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SIMPLIFIED MODEL FOR DESIGN RCC BOX CULVERTS BY STAAD.PRO

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ABSTRACT

Reinforced concrete box culvert consists of top slab, bottom slab and two vertical side walls built monolithically which form a closed hollow rectangular or square single cell or multiple cells. Culverts are required to be used under earth embankment to construct and pass roads or railways at the moment for crossing of water from both sides of earth embankment. Current of great rivers and their tributaries in my country have encouraged me to go ahead to find simplified method for design box culvert. This research focuses on analysis and design of single cell by software "STAAD.Pro" on a segment in one meter length from culvert barrel to produce a plane structure like instead of space structure. The structure is subjected to various types of loads and supported by a bed of springs instead of soil interaction according to Winkler's modeling. The author believes that he is able to create a method which is quick, accurate and optimal solution for design RCC box culvert. This paper was carried out using ACI-code 2011 with SI units.

Keywords: box culvert, RCC culvert, single cell, soil interaction, spring stiffness.

1. INTRODUCTION

Tigris and Euphrates are two great rivers in Iraq having many tributaries which need to construct more box culvert to facilitate the construction of roads and railways passing through water streams. A culvert is a cross-drainage structure having types such as box, pipe and RCC Solid Slab Culverts. RCC box culvert is the most common and its structural components are top slab (called, deck), base slab (called, invert) and two vertical side walls (called, upright) built monolithically which form a closed hollow rectangular or square single cell or multiple cells. By reading and browsing a number of research papers, anyone can find many methods to analysis and design box culvert such as finite element, moment distribution, genetic algorithms…etc. Sometimes these methods used manual calculations or software. All of these methods are correct, but need more time and effort. So, this paper deals with study of simplified method for design single cell RCC box culvert using software STAAD.ProV8i according to ACI-code 2011, after inserting modification to the culvert structure.

The Winkler's model was used to represent the structure supported by a bed of springs instead of soil interaction. The earliest use of these springs to represent the interaction between soil and foundation has been attributed to Winkler (1876). In its classical form the, Winkler method assumes each spring is linear and acts independently from the others, and that all the springs have the same stiffness k_s. This representation has the desired effect of increasing the bearing pressure beneath the columns, and thus is a significant improvement over the rigid method. However, it is still only a coarse representation of the true interaction between mats and soil (Hain and Lee, 1974, Horvath, 1983, Coduto, 2001).

2. EXPERIMANTAL PROCEDURE

To know the details of the study, the structural analysis and design will be focused on the culvert that has the following characteristics:

A. Geometry

- Total length of culvert is equal 15 meters. Segment in one meter length will be taken to perform the analysis and design so that considers the structure as a plane instead of space structure.
- Depending on the discharge data every ten years, the highest level of water in front of the culvert is one meter. Choose, squire section single cell with dimensions (2x2 c/c) meters.Precisely, the dimensions can be chosen from the equation $Q_{10} = V * A$.
- Thickness of all components will be chosen equal to 400mm, as a condition that not less than sixth of dimensions. So, D=2+0.4=2.4m.

B. Loads analysis

After the verification and collection of the field data, the worst case of loading that applied to the culvert barrel will be calculated.

The Loads that applied to the deck are:

- Due to earth embankment,

$$W_1 = \frac{L_1 + L_2}{2} * d * \gamma_e * \frac{1}{L_2} \qquad (1)$$

$$W_1 = \frac{8 + 11}{2} * 3 * 18 * \frac{1}{11} = 46.6\text{kN/m}$$

- Due to live loads,

$$W_2 = \frac{\omega * L_1}{L_2} \qquad (2)$$

$$W_2 = \frac{20 * 8}{11} = 14.5\text{kN/m}$$

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- Due to wheel loads as shown in Figure-1,

$$W_3 = \frac{2P}{[2(a+d)-x]d} \quad (3)$$

$$W_3 = \frac{2(70)}{[2(0.6+3)-1.8](2)} = 13\text{kN/m}$$

Summary of loads that applied to the deck,
W_u = 46.6+14.5+13=74.1 kN/m

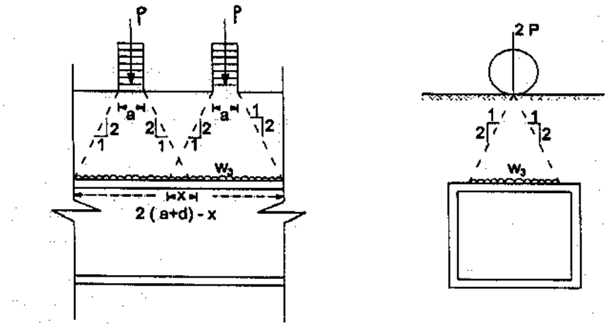

Figure-1. Dispersion of wheel loads.

