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Research Article

Embankment Filling Loads on an Assembled Concrete Culvert beneath High Embankment

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A culvert with prefabricated and assembled structural components is introduced to speed up the progress of highway construction in China. In order to clear the behavior of the prefabricated and assembled slab culvert, the center line section and the shoulder section of the embankment are selected for field tests. In the tests, the distribution and the growth of the earth pressures on the top slab and the lateral walls and the displacements and the deformations of the top slab and lateral walls are investigated, thereafter, the tested earth pressures are linearly fitted, and the formulas of fitting lines are obtained. The results show that the deflections of the lateral walls and of the cover slab are very small, and the variation of distribution and growth of the earth pressures presents significantly nonlinear characters, which is totally different from the linear earth pressure theory proposed by the current Chinese code. The vertical pressure is much smaller in the middle part of the top slab than that on both ends, and it is much larger than the linear theory results. The distribution curve of the lateral earth pressures on the lateral walls is approximately "3" in shape, and the maximum earth pressure locates at the junction of the cap and the lateral wall. The formula of the fitted line obtained from the primary stage pressure can be employed to estimate the earth pressure of embankment completion. The results of the field tests can provide references for the calculations of the components and the strength in the junctions of the assembled culverts.

1. Introduction

The stress state of culvert beneath embankment fill in mountainous area is very difficult to determine, as there are many influences on pressure distribution [1]. It is very important to correctly clear the distribution state of the surrounding earth pressures, which is of great significance to the design and construction of assembled concrete culverts [2].

So far, there have been a lot of studies on calculation of earth pressure on culvert crown and influences of earth pressure distribution, in which the stress states of the culvert with different embankment height are focused on. The previous studies on instrumented culverts date form 1919, in the year Marston measured a culvert with height of 1.02 m beneath 6.10 m backfill and found that the pressure on its top was nearly 1.92 times the weight of the overburden soil (Spangler 1968) [3]. Thereafter, Spangler (1947) [4] gave the testing results of two rigid circular culverts, one of the culverts with soft soil placed on the crown, the unit weight of which was $15\ kN/m^3$, and the measured pressure was about 1.9 times the overburden soil weight. For the other culvert beneath gravel filling of $20 kN/m^3$, the measured pressure was about 1.5 times the overburden pressure. And, then, Spangler (1950) [5] reported the load measurements for seven positive projection culverts with the width ranging from 0.61 m to 2.44 m. The average pressure of the culverts was measured and a method for predicting culvert load was developed by observing soil deflection compared to culvert deflection. And it was found that the design pressure should be a function of projection conditions, various soil properties, and backfill height (H) to culvert width (B) ratio(H/B). Based on Spangler's study, Clarke (1967) [6] pointed out that the growth ratio of the vertical pressure of the culvert was essentially considered constant when the embankment heights were greater than the plane of equal settlement (the plane of equal settlement was defined by Spangler (1947) [4] as the horizontal plane in the embankment at which the settlements of the interior soil prism above the culvert and the exterior soil prism outside the culvert were equal). Woodbury et al. (1926) [7] gave the test report on eight different culverts from the American Railway Engineering Association on the Illinois Central Railway embankment. In the report the pressure reading of the two culverts indicated that the crown pressure was about 1.58 times the cover backfill weight pressure. Braune et al. (1929) [8] reported the tests on the culverts placed on the weighing device, for the cast iron pipes with different H/B ratios and the inner diameters and thicknesses, the pressure was about 1.27 to 1.40 times the overburden backfill weight pressure. Binger (1947) [9] reported a pressure measurement at the center of the box culvert which was 2.74 meters wide and 3.30 meters high and about 15.2 m of sandstone filled above it, and the vertical pressure measured at the culvert center was about 1.8 times the overburden soil unit weight. Trollope et al. (1963) [10] reported on pressure measurements of a culvert in horseshoe shape under the embankment of a dam, there were 8 points with different positions measured and the pressures were 1.6, 2.6, 1.5, 1.7, 1.7, 2.9, 1.9, and 3.2 times the overburden pressure, respectively. Höeg (1968) [11] investigated the behavior of the model cylinders in the test chamber filled with Ottawa sand, there was one or two cylinders of sand at the top of the culvert, and then pressure was applied to the top of the sand with an air bag, the crown pressure was 1.42 to 0.69 times the applied pressure, which depended on the stiffness of the culvert, and these stiff culverts would support greater pressure than overburden pressure. Girdler (1974) [12] reported a 1.73-meter-wide single cell box culver, with overburden 23.5-meter-high backfills, the pressure was very asymmetrical, with one side of the crown pressure 0.90 times and the other side 1.74 times the overlying soil pressure, and the average pressure was 1.32 times the overlying soil unit weight. Penman et al. (1975) [13] reported pressure measurements made on a culvert passing under a 53m high rockfill dam. They found that, with increasing fill heights more than H/B=9, the ratio of measured pressure to overburden pressure decreased. At the final fill height corresponding to an H/B ratio of 12.9, the crown pressure was 1.76 times the overburden pressure. Dasgupta and Sengupta (1991) [14] studied 1.35 m×1.35 m model box culvert which was covered with 2.4 m height dry sand as backfill, and the measured pressure values at three positions on the top of the culvert from the edge were 0.09 B, 0.3 B, and 0.5B. The pressure presented a parabolic distribution with a ratio of measured pressure to overburden pressure at each of the three corresponding positions of 1.90, 1.06, and 0.66, and the average pressure was about 1.32 times the overburden pressure. Vaslestad et al. (1993) [15] reported the pressure measurement of a 2.0 m wide by 2.55 m high box culvert, with 9.8 meters' silty clay on top as backfill; the measured pressure was 1.24 times the overburden pressure. And a series of finite element analysis results given by Katona et al. [16] (1981) and the measured results given by Dasgupta and Sengupta (1991) [14] show that the pressure at the culvert center was usually the lowest on the culvert top plane. Yang (2000) [17] reported the results of pressure measurements on a 9.9 m wide by 3.7 m high double box culvert, with 2m incompact backfill around the culvert. The measured pressure was 1.26 times the soil overburden. As the pressure is commonly bigger than the overburden soil weight, the lightweight and compressible materials such as straw, EPS geofoam, compressible soil, or tire chips are placed on the top of culverts to decrease the vertical load on the crown. Stone et al. (1991) [18] carried out a series of centrifugal model tests to study the effects of load reduction with lightweight and compressible materials filled on the culverts crown. Dancygier et al. (1996) [19] studied the fill-soil interaction mechanism of deep buried structures and obtained an optimum dimension of the soft zone for reducing vertical pressure. Sun et al. (2005) [20] performed a series of finite element analyses to study the stresses and deformations of a slab culvert with lightweight geofoam on the roof. Mcguigan et al. (2012) [21] carried out field tests of a twin 3660 mm inside diameter induced trench culverts installed under 21.7 m of fill, and the monitoring results showed that the average earth pressures measured at the crown and spring line were 0.67 and 0.32 times the overburden. And his centrifuge test results of an induced trench culvert indicated that the base contact pressures were 25%–76% greater than the top pressure plus dead load because of shear stresses mobilized along the sidewalls (Mcguigan and Valsangkar, 2011) [22], and the induced trench culvert partially transferred the earth pressure from interior backfill prism to the lateral prisms, leading to increases of the earth pressure on the lateral walls and the foundation. An investigation was carried out by Turan et al. (2013) [23] of induced trench method using a full-scale test embankment, and the results also showed that the loads on the crown of the induced trench installed culvert were 30% to 60% less than the overburden. Dong et al. (2013) [24] performed a series of finite element analyses to study the variation law of pressure on crown under grid-shaped treatment. Thereafter, Chen et al. (2013, 2014) [25, 26] and Osama et al. (2015) [27] carried out a series of field tests and mechanical analyses, and the results indicated that the differential stiffness between the culvert and the adjacent fill mass caused the differential settlement between the surrounding soil prism and the central soil prism above the culvert. Hence, the shear stress between the surrounding soil prism and the central soil prism resulted in backfill pressure concentration on the culvert. Zhang et al. (2017, 2018) [28, 29] carried out a series of field tests and demonstrated the efficacy of digital photogrammetry as a powerful technique for deformation measurement in the geotechnical model tests. The previous studies mainly aimed at cast-in-place constructed culverts, but, seldom at assembled culverts, the distribution and the growth of the earth pressures on an assembled culvert have not been reported, and hence calculation methods of the strength of the assembled culvert are lacking testing data support.

