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REDUCTION OF BOX CULVERT STRESSES

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Abstract

A culvert is a crosswise and fully enclosed drainage structure that runs under a road. The amount of water flowing is the main role in determining the dimension of the opening and then which type of culvert, the area that is discharged into it and how deep the culvert is being installed. Whereas the thickness of the culvert section is designed based on the loads applied to the culvert. Therefore, this research focuses on the impact of using haunches on the economy of the culvert design. The results show the effect of haunch on the stresses of the box culvert while prediction equations for most of the cases are provided. The study considered the cost comparison made for different width of the haunch.

Keywords: haunch, rectangular box culverts, thickness of culvert, width of culvert

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1. Introduction

Culverts can be of many shapes such as arch, and box. They are built of stone, brick, or reinforced concrete. R.C. box culvert consists of two slabs (top & bottom) and two walls constructed concurrently to constitute a closed box has one cell or more than one. Construction of box culvert depends on the many factors such as soil parameters. There are two methods of construction: as U-shaped with a top, slab and as a raft foundation with an inverted U pattern. Multiple cell box culverts are formed from one or more intermediate vertical wall.

The design engineers calculate the size of opening as being the amount of flow from the upper level to the lower level. Because the culvert passes through underground from side to another side, it is exposed to the same traffic loads from the street and consequently constructed for such loads. Box culvert has an important advantage since is less expensive in construction and maintenance and can be constructed in a brief time.

The loads of box culvert can be aligned vertically and horizontally. The vertical load is the weight of infill, slab and walls, while the horizontal load is the lateral earth pressure on the walls.

Kim and Yoo (2005) used the Duncan soil model for backfill properties and in situ soil. Characterized and quantified the data from numerous models have many parameters under three typical installation methods: embankment, trench, and imperfect trench installation by using regression analysis. In the research of Chen et al. (2009), a full-scale experiment with numerical simulation was accompanied to evaluate the deviation of vertical earth pressures on the culvert and soil arching in backfill. They calculated the differences in footing stress. They concluded that when the height of the culvert is beyond a certain value the soil arch forms. The vertical earth pressure on the culvert is considerably changed from that mentioned by the CGCDHBC. Chen and Sun (2014) investigated the difficult soil-structure interaction and provide a reference for the design of the trapezoid trench installation (TTI) culverts. Parametric studies were carried out to inspect the important influencing factors (the gradient angle of the trench, the bottom breadth of the trench, the culvert sizes, and the stiffness of backfill adjacent to the

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culvert) of the culvert act. The amount of the vertical earth pressure and deformations of the (TTI) culvert is influenced by the soil arches as long as the backfill is high enough. Bian et al. (2016) presented full-scale model experiments with tire loads applied for different locations. Based on the outcomes, they pointed out that the depth of cover is at least 1m. Lee et al. (2017) discussed about the Jointed Concrete Pavement from the point of freezing view on the box culvert. They concluded that there are two methods for avoiding the freezing: by using anti-freezing material and by applying subgrade to the surface of the culvert.

Vaslestad and Sayd (2018) described three instrumented full-scale experiments using geofoam for load reduction on buried stiff culverts. The method involved installing a compressible presence (EPS Geofoam) above rigid culverts in order to reduce the vertical earth pressure. The vertical earth pressure will reduce by using geofoam. Liu et al. (2018) determined a reason to mitigate early-age cracking in culverts by evaluating the cracking risk. The finite-element analysis was used in the model and the results pointed out that the use of concrete with a lower coefficient of thermal expansion, contraction joints, and sand-lightweight concrete will decrease the risk of early-age cracking in cast-in-place concrete culverts. Ghahremannejad et al. (2019a) focused on decisive of the shear strength of R.C. box culverts with a uniformly distributed load at the top slab. A structure was designed to change the concentrated displacement to the equivalent uniformly distributed forces applied at the top of the structure permitting a displacement control analysis algorithm to be performed. The results of the numerical models and experimental program differed from ACI 318-14 formulation for the shear strength of top slabs of R.C. box culverts. Ghahremannejad et al. (2019b) focused on the concrete shear strength of the top slab of R.C. box culverts under uniformly distributed loads. The evaluation of the outcomes of the study agrees with the AASHTO's approach results. Hussien (2020) focused on the ratio between stresses (0-40) cm haunch. He concluded that the increase of the concrete amount of haunch is less than the effect of haunch on the stresses.

