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Design Based Parametric Study of Box Culvert using Finite Element Method

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Abstract—*Reinforced concrete box culverts are widely used throughout the world to provide safe and relatively economical structures for the conveyance of water, vehicles, utilities, or pedestrians. Although single cell or multicell box culverts are rather simple structures, the loadings applied to these structures during their construction and subsequent service life can be complex. Problems frequently take place because of improperly estimated load of cushion on culverts and considered coefficient of earth pressure. Depth of cushion, coefficient of earth pressure for lateral pressures on walls, width or angle of dispersion for live loads on box culvert without cushion and with cushion for structural deformations are important items where opinion of the designers vary and need to be considered in much detail. Therefore for live load, an attempt is made to study the effects of cushion, co-efficient of earth pressure (K_a) and width/angle of dispersion (θ).*
Finite element method (FEM) simulation were conducted to evaluate effect of the variation of cushion depth, coefficient of earth pressure, width or angle of dispersion on the structural behavior of the three-dimensional box culvert and to examine the accuracy of FEM by comparing the FEM results with IS Code methods. The calculated bending moments, shear forces from the FEM were compared with those from the current theoretical methods which showed close correlation. It is recommended to design box culvert structure without cushion condition along with Coefficient of earth pressure (K_a) = 0.5 & Angle of dispersion (θ) = 45^0 which will perform safely even in additional cushion loads which may come due to change in road profile. This work guides engineers using IS code in evaluating box culvert behavior under different cushion depths so that they can decide up to what depth of cushion, the box culvert need not be reconstructed during widening of roads.

1. INTRODUCTION

The term *culvert* encompasses practically all closed conduits used for drainage, with the exception of drains. There are many similarities between bridges and culverts because they perform similar tasks. Culverts, however, are usually differentiated from bridges because the top of the culvert does not form a part of the traveled roadway. Culverts are to be found in three general locations: at the bottom of depressions where no natural watercourse exists, where natural streams intersect the roadway, and at locations required for passing surface drainage carried inside ditches beneath roads and driveways to adjacent property.

A few things like depth of cushion, coefficient of earth pressure for lateral pressure on walls, width or angle of dispersion for live loads on box without cushion and with cushion for structural deformation are important items where opinion of the designers vary and need to be dealt in much detail. These affect the design significantly and therefore, required to be assessed correctly for designing a safe structure.

It is customary to consider box a rigid frame and unit length of box is taken for design by considering the effect of all forces acting on this unit length (generally 1.0 m of box). While calculating weight of cushion on top slab, some designer take average height of earth fill coming over full length of box including sloping side fill. This is not correct and full height of cushion should be taken at the worst section of the box (central portion) will be subjected to this load and the section needs to be designed accordingly. A question has been raised frequently whether culverts designed for four lane divided carriageway are safe for more number of lanes, a situation which occurs on widening of the road and frequently encountered for road development, and whether the culvert designed for no cushion shall be safe for cushion loads which may become a necessity at a future date due to change in road profile. If so, up to what height of cushion, the box need not be reconstructed.

The problem, therefore, is that using today's culvert analysis methods on older culverts does not appear to accurately predict performance and structural capacity. A disconnect exists between current culvert structural analysis methods and actual culvert performance. ***This call for research*** into the design and performance of the culvert which shall be safe for cushion loads which may become a necessity at future date due to change in road profile and can be used to develop rational performance-based load rating guidelines. Therefore an attempt is made to study the effects of cushion, co-efficient of earth pressure and angle of dispersion for live load.

2. HISTORICAL DEVELOPMENT

The last few decades have been witness to some remarkably interesting development of structural analysis of box culvert as well as the response of structure for different loading condition as a result of significant amount of research activity devoted in this field. Marston (1930) pioneered research on the behavior of underground conduits analytically and experimentally in the early years of the 20^{th} century. One of the outstanding contributions of the Marston theory of loads on buried conduits is its demonstration, by the principles of mechanics, that the load on a structure is affected by installation conditions in addition to the height of fill over the structure.

