International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-8 Issue-8 June, 2019

A Solution for Reduction of Bearing Pressure for Sea Dike Foundation Using Wedge-Block Foundation

Nguyen Vu Viet, Do the Quynh, Quang Hung Nguyen

Abstract*: Vietnam is considered one of the most affected countries of climate change, in which the Mekong Delta is one of the three plains in the world most vulnerable to sea level rise. In order to respond to these challenges, the Mekong Delta has a great need to build sea dykes. Although the dyke has a small height of only 2 m to 3 m, the difficult problem is that the soil here is very weak, threatening to the stability of the works. There are many solutions that have been proposed to deal with this issue but they show limitations such as not taking advantage of on-site materials, long construction times, and expensive prices. This paper suggests a new type of foundation - Wedge foundation foundation which is mainly constructed from soft reinforced soil in place, environmentally friendly, reducing construction costs and being able to reduce the pressure on the foundation. The study has also proposed a reasonable bevel angle of the wedge block to be used to sea dike foundation on weak soil areas based on the results from FEM and testing the mechanism of stress reduction of the wedge foundation with physical models.

***Keywords*: Wedge-block foundation, Soft foundation, Sea dike, Mekong delta.**

I. INTRODUCTION

Vietnam is considered one of the most affected countries of climate change, in which the Mekong Delta is one of the three plains in the world most vulnerable to sea level rise [12]. For the purpose of coping with flooding due to the sea level rise, the Mekong Delta has a great demand to construct sea dikes. According to the Mekong Delta irrigation plan until 2020 and orientation to 2050 [13], it is necessary to build 24 new dykes in order to control saline water intrusion, flood and prevent disasters related to climate change impact and sea level rise. The results of a project managed by United Nations Development Programme [14] also show that it is necessary to construct a second sea dyke circle in the Mekong Delta with a total length of 580 km in order to prevent negative impacts from sea level rise, tsunami, fresh and saline water division. The result also suggests that the distance between the first and second dyke lines is 5 km to 6.5 km and the middle area is the immediate and long-term residential layout.

Revised Manuscript Received on June 8, 2019

Nguyen Vu Viet , Vietnam Academy for Water Resources, 100000 Ha noi.

Do The Quynh, Hydraulic Construction Institute, 100000 Ha noi.

Quang Hung Nguyen, ThuyLoi University, Hanoi, 100000 Ha noi, Vietnam.

Sea dykes in the Mekong Delta are mainly earth embankments. Foundation of the dyke construction is the weak soil, causing the instability of the dikes [11] even though the height of these dykes is only 2 m to 3 m. Therefore, it is necessary to research and design new and suitable foundation solutions to ensure economic-technical efficiency, environmentally friendly and lower costs.

There are many foundation solutions that can be applied to sea dikes in the current Mekong Delta region, such consolidation over time, replacing sandy foundation and covering on tree rafts. In addition, vertical consolidation; embankment on foundation piles, Top-base foundation and reinforced foundation blocks are often applied for dike foundations. The over-time consolidation method is a solution in which the dike is divided into 2 to 3 layers. These are filled in order within different dry seasons [10]. The replacing sandy approach is a solution in which the top layers of existing soft soil are replaced by sand before building the dyke [2, 5]. The foundation on the tree rafts which are made of cajuput, eucalyptus, and bamboo is used commonly for dike construction on weak soil foundation [5]. The vertical-drain consolidation solution (e.g., sand piles, absorbent wicks, vacuum) is applied to thick soft foundations. To ensure efficiency, the minimum fill height is 4 m [2] and it takes time to consolidate the drainage floor. The pile foundation is a solution that uses concrete piles to transit load to the fine soil. The piles are linked together into a hard system by the platform[16]. This solution is commonly applied for embankment with great height. Top-base solution is the foundation that uses the concrete Top-block linked together by reinforced concrete beams and the gap between them is tightly packed with macadam [4,18]. The material of this foundation is not available locally and has a higher intensity than the load of dike body. Block reinforced foundation solution is created by using a heavy mixer of at least 200 kN to knead weak soil in place with cement and additives [16]. In order to apply this foundation solution, it is necessary to use geotextile. The next step is to cover the geotextile layer with a layer of soil or a layer of macadam about 1 m thick in order to create a surface for the machine to stand and construct.