The loads that applied to the uprights according to diagram shown in Figure-2 are:

- Due to earth pressure,

$$K_a = \frac{1-\sin\emptyset}{1+\sin\emptyset} \quad (4)$$

$$K_a = \frac{1-\sin 30}{1+\sin 30} = \frac{1}{3}$$

at top outer edge of the culvert section,
$e_1 = \gamma_e.d.K_a$, while at bottom,
$e_2 = \gamma_e.(d+D).K_a$. Easily, pressure can be considered as uniform distributed and its amount,

$$e = \gamma_e.\left(d+\frac{D}{2}\right).K_a \quad (5)$$

$$e = 18\left(3+\frac{2.4}{2}\right)\frac{1}{3} = 25.2\text{kN/m}$$

- Due to surcharge of live loads,

$$e_s = \omega.K_a \quad (6)$$

$$e_s = 20\left(\frac{1}{3}\right) = 6.7\text{ kN/m}$$

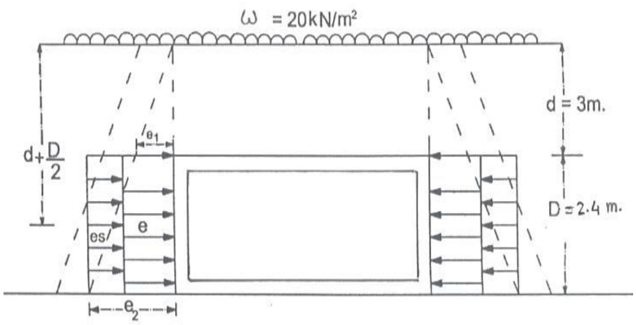

Figure-2. Pressure diagram on uprights.

Summary of loads that applied to the uprights,
e_u = 25.2+6.7=32 kN/m

The Loads that applied to the invert due to water pressure are, $W_w = \gamma_w *$ water height $= 10(1) = 10$kN/m.

C. Input file

To provide the simplified culvert model which is suggested as shown in fig.3, the following well be considered:

a) Invert member well be divided in to four members each 0.5m to induce springs at the ends of each member to create bed springs as that Winkler has denoted.

b) (Bowles, 1996) has suggested the following for approximating soil stiffness K_s,

$K_s = 40(S.F)q_a$kN/m^3(7) K_s = 40(2)(80) =6400 kN/m^3

For the inner support at intermediate nodes of invert member,
KFY will be calculated equal to,
KFY=6400(0.5*1.00)= 3200kN/m,
While for the outer supports,
KFY=6400(0.25*1.00)= 1600kN/m.

- The input file content the following date,

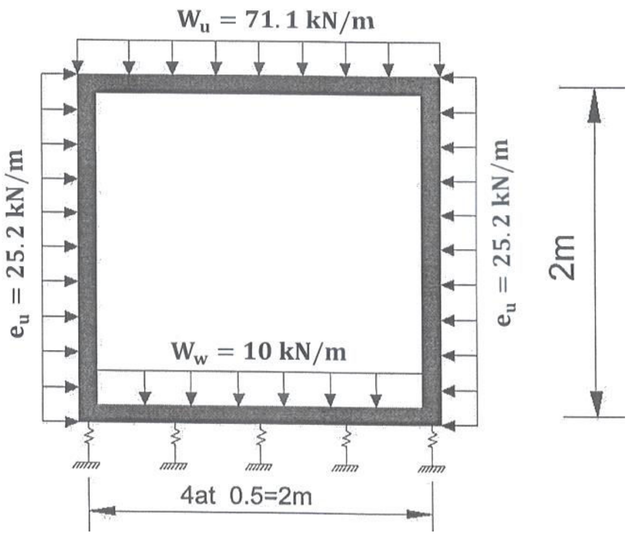

Figure-3. The simplified model .

