have to increase the size of the box culvert and hence this leads to increase in thickness of the walls. This may lead to uneconomical section. In this criteria we have to go for multiple celled box culvert, in this we can decrease the depth of slabs.The thickness of the box culvert is assumed and later checked in conventional method. But this may leads to uneconomical design therefore an attempt is made to evaluate optimum thicknesses for economical design. Pre cast culverts are more suitable than cast in-situ.

Computational Methods

In this paper we are going to look at the computational methods in Analysis of Box culvert. Computational method indicates that solving complex problems by using computer methods. Over the years ago engineers solving complex problems by using numerical methods. Due to development took place in structures and materials problems become more complex. They can't solved those structures by using numerical methods. So they are going to solve those methods by using computational methods.

Here, we are going to discuss about Grillage analysis and Finite element analysis. Grillage analysis is one of the most familiar computer aided methods for analyzing bridge decks. In this method deck slab or a structure like culvert is converted in to equivalent grillage of beams. These beams are rigidly connected at discrete nodes. Beam deformations are related to torsional and bending moments. The beam stiffness is chosen so that the epitome and equivalent grillage of beams are subjected to indistinguishable deformations under loading. For simple and complex configurations of bridge decks this method is adoptable. Finite element method is most preferable method for the analysis of simple and complex problems without errors and accuracy. For a continuum problem it a discrete solution. A continuous complex problem is divided into separate entities referred as finite elements, connected together at a number of nodes.

2. LOADS ON BOX CULVERTS

Dead Load

Box Culverts are subjected to dead load comprising of self-weight of top and bottom slab of the culvert and two side walls of the structure. Super imposed dead load consisting of rail weigh, sleeper weight, ballast cushion and formation layer. Theses loads are applied on the transverse beams in grillage analysis by using effective area method. Directly applied on the top slab in Finite element method. Self-weight is calculated based on clear dimensions of the culvert and thickness of the culvert. Super imposed dead load is calculated from IRS Standards and Specifications code of practice.

Data Collected from IRS Code Specifications and Standards

Weight of Rail = 52 kg/m

Weight of Sleeper = 285.4 kg/Sleeper

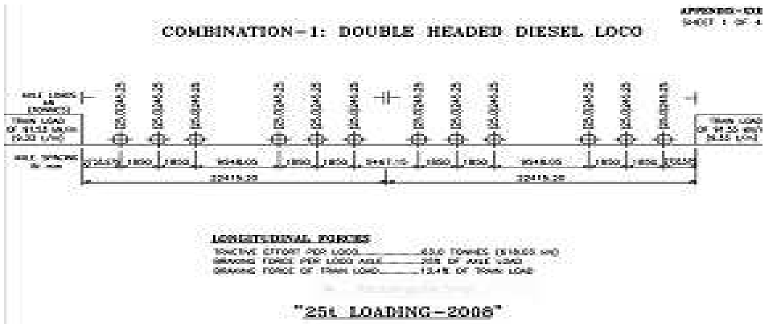
Spacing between consecutive Sleepers = 600mm

Quantity of ballast = 1.682 m^3/m

Live load

Live load on culvert is vehicular loading. The vehicular live load consists set of wheel loads moving on top slab of culvert. These loads are distributed through sleepers and ballast cushion which is on top slab of the culvert. For that loads we are calculating the results.

Indian Railway Standards (IRS) recommends different types of loading. Here, we considering the broad gauge of 1676mm width of rails. For broad gauge IRS given two types of loading. One is 25t Loading – 2008 and another one is DFC Loading (32.5t axle load). In 25t loading maximum axle load is 245.2 KN and train weight of 91.53 KN/m and in 32.5t loading maximum axle load is 245.25 KN and train weight of 118.93 KN/m. In this paper we study the structural responses by applying 25t loading - 2008



For manual method and grillage analysis we have to apply EUDL (Equivalent Uniformly Distributed Load) on the generated models. These are recommended by IRS Bridge rules. EUDL is converted into uniformly distributed load. Whereas in finite element method applying truckloads of double headed diesel loco as shown in above figure.

