 DOI: 10.35382/TVUJS.14.8.2024.108

RESEARCH ON THE SETTLEMENT OF BRIDGE APPROACH EMBANKMENTS DURING THE OPERATION PROCESS: A CASE STUDY OF THREE BRIDGES IN TRA VINH PROVINCE, VIETNAM

Van Hiep Huynh[1*], Tri Huu Huynh[2], Truyen Ngo Gia[3]

Abstract – *In the Mekong Delta in general and Tra Vinh Province in particular, the settlement of bridge approach embankments has occurred for many years. However, the current solution to compensate for settlement has not been resolved completely and sustainably. The study was conducted to learn about the nature of the settlement phenomenon and predict the amount of settlement compensation for bridge approach embankments during operation throughout the province. The results show that in the settlement of bridge approach embankments, in the case of not treating the ground, the total settlement is 0.21 m, and the time to stop settlement is 100 years; in the case of treating the ground, the total settlement is 0.12 m, the time to stop settlement is 50 years. This study helps designers and constructors have solutions to properly treat the bridge approach embankments to avoid the settlement of the bridge approach.*

Keywords: settlement of bridge approach, time to stop settlement, Tra Vinh.

I. INTRODUCTION

The problem of settlement at the junction of the bridge approach embankments on soft soil (settlement, sudden change in hardness, large shock force) leads to the phenomenon of vehicles participating in traffic suddenly changing when entering or exiting the bridge, affecting the comfort of people and goods on the vehicle, can also cause accidents, reduce vehicle speed and increase construction maintenance costs. This is a common phenomenon, appearing not only in Vietnam but also in developed countries. Currently, in Tra Vinh Province, there are about 186 reinforced concrete bridges managed by the Department of Transportation, of which about 41 bridges, large and small, are deteriorating, typically with the settlement of bridge approach embankments. Briaud et al. [1] indicated that at least 25% of the 600,000 bridges in the USA, or about 150,000 bridges, are affected by bridge approach settlement. Stark et al. [2] reported that 27% of the 1,181 bridges in Illinois had significant differential bridge approach movement, and those adjacent states such as Iowa, Wisconsin, Michigan, Ohio, Indiana, Missouri, and Kentucky exhibited similar percentages. Ha et al. [3] reported that 24.5% of the Texas DOT bridges indicated a bump. Another study by Luna et al. [4] for Missouri DOT (MoDOT) reported that 17% of the bridges exhibited bridge approach settlement, and an additional 15% required remediation. In Long An, according to Do Thi My Chinh et al. [5], the settlement of bridge approach embankments with the bridge abutment using soil cement piles was treated; after 15 years, the settlement was 8.601 cm. If the ground was not treated with soil cement piles later in 15 years, the settlement is 17.344 cm, more significant than standard 22TCN 211:2006 [6]. In addition, in Ho Chi Minh City, the application of Geofoam material to build bridge approach embankments on soft soil was carried out by Nguyen Hoang Hung [7]. Accordingly, the roadbed during the construction and operation process ensures load-bearing capacity requirements according to 22TCN 262-2000 [8]. The load applied to Geofoam is less than the compressive strength of Geofoam with a safety factor FS > 1.2 [9, 10], ensuring the load-

[1,2,3]Tra Vinh University, Vietnam
*Corresponding author: hvhiep@tvu.edu.vn
Received date: 01st July 2024; Revised date: 23rd August 2024; Accepted date: 03rd December 2024

bearing capacity and deformation are within the elasticity of materials. The design plan for the bridge approach embankments using Geofoam ensures the requirements for instantaneous settlement when there is a live vehicle load and the allowable consolidation settlement of the roadbed over 15 years, according to 22TCN 262-2000 [8]. The overall stability of the bridge approach embankments is guaranteed according to 22TCN 262-2000 [8], with safety factor FS > 1.4; ensure buoyancy stability with safety factor FS > 1.2. According to Do Thi My Chinh [11], the cause of the bridge approach embankments in Dong Thap is the consolidation settlement of the soft soil layer below. The research was conducted on 16 bridges. Although studies and solutions have been proposed, the problem has not been completely overcome. Therefore, the road embankment to the bridge is one of the essential items, requiring analysis and specific technical measures to meet the requirements of strength, stability, and aesthetics.