David Z. Yankelevsky (1989) has analyzed Rigid Box Buried in Non-linear medium by considering different parameters. The study deals with the design parameters like compressibility, stiffness, settlement, slope of trench wall on displacement and stress variations with depth. More recently, along with increased concrete BC use, other studies have been developed. Concerning experimental works, Dasgupta and Sengupta (1991) developed a laboratory scale model of a buried BC and concluded that the magnitude and distribution of the applied load is very different from the load provided by the geostatic condition.

Kiangsi Kim and Chaih.Yoo (2005) [10] has evaluated design loading on deeply buried Box Culverts. Linear and non linear finite element analyses were used to investigate the effective density or soil-structure interaction factor for deeply buried box culverts. ABAQUS (1998) and ISBILD were used primarily for the analysis and CANDE -89 for verification and comparison. Richard M. Bennett et al. (2005) analyzed vertical loads on concrete box culverts under high embankments. Vibrating wires, strain gages and pressure cells were used to determine the internal forces and pressures on the culvert due to backfill. Strong correlation was obtained between the height of fill and the pressure and internal forces in the culvert.

2.1. Research Significance

Many researchers have done work both experimentally and analytically in the area of Finite element modelling and analysis of RCC Box Culvert. The concept of design parametric study of RCC Box Culvert is rapidly growing due to enable the early identification of damage and provides warning for unsafe condition. From the previous studies, it was understood that the parameters such as depth of cushion, coefficient of earth pressure and angle of dispersion were studied individually in a single head. In the present study, an attempt is made to combine and study the effects of those parameters for live load.

3. ANALYSIS AND DESIGN METHOD

For a box culvert, the top slab is required to withstand dead loads, live loads from moving traffic, earth pressure on sidewalls, water pressure from inside, and pressure on the bottom slab besides self weight of the slab. Box culverts are analyzed and designed as rigid frames with equal bending moments at the end supports. The moment distribution method is generally adopted for determination of final moments at the frame joints. The method is well known and does not need any elucidation. The mid span moments are computed with free supported ends and adjusting it for moments at support obtained after distribution. The moments at center and supports for slabs and walls are obtained for various combinations of loads and the member is designed for the maximum moment it may be subjected to [3].

4. LOADS

Box culverts are often used as conduits to carry water from one side of highway to the other. Although this is a simple role, the loadings applied to these structures are rather complex [1]. Hence, a simple approach must be used for the analysis and design due to the large number of culverts that are being built. The structural design of a reinforced concrete box culvert includes various types of loads outlined below.

- Uniform distributed load
- Weight of side walls
- Water pressure inside culvert
- Earth pressure on vertical side walls
- Uniform lateral load on side walls

The problem considered is the analysis and design of concrete box culverts. First, the analysis of bending moments per meter length of the culvert was carried out assuming a value for the thickness of the walls and roof. The bending moments were determined by considering the culvert as a rigid frame with equal bending moments at the end supports. The bending moments were calculated by considering the possible incidence of the loads and pressures. Generally, there are three conditions to consider [4,5]:

- Culvert empty: full load and surcharge on the top slab, the weight of the walls, maximum earth pressure, and live load surcharge on the walls.
- Culvert full: full load and surcharge on the top slab, weight of the walls, minimum earth pressure on the walls, maximum horizontal pressure from water in the culvert, possible upward pressure on the top slab, and no lateral pressure attributable to live load surcharge
- Culvert full: full load and surcharge on the top slab, the weight of the walls, maximum earth pressure and live load surcharge on the walls, maximum horizontal pressure from water in the culvert, and possible upward pressure on the top slab.

The above mentioned load cases are to be examined for box with cushion and without cushion. In case of box without cushion live load surcharge shall straightway be considered to act on the top slab, of course with dispersal through wearing coat and slab thickness as applicable. In case of box with cushion the live load surcharge is supposed to disperse through such cushion in both directions thereby reducing intensity of load on top slab. This shall be obtained for heaviest live load wheel, generally 70R (T) vehicle, with due restrictions due to several wheels placed simultaneously [8,15].