Coefficient of Dynamic Augment (Dynamic Effect)

Another predominant force on railway track is Dynamic effect. This force is caused by vibrations when vehicle is moving over the culvert. This coefficient of dynamic augment calculated from IRS Bridge Rules clause no: 2.4 for bridges and clause 2.4.2 for culvert type structures for all gauges.

It is based on type of Structure and depth of Cushion.

Coefficient of Dynamic Augment for depth of cushion up to 900mm = (2-d/0.9)*CDA/2

Where CDA = 0.15+8/ (6+L) For Single Track

= 0.72 (0.15+8/ (6+L)) For double line tracks

This Coefficient of Dynamic Augment (CDA) is multiplied by the live load and added to the Load applied on structure.

Tractive Effort, Breaking Force for Axle and Train

With this dynamic effect there are some forces which are applied on rails. Those are Tractive effort, breaking force coming to the structure when the sudden breaks are applied and when the train ready to start.

Tractive effort = 510KN

Breaking force for Axle = 25% of Axle load (245.2KN)

Breaking Force for Train = 13.5% of Train Weight (91.5 KN/m)

Effective width method

Applied live load on the structure is distributed along the transverse direction, perpendicular to the loading direction. From IRS Bridge Rules clause 2.3.4.2 the load assumed to be distributed through sleepers to the ballast and then dispersed by fill at a slope not greater than half horizontal to one vertical. This also called as length of dispersion. This dispersion length is pays a key role in moving loads.

Earth pressure

Earth can exert pressure as active and passive. Minimum is active and maximum is passive earth pressure and the median is rest. The coefficient of earth pressure is calculated as shown below and the angle of repose is taken as 30^0.

Earth pressure due to Earth from side in lateral direction

Earth Pressure due to Side earth from lateral direction = K_a*Unit Weight of Soil*Height of wall

Surcharge is calculated as 1.2m height of soil rest on both sides of the box culvert.

Earth Pressure due to Surcharge from top and live load effect on side walls i.e Earth Pressure due to surcharge = K_a*q

3. GRILLAGE ANALYSIS

In this method deck slab or a structure like culvert is converted in to equivalent grillage of beams. These beams are rigidly connected at discrete nodes. Beam deformations are related to bending and torsional moments.

Steps for Analysis

- ✓ Bridge deck or slab of the culvert is split into equivalent grillage of beams.
- ✓ Calculating the numerical value of equivalent elastic inertias of the members.
- ✓ Loads to be applied and transfer to various nodes of grillage
- ✓ Evaluation of stresses and design envelopes.
- ✓ Explanation of results

Idealizing of slabs into equivalent grillage:

Grid lines are to be adopted along lines of Strength. Centre line of the slab is parallel to edge lines and also parallel to longitudinal lines. Transverse lines are perpendicular to the center line. The odd number of longitudinal and transverse lines are to be adopted.

- ✓ In longitudinal direction minimum three grid lines are to be provided.
- ✓ Transverse line are five to be provided.
- ✓ The ratio may be chosen between one and two for spacing of transverse lines and longitudinal lines.
- ✓ Grid lines are usually placed uniformly.
- ✓ Longitudinal moment is steep at continuous supports hence we have to provide closer Transverse lines at those places.
- ✓ Computation increases by increase in grid lines.
- ✓ The minimum distance between longitudinal lines is limited to 2 or 3 times of thickness of slab.
- ✓ Almost transverse and longitudinal lines are perpendicular, sometimes they may be skew angled up to 15^0.

4. FINITE ELEMENT ANALYSIS

Finite Element analysis is a discretized solution to a continuum problem using Finite element method. Finite element method is a numerical procedure for solving differential equations associated with field problems, with an accuracy acceptable to engineers. For stress analysis of problems the FEM was first used, and has since been applied to many other simple to complex problems. Sometimes we may have to find out variables like displacements in stress analysis. It is done by dividing the problem domain into discrete elements. Physical properties are applied to each discrete element.

The variation of stresses in a system depends upon the geometrical property or effective area of the system of the system, the material property or surrounding environment, the boundary conditions and loading conditions. The domain and geometry are very complex in an engineering system. After that, the initial and boundary conditions are also be complicated. So generally it is difficult to get solution of governing differential equation by analytic methods. Numerical methods are most frequently using to get those solutions of the problems. So we are discretizing the problem by using Finite element techniques because of its practicality and versatility.