II. THEORETICAL BASIS

A. Analysis of embankment settlement

Embankment settlement is the vertical displacement under the effect of vertical everyday stress. The total settlement of the embankments on soft soil includes three components, as shown in Equation (1), with settlement immediately, S_i; consolidation settlement, S_c; and creep settlement, S_s.

$$S = S_i + S_c + S_s \qquad (1)$$

Settlement of the embankments usually occurs quickly, right after the project is constructed. The settlement is of small value and does not affect the settlement of the embankments during the operation process. Consolidation settlement results from a decrease in the void ratio in saturated clay due to water escaping over time and external load pressure being slowly transmitted to the grain structure. The settlement occurs slowly depending on time due to the low permeability coefficient of the soft soil layer. Consolidation settlement can occur over many years. Creep settlement is the decrease in a void ratio in soil when pore water pressure has dissipated under constant stress. Therefore, creep settlement occurs after consolidation settlement has ended. Gradual settlement does not affect the settlement of the embankments during the operation process because the residual settlement under the flexible road surface calculated over 15 years is insignificant compared to when consolidation settlement ends, especially in bridge locations where the soft soil is not treated or reinforced.

B. Consolidation settlement

The consolidation settlement of the soil is calculated based on the parameters from the results of the 1-dimensional consolidation compression test. The settlement formula depends on the history of the soil determined through the pre-consolidation ratio. Over-consolidated ratio (OCR) is shown in Equation (2).

$$OCR = \frac{\sigma'_p}{\sigma'_{v0}} \qquad (2)$$

Equation (3) shows consolidation settlement in the case of over-consolidated soil OCR > 1.

$$S_c = \frac{H_0}{1+e_0} \times C_c \times \log\frac{\Delta\sigma + \sigma'_{v0}}{\sigma_p} + \frac{H_0}{1+e_0} \times C_r \times \log\frac{\sigma'_p}{\sigma'_{v0}} \qquad (3)$$

Equation (4) is used to calculate consolidation settlement in case of normally consolidated soil (OCR = 1) or not yet consolidated OCR < 1.

$$S_c = \frac{H_o}{1+e_o} \times C_c \times \log\frac{\Delta\sigma + \sigma'_{v0}}{\sigma'_p} \qquad (4)$$

Where:

$S_c(t)$ is the total consolidation settlement of all layers at time t.

H_o is the initial thickness of the soft soil layer with a large settlement (m).

e_o is the initial void ratio of the soil layer.

C_c is the compression index.

Δ_σ is the dissipation of pore pressure of the considered layer at time t.

σ_{vo} is the effective stress of the considered layer .

σ_p is the preconsolidation pressure.

C_r is the recompression index.

Note: Settlement is the ground reaches 100% consolidation under the reloading level Δ_σ.

C. Settlement consolidation over time

Determination of consolidation settlement over time for embankment works on soft soil includes determining consolidation settlement of the embankment over time from the time the project was put into use and determining the remaining settlement from the present time to the 15^{th} year of the operation process.

Consolidation settlement over time is determined according to Terzaghi's theory as in Equation (5).

$$S_t = U \times S_c \qquad (5)$$

Where:

U is the consolidation ratio.

$S_c(t)$ is the total consolidation settlement of all layers at time t.