In this framework, the main objective of the present paper consists in recognizing the behavior of the culvert and to present the useful equations which help the designer engineer to calculate the percentage of the reduction of stresses.

2. Case study

The finite element method is a famous method to calculate the stresses in the structures. We used this method to know the reduction percentage for the culvert stresses when we use the haunch. As it is already known, when the element model has many nodes the results will be more accurate so we use a solid element of this research. We apply the spring model as a support for the culvert.

The box culvert is shown in Fig. 1 and was studied by using finite element program to determine the internal stresses and to clarify the performance of a box culvert under different loads, by changing the geometry of box culvert such as thickness (t), width (B), and the haunch dimensions (DH). Then we write some of the prediction equations for some specific cases by using Coulomb's Theory to compute the earth pressure on vertical side-walls of the box culvert.

The value of earth pressure is given by $P = \rho\ Ki\ H$, where Ki is an active earth pressure coefficient, ρ is the soil density and H is the box height. The earth applies pressure on the sidewall, maximum as passive and minimum as active. The Ki value is governed by the soil condition. The earth pressure coefficient is 0.333 for soil having φ=30°. The soil density is 1.8 t/m^3, the concrete density is 2.5 t/m^3, the fill over the culvert is 0.5 m, and 0.4 t/m^2 for live load.

The culvert width was varied from 5.0 to 6.0 m, the culvert height was 4.0 m, the culvert thickness was varied from 0.4 - 0.6 m, and the dimensions of haunch was varied from 0 - 0.5 m.

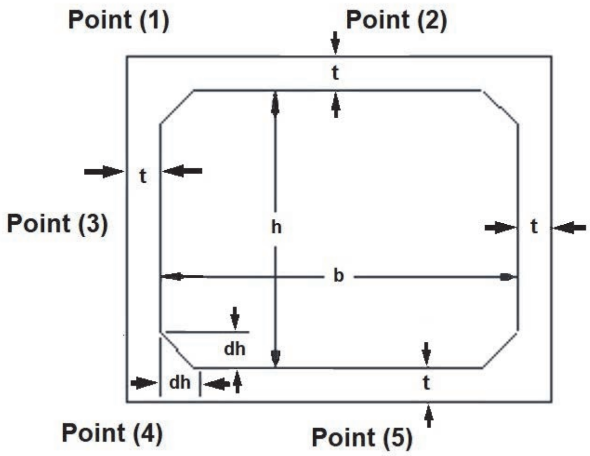


Fig. 1. The section of culvert

3. The standard recommendations for box culverts (JTG D60-2004)

The designer engineer should be familiar with the cases of loading as follows:

1) Permanent load: this case of loading occurs after construction and the culvert is working, the limit state design is required for all internal forces.

2) Temporary load: this case of loading occurs during the construction and the culvert is not working yet; the limit state design requires estimation of the bearing capacity.

3) Emergency situation: this case of loading occurs during the construction and the culvert is not working at the time because of an emergency situation; the limit state design requires the estimation of the bearing capacity.

For reduction of the stresses of the box culvert by using the haunch, the stresses are calculated using SAP2000. S11 and S22 refer to horizontal and vertical direction stresses.

4. Results and discussion

Figs. 2a-e and 3a-e, show the relationship between the dimensions of the haunch and thickness of culvert for S11 and S22 at the points (1, 2, 3, 4 and 5) in Fig. 1. With increasing the dimensions of haunch by 12.5% of the initial thickness of culvert, S11 and S22 decreased with (19, 2, 1, 34 and 1% for points 1-5 and with 12, 2, 12, 11 and 2% for points 1-5). The same pattern occurred with the increasing of the culvert thickness for the same percentage, S11 and S22 decreased by average values (10, 13, 1, 10 and 8% for points 1-5 and with 10, 14, 26, 8 and 10% for points 1-5). These results limited the haunch dimensions from 0-50 cm and culvert thickness from 40-60 cm. From Tables 1-3, when the dimension of haunch equals 50 cm, the values of S11 and S22 have been reduced at the points (1,4) by a large average (79 and 67%), (91 and 64%) respectively, and at points (2,5) by a little average (17 and 18%), (11 and 14%).