Procedure for computational modelling using FEM:

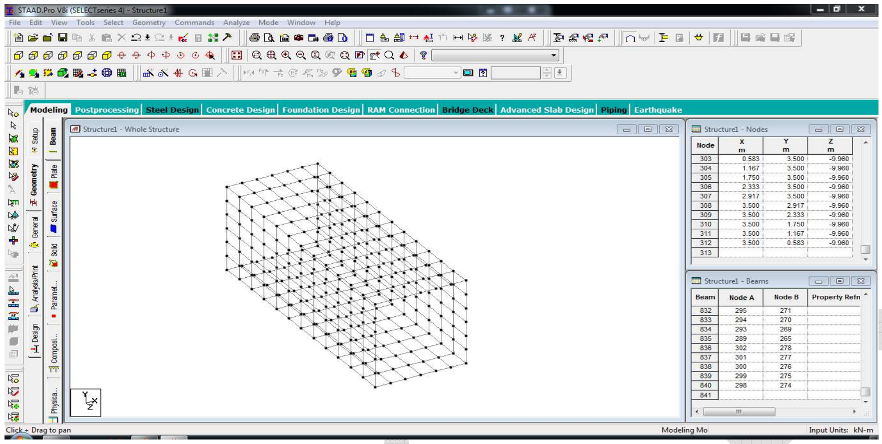
- ✓ Modelling
- ✓ Meshing(Discretization)
- ✓ Specification of material

- ✓ Assigning Restrains
- ✓ Applying Loading

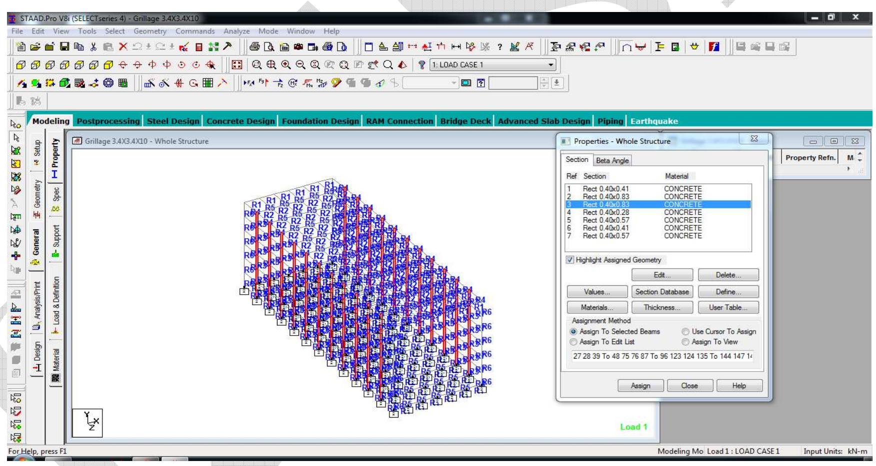
5. ANALYSIS MODELLING STEPS

Grillage Analysis modelling using STAAD Pro:

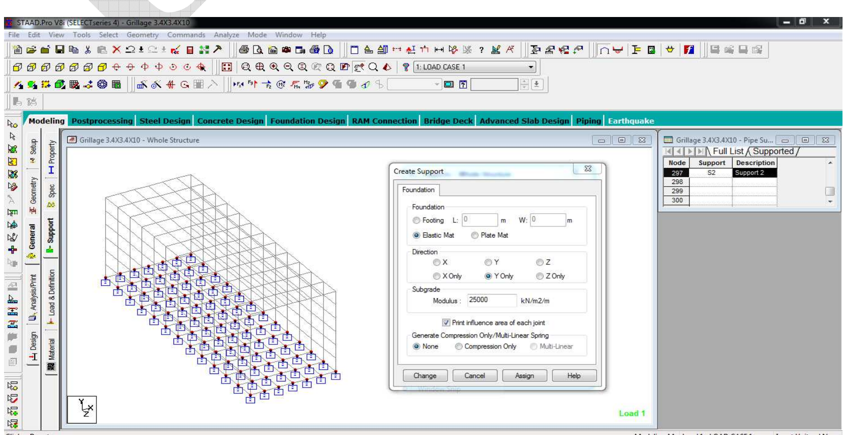
Step 1: Idealization of slabs into equivalent grillage.