5. DESIGN CONSIDERATIONS

5.1 Co-Efficient of Earth Pressure

The earth can exert pressure, minimum as active and maximum as passive, or in between called pressure at rest. It depends on the condition obtained at the site. In cases where the structure is constructed before the backfill earth is placed in position and the situation is such that structure is not in position to yield on either side, the earth pressure shall reach a state at rest. In such situation the coefficient of earth pressure shall be more than active condition. In case of box since it is confined with earth from both sides the state of earth shall be at rest and a co-efficient more than the active pressure is normally adopted in the design. The earth is filled after construction of the box further the box is not in a position to move/yield therefore the pressure shall be at rest [6,7]. The co-efficient of earth pressure in case of box is taken to be 0.333 for a soil having $\phi = 30^0$ or may take value 0.5 for normal soil having $\phi = 30^0$. It is suggested that these co-efficient even when taken differently have little effect on the overall design of the section. To bring out difference in more appreciable form the two designs are compared.

5.2 Cushion

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. A box can also be placed within the embankment where top slab is few meters below the road surface and such boxes are termed with cushion [7, 14]. The height of cushion is governed by the road profile at the location of the culvert. While calculating weight of cushion on top slab, some designers take average height of earth fill coming over full length of box including sloping side fill. If so, up to what height of cushion, the box need not be reconstructed. These shall be addressed in this study.

5.3 Width or Angle of Dispersion

The maximum live load bending moment is calculated by considering the effective width of the slab. This effective width is also called the effective width of dispersion and is measured parallel to the supporting edges of slab. Dispersion of the wheel load along the span is known as the effective length of dispersion. It is also called the dispersion length [2,9]. To consider the effective width the load is dispersed over an angle with respect to the vertical. If the angle with respect to vertical line or 0 dispersion increases, the effective width of dispersion of live load also increases thus reducing the intensity of live load. This angle through which live load is dispersed is varied and the effect on final moments is studied in the present study.

6. PROBLEM FORMULATION

The following problem was considered and the above mentioned parameters were varied.

Clear Span	3 m
Clear Height	3 m
Top Slab Thickness	0.42 m
Bottom Slab Thickness	0.42 m
Side Wall Thickness	0.42 m
Clear Span	3.42 m
Thickness of Wearing Coat	0.065 m
Concrete grade	M 25
Steel grade	Fe 415

7. RESULTS AND DISCUSSIONS

IRC class 70R (Tracked) loading is considered on the box culvert. The parametric study contains variation of cushion, co-efficient of earth pressure and angle of dispersion for three load cases. The values obtained by analysis of load case I are considered in this work [11, 12, 13]. The single cell models are prepared in STAAD PRO software. The loading is applied on the box frame and the bending moments values are obtained from STAAD PRO.

7.1 Co-efficient of Earth Pressure

The co-efficient of earth pressure in case of box is taken to be 0.33 for a soil having $\phi = 30^o$ equivalent to active condition by many authors in their design. Some authors take this value as $K_a=0.50$ for normal soil having $\phi = 30^o$. A box culvert has been designed keeping all factors to be same for the two values of earth pressure co-efficient. The co-efficient of earth pressure is varied in between rest and active state i.e. $K_a=0.33$ and $K_a=0.5$.

It is observed that even though co-efficient of earth pressure increases, the combined effect with all other load combinations remains constant except for a slight increase in end moments of top, bottom & Side Wall of structure. It is also observed that difference in design of culvert without cushion is marginal. However, box with cushion shows more difference. Small variation in co-efficient of earth pressure has influence on the design of box particularly without cushion.

