

Rehabilitation Method of Culvert Foundation Failure using Polygeo Foam

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ABSTRACT

A concrete box culvert with a dimension of 2.1 x 2.1 m and a concrete pipe culvert of 0.9 m diameter founded on soft soil were experiencing soil settlement causing undulation and discomfort to the traffic users. Voids that appeared beneath the culvert foundations triggering the road surface to sag. Objectives of the study are to assess the settlement of culverts underlain by soft soil using PLAXIS simulations on the initial subsoil conditions, after rehabilitation works with Polygeo foam injection and to evaluate the performance of Polygeo foam as a rehabilitation method. The settlement of the culverts underlain by the soft soil will be determined using finite element model based on the data and information obtained from geoforensic assessments including 12 nos. of deep borehole as well as soil laboratory tests. There were six culverts area undergone settlement problem, with two boreholes were executed at the side of each culvert. Throughout the five-year period of Post Construction stage with Polygeo rehabilitation works, the pipe culvert was shown to settle around 22 mm whilst the box culvert with pile settled around 14 mm. The study concluded that the rehabilitation works using Polygeo foam has been successfully reduced the rate of settlement and complied to JKR settlement criteria.

Keywords: Culvert; finite element method; polygeo foam injection; geoforensic; settlement

INTRODUCTION

The benefits of installing culverts instead of short-spanned bridges include simple construction, the reduction of construction time and maintenance cost (Voitenko and Anderson 2017). However, it is not suggested for a region with excessive settlement by which deep foundations such as piles are to be installed, making the procedure complex and a steep increase in construction cost (Miura et al. 1995). At the valley area or the lowlands which is impractical to install a bridge, culvert is an option. There is a lack of knowledge on the determination of settlement subjected to the culvert crown (Ma et al. 2019). Numerical analysis involves the study of computing numerical data. Some of the continuum methods in numerical model approaches include finite element method (FEM), finite difference method (FDM) and boundary element method (BEM). An analysis of the earth pressure on the culvert crown was done using FEM and the results are more in-line with in-situ test compared to calculations by AASHTO. However, there are little to no research on the prediction of soil behaviour involving settlement and culvert settlement by using FEM in Malaysia generally, and Sarawak specifically. There are limited studies on the determination of settlement subjected to the culvert crown, including the use of finite element method (FEM) (Ma et al. 2019). The objectives for this study are to evaluate

the settlement obtained involving culverts from simulations in PLAXIS during initial condition, after rehabilitation works and analyse the efficiencies of rehabilitated culverts using Polygeo. The outcomes achieved from this study will benefit road users and concessionaires in terms of economic, social and environment aspects. There are two conditions of the box culvert, those are the one equipped with a piled foundation and another one is without a pile foundation allowing for different analysis and results related to the shapes and foundations of the culverts. The culverts are positioned on a soft clay layer with a trace of decayed wood, and the above-mentioned clay layer is then filled with a layer of compacted fill material. Both culverts are simulated with the same existing subsoil conditions obtained at a study area of Kanowit, Sarawak, therefore the geotechnical soil parameters used for both types of culverts are identical.

There were numerous studies done to demonstrate and be aware of the behaviour of culvert materials subjected to loading originating from the encroached soil by various means such as laboratory tests, finite element modelling, full-scale field tests and field performance data (Garg and Abolmaali (2009); Abel (2018); Sargand et al. (2005); Kunecki (2006). Despite the availability of various culvert materials, they were unable to be utilized properly with the absence of other important aspects, namely the proper soil support to the culvert and adequate compaction. Culverts

are distinctive as the distribution of loading projected by the soil towards the culvert is unknown, unless the deformation of the culvert is investigated through soil-structure interaction (Katona 2018). To further understand the culvert condition under exertion of soil pressure above it, there are a few notable soil – structure interaction models to be discussed; namely soil arching model and numerical model. The fundamental concept of soil arching was introduced by Marston and Spangler in 1920s (Katona 2018). The arching effects depend on the relative soil movement around the proximity of the structure. Marston and Spangler further concluded that there are two types of soil arching which are negative arching and positive arching. Negative arching occurs when loading from the soil converges towards the pipe. This scenario happens due to the pipe stiffness parameters are larger than the soil stiffness parameter, such as the case of a rigid pipe.

Meanwhile, positive arching occurs when the pipe redirects the loading originated from the soil away. This is due to the pipe stiffness parameters being smaller than the soil stiffness parameter, such as the case of a flexible pipe. The fundamental concepts of soil arching are shown in Figure 1. Once the calculated load is obtained, the pipe is classified whether it is rigid or flexible. A rigid pipe is similar to reinforced concrete pipe meanwhile a flexible pipe is usually made up of corrugated metal. Based on Figure 2, the weight of the soil column is derived in Equation (2.1) as follows:

$$W = HD\gamma \pm 2S \tag{1}$$

where H is the height of the soil column, D is the width of the pipe, γ is the soil unit weight and S is known as frictional shear. The magnitude and direction of S is obtained from the settlement ratio, which depends on the stiffness of pipe to the soil. For flexible pipes, the direction of S moves upwards. On the contrary, the direction of S moves downwards for rigid pipes. Assumptions made were the point load distributed evenly over the culvert crown and partially over the invert depending on the bedding angle. Lateral soil is assumed to be in a parabolic shape. When a culvert is installed in a trench, the backfill material is more compressible than the soil beside it, therefore has a possibility to consolidate and settle. In addition, the deformation of culvert and the settlement of culvert into the bedding would trigger the backfill material on the culvert crown to transfer further downwards relative to the existing trench soil on the side. However, the earth pressure calculation method based on unloading arch theory of the tunnel had been ignored) (Chen et al. (2010). This design approach is still in practice today but cannot be applied to plastic pipe. Later on, a study was done which mainly focused on reducing the vertical load on pipe culverts by setting them on a trench (Bryden et al., 2019). This study conceptually modified Marston’s approach of the soil column load above the pipe by arching action. A portion of weight of the soil shifted towards the adjacent side of the soil resulting in vertical pressure on the pipe is observed to

be less than the overburden pressure (Mamaqani and Najaifi 2014, 2015) further observed the stress reduction on box culverts crown was less compared to pipe culverts.

