RESEARCH ON EVALUATING THE STABILITY OF EMBANKMENT STRUCTURES AT BUN XANG LAKE UNDER CHANGING WATER LEVELS DUE TO TIDAL AFFECTS

NGHIÊN CỨU ĐÁNH GIÁ SỰ ỔN ĐỊNH CỦA CÔNG TRÌNH BỜ KÈ HỒ BÚN XÁNG TRONG ĐIỀU KIỆN THAY ĐỔI MỰC NƯỚC DO TRIỀU CƯỜNG

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Tóm tắt:

Nghiên cứu này nhằm mục đích đánh giá sự ổn định của kè Bung Xang trong bối cảnh mực nước thay đổi do biến đổi khí hậu, cụ thể là các đợt triều cường gần đây. Trong nghiên cứu này, dữ liệu từ hai mặt cắt ngang đã được thu thập và phân tích bằng phần mềm Plaxis 2D V22. Kết quả mô phỏng cho thấy rằng các cọc có chiều dài 11,30 mét, theo thiết kế, vẫn nằm trong khoảng biến dạng của lớp đất nền, đặc biệt là tại vị trí được khảo sát với điều kiện địa chất yếu và dày (MC2-2), hạn chế tác dụng của các cọc. Tuy nhiên, kết quả phân tích sự ổn định tại hai mặt cắt ngang đại diện cho thấy tổng hệ số ổn định của các công trình đê nằm trong khoảng từ 1,380 đến 2,618, đều nằm trong giới hạn cho phép theo tiêu chuẩn Việt Nam TCVN 9902:2013, kết quả phân tích của nghiên cứu này cho thấy hệ thống công trình kè được đảm bảo và tuân thủ theo tiêu chuẩn TCVN hiện tại.

Từ khóa: *Ổn định, thủy triều, Mực nước, công trình kè.*

Cô xem lại số thứ tự bài này dùm

Abstract:

This research aims to assess the stability of the Bung Xang Lake embankment in the context of changing water levels due to change climate, specifically recent high tides. In this research, data from two cross-sections were collected and analyzed using Plaxis 2D V22 software. The simulation results indicate that the piles with a length of 11.30 meters, as per the design, still fall within the deformation range of the subsoil, especially at the surveyed location with weak and thick geological conditions (MC2-2), which limits the effectiveness of the piles. However, the stability analysis results at two representative cross-sections show that the overall stability factor of the embankment structures ranges from 1.380 to 2.618, which falls within the allowable limits according to the Vietnamese standard TCVN 9902:2013. The analysis results of this research showed that the embankment system is ensured and complies with the current Vietnamese standards.

Keywords: *Stability, Tidal Affects, Water level, Embankment.*

1. INTRODUCTION

Today, the global landscape is marked by substantial dynamism in economic, societal, and environmental dimensions. These fluctuations exert profound influences on the development and stability of nations and regions on a global scale. Among the paramount concerns that have garnered unanimous international attention is the issue of Earth's climate change. Regarded as an urgent, worldwide matter, its repercussions directly impact various facets of economic, social, and human well-being, leaving no nation or individual untouched by its consequences (Linh et al., 2022 [1]).

The research of Thang and colleagues in 2010 [2] have ascertained that Vietnam ranks among the nations most severely affected by climate change. Specifically, the Mekong Delta stands as one of the three largest and most susceptible deltas globally, alongside the Nile Delta in Egypt and the Ganges Delta in Bangladesh, with regards to sea-level rise. As detailed in the "Climate Change and Sea-Level Rise Scenarios for Vietnam" report in 2012 [3], published by the Ministry of Natural Resources and Environment, projections suggest that by the conclusion of the 21st century, Vietnam's average annual temperature is anticipated to rise by approximately 2 to 3 degrees Celsius. Concurrently, total annual precipitation and rainy-season rainfall are expected to increase, while dry-season precipitation is poised to decrease. Further compounding the issue, sea levels may elevate by an estimated range of 75 cm to 1 m, directly impacting around 10% to 12% of Vietnam's populace and incurring an approximate 10% loss in GDP.