The following graphs represent the effect of variation of Co-efficient of Earth Pressure at the ends of top and bottom slab respectively:

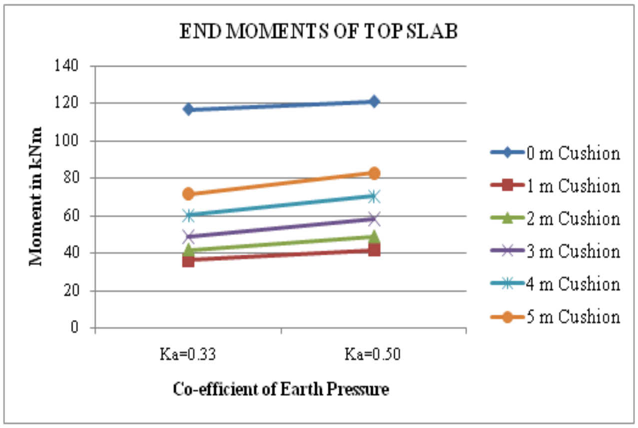

Fig. Error! No text of specified style in document.**-1 Variation of BM with co-efficient of earth pressure at end of top slab**

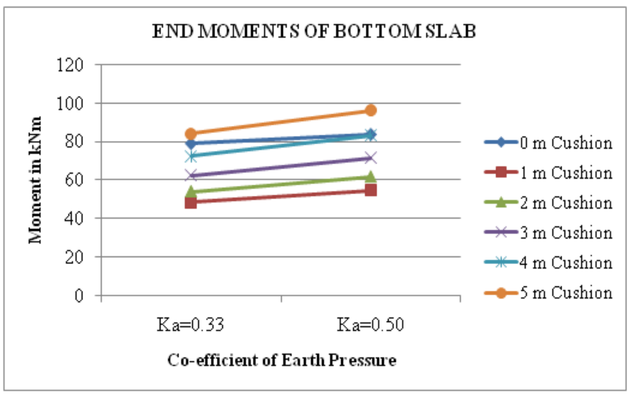

Fig. Error! No text of specified style in document.**-2: Variation of BM with co-efficient of earth pressure at end of bottom slab**

7.2 Cushion

The cushion depends on road profile at the culvert location. The height of cushion is governed by the road profile at the location of the culvert. The cushion is varied from 0m to 5m with 1m interval. Where however, there is large cushion, the live load gets dispersed on a very large area through the fill and the load per unit area becomes less and does not remain significant for the design of box, particularly in comparison to the dead load due to such large cushion.

It is observed that greater stresses are found in box structures without cushion (0m cushion). In case of box with cushion the live load surcharge is supposed to disperse through such cushion in both directions thereby reducing intensity of load on top slab. No impact factor shall be considered for box with cushion. It can be seen that the results obtained from the finite element model are very close to results obtained from one dimensional model (IS Code Method). It can be observed that in three-dimensional structural model, the whole structure working as one unit and all structural elements participating together in carrying the loads. The loadings locations for maximum shear and bending moments are at the same location as one dimensional model.

The following graphs represent the effect of variation of cushion at ends and centers of top and bottom slab respectively for K_a=0.33 and K_a=0.5:

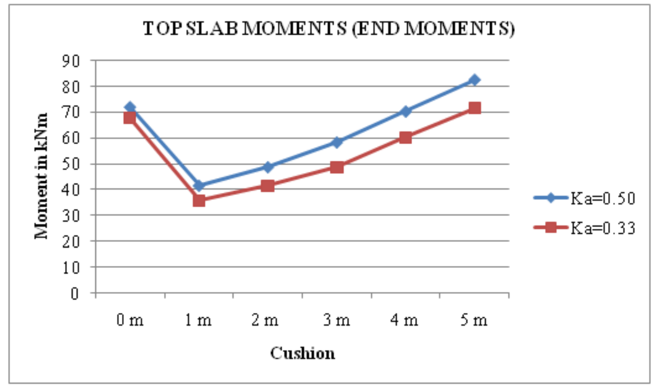

Fig. Error! No text of specified style in document.-3: Variation of BM with cushion for top slab

(End Moments)

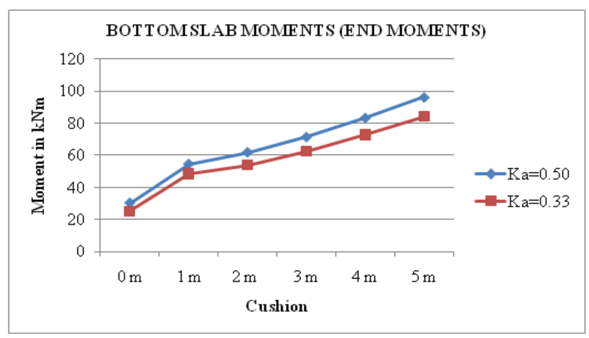

Fig. Error! No text of specified style in document.**-4: Variation of BM with cushion for bottom slab**