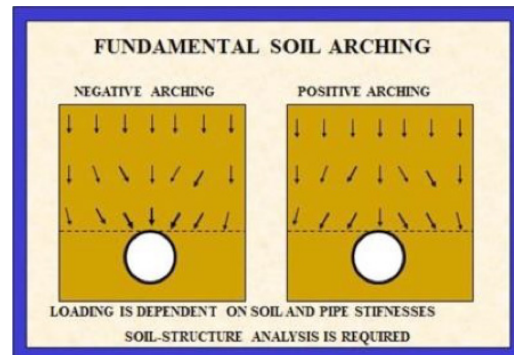


FIGURE 1. Fundamental Concepts of Soil Arching (Katona 2018)

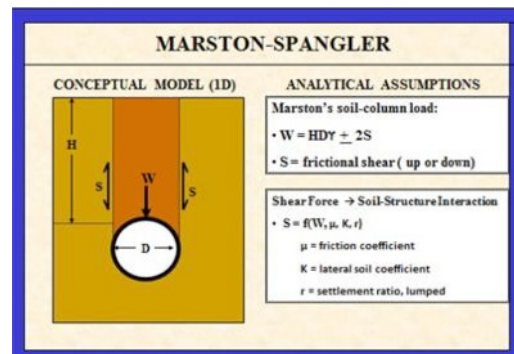


FIGURE 2. Marston – Spangler Model (Katona 2018)

Settlement always occurs around culvert approach, especially when the culvert is constructed on soft soil layer. Previously, the studies related to prediction of settlement of culvert rehabilitated with polyurethane foam injection on soft soil layer by method of PLAXIS FEM simulation has been insufficient. This study assists in determining the reduction in rate of settlement with the application of polyurethane foam injection, which may preserve the structural integrity of culverts and avoid cracking on the pavement surface, which will extend the service life of culverts and pavement quality. Furthermore, any type of damage caused by the settlement such as cracks on culverts and pavement; water and soil infiltration through culvert cracks; roadway collapse; and sinkhole, could be avoided. The findings obtained from this study will benefit the road users in terms of comfortability, and the concessionaire in terms of cost maintenance and time effective. Therefore, the economic, social and environment aspects involving the well-being of the road pavement and culvert structure could be preserved.

MATERIAL AND METHOD

GEOFORENSIC ASSESSMENTS

Settlement always occurs around the culvert approach, especially when the culvert is constructed on soft soil layer.

Previously, the studies related to prediction of settlement of culvert rehabilitated with polyurethane foam injection on soft soil layer by method

SITE GEOMORPHOLOGY

Kanowit is a town and a district capital situated within Sibuan, Sarawak, comprising of 2,253.5 km². The population of Kanowit is 28,985 as of 2010. It is developed on the mouth of Kanowit River at the bank of Rajang River, roughly 174 km from the coast of South China Sea. Kanowit is located at 169 km from the sea, close to the Rajang River. While the Rajang river is flowing from east to west in its general course of direction, the Kanowit river flows from south to north, with the Kanowit river entering Rajang from south to north direction. The part of Rajang river situated nearby Kanowit is 0.8 km wide. Kanowit town is located in the north-south direction. Figure 3 shows the topography of the site location.



FIGURE 3. Site Topography of Sabah and Sarawak. (Borneo Topography, n.d)

SITE GEOLOGY

The area bound in Kanowit comprises of mainly tertiary stage of Paleozoic rocks such as sandstones, greywacks, siltstone, shales, and slate. The riverbanks at Kanowit are below sea level. Hence, Kanowit is subjected to frequent flooding during monsoon season. There are typically three types of soils in the Kanowit area: acid yellow soils discovered in the mountainous areas; podsoils developed from sandy material at the moderately high terrains; and alluvial deposits at the flood plain areas. Coastal and riverine alluvium, and terraces of clay, silt, sand and gravel with layers of peat can also be found in this area.

SUBSURFACE INVESTIGATION

The findings of the subsurface investigation were compiled and presented in the soil investigation report. The objective of the site investigation was to acquire the geological information underlying the proposed site and

the geotechnical parameters required for the geotechnical assessment, design and simulation. The fieldworks were comprised of sinking twelve (12) numbers of deep boreholes. The information obtained from the fieldworks are shown in Appendix A. Standard Penetration Tests (SPT) were carried out in each borehole at 1.5 m intervals over the full borehole depth within the soil stratum. Upon completion of fieldwork at each borehole location, samples were then sent to the approved laboratory for testing.