The consolidation ratio is the percentage of water released corresponding to a load level. The consolidation ratio U depends on the time factor calculated according to Equation (6).

$$\text{If } U = 0\text{-}60\% \text{ then } T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$$
$$\Rightarrow U = 100\sqrt{\frac{4 \times T_v}{\pi}} \qquad (6)$$
$$\text{If } U > 60\% \text{ then } T_v = 1.781 - 0.933\log(100 - U\%)$$
$$\Rightarrow U = 100 - 10^{\frac{1.781 - T_v}{0.933}}$$

The time factor is determined as in Equation (7).

$$T_v = \frac{C_v^{tb}}{H^2} \times t \qquad (7)$$

Equation (8) indicates the average consolidation coefficient.

$$C_v^{tb} = \frac{Z_a^2}{\left(\sum \frac{h_i}{C_{vi}}\right)^2} \qquad (8)$$

Where:

C_v^{tb} is the average consolidation coefficient (m^2/y); t is the consolidation time.

h_i is the thickness of the soft soil layer within the range Z_a, the depth is shown in Equation (9).

$$Z_a = \sum_{i=1}^{n} h_i \qquad (9)$$

Z_a is the depth (m).

C_{vi} is determined through compression and settlement tests without swelling for undisturbed samples representing soft soil layer i corresponds to the average pressure $\frac{\sigma_{vo} + \Delta_\sigma}{2}$. During consolidation, H is the drainage depth that soft soil layer i is subjected to Equation (10). Consolidated water follows the drainage surface both above and below.

$$H = \frac{1}{2 \times Z_a} \qquad (10)$$

III. CALCULATION DATA

A. Geological data

All geological data were collected at geological boreholes at three projects, including Bridge No. 01, Bridge No. 02 (asphalt road connecting Tan Quy 1 and 2 hamlets, An Phu Tan Commune, Cau Ke District), Duong Khai Bridge (Dong Hai Commune, Cau Ke District). Data includes soil layer name, unit weight, and thickness (Table 1, Table 2, Table 3).

B. Bridge data

All bridge data were collected at three projects, including Bridge No. 01, Bridge No. 02 (asphalt road connecting Tan Quy 1 and 2 Hamlets, An Phu Tan commune, Cau Ke District), Duong Khai

Table 1: Geological data Duong Khai Bridge

Layer	Describe	Unit weight (kN/m^3)	Thickness (m)
layer 1A	Yellow-brown clay, soft plastic state	16.6	1.5
layer 1	Clay mud, dark gray, mixed with plant roots	16.6	5.7
layer 2	The sand is small, blue-gray, and has a poor texture	18.7	1.1
layer 3	Clayey mud, dark gray-blue gray, sometimes interspersed with sand, flowing state	16.5	15.9
layer 4	Clay, yellow brown-gray brown, complex plastic state	19.3	3.4
layer 5	Mixed sand, light yellow-gray white, plastic state	18.6	9.1
layer 6	Clay, brownish-gray-greenish-gray, semi-hard state	19.1	3.9
layer 7	Mixed sand, light yellow-gray white, plastic state	19	7.1
layer 8	Small sand, light yellow, medium to tight texture	19.9	3.9

Source: Tra Vinh General Construction Design Consulting Joint Stock Company [12]

Table 2: Geological data Bridge No. 01

Layer	Describe	Unit weight (kN/m^3)	Thickness (m)
layer 1	Clay mixed with yellow-brown-gray-brown color, soft plastic state	17.9	1.4
layer 2	Clay mud, gray-brown, gray-green, flowing state	16.0	5.1
layer 3	Small sand, gray-brown, gray-green, flowing state	16.1	2.1
layer 4	Clay mud, gray-brown, gray-green, flowing state	16.1	1.6
layer 5	The sand is small, grey-brown, grey-green, less dense	18.4	1.8
layer 6	Clay mud, gray-brown, gray-green, flowing state	16.1	2.6
layer 7	Mixed clay, grey-brown-gray green, semi-hard state	19.6	21.7
layer 8	Mixed sand, yellow brown-gray white, good condition	19.7	8.0
layer 9	Mixed clay, yellow-brown, red-brown, semi-hard	20.1	5.7

Source: Hung Long Construction Design Consulting Joint Stock Company [13]

Bridge (Dong Hai Commune, Cau Ke District). Data includes name, sign, size, and unit (see Tables 4, 5, 6).

