

Analysis and Design of Box Culvert

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Abstract

Box Culverts are required to be provided under earth embankment for crossing of water course like streams, Nallas across the embankment as road embankment cannot be allowed to obstruct the natural water way. The culverts are also required to balance the flood water on both sides of earth embankment to reduce flood level on one side of road thereby decreasing the water head consequently reducing the flood menace. Culverts can be of different shapes such as arch, slab and box. These can be constructed with different material such as masonry (brick, stone etc) or reinforced cement concrete. Since culvert pass through the earthen embankment, these are subjected to same traffic loads as the road carries and therefore, required to be designed for such loads. The size, invert level, layout etc. are decided by hydraulic considerations and site conditions. The cushion depends on road profile at the culvert location. The structural design involves consideration of load cases (box empty, full, surcharge loads etc.) and factors like live load, effective width, braking force, dispersal of load through fill, impact factor, co-efficient of earth pressure etc. Relevant IRC Codes are required to be referred in the analysis and design of box culverts. The aim of this project is to model and analyse the box culvert using STAAD PRO software. This software is an effective and user friendly tool for three dimensional model generation, analysis and multi material design. The results obtained from STAAD PRO are compared with the manual calculations obtained using MATLAB. The structural elements of box culvert are designed to withstand maximum bending moment and shear force. The results obtained from STAAD are almost similar to manual calculations.

Keywords: Staad pro, Mat lab, Excel Sheet

I. INTRODUCTION

A. Introduction

Box culvert has many advantages compared to slab culvert or arch culvert. The box is structurally strong, stable and safe and easy to construct. The main advantage is, it can be placed at any elevation within the embankment with varying cushion which is not possible for other type of culverts. A multi cell box can cater for large discharge and can be accommodated within smaller height of embankment. It does not require separate elaborate foundation and can be placed on soft soil by providing suitable base slab projection to reduce base pressure within the safe bearing capacity of foundation soil. Bearings are not needed. It is convenient to extend the existing culvert in the event of widening of the carriageway at a later date as per future requirement, without any problem of design and/or construction.

The culvert cover up to waterways of 6 m (IRC: 5-1981) and can mainly be of two types, namely, box or slab. The box is one which has its top and bottom slabs monolithically connected to the vertical walls. In case of a slab culvert the top slab is supported over the vertical walls (abutments/ piers) but has no monolithic connection between them. A box culvert can have more than single cell and can be placed such that the top slab is almost at road level and there is no cushion.

B. Types of Box Culvert

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.

Types of Culverts

- Slab Culverts
- Pipe Culverts
- Box Culverts

1) 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.

2) Advantages of Box Culverts:

- Prevent Erosion
- Prevent Flooding
- Allow Water to Flow Unobstructed
- Divert Water for Farming/Engineering Purposes

C. Objective of the Project

The aim of this study is to achieve the following goals: -

- 1) To model and analyze box culvert using STAAD PRO software.
- 2) To assess and compare the results of STAAD PRO and manual calculations.
- 3) To design elements of the box culvert as per IS specifications.

D. Necessity of the Project

Over the years ago engineers solving problems by using numerical methods. Due to development took place in structures and materials problems become more complex. They can't solve those structures by using numerical methods. So they are going to solve those methods by using computational methods using Software. Hence in the present study an analysis has been carried out by using STAAD Pro and the results obtained are compared that of manual calculations obtained using EXCEL and Mat Lab coding. Also box culvert is designed for three conditions to study stresses in terms of bending moment and shear.

- 1) No water flowing in the drain. The box culvert will be dry from inside, and sidewalls will be subjected to earth pressure from outside.
- 2) Water in box, will be subjected to earth pressure from outside and water pressure from inside.
- 3) Live load and dead load on top and water pressure from inside no live load on the sides.

E. Applications of Box Culvert

These are the following applications of the box culvert.

1) Box Culverts in Road and Highway Construction:

Box culverts are prevalent features in road and highway construction. In order to withstand traffic loads and aggressive weather conditions, these culverts must be tough—that's why we recommend building yours out of concrete. These box culverts allow water to flow under roads and highways without impeding the flow of traffic.

2) Box Culverts in Utility Work:

Utility work also utilizes box culverts. These culverts serve as utility tunnels that carry electricity, water and sewer lines. Sometimes, they also carry communication lines, such as telephone and cable television. Utility tunnels are ideal for cold climates where it's difficult to bury lines below the frost level. They can also be found in areas where the water table is too high to bury water and sewer mains, or in areas like Tokyo where utility poles are likely to succumb to earthquakes or storms.

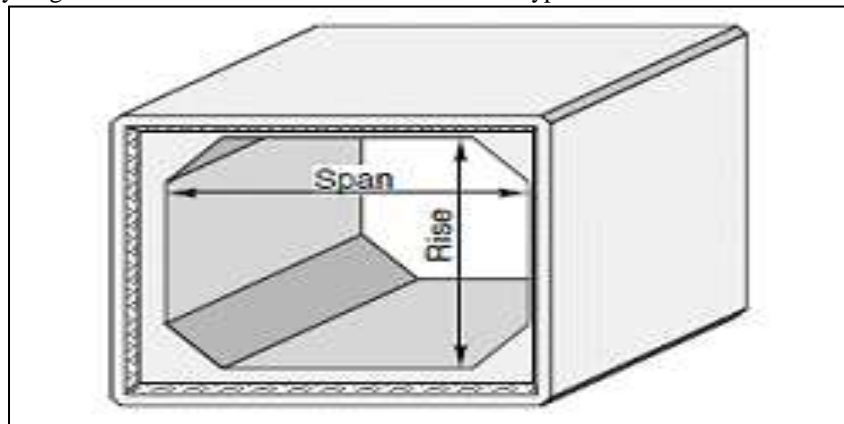
3) Box Culverts in Railroads:

Railroad construction and maintenance relies on the use of box culverts. They can replace small bridges or create crossings over creeks or other waterways. Under track culverts are vital to the success of modern railroads.

F. Various Types of Box Culvert

1) Box Culverts

Where pipe solutions are inappropriate, box culverts are the default buried structure type. Their larger openings are often required to provide adequate hydraulic capacity. Box culverts are also frequently used for pedestrian or cattle underpasses. The reinforcement used in concrete box culverts can be either conventional bar reinforcement or welded wire fabric. Welded wire fabric has yield strength slightly larger than conventional bar reinforcement. A typical box culvert is shown in Fig



2) Precast Concrete Box Culverts

Standard designs for precast concrete box culverts are available with spans varying from 2 to 5 m and rises varying from 1.5 to 4 m. Standard precast concrete box culverts are typically fabricated in 2 m sections; however larger boxes are fabricated in 1.5 m sections to reduce section weight. The designs utilize concrete strengths are suitable for fill heights ranging from less than 0.6 m to a maximum of 7.5 m. Box culverts outside of the standard size ranges must be custom designed.

Each culvert size has three or four classes. Each class has specified wall and slab thicknesses, reinforcement areas, concrete strength, and fill height range to which it applies.

To prevent corrosion at the ends of welded wire fabric, nylon boots are required on the ends of every fourth longitudinal wire at the bottom of the form. A maximum of two layers of welded wire fabric can be used for primary reinforcement. If two layers are used, the layers may not be nested. A typical section of precast box culvert is shown in Fig



3) Cast-In-Place Concrete Box Culverts

The first box culverts constructed in Minnesota were made of cast-in-place concrete. The performance of these structures over the years has been very good. Currently, most box culvert installations are precast due to the reduced time required for plan production and construction. Cast-inplace culverts continue to be an allowable option. A model of Cast in place concrete box culvert is shown in Fig.



4) Buried Structures

Buried structures serve a variety of purposes. They are typically used for conveying water. At other times they are used to provide a grade separated crossing for pedestrian and bicycle traffic. A variety of structure and material types are used. The most prevalent types are pipes and box culverts. Buried structures with horizontal dimensions less than 3 m are not classified as bridges. Typically these smaller buried structures do not require extensive design and are selected from standard design tables. Buried structures with horizontal dimensions greater than or equal to 3 m are considered bridges. In addition to pipes and box culverts, precast concrete arches, precast three-sided structures, and long-span corrugated steel structures are used as buried structures. A model of buried structure is shown in Fig



II. DESIGN CONSIDERATIONS AND METHODOLOGY

RCC box culverts comprising of top slab, base slab and stem are cast monolithically to carry live load, embankment load, water pressure and lateral earth pressure in a better way. 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. The required height and number of boxes depends on hydraulic and other requirements at the site such as road level, nalla bed level, scour depth etc. The barrel of the box culvert should be of sufficient length to accommodate the carriageway and the kerbs.

A. Design Considerations

1) Loads:

The loads considered for the analysis of box culverts are Dead load, Live load, Soil pressure on side walls, Surcharge due to live load, and Water pressure from inside.