Therefore, this study introduces the assembled culvert in the construction process of the Huixing expressway located in Guizhou province China. Then the distribution of earth pressure around the assembled slab culvert and the displacement of the culvert are investigated by the field instruments, with particular emphasis on the maximum earth pressure location. After that the tested earth pressures are linearly fitted to obtain the fitting formulas of load on the assembled culvert.

Figure 1: Assembly scene of assembled culvert.

2. Introduction of Assembled Slab Culvert

In mountainous areas, concrete culverts casted in situ cannot conduct follow-up process of the construction until the strength of concrete reaches 75% of the designed strength, which slows the construction progress of embankment frequently. And the mechanical compaction of embankment filling causes additional stress on the concrete culvert structures, which breaks the components of the culvert as the strength is not fully formed during the process of embankment filling. In addition, the construction quality, especially in winter and rainy days, is difficult to guarantee, which has a negative effect on the structure safety. To solve the above problems, an assembled culvert construction method was adopted for the first time in the process of Huixing expressway culvert construction in China.

This method produced the components of a culvert in prefabrication plant, which were prefabricated with C25 concrete. C20 rubble concrete was used to form foundation in the construction field by in situ casting. The prefabricated concrete wall and slab were installed after the strength of foundation concrete reaches 70% of its full strength. A 5.0cm depth groove is preserved at the installation junction of culvert lateral wall on foundation. Double hook gantry crane was adopted to lift the lateral walls and to put them to the groove on foundation, as shown in Figure 1. Two abutment caps were installed on the top of each lateral wall, and the ends of cover slab was placed on each abutment cap to avoid crushing the lateral wall. In addition, C25 self-compacting concrete was used in the junction area to bond the assembled components.

According to the practice, the assembled culvert has many advantages.

(1) It is of light weight and delicate structure, especially suitable for low humidity and cold areas.

(2) Compared with cast-in situ culvert, it has the advantages of material saving and low cost.

(3) The construction period is shortened by fast assembly in field. After excavation of the foundation to the design depth, the lateral walls of culvert are lifted and placed by portal crane.

(4) It is suitable for industrial production, thus the quality of culvert components can be guaranteed, and it overcomes the disadvantages of the cast-in situ culvert.

3. Field Test

3.1. Project Profile. The chosen field test section of an assembled culvert located at the Huixing expressway, in Guizhou province, China. The dimensions and profile of the culvert are shown in Figure 2.

As shown in Figure 2, the largest height of filling on the slab of the culvert is 7 m, the ground width of the valley of the culvert installation is about 13.4 m, and the culvert axis is about 9.2 m to the valley slope at left side, the inclined angle of the left slope is about 45°, and it is about 4.2 m to the slope at right side, inclined angle of which is about 60°. The culvert is trench installed and nonsymmetric trench buried. The subgrade of the culvert foundation is replaced with gravel excavated from slope (Subgrade I) and tunnel (Subgrade II), and there it replaced totally 2.5 m thick gravel underneath the culvert foundation. The embankment backfill is crushed stone. The parameters of the mentioned materials listed in Table 1 are obtained by triaxial test in laboratory.

3.2. Layout of the Measuring Point. Two sections of culvert were chosen for field tests, which are vertically via the center line and shoulder edges of the embankment, as shown in Figure 3. And the measurements are taken to investigate the vertical earth pressure on crown, the lateral earth pressure on the lateral walls, and the relative displacement of the culvert structural components. The measuring point and layout of instrument in field are shown in Figure 4.

The earth pressure cells are horizontally installed on the top of culvert slab, and the installations of the earth pressure cells are parallel to the lateral wall outer surface on both sides of the culvert. The vertical displacement measuring points are placed on the bottom surface of the culvert slab, a high-precision digital level is employed to measure the vertical displacements of each point, and the deflection of the slab is calculated by the difference of vertical displacement among each measuring point. The horizontal displacement measuring point is placed on the inner surface of the culvert lateral walls, and a high-precision steel rule is employed to measure the relative displacement of the left and right lateral wall.

3.3. Analyses of Test Results

3.3.1. Embankment Center Line Section (Section II). The deflection of culvert slab and the relative displacement of left and right lateral walls are shown in Figures 5 and 6, after the backfill process of embankment fill.

