A review paper on analysis and cost-comparison of box culvert for different aspect ratio of cell

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Abstract — *A Reinforced concrete box culvert consists of bottom slab, top slab and two vertical side walls built monolithically and form a closed rectangular or square single cell. Multiple cell box culverts are obtained by inserting one or more intermediate vertical walls. If the discharge in a stream is large, multiple cell reinforced box culverts are ideal bridge structure. If the bearing capacity of the soil is low, the single box culvert becomes uneconomical because it requires higher thickness of the slabs and walls. In such cases, more than one box can be constructed side by side monolithically. This paper deals with the study of design parameters of box culverts like effect of co-efficient of earth pressure, angle of dispersion of live load and depth of cushion provided on top slab of box culverts. Coefficient of earth pressure for lateral pressure on walls, depth of cushion, width or angle of dispersion for live loads on box without cushion and with cushion for structural deformation are important items for designing the box culvert.*

Keywords — *Box culvert, Single cell, multiple cells, Aspect ratio, co-efficient of earth pressure, lateral earth pressure, cushion, angle of dispersion.*

I. Introduction

Culverts are cross drainage works with clear span less than six meters. In any highway or railway project, the majority of cross drainage works fall under this category. Hence these structures collectively are important in any project, though the cost of the structures are small.

The box culvert is the structure in which top and bottom slabs monolithically connected to the vertical walls. In slab culvert type the top slab is supported over the vertical walls (abutments/piers) but there is no monolithic connection between them. A box culvert can be constructed with single cell or multi cell. In the case of no cushion, the top slab is placed almost at road level. In the case of box culvert with cushion, box can be placed within the embankment such that top slab is few meters below the road surface. The height of cushion is governed by the road profile at the location of the culvert.

Box culvert generally provided at right angle to the stream or drainage, but sometimes road alignment may cross the stream or drainage at an angle other than right angle, in such situation a skew culvert may be provided. For a shorter span, there would be no difference in the design of culvert but it may require an edge beam and the layout of wing walls will have to be planned as per skew angle.

In box culvert, the top slab is subjected to dead loads, live loads from moving traffic. Side walls are subjected to lateral earth pressure and water pressure. And the bottom slab is subjected to self-weight of box.

The coefficient of earth pressure for lateral pressure on walls, depth of cushion, effective width (run of culvert) for live loads and applicability of braking force on box without cushion (or little cushion) for structural deformation are important items where opinion of the designers varies and need to be dealt in much detail. The effect of these parameters on the design of box culvert are significantly and therefore, required to be calculated and assessed correctly for safe designing. Some of the designer are consider the box as a rigid frame and take the length of box is one meter for design. And they consider the effect of all forces acting on this unit length. 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.

Among the types of culvert, box type culvert has many advantages compared to slab culvert or arch culvert. The box is structurally strong, safe, stable 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.

II. DESIGN CONSIDERATION

A. Co-efficient of earth pressure

The earth can exert pressure on the side wall, minimum as active and maximum as passive, or in between called pressure at rest. The value of co-efficient of earth pressure is depends on the site condition. If the structure is constructed before the backfilling of earth, take the co-efficient of earth pressure at rest. In such situation, the value of coefficient of earth pressure shall be more than active condition. The co-efficient of earth pressure in case of box is taken to be 0.333 for a soil having φ=30°or may take value 0.5 for normal soil having φ=30°. It is suggested that these co-efficient even when taken differently have little effect on the overall design of the section.

B. Cushion

In the case of no cushion, the top slab is placed almost at road level. In the case of box culvert with cushion, box can be placed within the embankment such that top slab is few meters below the road surface. 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.

C. 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. 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.

D. Load cases for design

There are three load cases which govern the design. These are given below

a) Empty box, top slab is subjected to live load and side wall is subjected to lateral earth pressure.
b) Box inside full with water, top slab is subjected to live load and side wall is subjected to lateral earth pressure.
c) Box inside full with water, top slab is subjected to live load and there is no lateral earth pressure on side wall.

III. LITERATURE REVIEW

Vinod and Chava [17] had found out stresses such as bending moment and shear force of the structure under railway loading and those stresses were computed by computational methods and also compared with conventional method. Design parameters are also computed based on Indian Railway Standards. They studied study about design of box culvert and comparative study of reinforcement details. They had done analysis on box culvert using STAAD Pro and SAP200 and find out B.M, S.F. and stresses. Size of the box culvert was 3mx3m. Area of reinforcement for top and bottom slab was also calculated.

Pavan D. Tikate and S.N. Tande [12] had studied the effect of the variation of cushion depth, coefficient of earth pressure, width or angle of dispersion on the structural behaviour 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. They concluded that for safer design the co-efficient of earth pressure can be taken 0.5 which gives higher results than 0.33.

Abhijeet and Vidya [8] had done analyse of box culvert using STAAD Pro software and find out B.M. and S.F. at support and mid span. They had presented analysis of a Reinforced concrete box culvert using finite element method. Three-dimensional configuration of the space has been considered and computer code has been developed for finding the bending moments, member forces and support reactions due to equivalent traffic load, lateral soil pressures.