The variance in the concrete amount is 3.36% between the minimum and maximum hunch dimension. From Tables 4-6, the effect of 50 cm haunch reduces the values of S11 and S22 by an average of 79.43% and 67.6% for point (1), 91.41% and 64.8% for point (4). Also, the average is 19.08% and 21.9% for point (2), 15.15% and 19.34% for point (5). The variance in the concrete amount is 3.45% between the minimum and maximum hunch dimension. From Tables 7-9, when the dimension of haunch equal 50 cm, the values of S11 and S22 have been reduced by an average of 79.60% and 68.08% for point (1). 93.68% and 65.22% for point (4). But the average is 25.74% and 32.8% for point (2), 18.7% and 25.73% for point (5). The variance in the concrete amount is 3.55% between the minimum and maximum hunch dimension. Figs. 4a-b show the relationship between the haunch dimensions and S11, S22 for the culvert width = 5, 5.5 and 6 m in thickness = 0.4 m, for points 1 and 2.

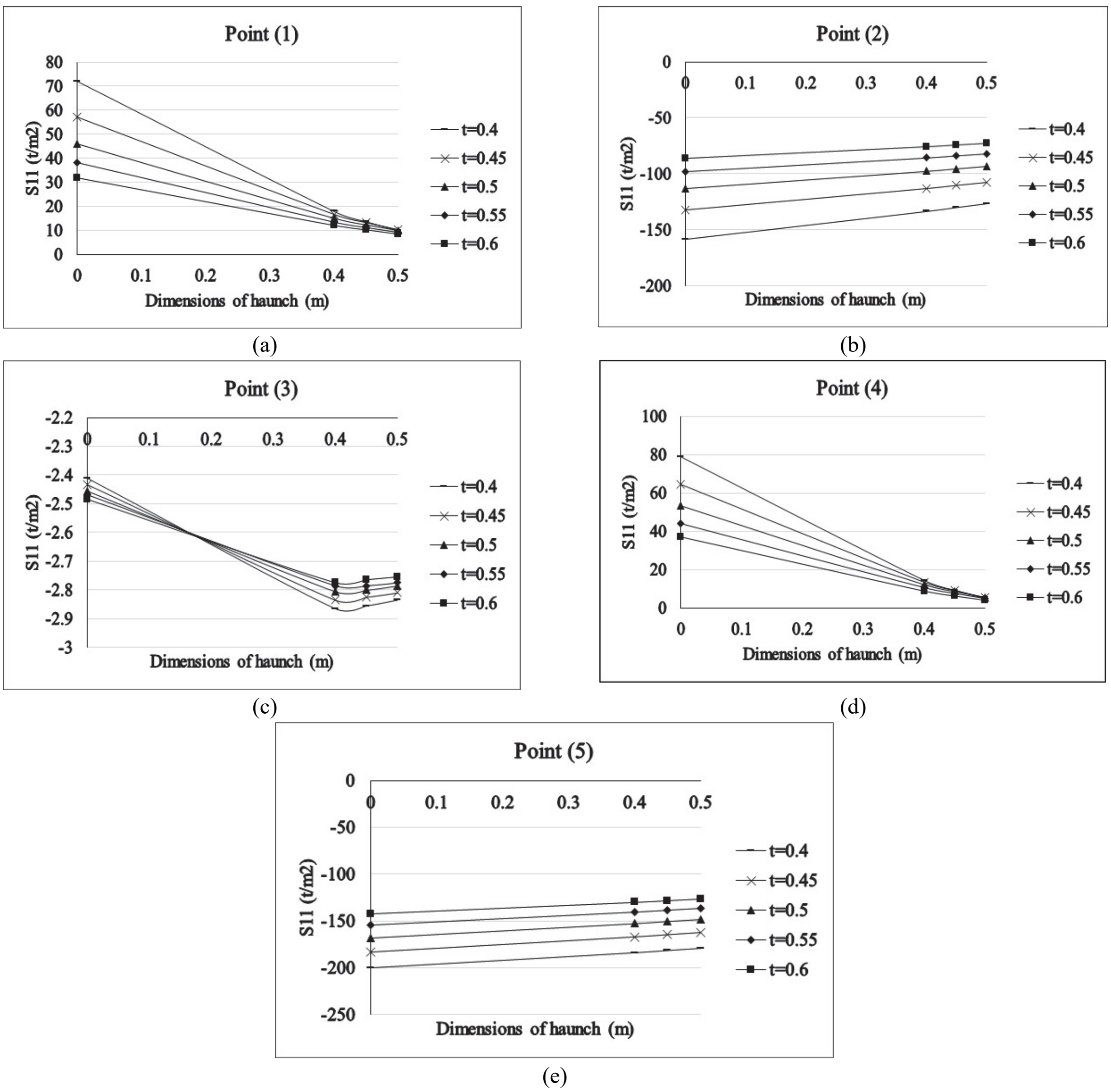


Fig. 2. The relation between haunch dimensions and culvert thickness for S11 for case b=6m (a) at point (1); (b) at point (2); (c) at point (3); (d) at point (4); (e) at point (5)

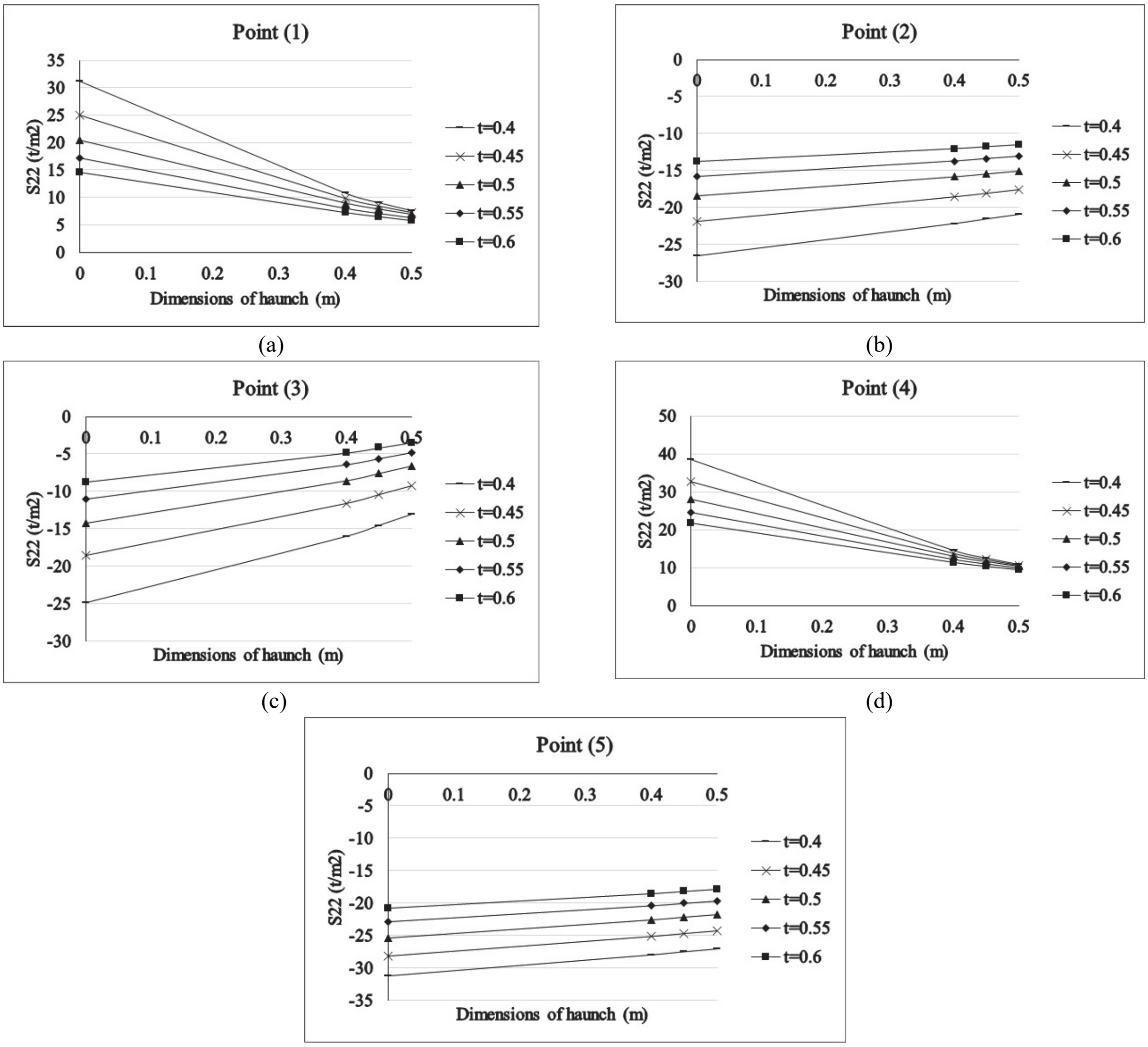
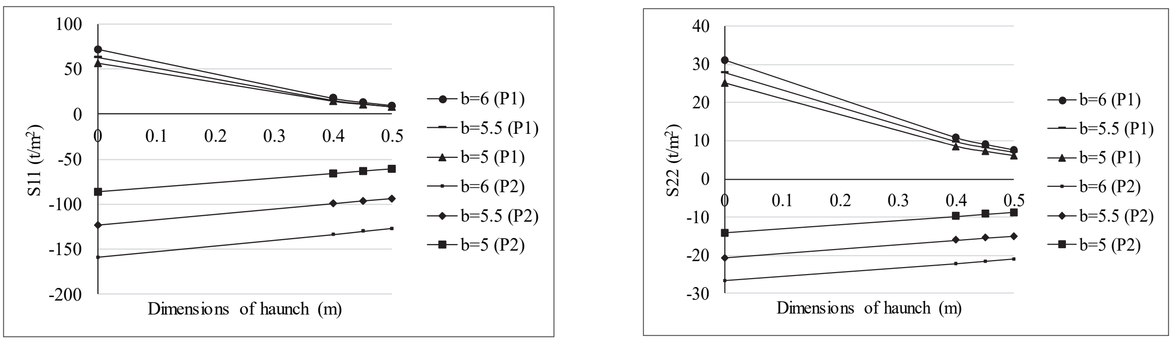