SOIL PROFILES

A total of twelve boreholes were sunk at the proposed site for the geotechnical design. From the commencement of the subsurface investigation, the soil data indicates that there are three distinctive soil strata on site. The sub-surface conditions at the site may be broadly summarized, in descending order of depth as shown in Table 1. Figures 4 to 8 show the borehole profiles interpreted from the subsurface investigation.

TABLE 1. Generalised Subsoil Profile

Stratum	Description
Residual Soil	Predominantly by Very Soft to Stiff sandy SILT, clayeySILT and CLAY with Loose to Medium Dense silty SAND, and clayey SAND with N ranges from 0 to 8 blows/ft. Up to 11.5 m thick.
Organic Matter/Peat	Predominantly by Very Soft to Stiff PEAT or decayed WOOD, with N ranges from 0 to 8 blows/ft. Up to 3.0 m thick.
Residual Soil	Stiff to Very stiff sandy SILT and sandy CLAY. N varies from 12 to 30 blows/ft. Up to 10.0 m thick.
Residual Soil	Very Stiff to Hard SILT and Dense to Very Dense silty SAND was encountered at 7.0m below ground. N variesfrom 30 to 50 blows/ft. Up to 3.0 m thick.

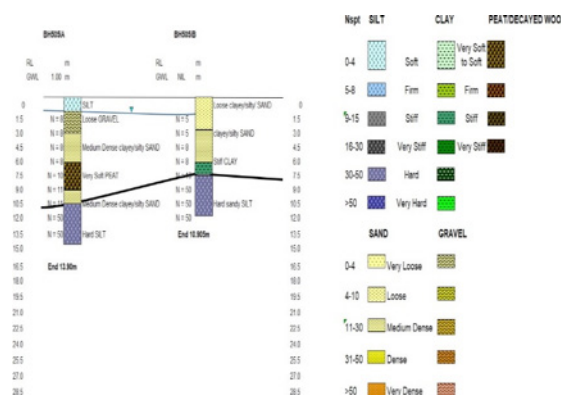


FIGURE 4. Borehole Profile across BH503A – BH503B

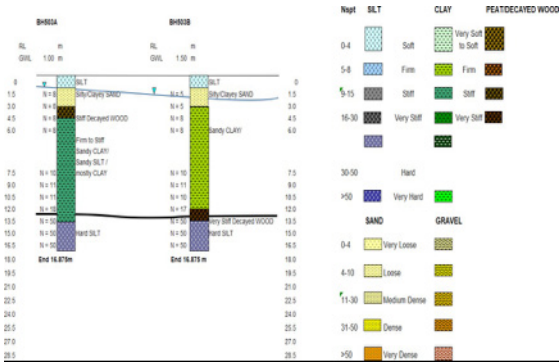


FIGURE 5. Borehole Profile Across BH505iA – BH505iB

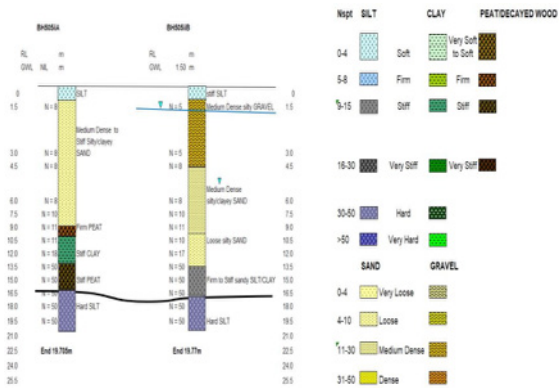


FIGURE 6. Borehole Profile Across BH505iiA – BH505iiB

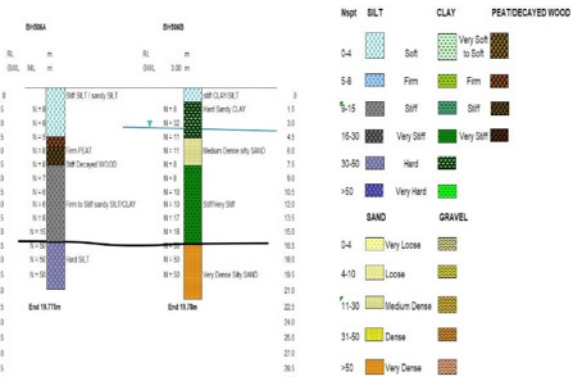


FIGURE 7. Borehole Profile Across BH506A – BH506B

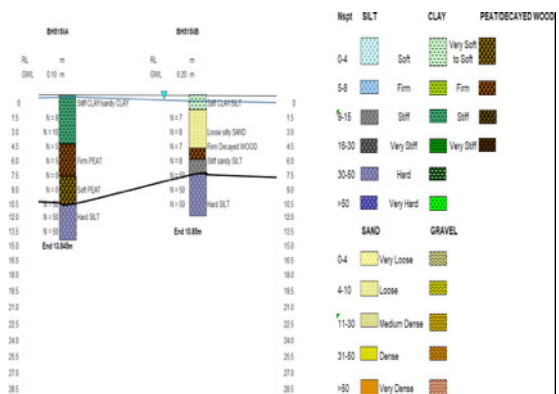


FIGURE 8. Borehole Profile Across BH515iiA – BH515iiB

GROUNDWATER PROFILE

The procedure of monitoring the groundwater level was employed during the investigation by monitoring of water level inside the boreholes. During the soil investigation phase, the groundwater level indicates that the water level ranges from 0 m (full) to 3 m below ground.