Under the load of the embankment fill, the slab of the culvert is bent downwards, and the maximum deflection of the slab is 2.4 mm. The distributions of the horizontal displacement of the culvert lateral wall are nonlinear, because of the support from the slab and the foundation, the displacements of the wall are smaller at the top and the bottom points, meanwhile, the horizontal displacement at the middle point of the lateral wall is larger, and the maximum differential displacement is 0.64 mm.

Continuous observations of the earth pressure were carried out during the embankment filling process, and the distribution of the horizontal earth pressure on the right and

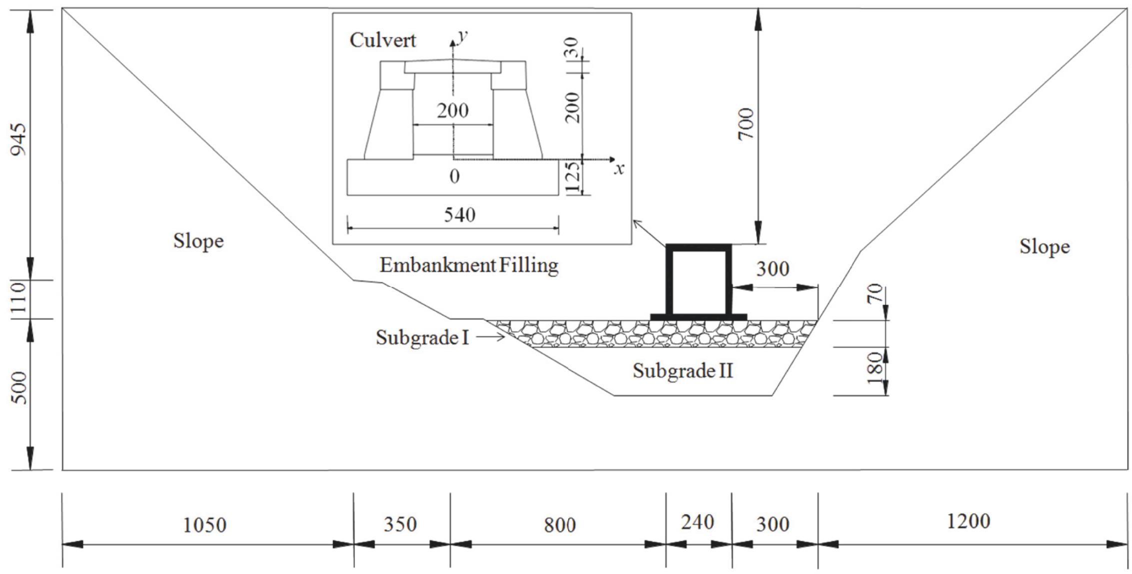


FIGURE 2: Diagram of culvert cross section (unit: cm).

TABLE 1: The parameters of the materials.

Parameter	Culvert	Filling	Slope	Subgrade I	Subgrade II
Elasticity modulus E (MPa)	30000	30	3000	13	40
Poisson's ratio μ	0.2	0.32	0.3	0.36	0.3
Cohesion c (kPa)	-	0	150	3	0
Internal friction angle φ (°)	-	32	35	28	32
Density ρ (kg/m^3)	2500	1800	2000	1800	2000

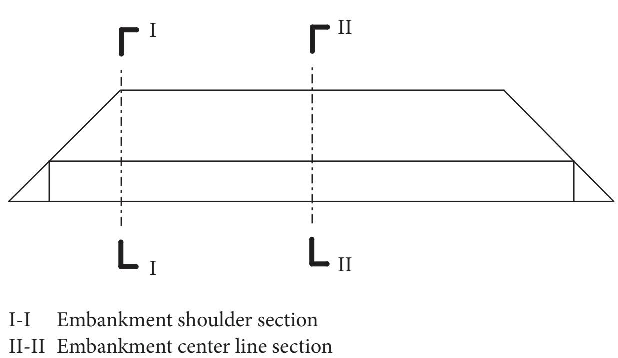


FIGURE 3: Sketch of the test section.

left lateral walls of the culvert is shown in Figures 7 and 8.

It can be seen that the distribution of the horizontal earth pressures on the lateral wall of the culvert is nonlinear. The earth pressures at the left 4# and the right 4# points which are 1.6 m to the top surface of the foundation are larger, which is due to the geometric abrupt change on the lateral wall, and the lateral pressures of the wall are relatively concentrated at the junction area of the cap and wall. In addition, in the top and bottom end of the wall, because of the supporting role of culvert slab and foundation, the supporting stiffness on lateral wall at both ends is larger than that in the span of the wall, an inward slight deflection is conducted under the role of horizontal earth pressure in the span of the wall, and the deflection produced a load reduction effect of horizontal earth pressure, therefore, resulting in less pressure in the span. In addition, due to the fact that the thickness of the culvert foundation is greater than the slab thickness, the compressible deformation of the foundation under horizontal earth pressure is less than that of the slab, which leads the minimum horizontal earth pressure position to move upward from the middle part, and the horizontal earth pressure at the middle of the lateral wall is the smallest.

The vertical earth pressure and horizontal earth pressure on the culvert are calculated by linear theory listed in current Chinese ***Highway bridge design common specification*** (JTG D60-2015), which proposes earth pressure increasing linearly