2) Uniform Distributed Load:

The weight of embankment, deck slab and the track load are considered to be uniformly distributed loads on the top slab with the uniform soil reaction on the bottom slab. For live load distribution, the width of dispersion perpendicular to the span is computed first. Width of dispersion parallel to the span is also calculated. Then the maximum magnitude of load is divided by width of dispersion parallel to span and width of dispersion perpendicular to the span to get the load intensity on the top slab.

3) Live Load:

For calculation of load dispersion along the traffic direction as per clause 305.16.3, IRC 21-2000, the effect of contact of the wheel or track load in the direction of span length shall be taken as equal to the dimension of the tyres contact area over the wearing surface of the slab in the direction of span.

$$\text{The effective width} = b_{\text{eff}} = kx(1-x/l_0) + b_w$$

If the effective width is greater than the distance between wheel and tracks of the vehicle, overlapping of load dispersion occurs and not effective width is considered by taking the load dispersion due to both wheels without overlapping and for calculation of loads for both wheels and tracked vehicle.

4) Tire Contact Area:

The tire contact area of a wheel consisting of one or two tires is assumed to be a single rectangle, whose width is 850 mm and whose length is 290 mm. The tire pressure is assumed to be uniformly distributed over the rectangular contact area on continuous surfaces.

All overabundance soil and other material from the exhuming including logs, stones and so forth would be expelled from the site and arranged to the areas affirmed by the architect.

The most important step in the fixation of water way of a cross drainage structure is to determine the design flood discharge. An accurate determination of the discharge will-

- Govern the safety of the structure.
- Influence the selection of design of foundation, water way and protective works.
- Affect the cost of structure.

5) 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.

6) Water pressure inside culvert

The pressure distribution on side walls is assumed to be triangular with a maximum pressure intensity of $p=wh$ at the base, where w is the density of water and h is the depth of flow. Designers need to consider two loading conditions:

- 1) The culvert is full of water, and
- 2) The culvert is empty.

7) Earth pressure on vertical side walls

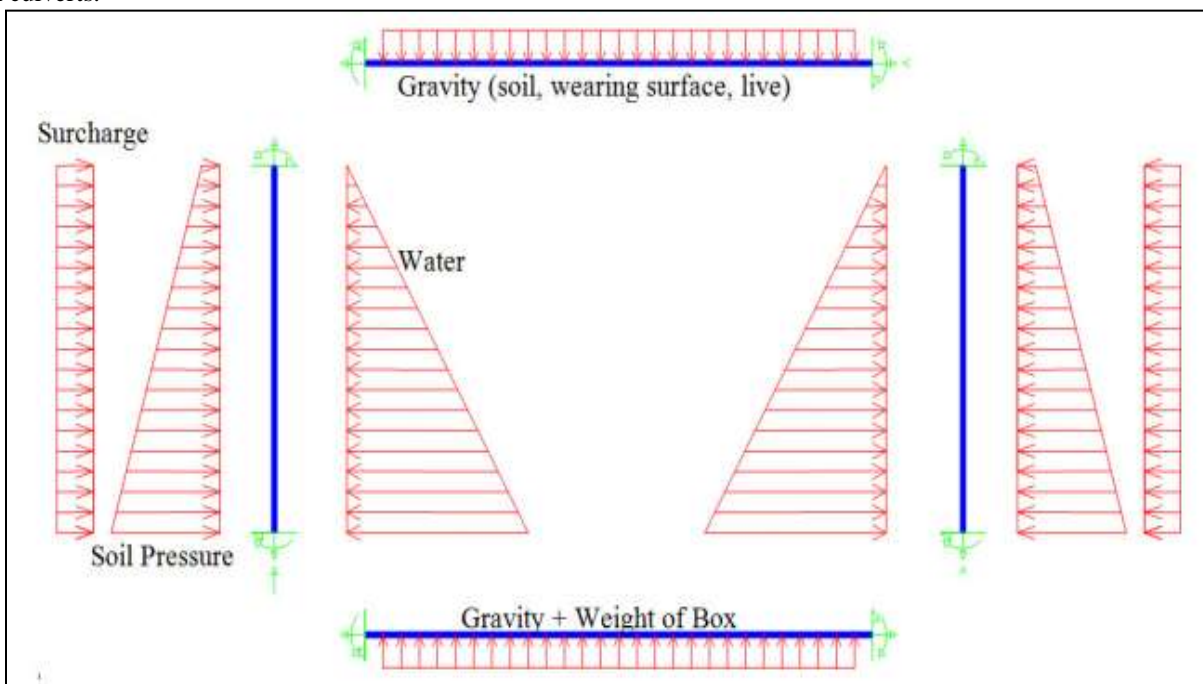
The earth pressure on the vertical side walls of the box culvert is computed according to the Coloumb's theory. The earth pressure intensity on the side walls is given by $p=K_a \delta H$, where K_a is coefficient of active earth pressure, δ is the density of soil and H is he vertical height of box.

8) Uniform lateral load on side walls

Uniform lateral pressure on vertical side walls is considered due to the sum of effect of embankment loading and live load surcharge. Also the uniform lateral pressure on vertical side walls is considered due to embankment loading alone.

9) Design moments, shears and thrusts

The box culvert is analysed for moments, shear forces and axial thrusts developed at the critical sections due to the various loading conditions by moment distribution method. The critical sections considered are at the centre of top slab, bottom slab and vertical slab and at the corners of top slab, bottom slab and vertical wall. The moments, shear forces and axial thrusts at the critical sections for different loading cases are computed for different ratios of $L/H = 1.0$, $L/H = 1.25$ and $L/H = 1.5$ for single cell box culverts.



III. RESULTS AND DISCUSSION

The results are presented in the form of tables and graphs for the box culvert analysed for moments, shear forces, axial thrusts and stresses developed at the critical sections due to the various loading conditions. The critical sections considered are at the centre of top slab, bottom slab and vertical slab and at the corners of top slab, bottom slab and vertical wall. The design coefficients for moments, shear forces and axial thrusts at the critical sections for different loading cases are computed for different ratios of $L/H = 1.0$, $L/H = 1.25$ and $L/H = 1.5$ for single cell box culvert.

In this section the results are presented for the box culvert analysed using STAAD PRO and manual calculations by MAT LAB and Excel programs for different span to height ratios of box culvert.

The values of moments, shears, and thrusts obtained at the critical sections for various loading conditions are presented in Tables ---- and graphs (Figs. ----). The variation of bending moment, shear forces and thrusts for various ratios of box culvert can be observed from the graphs plotted for various loading cases..

The various loading cases are as given below:

- 1) Live load, dead load and earth pressure acting, with no water pressure from inside.
- 2) Live load, dead load and earth pressure acting from outside and water pressure acting from inside.
- 3) Dead load and earth pressure acting from outside and water pressure acting from inside.

The critical sections considered for analysis of the box culvert are as shown in Fig.5.1.

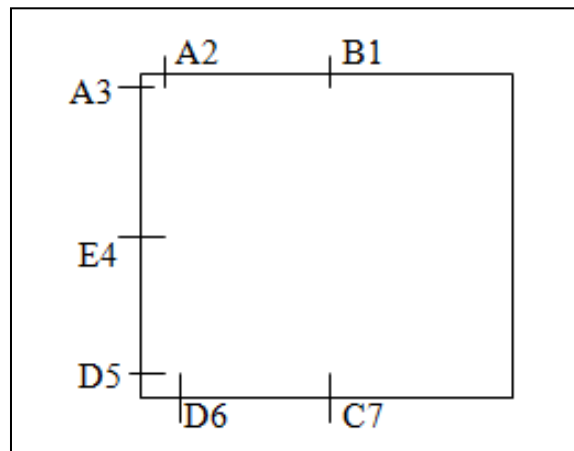


Fig. 7.0: Critical Sections for box culvert

For the above three loading cases, variation of the maximum bending moment, shear force, axial force and stresses are observed. The results obtained from both manual and Staad Pro are presented below.

A. Box Culvert L/H 1:1

The bending moment is the most important for the design of box culverts. The values of bending moment, shear force, axial force and stresses obtained from manual calculations are presented in Tables 6.1 to 6.5.

Table - 6.1

Values of Bending Moment (Manual) on the ends of components of box culvert for L/H ratio 1:1

CASE	TOP SLAB	BOTTOM SLAB	SIDE WALLS
1	40233	40233	51341
2	33631	43271	43271
3	26825	36466	36466

Table - 6.2

Values of Bending Moment (Manual) on the centre of components of box culvert for L/H ratio 1:1

CASE	TOP SLAB	BOTTOM SLAB	SIDE WALLS
1	47568	56878	6447
2	54170	64948	21122
3	60976	71753	34736

Table - 6.3

Values of the maximum bending moments for the members of box culvert with 1:1 manual.

