International Journal of Bridge Engineering (IJBE), Vol. 9, No. 3, (2021), pp. 01-12

NUMERICAL MODELLING OF DOUBLE CELL RCC BOX CULVERT

Vinay Kumar Singh[1], Puja Rav[2]

[1,2]Department of Civil Engineering, MMMUT, Gorakhpur, Uttar Pradesh, India.
e-mail: vinay011990@gmail.com, pujarav33@gmail.com

ABSTRACT: The culvert played an important role in the transportation system by allow the crossing of the barrier from one side to the other under the railways and roads. A three-dimension double cell RCC box culvert has been designed to complex nature of the box culvert and analysis of box culvert has been done for self-weight of box culvert (dead load) as well as live load (IRC Class 70R load) for maximum eccentricity at the mid span along with zero eccentricity. This paper shows design and analysis of double cell RCC box culvert by numerical modelling (MIDAS Gen and STAAD Pro V8i) using IRC code. The top, bottom and side wall were analyzed to maximum bending moment as well as shear force due to the dead load, live load as well as live load surcharge. Its design and analysis is based upon the finite element analysis. The results obtained from STAAD Pro V8i software is compared with MIDAS Gen software. The structural elements of RCC Box Culvert are designed to resist the bending moment and shear force values. It is concluded that using of MIDAS Gen and STAAD Pro V8i software gives best and accurate result in a very short time. As a result, design and analysis of double cell RCC box culvert was concluded and find with the reduction in the size of proposed RCC box culvert, the self-weight of the RCC box culvert is significantly reduced. This paper is provided full discussion on provision in IRC code and consideration.

KEYWORDS: Finite element method; IRC code; Numerical modelling; Optimal design; RCC box culvert.

1 INTRODUCTION

The behaviors of the RCC box culverts are different to bridges. There are large numbers of the factor as well as variable that played important roles in difficulty of RCC box culvert. From the measurable view, culvert has been increasing in the number due to increasing of the population as well as related necessity. In addition, large part of the culvert is old and was made several years ago. The older culverts will not have same usability over the time because of the heavy weight of the truck and the higher strength material used in the new practice. The initial efficiency of any RCC box culvert gets reduced after a few years due to overloading and material depreciation.

Additionally, culverts may change over the time result change in culvert load. These included change in the fill of height as well as thickness of pavement due to changes in road elevation. As per IRC: 5-1998, the culvert having total span length 6m. Box culvert can be used for a single span length of 3m or for a double span length of 6m.

There are many advantages of box as compared to pipe slab and arch culvert. The designing of box culvert is easy and stable to construct and it is very strong. The ability of an RCC box culverts to withstand impose load depend on several factor included age as well as type of materials, dimension as well as structure of box culvert, and bearing material background box culverts. The effects of an RCC box culvert were slightly decreased from aging and material deterioration after the culvert was loaded with heavy force. If the top of the box culvert is not subjected to some embankment such box are termed as without cushion. If the top of the box culvert is subjected to some embankment such box culverts are termed as with cushion. The main goal is to check the behavior of the box channel under loading conditions according to the IRC codes and the combination of the RCC box channel that produces the worst loading effect for the safe box culvert. According to IS: 1893-1984 (Section 6.1.3), seismic forces do not have to be designed with an RCC box channel.

Therefore, seismic forces are not taken into account in the construction of the RCC box culvert. According to IRC: 78-2000, equalizing water level on the both side of the dam throughout the flood is called a balancer. Dead load coming on the top slab from upward direction because of the dead load of the top slab as well as the wear coat. They act like as a uniformly distributed load has shown in the figure. Live load also coming on the top slab from upward direction because of the live load. Wheel load in actual live load. It is basically concentrated load, but by the effective length of the load and the effective width of the dispersion the concentrated loads changes into uniformly distributed load like dead load on the top slab. RCC box culvert has two side walls, one is called left side wall and the other is called right side wall and both the walls are always in the direct contacts of the Earth fill by the outside and the soil fill increases the soil pressure on side wall in a triangular shape. If culverts are full water, then in this case the water exerts pressure from the inside to the side wall. The pressure of water also changes in a triangular shape. From the outside with filling the earth pressure and from the inside the pressure of water of the box culvert. The pressure base of the soil is too connected to the box culvert. It acts in vertical directions from bottom of the bottom slab to the top. It is also assumed that on top slab live load is increasing the pressure at side walls equal to special heights of the side walls and it differs in a similar pattern with heights of the side walls.