STAAD PLANE .... analysis and design of the culvert
START JOB INFORMATION
ENGINEER DATE 31-Jan-18
END JOB INFORMATION
INPUT WIDTH 79
UNIT METER KN
JOINT COORDINATES
1 0 0 0; 2 2 0 0; 3 2 2 0; 4 0 2 0; 5 0.5 0 0; 6 1 0 0; 7 1.5 0 0;
MEMBER INCIDENCES
1 1 5; 2 2 3; 3 3 4; 4 4 1; 5 5 6; 6 6 7; 7 7 2;
DEFINE MATERIAL START
ISOTROPIC CONCRETE

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E 2.17185e+007
POISSON 0.17
DENSITY 23.5616
ALPHA 1e-005
DAMP 0.05
TYPE CONCRETE
STRENGTH FCU 27579
END DEFINE MATERIAL
MEMBER PROPERTY AMERICAN
1 TO 7 PRIS YD 0.4 ZD 1
CONSTANTS
MATERIAL CONCRETE ALL
SUPPORTS
1 2 FIXED BUT MZ KFY 1600
5 TO 7 FIXED BUT MZ KFY 3200
LOAD 1 LOADTYPE None TITLE LOAD CASE 1
SELFWEIGHT Y -1
MEMBER LOAD
1 5 TO 7 UNI GY -10
3 UNI GY -71.1
4 UNI GX 25.2
2 UNI GX -25.2
PERFORM ANALYSIS
PRINT ANALYSIS RESULTS
START CONCRETE DESIGN
CODE ACI
UNIT MMS NEWTON
FYMAIN 350 ALL
FC 25 ALL
CLS 75 ALL
CLB 75 ALL
CLT 75 ALL
MAXMAIN 20 ALL
MINSEC 6 ALL
DESIGN BEAM 1 TO 7
END CONCRETE DESIGN
FINISH

D. Output file

From Figure-4 till Figure-7 are drawn for whole structure by STAAD. Pro except of fig. 8. As a result of STAAD. Pro has no facility to draw main reinforcement details for whole structure, the author is drawn Figure-8 according to the data of the outputs.

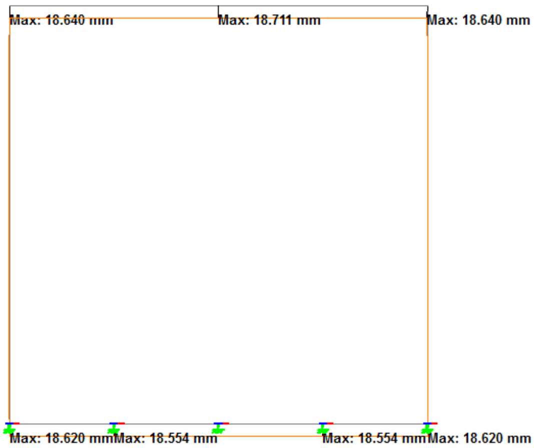

Figure-4. Displacement diagram, drawn by STAAD.Pro.

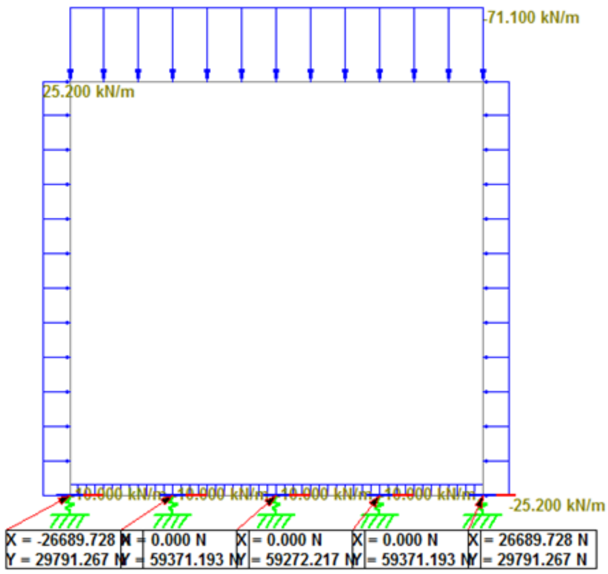

Figure-5. Actions and reactions, draw by STAAD.Pro.

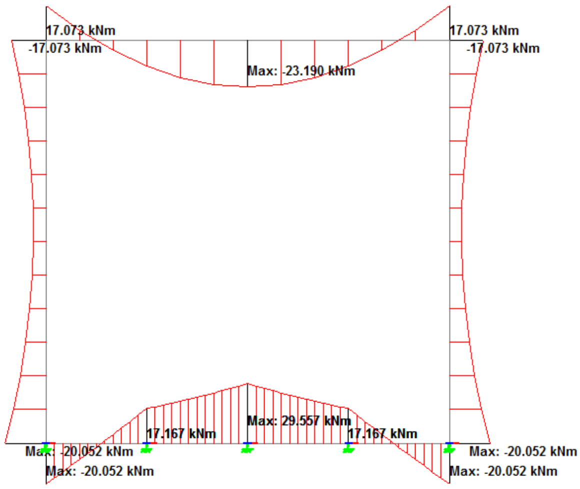

Figure-6. Bending moment diagram, draw by STAAD.Pro.

