"COMPARATIVE STUDY OF BOX CULVERT WITH AND WITHOUT HAUNCHES"

A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

Mr. Saurav
Assistant Professor

By

Md Subaktageen Ola

(131697)

Aman Gupta

(131642)

to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173 234

HIMACHAL PRADESH, INDIA

May-2017

CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"COMPARATIVE STUDY OF BOX CULVERT WITH AND WITHOUT HAUNCHES"** in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by MD SUBAKTAGEEN OLA (Enrolment no. 131697) & AMAN GUPTA (Enrolment no. 131642) during a period from July 2016 to May 2017 under the supervision of **Mr. Saurav** Assistant Professors, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

Date: - ………………………

Dr. Ashok Kumar Gupta Head of Department, Civil Engineering, JUIT, Waknaghat	Mr. Saurav Assistant Professor, Civil Engineering, JUIT, Waknaghat	External Examiner

ACKNOWLEDGEMENT

It gives us immense pleasure to express our deepest sense of gratitude and sincere thanks to our highly respected and esteemed guides **Mr. Saurav** for their valuable guidance, encouragement, willingness to motivate us and contribution for completion of this project report. We would also like to thank them for giving us their valuable time, showing us the path to achieve our objectives and goals and for being there whenever we needed their expert guidance. Their useful suggestions and cooperative behaviour are sincerely acknowledged.

Besides, we would like to express our sincere thank to our Head of Department **Prof. Dr. Ashok Kumar Gupta** for providing us good environment and facilities to complete this project report.

We would also like to take this opportunity to thank **Jaypee University of Information Technology** for offering this project.

Finally, we would like to thank our faculty members, family and friends for their understanding and supports towards us for completing this report.

Date - ....   -Md Subaktageen Ola

-Aman Gupta

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Box culverts consisting of two horizontal and two vertical slabs built monolithically are ideally suited for a road or a railway bridge crossing with high embankments crossing a stream with a limited flow. Reinforced concrete rigid frame box culverts with square or rectangular openings are used upto spans of 4m. The height of the vent generally does not exceed 3m.If the discharge in a drain or channel crossing a road is small, and if the bearing capacity of the soil is low, then a box culvert is an ideal bridge structure.

Recent software developments have made possible the use of Moment Distribution Method and Finite element methods for 3D modeling. Several works have already been done on analysis and design of Box Culverts. In the past study of box culverts, effect of haunch has not been considered in the reduction of Shear Force and Bending Moment in Box Culvert resulting in reduction of Shear Stress which leads to more efficient Box Culvert design.

In this project we are designing Box Culvert in STAAD-Pro V8i and ANSYS 14.5. In STAAD we are comparing Box Culvert with and without Haunches, expecting the reduction of Shear Force in Box Culvert. With the help of Box Culvert design in ANSYS we are comparing Moment Distribution Method and Finite Element Method, expecting the design by Finite Element Method is more efficient than that by Moment Distribution Method.

For FEM, we are modeling using Solid65 element. This element has eight nodes with three DOFs at each node – rotational in the nodal x, y, and z directions. This element can undergo plastic deformation, cracking in three orthogonal directions, and crushing. The cracking and crushing of concrete through this material model is decided bySolid65 element. A material model composed of two or more material definitions. Concrete material should have material definition and Elastic definition of concrete. In Elastic definition, the modulus of elasticity and Poisson’s ratio are necessary. The modulus of elasticity of concrete is decided by conventional methods and formulae. For Concrete definition, axial tension strength of concrete and shear transfer coefficients between crack surfaces for open and closed cracks are required. If transfer of shear from one crack surface to the other does not exist then the shear transfer coefficient is 0, if it fully exists then the coefficient is 1.0.

For the tension behaviour of concrete, ANSYS does not allow for the definition of an additional material model. However, if requested/required, an additional stress-strain

relationship for compressive behaviour of element can be defined through a hardening model such as Multilinear Isotropic Hardening. If this is the case, then modulus of elasticity must be same as the slope of the initial tangent of the defined stress-strain curve.

CHAPTER - 1

INTRODUCTION

1.1 General

Box culverts consisting of two horizontal and two vertical slabs built monolithically are ideally suited for a road or a railway bridge crossing with high embankments crossing a stream with a limited flow. Reinforced concrete rigid frame box culverts with square or rectangular openings are used upto spans of 4m. The height of the vent generally does not exceed 3m.

Box culverts are economical for the reasons mentioned below:

a) Due to the rigidity and monolithic action of box culvers separate foundations are not required since the bottom slab resting directly on the soil, serves as raft slab.
b) The box is a rigid frame structure and both the horizontal and vertical members are made of solid slab, which is very simple in construction.
c) In case of heavy embankments, an ordinary culvert will require very heavy abutments that will not only be expansive but also transfer heavy loads to the foundations.
d) The dead load and superimposed load are distributed almost uniformly over a wider area as the bottom slab serves as a raft foundation, thus reducing pressure on soil.

Concrete material model used in ANSYS: The concrete is modeled using Solid65 element in Fig. 1.1. This element has eight nodes with three DOFs at each node – rotational in the nodal x, y, and z directions. This element can undergo plastic deformation, cracking in three orthogonal directions, and crushing. The cracking and crushing of concrete through this material model is decided bySolid65 element. A material model composed of two or more material definitions. Concrete material should have material definition and Elastic definition of concrete. In Elastic definition, the modulus of elasticity and Poisson's ratio are necessary. The modulus of elasticity of concrete is decided by conventional methods and formulae..For Concrete definition, axial tension strength of concrete and shear transfer coefficients between crack surfaces for open and closed cracks are required. If transfer of shear from one crack surface to the other does not exist then the shear transfer coefficient is 0, if it fully exists then the coefficient is 1.0.

For the tension behaviour of concrete, ANSYS does not allow for the definition of an additional material model. However, if requested/required, an additional stress-strain relationship for compressive behaviour of element can be defined through a hardening model such as Multilinear Isotropic Hardening. If this is the case, then modulus of elasticity must be same as the slope of the initial tangent of the defined stress-strain curve.

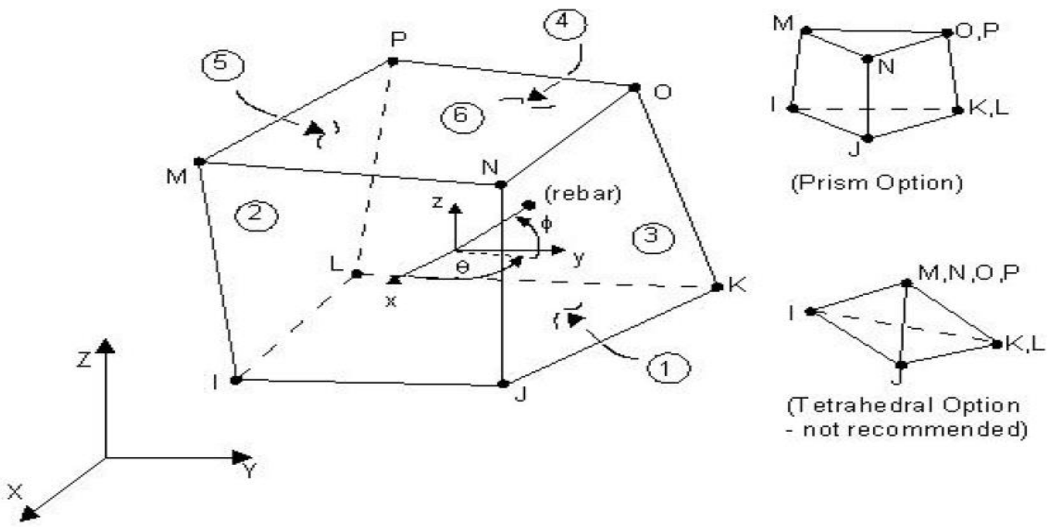

Fig. 1.1 Solid65 Element

1.2 Design Loads

The structural design of a reinforced concrete box culvert comprises the detailed analysis of the rigid frame for moments, shear forces and thrusts due to various types of loading conditions outlined below:

1.2.1 Uniform Distributed Load

The weight of embankments, wearing coat, and deck slab and the track load (including live load) are considered to be uniformly distributed loads on the top slab with the uniform soil reactions on the bottom slab. Fig. 1.2 shows the behaviour of Uniform Distributed Load.

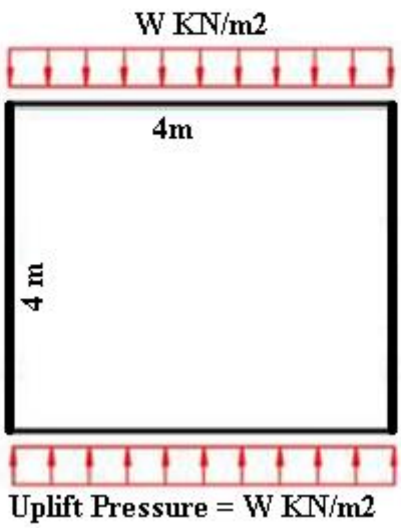

Fig. 1.2 Uniform Distributed Load

1.2.2 Weight of Side Walls

The self-weight of two side walls acting as concentrated loads are assumed to produce uniform soil reaction on the bottom slab. Fig. 1.3 shows the behaviour of Weight of Side Walls.

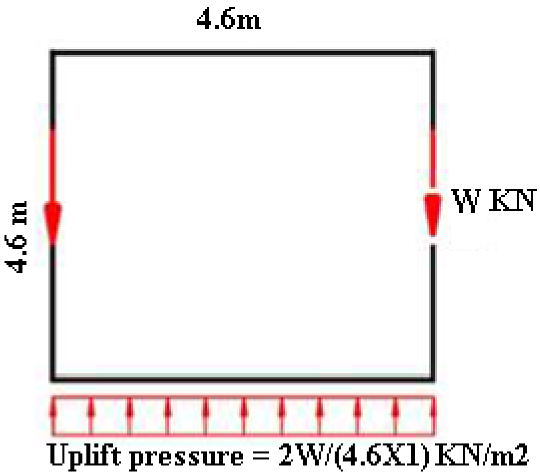

Fig. 1.3 Weight of Side Walls

1.2.3 Water Pressure inside Culvert

When the culvert is full with water, the pressure distribution on side walls is assumed to be triangular with a maximum pressure intensity of $P=\gamma H$ at the base,

Where, γ = unit weight of water (10 KN/m^3) and 'H' is the depth of flow. Fig. 1.4 shows the behaviour Water Pressure inside Culvert.

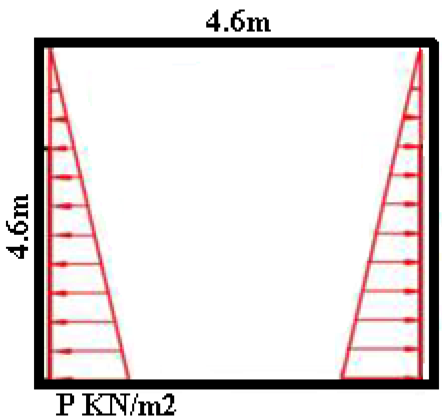

Fig. 1.4 Water Pressure inside Culvert

1.2.4 Earth Pressure on Vertical Side Walls

The earth pressure on the vertical side walls of the box culvert is computed according to the Coulomb's Theory. The distribution of earth pressure on the side walls is shown in figure. where P(maximum pressure intensity) = $K_a\gamma H$, K_a = Active earth pressure coefficient and γ = unit weight of soil. Fig. 1.5 shows the Earth Pressure on Vertical Side Walls.

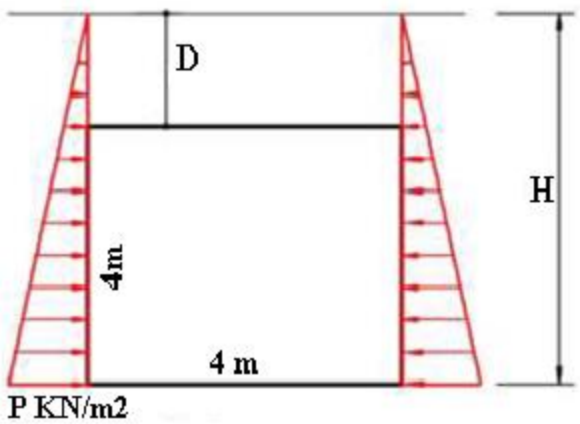

Fig. 1.5 Earth Pressure on Vertical Side Walls

1.2.5 Uniform Lateral Load on Side Walls

Uniform lateral pressure on vertical side walls has to be considered due to the effect of live load surcharge. Also trapezoidal pressure distribution on side walls due to embankment loading can be obtained by combining the last and this case. Fig. 1.6 shows the behaviour of Uniform Lateral Load on Side Walls. Where, Q = Surcharge load, P = Pressure intensity (K_aq)

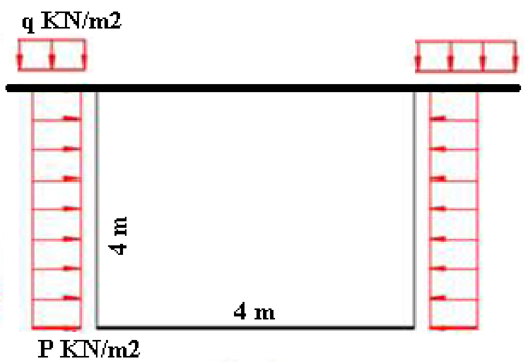

Fig. 1.6 Uniform Lateral Load on Side Walls

1.3 Moments, Shears and Thrusts

The box culvert is analysed for moments, shear forces, and axial thrusts developed due to the various loading conditions by any of the classical methods such as moment distribution, slope deflection, or finite element method.

1.4 Critical Sections

The maximum design moments resulting from the combination of the various loading cases are determined. The moments at the centre of span of span of top and bottom slabs and the support sections and at the centre of the vertical walls are determined by suitably combining the different loading patterns. The maximum moments generally develop for the following loading conditions.

a) When the top slab supports the dead and live load and the culvert is empty.
b) When the top slab supports the dead and live loads and the culvert is running full.
c) When the sides of the culvert do not carry the live load and the culvert is running full.

The slabs of the box culvert are reinforced on both faces with fillets at the inside corners.

1.5 Objective of Project

1.5.1 Comparison of Methods

Since, in this project we are designing box culvert in STAAD-pro and ANSYS which works on moment distribution method and finite element method respectively. Therefore, we are able to compare between the MDM & FEM which works on different principles (transfer of load from member to member and transfer of load from point to point).

1.5.2 Comparison of Reactions of Box Culvert with and without Haunches

Box culvert fails due to shear force. Therefore, box culverts are designed considering shear strength of box culvert. In this project we are increasing the shear strength of box culvert by providing haunches in box culvert and observing the increment of shear strengthby comparing box culvert with or without haunches.

1.5.3 Comparison of Cost estimation per metre of Box Culvert

Under this project, we will derive the cost estimation per metre of Box Culvert at different cases and compare the estimation results to get most cost effective design of Box Culvert.

CHAPTER - 2

LITERATURE REVIEW

2.1 General

Literature Review contains investigation of different aspects of Box Culverts by Researches. This helps in further understanding of Box Culverts and improves our vision of Box Culverts. Following are the brief explanation of Research papers:

2.2 Patil, A.D. et al [1] gave report which devotes to the, "box culverts constructed in reinforced concrete having different aspect ratios. The box culverts are analysed for various cushion and no cushion loading. The main emphasis is given to behaviour of the structure under the types of loading as per IRC codes and their combinations which produces worst effect for safe structural design. The study showed that the load combination with empty box is found to be the critical combination for all values of aspect ratios under consideration. Bending moments for aspect ratio 1 and 1.5 are found to be varying and for aspect ratio 2 and 3 are found to be constant for all load combinations, with and without cushion. The effect of soil pressure and water pressure is considerable for aspect ratio 1 and 1.5 and negligible for aspect ratio 2 and 3".

2.3 Sulke, M.S. et al [2] suggested that, "Box culvert problems are complicated examples of soil structure interaction where relative stiffness between backfill soil and the culvert materials is a critical factor in the load carrying capacity of culvert. Ducan et al proposed and equation for the design of this class of structure. This equation doesn't take into consideration the soil structure interaction phenomenon. The presence of PCC relieving slabs and their action in transferring live loads is analysed and another better agreement with the finite element method is obtained. A sophisticated computer program called STAAD-Pro is used to verify the results obtained from Moment Distribution Method. The result of both is compared with an experimental data on box culvert. We are going to compare moments calculated theoretically by MDM (Moment Distribution Method) and STAAD-PRO program. Moment values calculated by STAAD-PRO program may be greater than moment values calculated by MDM (Moment Distribution Method). Hence, structure will be design with maximum applied moments and it will become safer as well as efficient”.