IV. RESULTS AND DISCUSSIONS

A. Duong Khai Bridge

Applying the above calculation method and formulas, this study obtains the following calcu-

Table 3: Geological data Bridge No. 02

Layer	Describe	Unit weight (kN/m^3)	Thickness (m)
layer 1	Clay mixed with yellow-brown-gray-brown color, soft plastic state	18	1.7
layer 2	Clay mud, gray-brown, gray-green, flowing state	16.0	4.7
layer 3	Small sand, gray-brown, gray-green, flowing state	18.4	1.6
layer 4	Clay mud, gray-brown, gray-green, flowing state	16.1	2.0
layer 5	The sand is small, grey-brown, grey-green, less dense	18.4	1.7
layer 6	Clay mud, gray-brown, gray-green, flowing state	16.1	3.5
layer 7	Mixed clay, grey-brown-gray green, semi-hard state	19.6	21.3
layer 8	Mixed sand, yellow brown-gray white, good condition	19.7	7.5
layer 9	Mixed clay, yellow-brown, red-brown, semi-hard	20.1	6.0

Source: Hung Long Construction Design Consulting Joint Stock Company [13]

Table 4: Duong Khai Bridge

Name	Sign	Size	Unit
Road surface breadth	b	4	m
Roadbed breadth	B	11	m
Height of embanked soil	H_{em}	0.89	m
Height of excavation base	H_{exb}	2.7	m
Embankment design elevation	H_d	5.4	m
Reinforcement taluy design elevation	H_{td}	5.4	m
Excavation elevation	H_{ex}	1.8	m
Natural elevation of the ground	H_n	4.5	m
Unit weight of embankment	γ_w	16.6	kN/m^3
Roadbed slope	m	1.3	%

Source: Hung Long Construction Design Consulting Joint Stock Company [14]

Table 5: Bridge No. 01

Name	Sign	Size	Unit
Road surface breadth	b	4	m
Roadbed breadth	B	11	m
Height of embanked soil	H_{em}	0.89	m
Height of excavation base	H_{exb}	2.7	m
Embankment design elevation	H_d	5.4	m
Reinforcement taluy design elevation	H_{td}	5.4	m
Excavation elevation	H_{ex}	1.8	m
Natural elevation of the ground	H_n	4.5	m
Unit weight of embankment	γ_w	17.9	kN/m^3
Roadbed slope	m	1.3	%

Source: Hung Long Construction Design Consulting Joint Stock Company [15]

Table 6: Bridge No. 02

Name	Sign	Size	Unit
Road surface breadth	b	4	m
Roadbed breadth	B	11	m
Height of embanked soil	H_{em}	0.89	m
Height of excavation base	H_{exb}	2.7	m
Embankment design elevation	H_d	5.4	m
Reinforcement taluy design elevation	H_{td}	5.4	m
Excavation elevation	H_{ex}	1.8	m
Natural elevation of the ground	H_n	4.5	m
Unit weight of embankment	γ_w	17.9	kN/m^3
Roadbed slope	m	1.3	%

Source: Hung Long Construction Design Consulting Joint Stock Company [15]

lation results:

- Rectangular load case: Consolidation settlement depth is 11.3 m; Total consolidation settlement is 0.547 m; Settlement immediately is 0.22 m; Total settlement is 0.77 m. The remaining settlement required over time t is 20 cm. To achieve a remaining settlement of 20 cm, with the height of the backfill soil, it is necessary to wait 10.06 years (Figure 1).