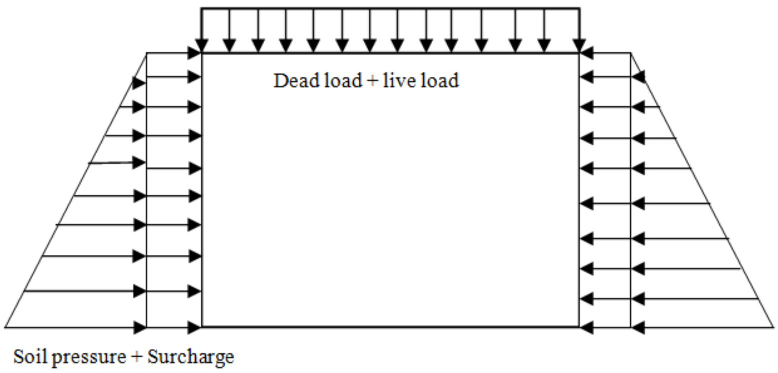


Figure 1. Loads on the box culvert

2 OBJECTIVE

The objective of this study is to find the following aims

- To design all structural elements of double cell RCC box culvert as per IRC:6-2000 code.
- To evaluate and compare the results of STAAD V8i Pro software and MIDAS Gen software.
- To analysis and design RCC box culvert with computational approach STAAD V8i Pro software and MIDAS Gen software.
- To check safety of double cell RCC box culvert and work out material economy by compared the results of STAAD V8i Pro software and MIDAS Gen software.

3 LITERATURE REVIEW

Ping Zhu, Run Liu, Wenbin Liu, and Xinli Wu [1] have previously shown that the box channel design uses the finite element method. In this research work, an optimal design of a box channel under the road using the finite element method was also evaluated. Based on the finite element analysis, the thickness of the side wall is 1.8 m and the thickness of the base plate is 1.5 m to achieve an optimal design. The result is an optimal design that not only reduced use of concrete, but also reduced requirements for the load-bearing capacity of foundation floor. Abuhajar and Naggar [2] performed a series of centrifugation tests and a numerical model using 2D finite difference codes. The authors found an excellent agreement between measure and calculated static results. During parametric study, different depths of the land cover and foundation positions were examined. The effect of the foundations position on bending moments, soil pressure as well as the interaction factor between soil and culvert are important for case where foundations are on the surface directly above culvert as well as decreasing far from the square culvert (i.e. distance ≥ 2BF). Jerin Jose, Kiran S. Chirayath, Muhammed Riswan, Megha Shankar, Rose Mariya

George [2], many researchers have proposed various methods for analyzing and constructing box-shaped culverts, for example the limit state method. the working state method, the finite element method, the seismic design method and the moment distribution method, etc.

However, the researchers concluded that the construction of the upper plate, lower plate, retaining walls and side walls using the limit state method according to the relevant codes has been carried out. Bending moments and shear forces were calculated with the STAAD Pro software and after the design the details of the culvert and the retaining wall were created with the AutoCAD software. Diego Calderon, Mohammad Najafi [4], it has been observed in this work and in related references that culvert failures result in sudden collapses and catastrophic events most of the time, and replacing these culverts without disrupting traffic is one of the most difficult tasks. Only field tests and design case studies have been found in the literature. Some trenchless technologies, such as pipe bursting as an in-line replacement method, are the only fully tested and proven method for replacing culverts. Abdul Kareem, AL-Shammaa [4], in recent years research on the design of RCC box culverts with STAAD Pro software has become very popular because this software provides quick results, a precise and optimal solution for the design of rectangular RCC culvert. The 2011 ACI code in SI units was used in this study and performed the analysis of a one cell box culvert with RCC design by the STAAD Pro software. From the result obtained, it was found that the STAAD Pro software found more accurate values for bending moments, shear forces and support reactions. N. Sinha, RP Sharma [6]: this article presents the comparative analysis of two standards, namely the STAAD Pro software and the torque distribution method used in building the load capacity of the RCC box liner of heavy vehicles. Research paper. Numerous studies have been carried out on RCC ports. For several years now, great efforts have been made to study RCC culverts. In this article, the calculation method was carried out using the STAAD Pro software and the manual calculation using the moment distribution method. It turned out that the box offers many advantages over a plate aperture. Box is structurally very strong, rigid and secure.