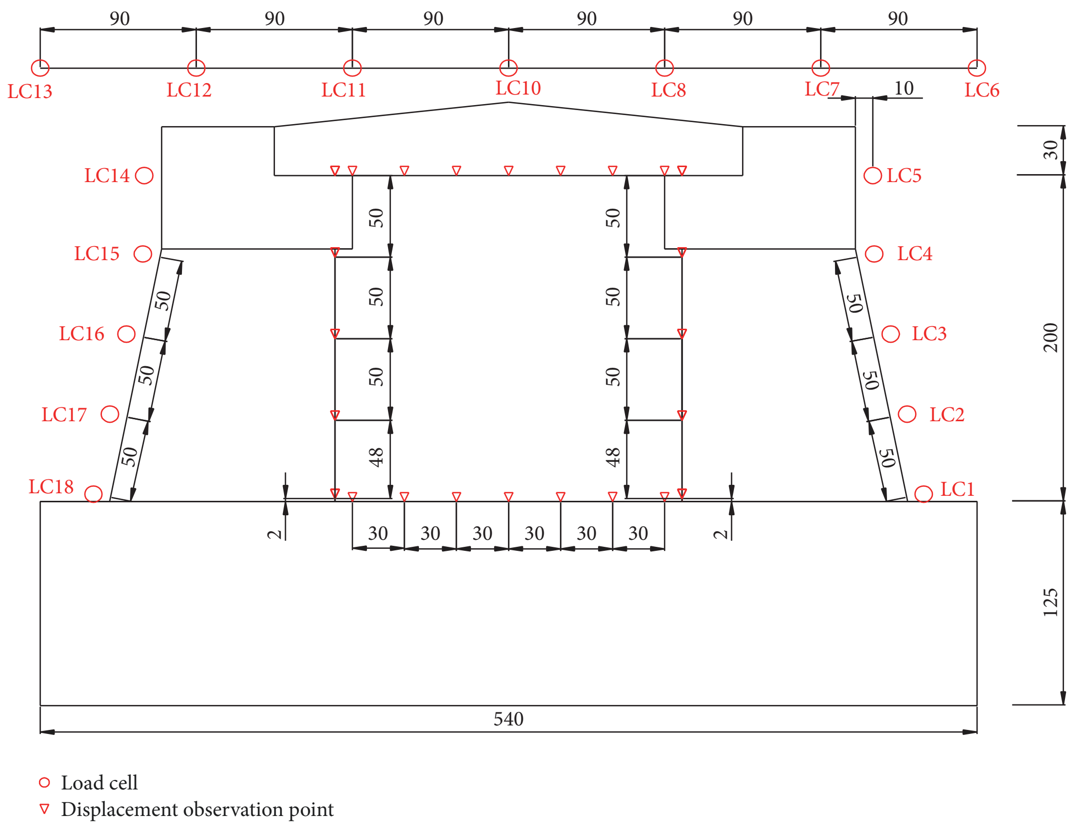


Figure 4: Test section and instrument layout of culvert (unit: cm).

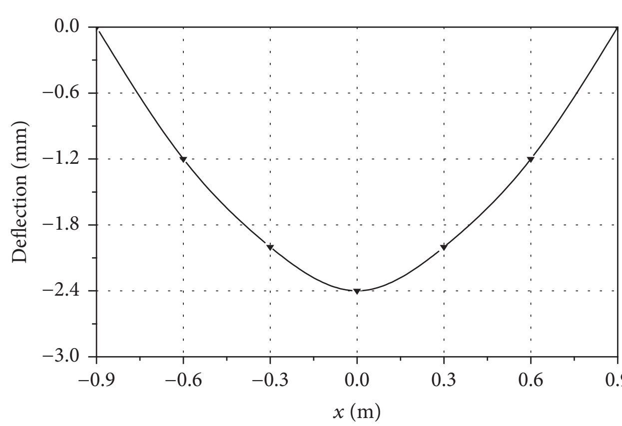


Figure 5: Slab deflection.

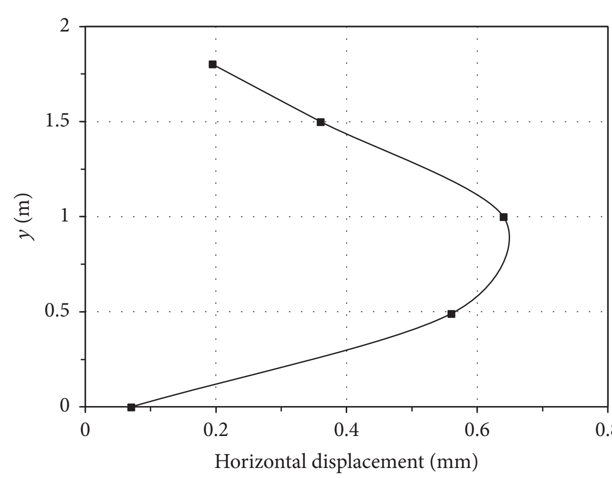


Figure 6: Relative displacement of the lateral wall of the culvert.

with the height of the embankment fill and does not take into account the influence of the interaction between the backfill and the structure on the earth pressure; hence its results are inconsistent with the field testing results.

Through continuous observation of the vertical earth pressure on crown during the embankment filling, the distribution of vertical earth pressure on crown is shown in Figure 9.

As shown in Figure 9, the distribution of the vertical earth pressure is nonlinear, and the stress concentration is produced on both ends of the culvert slab, and the earth pressures on both ends are larger than the self-weight of the above embankment fill. There are two main causes: (1) the first is the friction (or shear stress) effect between slab top earth column and the lateral earth column. Because of the difference of stiffness between culvert and fill, there exists differential settlement at the top level of culvert, which results in the redistribution of the earth pressure on crown, leading to the phenomenon of the earth pressure concentration above the wall cap. (2) The second is the influence of the stiffness

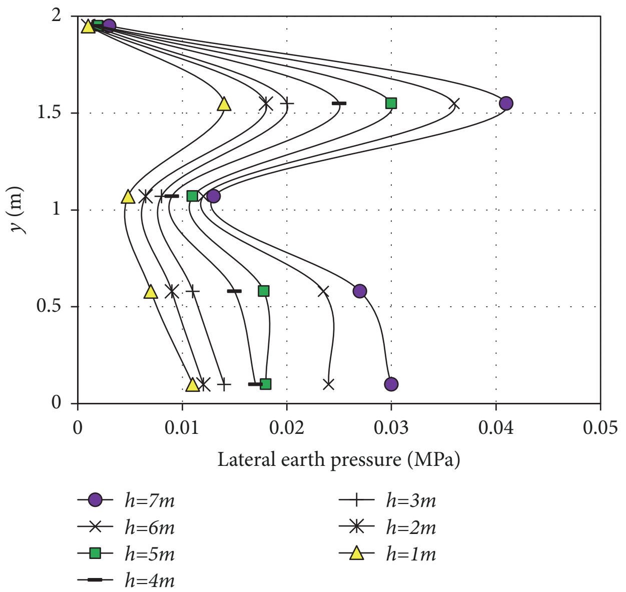


FIGURE 7: Distribution of lateral pressure on the left wall of section II.