PLAXIS 2D MODELLING

A concrete box culvert with a dimension of 2.1 x 2.1 m and a concrete pipe culvert of 0.9 m diameter were experiencing settlement causing undulation and discomfort to the traffic users. Initially, the pavement was about to be regulated to even the surface level. However, the voids appeared beneath both of the culvert foundations triggering the road surface to sag. Figures 9 and 10 show the detailed drawings of box culvert and pipe culvert.

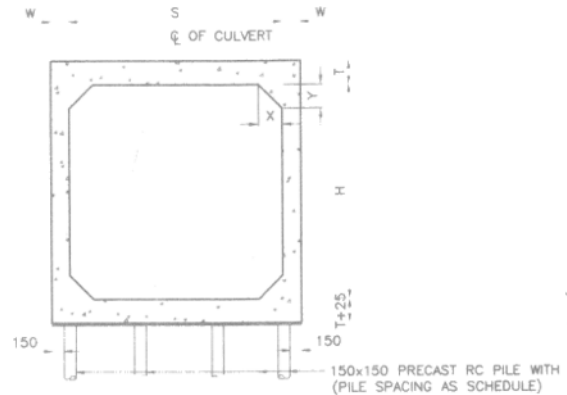


FIGURE 9. Detailed Drawing of Box Culvert

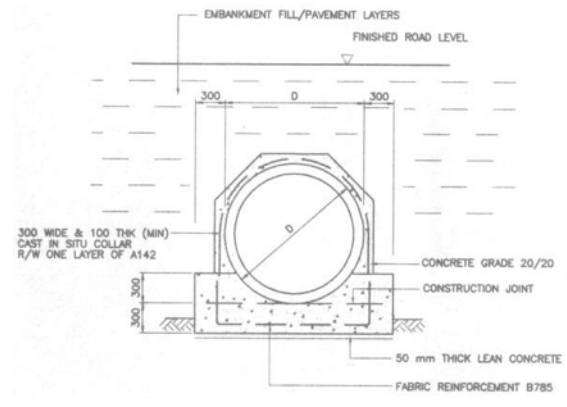


FIGURE 10. Detailed Drawing of Pipe Culvert

Next, the box culvert with a dimension of 2.1 m wide and 2.1 m depth was modelled, coupled with three 150 x 150 mm precast RC piles with pile spacing of 1 m. Thereafter, the pipe culvert with a dimension of 1.8 m diameter was modelled. It was noted to model the Polygeo injection foam installed beneath the box culvert area with the dimension of 3 m wide and 0.3 m thick, and also underneath the pipe culvert

area with the dimension of 2.8 m wide and 0.3 m thick. This was done earlier to ease up the execution of defining Polygeo foam in the geometry later in PLAXIS FEM Calculations program. Meanwhile, 12 boreholes were commenced to capture the soil condition. There were six areas with culverts affected by the settlement, with two boreholes done nearby each side of all six culverts. The two boreholes selected for this study were BH505iA and BH505iB. The soil profile for both above-mentioned boreholes is shown in Figure 8. Therefore, it was determined that compacted fill as the top layer covering 3 m depth followed by a thick layer of clay with decayed woods. The bottom most layer was a layer of hard silt with 5.5 m depth. Hence, the geometry model input was able to be done from the information captured. Figures 11 and 12 show the geometry models for box culvert and pipe culvert cases respectively.

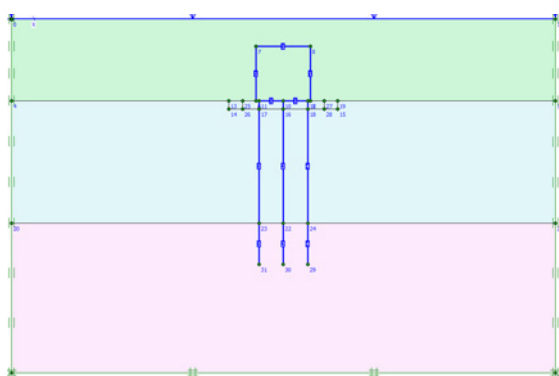


FIGURE 11. Geometry model for box culvert case

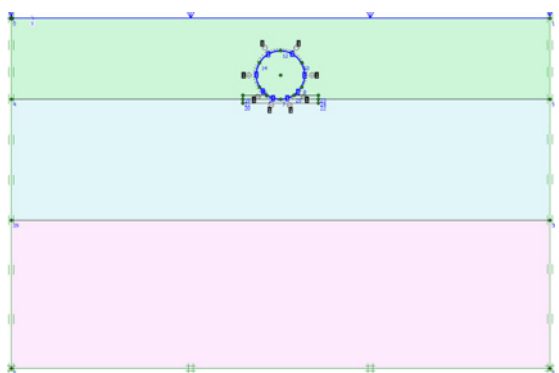


FIGURE 12. Geometry model for pipe culvert case

For the assumption values, it was noted that saturated clay yields $c = 0$ kN/m². However, the cohesion value cannot be nil as to allow the computation in the software. Therefore, the assumption was $c = 0.001$ kN/m². Meanwhile, $c\alpha = 0.001$ was taken from the typical values of geotechnical design parameters with the assumption that the clay has a very low secondary compressibility. Table 2 shows the soil parameters set for clay soil.