These above-mentioned solutions still have several limitations. The over-time consolidation has a long construction period, so it is not suitable for the dykes that need to be completed early. The replacing sandy solution

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

does not take advantage of weak soil in place but need to be excavated while sand is not available in the locality and has to move from far away. Hence, the cost of construction is high while the removal of weak soil, reclamation and transportation will affect negatively the ecological environment. The tree raft solution requires a huge amount of trees which is a major influence on the environment whereas this solution has not applicable standards for application yet. The vertical consolidation solution requires complicated construction equipment and is not suitable for the construction site in tidal conditions. It also needs more time to consolidate, prolonging the project completion time and high costs. Also, the pile foundation solution requires complicated construction equipment and does not take advantage of local materials. The solution of using Top-base foundation does not make use of on-site materials. The materials used for the foundation have many times higher intensity than the required load, leading to waste of budget and affect the environment due to transportation. The reinforced concrete blocks requires heavy construction machines while construction materials for standing machines are not in place and must be transported from other places so that the price is high, affecting the environment. In addition, this solution is not suitable for conditions of soft soil in the southern plain.

In 2014, a research group of the Vietnam Academy for Water Resources proposed and recommended the use of wedge blocks made of on-site soft soil mixed with cement and additives to create wedge-block foundation for the sea dike built in Mekong Delta. This foundation consists of wedge blocks with oblique surfaces that are tightly packed together and the gap between them is tightly inserted with sand. The wedge blocks foundation increases the contact surface area wherea it can reduce the stress on the ground and increase the stability of the dyke base. The sand in the foundation has the ability of water drainage, leading to a rapid increase in the consolidation of the foundation and reducing the time of settlement. Since the volume of the foundation is mainly made of soft soil in place, it can be constructed manually or by machine, so that it can reduce the construction time and costs flexibly and is environmentally friendly. Figure 1 shows the layout of the wedge blocks foundation using for the sea dike.

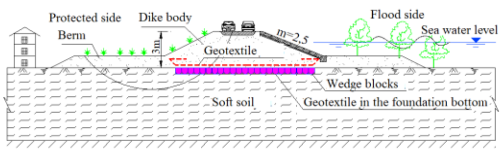
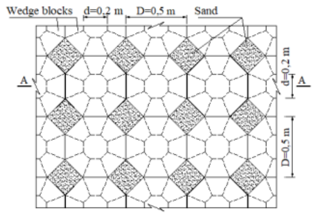
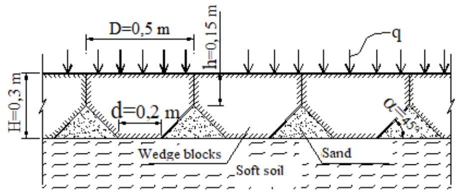


Figure 1 – The layout of the wedge blocks foundation using for the sea dike

The detailed structure of wedge blocks foundation is denoted by IDH-α (symbol I is a octagon; or symbol II means a circle; D is top size of the wedge; H is height of the wedge; and α is oblique angle of the wedge block) with D = 0.5 m; H = 0.3 m; and oblique angle α = 45^0 (degree) as shown in Figure 2.



a) Verical projection



b) Cross section of A - A

Figure 2 – Structure of I-D-H- α wedge blocks [7]

In order to apply this foundation in Mekong Delta, two main problem of the wedge blocks need to be studied. The first one is the scientific basis for proposing a reasonable oblique angle of the wedge block while the second one is how to reduce the load of wedge blocks on the base. These issues will be studied and presented in this article.