2.4 Chijiwa, N. et al [3] monitored, “Long-term excessive deformation of underground RC box culverts in service over 20 years and its mechanism is analytically discussed in this study. The long-term excessive deformation possibly attributes to synergy effects accompanying delayed shear failure of RC slabs subjected to vertical soil pressures and the time-dependent creep-shrinkage of structural concrete. Special attention is directed to the delayed shear cracking which was actually found in real underground box culverts over the service life. The study showed that the excessive deflection of the top slab in the culvert is caused by not only by the shrinkage and creep of the concrete but also by the slip on this delayed shear crack”.

2.5 Sahu, K.K. et al [4] devoted to, “box culverts constructed in reinforced concrete having one, two or three cells and varying their operating conditions and analysis for their design. The cost by considering optimum thickness and the cost without considering optimum thickness are compared. Accordingly, results are presented which justifies that optimum thicknesses presented over here are leads to economical design of box culverts. An attempt is made to generate the charts of bending moments for top and bottom members. Such that from these charts at any intermediate aspect ratio the values of bending moments can be evaluated. The study showed that the L:H aspect ratio of 4:3 and 4:2has less end moments value and more maximum bending moment compared to L:H aspect ratio of 4:4. The box culvert of L:H aspect ratio of 4:2 will be more economical because the percentage saving will be more in velocity, depth of water, perimeter, area, hydraulic mean depth, volume of concrete and the end moments value will be less as on top slab, bottom slab, vertical side wall portion as well as the maximum bending moment of this section will be more safe, compared to other sections”.

2.6 Shreedhar, S. et al [5] suggested, “Multiple-cell reinforced box culverts are ideal bridge structure if the discharge in a drain crossing the road is large and if the bearing capacity of the soil is low as the single box culvert become uneconomical because of the higher thickness of the slab and walls. It is very tedious for the designer to arrive at the coefficient for moments, shear forces and axial thrusts for different loading cases and for different ratios of L/H for multiple cell box culverts by using classical methods such as moment distribution methods, slope deflection method etc. Thus, design coefficients help designer to decide the combination of various loading cases to arrive at the maximum design forces at the critical section, saving considerable time and effort. The results of the study showed that the critical sections considered are the centre of span of top and bottom slabs and the support sections and at the centre of the vertical walls since the maximum design forces develop at these sections due to various combinations of loading patterns. The maximum positive moment develops at the centre of top and bottom slab for the condition that the sides of the culvert not carrying the LL and the culvert is running full of water. The maximum negative moment develops at the support sections of the bottom slab for the condition that the culvert is empty and the top slab carries the DL and LL. The multi celled box culverts are economical for larger spans compared to single cell box culverts as the maximum bending moment and shear force values decreases considerably, thus requiring thinner sections”.

2.7 Vaslestad, J. et al [6] monitored that the, “earth pressure on deeply buried culverts is significantly affected by arching. Both magnitude & distribution of earth pressure on buried culverts are known to depend on the relative stiffness of culvert & soil. As the embankment is constructed, soft zone compresses more than surrounding fill. The culverts were built & instrumented in the period from 1988 to 1992. Three of the field tests are concrete pipes with granular backfill, & one field test is a cast in place concrete box culvert with silty-clay backfill. The long-term observations of earth pressure & deformation are presented, & compared with a simplified design method. The average measured earth pressure above the crown of pipe ranged from 23 to 25% of overburden pressure for installations with granular backfill material & about 45% for the one with cohesive backfill material. Long term monitoring of field installations indicates no increased pressure or deformations on buried culverts compared to situation right after construction. The measured vertical pressures are comparable with design method".

2.8 Woo, S.K. et al [7] investigated that the, "fracture behaviour characteristics of box culvert & incremental crack width of upper slab for the applied loading by the 3-axis loading system. In the 3-axis loading system, loading directions are upper side, left, & right side which simulates static traffic load & earth pressure, respectively. Especially, on the upper slab, crack width is measured by crack gauge. Based on the experimental results, structural internal force indices of box culvert are estimated quantitatively. Failure tests using static 3-axes loading system were done on 3 box culvert model specimens. A vertical load increase on lower part of top slab causes preliminary crack of 2mm width & 8mm depth. The structural damage index of reinforced concrete structure for the crack width of the top slab was developed & the formula for calculating the structural internal force index was proposed. Electric culvert structure is divided into 5 stages & crack widths of the top slab were proposed for each stage. It is deemed possible to express the degree of internal force reduction of the localized area as well as the whole structure just by using current crack width & damage estimation function".

2.9 Cheema, D.S. et al [8] knows that, "Geopolymer is a material which has been studied extensively over the past several decades and shows promise as a greener alternative to ordinary Portland cement concrete and it has good engineering properties with a reduced carbon footprint resulting from the zero-cement content. It was found that durability parameters depend on permeability of concrete of concrete matrix. Tests performed to measure absorption, void, and permeability coefficient have shown that Geopolymer concrete has the potential to be a durable concrete. This paper presented the results of a preliminary study carried out to study the application of fly ash-based Geopolymer concrete in reinforced box culverts. The study demonstrated that reinforced Geopolymer concrete box culverts can be manufactured using facilities currently available in a precast concrete plant. The test data showed that Geopolymer concrete box culverts meet the requirements of relevant standards with regard to strength preliminary data on durability parameters are also promising. Further, work in this area is currently in progress".

2.10 Fairless, G.J. et al [9] used dynamic numerical modelling to, “investigate seismic performance of an 11.66m span, 7.29m rise, and high profile arch culvert in 2005-2007. The horizontal components of three earthquakes were used, scaled for wellington conditions for 1:500 & 1:2500year recurrence intervals. The effects of a number of parameters were tested by varying their values. These parameters were soil shear strength, dilation angle & stiffness, cover over culvert, presence & size of concrete stiffening beams & whether or not slipping occurred between soil & culvert. Maximum structural seismic bending moments were usually controlled by maximum construction bending moments. Maximum bending is also more clearly related to PGA than to Aris Intensity. The upper bound of bending with PGA appears to be nearly linear”.

2.11 Malone, T. et al [10] investigated, “bend losses for open channel flow in rectangular culverts. Laboratory experiments were performed for sub-critical flow in rectangular culverts with abrupt bends. Bend angles of approximately 30, 45, 60, 75 and 90 degrees were tested. A procedure was developed to estimate head loss for gradual bends in rectangular channels flowing as free surface flow. This study produced results that can be used by practicing engineers to compute head losses for abrupt and gradual culvert bends. The bend-loss coefficients can be input HEC-RAS via the Steady Flow Data editor”.

2.12 Garg, A.K. et al [11] evaluates the, “shear behaviour and capacity of the precast concrete box culverts subjected to HS 20 truck wheel load. Three major phases were considered to complete the study which included experimental program, finite element modelling, development of distribution width and the determination of shear capacity”.

2.13 Pearson, W.H. et al [12] monitored the, “behavioural observations, which indicates that the fish use low-velocity pathways to accomplish passage and that these pathways differ between the baffled and unbaffled conditions and perhaps differ with flow for the baffled condition. The fish appear to be able to find and use low-velocity pathways to accomplish the passage in several different settings. Overall, the results obtained thus far in the culvert test bed system demonstrate that the juvenile Coho salmon have remarkable abilities to adapt their behaviour to accomplish upstream passage in different system configurations and under different flows. The fish appear to be able to find and use low velocity pathways to accomplish the passage”.

CHAPTER - 3

EXPERIMENTAL INVESTIGATION

3.1 Box Culvert without Haunches on STAAD-Pro

Box Culvert of size 4m X 4m having thickness of 0.3m. Using M25 concrete and Fe 415 steel, unit weight of soil is 18 KN/m^3 with angle of repose 30^o (sand)

Loads applied on Box Culvert:

a) Given Loads:

On Top Slab, Dead load of 2 KN/m and Live Load of 4 KN/m and on Side Slabs and Bottom Slab, impact pressure of water 2.5 KN/m

b) Loads Calculated:

Self weight of Top/Bottom Slab is 7.5 KN/m and of Side Slabs is 30 KN

Resulting Uplift pressure on Bottom Slab is 37 KN/m

Maximum pressure intensity of hydrostatic pressure by water flowing inside box culvert on inner side of Side Slabs is 40 KN/m. Maximum pressure intensity of linear varying load by soil on outside of Side Slabs is 27.6 KN/m

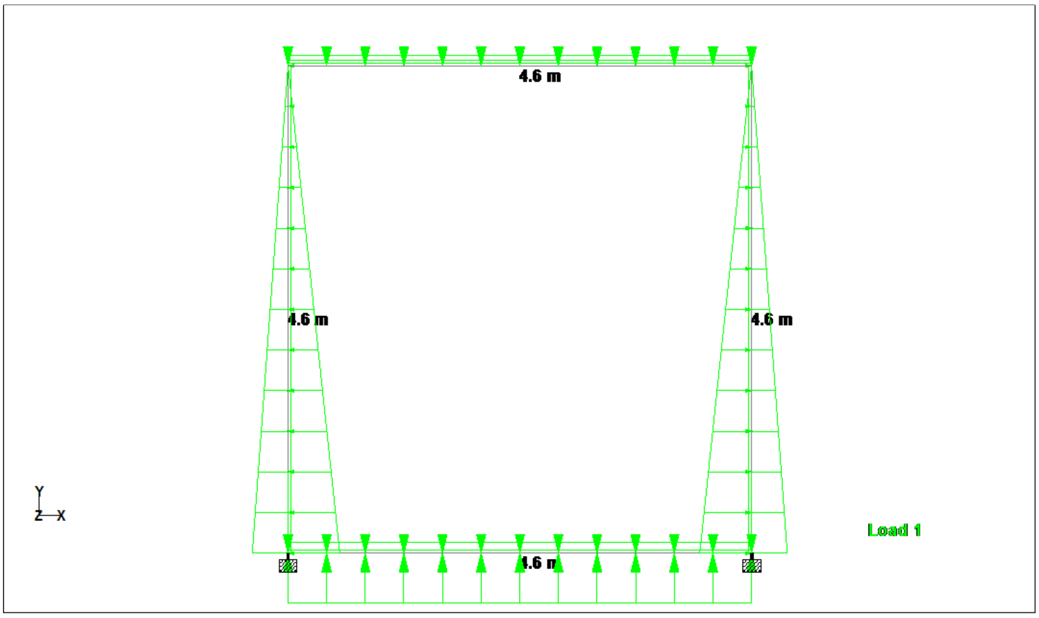

Fig. 3.1 Loading on Box Culvert

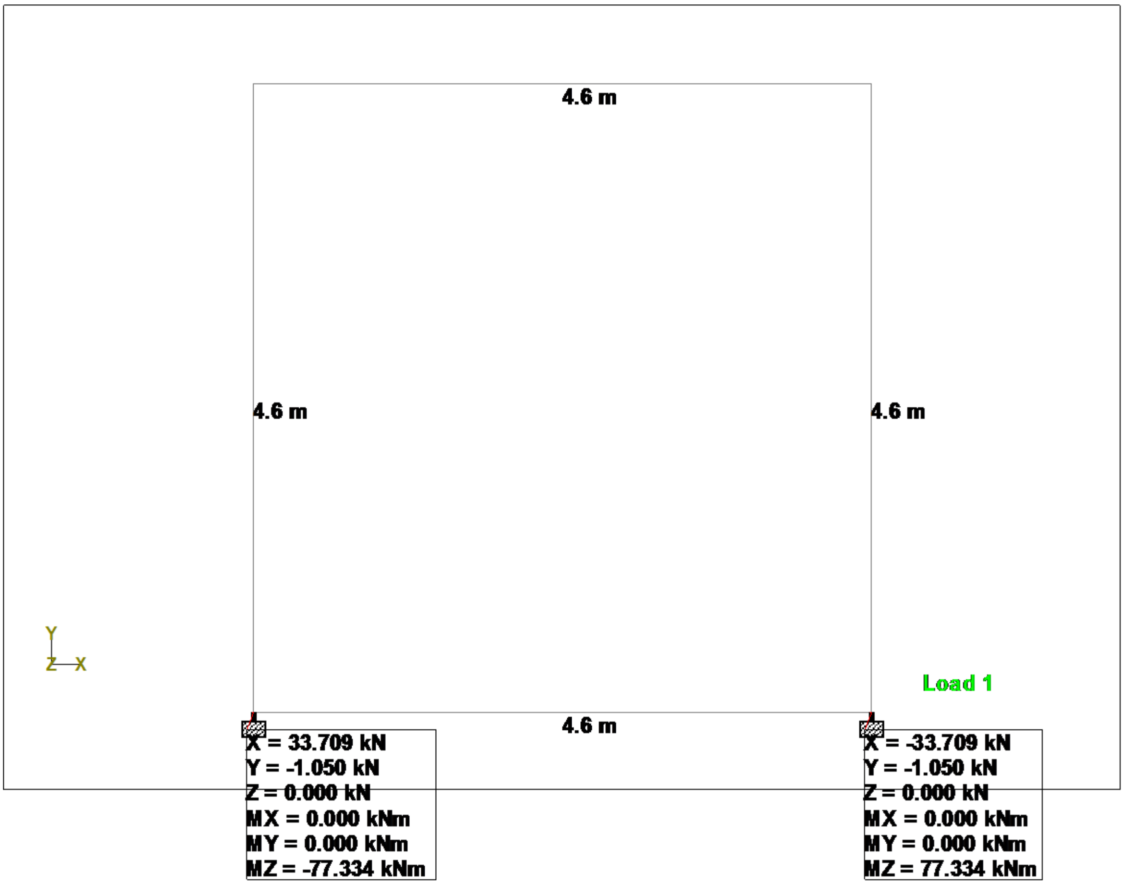

Fig. 3.2 Support Reactions

Fig. 3.2 gives the values of fixed end moment and reaction forces at fixed end supports after analysing the box culverts under applied loads.

F_x (reaction in x-axis direction) = 33.709 KN

F_y (reaction in y-axis direction) = 1.050KN

M_z (fixed end moment) = 77.334 KN.m

3.1.1 Top Slab

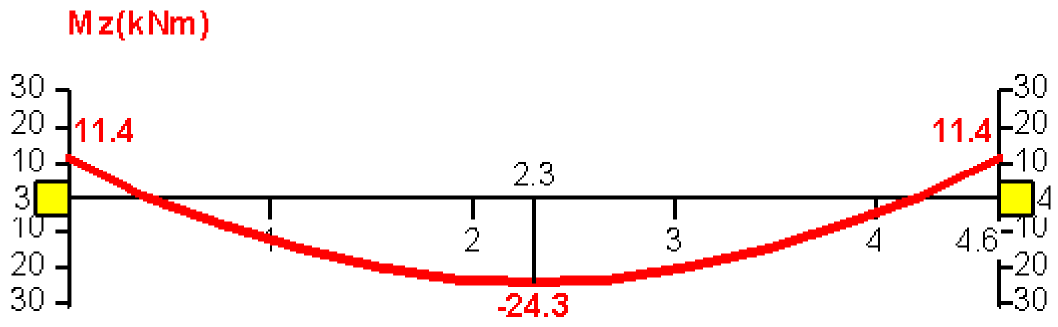

Fig. 3.3 Bending Moment Diagram

Fig. 3.3 shows the bending moment diagram of the top slab of box culvert. We observe that maximum bending moment of -24.3KN.m is acting at mid span of top slab and at ends of top slab bending moment of + 11.4 KN.m is acting. Thus, resulting in two point of contraflexure.

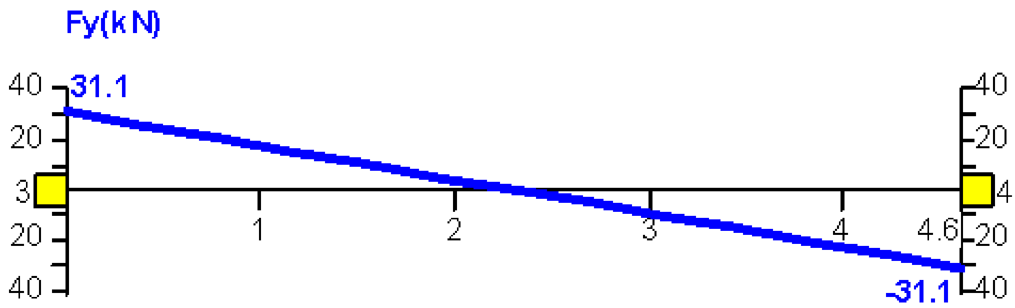

Fig. 3.4 Shear Force Diagram

Fig. 3.4 shows the shear force diagram of top slab of box culvert in y-axis direction. We observe that the maximum shear force of 31.1 KN is acting at ends of top slab and the value of shear force is zero at mid span of top slab in y-axis direction.