DESIGN	B.M AT CENTRE	B.M AT ENDS
TOP SLAB	60976	40233
BOTTOM SLAB	71753	40233
SIDE WALLS	34736	51341

Table - 6.4

Values of Shear Force (Manual) at ends of components of box culvert for L/H ratio of 1:1

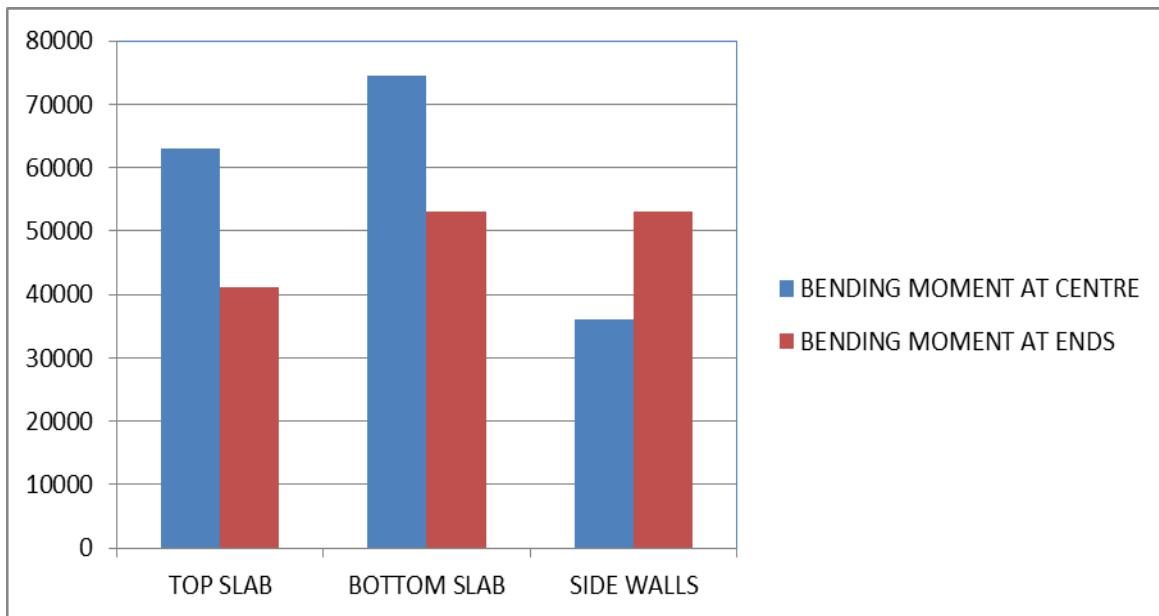
CASE	TOP SLAB	BOTTOM SLAB	SIDE WALLS
1	38874	56496	131175
2	21532	20477	131175
3	3219	4272	131175

Table - 6.5

Values of the maximum shear force for L/H ratio of 1:1

Item	S.F. AT ENDS
TOP SLAB	38874
BOTTOM SLAB	56496
SIDE WALLS	131175

The bending moment variation for top and bottom members of single cell for the aspect ratio 1:1 is shown in Fig.



The values of bending moment, shear force, axial force, deflection and stresses obtained from STAAD PRO are presented in Tables 6.6 to 6.10.

Table - 6.6
Values of Bending Moment (STAAD) at ENDS for L/H ratio of 1:1

CASE	TOP SLAB	BOTTOM SLAB	SIDE WALLS
1	40870	-52270	-52270
2	34237	-44672	-44672
3	27401	37151	37151

Table - 6.7
Values of Bending Moment (STAAD) at Centre of components of the box culvert for L/H ratio of 1:1

CASE	TOP SLAB	BOTTOM SLAB	SIDE WALLS
1	48.535	57.926	6.751
2	-55167	66.124	-21.615
3	62004	73045	35403

Table - 6.8
Values of the critical bending moment (Staad) for the members of box culvert for L/H ratio of 1:1

DESIGN	B.M AT CENTRE	B.M AT ENDS
TOP SLAB	62004	40870
BOTTOM SLAB	73045	52270
SIDE WALLS	35403	52270

Table - 6.9
Values of Shear Force (STAAD) for the members of box culvert for L/H ratio of 1:1

CASE	TOP SLAB	BOTTOM SLAB	SIDE WALLS
1	39062	56856	132368
2	21639	-20625	132368
3	-3236	4301	132368

Table - 6.10
Values of maximum shear force (Staad Pro) for L/H ratio of 1:1

DESIGN	S.F. AT ENDS
TOP SLAB	39062
BOTTOM SLAB	56856
SIDE WALLS	132368

Table - 6.11
Comparison of values of Bending Moments of STAAD and Manual methods at ends of box culvert for L/H ratio 1:1

LOAD CASES	BENDING MOMENT (kN-m) for the length and depth ratio 1:1(ENDS)					
	TOP SLAB		BOTTOM SLAB		SIDE WALLS	
	MANUAL	STAAD	MANUAL	STAAD	MANUAL	STAAD
1	40233	40870	51341	-52270	51341	-52270
2	33631	34237	43271	-44672	43271	-44672
3	26825	27401	36466	37151	36466	37151

Table - 6.11

Comparison of values of Bending Moments of STAAD and Manual methods at centre of box culvert for L/H ratio 1:1

LOAD CASES	BENDING MOMENT (kN-m) for the length and depth ratio 1:1(CENTRE)					
	TOP SLAB		BOTTOM SLAB		SIDE WALLS	
	MANUAL	STAAD	MANUAL	STAAD	MANUAL	STAAD
1	47568	48535	56878	57926	6447	-6751
2	54170	55167	64948	66124	21122	-21615
3	60976	62004	71753	73045	34736	35403

Table - 6.12

Comparison Of values of Shear Force of STAAD and Manual method for L/H ratio 1:1

LOAD CASES	SHEAR FORCE (kN) the length and depth ratio			
	TOP SLAB		BOTTOM SLAB	
	MANUAL	STAAD	MANUAL	STAAD
1	38874	39062	56496	56856
2	21532	21639	20477	-20625
3	3219	-3236	4272	4301

Following Figs. show the variation of maximum bending moment, shear force, deflection, stress variation and axial force on all components of the box culvert for L/H ratio of 1:1 for various loading cases using STAAD PRO.

1) Case-1: Live Load, Dead Load and Earth Pressure Acting, With No Water Pressure From Inside:

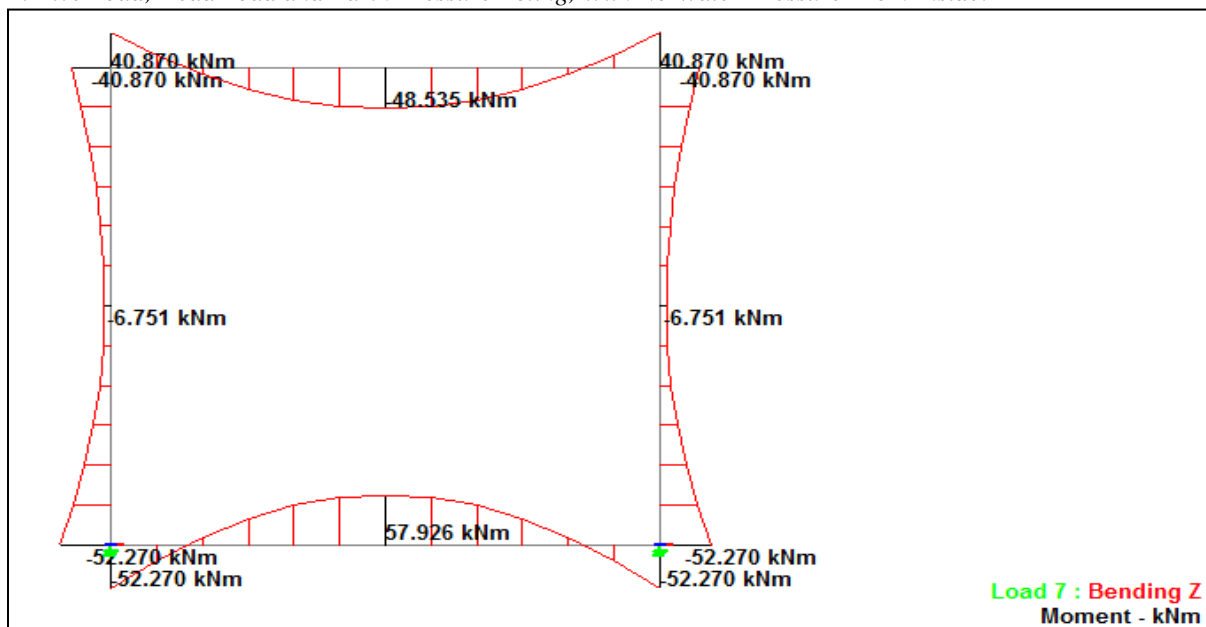


Fig. 6.1: Variation of bending moment across the section of box culvert for L/H ratio 1:1