(End Moments)

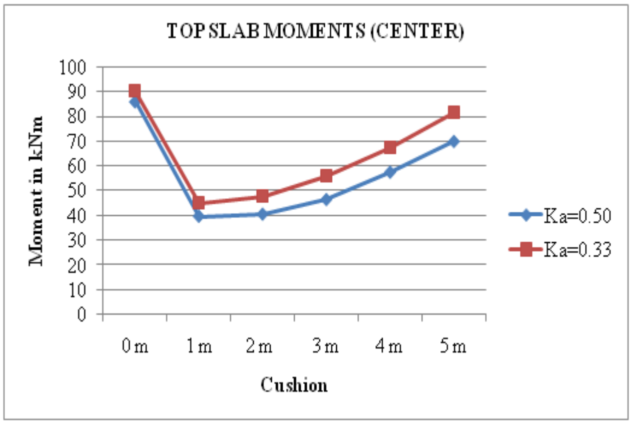

Fig. Error! No text of specified style in document.-5: Variation of BM with cushion for top slab (Center Moments)

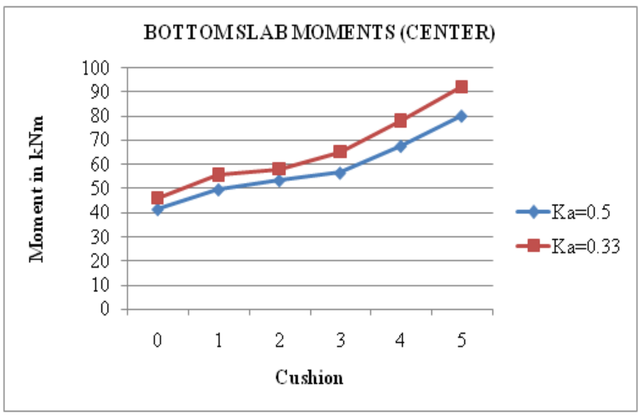

Fig. Error! No text of specified style in document.**-6: Variation of BM with cushion for bottom slab (Center Moments)**

7.3 Angle of Dispersion

The angle of dispersion through which live load is dispersed is varied. To consider the effective width, the load is dispersed over an angle with respect to the vertical. The slopes through which the loads get dispersed on the culvert were varied as 0, 0.8, 0.9, 1.0, 2.0, 2.6 and the corresponding angles are 0^0, 38.66^0, 41.98^0, 45^0, 63.43^0 and 68.96^0 respectively. In case of dead load or uniform surcharge load the effective width has no role to play and such loads are to be taken over the entire area for the design.

Angle of dispersion plays a significant role as far as consideration of live load in the design of culvert. It may be seen that considering any value for θ shall affect mainly the top slab. Bottom slab due to dispersal through walls and box with cushion due to dispersal through fill to even the top slab, are not affected much.

It was observed that even though the angle of dispersion has an impact on intensity of live load for 0^0 dispersion, the intensity of live load is maximum. If the angle with respect to vertical line or 0 dispersion increases, the effective width of dispersion of live load also increases thus reducing the intensity of live load. Similarly intensity decreases with increase in angle from 38.66^0 to 68.96^0 from the vertical axis of the road or wheel. It is found that even though intensity of live load varies with angle the overall effect when combinations of all loads are considered moments remain constant.