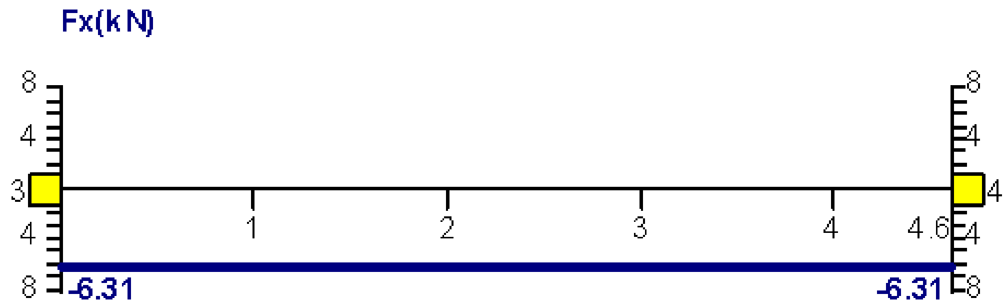

Fig. 3.5 Shear Force Diagram

Fig. 3.5 shows the shear force diagram of top slab of box culvert in x-axis direction. We observe that shear force of 6.31 KN is acting uniformly on top slab in x –axis direction.

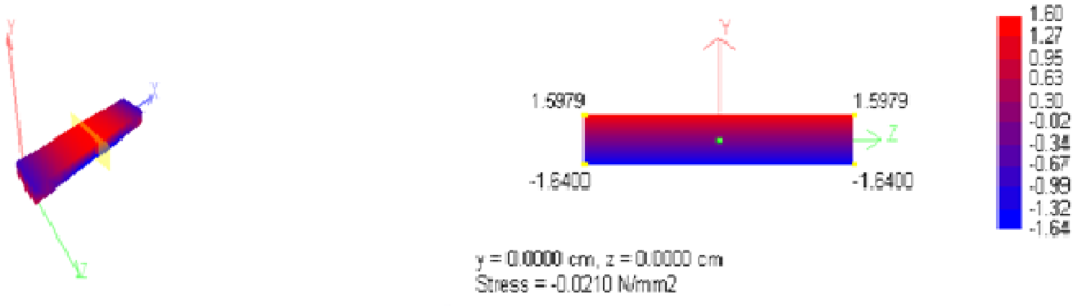

Fig. 3.6 Shear Stress Variation

Fig. 3.6 shows the shear stresses over the top slab of culvert. We observe that maximum shear stress of 1.64 N/mm^2 is acting on the mid span of top slab. The positive stress sign shows that the surface is under compression and negative stress sign shows that the surface is under tension.

3.1.2 Bottom Slab

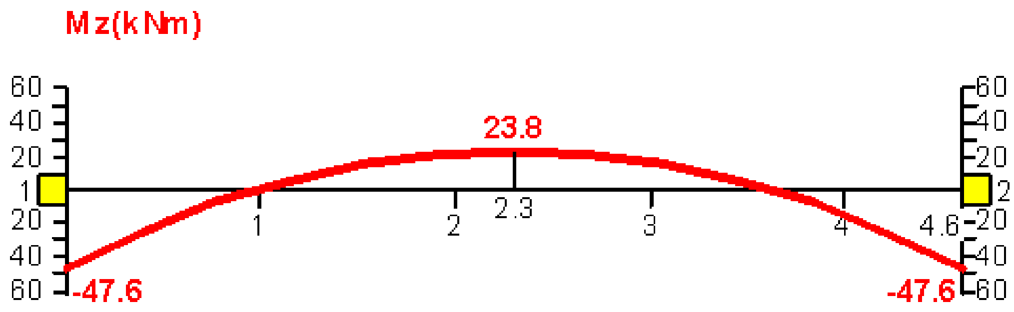

Fig. 3.7 Bending Moment Diagram

Fig. 3.7 shows the bending moment diagram of the bottom slab of box culvert. We observe that maximum bending moment of -47.6 KN.m is acting at ends of bottom slab and at middle of bottom slab bending moment of + 11.4 KN.m is acting. Thus, resulting in two point of contraflexure.

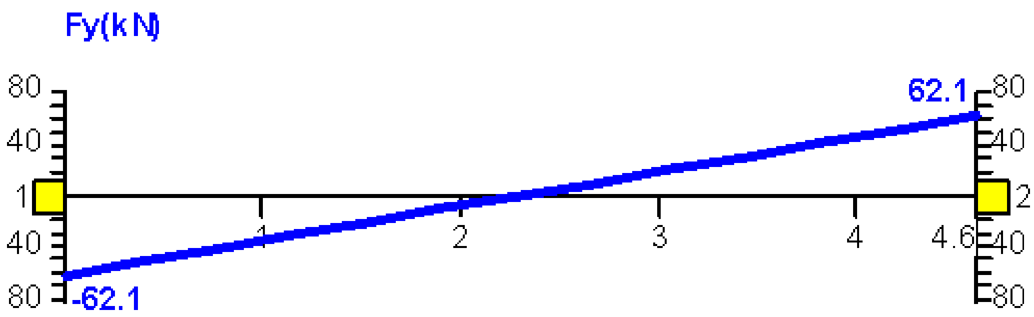

Fig. 3.8 Shear Force Diagram

Fig. 3.8 shows the shear force diagram of bottom slab of box culvert in y-axis direction. We observe that the maximum shear force of 62.1 KN is acting at ends of bottom slab and the value of shear force is zero at mid span of bottom slab in y-axis direction.

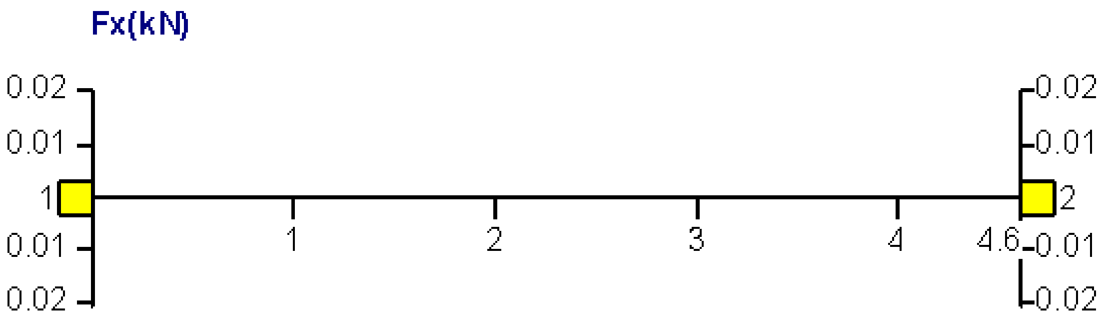

Fig. 3.9 Shear Force Diagram

Fig. 3.9 shows the shear force diagram of bottom slab of box culvert in x-axis direction. We observe that no shear force is acting on bottom slab in x –axis direction.

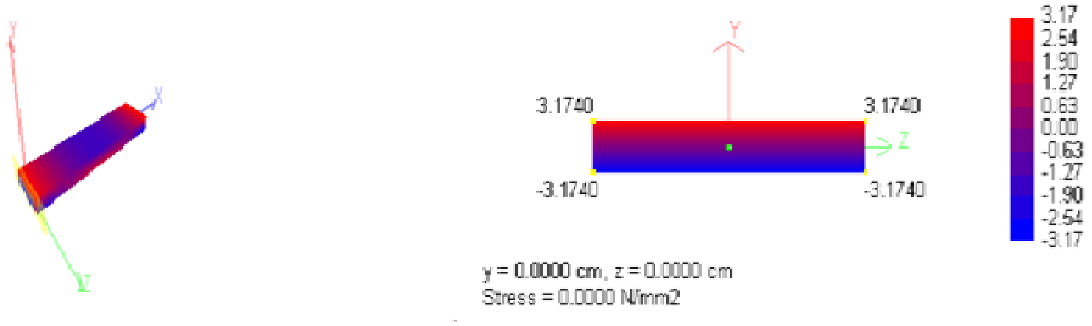

Fig. 3.10 Shear Stress Variation

Fig. 3.10 shows the shear stresses over the bottom slab of culvert. We observe that maximum shear stress of 3.17 N/mm^2 is acting on the mid span of bottom slab. The positive stress sign shows that the surface is under compression and negative stress sign shows that the surface is under tension.

3.1.3 Side Slab on Left

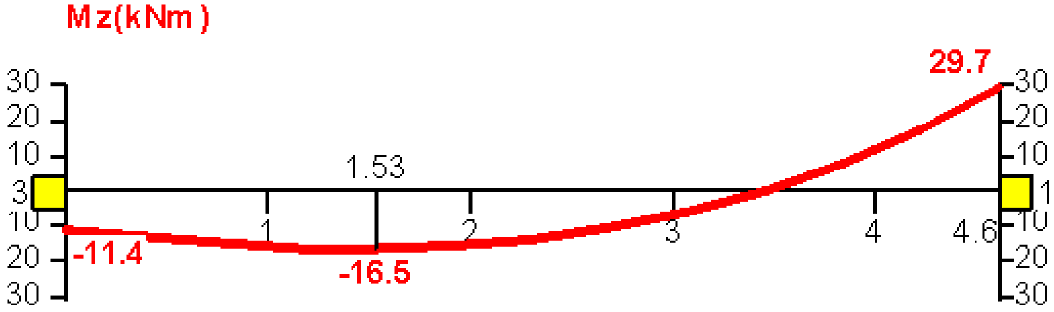

Fig. 3.11 Bending Moment Diagram

Fig. 3.11 shows the bending moment diagram of the side slab of box culvert on left side. We observe that maximum positive bending moment of + 29.7 KN.m is acting at bottom end of side slab and maximum negative bending moment of – 16.5 KN.mis acting at a distance of 1.53m from the top. Thus, resulting in one point of contraflexure.

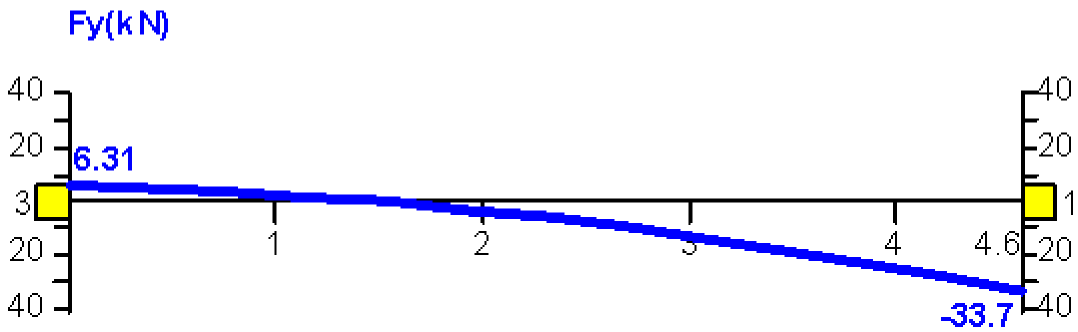

Fig. 3.12 Shear Force Diagram

Fig. 3.12 shows the shear force diagram of side slab on left side of box culvert in y-axis direction. We observe that the maximum shear force of 33.7 KN is acting at bottom end of side slab.

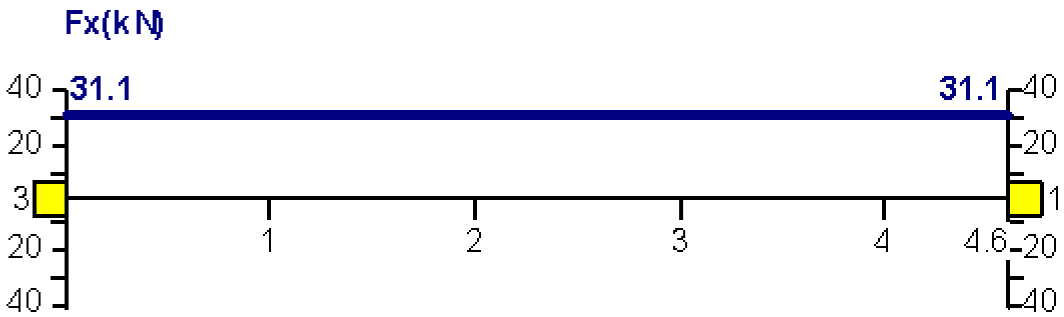

Fig. 3.13 Shear Force Diagram

Fig. 3.13 shows the shear force diagram of side slab on left of box culvert in x-axis direction. We observe that shear force of 31.1 KN is acting uniformly on top slab in x –axis direction.

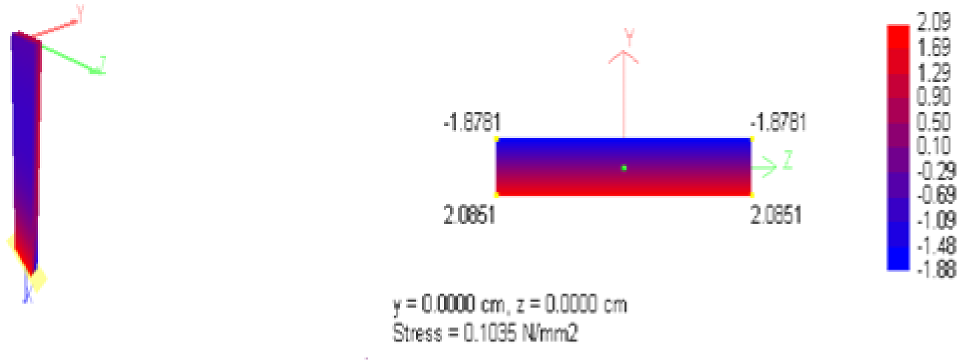

Fig. 3.14 Shear Stress Variation

Fig. 3.14 shows the shear stresses over the side slab of culvert on left side. We observe that maximum shear stress of 2.09 N/mm^2 is acting on the bottom end of the side slab. The +ve stress sign shows that the surface is under compression and negative stress sign shows that the surface is under tension. In side slab the compression stress is higher compare to tension stress.

3.1.4 Side Slab on Right

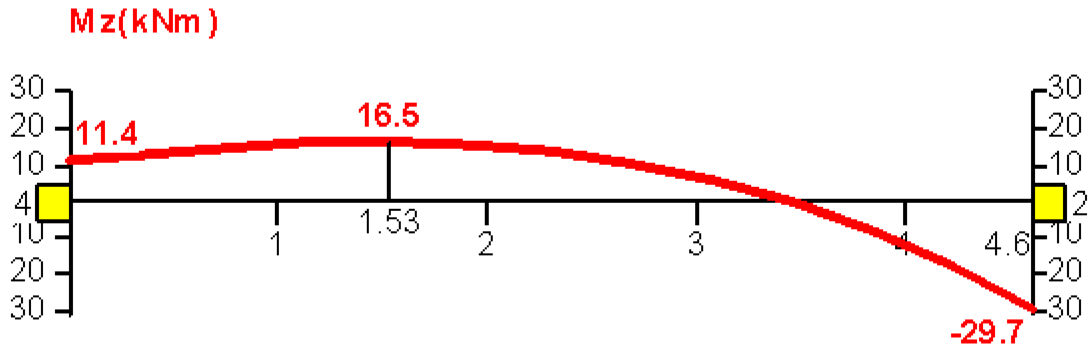

Fig. 3.15 Bending Moment Diagram

Fig. 3.15 shows the bending moment diagram of the side slab of box culvert on right side. We observe that maximum negative bending moment of - 29.7 KN.m is acting at bottom end of side slab and maximum positive bending moment of + 16.5 KN.m is acting at a distance of 1.53m from the top. Thus, resulting in one point of contraflexure. It is noted that bending moment diagram of side slab on right is opposite to that on left side.

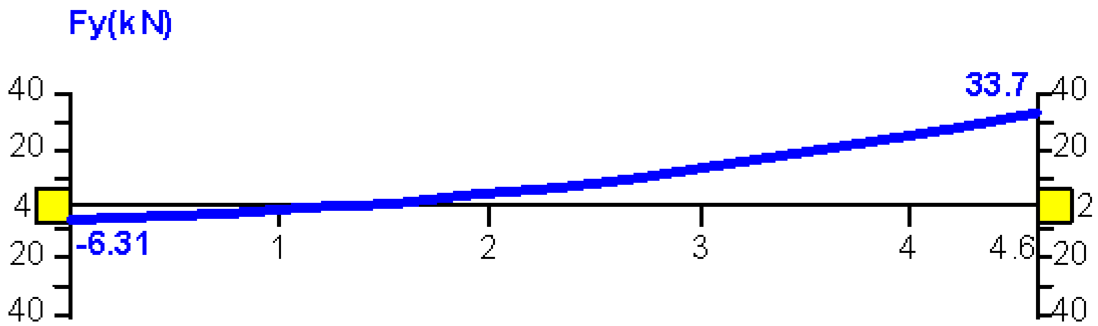

Fig. 3.16 Shear Force Diagram

Fig. 3.16 shows the shear force diagram of side slab on right side of box culvert in y-axis direction. We observe that the maximum shear force of 33.7 KN is acting at bottom end of side slab. It is noted that bending moment diagram of side slab on right is opposite to that on left side.