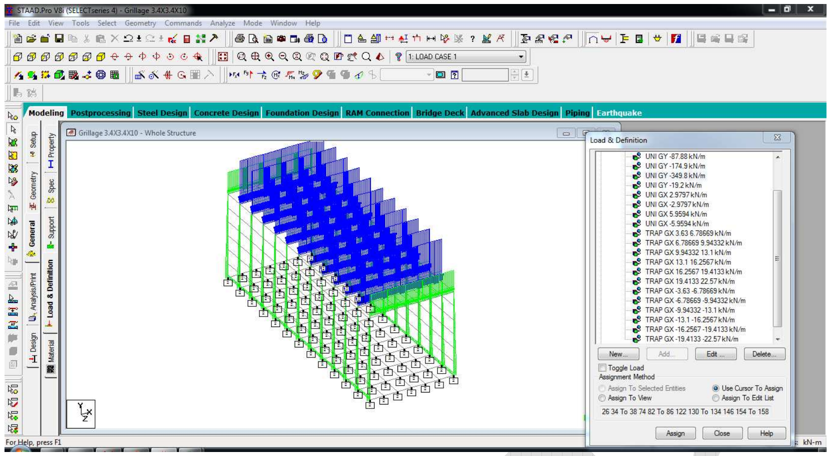
Step 2: Assigning Properties



Step 3: Assigning Subgrade modulus for elastic Mat

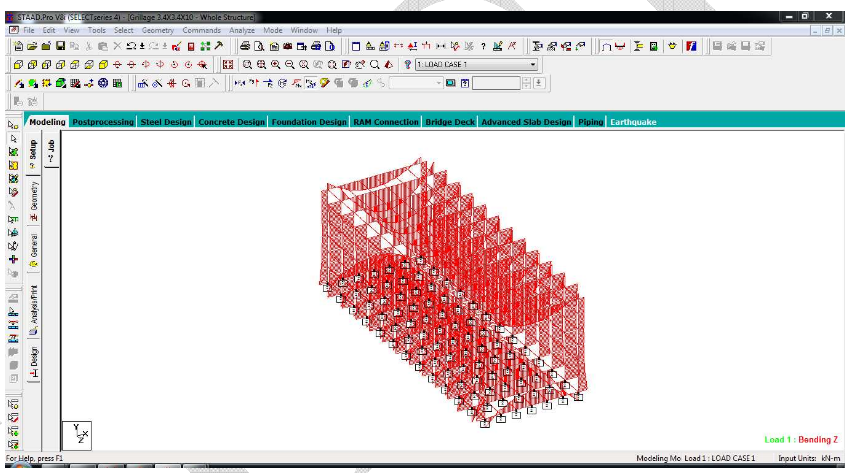


Step 4: Assigning Loads on Grillage beams

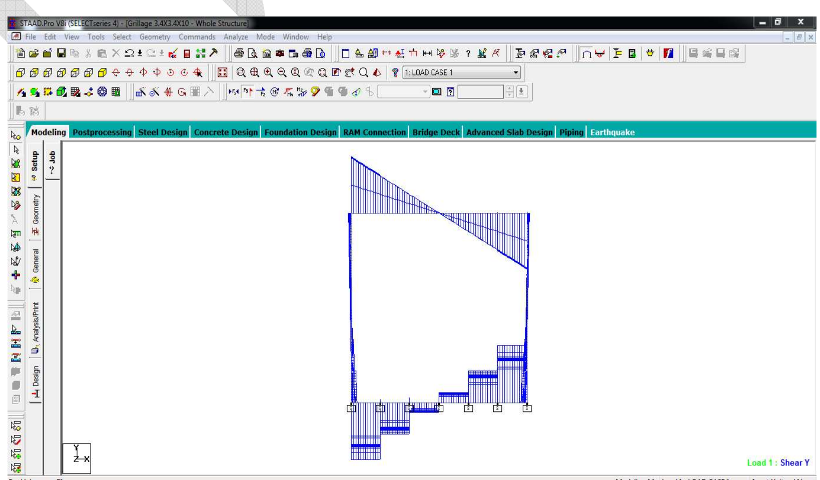


Step 5: RESULTS

Bending Moment

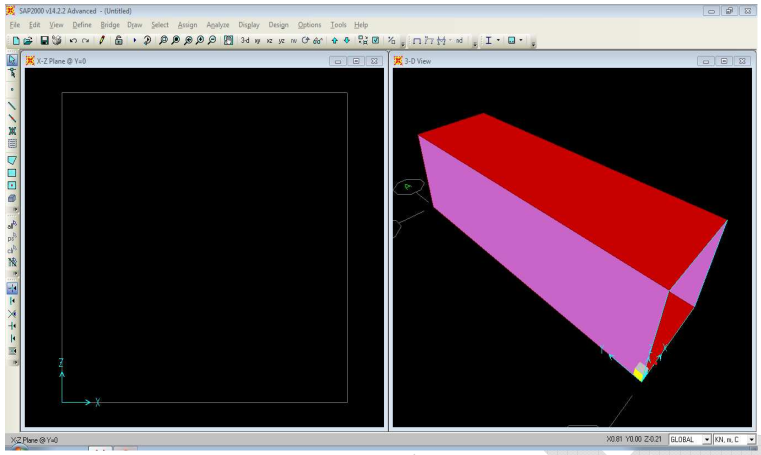