TABLE 2. Soil Parameters for Clay

Parameter	Name	Value	Unit
Material model	Model	Soft Soil Creep	-
Material behaviour	Type	Undrained	-
Unsaturated soil unit weight	γ_{unsat}	8.75	kN/m ³
Saturated soil unit weight	γ_{sat}	14	kN/m ³
Permeability in horizontal direction	k_x	1.36×10^{-4}	m/day
Permeability in vertical direction	k_y	1.36×10^{-4}	m/day
Compression index	cc	0.34	-
Swelling index	cs	0.057	-
Creep index	$c\alpha$	0.001	-
Initial void	e_{init}	1.15	-
Cohesion	c_{ref}	0.001	kN/m ²
Friction angle	ϕ	31	°
Dilatancy angle	ψ	0	°

Afterwards, the other type of soil to be input its properties was silt and compacted fill. The parameters of silt and compacted fill were obtained from the previous experience of finite element analyses. Table 3 below presents the soil parameters for silt and compacted fill.

TABLE 3. Soil Parameters for Silt and Compacted Fill

Parameter	Name	Silt	Compacted fill	Unit
Material model	Model	Hardening Soil	Hardening Soil	-
Material behaviour	Type	Undrained	Undrained	-
Unsaturated soil unit weight	γ_{unsat}	18.0	18.5	kN/m ³
Saturated soil unit weight	γ_{sat}	18.0	21	kN/m ³
Permeability in horizontal direction	k_x	0.1	0.1	m/day
Permeability in vertical direction	k_y	0.1	0.1	m/day
Secant stiffness for consolidated drained triaxial	E_{50}^{ref}	10000	25000	kN/m ²
Tangent oedometer stiffness	E_{oed}^{ref}	10000	25000	kN/m ²
Unloading/reloading stiffness	E_{ur}^{ref}	30000	75000	kN/m ²
Power	m	0.5	0.5	-

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Cohesion	c _{ref}	0.1	0	kN/m ²
Friction angle	φ	28	30	°
Dilatancy angle	ψ	3	5	°
Poisson's ratio	ν _{ur}	0.2	0.2	-
Reference stress	p _{ref}	100	100	kN/m ²
Lateral stress coefficient	K ₀ NC	0.531	0.5	-

TABLE 4. Parameters for Polygeo Foam

Parameter	Name	Value	Unit
Material model	Model	Linear Elastic	-
Material behaviour	Type	Non-porous	-
Unsaturated soil unit weight	γ _{unsat}	1.5	kN/m ³
Stiffness	E _{ref}	25000	kN/m ²
Poisson's ratio	ν _{ur}	0.3	-

Lastly, PU foam parameters were input in the soil and interface data set window. The values of the parameters were acquired from the company providing the PU foam. Table 4 presents the parameters for PU foam. There were three types of plates involved in this study, namely box culvert, pipe culvert and pile. The parameters introduced for plates set type were axial stiffness (EA), flexural rigidity (EI), weight (w) and Poisson's ratio (ν). The parameters for box culvert, pipe culvert and piles are presented in Table 5.

TABLE 5. Parameters for Box Culvert, Pipe Culvert and Pile

Parameter	Name	Box culvert	Pipe culvert	Pile	Unit
Material model	Type	Elastic	Elastic	Elastic	-
Normal stiffness	EA	4.247 × 10 ⁵	1.169 × 10 ⁶	1.978 × 10 ⁴	kN/m
Flexural rigidity	EI	1872.2	4296.075	37.095	kNm ² /m
Equivalent thickness	d	0.23	0.21	0.15	m
Weight	w	24	24	24	kN/m/m
Poisson's ratio	ν	0.3	0.3	0.3	-

The materials and methods section should contain sufficient detail so that all procedures can be repeated. It may be divided into headed subsections if several methods are described.

RESULTS AND DISCUSSION

INITIAL CONDITION

Based on the specific calculation phase, namely Initial Condition done in the PLAXIS FEM Calculations program, four output were able to be produced in PLAXIS FEM Output i.e., deformed mesh, vertical displacement shading, vertical displacement cross-section on the surface and culvert total displacement for both cases. Another result that was considered for box culvert case was the horizontal displacement of the piles. This phase was simulated in a time interval of 730 days or two years.

BOX CULVERT

First and foremost, the deformed mesh of box culvert case towards the end of the initial condition period was generated as shown in Figure 13 with highest total displacement value of 112 mm.

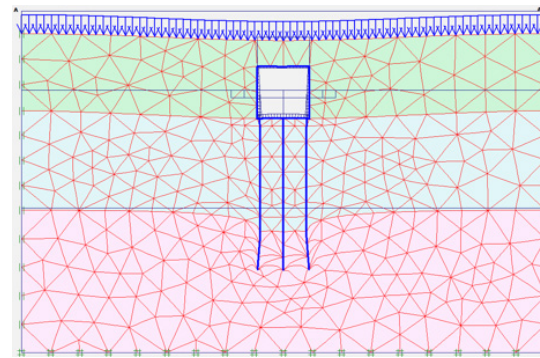


FIGURE 13. Deformed Mesh – Box Culvert Initial Condition

Next, the vertical displacement shading output was generated as shown in Figure 14 where the maximum downward vertical displacement occurring on top of the culvert crown with a value of 112 mm.