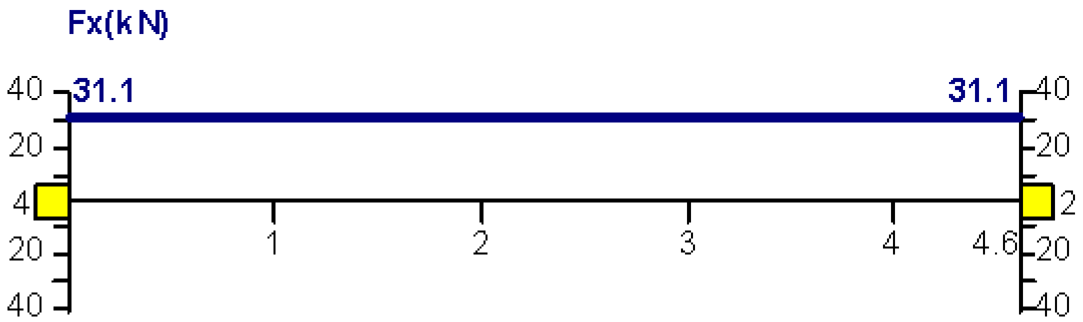

Fig. 3.17 Shear Force Diagram

Fig. 3.17 shows the shear force diagram of side slab on right of box culvert in x-axis direction. We observe that shear force of 31.1 KN is acting uniformly on top slab in x –axis direction.

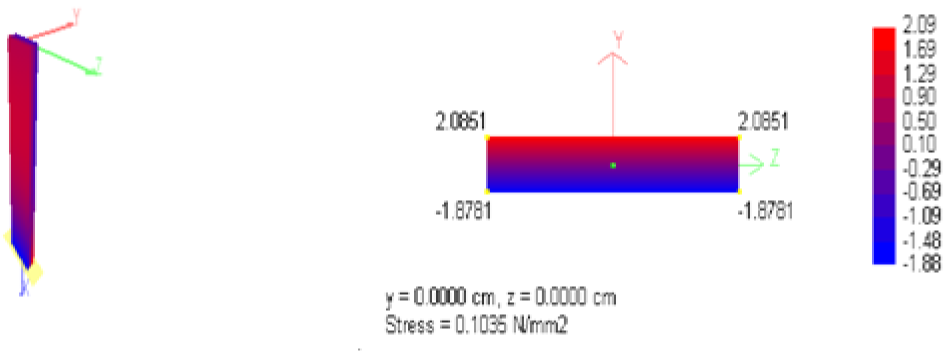

Fig. 3.18 Shear Stress Variation

Fig. 3.18 shows the shear stresses over the side slab of culvert on right side. We observe that maximum shear stress of 2.09 N/mm^2 is acting on the bottom end of the side slab. The positive stress sign shows that the surface is under compression and negative stress sign shows that the surface is under tension. In side slab the compression stress is higher compare to tension stress.

3.2 Box Culvert with Haunches on STAAD-Pro

Box Culvert of size 4m X 4m having thickness of 0.3m

Length (outer) of Slabs is 3.6m and Length (outer) of Haunches is 0.707m with thickness of 0.3m. Using M25 concrete and Fe 415 steel, unit weight of soil is 18 KN/m^3 with angle of repose 30^o (sand)

Loads applied on Box Culvert:

a) Given Loads:

Top Slab and Haunches with top slab carries Dead load of 2 KN/m and Live Load of 4 KN/m

Side Slabs, Bottom Slab and Haunches with Bottom Slab carries impact pressure of water 2.5 KN/m

b) Loads Calculated:

Self weight of Top/Bottom Slab and Haunches is 7.5 KN/m and of Side Slabs is 27 KN

Resulting Uplift pressure on Bottom Slab is 30 KN/m

Maximum pressure intensity of hydrostatic pressure by water flowing inside box culvert on inner side of Side Slabs is 36.5 KN/m and minimum pressure intensity is 3.5 KN/m

Maximum pressure intensity of linear varying load by soil on outside of Side Slabs is 24.6 KN/m and minimum pressure intensity is 3 KN/m

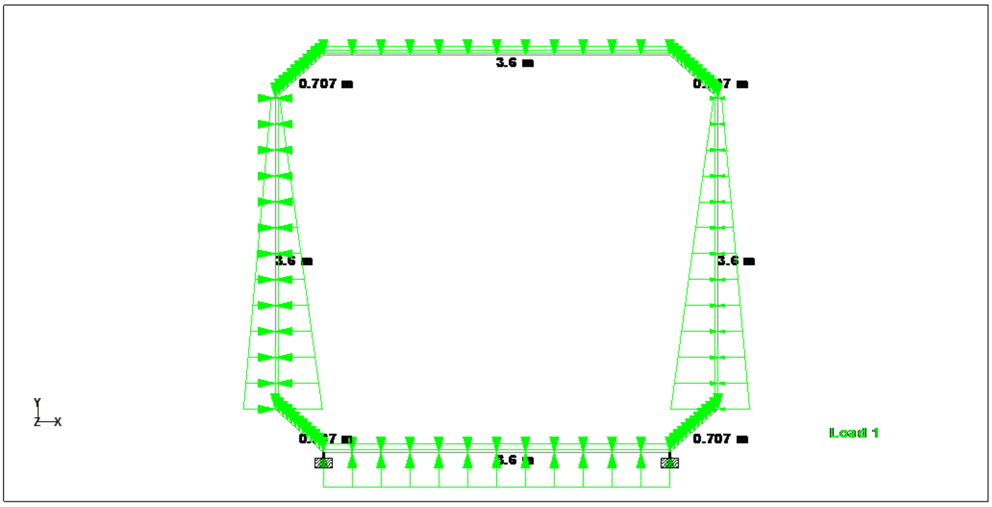

Fig. 3.19 Loading on Box Culvert

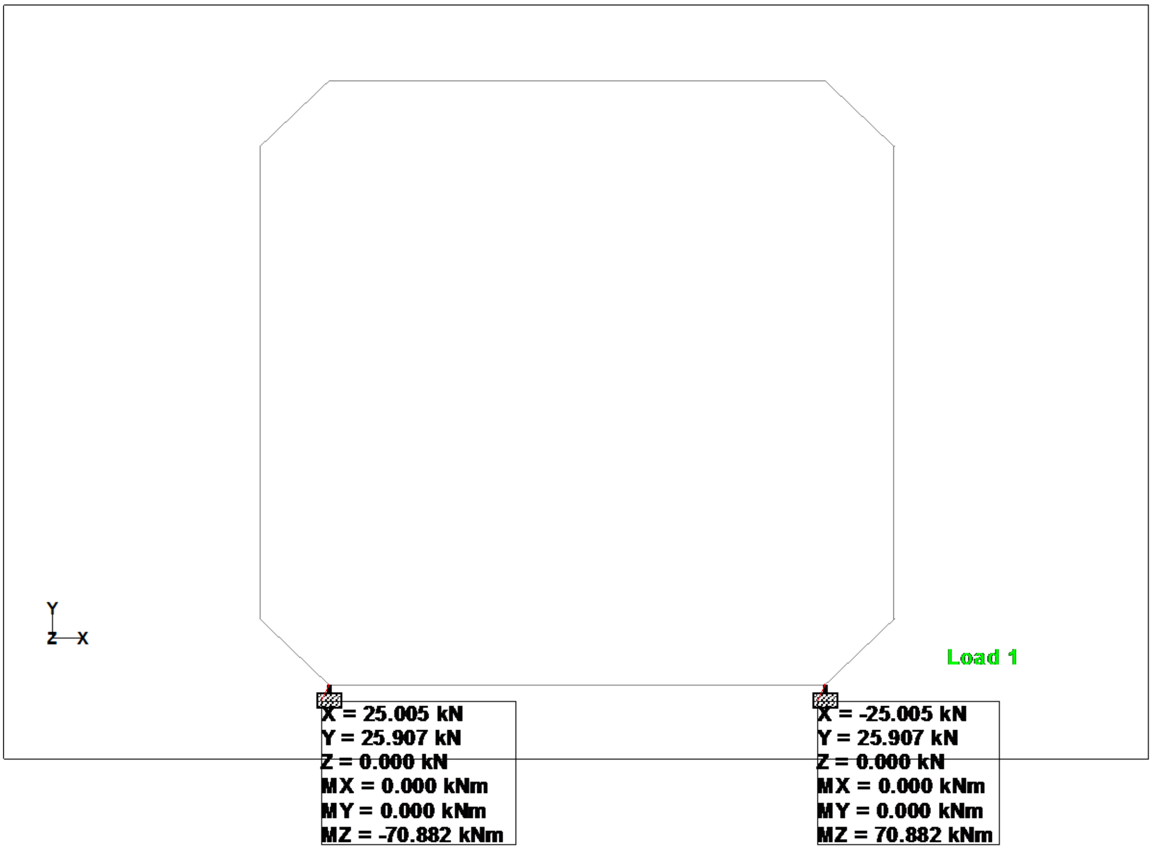

Fig. 3.20 Support Reactions

Fig. 3.20 gives the values of fixed end moment and reaction forces at fixed end supports after analysing the box culverts under applied loads.

F_x (reaction in x-axis direction) = -25.005 KN

F_y (reaction in y-axis direction) = 25.907 KN

M_z (fixed end moment) = 70.882 KN.m

3.2.1 Top Slab

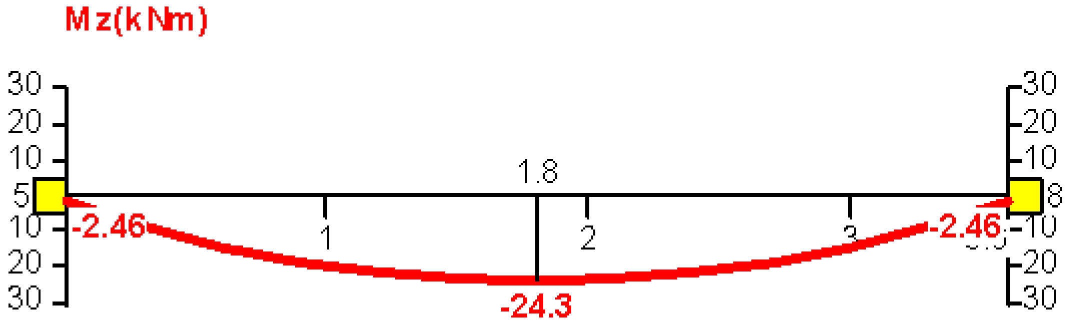

Fig. 3.21 Bending Moment Diagram

Fig. 3.21 shows the bending moment diagram of the top slab of box culvert. We observe that maximum bending moment of - 24.3 KN.m is acting at mid span of top slab and at ends of top slab bending moment of - 2.46 KN.m is acting. Thus, resulting in no point of contraflexure.

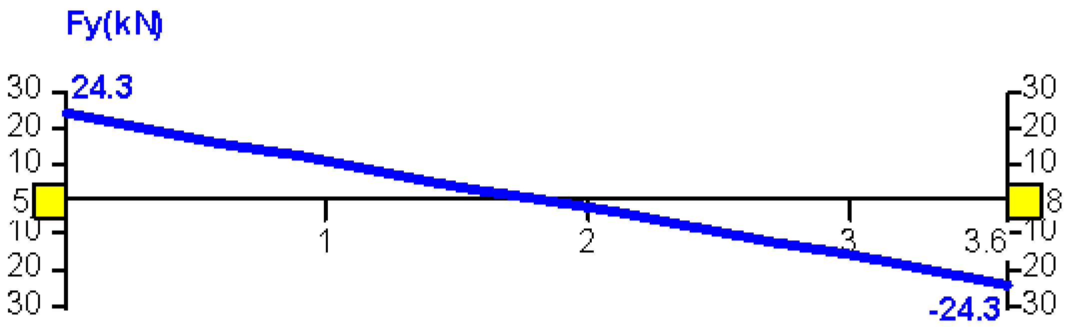

Fig. 3.22 Shear Force Diagram

Fig. 3.22 shows the shear force diagram of top slab of box culvert in y-axis direction. We observe that the maximum shear force of 24.3 KN is acting at ends of top slab and the value of shear force is zero at mid span of top slab in y-axis direction.

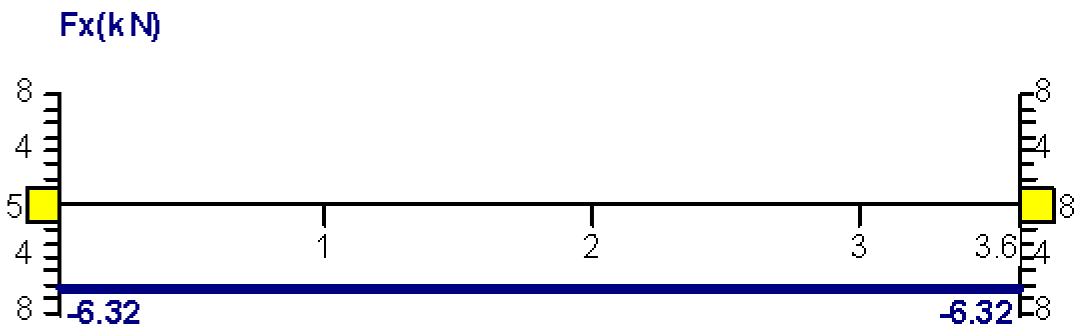

Fig. 3.23 Shear Force Diagram

Fig. 3.23 shows the shear force diagram of top slab of box culvert in x-axis direction. We observe that shear force of 6.32 KN is acting uniformly on top slab in x –axis direction.

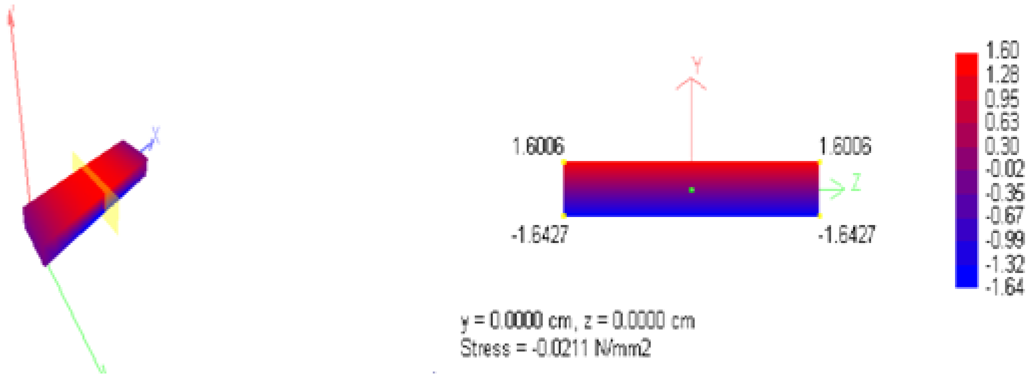

Fig. 3.24 Shear Stress Variation

Fig. 3.24 shows the shear stresses over the top slab of culvert. We observe that maximum shear stress of 1.64 N/mm^2 is acting on the mid span of top slab. The positive stress sign shows that the surface is under compression and negative stress sign shows that the surface is under tension.

3.2.2 Bottom Slab

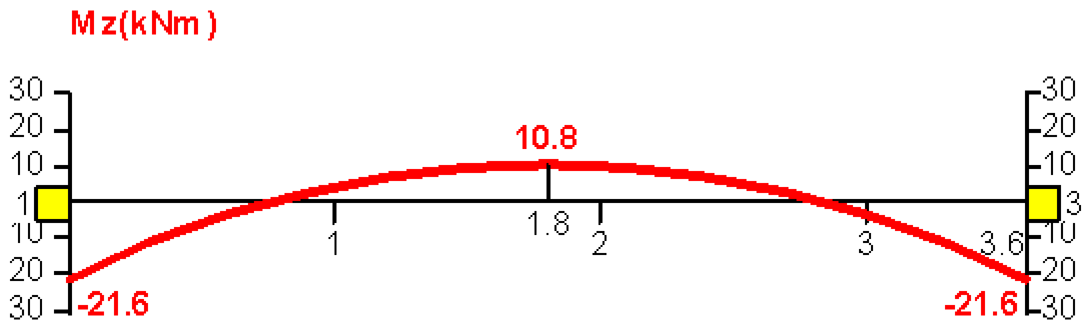

Fig. 3.25 Bending Moment Diagram

Fig. 3.25 shows the bending moment diagram of the bottom slab of box culvert. We observe that maximum bending moment of - 21.6 KN.m is acting at ends of bottom slab and at middle of bottom slab bending moment of + 10.8 KN.m is acting. Thus, resulting in two point of contraflexure.