In recent years, the Mekong Delta has assumed a pivotal role in Vietnam's agricultural production. Various policies promulgated by the Party and State have yielded positive outcomes, facilitating transformative progress within the Mekong Delta and its integration into the broader developmental trajectory of the region. Geographically encompassing 12 provinces and one city (Can Tho), the Mekong Delta sustains a regional population of 17.40 million individuals, accounting for roughly 20% of the nation's inhabitants. The land area of this region spans 40.90 thousand square kilometers (Statistical Yearbook 2021 [4]). These statistics underscore the region's inherent potential and geographical advantages, rendering it a focal point for agricultural production, aquaculture, and fruit cultivation in the nation. It significantly contributes to the preservation of food security and the exportation of agricultural and aquatic products on a national scale. In accordance with the Prime Minister's Decision No. 245/QD-TTg [5] dated February 12, 2014, which pertains to the "Approval of the Comprehensive Socio-Economic Development Master Plan for the Mekong Delta Economic Region until 2020, with a Vision to 2030," a coherent strategy has been outlined for the development of the Mekong Delta region. The government's vision encompasses the establishment of a synchronized infrastructure framework, encompassing economic and social infrastructure, to propel the economic and societal development of the region and position the Mekong Delta as a catalyst for the nation's holistic advancement.

However, despite being one of the affluent deltas, the Mekong Delta region faces numerous significant challenges. These challenges encompass negative impacts arising from climate change, as well as mounting pressures stemming from the ongoing struggle to achieve truly sustainable economic and societal development. The work of Hanh and Tuan in 2014 [6] has highlighted that in recent years, economic development and climate change have placed added stress on the Mekong Delta system, increasing the risk of natural disasters both presently and in the foreseeable future. The unmistakable signs of climate change in the Mekong Delta are manifested through extreme weather phenomena such as storms, floods, and other climatic events. The consequences of rising temperatures, including increased sea levels, expanded saline intrusion, and erosion, all have adverse effects on the region's economy, society, and environment. Additionally, according to the "Climate Change and Sea-Level Rise Scenarios for Vietnam" report in 2012 [3] by the Ministry of Natural Resources and Environment, by the year 2100, in a high-end sea-level rise scenario, sea levels could rise by more than 1 meter. This projection implies that roughly 90% of the Mekong

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Delta's land area would be inundated, with the city of Can Tho, the region's central hub, submerged over 70% of its total area.

Moreover, the impacts of climate change, combined with the development activities in the upper Mekong River region, have significantly influenced and altered the hydrological regime in the Mekong Delta. These impacts and their consequences pose formidable challenges and difficulties in land and water resource utilization, as well as in pursuing economic development within the Mekong Delta region, as stipulated by the Mekong Delta Regional Planning [5].

Studies by Thai and colleagues in 2014 [7] and C.T. Vinh in 2013 [8] have demonstrated that as Can Tho City is a low-lying area close to the sea, the hydrological and hydraulic regimes of the region's rivers, canals, and waterways are inevitably influenced by tidal effects, which subsequently affect water flow rates and water levels in the area. Therefore, the research process should take into consideration the tidal mechanisms in the rivers. At present, tidal inundation can negatively impact the lives of the general population and the infrastructure of transportation roads and embankments. Additionally, the canals and waterways in Can Tho City serve as the receiving points for wastewater from households on both sides of the riverbanks, resulting in severe water pollution. One such affected water body is Bung Xang Lake (Lien et al., 2019 [9]). In light of these multiple impacts, this study is undertaken to investigate and assess the operational status of the Bung Xang Lake embankment structure under the conditions of rising tidal levels in recent years, with the aim of analyzing and evaluating the working condition of the Bung Xang Lake structure.

2. METHODOLOGY

To gather data for the study area's topography, hydrology, and hydraulics, as well as to inherit technical data (such as soil properties, geological characteristics, the quantity and density of structures, and hydrogeological characteristics of the research area), measurements were taken for flow velocity and hydraulics of the watercourse during high-tide conditions to validate the model. Additionally, surveys of the terrain cross-sections at Bung Xang Lake were conducted. Hydrological data from the Can Tho River station were analyzed and synthesized, and essential data from the design and construction plans of the Bung Xang Lake project were collected.