Afzal Hanif Sharif [7], carried out a study on the analysis and construction of the railway bridge using the moment distribution method and STAAD Pro software, and also evaluated various parameters of the railway box bridges according to the codes IRS and RDSO (Research Designs and Standards Organization). Compare them and also check all structural elements for the safety of the railway bridge. The box bridge is easy to construct and select number of cell with the desire span to the depth ratio. Zaman Abbas Kazmi, Ashhad Imam and Vikas Srivastava [8], have published several papers in recent years to document the analysis and design of the small box-shaped railway bridge. The authors conducted a study using the moment distribution method and STAAD Pro software. The result is that the maximum design forces develop at the critical sections and the calculation method was significantly more competent than the moment distribution method in terms of efficiencies and consumptions. Roshan Patel, Sagar Jamle [9], in this study the complete design of the box channel was carried out manually according to the IRC rules and the design parameters were examined. The authors examined using charts, graphs, tables showing the variations of the test result for bending moment, shear force, etc. This leads to small fluctuations in the observed earth pressure coefficient, and normal stresses, maximum principal stresses as well as the equivalent stresses are without more cushion than with cushion. Box channel without cushion, braking forces are require for small span. Miss Apurva J. Chavan, Prof. KK Tolani, Prof. Chetan G. Joshi [10], previous studies show that the authors performed an analysis using the limit state method. Another method (ANSYS finite element method) was also described in this paper report and a steel box culvert in the ANSYS was analyzed using finite element method. He concludes that the box canal's performance is heavily dependent on the payload, effective width, ground pressure impact factor coefficient, cushion depth and water flow. Therefore, designing and analyzing the box duct by changing the material and, according to the authors, the steel box culvert could be the next choice for further study.

4 STANDARD SPECIFICATION LOADINGS

4.1 IRC loadings

There are various standard loading which has been given by IRC for highway bridges and culverts.

4.1.1 IRC Class 70R loading

IRC Class 70R loading is the improved version of the IRC Class AA loading as per IRC 6-2000. IRC 70R loading has a higher magnitude than others IRC loading. It is used to build bridges in the industrial and military sector. The IRC Class 70R loading consist of three types of vehicles. The first one is the tracked vehicle of total load 700 KN capacity so with the two tracks will distribute this complete 700 KN to each weighing the 350 KN. The second one is the wheeled vehicle comprising four wheels each with the loads of 100 KN totalling 400KN, and third one is wheeled vehicle with a train of vehicles on seven axles with a total load of 1000KN. The contact length of track is 4.57m and the nose to tail length of the vehicle is 7.2m. The specified minimum spacing between the successive vehicles are 30m.

4.1.2 IRC Class AA loading

There are two different types of vehicles under this category grouped as tracked and wheeled vehicles. So, the tracked vehicles are nothing but stimulating on army tank 700 KN and the wheeled vehicles are heavy army truck 400 KN. The load of the longitudinal length is 3.6m. All the bridges located on national highways and state highways designed for the heavy loading. IRC Class AA loading has two set of wheeled vehicles, first axle is 62.5 and second axle is 32.5KN.

4.1.3 IRC Class A and IRC Class B loading

The heavy duty truck with two trailers transmit loads from 8 axles varying from a minimum of 27KN to a maximum of 114 KN. The class A loading is a 554 KN train of wheeled vehicles on 8 axles. The axle loads of class B are a 332 KN train of wheeled vehicles on 8 axles. This type of loading is adopted for temporary structure and timber bridges and the combinations of different types of live loads IRC:6-2000.

4.2 Effect of impact

Due to dynamic action consider the effect in increasing stress. The allowance of impact is given as per Indian Roads Congress code. This is equal to the live load share. Taking this into consideration to counteract the effect of impact caused by the live load. There is the following factor of impact by as per IRC:6-2000.