Fig. 3. The relation between haunch dimensions and culvert thickness for S22 for case b=6m (a) at point (1); (b) at point (2); (c) at point (3); (d) at point (4); (e) at point (5)



(a) (b)

Fig. 4. The relation between haunch dimensions and stresess for culvert width for case t=0.4m at points 1,2 (a) S11; (b) S22

Table 1. The percentage between values of S11 from (0-50cm) haunch dimension for b=6m

S11	***t=0.4***	***t=0.45***	***t=0.5***	***t=0.55***	***t=0.6***
P1	86.11	82.08	78.69	75.84	73.90
P2	20.13	18.68	17.43	16.34	15.35
P3	-17.63	-15.40	-13.44	-12.35	-10.87
P4	93.79	91.40	89.88	89.23	89.02
P5	10.35	11.14	11.50	11.61	11.57

Table 2. The percentage between values of S22 from (0-50cm) haunch dimension for b=6m

S22	t=0.4	t=0.45	t=0.5	t=0.55	t=0.6
P1	75.49	70.59	66.46	62.91	60.08
P2	21.02	19.54	18.21	16.99	15.99
P3	47.38	50.11	53.12	56.49	60.25
P4	71.94	67.26	63.26	59.84	56.79
P5	13.12	13.87	14.19	14.27	14.20