The following graphs represent the effect of variation of angle of dispersion for K_a=0.33 and K_a=0.5 at the ends of culvert:

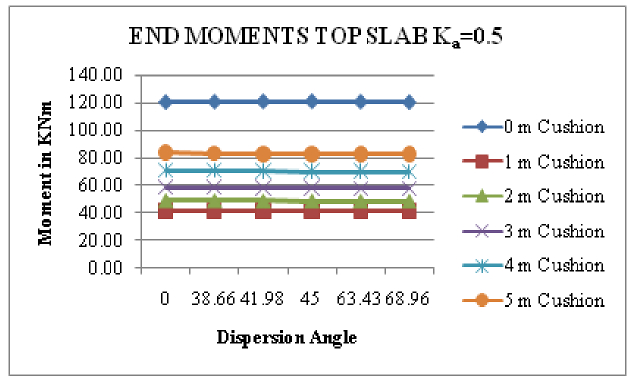

Fig. Error! No text of specified style in document.**-7: Variation of BM with angle of dispersion at ends of top slab for K_a= 0.5**

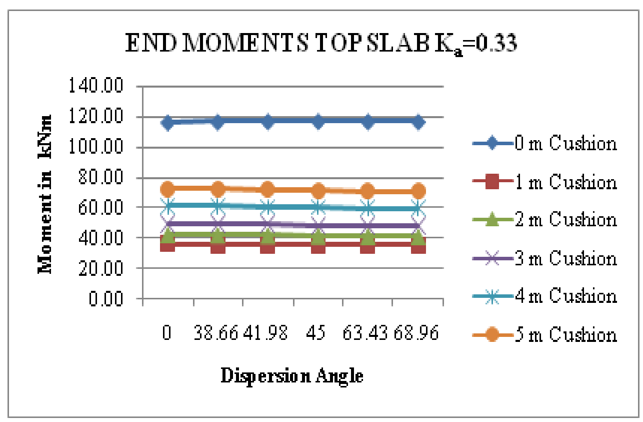

Fig. Error! No text of specified style in document.**-8: Variation of BM with angle of dispersion at ends of top slab for K_a = 0.33**

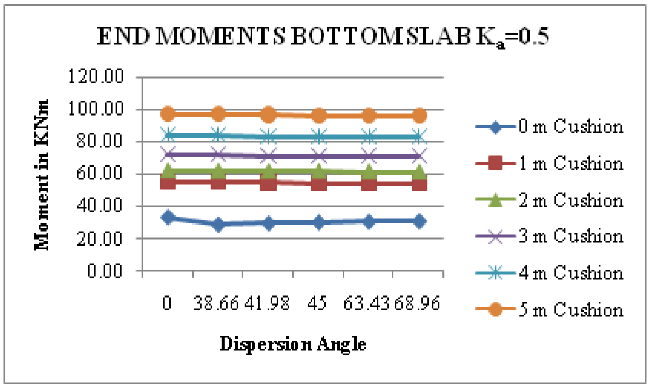

Fig. Error! No text of specified style in document.**-9: Variation of BM with angle of dispersion at ends of bottom slab for K_a = 0.5**

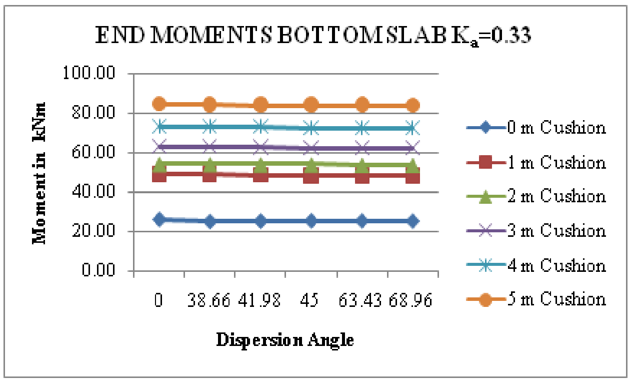

Fig. Error! No text of specified style in document.-10: Variation of BM with angle of dispersion at ends of bottom slab for K_a = 0.33

8. CONCLUSION

The box structure is analyzed for various conditions by variation of cushion, co-efficient of earth pressure and angle of dispersion for three load cases, for IRC class 70R tracked load. Based on above study prominent conclusions are presented below.