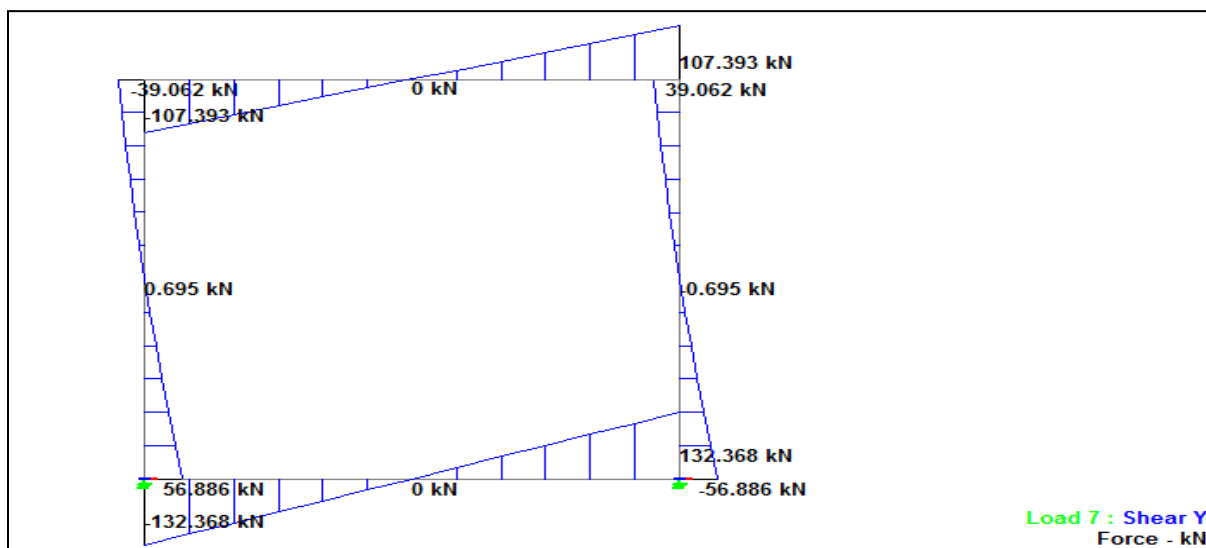


Fig. 6.2: Variation of shear force across the section of box culvert for L/H ratio 1:1 Stresses

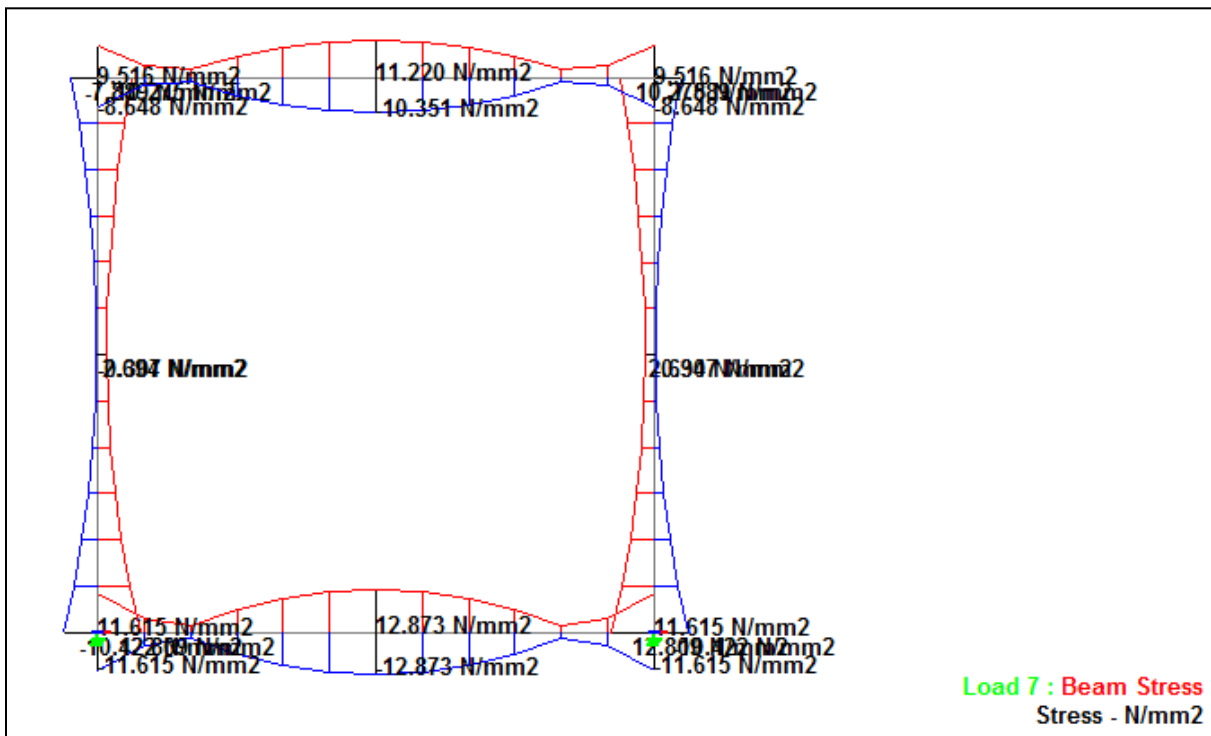


Fig. 6.3: Variation of stress across the section of box culvert for L/H ratio 1:1

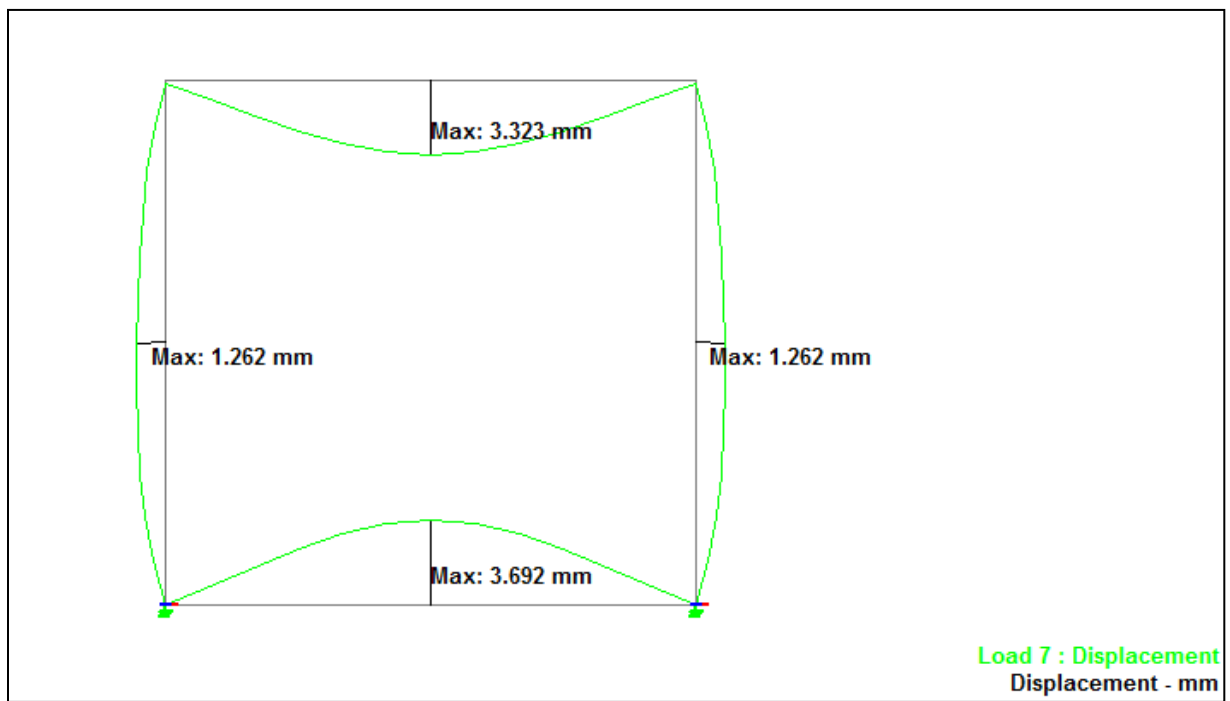


Fig. 6.4: Variation of deflection across the section of box culvert for L/H ratio 1:1