Table 3. The percentage between values of concrete from (0-50cm) haunch dimension for b=6m

	t=0.4	t=0.45	t=0.5	t=0.55	t=0.6
dh=0.4	2.17	2.06	1.96	1.87	1.79
dh=0.45	2.74	2.6	2.47	2.35	2.25
dh=0.5	3.36	3.18	3.03	2.89	2.76

The same trend in cases b=5. 5m & b=5m but with deference values

Table 4. The percentage between values of S11 from (0-50cm) haunch dimension for b=5.5m

S11	t=0.4	t=0.45	t=0.5	t=0.55	t=0.6
P1	86.20	82.01	78.73	75.99	74.21
P2	24.32	20.86	19.30	17.93	13.00
P3	-16.56	-14.11	-12.37	-11.09	-10.24
P4	94.18	91.53	90.43	90.27	90.64
P5	17.22	15.43	14.92	14.36	13.83

Table 5. The percentage between values of S22 from (0-50cm) haunch dimension for b=5.5m

S22	t=0.4	t=0.45	t=0.5	t=0.55	t=0.6
P1	75.28	70.96	66.98	63.67	61.09
P2	27.54	23.92	22.25	20.69	15.10
P3	38.51	40.18	41.66	43.32	45.15
P4	72.16	68.30	64.39	61.06	58.06
P5	21.59	19.56	19.05	18.50	17.97

Table 6. The percentage between values of concrete from (0-50cm) haunch dimension for b=5.5m

	t=0.4	t=0.45	t=0.5	t=0.55	t=0.6
dh=0.4	2.23	2.12	2.02	1.93	1.85
dh=0.45	2.81	2.67	2.55	2.43	2.33
dh=0.5	3.45	3.28	3.13	2.99	2.86

By increasing the culvert width with 10% of the initial culvert width, the S11and S22 increased by an average of (10.54%, 29.29%) and (10.62% and 32.65%) for points 1 and 2, respectively. Tables 10 to 12 show the equations for the ratio between S11 and S22 without haunch and with haunch for different width of the culvert. These equations help the engineer to know the difference of stresses when using haunch.

Table 7. The percentage between values of S11 from (0-50cm) haunch dimension for b=5m

S11	t=0.4	t=0.45	t=0.5	t=0.55	t=0.6
P1	85.90	82.12	78.97	76.32	74.70
P2	30.69	27.83	25.40	23.31	21.46
P3	-15.02	-12.83	-11.54	-10.26	-9.00
P4	94.59	93.12	92.69	93.35	94.65
P5	20.84	19.72	18.63	17.61	16.71

Table 8. The percentage between values of S22 from (0-50cm) haunch dimension for b=5m

S22	t=0.4	t=0.45	t=0.5	t=0.55	t=0.6
P1	75.67	71.18	67.38	64.28	61.88
P2	38.42	35.26	32.47	29.98	27.85
P3	31.66	32.30	33.03	33.89	34.76
P4	72.88	68.43	64.69	61.48	58.63
P5	28.00	26.82	25.65	24.59	23.57

Table 9. The percentage between values of concrete from (0-50cm) haunch dimension for b=5m

	t=0.4	*t=0.45*	*t=0.5*	*t=0.55*	*t=0.6*
dh=0.4	2.30	2.19	2.09	2.00	1.91
dh=0.45	2.89	2.75	2.63	2.51	2.41
dh=0.5	3.55	3.38	3.23	3.09	2.96

Table 10. Equations for the ratio between S11 & S22 without haunch and with haunch for b=6m

Point	*S11*		*S22*	
	Equation	R^2	*Equation*	R^2
1,4	$y = 1.4573x^2 - 1.8999x + 1.3703$	1	$y = 1.2666x^2 - 2.0191x + 1.2933$	1
2,5	$y = -0.1x^2 + 0.0166x + 0.1452$	0.9995	$y = -0.0931x^2 - 0.0008x + 0.1674$	0.9987
3	$y = -0.7965x^2 + 1.1454x - 0.5138$	0.9989	$y = 0.6275x^2 - 0.0845x + 0.3484$	1

** x is the thickness of culvert varied between 0.4-0.6 m*

Table 11. Equations for the ratio between S11 & S22 without haunch and with haunch for b=5.5m