Shear Force

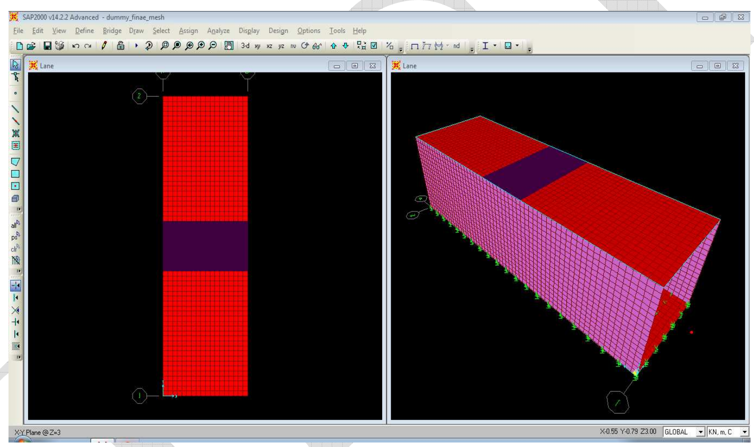


Finite Element Modelling using SAP 2000

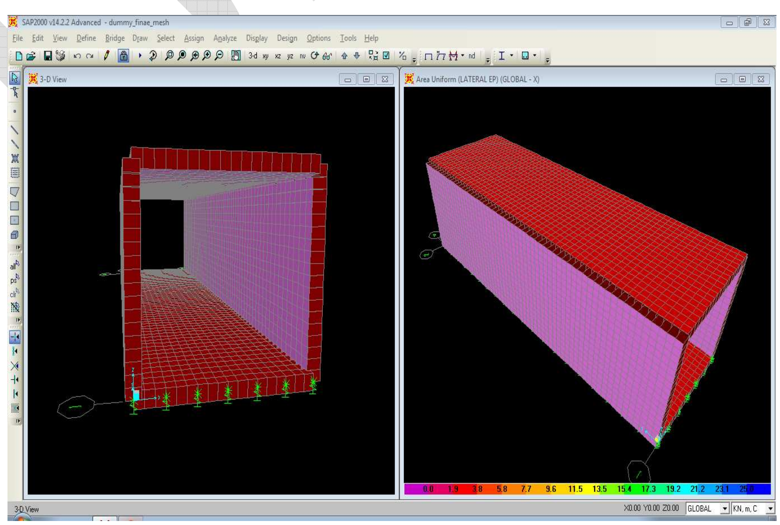
Step 1: Preparing model



Step 2: Meshed model with defined LANE

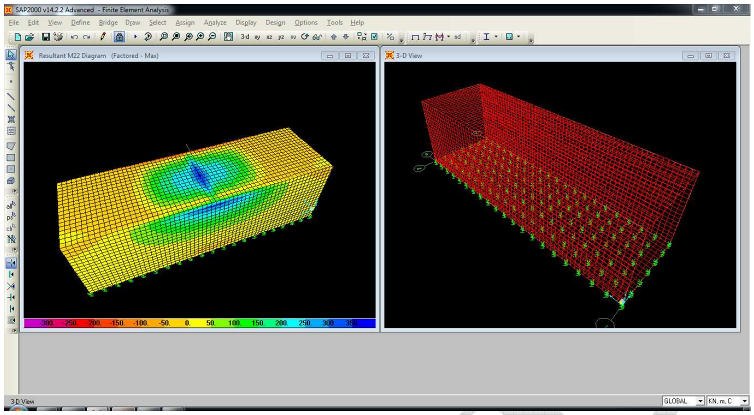


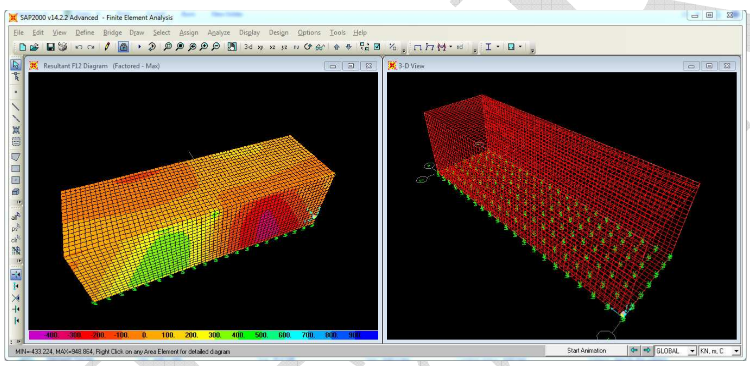
Step 3: Extrude view