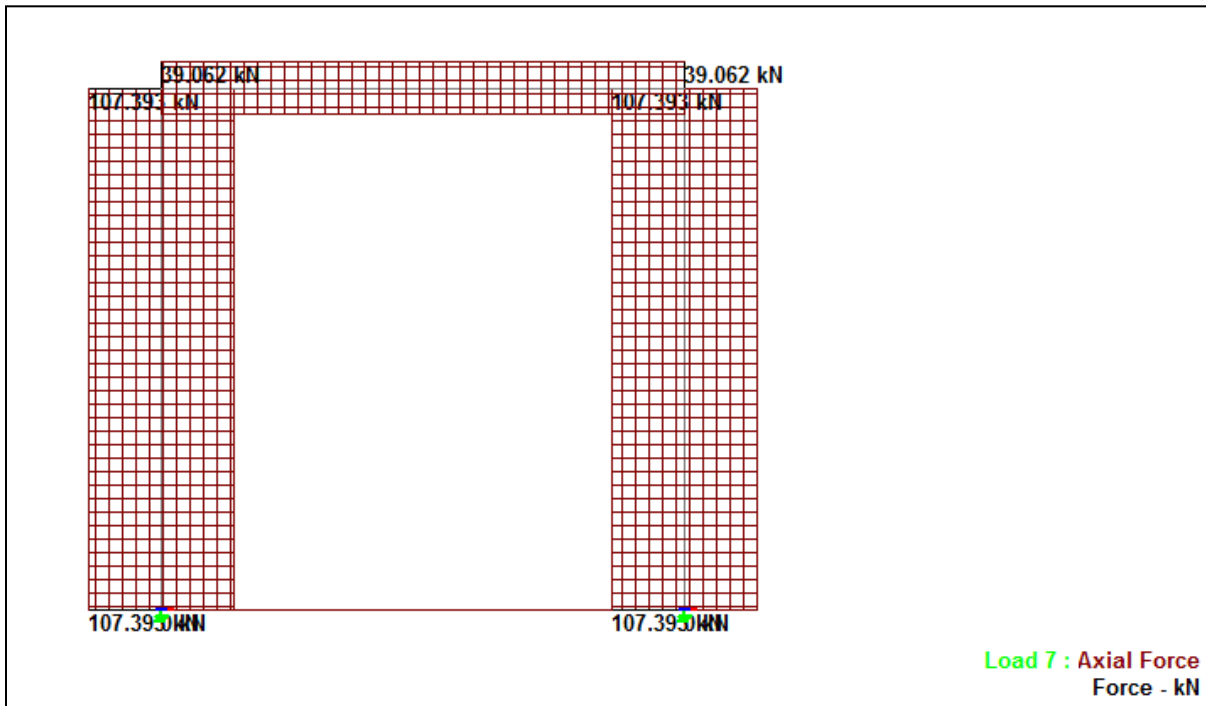


Fig. 6.5: Variation of axial force across the section of box culvert for L/H ratio 1:1

2) Case-2: Live Load, Dead Load and Earth Pressure Acting from Outside, and Water Pressure Acting From Inside

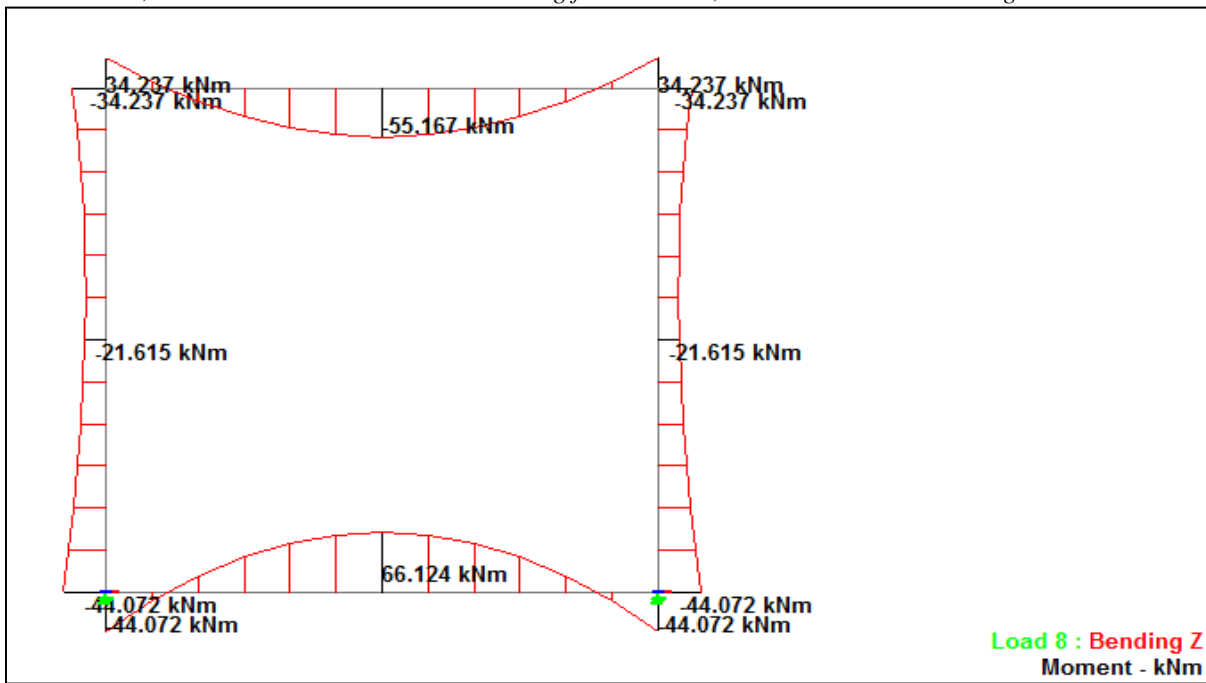


Fig. 6.6: Variation of bending moment across the section of box culvert for L/H ratio 1:1 and for Case II condition.

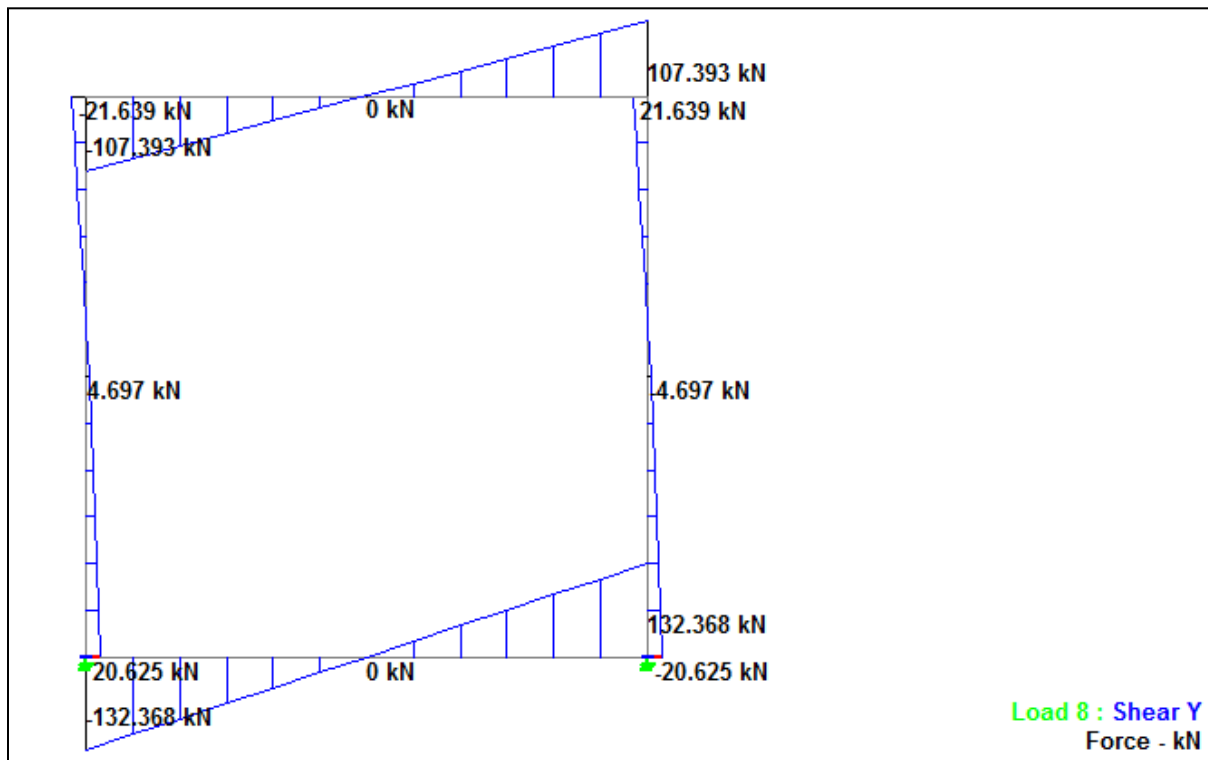


Fig. 6.7: Variation of shear force across the section of box culvert for L/H ratio 1:1 and for Case II condition