The Finite Element Method (FEM) is an approximate numerical method used to solve problems described by partial differential equations on a defined domain with arbitrary shapes and boundary conditions where exact solutions are not readily obtainable through analytical methods. The FEM is frequently employed in structural mechanics (structural engineering, environmental mechanics) to determine stress and deformation fields in objects. Plaxis is a numerical analysis software developed based on the Finite Element Method. It is equipped with special features to handle various aspects of complex geotechnical structures. Plaxis is used for calculations related to slopes, excavations, tunnels, road embankments, foundation engineering, underground rail systems, and other underground structures.

3.2 GEOLOGICAL AND HYDROLOGICAL CHARACTERISTICS

In the project area, a comprehensive geotechnical survey was conducted, comprising 55 boreholes, in-situ Standard Penetration Tests (SPT), trenching, and 17 laboratory tests focusing on physical properties. Among these boreholes, 5 boreholes (BH34, BH33, BH10, BH11, BH37) exhibited distinct differences and were selected for further analysis. These selected borehole locations were utilized in combination with scenarios involving changes in water levels due to recent tidal variations, which are contributors to climate change. In a summarized overview of the average geological characteristics, the soil profile consists of the following layers: Layer 1: Sandy silt fill layer with a variable thickness ranging from 1.0m to 3.6m. It exhibits a relatively good load-bearing capacity; Layer 2: Highly plastic and organic clay layer, characterized by gray-green to gray-black coloration and a plastic to fluid state. The thickness varies between 19.2m and 20.5m; Layer 3: Highly plastic and organic clay layer, with similar gray-green to gray-black coloration and a softer plastic state. The thickness ranges from 1.0m to 17.4m.; Layer 4: Less plastic clay layer with brown-yellow to brown-red coloration, exhibiting a firm to semi-firm state. The thickness varies between 4.0m and 20.4m; Layer 5: Less plastic clay with a sand component, presenting a brown-yellow color and a firm state. The thickness varies from 1.2m to 6.0m.

The soil layers generally possess similar soil characteristics. However, due to the substantial length of the embankment, variations in layer thickness are inevitable. Notably, Layer 1 shows considerable variation, ranging from 20m to 30m in thickness. This layer is particularly weak and has the potential to undergo significant deformation during construction and utilization phases.

The study focused on two survey locations: the first one, with coordinates (10.032278, 105.763025), corresponding to borehole BH33 and represented by cross-section 1-1 (MC 1-1); the second, with coordinates (10.036424, 105.766419), corresponding to borehole BH10 and depicted in cross-section 2-2 (MC 2-2). The geotechnical properties of the soil at these borehole locations are presented in detail in Table 1 and Table 2, providing valuable insights into the soil's behavior in the project area.

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Figure 1. *Survey Cross-Section Locations*

Table 1. Properties of Soil Layers at Research Location - Cross-Section 1-1

	Fill soil	Layer 1	Layer1a	Unit
Thickness		H=22.6	H=20.4	m
Model	MC	MC	MC	
	Drained	Undrained	Undrained	
g_{unsat}	16	15.94	19.7	kN/m^3
g_{sat}	18	16.08	19.7	kN/m^3
E_{oed}	16000	2312	3390.8	kN/m^2

	Fill soil	Layer 1	Layer1a	Unit
v	0.3	0.32	0.30	
k_x	0.120	2.28×10^{-4}	6.26×10^{-6}	m/day
k_y	0.120	9.12×10^{-5}	2.51×10^{-6}	m/day
c	8	7.8	32.5	kN/m^2
j	27	3.1	13.1	degree
R_{inter}	0.75	0.75	0.75	