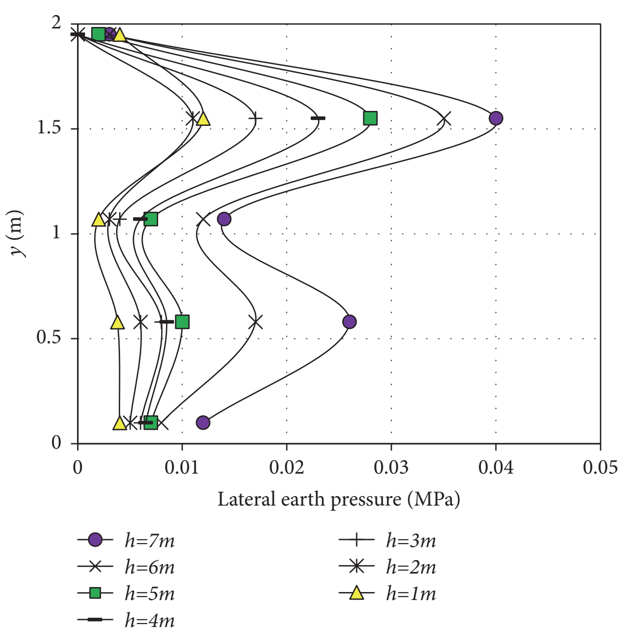


FIGURE 8: Distribution of lateral pressure on the right wall of section II.

difference of the culvert structure itself. Under the vertical earth pressure, wall cap of culvert slab is supported by lateral walls, stiffness apparently increased, and the slab bent produced a deflection, which lead to soil arch effect in the embankment fill on the culvert slab, thus the phenomenon that earth pressure is reduced on the slab.

Because the linear theory to calculate the earth pressure on crown adopted the weight of the overlying fill, which ignored the interaction between the earth and the structure, when the height of the fill is constant, the earth pressure of the points in the culvert top plane is the same, and the calculation

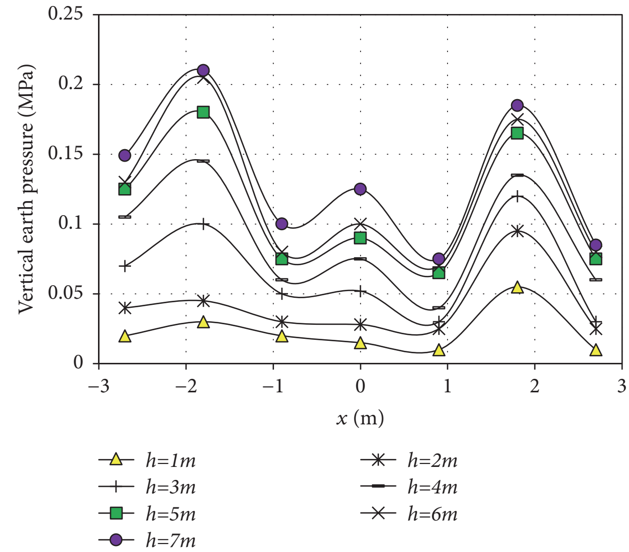


FIGURE 9: Distribution of vertical pressure on the slab on section II.

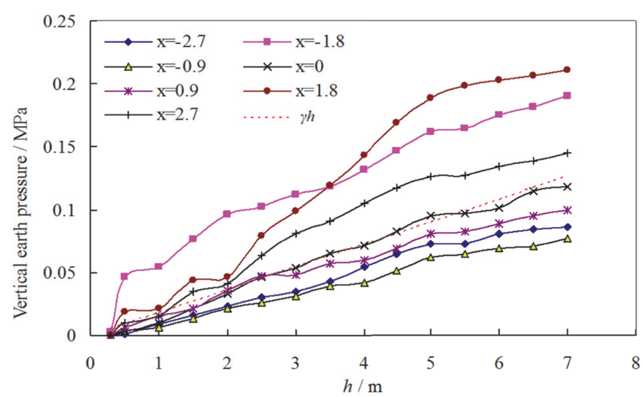


FIGURE 10: Variation of vertical pressure on the slab on section II.

results can not reflect the actual situation of the earth pressure distribution.

The variation of the earth pressure with height in the culvert top plane is shown in Figure 10 (the coordinates in the legend are seen in Figure 2).

As shown in Figure 10, the test results at the center point on the culvert slab (x = 0) is relatively close to the linear earth pressure theory result, and there is a big difference between the earth pressure deviated from the center point of the culvert and the linear pressure.

3.3.2. Embankment Shoulder Section (Section I). The construction pavement for filling is next to the right lateral wall of the embankment section; therefore, the earth pressure cells are not installed on the right lateral wall. The distribution law of the earth pressure at the left wall and the culvert top are shown in Figures 11 and 12.

The measured earth pressures in embankment shoulder section have similar distribution and variation law in Figures 11 and 12. Because the height of filling decreased gradually from the shoulder to the toe of the inclined embankment

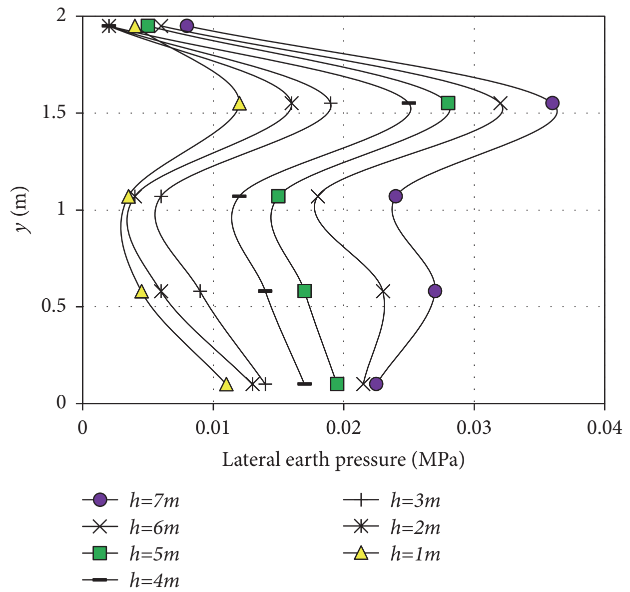


FIGURE 11: Distribution of lateral pressure on the left wall of section I.

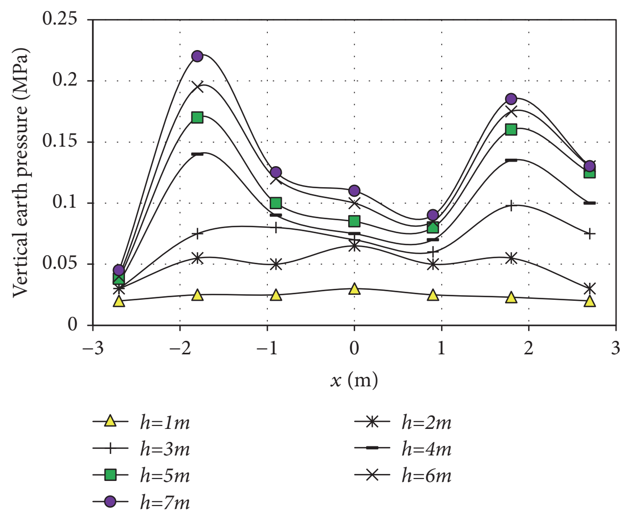


FIGURE 12: Distribution of vertical pressure on the left wall of section I.