M.G. Kalyanshetti and S.A. Gosavi [9] prepared model of single, double, triple cell box culvert in STAAD Pro and developed C language program which gives quantity of steel and total cost of culvert. IRC class AA tracked live load was considered. The analysis was done by using stiffness matrix method and a computer program in C language was developed for the cost evaluation. Study has carried out related to variation in bending moment; subsequently cost comparison was made for different aspect ratios. 12m channel length was fixed and 2 to 6m height variation was taken in size of box culvert. They concluded that for different cells and different heights the optimized thickness of box culverts was to be obtained by the different formulas which will a cost-effective design of the box.

Feirusha S. H. [5] had studied Finite element analysis for find out the value and location of maximum and minimum principal stresses and compare the value and location of principal stresses between three loading condition of analysed box culvert. COMSOL software was used for analysis. Dimension of box culvert = 3.6m x 3.6m.

Neha et al. [10] considered the parameter like angle of dispersion, depth of cushion, co-efficient of earth pressure for analysis of box culvert. Size of culvert was taken as 3m x 3m with and without cushion of 5m. they concluded that Small variation in co-efficient of earth pressure has little influence on the design of box particularly without cushion. For box without cushion braking force is required to be considered particularly for smaller span culverts.

Osama Abuhajar et al. [11] carried out study on soil culvert interaction(SCI). Small scale centrifuge physical model tests were conducted to investigate SCI considering the height and density of soil above the culvert and the geometry of the culvert. The results of those centrifuge tests were used to calibrate and verify a numerical model that was used to further investigate the response of box culverts to static Loads.

Sujata and R. Shreedhar [16] had carried out the work to evaluate the design coefficients for shear force, bending moment and normal thrust for single cell, two celled and three celled box culvert subject to various loading cases. The study showed that 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 live load and the culvert is running full of water and 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.

Anil K. Garg and Ali [3] presented the development of an analytical program to investigate the shear capacity of precast reinforced concrete box culverts. They were prepared three-dimensional finite-element models (FEMs) and analysed using ABAQUS software. Three-dimensional shell and solid elements were used to model the culvert systems. The load was placed at a distance d from the tip of the haunch of the box culvert, where d is the effective depth of tension reinforcement at mid span, in the top slab of the box culvert. To simulate the wheel, load a 25.4 cm x 51 cm plate is used experimentally as well as in finite-element modelling, which is used by AASHTO to model the wheel load of a HS20 truck. The load-deflection plots obtained from the FEM analyses were compared with the experimental test results, which showed close correlation.

Ping Zhu et al. [13] had found an optimal design with the best combinations of sidewalls, floor, and roof thickness of the box-culvert structure. Finite element method was used for analysis of the stress and deformation of the box-culvert structure. As a result, an optimal design was obtained, which not only reduces the use of concrete, but also reduces the demands on the bearing capacity of the foundation soil.

A.D. Patil et al. [1] had discussed the behaviour of box culvert with cushion and without cushion load for different aspect ratios and also studied the effect of different load combinations which will produces worst effect for safe structural design. They concluded that the load combination with empty box was found to be the critical combination for all values of aspect ratios under consideration. They used SAP2000 for analysis of box culvert.

Ali Abolmaali et al. [2] experimented on six full-scale 2.4 m span box culverts. Box culvert were tested to failure by subjecting each culvert to the AASHTO HS-20 wheel load. The location of the wheel load was varied in order to identify the critical shear location. Size of the box culvert was 2.4m x 1.2m x 1.2m.

Raju Acharya et al. [14] had measured Deflections under the culvert roof and pressures on the culvert measured at field during loading. A three-dimensional (3D) numerical model of the culvert was developed using a finite-difference program. The numerical model with material properties was verified with the field test results. They used FLAC3D software for analysis. Size of box culvert was 3m (H) x 6.75m (L) and span (varies).

Sarah L. Orton et al. [15] had determined the effects of live load (truck loads) on RC box culverts under soil fills of different thicknesses. The study considered the field testing of 10 existing reinforced concrete box culverts with fill depths ranging from 0.76 m (2.5 ft) to 4.1 m (13.5 ft).

IV. CONCLUSIONS

From the above literature following conclusion are made:

- Depth of cushion, co-efficient of earth pressure, width or angle of dispersion for live loads on box culvert without cushion and with cushion are the important items for designing the box culvert.

- Greater stresses are found in box culvert structures without cushion, compare to box culvert with cushion.
- If the angle of dispersion is 0°, the intensity of live load is maximum.
- For the safe design, the co-efficient of earth pressure can be taken 0.5 which gives higher results than 0.33.
- Box culvert does not need any elaborate foundation, and can easily be placed over soft foundation by increasing base slab projection to retain base pressure within safe bearing capacity of ground soil.
- Box culvert is easy to add length in the event of widening of the road.

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