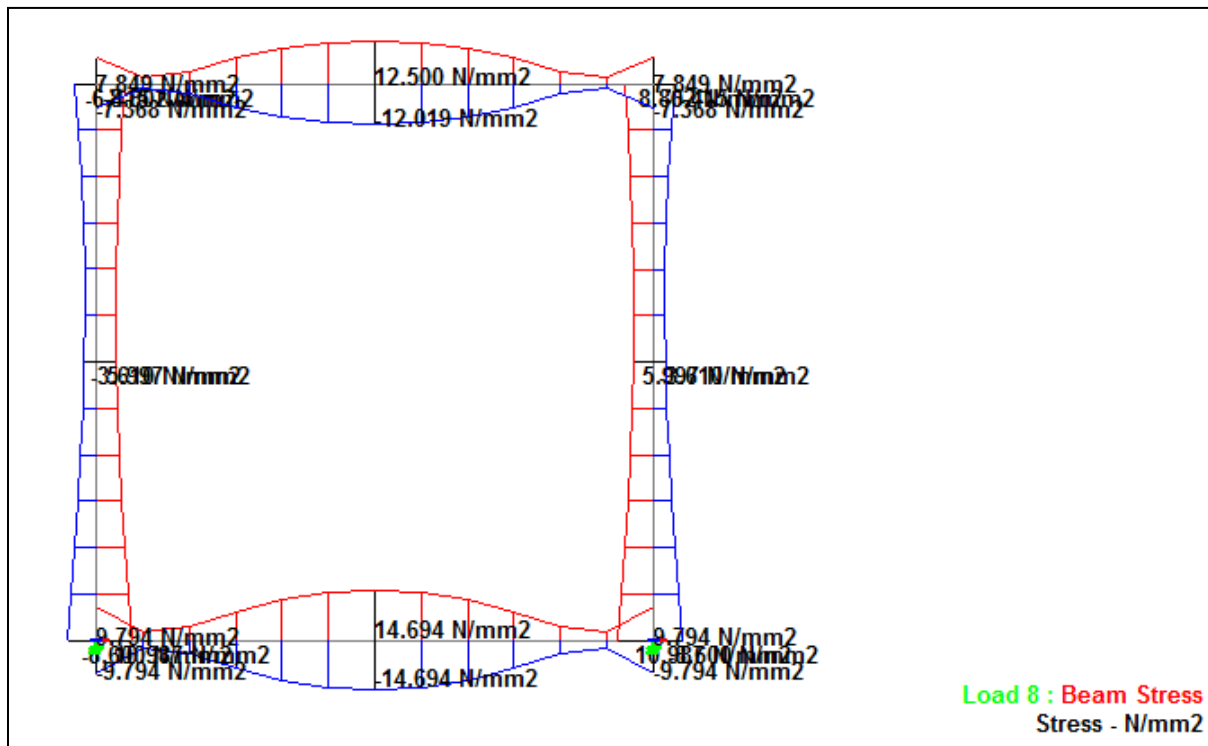


Fig. 6.8: Variation of stress variation on the section of box culvert for L/H ratio 1:1 and for Case II condition.

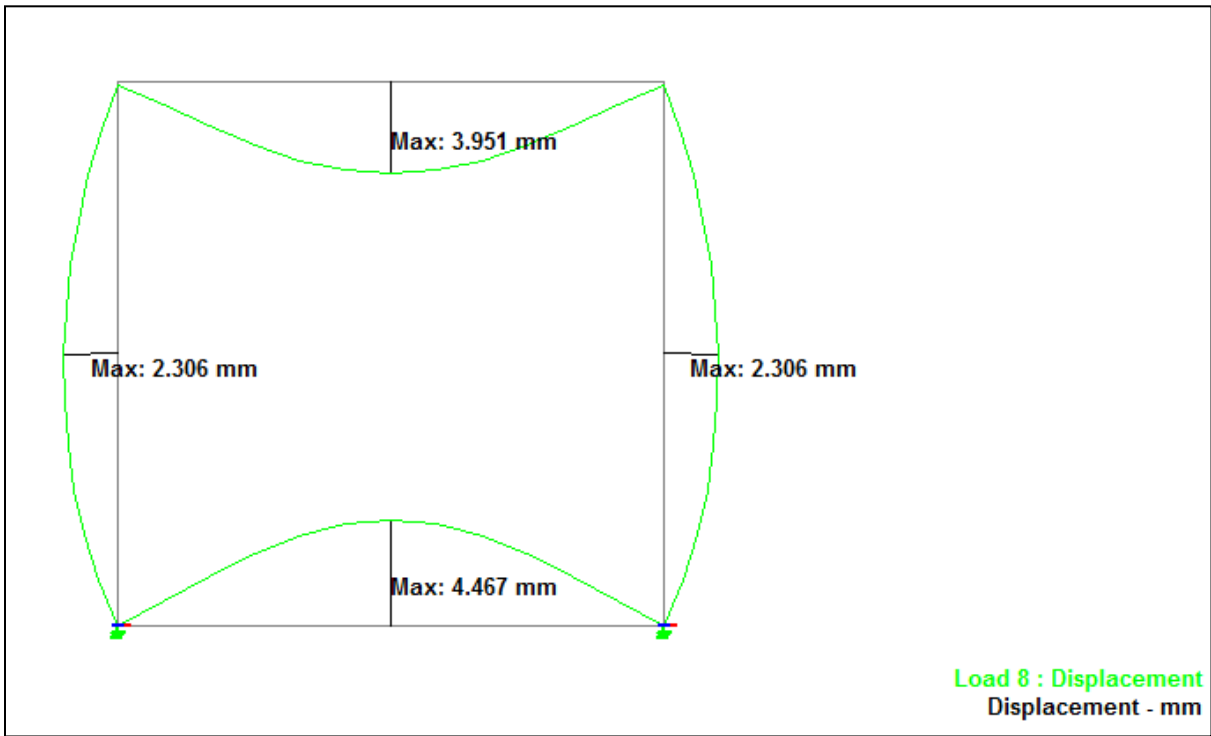


Fig. 6.9: Variation of deflection across the section of box culvert for L/H ratio 1:1 and for Case II condition.

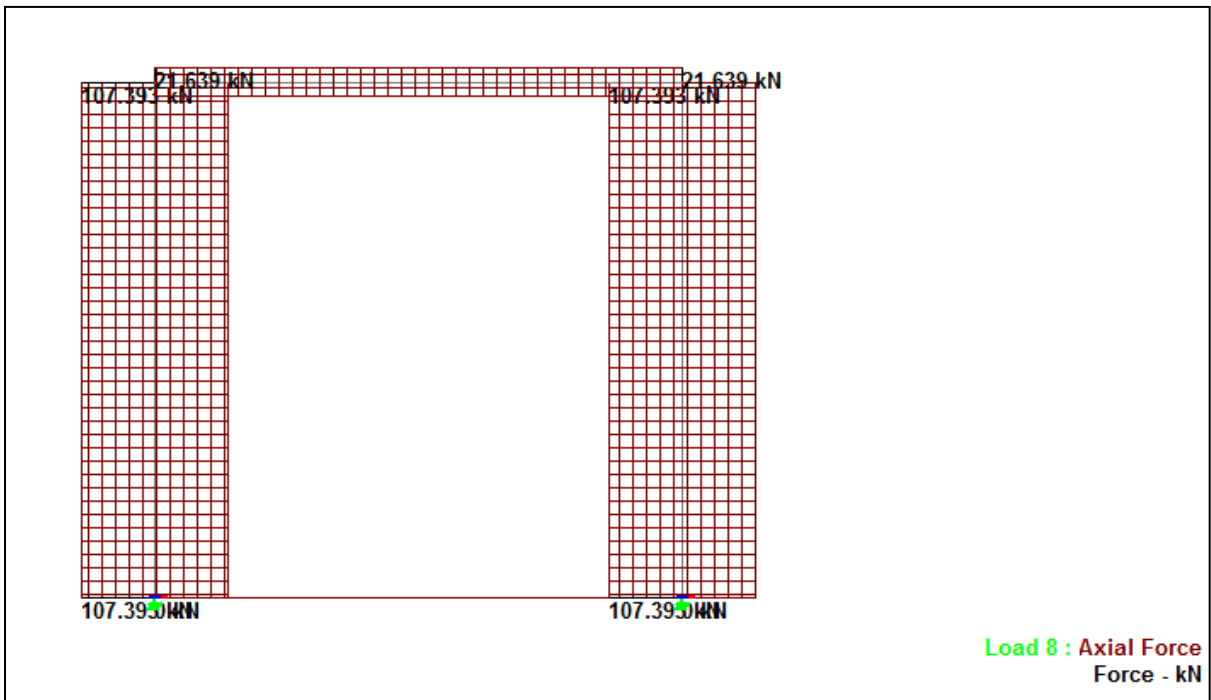


Fig. 6.10: Variation of axial force across the section of box culvert for L/H ratio 1:1 and for Case II condition.