Table 2. Properties of Soil Layers at Research Location - Cross-Section 2-2

	Fill soil	Layer 1	Unit
Thickness		**H = 30**	**m**
Model	MC	MC	
	Drained	Undrained	
g_{unsat}	16	16.26	kN/m^3
g_{sat}	18	16.80	kN/m^3
E_{oed}	16000	698.5	kN/m^2
v	0.30	0.31	
k_x	0.1206	2.92×10^{-5}	m/day
k_y	0.1206	1.17×10^{-5}	m/day
c	8	8.3	kN/m^2
j	27	3.9	degree
R_{inter}	0.75	0.75	

In the flood season of 2022, based on meteorological and hydrological data compiled by the General Department of Meteorology and Hydrology, key stations located at the lower reaches of the Mekong River, specifically in the Dong Thap 10 and Tứ Giác Long Xuyen regions, experienced their flood peaks around mid-October. These peak flood levels were generally categorized within Alert

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Level III, with values ranging from 0.05 to 0.25 meters. Notably, the My Thuan station on the Tien River and the Can Tho station on the Hau River exceeded the historical water levels recorded in 2019, resulting in significant inundation of low-lying areas across the Cần Thơ and Vĩnh Long provinces.

Furthermore, the highest water level observed in 2022 on the Sai Gon River, specifically at the Phu An station, reached 1.70 meters on November 5, 2022, corresponding to an Alert Level III threshold of 0.10 meters. This elevated water level led to localized flooding on certain low-lying roads within Ho Chi Minh City [10]. Additionally, this study incorporated on-site surveys conducted at the MC1-1 and MC2-2 locations during the high tide periods of October and November 2022. These surveys served as empirical data for constructing scenarios related to water level fluctuations induced by high tides within the context of this research.

3.3 ANALYSIS MODEL

Figure 3 introduces the Plaxis 2D V22 model employed for analyzing the behavior of the embankment structure system. The analysis model is simulated based on the construction sequences leading to the completion of the embankment structure. Specifically, the scenario for behavior assessment is focused on the post-completion phase.

It is assumed that the analysis corresponds to the high-water season, and thus, scenarios considering working conditions at the lowest water level Hmin = -1.60m (as per design) are omitted. Additionally, reports on tidal water levels and survey results indicate that the average tidal water level rises to a maximum of +2.8m. Consequently, the model analysis scenario corresponds to the embankment's working conditions under various tidal water level fluctuations due to tidal surges, as follows:

Phase 1: Analysis of effective stress of the subsoil under natural conditions.

Phase 2: Excavation to the design level.

Phase 3: Construction of timber and concrete pile foundations with a cross-section of 30cm x 30cm.

Phase 4: Soil filling (comprising multiple layers and phases of soil filling).

Phase 5: Construction of the road pavement structure.

Phase 6: Evaluation of working conditions at the design water level H = ±0.00m.

Phase 7: Evaluation of working conditions at the design water level H_{max} = +2.18m.

Phase 8: Analysis of behavior under rising tide conditions with HTC = +2.80m.

Phase 9: Analysis of behavior as the water level decreases to the level H_{max} = +2.18m.

Phase 10: Analysis of behavior as the water level decreases to the level H = ±0.00m.