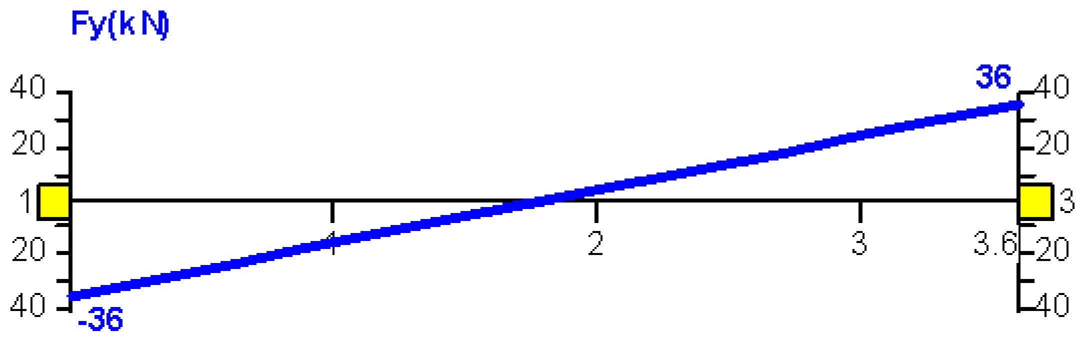

Fig. 3.26 Shear Force Diagram

Fig. 3.26 shows the shear force diagram of bottom slab of box culvert in y-axis direction. We observe that the maximum shear force of 36 KN is acting at ends of bottom slab and the value of shear force is zero at mid span of bottom slab in y-axis direction.

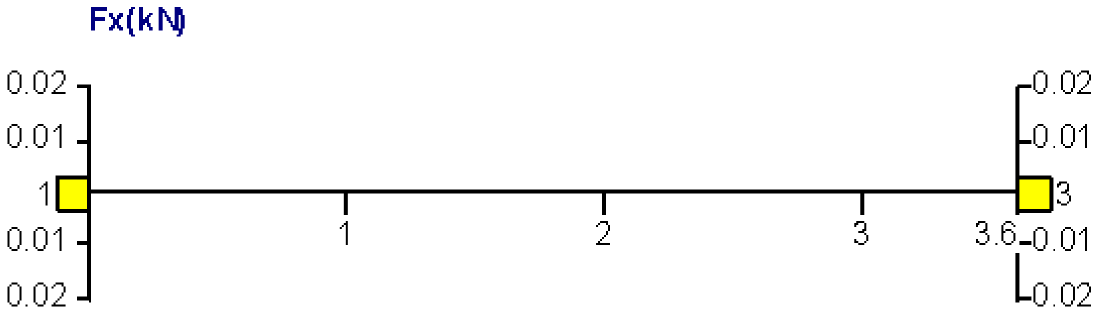

Fig. 3.27 Shear Force Diagram

Fig. 3.27 shows the shear force diagram of bottom slab of box culvert in x-axis direction. We observe that no shear force is acting on bottom slab in x –axis direction.

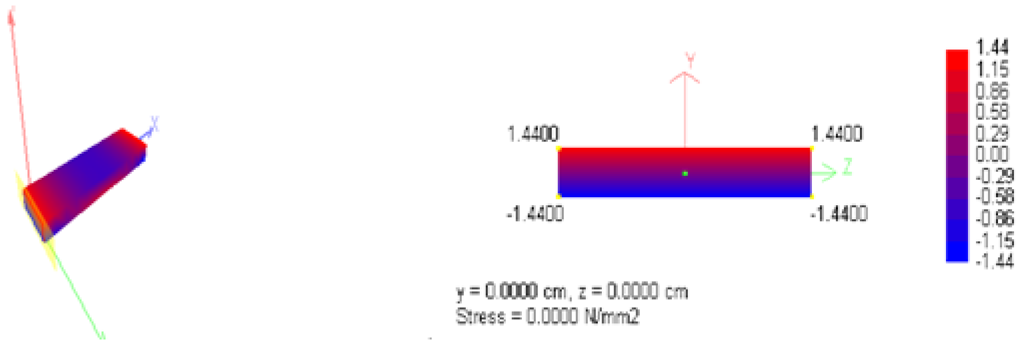

Fig. 3.28 Shear Stress Variation

Fig. 3.28 shows the shear stresses over the bottom slab of culvert. We observe that maximum shear stress of 1.44 N/mm^2 is acting on the mid span of bottom slab. The positive stress sign shows that the surface is under compression and negative stress sign shows that the surface is under tension.

3.2.3 Side Slab on Left

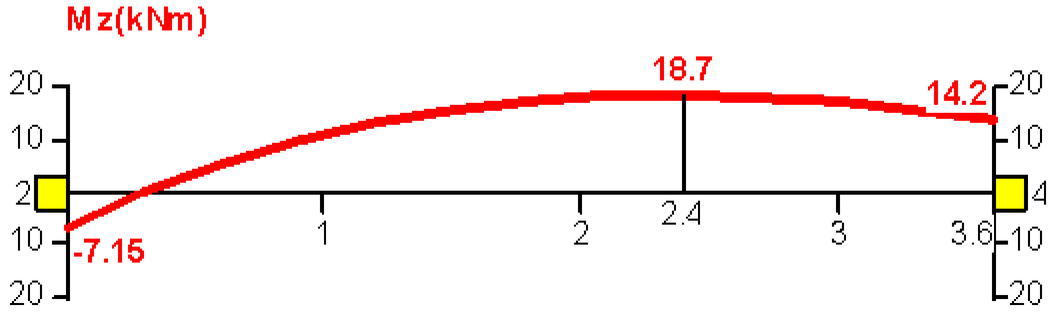

Fig. 3.29 Bending Moment Diagram

Fig. 3.29 shows the bending moment diagram of the side slab of box culvert on left side. We observe that maximum positive bending moment of + 18.7 KN.m is acting at 2.4 m from top of side slab and maximum negative bending moment of – 16.5 KN.m is acting at top end of slab. Thus, resulting in one point of contraflexure.

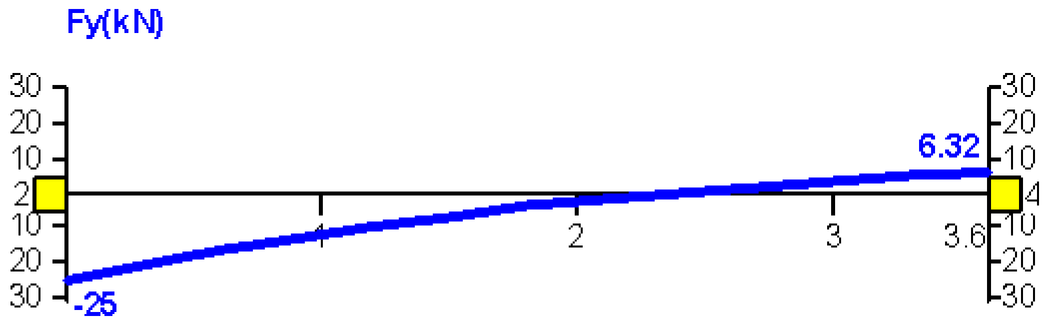

Fig. 3.30 Shear Force Diagram

Fig. 3.30 shows the shear force diagram of side slab on left side of box culvert in y-axis direction. We observe that the maximum shear force of 25 KN is acting at top end of side slab.

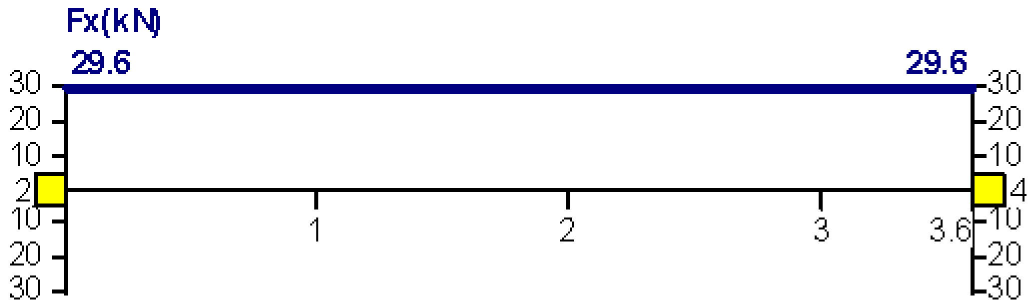

Fig. 3.31 Shear Force Diagram

Fig. 3.31 shows the shear force diagram of side slab on left of box culvert in x-axis direction. We observe that shear force of 29.6 KN is acting uniformly on top slab in x –axis direction

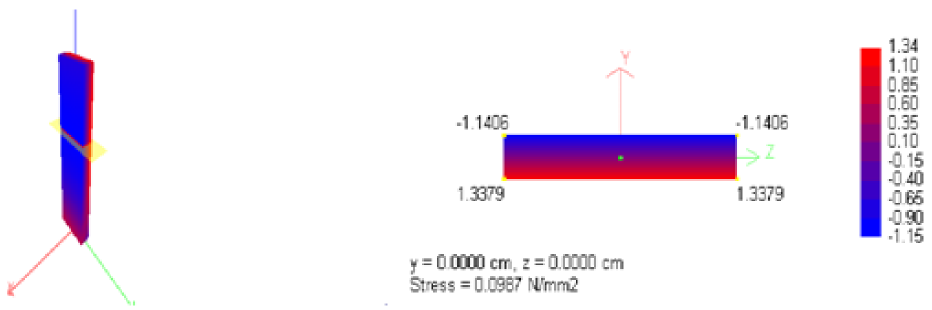

Fig. 3.32 Shear Stress Variation

Fig. 3.32 shows the shear stresses over the side slab of culvert on left side. We observe that maximum shear stress of 1.34 N/mm^2 is acting on the middle of the side slab. The positive stress sign shows that the surface is under compression and negative stress sign shows that the surface is under tension. In side slab the compression stress is higher compare to tension stress.

3.2.4 Side Slab on Right

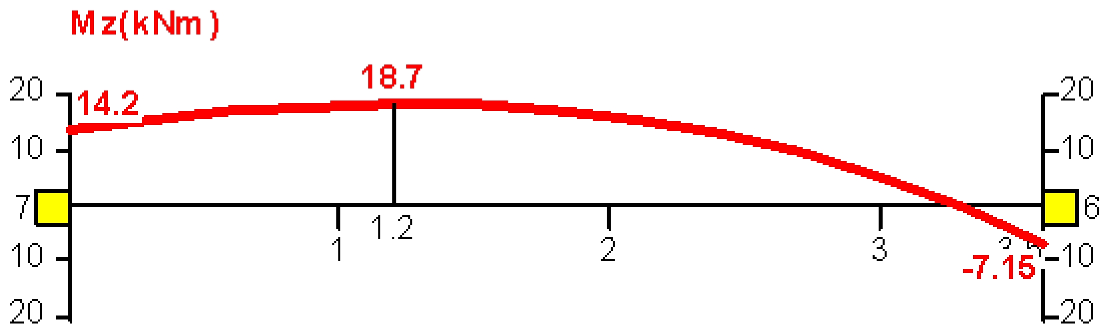

Fig. 3.33 Bending Moment Diagram

Fig. 3.33 shows the bending moment diagram of the side slab of box culvert on right side. We observe that maximum negative bending moment of – 7.15 KN.m is acting at bottom end of side slab and maximum positive bending moment of + 18.7 KN.m is acting at a distance of 1.2 m from the top. Thus, resulting in one point of contraflexure. It is noted that bending moment diagram of side slab on right is opposite to that on left side.

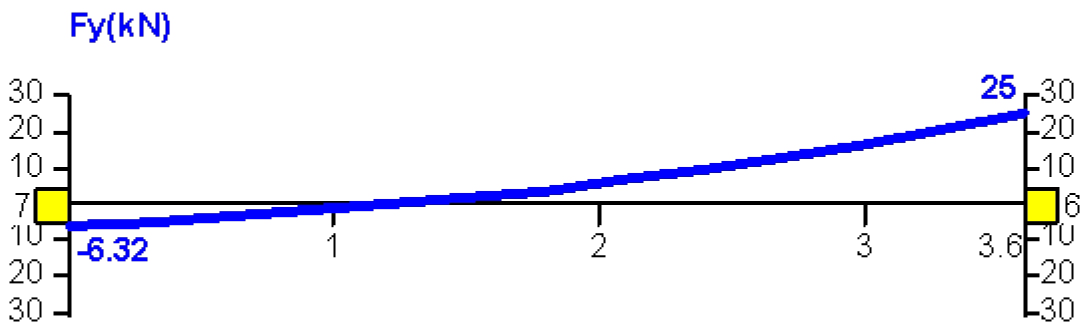

Fig. 3.34 Shear Force Diagram

Fig. 3.34 shows the shear force diagram of side slab on right side of box culvert in y-axis direction. We observe that the maximum shear force of 25 KN is acting at bottom end of side slab. It is noted that bending moment diagram of side slab on right is opposite to that on left side

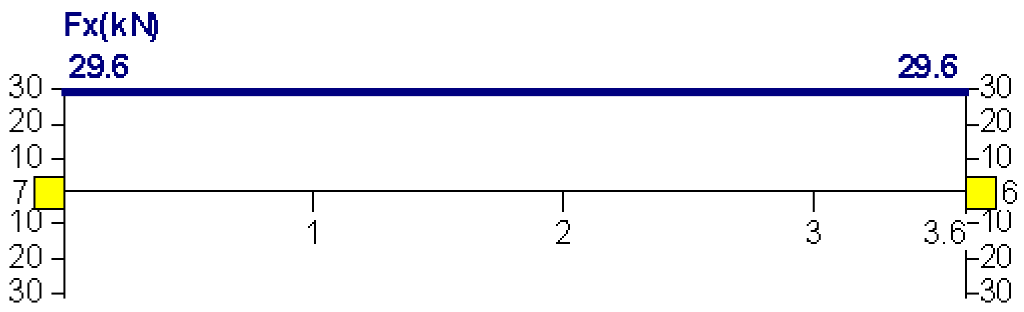

Fig. 3.35 Shear Force Diagram

Fig. 3.35 shows the shear force diagram of side slab on right of box culvert in x-axis direction. We observe that shear force of 29.6 KN is acting uniformly on top slab in x –axis direction.

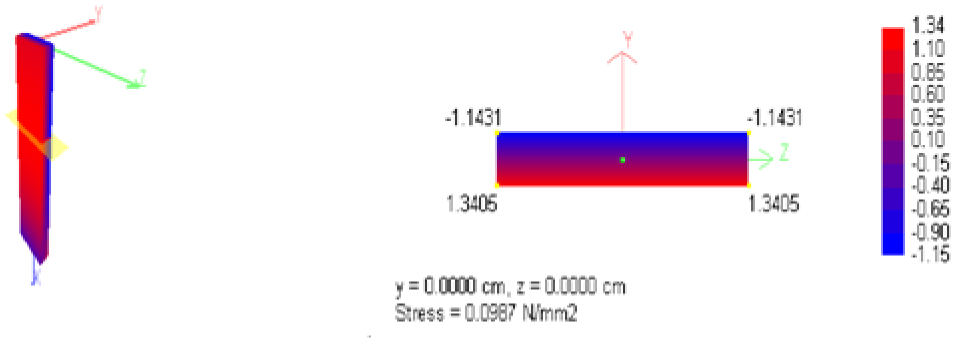

Fig. 3.36 Shear Stress Diagram

Fig. 3.36 shows the shear stresses over the side slab of culvert on right side. We observe that maximum shear stress of 1.34 N/mm^2 is acting on the middle of the side slab. The positive stress sign shows that the surface is under compression and negative stress sign shows that the surface is under tension. In side slab the compression stress is higher compare to tension stress

3.3 Box Culvert without Haunches on ANSYS

Box Culvert of size 4m X 4m having thickness of 0.3m

Using M25 concrete and Fe 415 steel, unit weight of soil is 18 KN/m^3 with angle of repose 30^o (sand)

Loads applied on Box Culvert:

a) Given Loads:

On Top Slab, Dead load of 2 KN/m and Live Load of 4 KN/m and on Side Slabs and Bottom Slab, impact pressure of water 2.5 KN/m

b) Loads Calculated:

Self-weight of Top/Bottom Slab is 7.5 KN/m and of Side Slabs is 30 KN (15 KN at each vertices)

Resulting Uplift pressure on Bottom Slab is 37 KN/m

Maximum pressure intensity of hydrostatic pressure by water flowing inside box culvert on inner side of Side Slabs is 40 KN/m

Maximum pressure intensity of linear varying load by soil on outside of Side Slabs is 27.6 KN/m