Stress Diagrams

Moment Diagram and Shear diagrams



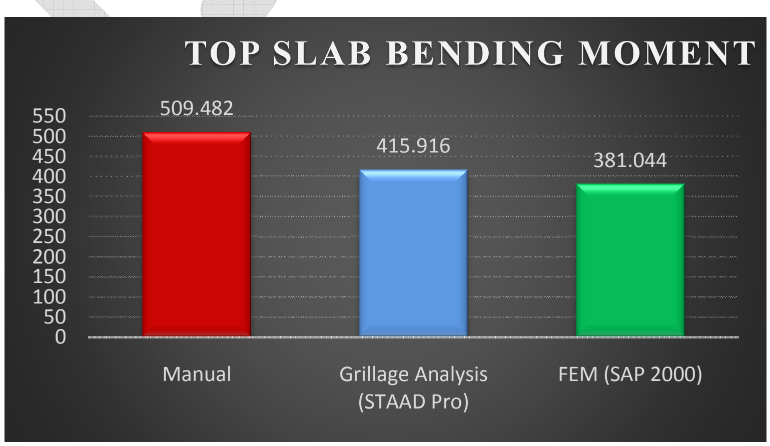


6. RESULTS AND DISCUSSION

Bending Moment

Table 1: Maximum Bending Moment on Top Slab

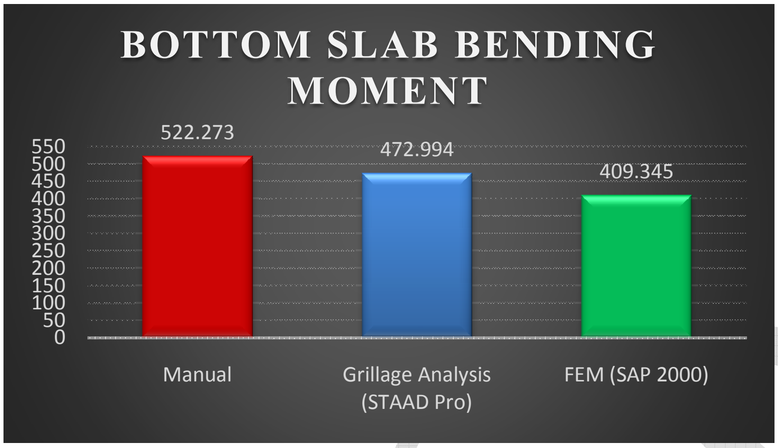
Method of Analysis	BENDING MOMENT
Manual	509.48
Grillage Analysis	415.92
FEM	381.04