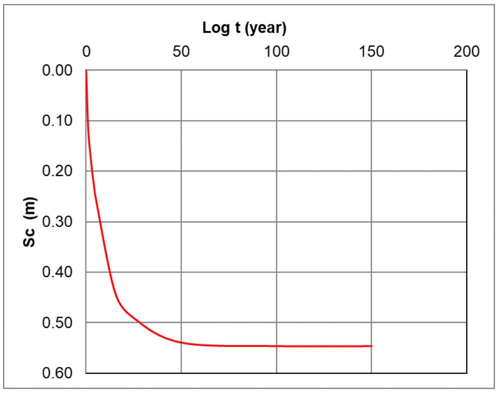

Fig. 1: Chart calculating settlement over time - Case 1, Road connecting Dong Hai Commune

- Trapezoidal load case: Consolidation settlement depth is 7.8 m; Total consolidation settlement is 0.93 m; Settlement immediately is 0.37 m; Total settlement is 1.3 m. The remaining settlement required over time t is 20 cm. Given the height of the backfill soil, achieving a remaining settlement of 20 cm requires a waiting period of 12.83 years (Figure 2).

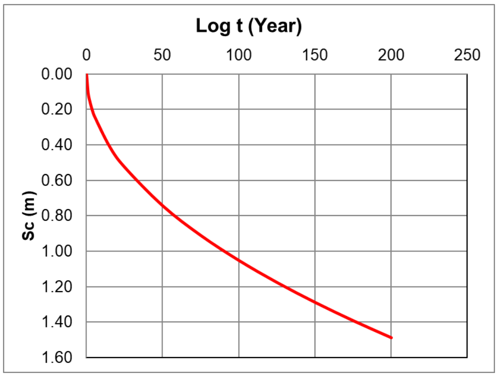

Fig. 2: Chart of settlement over time

B. Bridge No. 01

- Rectangular load case: Consolidation settlement depth is 10.2 m; Total consolidation settlement is 0.667 m; Settlement immediately is 0.267 m; Total settlement is 0.934 m. The remaining settlement required over time t is 20 cm. With the given height of the backfill soil, a remaining settlement of 20 cm will be reached after 1.64 years (Figure 3).

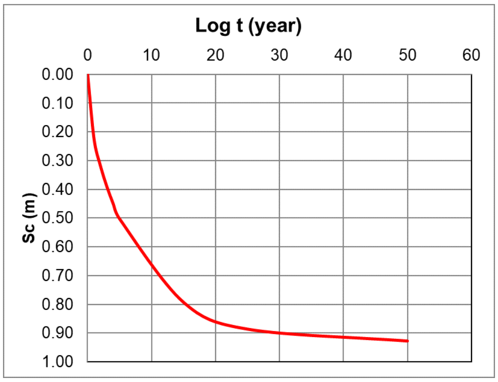

Fig. 3: Chart of settlement over time for Bridge No. 01 – Rectangular case

- Trapezoidal load case: Consolidation settlement depth is 8.5 m; Total consolidation settlement is 1.156 m; Settlement immediately is 0.462 m; Total settlement is 1.619 m. The remaining settlement required over time t is 20 cm. Attaining a remaining settlement of 20 cm, given the height of the backfill soil, requires a waiting period of 8.97 years (Figure 4).

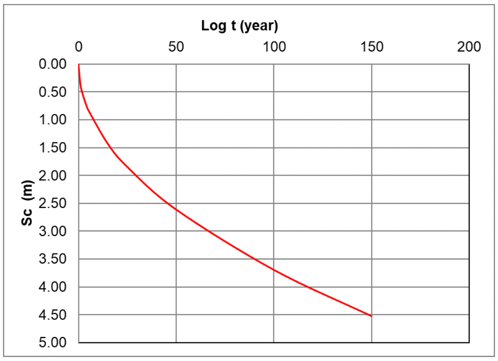

Fig. 4: Chart of settlement over time for Bridge No. 01 – Trapezoidal case

C. Bridge No. 02

- Rectangular load case: Consolidation settlement depth is 10 m; Total consolidation settlement is 1.177 m; Settlement immediately is 0.471 m; Total settlement is 1.648 m. The remaining settlement required over time t is 20 cm. With the specified height of the backfill soil, a remaining settlement of 20 cm will require 3.14 years to occur (Figure 5).