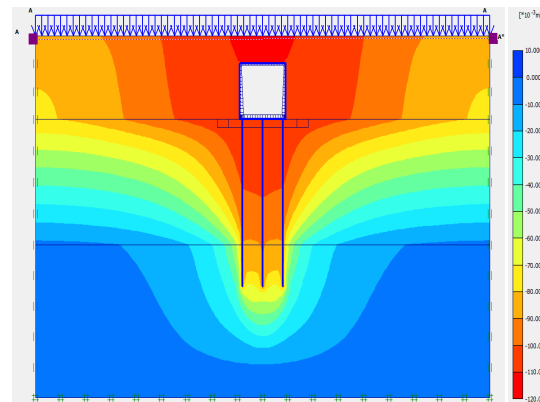


FIGURE 14. Vertical Displacement Shading – Box Culvert Initial Condition

Finally, the horizontal displacement or bending movement of the three piles were attained. The maximum values obtained as shown in Figure 15 for left pile, middle pile and right pile were 9 mm in the left direction, 0.55 mm in the right direction and 8 mm in the right direction respectively.

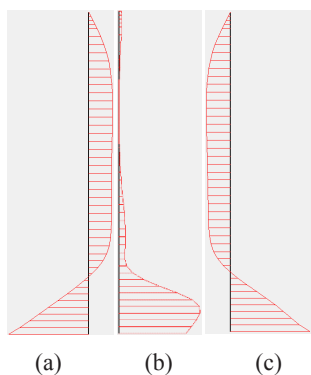


FIGURE 15. (a) Left, (b) Middle and (c) Right Pile Horizontal Displacement– Box Culvert Initial Condition

PIPE CULVERT

Firstly, the deformed mesh of pipe culvert case reaching the end of the initial condition period was produced as shown in Figure 16 with maximum total displacement value of 150 mm.

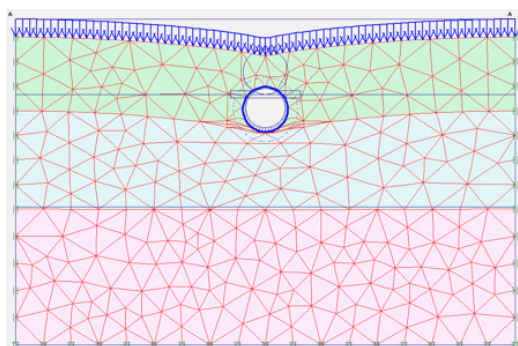


FIGURE 16. Deformed Mesh – Pipe Culvert Initial Condition

Subsequently, the vertical displacement shading output was generated as shown in Figure 17 where the highest downward vertical displacement occurring on top of the culvert crown with a value of 150 mm.

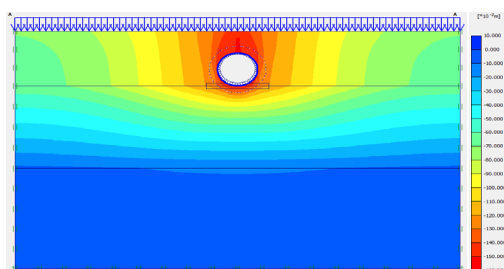


FIGURE 17. Vertical Displacement Shading – Pipe Culvert Initial Condition

DURING CONSTRUCTION WORKS WITH POLYGEO FOAM

According to this specific calculation phase which is termed as Polygeo Installation done in the PLAXIS Calculations program, four types of results were able to be generated in PLAXIS Output i.e., deformed mesh, vertical displacement shading, vertical displacement cross-section on the surface and culvert total displacement for both culvert cases. An additional result was considered for box culvert case in form of horizontal displacement of the piles. This phase was simulated within a time period of 30 days or one month.

BOX CULVERT

Initially, the deformed mesh of box culvert case towards the completion of the polyurethane foam injection works period was generated as shown in Figure 18 with a total displacement maximum value of 9 mm.

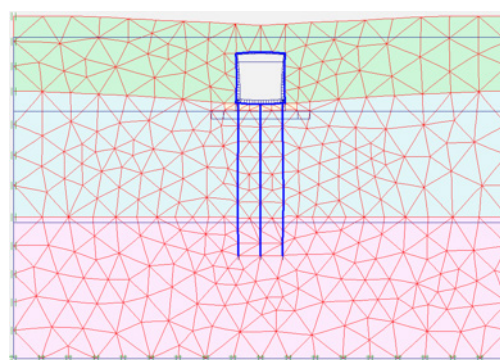


FIGURE 18. Deformed Mesh – Box Culvert PU Installation

Thereafter, the vertical displacement shading was generated as presented in Figure 19 where the highest upward vertical displacement occurring on the side of the culvert crown with a value of 9 mm.

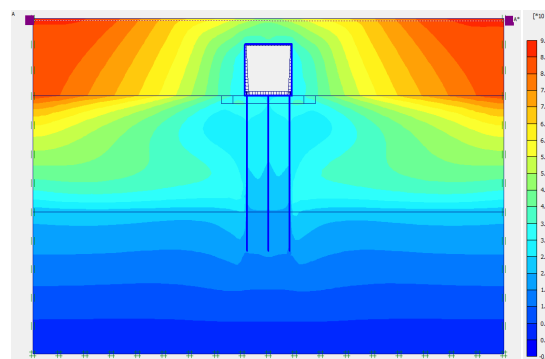


FIGURE 19. Vertical Displacement Shading – Box Culvert PU Installation

Finally, the horizontal displacement of the three piles were acquired. The maximum values obtained as shown in Figure 20 for left pile, middle pile and right pile were 0.3 mm in the left direction, 0.03 mm in the right direction and 0.3 mm in the right direction respectively.