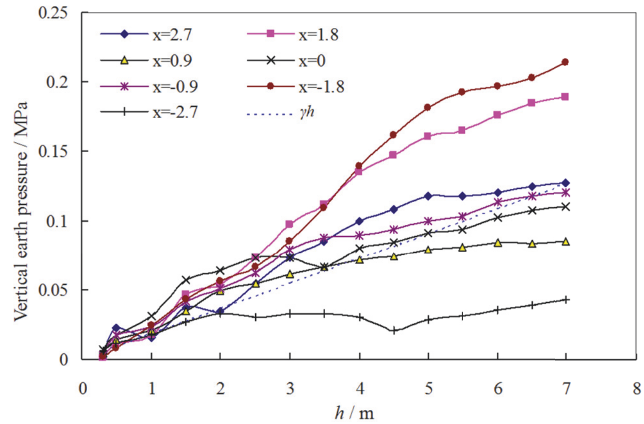


FIGURE 13: Variation of vertical pressure on the left wall of section I.

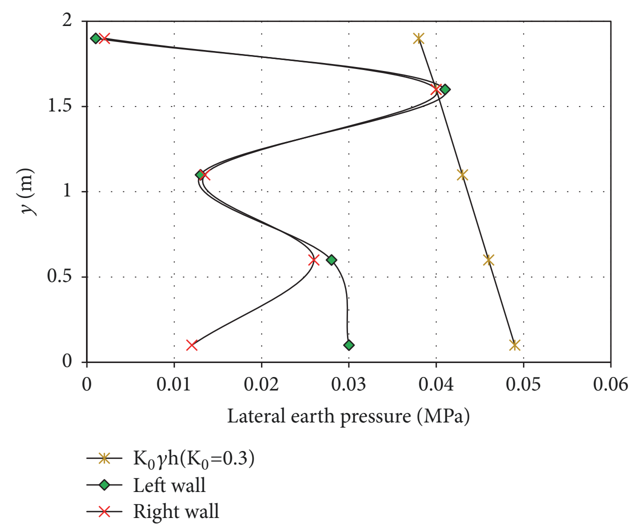


FIGURE 14: Lateral earth pressure on lateral wall under 7 m filling.

slope, the earth pressures on lateral wall and crown are less than that in the center line section of embankment.

The growing law of earth pressure in the measuring points on culvert top is shown in Figure 13, and it is similar to that of the center line of the embankment. The results of the earth pressure at the middle point of the slab top of the culvert (x=0) are close to the linear theory results, and there is a big difference between the earth pressures in deviated points from middle span of culvert slab and the theory results.

In summary, the deflections of the culvert lateral walls and the cover slab are small, and the distribution and variation law of earth pressures on assembled culvert are obviously nonlinear, which is quite different from linear earth pressure theory. The test results provide the reference and basis for the analysis of the stress characteristics and the bond strength of the components.

3.4. Fitting of Tested Earth Pressure

3.4.1. Approximate Earth Pressure on Lateral Wall. From the field test results, it can be seen that the distribution of the horizontal earth pressures on the lateral wall of the culvert is nonlinear. But the current Chinese ***Highway bridge design common specification*** (JTG D60—2015) recommends that the horizontal earth pressure should be regarded as trapezoidal load to calculate the internal force of the culvert components, which is quite different from the actual situation, as shown in Figure 14.

In Figure 14, the horizontal earth pressure on the left wall is slightly larger than that on the right wall, and the measured results of the earth pressure at both sides are significantly smaller than those calculated by the standard method. Therefore, we calculate the internal force of the lateral wall according to the measured horizontal earth pressure on the left wall, and the result is partial to the safety.

Table 2: Lateral pressure coefficient on lateral wall.

h/m	a_1	b_1	a_2	b_2	a_3	b_3
1	-0.0074	0.0120	0.0199	-0.0169	-0.0302	0.0608
2	-0.0067	0.0131	0.0247	-0.0204	-0.0452	0.0882
3	-0.0064	0.0148	0.0287	-0.0228	-0.0546	0.1065
4	-0.0072	0.0175	0.0330	-0.0262	-0.0628	0.1225
5	-0.0074	0.0201	0.0391	-0.0305	-0.0756	0.1473
6	-0.0117	0.0263	0.0517	-0.0429	-0.0938	0.1829
7	-0.0175	0.0338	0.0580	-0.0488	-0.1020	0.1995

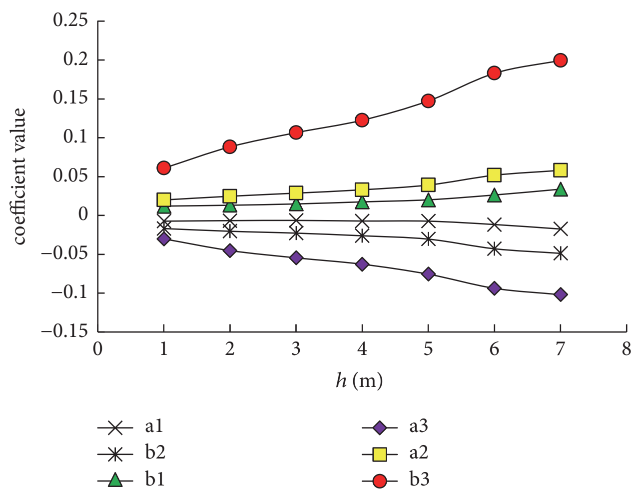


Figure 15: Relationship between filling height and a_i, b_i.

The horizontal earth pressure on the lateral wall can be roughly divided into three sections. To simplify the calculation, the measured data are fitted by broken line with formula (1a), (1b), and (1c). The lateral pressure coefficient on lateral wall from h=1m to h=7m can be obtained. The results are shown in Table 2.

$$p_{L1} = a_1 y + b_1, \quad (0 < y \leq 1.07) \tag{1a}$$

$$p_{L2} = a_2 y + b_2, \quad (1.07 < y \leq 1.55) \tag{1b}$$

$$p_{L3} = a_3 y + b_3, \quad (1.55 < y \leq 1.95) \tag{1c}$$

in which y is the vertical distance of each point on the lateral wall, from the bottom to the top are the measuring points 1, 2, 3, 4, and 5 successively, and the y values of the five measuring points are 0.10, 0.58, 1.07, 1.55, and 1.95 m. p_{Li} $(i = 1, 2, 3)$ is the lateral soil pressure (unit: MPa) at each point on the lateral wall. And h is the height of the embankment fill on the top of the culvert slab.