Graph 1: Variation of Bending Moment on Top Slab

Table 2: Maximum Bending Moment on Bottom Slab

Method of Analysis	BENDING MOMENT
Manual	522.27
Grillage Analysis	472.99
Finite Element Method	409.35

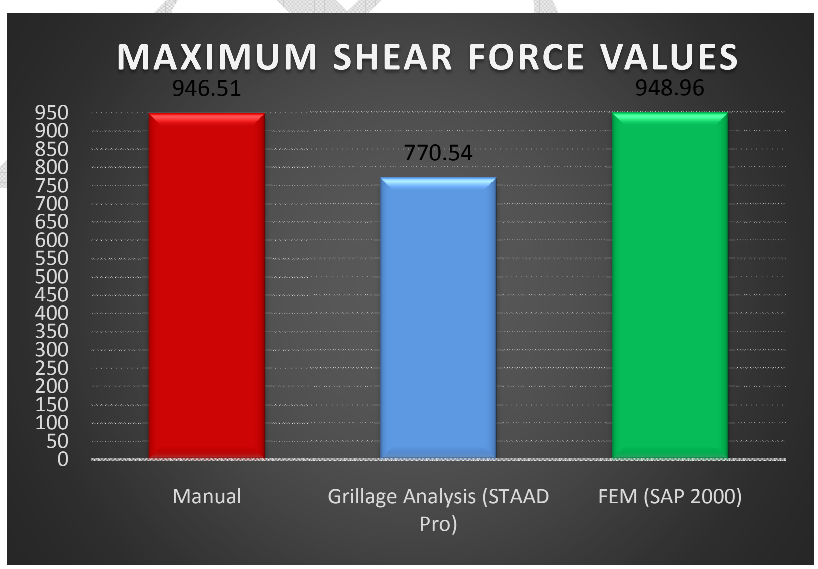


Graph 2: Variation of bending moment on Bottom slab

Shear Force

Table 3: Maximum Shear Force

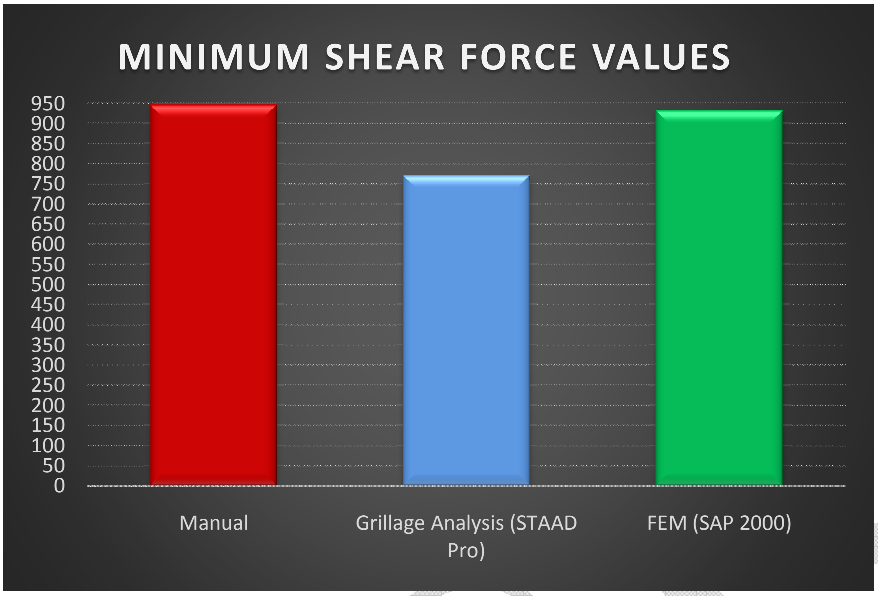
Method of Analysis	SHEAR FORCE
Manual	946.51
Grillage Analysis	770.54
Finite Element Method	948.96



Graph 3: Maximum Shear Force

Table 4: Minimum Shear Force

Method of Analysis	SHEAR FORCE
Manual	-946.51
Grillage Analysis	-770.54
Finite Element Method	-948.96