4.2.1 Consider IRC Class A or IRC Class B loading

If any bridge member design either IRC class A or IRC class B loading the percentage of impact will determined in the following figure. The fraction of impact will determine for the length of the span which is vary from 3m to 45m are following.

RC bridge impact fraction = $\frac{4.5}{6+\mathrm{L}}$

Steel Bridge impact fraction = $\frac{9}{13.5+L}$

Where: length of span L is in meter.

4.2.2 Consider IRC Class 70R or IRC Class AA loading

The percentage of impact value will be taken by following.

The 25% of impact value up to span length 5m and linearly for the RC bridge design for the tracked vehicles reducing it by 10% for the span length 9m and the span length over 9m the impact value is 10% to the length of the span of 40m. The 25% of impact value up to span length 12m for the RC bridge design for the wheeled load and more than 12m curve for spans.

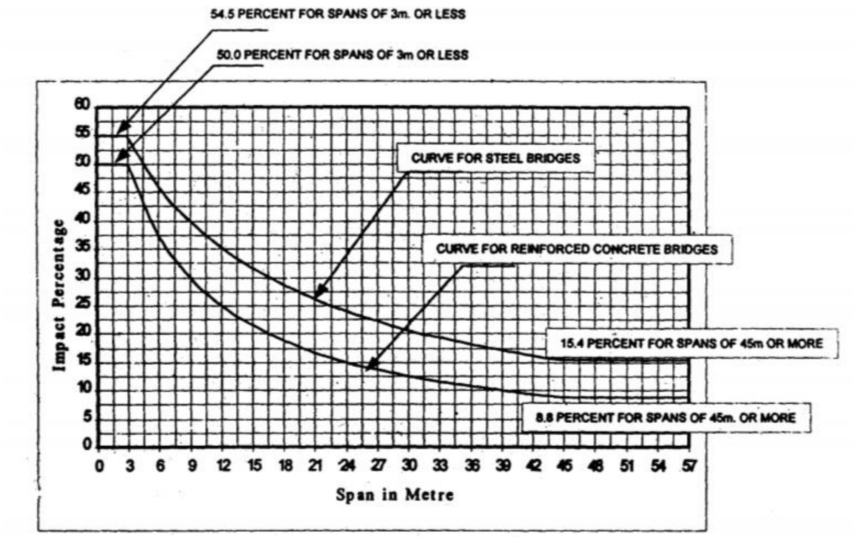


Figure 2. Percentage of the impact curve for the highway bridge for a class A and B load (Clause 211.2).

4.3 Longitudinal impact reduction for traffic over two lanes

Longitudinal impact reduction on the bridges with over two lanes of traffic, Because of that less likely all those lanes will be subject to specific loads Simultaneously According to IRC section B205:6-2014.

Table 1. Longitudinal impact reduction for traffic over two lanes

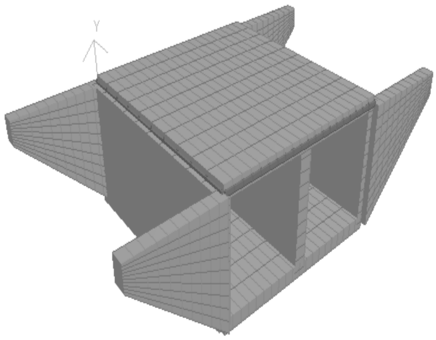
Lanes number	**Longitudinal impact reduction**
2 lanes	No reduction
3 lanes	10 percent reduction
4 lanes or over 4 lanes	20 percent reduction

5 METHODOLOGY

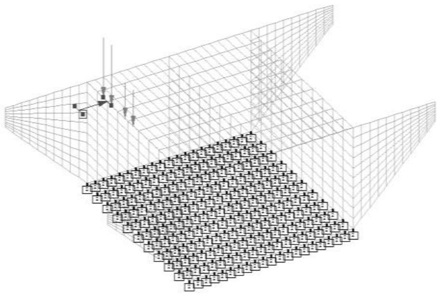
- The data used for this study are collected by Indian Road Congress, IRC: 21-2000 & IRC: 6-2000.
- The design and analysis of double cell RCC box culvert is done by STAAD Pro V8i and MIDAS Gen software.