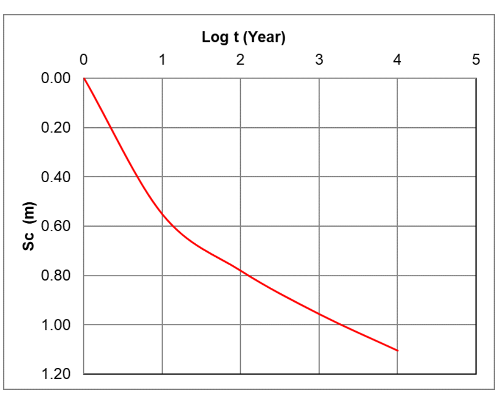

Fig. 5: Chart of settlement over time for Bridge No. 02 – Rectangular case

- Trapezoidal load case: Consolidation settlement depth is 8.0 m; Total consolidation settlement is 1.350 m; Settlement immediately is 0.54 m; Total settlement is 1.89 m. The remaining settlement required over time t is 20 cm. Based on the height of the backfill soil, it will take 11.35 years for a remaining settlement of 20 cm to be achieved (Figure 6).

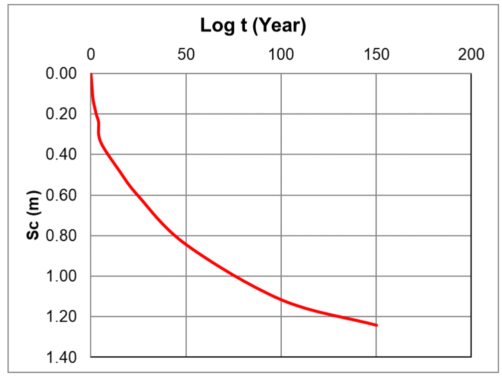

Fig. 6: Chart of settlement over time for Bridge No. 01-Trapezoidal case

The results of this study show that the settlement of bridge approach embankments is almost equal to the results of the previous studies [5, 6]. This shows that the study was conducted appropriately in both the method and geological situation of a similar area.

V. CONCLUSIONS

Research on the nature of bridge approach embankment settlement under operation throughout Tra Vinh Province is carried out based on settlement analysis using analytical methods and comparison with actual data. The settlement analysis data and actual settlement data are taken from survey results and measurements of the current situation. The analysis results allow us to conclude the causes of the settlement of bridge approach embankments during the operation process throughout Tra Vinh Province. Based on the bridges' geological survey records, the structures' geology is generally soft soil layers with relatively low bearing strength, relatively high settlement and compression ability, and relatively low deformation capacity. In addition, the settlement calculation results of the collected design documents show that the settlement of bridge approach embankments in different areas will produce different settlement calculation results in terms of settlement level and completion time. Therefore, proposing a general mudslide cycle for the entire Tra Vinh Province is unsuitable for local conditions.

REFERENCES

[1] Briaud JL, Maher SF, James RW. Bump at the end of the bridge. *Civil Engineering*. 1997;67(5): 68–69.

[2] Stark TK, Olson SM, Long JH. *Differential movement at the embankment/structure interface-mitigation and rehabilitation*. Springfield, US: Illinois Department of Transportation. Report No: IAB=H1, FY93, 1995.

[3] Ha HS, Seo J, Briaud J. *Investigation of settlement at bridge approach slab expansion joint: survey and site investigations*. Austin, US: Texas Department of Transportation. Report No: FHWA/TX-03/4147-1, 2002.

[4] Luna R, Robison JL, Wilding A. *Evaluation of bridge approach slabs, performance and design*. Washington D.C., US: Department of Transportation. Report No. UTC R80, 2003.

[5] Do Thanh Hai, Nguyen Trung Hau. Research on solutions to difference subsidence of bridge approach embankments with Long Son bridge abutments in Ben Luc-Long An [Nghiên cứu giải pháp xử lý lún lệch đường dẫn vào cầu với mố cầu Long Sơn ở Bến Lức, Long An]. *Ho Chi Minh City Open University Journal of Science [Tạp chí Khoa học Trường Đại học Mở TP. Hồ Chí Minh]*. 2016;11(2): 105–112.