- The method of analysis of box culvert is different from that for other bridges, since they are analyzed and designed as rigid frames with equal bending moments at the end supports. The moment distribution method is used for determination of final moments at joints of the frame.
- The critical sections considered are the centre of span of top and bottom slabs and the support sections since the maximum design forces develop at these sections due to various combinations of loading patterns.
- The co-efficient of earth pressure has a little influence on the final moments therefore for safer design the co-efficient of earth pressure can be taken 0.5 which gives higher results than 0.33.
- By the studies on cushion depth it is feasible to design box type of structure with 0 meter or no cushion which shall be safe for cushion loads which may become a necessity at future date due to change in road profile.
- From the study it is seen that the moments for no cushion are higher than the moments for a cushion of 5 meters.
- Angle of dispersion affects effective width, mainly applicable for the top slab (particularly for box without cushion). As regards top and bottom slabs of box with cushion due to dispersal of loads either through walls or through fills, effective width loses its applicability.
- The angle of dispersion increases the intensity of live load but when overall effect of all loads is taken, the moments remain constant. Therefore the angle of dispersion as considered in IRC 6-2000 which is 45^0 can be considered for design.
- The results of the analysis of box culvert using the moment distribution coefficients gave accurate results when compared with analysis using FE based Software STAAD. Pro.

REFERENCES

[1] Abdel-Karim A.M., Tadros M.K., and Benak A.J. (1993). "Structural response of full-scale concrete box culvert." *Journal of Structural Engineering*, 119(11), 3238-3254.ASCE.

[2] Abolmaali A., and Garg A. K. (2008). "Effect of wheel live load on shear behavior of precast reinforced concrete box culverts." *Journal of Bridge Engineering*, Vol. 13, No. 1, January 1, 2008, 93-99, ASCE.

[3] Alia Osman Mohamed Ahmed and El Hussein Alarabi. (2011). "Development Formulation for Structural Design of Concrete Box Culverts." *Practice Periodical on Structural Design and Construction*, Vol. 16, No. 2, May 1, 2011. ASCE.

[4] Anil K. Garg, Ali Abolmaali, and Raul Fernandez. (2007). "Experimental Investigation of Shear Capacity of Precast Reinforced Concrete Box Culverts." *Journal of Bridge Engineering*, Vol. 12, No. 4, July 1, 2007. 511-517. ASCE.

[5] Anil K. Garg, Ali Abolmaali. (2009). "Finite-Element Modeling and Analysis of Reinforced Concrete Box Culverts."*Journal of Transportation Engineering*, Vol. 135, No. 3, March 1, 2009. ASCE.

[6] Awwad E.E. (2000). "Finite element analysis of concrete box culverts." *Computing in Civil and Building Engineering, Proceedings of the Eight International Conference*, ASCE, 1051-1053.

[7] Bao-guo Chen, Jun-jie Zheng, and Jie Han. (2010). "Experimental Study and Numerical Simulation on Concrete Box Culverts."*Journal of Performance of Constructed Facilities*, Vol. 24, No. 3, June 1, 2010. ASCE.

[8] Baoguo Chen and Liang Sun. (2014). "Performance of a reinforced concrete box culvert installed in trapezoidal trenches." *Journal of Bridge Engineering*, 19(1), 120-130, ASCE.

[9] Dasgupta A., and Sengupta B. (1991). "Large scale model test on square box culvert backfilled with sand." *Journal of Geotechnical Engineering*, 117(1), 156–161, ASCE.

[10] Kyungsik Kim, Chai H. Yoo. (2005). “Design Loading on Deeply Buried Box Culverts.” *Journal of Geotechnical and Geo-environmental Engineering*, Vol. 131, No. 1, January 1, 2005. ASCE.

[11] IRC: 21-2000, “Standard Specifications and Code of Practice for Road Bridges”, Section III.

[12] IRC: 6-2000, “Standard Specifications and Code of Practice for Road Bridges”, Section II.

[13] IS 456: 2000 “Plain and Reinforced Concrete Code Of Practice”

[14] Krihnaraju N., *“Design of Bridges”*, Third Edition Oxford and IBH publishing Co.Pvt.Ltd, New Delhi.

[15] Ramamurtham, S., “Design of Reinforced Concrete Structures”, Dhanpat Rai Publishing Company, Tenth Edition, 1985.