6 NUMERICAL MODELLING

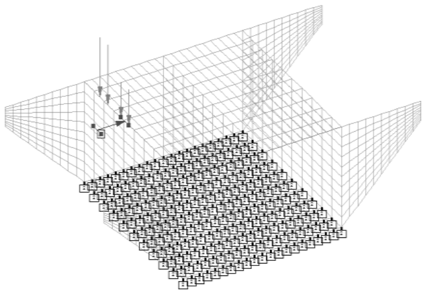
Under the consideration RCC box culvert is indicate in the figure. This is investigated using the program (MIDAS Gen and STAAD Pro) to evaluate bending moment as well as shear force and explain elastic nature of RCC box culvert under the various loads, by replacing dimension of culvert width (B) as well as thickness (T). The vertical side wall earth pressure of box channel is calculated according to Coulomb's principle. The experimental modeling provided a scope to achieve basic understanding to design of box culvert. Differently, modeling of numerical is beneficial for simulate complex system under the control condition. The MIDAS Gen and STAAD Pro V8i software was applied to do numerical analysis.



(a)

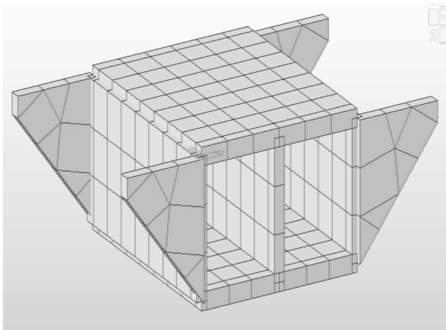


(b)

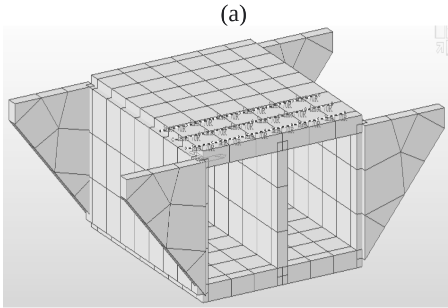


(c)

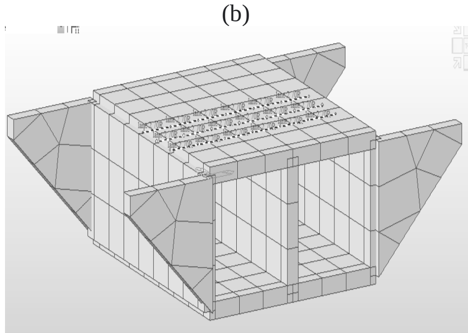
Figure 3. (a) Meshing of the double cell RCC box culvert in STAAD Pro;
(b), (c) Loading on double cell RCC box culvert in STAAD Pro.



(a)



(b)



(c)

Figure 4. (a) Meshing of the double cell RCC box culvert in MIDAS Gen;
(b), (c) Loading on double cell RCC box culvert in MIDAS Gen.

7 RESULT AND DISCUSSION

A 3m height and span of double cell RCC Box Culvert is designed by computational analysis by MIDAS Gen and STAAD Pro V8i software. Its design and analysis is based upon the finite element analysis. The effect of variation of parameters such that variation in shear force, bending moment on the analysis of RCC Box Culvert were investigated using MIDAS Gen and STAAD Pro V8i software. The limitation of this study is that Midas Gen Software gives best results in a short time and STAAD Pro V8i software provided only main reinforcement without secondary reinforcement. Different method was used by different researchers for the purpose of designing and analyzing RCC box culvert. By comparing this simplified method with the previous discussed method for the analysis and design of the RCC box culvert, it was found that there is no major difference in the values of bending moments and shear forces and size of the RCC Box Culvert. The bending moment and shear force result of RCC box culvert is analysis and design by computational method by MIDAS Gen and STAAD Pro V8i software as shown.