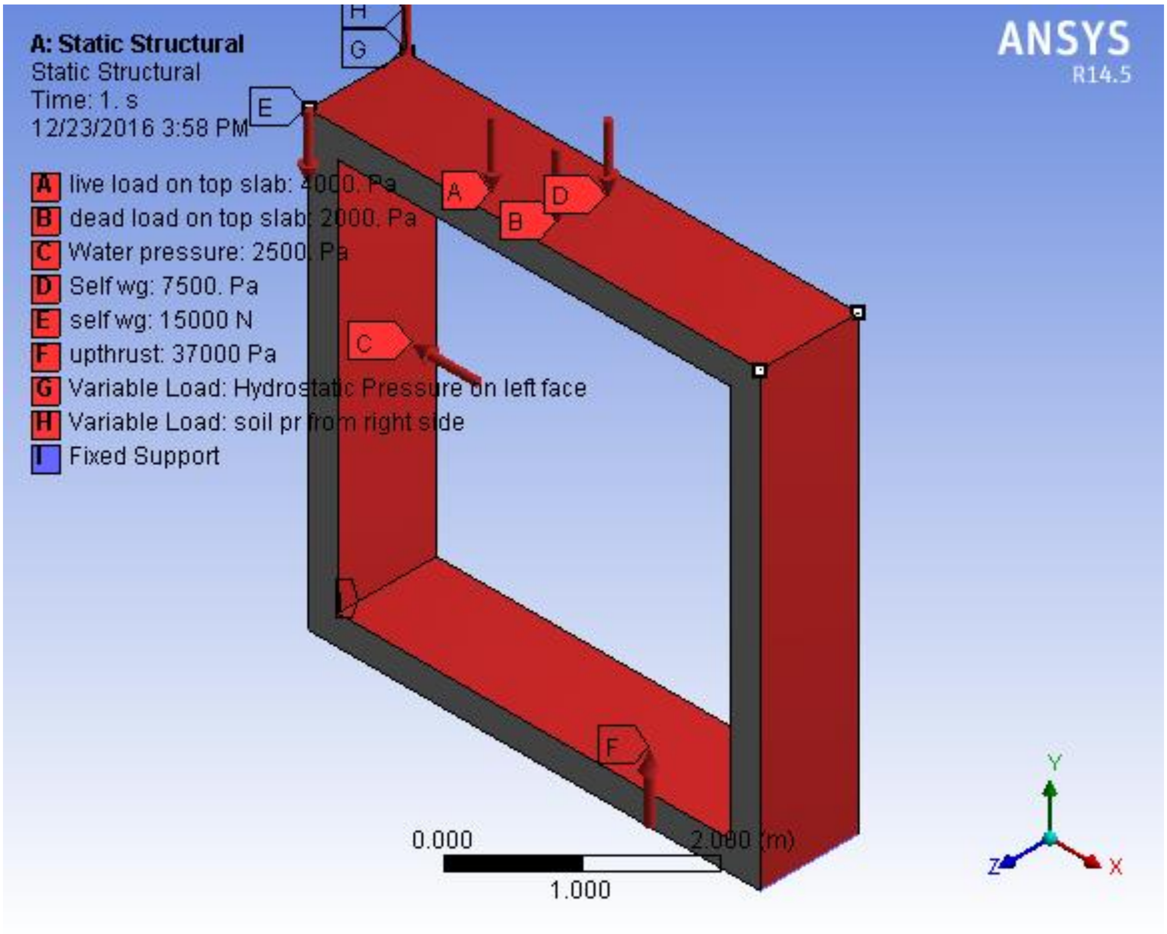

Fig. 3.37 Loads on Box Culvert

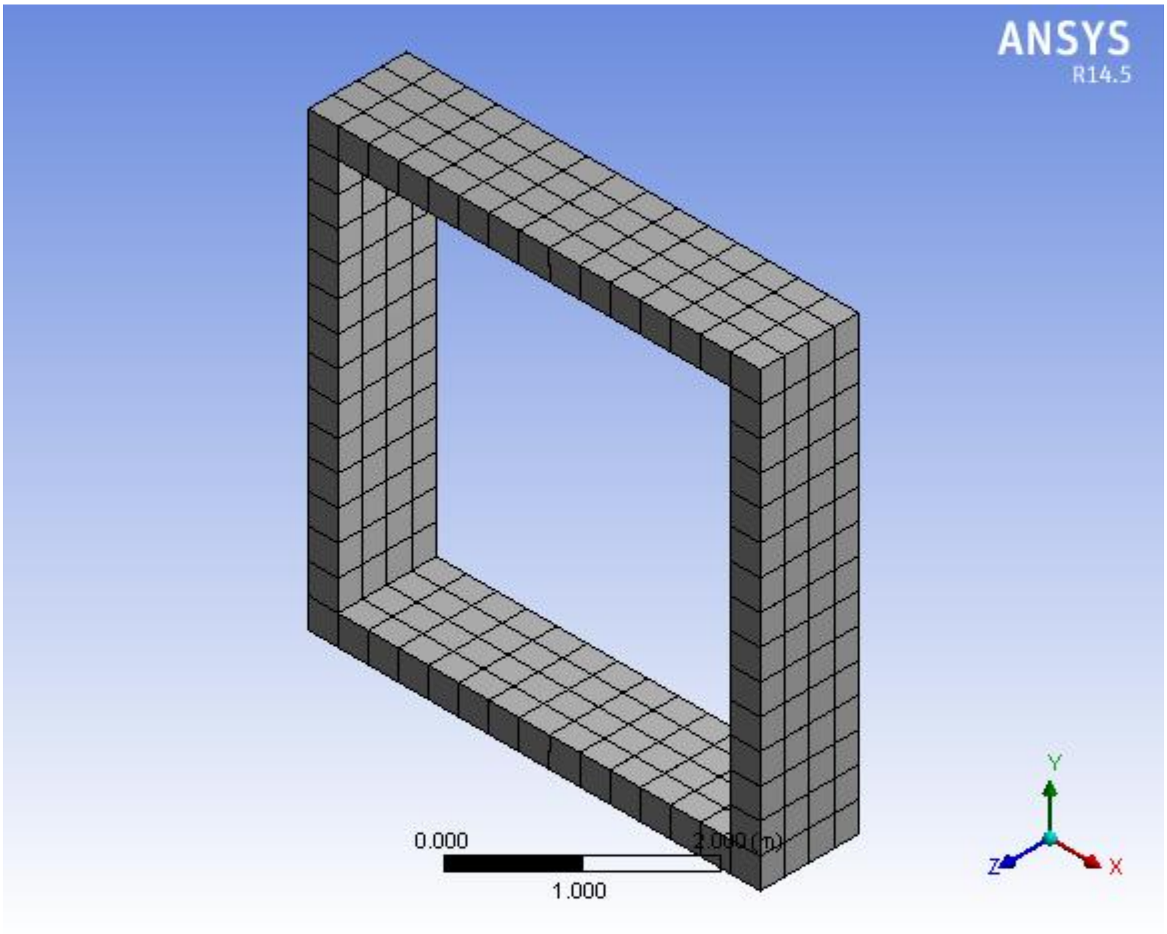

Fig. 3.38 Mesh Model

The concrete is modeled using Solid65 element. This element has eight nodes with three DOFs at each node – rotational in the nodal x, y, and z directions. This element can undergo plastic deformation, cracking in three orthogonal directions, and crushing. The cracking and crushing of concrete through this material model is decided bySolid65 element. A material model composed of two or more material definitions. Concrete material should have material definition and Elastic definition of concrete. In Elastic definition, the modulus of elasticity and Poisson’s ratio are necessary. The modulus of elasticity of concrete is decided by conventional methods and formulae..For Concrete definition, axial tension strength of concrete and shear transfer coefficients between crack surfaces for open and closed cracks are required. If transfer of shear from one crack surface to the other does not exist then the shear transfer coefficient is 0, if it fully exists then the coefficient is 1.0.

For the tension behaviour of concrete, ANSYS does not allow for the definition of an additional material model. However, if requested/required, an additional stress-strain

relationship for compressive behaviour of element can be defined through a hardening model such as Multilinear Isotropic Hardening. If this is the case, then modulus of elasticity must be same as the slope of the initial tangent of the defined stress-strain curve.

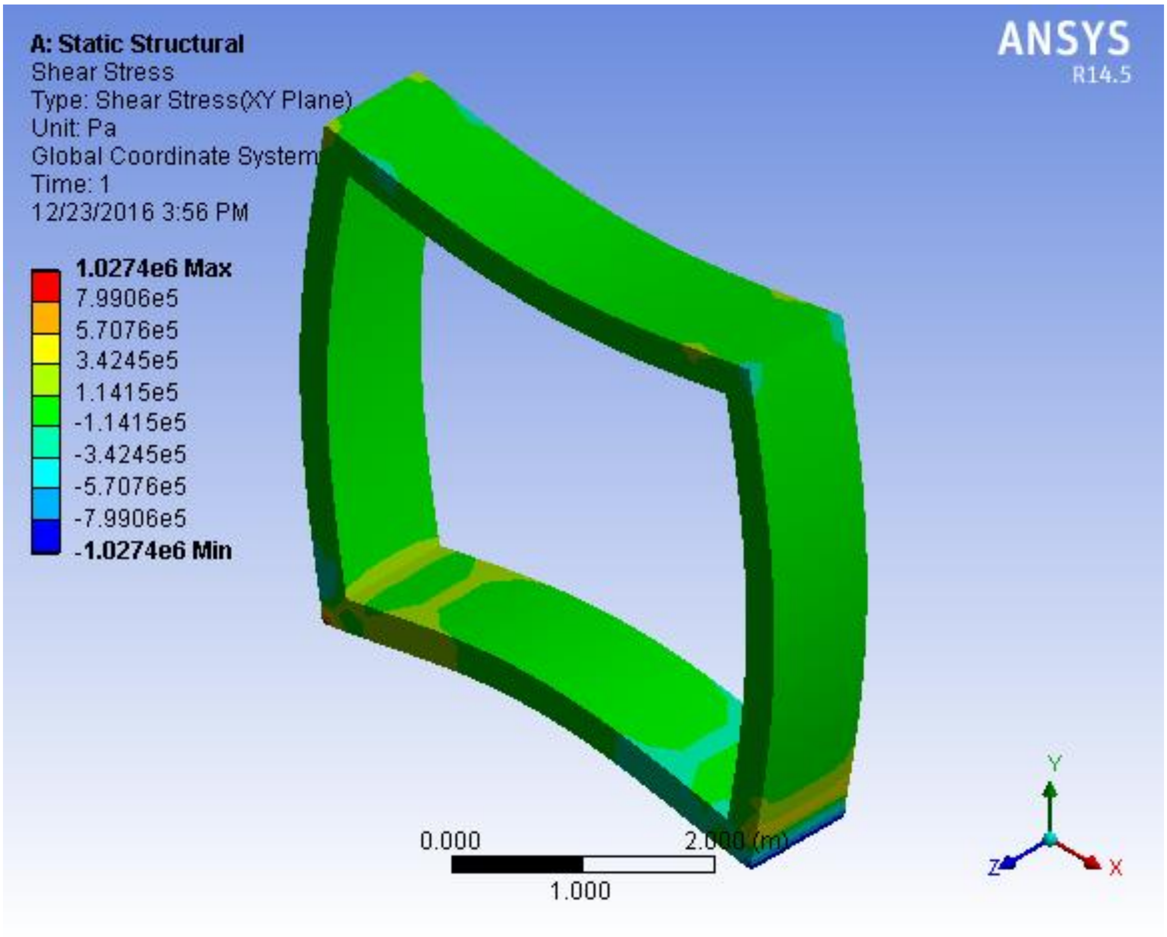

Fig. 3.39 Shear Stress (XY Plane)

Fig. 3.39 shows shear stress on box culvert after analysing the box culvert under applied loads in ANSYS. We observe that maximum shear stress of 1.0274 N/mm^2 is acting at the fixed supports.

Therefore maximum bending moment,

$M/I = \sigma /y$ which gives $M = (\sigma/y)*I$ Where, $\sigma = 1.0274\ N/mm^2$, $I = 22.5*10^8\ mm^4$ and $y = 150$ mm

Bending moment, M = 15.41 kNm

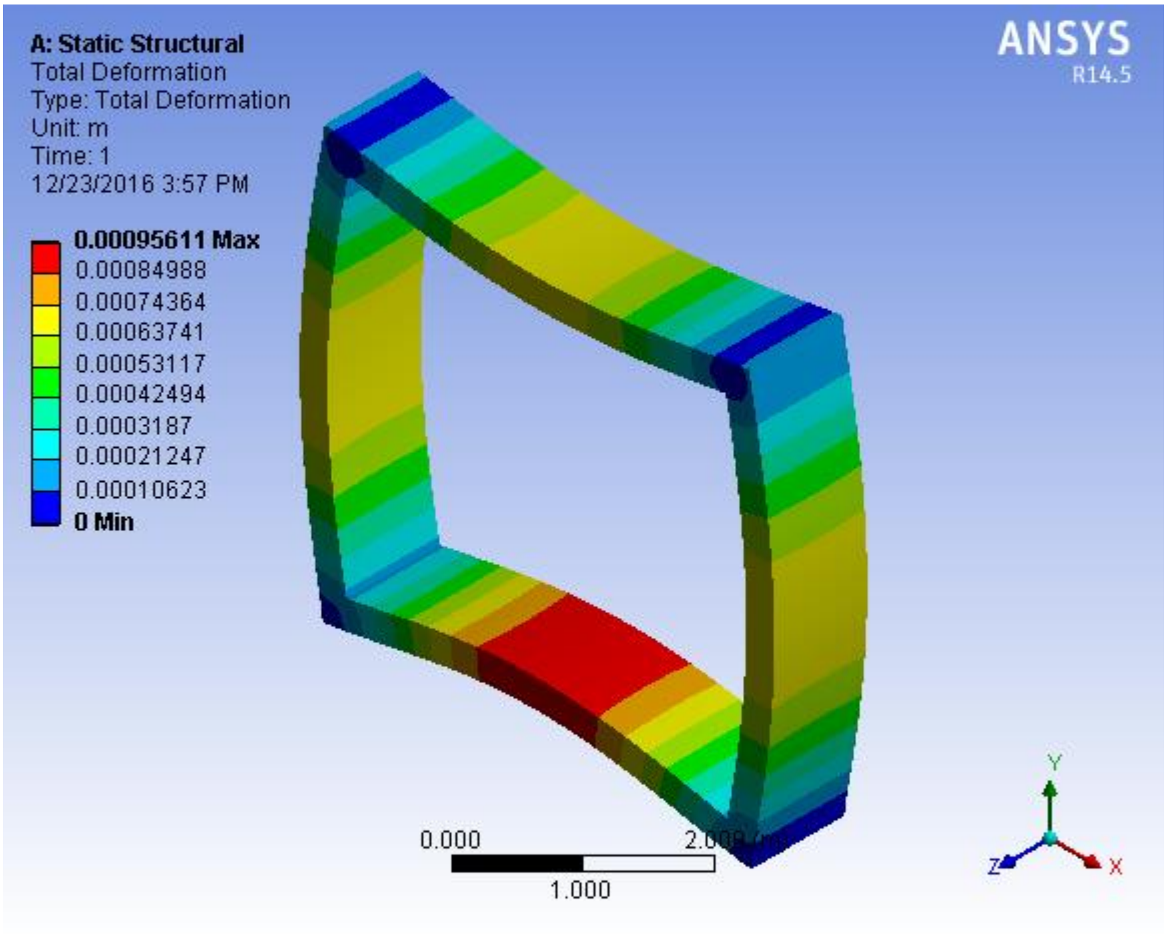

Fig. 3.40 Total Deformation

Fig. 3.40 shows deformation on box culvert after analysing the box culvert under applied loads in ANSYS. We observe that maximum deformation of 0.956 mm is at the middle of bottom slab.