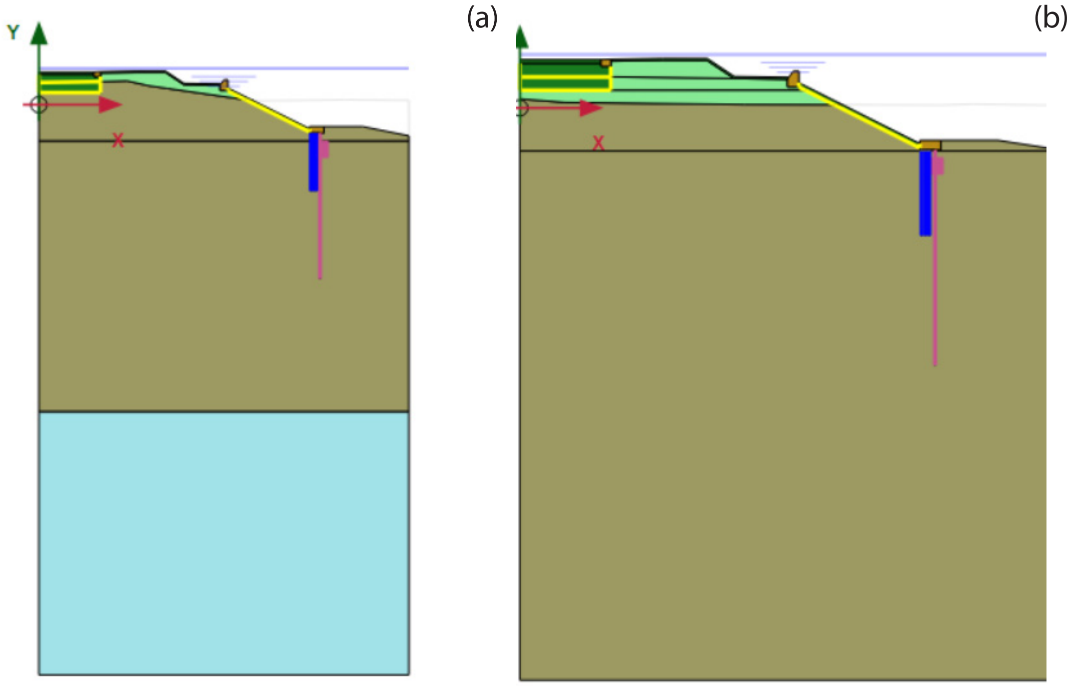

Figure 3. *Model at 02 Typical Sections*
(a) Section 1-1; (b) Section 2-2

3.4 ANALYSIS RESULTS

The comprehensive results of the subsoil behavior analysis across different stages are presented in Figure 4. It can be observed that the lateral displacement at the crest of the embankment varies from -36.8mm to -108mm, while the total vertical settlement of the subsoil ranges from -253.8mm to -400.6mm over stages 6 to 10. Comparing the geological conditions between the two cross-sections, it is evident that the weak soil layer at cross-section 2-2 is relatively thicker. This explains the greater lateral displacement at the embankment's crest and the larger settlement of the subsoil at cross-section 2-2 compared to the results of the analysis at cross-section 1-1, under the same working conditions and load impacts, including water level changes.

The impact of recent climate variations, as reflected in the increasing tide levels year by year, is evident. The results of the survey of tide level changes due to tidal surges over 2 hours, ranging from +2.18m (stage 7) to +2.8m (stage 8), and the subsequent return to +2.18m (stage 9) over 2 hours, show that the rising and falling tide due to tidal surges does not significantly affect the deformation behavior of the subsoil in terms of both lateral displacement and vertical settlement (subsoil settlement).

Furthermore, the analysis results in Figure 4c, with values ranging from 1.380

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to 2.618, indicate that the safety factor in the analysis at all survey stages meets the requirements for high safety, with a safety factor $K_f > 1.20$ (Clause 5.3, TCVN 9902:2013 Waterworks - Design requirements for river embankments [11]).