As can be seen from Table 2, the coefficients a_i and b_i are related to the height of the fill h. Figure 15 shows the variation law of a_i and b_i under different fill heights.

With the increase of embankment fill height h, the absolute values of each coefficient increase, and the growing law is approximately linear. Therefore, linear function is adopted to describe the variation law of coefficients a_i, b_i with fill height h. The calculation results are listed in Table 3.

Table 3: Relationship between filling height and a_i, b_i.

a_1 = -0.0015h - 0.0033
b_1 = 0.0035 h + 0.0058
a_2 = 0.0064 h + 0.0109
b_2 = -0.0053 h - 0.0086
a_3 = -0.0119 h - 0.0187
b_3 = 0.0231 h + 0.0373

Summarizing the calculation results in Tables 2 and 3, the horizontal earth pressure on the lateral wall can be approximately expressed in following formula:

$$p_{L1} = (-0.0015h - 0.0033)\, y + 0.0035h + 0.0058, \quad (0 < y \leq 1.07) \tag{2a}$$

$$p_{L2} = (0.0064h + 0.0109)\, y - 0.0053h - 0.0086, \quad (1.07 < y \leq 1.55) \tag{2b}$$

$$p_{L3} = (-0.0119h - 0.0187)\, y + 0.0231h + 0.0373, \quad (1.55 < y \leq 1.95) \tag{2c}$$

3.4.2. Approximate Earth Pressure on the Slab. The distribution of vertical earth pressure measured on the culvert slab is also nonlinear, and the linear theory assumes that the vertical earth pressure at each point on the slab is equal, and there is a big difference between the measurement and the linear theory, as shown in Figure 16.

In Figure 16, the vertical earth pressure on the right side of the cover slab is slightly larger than that on the left, and the vertical earth pressure at the middle point of the slab is a little smaller than that calculated by the linear theory, but the earth pressure at both ends of the cover slab is greater than that calculated by the linear theory. To simplify the calculation, it is assumed that the vertical earth pressure on the left and the right half of the cover slab is completely symmetrical, and the test data of the right half of the cover slab is adopted for calculation, which leads the result to be a little safer.

Referring to the culvert top earth pressure section figure in the previous test results, the earth pressure on the right cover slab can be roughly divided into two sections. The measured data is fitted by broken line with formula (3a) and

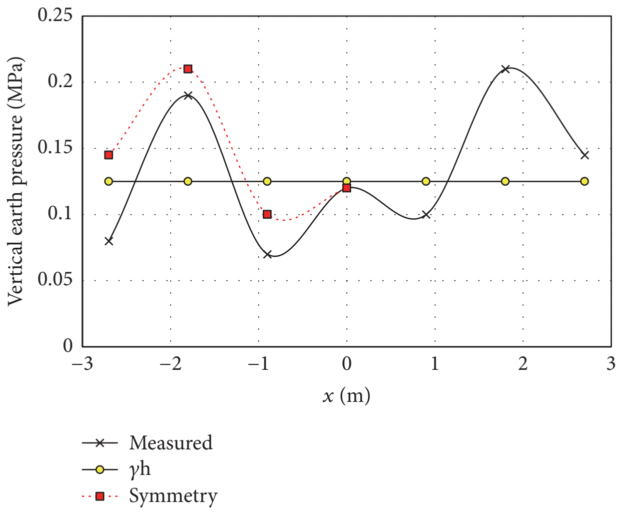


Figure 16: Vertical earth pressure on slab under 7 m filling.

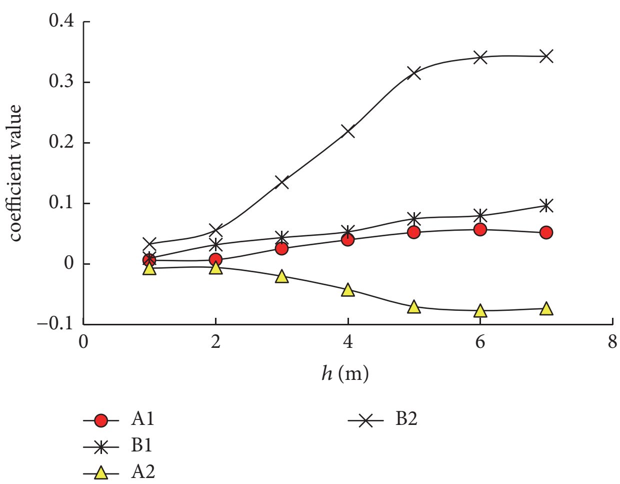


Figure 17: Relationship between filling height and A_i, B_i.

(3b), and the vertical pressure coefficient on slab from h=1m to h=7m can be gained. The results are shown in Table 4.

$$p_{V1} = A_1 x + B_1, \quad (0 < x \leq 1.8) \tag{3a}$$

$$p_{V2} = A_2 x + B_2, \quad (0.9 < x \leq 2.7) \tag{3b}$$

in which x is the horizontal distance of each point on the slab, from the left to the right, and the x values of the measuring points are 0, 0.9, 1.8, and 2.7 m. p_{Vi} $(i = 1, 2)$ is the vertical soil pressure (unit: MPa) at each point on the slab. And h is the height of the embankment fill on the top of the culvert slab.

Coefficients A_i and B_i are related to filling height h. Figure 17 shows the variation law of coefficients A_i and B_i of different filling height.

As can be seen from Figure 17, the absolute values of the coefficients increase with the increase of the filling height h. But the rate of growth is changing, it grows slowly at the beginning, and then it rapidly increases with increases of the

Table 4: Vertical pressure coefficient on slab.

h/m	A_1	B_1	A_2	B_2
1	0.0061	0.0098	-0.0067	0.0330
2	0.0072	0.0318	-0.0056	0.0560
3	0.0256	0.0437	-0.0200	0.1350
4	0.0400	0.0533	-0.0422	0.2190
5	0.0522	0.0747	-0.0700	0.3150
6	0.0567	0.0800	-0.0767	0.3410
7	0.0517	0.0965	-0.0733	0.3430

Table 5: Relationship between filling height and A_i, B_i (h>5).