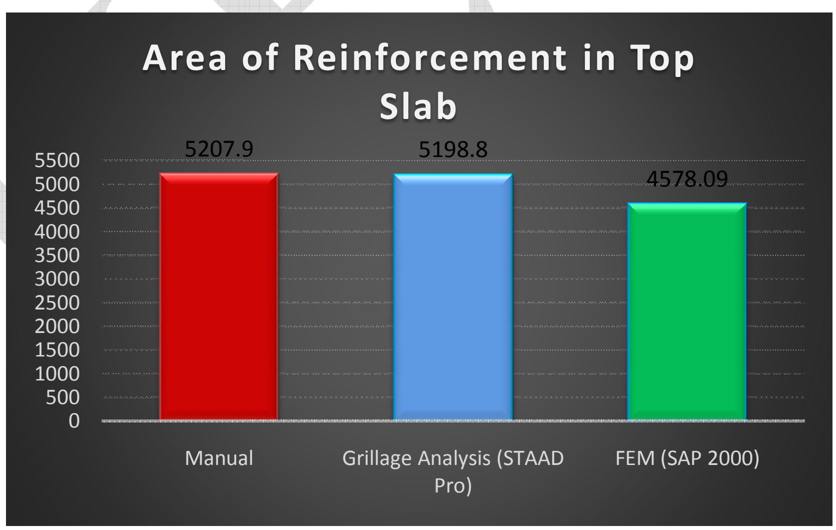


Graph 4: Minimum Shear Force

Reinforcement

Table 5: Area of reinforcement in top slab

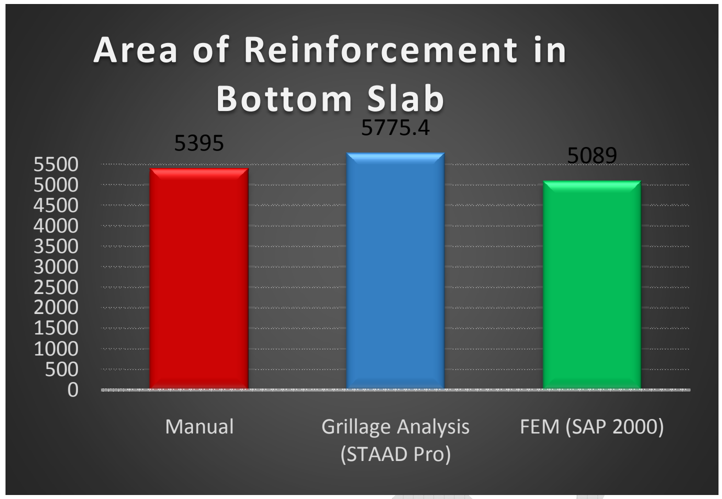
Method of Analysis	Area of reinforcement
Manual	5207.9
Grillage Analysis	5198.8
Finite Element Method	4578.09



Graph 5: Area of reinforcement in top slab

Table 6: Area of reinforcement in bottom slab

Method of Analysis	Area of reinforcement
Manual	5395
Grillage Analysis	5775.4
Finite Element Method	5089



Graph 6: Area of reinforcement in bottom slab

Discussion

1. In grillage analysis the bending moment value on top slab decreased by 18.3% when compared to conventional method.
2. In Finite element analysis bending moment value on top slab decreased by 25.21% when compared to conventional method and 8.71 lesser than grillage analysis.
3. In grillage analysis the bending moment value on bottom slab decreased by 9.4% when compared to conventional method.
4. In Finite element analysis bending moment value on top slab decreased by 21.62% when compared to conventional method and 13.4% lesser than grillage analysis.
5. Shear values are almost nearer in conventional method and finite element method.
6. Reinforcement area is decreased in top slab by 12.1% when compared to conventional method.
7. Reinforcement area is decreased in bottom slab by 5.67% when compared to conventional method.
8. Hence depth of slab is decreased to 300mm from 350.

7. CONCLUSION

The main objective of this paper is to know the behavior of box culvert and variation of stresses in terms of Shear force and bending moment values. Comparative study of computational methods with conventional method. Computational methods modelling and analysis done by using STAAD Pro and SAP 2000. So from analysis and design we conclude that

1. Finite Element Method gives the less value of stresses than grillage and conventional method.
2. Area of reinforcement is decreased
3. So we could achieve economical design from this result.
4. Grillage analysis is easy for modelling of structure.

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