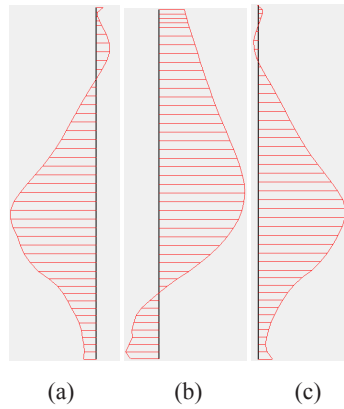


FIGURE 20. (a) Left, (b) Middle and (c) Right Pile Horizontal Displacement – Box Culvert PU Installation

PIPE CULVERT

Firstly, the deformed mesh of pipe culvert case reaching the end of the polyurethane installation period was generated as shown in Figure 21 with highest total displacement value of 9 mm.

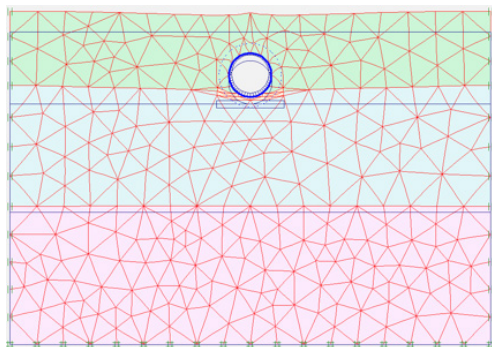


FIGURE 21. Deformed Mesh – Pipe Culvert PU Installation

Next, the vertical displacement shading output was generated as shown in Figure 22 where the maximum upward vertical displacement occurring on the side of the culvert crown with a value of 9 mm.

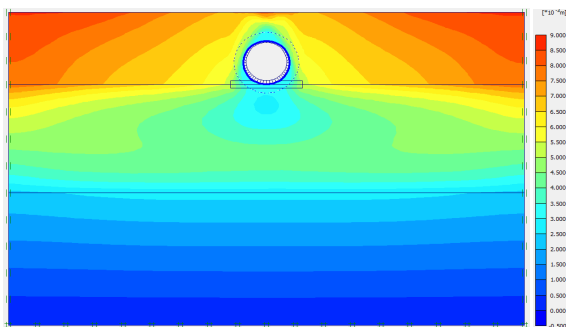


FIGURE 22. Vertical Displacement Shading – Pipe Culvert PU Installation

POST CONSTRUCTION WORKS

This particular calculation phase which is known as Post Construction, was done in the PLAXIS Calculations program, whereby four types of results were able to be produced in PLAXIS Output program i.e., deformed mesh, vertical displacement shading, vertical displacement cross-section on the surface and culvert total displacement for both culvert cases. A further result was contemplated for box culvert case in form of horizontal displacement of the piles. This phase was simulated within a time interval of 1825 days or 5 years.

BOX CULVERT

Firstly, the deformed mesh of box culvert case towards the end of the post construction period was produced as shown in Figure 23 with maximum total displacement value of 14 mm.

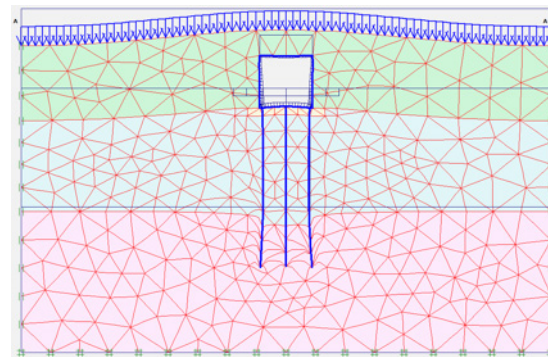


FIGURE 23. Deformed Mesh – Box Culvert Post Construction

Next, the vertical displacement shading output was created as shown in Figure 24 where the maximum downward vertical displacement occurring on the side of the culvert crown with a value of 14 mm.

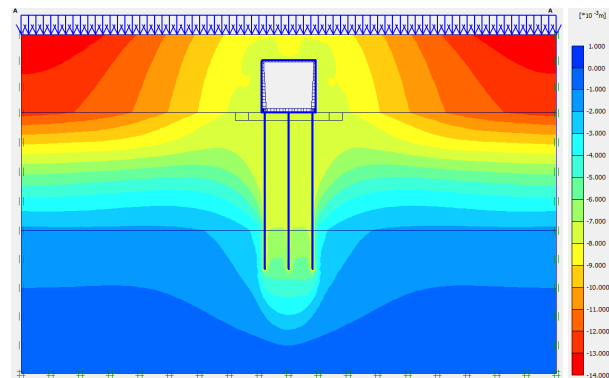


FIGURE 24. Vertical Displacement Shading – Box Culvert Post Construction

Finally, the horizontal displacement or bending movement of the three piles were attained. The maximum values obtained as shown in Figure 25 for left pile, middle pile and right pile were 0.8 mm in the left direction, 0.05 mm in the right direction and 0.8 mm in the right direction respectively.

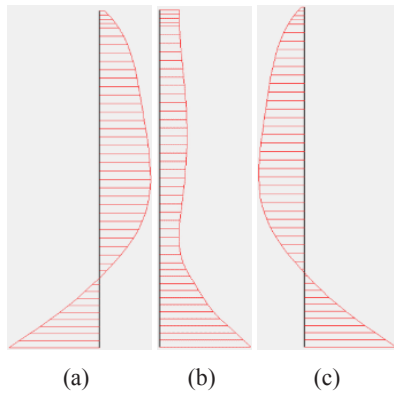


FIGURE 25. Left, Middle and Right Pile Horizontal Displacement – Box Culvert Post Construction

Pipe Culvert

First and foremost, the deformed mesh of pipe culvert case towards the end of the post construction period was produced as presented in Figure 26 with maximum total displacement value of 22 mm.