3) Case-3: Dead Load and Earth Pressure Acting from Outside and Water Pressure Acting From Inside

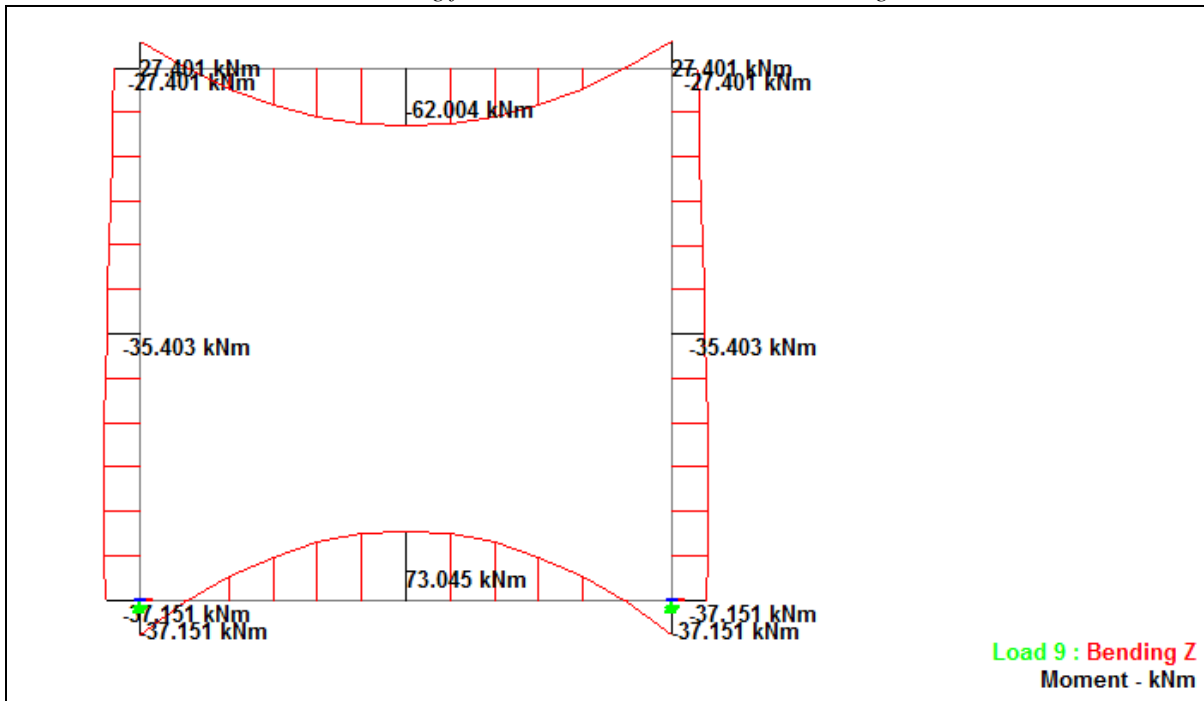


Fig. 6.11: Variation of bending moment across the section of box culvert for L/H ratio 1:1 and for Case III condition.

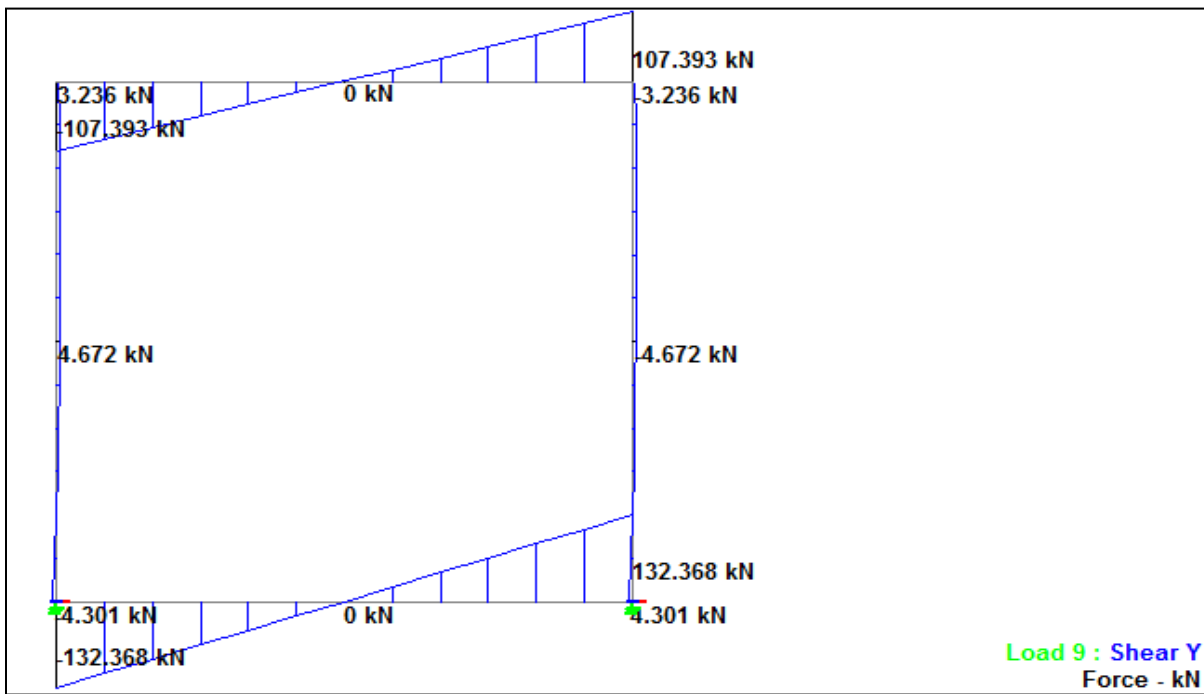


Fig. 6.12: Variation of shear force across the section of box culvert for L/H ratio 1:1 and for Case III condition.

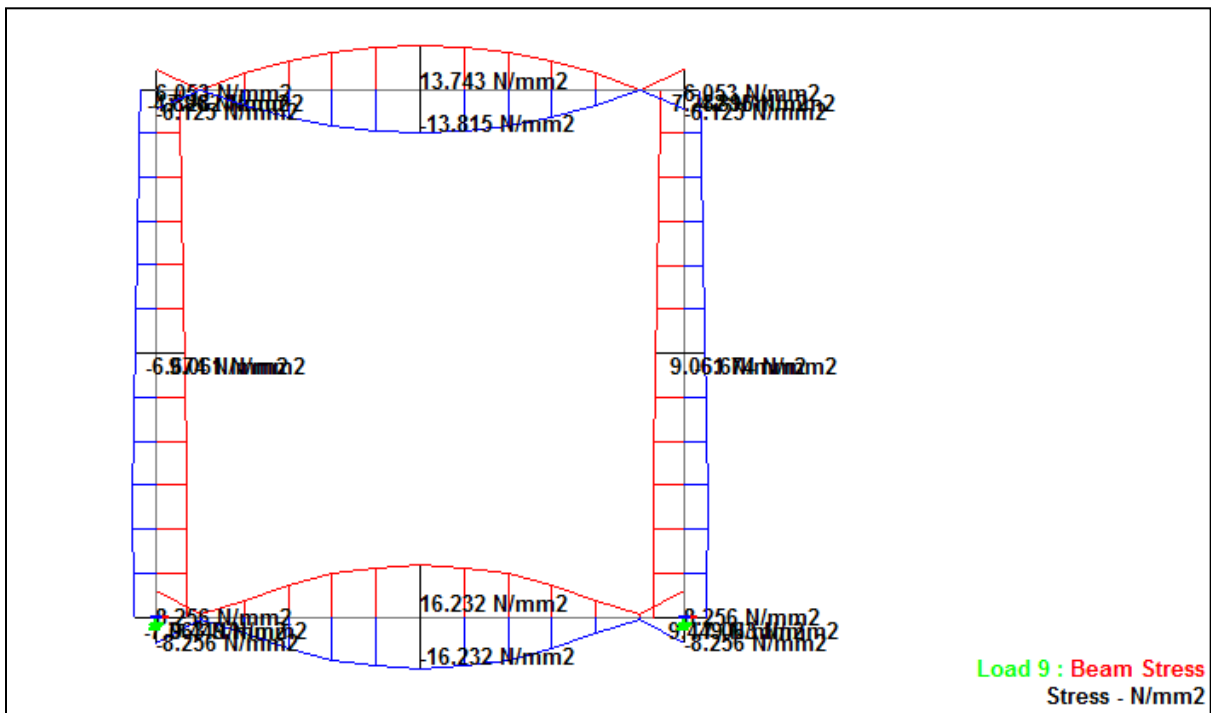


Fig. 6.13: Variation of stress across the section of box culvert for L/H ratio 1:1 and for Case III condition.