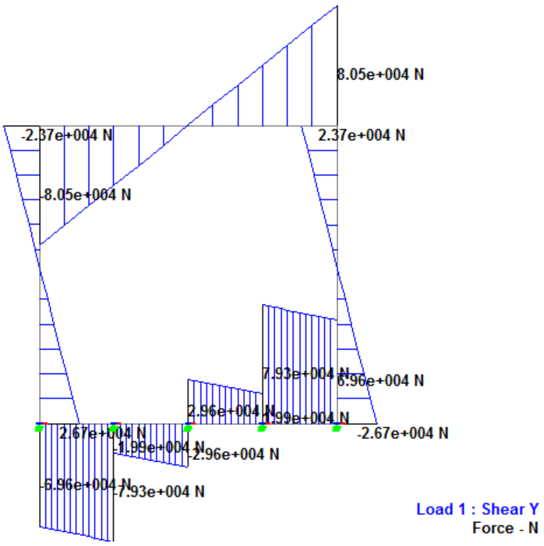

Figure-7. Shear force diagram, draw by STAAD. Pro.

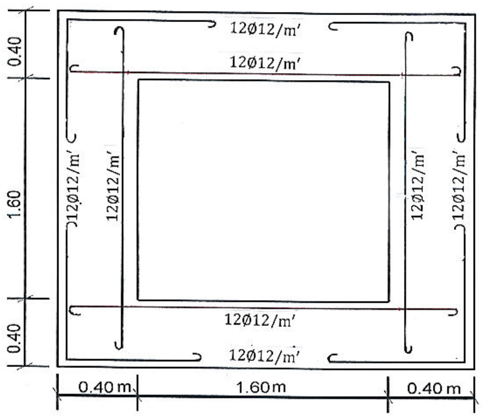

Figure-8. Reinforcement details, draw by the author.

3. RESULTS AND DISCUSIONS

- Several methods have been tackled in the analysis and design of RCC box culverts for researchers in this field. By comparing this simplified method with the previous methods, there is no noticeable difference in the values and shape of the bending moment and shear force diagrams.
- Spacing between the springs is installed by trial and error method till a logical space was reached. Closer of spacing means more accurate values that are obtained for the outputs, especially that for invert members.
- Symmetry of section properties and loads applied to the culvert barrel, causes that Joint displacement, support reactions, bending moment and shear force diagrams are symmetrical also.
- STAAD.Pro provided main reinforcement without secondary. Area of secondary reinforcement $A_{s,min}$ for resistance shrinkage and temperature stresses must be calculated by the users according to ACI.Code as follow,

  for deck and invert,

$A_{s,min}$= 0.002(400)(1000)=800mm^2,
for uprights,
$A_{s,min}$= 0.0025(400)(1000)= 1000mm^2.

- Reinforcement ratio (ρ) for maximum bending

moment is less than the minimum (ρ_{min}).

Therefore, STAAD.Pro calculates an equal reinforcement area from (ρ_{min}) for all effective sections. As mentioned in ACI.Code,
Max. bending moment M_u =29.55kN. m .

$$\rho = \frac{f_c'}{1.18 f_y}\left[1-\sqrt{1-\frac{2.36\mathrm{M_u}}{0.9\mathrm{b}(\text{effective depth})^2 f_c'}}\right] \quad (8)$$

$$\rho \frac{25}{1.18(350)}[1-\sqrt{1-\frac{2.36(29.55*10^6)}{0.9(1000)(400-75)^2(25)}}]$$

$$\rho = 0.0009$$

$$\rho_{min} = \frac{\sqrt{f_c'}}{4f_y} = \frac{\sqrt{25}}{4(350)} = 0.00357,$$

$$sothatnotlessthan \frac{1.4}{f_y} = \frac{1.4}{350} = 0.004$$

So, use $\rho_{min} =$ 0.004,
and the main reinforcement area ($\mathrm{A_s}$)is,
$\mathrm{A_s} = 0.004(1000)(450-75) = 1300\mathrm{mm}^2$,
use $12\text{Ø}12/\mathrm{m}'$, as shown in Figure-8.