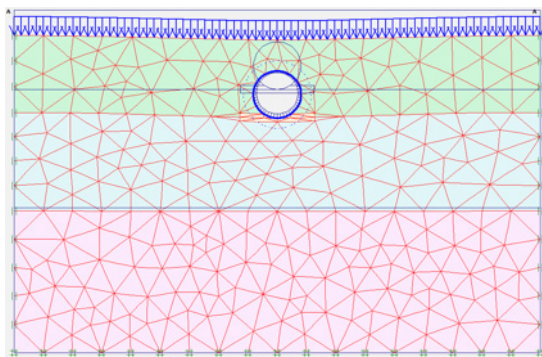


FIGURE 26. Deformed Mesh – Pipe Culvert Post Construction

Thereafter, the vertical displacement shading was generated as presented in Figure 27 where the highest downward vertical displacement occurring on top of the culvert crown with a value of 22 mm.

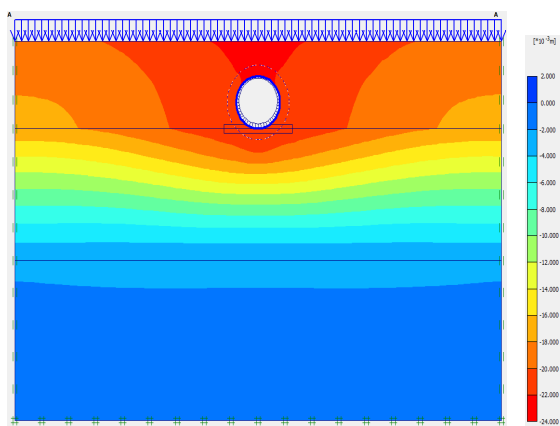


FIGURE 27. Vertical Displacement Shading – Pipe Culvert Post Construction

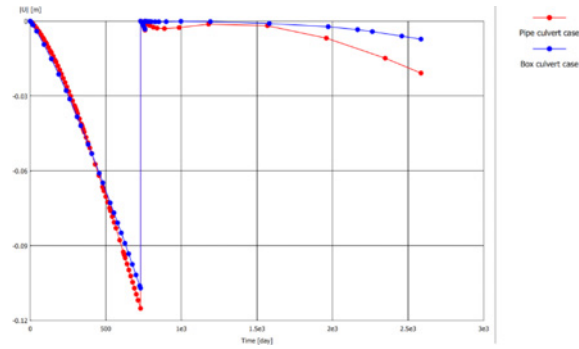


FIGURE 28. Vertical Settlement Beneath Culvert of Box Culvert Case Against Pipe Culvert Case

Two graphs representing both culvert cases were generated for this study as shown in Figure 28 relating to vertical displacement or settlement, and time period along the construction stages. There was a total of three construction stages i.e., Initial Condition, PU Installation and Post Construction. It was noted that the displacement was reset to zero during the initiation of all construction stages. For Initial Condition construction stage in a span of two years, the vertical settlement for pipe culvert case with maximum value of 150 mm was greater compared to box culvert with pile with a value of 112 mm. This indicated that the vertical settlement for pipe culvert case settled up to 34% more than the case of box culvert. At the end of PU Installation construction stage which lasted for a month, the value of vertical displacement for box culvert with pile was found to be approximately 9 mm upwards, which was similar to the pipe culvert case. Throughout the five-year period of Post Construction stage, the pipe culvert was shown to settle around 22 mm as opposed to the box culvert with pile which settled around 14 mm. These results suggested that the vertical settlement for pipe culvert case settled up to 57% more than the case of box culvert with pile.

CONCLUSION

Three objectives presented here have been achieved. The first objective was achieved by obtaining the desired results by running simulations on both culvert cases in initial condition which features the introduction of soft soil that can trigger secondary compression or creep. Two case studies of consolidation analysis simulations were done in PLAXIS FEM involving box culvert and pipe culvert related to soft soil. It was noted that the box culvert was designed with piled foundation, while no foundation was modelled for the pipe culvert. The results obtained were both of the culvert cases settled more than 100 mm in a span of only two years. However, the box culvert was undergoing less settlement as compared to pipe culvert. This was due to the introduction of piled foundation where the piles were set on a hard sandy silt layer. Both cases failed to meet the criteria set in Typical Design Criteria for Geotechnical Works prepared by JKR which stated that the 5 years

post construction settlement within 50 m from structure's approach must be lesser than 100 mm. The second objective was accomplished by acquiring the results by running simulations on both culvert cases during PU installation and post construction stages. The time interval for installation of polyurethane foam injection was set to one month. During the end period of PU foam installation, both box culvert and pipe culvert experienced a slight uplift. For the post construction phase, the time period was set to five years. Both cases have met the JKR requirement of settlement not exceeding 100 mm in less than 50 m from the culvert approach in a duration of five years. Piled foundation with an addition of PU foam injection have managed to prevent the box culvert from settling even deeper. The introduction of Polygeo foam to the culverts have successfully slowed the rate of settlement without requiring any major physical works such as excavation, prompting for a cost-effective option and environmentally neutral in culvert rehabilitation works.

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DECLARATION OF COMPETING INTEREST

None

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