Table 2. Bending Moment and shear force by MIDAS Gen and STAAD Pro V8i software

	Bending Moment (Kn-M)		Shear Force (Kn)	
Load →	Class 70R		Class 70R	
Members ↓	By MIDAS Gen Software	By STAAD Pro Software	By MIDAS Gen Software	By STAAD Pro Software
Top	50.9	51.2	67.9	68.5
Bottom	70.0	69.9	71.2	72.8
Side Walls	15.9	16.5	42.8	43.5

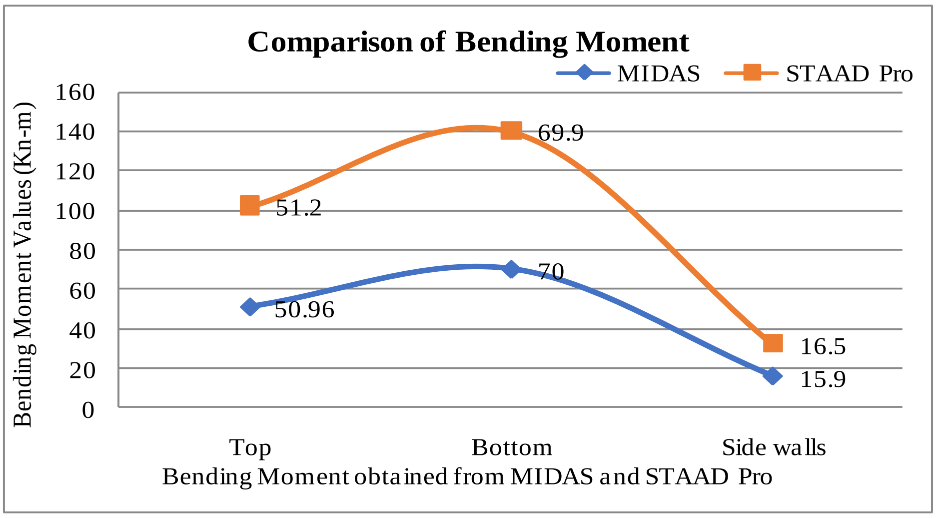


Figure 5. Bending Moment at top slab, bottom slab and side wall

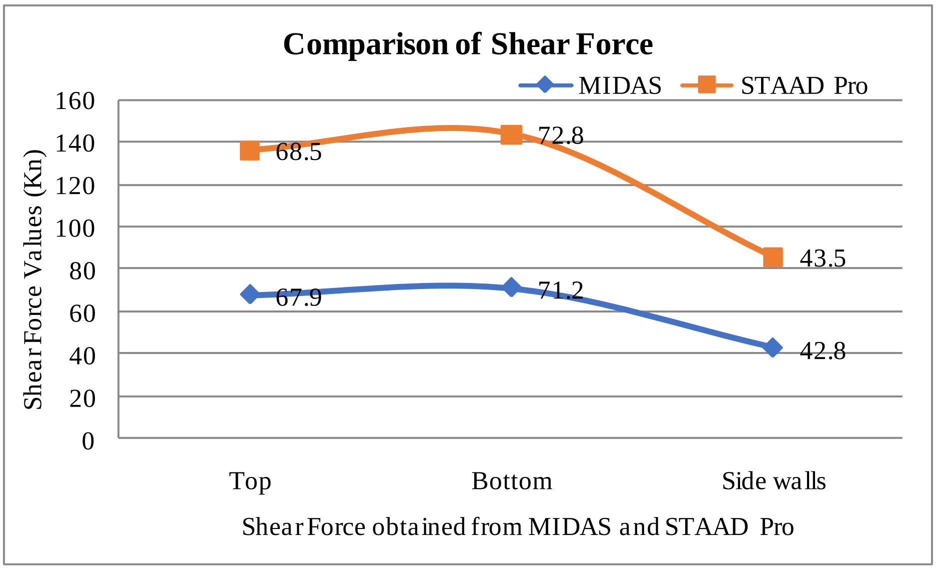
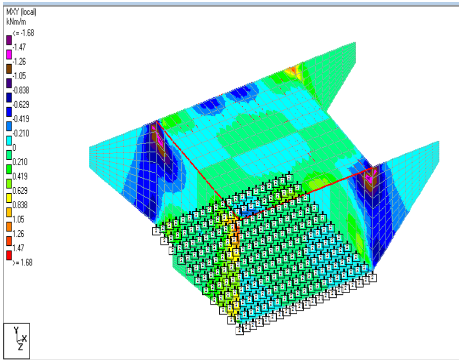