Point	*S11*		*S22*	
	Equation	R^2	*Equation*	R^2
1,4	$y = 1.8205x^2 - 2.2333x + 1.4473$	0.9992	$y = 1.0315x^2 - 1.7409x + 1.2217$	0.9999
2,5	$y = 1.0559x^2 - 1.3042x + 0.5399$	0.9831	$y = 1.1288x^2 - 1.3957x + 0.5992$	0.9832
3	$y = -0.9931x^2 + 1.3246x - 0.5419$	0.9998	$y = 0.1026x^2 + 0.1741x + 0.2522$	0.9992

Table 12. Equations for the ratio between S11 & S22 without haunch and with haunch for b=5 m

Point	*S11*		*S22*	
	Equation	R^2	*Equation*	R^2
1,4	$y = 1.6674x^2 - 1.9815x + 1.3721$	1	$y = 1.2535x^2 - 1.9521x + 1.2762$	1
2,5	$y = 0.3952x^2 - 0.7027x + 0.4498$	1	$y = 0.4061x^2 - 0.7542x + 0.5362$	1
3	$y = -0.6336x^2 + 0.9385x - 0.4289$	0.9976	$y = 0.1725x^2 - 0.0455x + 0.2693$	0.9999

5. Conclusions

With increasing the dimensions of haunch and culvert thickness, stresses decreased. The main zone affected by haunch is the corner. S11 and S22 were reduced by average values of 79.8% and 61.3% from the case without haunch, respectively. Haunch has a slight effect on the middle of the walls and slabs, S11 and S22 were reduced by average values of 15.2% and 25.7%, respectively from the same case.

The reduction of culvert stresses by the haunch is the best choice. Using the haunch in the box culvert reduces the stresses and the list of equations will help the engineer to calculate the percentage of the reduction of stresses.

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References

Bian X., Tang X.W., Shen W., Ling D., Chen Y., (2016), An experimental study on a culvert buried in granular soil subjected to vehicle loads, *Advances in Structural Engineering*, **15**, 1031-1040.

Chen B., Zheng J., Han J., (2009), Experimental study on concrete box culverts in trenches, *Frontiers of Architecture and Civil Engineering in China*, **3**, 73-80.

Chen B., Sun L., (2014), Performance of a reinforced concrete box culvert installed in trapezoidal trenches, *Journal of Bridge Engineering*, **6**, https://doi.org/10.1061/(ASCE)BE.1943-5592.0000494.

Ghahremannejad M., Abolmaali A, Mahdavi M., (2019a), Shear strength of top slab of reinforced concrete box culverts, *American Concrete Institute*, **116**, 63-74.

Ghahremannejad M., Abolmaali A., (2019b), Shear capacity of reinforced concrete box culverts compared with AASHTO shear equation, *Journal of Bridge Engineering*, **24**, 04019032-1 - 04019032-18.

Hussien O.S., (2020), Effect of haunch on the stresses of box culvert, *AIMS Environmental Science*, **7**, 31-45.

JTG D60, (2004), Code for Design of Highway Bridges and Culverts, Issued by Ministry of Communications of the People's Republic of China, On line at: http://www.codeofchina.com/standard/JTGD60-2004.html.

Kim K., Yoo C.H., (2005), Design loading on deeply buried box culverts, *Journal of Geotechnical and Geoenvironmental Engineering*, **131**, https://doi.org/10.1061/(ASCE)1090-0241(2005)131:1(20).

Lee J., Son D., Kwon S., Ryu S.W., (2017), Evaluation of methods to prevent soil on a box culvert from freezing-heaving, *KSCE Journal of Civil Engineering*, **21**, 752-757.

Liu Y., Schindler A.K., Davidson J.S., (2018), Finite-element modeling and analysis of early-age cracking risk of cast-in-place concrete culverts, *Journal of the Transportation Research Board*, **2672**, 24-36.

Vaslestad J., Sayd M.S., (2018), *Load Reduction on Buried Rigid Culverts, Instrumented Case Histories and Numerical Modeling*, 5th International Conference on Geofoam Blocks in Construction Applications, 115-128.