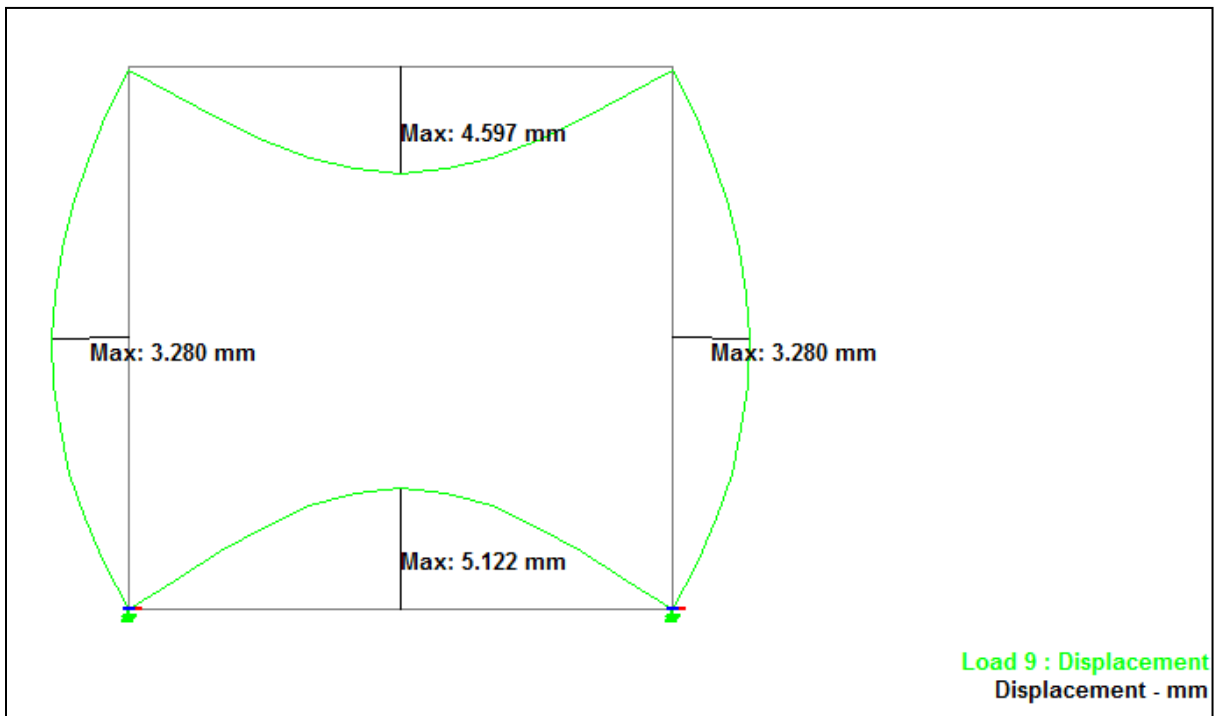


Fig. 6.14: Variation of deflection across the section of box culvert for L/H ratio 1:1 and for Case III condition.

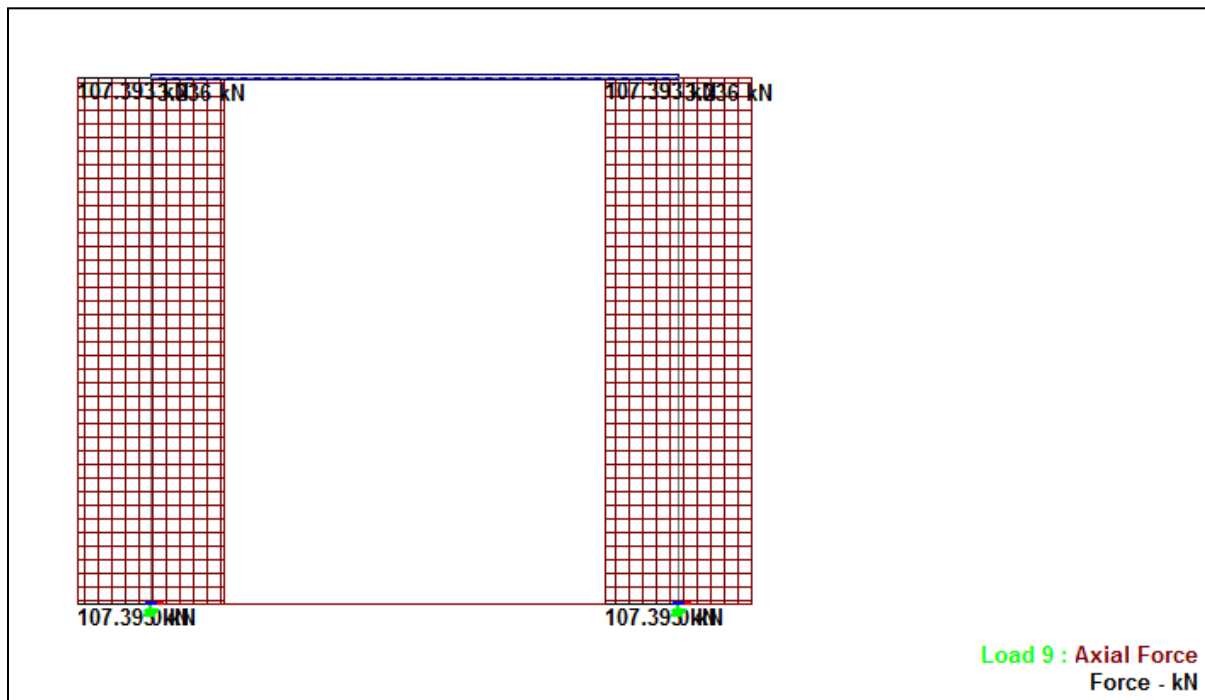


Fig. 6.15: Variation of axial force across the section of box culvert for L/H ratio 1:1 and for Case III condition.

From the Tables and Figs 6.1 to 6.12 and 6.1 to 6.15, it is observed that maximum value of bending moment occurs at centre of the top slab for load case 1 condition which is combination Live Load, Dead Load And Earth Pressure Acting, With No Water Pressure From Inside. Whereas values of bending moments increases as the length to height ratio increases. Values of bending moment, shear force, stress, axial force and deflection obtained for STAAD PRO are marginally more than the manual calculations. Axial forces obtained in the top and bottom slab portions of box culvert are very low values and hence are negligible. Maximum deflection is observed at centre of the components of the box culvert for all cases.

Similarly, values of bending moment, shear force, axial force, deflection and stress variation are observed for L/H ratios of 1:1.25 and 1:1.50 for various loading conditions. The variation of same represented in the form of graphs below respectively.

IV. CONCLUSIONS

The following conclusions are drawn from the 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 STAAD PRO.
- 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 centre of top and bottom slab for the condition that the sides of the culvert not carrying the live load and the culvert is running full of water that is case 1 condition.
- 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 centre 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,
- The study shows that there is significant contribution to positive normal thrust at centre of vertical wall (section E4) due to superimposed dead load & live load and weight of side walls.
- The study shows that the multi celled box culverts are more economical for larger spans compared to single cell box culvert as the maximum bending moment and shear force values decreases considerably, thus requiring thinner sections.
- The increase in manual values of maximum bending moment is observed when ratios of L/H 1:1.25 and 1:1.50 are compared to that of L/H 1:1 and are in the order of 29% to 47% in centre of top slab and 27% to 44% in centre of bottom slab. However, the support moments by 28% to 44% for top slab and by 27% to 60% for bottom slab. Similarly side walls varies from 40% to 60%.

REFERENCES

- [1] Reinforced concrete structure; volume:2; DR.B.C. PUNIMA, ASHOK.K.JAIN, ARUN.K.JAIN.
- [2] Design of bridge structure; T.R.JAGADEESH, M.A.JAYARAM.
- [3] IRC: 6-1996, "Standard Specifications and Code of Practice for Road Bridges", Section II.
- [4] SINHA & SHARMA ON Journal of the Indian Roads Congress, October-December 2009.
- [5] Y. Vinod Kumar, Dr. Chava Srinivas IJESR/ July 2015/ vol-5/ issue-7/850-861 international journal of engineering & science research.
- [6] Ketan Kishor Sahu, Shraddha Sharma IJSRD - International Journal for Scientific Research & Development Vol. 3, Issue 07, 2015 ISSN (online): 2321-0613.
- [7] M.G. Kalyanshetti, S.A. Gosavi IJRET: International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308.
- [8] Lande Abhijeet Chandrakant, Patil Vidya Malgonda International Journal of Advanced Technology in Engineering and Science Volume No.02, Issue No. 06, June 2014 ISSN (online): 2348 – 7550
- [9] Mr.Mangesh S.Sulke, Mr.Ganesh P. Chaudhari, Mr.Vishal B. Waghchaure and Mr.Swapnil G. Rane International Journal on Recent and Innovation Trends in Computing and Communication IJRITCC | April 2016 Volume: 4 Issue: 4
- [10] Sujata Shreedhar and R.Shreedhar INTERNATIONAL JOURNAL OF CIVIL AND STRUCTURAL ENGINEERING Volume 3, No 3, 2013 January 2013 Published on March 2013