3.4 Box Culvert with Haunches on ANSYS

Box Culvert of size 4m X 4m having thickness of 0.3m

Length (outer) of Slabs is 3.6m and Length (outer) of Haunches is 0.707m with thickness of 0.3m. Using M25 concrete and Fe 415 steel, unit weight of soil is 18 KN/m^3 with angle of repose 30^o (sand)

Loads applied on Box Culvert:

a) Given Loads:

Top Slab and Haunches with top slab carries Dead load of 2 KN/m and Live Load of 4 KN/m

Side Slabs, Bottom Slab and Haunches with Bottom Slab carries impact pressure of water 2.5 KN/m

b) Loads Calculated:

Self weight of Top/Bottom Slab and Haunches is 7.5 KN/m and of Side Slabs is 27 KN

Resulting Uplift pressure on Bottom Slab is 30 KN/m

Maximum pressure intensity of hydrostatic pressure by water flowing inside box culvert on inner side of Side Slabs is 36.5 KN/m and minimum pressure intensity is 3.5 KN/m

Maximum pressure intensity of linear varying load by soil on outside of Side Slabs is 24.6 KN/m and minimum pressure intensity is 3 KN/m

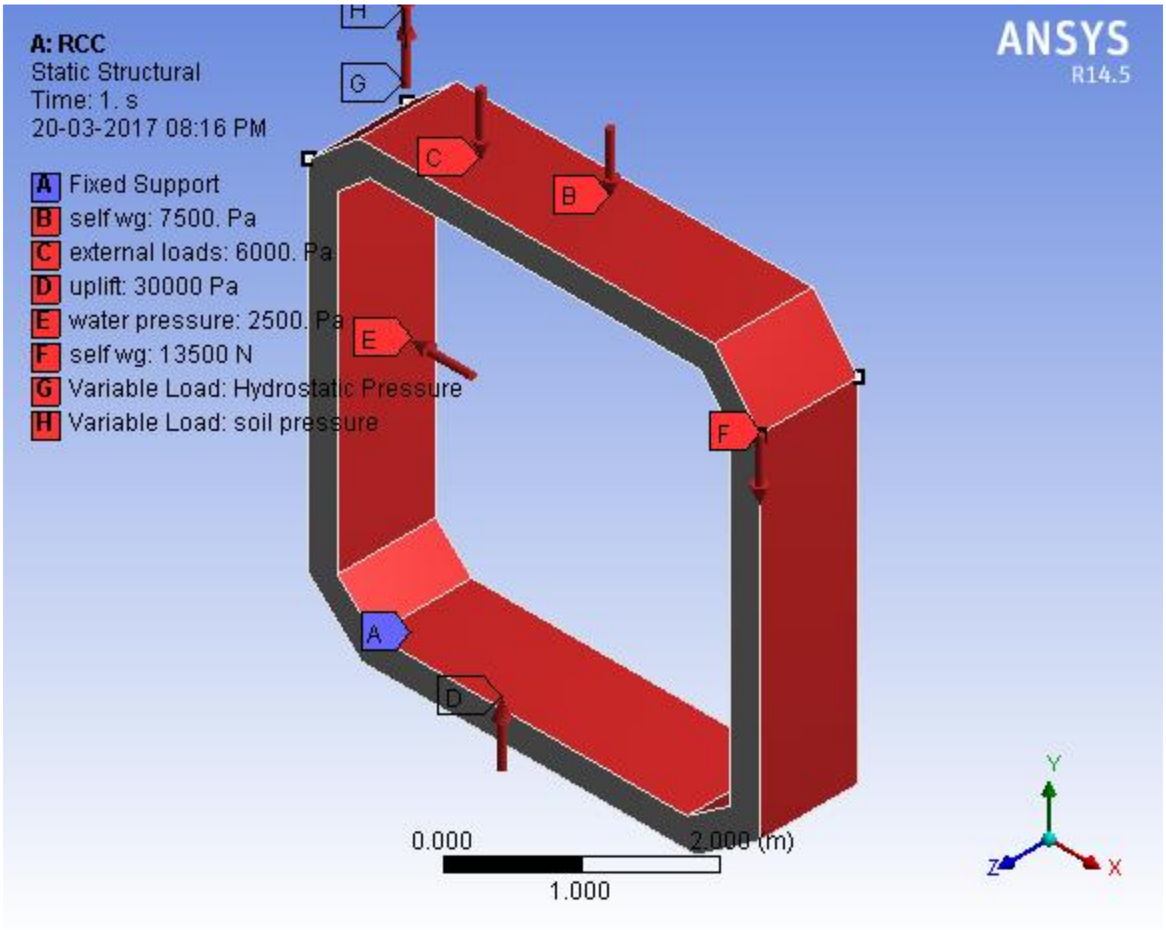

Fig. 3.41 Loads on Box Culvert

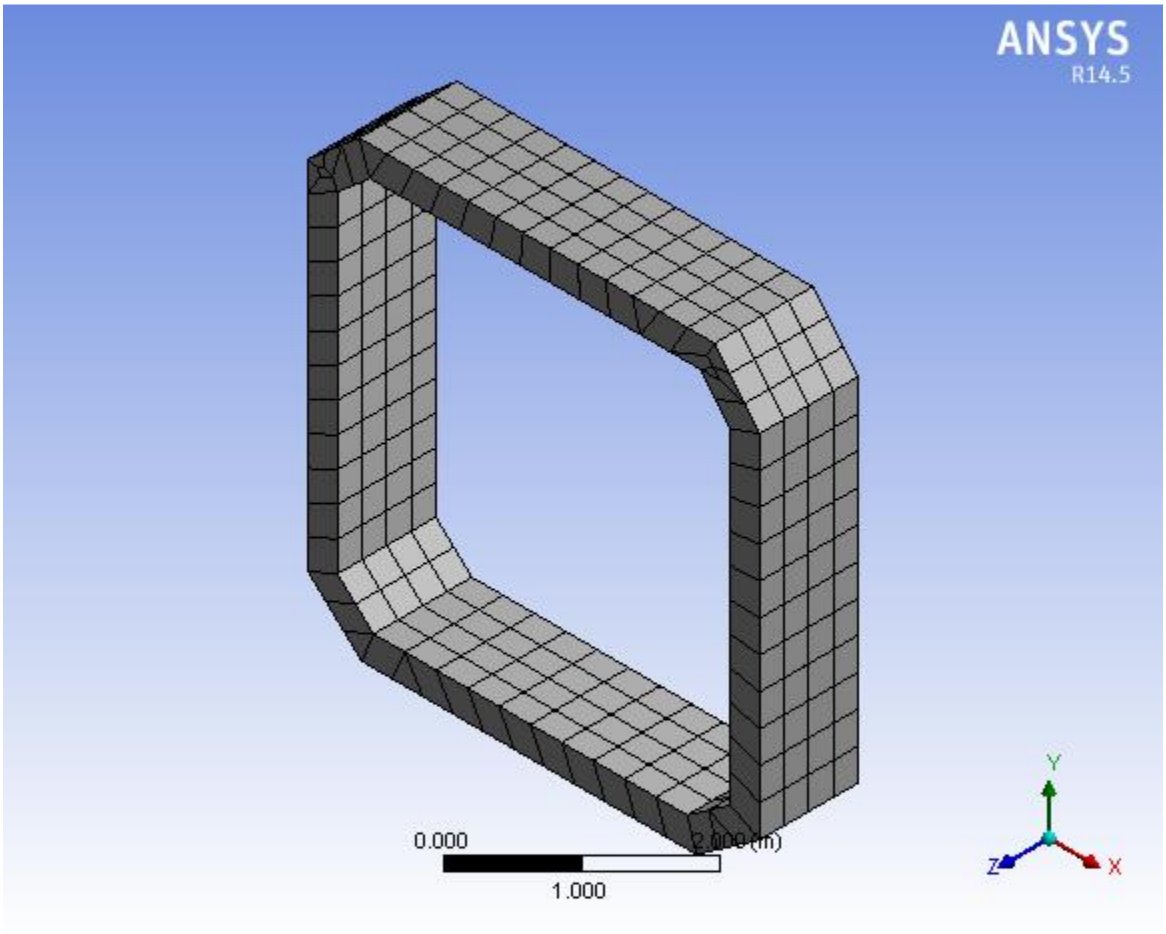

Fig. 3.42 Mesh Model

The concrete is modeled using Solid65 element. This element has eight nodes with three DOFs at each node – rotational in the nodal x, y, and z directions. This element can undergo plastic deformation, cracking in three orthogonal directions, and crushing. The cracking and crushing of concrete through this material model is decided bySolid65 element. A material model composed of two or more material definitions. Concrete material should have material definition and Elastic definition of concrete. In Elastic definition, the modulus of elasticity and Poisson’s ratio are necessary. The modulus of elasticity of concrete is decided by conventional methods and formulae..For Concrete definition, axial tension strength of concrete and shear transfer coefficients between crack surfaces for open and closed cracks are required. If transfer of shear from one crack surface to the other does not exist then the shear transfer coefficient is 0, if it fully exists then the coefficient is 1.0.

For the tension behaviour of concrete, ANSYS does not allow for the definition of an additional material model. However, if requested/required, an additional stress-strain

relationship for compressive behaviour of element can be defined through a hardening model such as Multilinear Isotropic Hardening. If this is the case, then modulus of elasticity must be same as the slope of the initial tangent of the defined stress-strain curve.

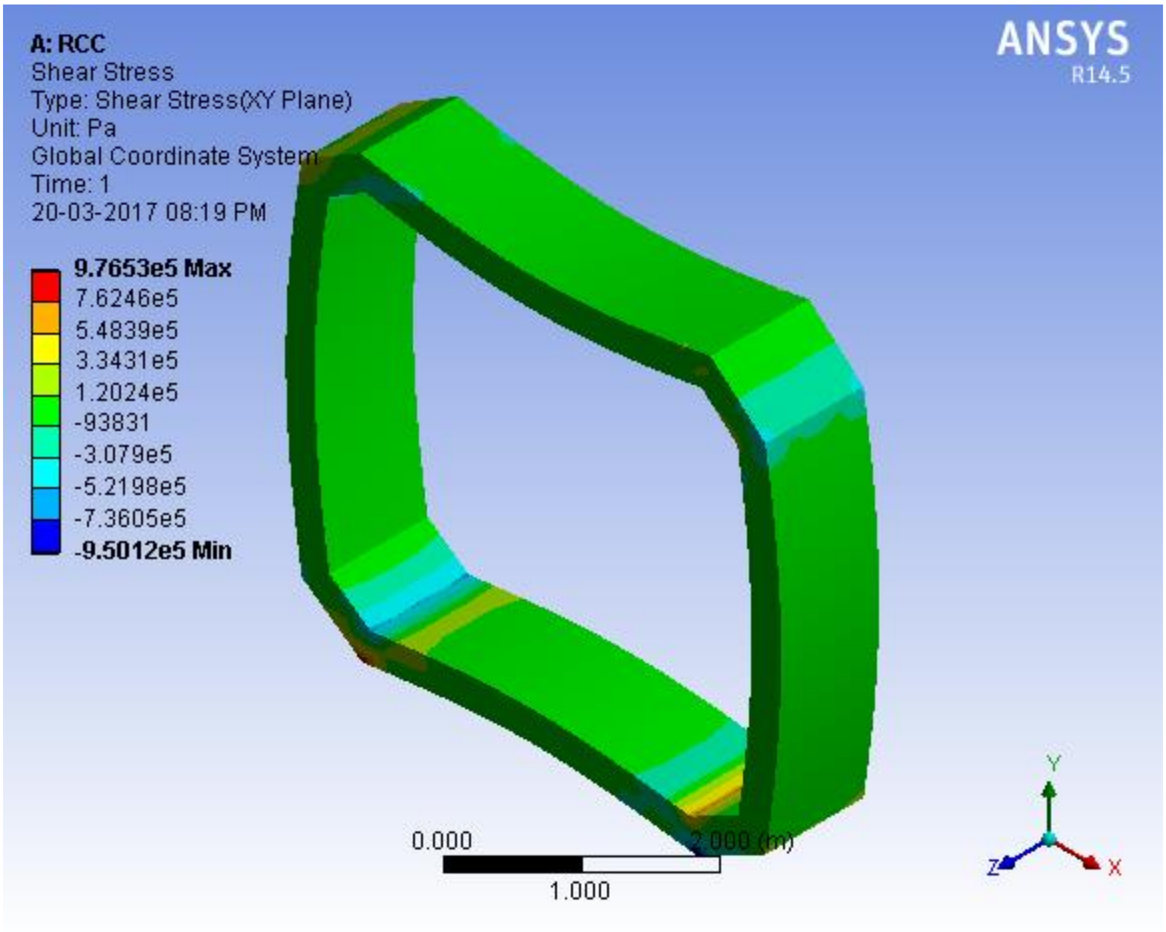

Fig. 3.43 Shear Stress (XY Plane)

Fig. 3.43 shows shear stress on box culvert after analysing the box culvert under applied loads in ANSYS. We observe that maximum shear stress of 0.976 N/mm^2 is acting at the fixed supports.

Therefore maximum bending moment,

M/I = σ /y which gives M = (σ/y)*I Where, σ = 0.976 N/mm^2, I = 22.5*10^8 mm^4 and y = 152mm

Bending moment, M = 14.45 kNm

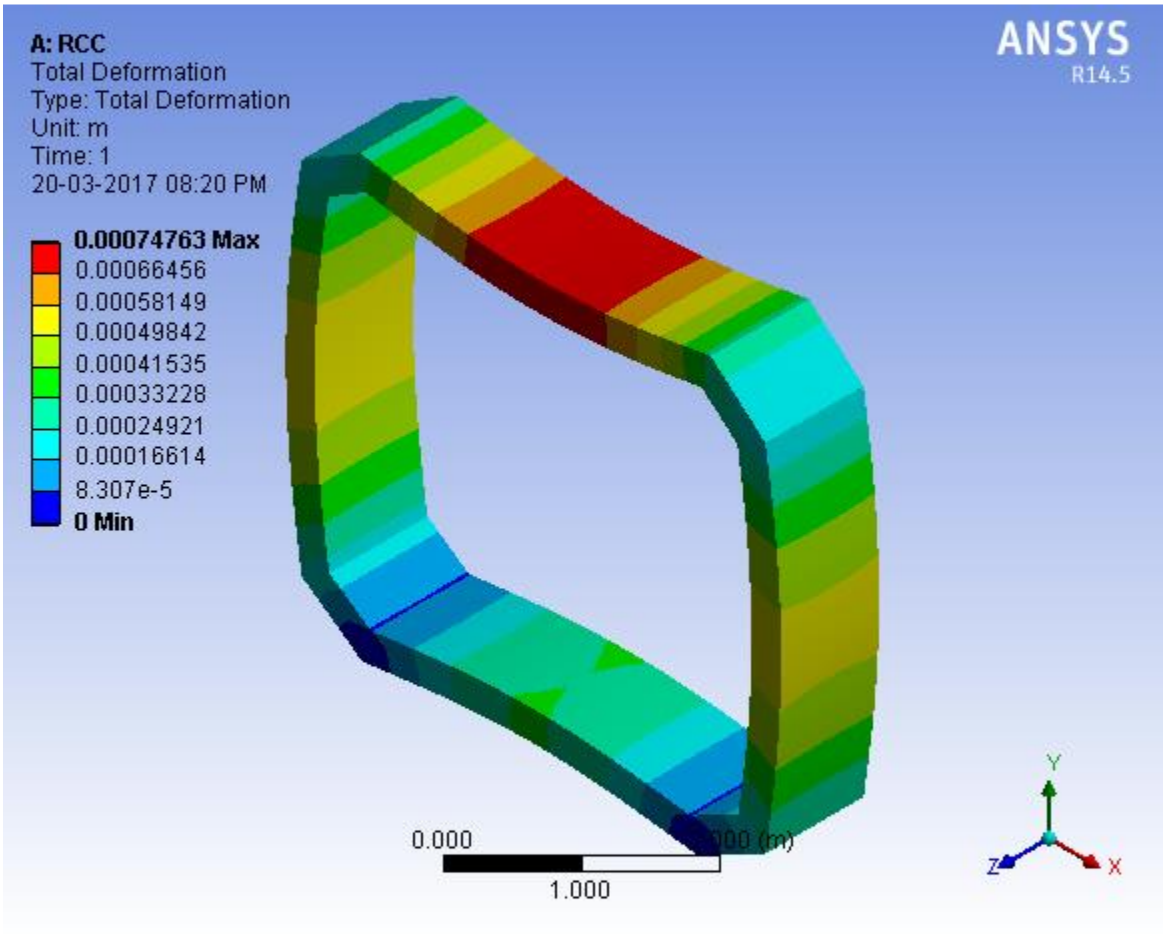

Fig. 3.44 Total Deformation

Fig. 3.44 shows deformation on box culvert after analysing the box culvert under applied loads in ANSYS. We observe that maximum deformation of 0.748 mm is at the middle of bottom slab.

CHAPTER – 4

RESULTS & DISCUSSION

4.1 STAAD Pro V8i

4.1.1 Box Culvert without Haunches

Table 4.1 Reactions of BC without Haunches on STAAD-Pro

Reactions	Top Slab	Bottom Slab	Side Slab
Max. Bending Moment (kN.m)	24.3	47.6	29.7
Max. Shear Stress (N/mm^2)	1.64	3.17	2.09

Max. Bending Moment 47.6 KN.m

Max. Shear Stress 3.17 N/mm^2

4.1.2 Box Culvert with Haunches

Table 4.2 Reactions of BC with Haunches on STAAD-Pro

Reactions	Top Slab	Bottom Slab	Side Slab
Max. Bending Moment (kN.m)	24.3	21.6	18.7
Max. Shear Stress (N/mm^2)	1.64	1.44	1.34

Max. Bending Moment 24.3 KN.m

Max. Shear Stress 1.64 N/mm^2

4.2 ANSYS 14.5

4.2.1 Box Culvert with and without Haunches

Table 4.3 Reactions of BC with and without Haunches on ANSYS

Reactions	BC without Haunches	BC with Haunches
Max. Bending Moment (kN.m)	15.41	14.45
Max. Shear Stress (N/mm^2)	1.027	0.976
Max. Deflection (mm)	0.956	0.748

4.3 Discussion

4.3.1 Comparison of Box Culvert with and without Haunches on STAAD-Pro

Table 4.4 Comparison of Reactions b/w BC with and without Haunches on STAAD-Pro

Reactions	BC without Haunches	BC with Haunches	% change
Max. Bending Moment (KN.m)	47.6	24.3	48.95
Max. Shear Stress (N/mm^2)	3.17	1.64	48.26

We observed that the value of Bending Moment and Shear Stress are significantly reduced in case of Box Culvert with Haunches compare to that of Box Culvert without Haunches as expected.