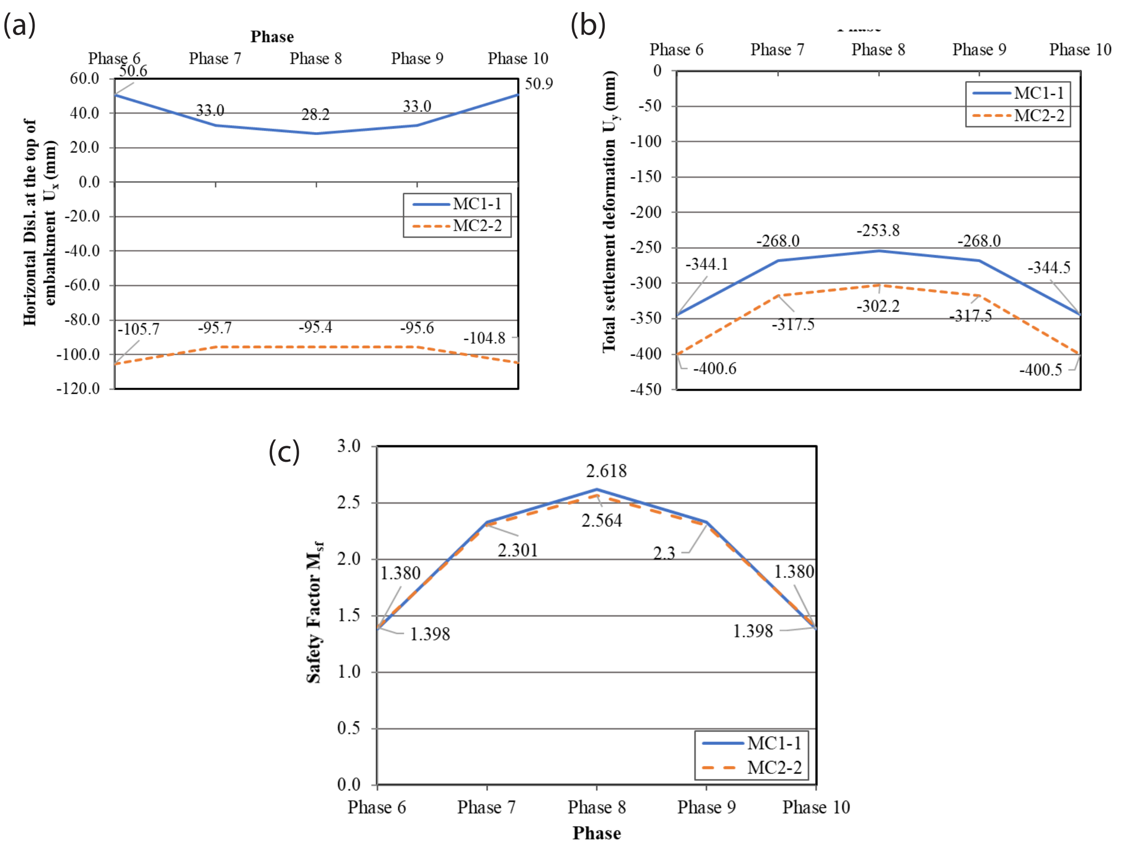

Figure 4. *The results of lateral displacement at the two cross-sections*
(a) Lateral displacement at the top of embankment u_x;
(b) Total settlement deformation u_y; (c) Safety factor

Figure 5 presents the results of lateral displacement analysis for a concrete pile measuring 30x30 with a length of 11.30 meters. It showed that the minimum lateral displacement of the pile varies from u_x = 29.2mm (in the case of the analysis at cross-section 1-1) to the maximum lateral displacement of u_x = 66.1m. Specifically, for cross-section 1-1, the lateral displacement is observed to range from 29.2mm to 53.6mm, while for cross-section 2-2, it ranges from 45.0mm to 66.1mm. Furthermore, the findings in Figure 6 indicate that the pile remains within the lateral deformation zone of the soil. In the case of cross-section 2-2, the substantial thickness of the weak soil layer constrains the pile's effectiveness, resulting in limitations in its performance concurrent with the soil.