4. CONCLUSIONS

Based on the results of this study, the following conclusions are drawn:

This study focuses on reinforcement concrete box culvert having single cell so that space structure for culvert barrel transformed to the plane structure represent segment of one meter length.

Plane structure is subjected to the various type of loads and supported on bed springs equivalent to the soil interaction according to Winkler's model.
Closer of spacing between springs, mean more accurate values that can be obtained for outputs of STAAD.Pro such as bending moments, shear forces and support reactions.

Finally, the author believes that he is able to create a simplified method which is quick, accurate and optimal solution for design RCC box culvert by using SI units, ACI-Code 2011 and software STAAD.Pro.

NOTATION AND DEFINITIONS

Q_{10}	rate of discharge each 10 years, $\mathrm{m^3/sec}$.
V	flow velocity 0f water, m/sec.
A	cross sectional area, m^2.
D	outer dimensions of culvert section, m.

d depth of earth embankment, 3m.
L_1 width of road or width of top earth embankment, 8m.
L_2 width of the base earth embankment or effective width of dispersed loads, as a result of assume that the angle of dispersion and side slope of earth embankment is the same and equal to 2:1. So, L_2 in both cases is equal to L_2 =d +L_1 = 11m.
γ_e density of wet soils, kN/m^3.
ω distributed live load, kN/m^2.
P concentrated wheel loads. According to AASHTO the load of vehicles (HS20-44) is equal to (16000Ib=70kN) and the distance between two wheels centers, (6ft=1.8m).
a width of double wheel, (2ft=0.60m).
$\emptyset$ angle of soil friction, for sandy soil taken 30°.
γ_w density of water, kN/m^3.
q_a allowable bearing capacity for the soil, kN/m^2.
S.F safety factor depend on type of soil. For sandy soil taken 2.
KFY spring stiffness for supports as denoted by STAAD.Pro, kN/m.
f_c' specified compressive strength of concrete, MPa.
f_y specified yield strength of steel, MPa.
b width of concrete section, mm.

REFERENCES

[1] 2011. ACI Committee 318.Building Code Requirements for Reinforced Concrete (ACI 318-11), American Concrete Institute, Detroit, USA.

[2] Bowles, J. E, P.E., S.E. 1996.Foundation Analysis and Design, Fifth Edition, McGraw-Hill, USA. pp. 503-506.

[3] Coduto, D.P. 2001.Foundation Design Principles and Practices, second edition, Prentice-Hall, New Jersey, USA. pp. 358.

[4] Komal S.Kattimani, R.Shreedhar. 2013. Parametric Studies of Box Culverts", IJRES.1(1): 58-65.

[5] Siva Rama Krishna, Ch. Hanumantha Rao. 2017. Study on Box Culvert Soil Interaction. IJCIET. 8(1): 734-738

[6] Abdul-Hassan K. Al. Shukur1, Mohammed Abbas Al. Jumaili2, Hawraa Ali Hussein3. 2014. Optimal Design of Reinforced Concrete Box Culvert by Using Genetic Algorithms Method. IJSER. 5(1): 1890-1898.

[7] PAUL TOM P. 2014. Analysis and Design of Bridge and Culvert.M. Eng. Thesis, National Institute of Cnology, Karnataka, Surathkal, Mangalore, India.

[8] Sujata Shreedhar1, R.Shreedhar2.Design coefficients for single and two cell box culvert. IJCSER.3(3): 475-494.

[9] Wang C., Salmon C.G. and Pincheira J.A. 2007.Reinforced Concrete Design, 7th Edition, Wiley, USA.pp. 581-592.

[10] Hassoun M. N. and Al-Manaseer A. 2008.Structural Concrete Theoryand Design, 4th Edition. Wiley, USA. pp. 581-592.

[11] Nilson, A.H., Darwin, D., and Dolan, C.W., Design of Concrete Structures, 14th Edition, McGraw-Hill, USA, 2010. pp. 300-320.

[12] Davis, C.V. 1990.Hand Book of Applied Hydraulics. McGraw-Hill, USA.

[13] Abdulkareem M.B. Al-Shamma. 2014. Novel Flowchart for Design of Concrete Rectangular Beams. IJSER. 5: 231-233.

[14] Abdulkareem M.B. Al-Shammaa. 2014. Create Shear Stair for Reinforcement of Concrete Beams. IJ RET. 3(1): 412-414.