[6] Ministry of Transport of Vietnam. *Standard 22TCN 211:2006. Flexible pavement – requirements and design instructions [Áo đường mềm – Các yêu cầu và chỉ dẫn thiết kế]*. Vietnam: Ministry of Transport; 2006.

[7] Nguyen Hoang Hung. *Research and application of Geofoam material to build bridge approach embankments on soft soil in Ho Chi Minh City [Nghiên cứu ứng dụng vật liệu Geofoam xây dựng đường đầu cầu trên đất yếu ở Thành phố Hồ Chí Minh]*. Project report. Ho Chi Minh City, Vietnam: Department of Science and Technology of Ho Chi Minh City; 2020.

[8] Ministry of Transport of Vietnam. Standard 22TCN 262:2000. *Survey and design process for alluvial embankments on soft soil [Quy trình khảo sát thiết kế nền đường ô tô đắp trên nền đất yếu]*. Vietnam: Ministry of Transport; 2000.

[9] Leshchinsky D, Hu Y, Han J. Limited reinforced space in segmental retaining walls. *Geotextiles and Geomembranes Journal*. 2004;22(6): 543–553.

[10] Dadson SJ, Hovius N, Chen H, Dade WB, Lin JC, Hsu ML, et al. Earthquake-triggered increase in sediment delivery from an active mountain belt. *Geology Journal*. 2004;32(8): 733–736.

[11] Do Thi My Chinh, Tran Nguyen Hoang Hung. Investigation on the nature of excessive settlement of bridge approaching embankments in service in Dong Thap Province [Nghiên cứu bản chất hiện tượng lún đường đầu cầu trong quá trình khai thác toàn tỉnh Đồng Tháp]. *Journal of Ministry of Construction [Tạp chí Bộ Xây dựng]*. 2016;8: 24–29

[12] Tra Vinh General Construction Design Consulting Joint Stock Company – Geotechnical Laboratory and LAS-Construction 286. *Construction geological survey report: Road connecting Dong Hai Commune Duyen Hai District, Tra Vinh Province - Duong Khai Bridge [Báo cáo khảo sát địa chất: đường kết nối xã Đông Hải, huyện Duyên Hải, tỉnh Trà Vinh - cầu Đường Khai]*. Tra Vinh, Vietnam: Tra Vinh General Construction Design Consulting Joint Stock Company; 2012.

[13] Hung Long Construction Design Consulting Joint Stock Company. *Construction geological survey report: Asphalt road inter-hamlet Tan Qui 1–Tan Qui 2, An Phu Tan Commune, Cau Ke District, Tra Vinh Province [Báo cáo khảo sát địa chất: đường nội ô Ấp Tân Qui 1–Tân Qui 2, xã An Phú Tân, huyện Cầu Kè, tỉnh Trà Vinh cầu Đường Khai]*. Tra Vinh, Vietnam: Hung Long Construction Design Consulting Joint Stock Company; 2018.

[14] Hung Long Construction Design Consulting Joint Stock Company. *Construction drawing design: Road connecting Dong Hai commune – Duyen Hai District – Tra Vinh Province – Duong Khai Bridge [Bản vẽ thiết kế xây dựng đường kết nối xã Đông Hải, huyện Duyên Hải, tỉnh Trà Vinh - cầu Đường Khai]*. Tra Vinh, Vietnam: Hung Long Construction Design Consulting Joint Stock Company; 2018.

[15] Hung Long Construction Design Consulting Joint Stock Company. *Construction drawing design: Asphalt road inter-hamlet Tan Qui 1–Tan Qui 2, An Phu Tan Commune, Cau Ke District, Tra Vinh Province [Bản vẽ thiết kế xây dựng đường nội ô Ấp Tân Qui 1–Tân Qui 2, xã An Phú Tân, huyện Cầu Kè, tỉnh Trà Vinh - cầu Đường Khai]*. Tra Vinh, Vietnam: Hung Long Construction Design Consulting Joint Stock Company; 2022.