$A_1 = 0.004h + 0.0284$
$B_1 = 0.0135h + 0.0019$
$A_2 = -0.010h - 0.0105$
$B_2 = 0.0398h + 0.0856$

Table 6: Fitting of the earth pressure (h=8 m).

Lateral wall	$p_{L1} = -0.0153y + 0.0338, \quad (0 < y \leq 1.07)$
	$p_{L2} = 0.0621y - 0.051, \quad (1.07 < y \leq 1.55)$
	$p_{L3} = -0.1139y + 0.2221, \quad (1.55 < y \leq 1.95)$
Slab	$p_{V1} = 0.0604x + 0.1099, \quad (0 < x \leq 1.8)$
	$p_{V2} = -0.0905x + 0.404, \quad (1.8 < x \leq 2.7)$

filling height h. When the fill height h exceeds 5 m, the growth rate slows down, and the absolute value of each coefficient tends to be stable. To describe the law of the variation of the earth pressures with the filling height h when h continues to increase, the data in condition h more than 5m is employed for linear fitting of A_i and B_i, and the results are listed in Table 5.

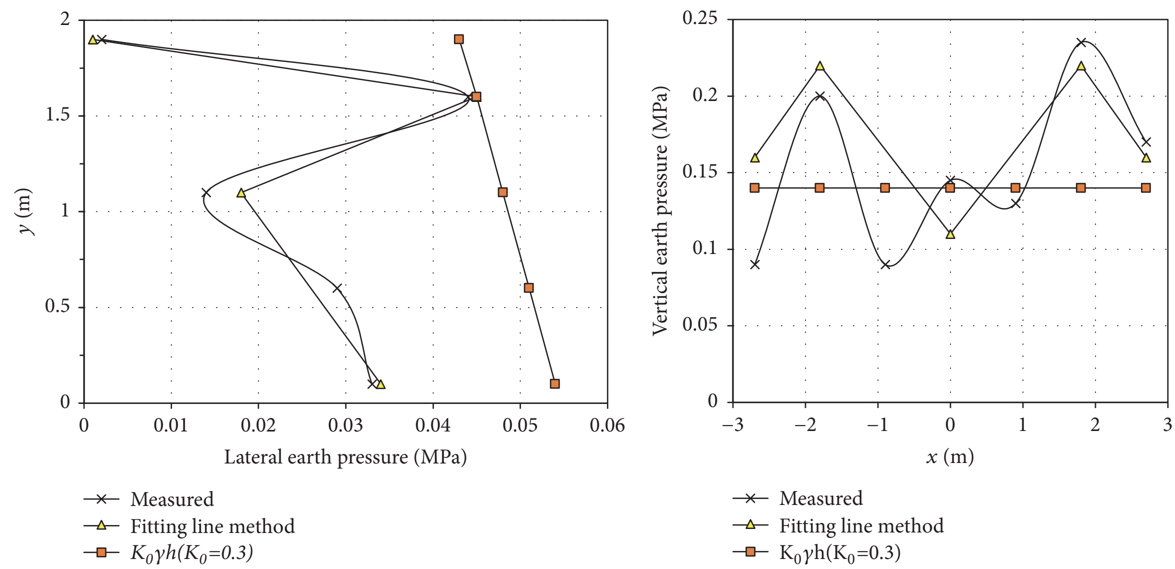
Summing up the calculation results in Tables 4 and 5, the vertical earth pressure on the cover slab can be approximately expressed by the following formula:

$$p_{V1} = (0.004h + 0.0284)\,x + 0.0135h + 0.0019, \quad (0 < x \leq 1.8) \tag{4a}$$

$$p_{V2} = (-0.01h - 0.0105)\,x + 0.0398h + 0.0856, \quad (1.8 < x \leq 2.7) \tag{4b}$$

The formulas are applicable to the calculation of the assembly culvert under fill height h=8m.

3.4.3. Estimate of Approximate Earth Pressure. After the embankment construction stage, the pavement and the roadbed are constructed. And the weight of the pavement and the roadbed is equivalent to that of 1m height embankment filling, and thus the final filling height on the K73+550 culvert is about 8 m. According to formula (2a), (2b), and (2c) and formula (4a) and (4b), the earth pressure on the lateral wall and on the slab is calculated separately in fill height h=8 m, and the results are shown in Table 6 and Figure 18.



(a) Lateral wall (b) Slab

Figure 18: Earth pressure under filling height 8 m.

Figure 18 shows that the estimate of earth pressures from the fitted line method agrees well with the tested results, and thus the formula of the fitted line obtained from the primary stage pressure can be employed to estimate the final earth pressure when the construction of the embankment fully completed.

4. Conclusions

The construction technique of an assembled concrete culvert is introduced, and the vertical and horizontal earth pressures on the assembled concrete culverts under high embankments are monitored in situ. The variation laws of earth pressure and deformation of the culvert structures are studied, and conclusions are made as follows:

(1) The lateral wall and the top slab of the assembled culvert deformed with the effect of the embankment fills loads, and the deformation of culvert components has a load reducing effect, but to a certain extent, to reduce the earth pressure of embankment fill.

(2) Because of the lateral prisms above the crown of the culvert and the load reducing effect caused by the deformation of the slab, the vertical earth pressure is nonuniformly distributed, which is smaller in the middle span of the slab and larger on both ends.

(3) The earth pressure presents an obviously nonlinear growth with the embankment height, because of the shearing forces caused by the differential settlement of the embankment fill on culvert crown level.

(4) Radical change of wall shape and support stiffness will lead to earth pressure concentration. The distribution curve of the lateral earth pressures on the lateral walls is approximately "3" in shape, and the maximum earth pressure locates at the junction of the cap and the lateral wall.

(5) The formula of the fitted line obtained from the primary stage pressure can be employed to estimate the final earth pressure when the construction of the embankment fully completed.

5. Prospects

(1) *Lack of Numerical Simulation*. Most of conclusions are gained through field test.

(2) In all theoretical studies, time effects of culvert and groundwater are not considered. Therefore, in engineering practice, with the extension of time, the calculation results of the theoretical formula in this paper need to be further studied.

(3) In practical engineering, there are many factors influencing the force of culvert, so the influence of different factors on the force of culvert needs to be further studied.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

There are no conflicts of interest regarding the publication of this article.

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