4.3.2 Comparison of Box Culvert with and without Haunches on ANSYS

Table 4.5 Comparison of Reactions b/w BC with and without Haunches on ANSYS

Reactions	BC without Haunches	BC with Haunches	% change
Max. Bending Moment (kN.m)	15.41	14.45	6.23
Max. Shear Stress (N/mm^2)	1.027	0.976	4.96
Max. Deflection (mm)	0.956	0.748	21.76

We observed that the value of Deflection, Bending Moment and Shear Stress are significantly reduced in case of Box Culvert with Haunches compare to that of Box Culvert without Haunches as expected.

4.3.3 Comparison of Box Culvert with Haunches on STAAD Pro and ANSYS

Table 4.6 Comparison of Reactions b/w BC with Haunches on STAAD-Pro and ANSYS

Reactions	BC on STAAD Pro	BC on ANSYS	% change
Max. Bending Moment (kN.m)	24.3	14.45	40.53
Max. Shear Stress (N/mm^2)	1.64	0.976	40.49

We observed that the values of Maximum Shear Stress and Bending Moment are significantly less in case of ANSYS to that in STAAD Pro as expected.

4.4 Reinforcement Estimation

4.4.1 Box Culvert without Haunches on STAAD-Pro

Maximum Bending Moment = 47.6 kNm

For M25 grade concrete and Fe415 steel, σ_{st} = 190 N/mm^2, σ_{cbc} = 8.5 N/mm^2

Neutral axis depth factor (k) = ($m\sigma_{cbc}$ / $m\sigma_{cbc}$ + σ_{st}) = 0.329

Lever arm factor (j) = 1-(k/3) = 0.89

Moment resisting factor (R) = 0.5 (σ_{cbc}×j×k) = 1.24

Depth of section = √M/(R×b) = 196 mm

Assume cover of 40 mm and maximum 20 mm diameter bars

Therefore thickness required = 196+40+(20/2) = 246 mm

Area of steel required for maximum bending moment = (M / σ_{st}×j×d) = 1144.27 N/mm^2

Distribution steel required = (0.12×b×d/100) = 235.2 mm^2

Total area of steel required per metre of Box Culvert = 2(235.2+1144.27) = 2758.94 mm^2

4.4.2 Box Culvert with Haunches on STAAD-Pro

Maximum Bending Moment = 24.3 kNm

For M25 grade concrete and Fe415 steel, σ_{st} = 190 N/mm^2, σ_{cbc} = 8.5 N/mm^2

Neutral axis depth factor (k) = ($m\sigma_{cbc}$ / $m\sigma_{cbc}$ + σ_{st}) = 0.329

Lever arm factor (j) = 1-(k/3) = 0.89

Moment resisting factor (R) = 0.5 (σ_{cbc}×j×k) = 1.24

Depth of section = √M/(R×b) = 140 mm

Assume cover of 40 mm and maximum 20 mm diameter bars

Therefore thickness required = 140+40+(20/2) = 190 mm

Area of steel required for maximum bending moment = (M / σ_{st}×j×d) = 756.33 N/mm^2

Distribution steel required = (0.12×b×d/100) = 228 mm^2

Total area of steel required per metre of Box Culvert = 2(228+756.33) = 1968.66 mm^2

4.4.3 Box Culvert without Haunches on ANSYS

Maximum Bending Moment = 15.41 kNm

For M25 grade concrete and Fe415 steel, σ_{st} = 190 N/mm^2, σ_{cbc} = 8.5 N/mm^2

Neutral axis depth factor (k) = (mσ_{cbc} / mσ_{cbc} + σ_{st}) = 0.329

Lever arm factor (j) = 1-(k/3) = 0.89

Moment resisting factor (R) = 0.5 (σ_{cbc}×j×k) = 1.24

Depth of section = √M/(R×b) = 112 mm

Assume cover of 40 mm and maximum 20 mm diameter bars

Therefore thickness required = 112+40+(20/2) = 162 mm

Area of steel required for maximum bending moment = (M / σ_{st}×j×d) = 562.53 N/mm^2

Distribution steel required = (0.12×b×d/100) = 194.4 mm^2

Total area of steel required per metre of Box Culvert = 2(194.4+562.53) = 1513.86 mm^2

4.4.4 Box Culvert with Haunches on ANSYS

Maximum Bending Moment = 14.45 kNm

For M25 grade concrete and Fe415 steel,

σ_{st} = 190 N/mm^2, σ_{cbc} = 8.5 N/mm^2

Neutral axis depth factor (k) = ($m\sigma_{cbc}$ / $m\sigma_{cbc}$ + σ_{st}) = 0.329

Lever arm factor (j) = 1-(k/3) = 0.89

Moment resisting factor (R) = 0.5 (σ_{cbc}×j×k) = 1.24

Depth of section = √M/(R×b) = 108 mm

Assume cover of 40 mm and maximum 20 mm diameter bars

Therefore thickness required = 108+40+(20/2) = 158 mm

Area of steel required for maximum bending moment = (M / σ_{st}×j×d) = 540.84 N/mm^2

Distribution steel required = (0.12×b×d/100) = 189.6 mm^2

Total area of steel required per metre of Box Culvert = 2(189.6+540.84) = 1460.88 mm^2

Table 4.7 Reinforcement and volume of concrete per metre of box culvert

Type of Box Culvert	Total Area of Reinforcement (mm^2)	Volume of Concrete per metre (m^3)
Without Haunches on STAAD-Pro	2758.94	0.243
With Haunches on STAAD-Pro	1968.66	0.188
Without Haunches on ANSYS	1513.86	0.160
With Haunches on ANSYS	1460.88	0.156

4.5 Cost Analysis

Unit weight of steel = 78.5 kN/m^3

Cost of Steel = Rs 5000/Quintal

Cost of concrete = Rs 5000/m^3

Quantity of Reinforcement per m of Box Culvert = (78.5×10×1×Total Area of Reinforcement)/10^6

Quantity of Concrete per m of Box Culvert = Volume of Concrete – (1× Total Area of Reinforcement)/10^6

Table 4.8 Total Cost per m of Box Culvert

Type of Box Culvert	Reinforcement per m of Box Culvert		Concrete per m of Box Culvert		Total Cost per m of Box Culvert (Rs)
	Quantity (Quintal)	Cost (Rs)	Quantity (m^3)	Cost (Rs)	
Without Haunches on STAAD-Pro	2.166	10830	0.243	1215	12045
With Haunches on STAAD-Pro	1.55	7750	0.188	940	8690
Without Haunches on ANSYS	1.188	5940	0.160	800	6740
With Haunches on ANSYS	1.147	5735	0.156	780	6515

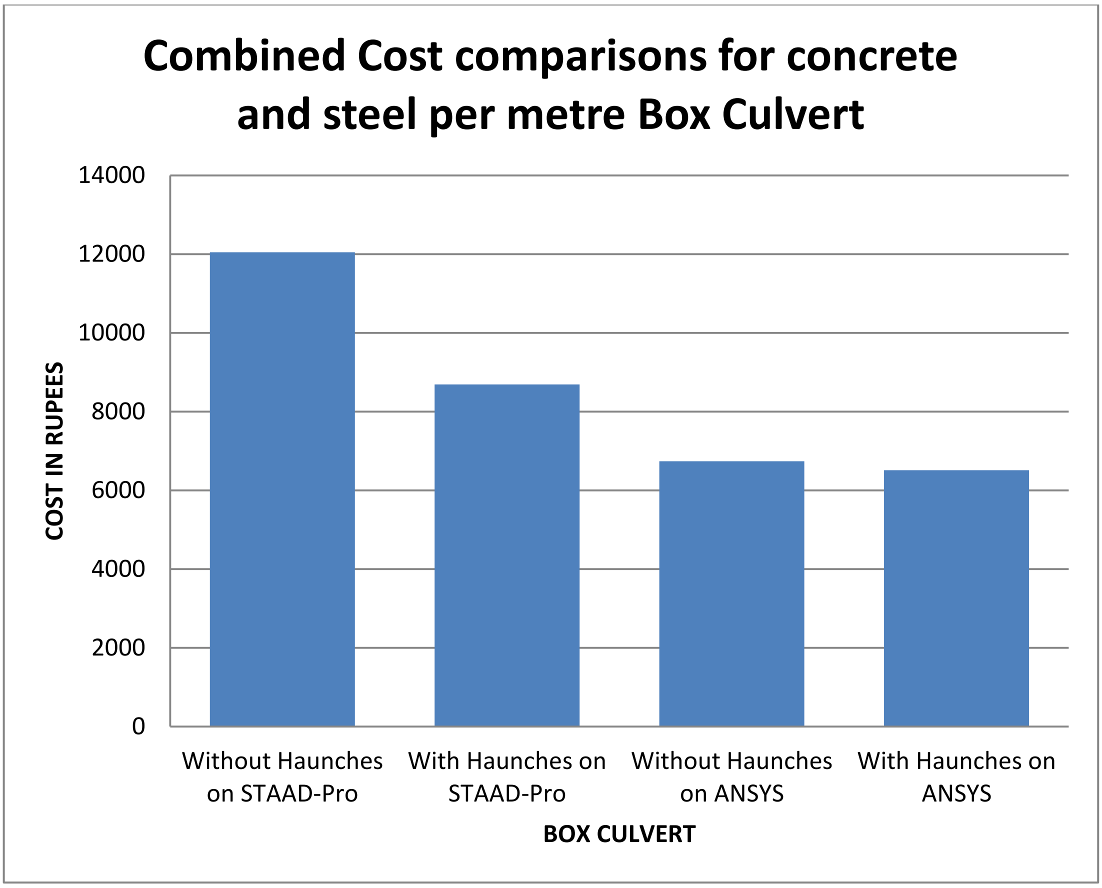

Fig. 4.1 Cost Comparison

From Table No. 4.8, it is found that volume of concrete required per metre of box culvert without haunches on STAAD-Pro is 0.243 m^3 which is reduced to 0.188 m^3 in case of box culvert with Haunches on STAAD-Pro.

It is observed that the volume of steel required per metre of box culvert without Haunches on STAAD-Pro is 2.166 quintal which is reduced to 1.55 quintal in case of box culvert with Haunches on STAAD-Pro. This results in reduction of cost per metre of box culvert from Rs.12,045 to Rs.8,690.

From Table No. 4.8, it is also found that volume of concrete required per metre of box culvert without haunches on ANSYS is 0.160 m^3 which is reduced to 0.156 m^3 in case of box culvert with Haunches on ANSYS.

It is also observed that the volume of steel required per metre of box culvert without Haunches on ANSYS is 1.188 quintal which is reduced to 1.147 quintal in case of box culvert with Haunches on ANSYS. Thus, resulting in reduction of cost per metre of box culvert from Rs.6,740 to Rs.6,515.

CHAPTER - 5

CONCLUSION

1. From the analysis of box culvert with and without haunches on STAAD-Pro, we observe that in case of box culvert without haunches we obtain maximum bending moment of 47.6 kNm whereas, in case box culvert with haunches we obtain maximum bending moment of 24.3 kNm. From these results it has been observed that there is 48.95% reduction in maximum bending moment in box culvert.

2. From the analysis of box culvert with and without haunches on STAAD-Pro, we observe that in case of box culvert without haunches we obtain maximum shear stress of 3.17 N/mm^2 whereas, in case box culvert with haunches we obtain maximum shear stress of 1.64 N/mm^2. From these results it has been observed that there is 48.26% reduction in maximum shear stress in box culvert.

3. From the analysis of box culvert with and without haunches on ANSYS, we observe that in case of box culvert without haunches we obtain maximum bending moment of 15.41 kNm whereas, in case box culvert with haunches we obtain maximum bending moment of 14.45 kNm. From these results it has been observed that there is 6.23% reduction in maximum bending moment in box culvert.

4. From the analysis of box culvert with and without haunches on STAAD-Pro, we observe that in case of box culvert without haunches we obtain maximum shear stress of 1.027 N/mm^2 whereas, in case box culvert with haunches we obtain maximum shear stress of 0.976 N/mm^2. From these results it has been observed that there is 4.96% reduction in maximum shear stress in box culvert.

5. From the analysis of box culvert with and without haunches on ANSYS, we observe that in case of box culvert without haunches we obtain maximum deflection of 0.956 mm whereas, in case box culvert with haunches we obtain maximum deflection of 0.748 mm. From these results it has been observed that there is 21.76% reduction in maximum deflection in box culvert.

6. While comparing box culvert with haunches on STAAD-Pro and ANSYS we observe 40.53% reduction of maximum bending moment and 40.49% reduction of maximum shear stress on ANSYS.

7. From Table No. 4.8, it is found that volume of concrete required per metre of box culvert without haunches on STAAD-Pro is 0.243 m^3 which is reduced to 0.188 m^3 in case of box culvert with Haunches on STAAD-Pro. It is observed that the volume of steel required per metre of box culvert without Haunches on STAAD-Pro is 2.166 quintal which is reduced to 1.55 quintal in case of box culvert with Haunches on STAAD-Pro. This results in reduction of cost per metre of box culvert from Rs.12,045 to Rs.8,690.

8. From Table No. 4.8, it is also found that volume of concrete required per metre of box culvert without haunches on ANSYS is 0.160 m^3 which is reduced to 0.156 m^3 in case of box culvert with Haunches on ANSYS. It is also observed that the volume of steel required per metre of box culvert without Haunches on ANSYS is 1.188 quintal which is reduced to 1.147 quintal in case of box culvert with Haunches on ANSYS. Thus, resulting in reduction of cost per metre of box culvert from Rs.6,740 to Rs.6,515.

From above conclusions, we found that after providing haunches to the box culvert we obtain more economical and much safer design of box culvert.

References

[1] A. D. Patil et al (2016) "Analysis of Box Culvert under Cushion Loading", *International Advanced Research Journal in Science, Engineering and Technology* Vol. 3, Issue 6, ISSN 2393-8021

[2] M.S. Sulke et al (2016) "Comparison between Design of RCC Box Culvert by Analytically and STAAD- Pro", *International Journal on Recent and Innovation Trends in Computing and Communication*, Volume: 4 Issue: 4 ISSN: 2321-8169, page no. 280 - 282

[3] N. Chijiwa et al (2015) "Delayed Shear Crack Formation of Shallow RC Box Culverts in Service", *Published by the American Society of Civil Engineers*, page no. 1579 - 1586

[4] Ketan Kishor Sahu et al (2015) "Comparison and Study of Different Aspect Ratio of Box Culvert", *International Journal for Scientific Research and Development*, Vol. 3, Issue 07, ISSN: 2321-0613

[5] Sujata Shreedhar et al (2013) "Design coefficients for Single and Two cell box culvert", *International Journal of Civil and Structural Engineering*, Volume 3, No 3, ISSN: 0976 – 4399

[6] Jan Vaslestad et al (2011) "Load reduction & arching on buried rigid culverts using EPS Geofoam, Design method & instrumented field tests", *NPRA – Norwegian Public Roads Administration*

[7] S.K. Woo et al (2010) "Failure behaviour characteristics of box Culvert using 3-axes loading system", Fracture Mechanics of Concrete and Concrete Structure – High Performance, Fibre Reinforced Concrete, Special Loading and Structural Applications- B.H. Oh, et al. (eds) *Korea Concrete Institute*, ISBN 978-89-5708-182-2

[8] D.S. Cheema et al (2009) "Durability of Geopolymer Concrete Box Culverts- A Green Alternative", *34th Conference on OUR WORLD IN CONCRETE & STRUCTURES*: 16-18 August, Singapore Article Online id : 100034010

[9] G.J. Fairless et al (2008) "Earthquake Performance of Long-span Arch Culverts", *NZ Transport Agency Research* Report 366 ISSN: 1173-3756

[10] Travis Malone et al (2008) "Bend Losses in Rectangular Culverts", K-TRAN: KU-05-5, *The Kansas Department of Transportation Topeka*, Kansas, September 2008

[11] ANIL KUMAR GARG (2007) “Experimental and Finite Element based investigation of Shear behaviour in RC Box Culvert”, *The University of Texas* at Arlington, May 2007

[12] W. H. Pearson et al (2003) “Research on the Upstream Passage of Juvenile Salmon through Culverts: Retrofit Baffles”, *Battelle Memorial Institute Pacific Northwest Division Richland*, Washington 99352, PNWD-3672

[13] STAAD Pro V8i is structural analysis and design computer program. Originally developed by Research Engineers International at Yoba Linda, CA in 1997. In late 2005, Research Engineers International was bought by Bentley systems.

[14] ANSYS Inc. is an American Computer Aided Engineering software developer headquartered South Pittsburgh in Cecil Township, Pennsylvania.

[15] IS SP 013 “Guidelines for the Design of Small Bridges and Culverts” special publication no 13, pp. 175