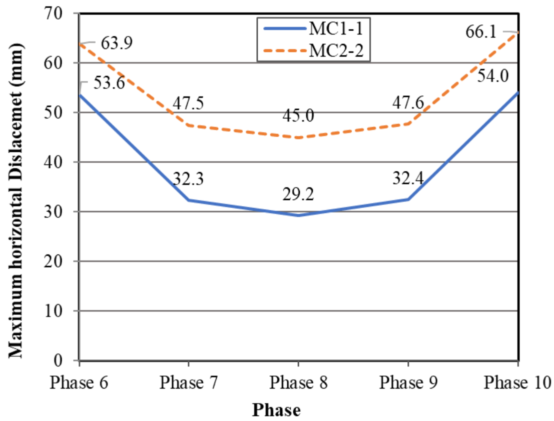

Figure 5. *The Maximum horizontal displacement in the pile*

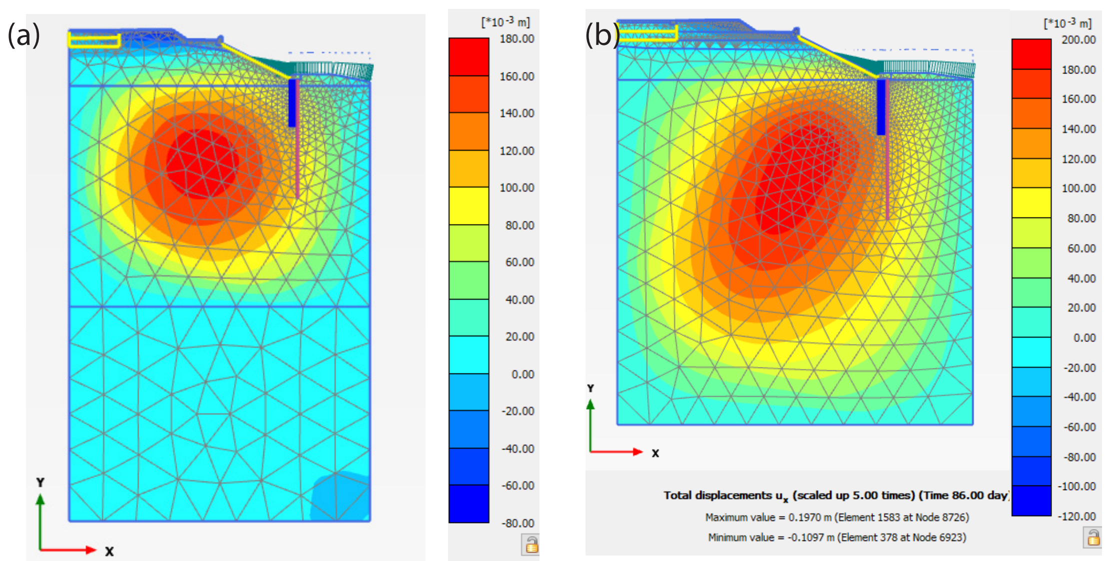

Figure 6. *Total horizontal deformations of the ground*
(a) Cross-section 1-1, (b) Cross-section 2-2

4. CONCLUSION

4.1. CONCLUSION

Based on the data collected regarding the impact on the Bun Xang Lake project during its operational phase, including the influence of tidal surges in recent years, several conclusions have been drawn from the simulation and analysis of the behavior of the embankment structure system:

- The analysis results using Plaxis 2D V22 show that the stability factor of the embankment structures is relatively suitable, and the analysis of the lateral displacement of the piles is within the allowable limits at cross-section 1-1.

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However, due to the relatively thick and weak first soil layer, the analysis results consistently indicate that the designed 11.3m piles are still within the sliding range of the first layer.

- At cross-section 2-2, the first soil layer is relatively weak and about 20 to 30m thick, and the lateral sliding analysis still occurs within the first layer. The reinforced concrete piles are limited in their effectiveness for the foundation structure due to the soil conditions.

- Nevertheless, fundamentally, the analysis results indicate that the safety factor of the embankment at various cross-sections ensures the structural safety, with values ranging from 1.380 to 2.618, which fall within the allowable limits according to Vietnamese standard TCVN 9902:2013 [11]. In comparison with reality, there have been no signs of structural damage or deterioration of the embankment.

4.2. RECOMMENDATIONS

The limitations of the model indicate that the use of reinforced concrete piles with a cross-section of 30cmx30cm in weak soil conditions, where horizontal displacement (sliding) still covers the piles, requires continuous monitoring of the performance of entire embankment structure. In the case of the embankment structural performance, the load applied to the retaining structure is considered safe according to the simulation results. Although the results of the stability factor analysis of the structure in this article are within the allowable limits of the Vietnamese standard. However, the deformation of the ground is relatively significant, and especially the piles are still inside of ground deformation zone. Therefore, it is necessary to continue implementing systematic monitoring solutions for the retaining system in the near future.

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