Figure 6. Shear force at top slab, bottom slab and side walls

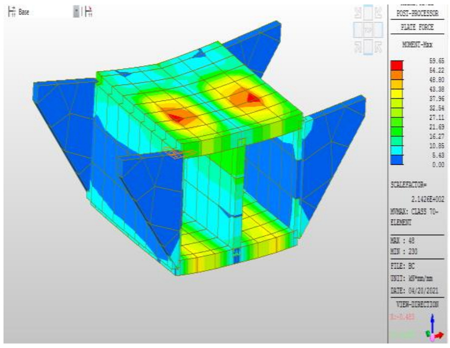
8 CONCLUSIONS

Compared to a single span box, a multi span box is more economical for a larger span and also decrease the bending moment and shear force value required thinner section. The result clearly predicts that if the box culvert is designed through the finite element method instead of the traditional method, the material as well as money will be saved and the design will also be safer. The results obtained from STAAD Pro V8i software are almost similar to result obtained by MIDAS Gen software. From this study there are following points concluded

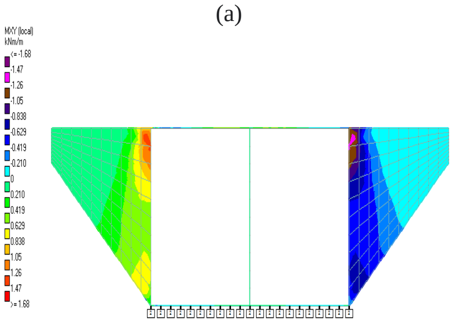
- The result shows the difference in bending moment of top slab, bottom slab and side walls are 0.24%, 0.11% and 0.65%.
- The result shows the difference in shear force of top slab, bottom slab and side walls are 0.6%, 1.6% and 0.7%.
- The design as well as modelling in MIDAS Gen and STAAD Pro V8i software is safer than the other numerical modelling and design is also easier.
- The finite element method application through MIDAS Gen and STAAD Pro software save the amount of the money as well as design effort and application of the box culvert.



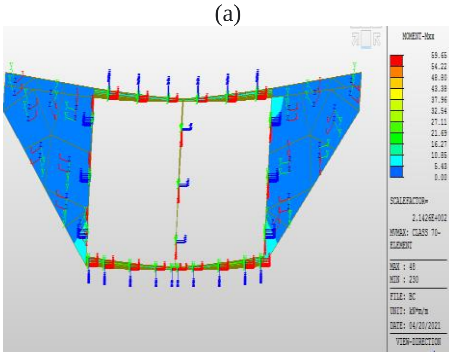
(a)



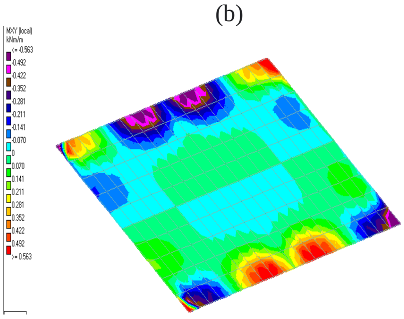
(a)



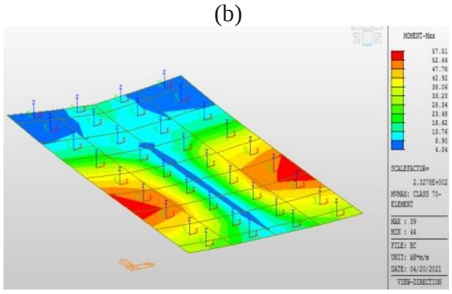
(b)



(b)



(c)



(c)

Figure 7. (a), (b), (c) Force contour on RCC box culvert on STAAD Pro software

Figure 8. (a), (b), (c) Force contour on RCC box culvert on MIDAS Gen software

REFERENCES

[1] Zhu, Ping, et al. "Study on optimal design of a box-culvert under road", Civil Engineering and Urban Planning 614-618, 2012.

[2] Abuhajar, Osama, Hesham El Naggar, and Tim Newson, "Numerical modeling of soil and surface foundation pressure effects on buried box culvert behavior", Journal of Geotechnical and Geo environmental Engineering 142.12, 04016072, 2016.

[3] Jerin Jose, Kiran S Chirayath, M.A Muhammed Riswan, Megha Shankar, Rose Mariya George," Design of Box Culvert using Limit State Method", International Journal of

Scientific Research and Review" ISSN no. 2279-543X, Vol.08, Issue-06, p.p. 311-319, 2019.
[4] Calderon, Diego, and Mohammad Najafi. "Development of a New Culvert Replacement Method." Advances and Experiences with Pipelines and Trenchless Technology for Water, Sewer, Gas, and Oil Applications, 1294-1301, 2009.
[5] Al-Shamma, Abdul Kareem M. B, "Simplified model of design RCC box culvert by STAAD Pro", 2006.
[6] Sinha, B.N. and R.P. Sharma, "RCC Box Culvert Methodology and Designs including Computer method," In Journal of the Indian Roads Congress, vol. 10, no. 555, pp. 189-219. 2009.
[7] Sharif, Afzal Hanif, "Review paper on analysis and design of railway box bridge", International Journal of Scientific Development and Research 1, 2016.
[8] Kazmi, Zaman Abbas, Ashhad Imam, and Vikas Srivastava. "Analysis and Design of Box Type Minor Railway Bridge ", Intern. Journal of Civil Engineering and Technology 8.7, 2017.
[9] Patel, Roshan, and Sagar Jamle, "Analysis and Design of Box Culvert: A Review", International Journal for Research in Engineering Application & Management, 266-270, 2019.
[10] Chavan, Miss Apurva J., K. K. Tolani, and Chetan G. Joshi. "Review On Box Girder Culvert Analysis Using ANSYS", 2017.
[11] Kolate, Neha, Molly Mathew, and Snehal Mali, "Analysis and Design of RCC Box Culvert", Intern. Journal of Scientific & Engineering Research, Vol. 5, Issue 12, 36-40, 2014.
[12] Krishna, P. Leela, and K. Rajasekhar. "Analysis and Design of Box Culvert ", International Journal of Science Technology and Engineering, Volume 4, Issue 10, 2018.
[13] Abdel-Karim, Ahmad M., Maher K. Tadros, and Joseph V. Benak. "Structural response of full-scale concrete box culvert "Journal of structural Engineering 119.11, 3238-3254, 1993.
[14] Sargand, Shad M., Glenn A. Hazen, and John O. Hurd, "Structural evaluation of box culverts ", Journal of structural engineering 118.12, 3297-3314, 1992.
[15] Roschke, Paul N., and Raymond E. Davis, "Rigid culvert finite element analyses ", Journal of geotechnical engineering 112.8, 749-767, 1986.
[16] Ahmed, Alia Osman Mohamed, and El Hussein Alarabi, "Development formulation for structural design of concrete box culverts ", Practice Periodical on Structural Design and Construction 16.2, 48-55, 2011.
[17] Wood, Timothy A., et al. "Evaluation of production models for load rating reinforced concrete box culverts ", Journal of Bridge Engineering 20.1, 04014057, 2015.
[18] Tikate, Pavan D., and S. N. Tande, "Design Based Parametric Study of Box Culvert using Finite Element Method ", Journal of basic and applied engineering research September, 2015.
[19] Tanwar, Vasu Shekhar, M. P. Verma, and Sagar Jamle, "Analysis of Box Culvert to Reduce Stress Values ", International Journal of Advanced Engineering Research and Science 5.5, 237470, 2018.
[20] Patil, A.D., and A.A. Galatage, "Analysis of box culvert under cushion loading", International Advanced Research Journal in Science, Engineering and Technology Vol. 3, Issue 6, June 2016, 163-166, 2016.
[21] Gupta, P.K., K.K. Singh, and A. Mishra, "Parametric study on behaviour of box-girder bridges using finite element method ", Asian Journal Of Civil Engineering (Building And Housing) Vol. 11, No. 1, 135-1482010, 2010.
[22] Saurav, Pandey I., and I. Pandey. "Economic Design of RCC Box Culvert through Comparative Study of Conventional and Finite Element Method ", International Journal of Engineering and Technology (IJET), Vol. 9, No. 3, 1707-1713, 2017.
[23] Ali, Nasir, Himanshu Guleria, and Himanshu Sharma,"Influence of Skew Angles on Box Type Bridge", 2020.
[24] IRC: 21-2000, "Standard Specifications and Code of Practice for cement concrete (plain and reinforced)", Section III.
[25] IRC: 6-2000, "Standard Specifications and Code of Practice for Road Bridges", Section II.