II. STUDY ON SELECTING REASONABLE SHAPES OF WEDGE BLOCKS

A. Calculation diagram

In order to decrease the stress distribution on the foundation, three types of the wedge blocks with different oblique angles were used in this experiment. The first type had a wedge top size D = 0.5 m with oblique angle being α = 450 while the other 2 types had the oblique angles α = 67^0 and α = 0^0, respectively. Figure 3, Figure 4 and Figure 5 showed all three types of foundation which had the same volume and material properties, placed in the same condition on the weak ground, bore the same load of 45 kPa (equivalent to the average pressure of a common sea dike to its foundation). The different height of dikes leads to different foundation depths and the effect of the additional stress on the foundation will be different. However, because the wedge foundation is placed on the soft ground with small shear resistance, it is influenced by the gravity load of dikes with the height of embankment from 2 m to 3 m. The foundation depth is expected to be less than 1 m. Therefore, the effect of horizontal pressure on additional stress is insignificant.

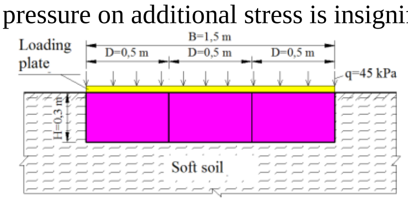


Figure 3 – Common shallow foundation (α = 0)

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

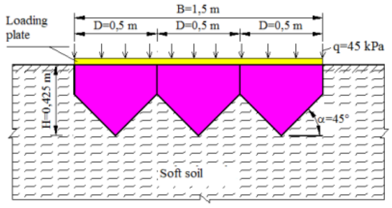


Figure 4 – Wedge-blocks foundation with α = 45⁰

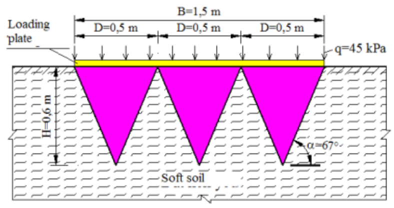


Figure 5 – Wedge-blocks foundation with α = 67⁰

In order to facilitate the comparison of foundation stress distribution between different types of wedge blocks, the author studied the problem of flat strain and considered only the additional foundation stress caused by the vertical load. In doing so, the results of calculating foundation stress distribution was more clear and favorable for analyzing, comparing and evaluating. The way to set up these research schemes was also used when comparing and analyzing foundation stresses with Top-base foundations [18, 20] which were done by Korean and Japanese scientists.

B. Materials

The criteria for calculation included mechanical and physical properties of foundation soil, wedge blocks and sand inserted between wedge blocks. The wedge blocks material included soft soil (similar to the soil of the dyke foundation), 200 kg / m3 of cement and Roadcem additive equal to 1% of cement weight. After mixing weak soil with cement and additives, we proceeded to cast the wedge block and maintained the wedge block 28 days in the room before conducting the experiment. The sand insearted between wedge blocks was compacted by pumped water, with compacting coefficient K = 0.9. Indicators of the soft soil, wedge blocks and sand were referred and tested according to current Vietnamese standards and presented in Table 1.

Table 1 – Mechanical and physical properties of the weak soil, wedge blocks and sand [1, 7, 15].

No	Parameters	Notation	Unit	Soft soil	Wedge	Sand
1	Natural unit weight	γ_w	kN/m^3	15,4	17	17,5
2	Saturation unit weight	γ_{bh}	kN/m^3	15,8	17	-
3	Initial void factor	e_0	-	1,78	-	-
4	The friction angle while wet	ϕ_w	o	$2^0 55' 48''$	$56^0 36'$	$22^0 18'$
5	Friction angle while dry	ϕ_k	o	-	-	$29^0 51'$
6	Unit adhesive force	C	kPa	9	105	-
7	Permeability coefficient	K_{th}	cm/s	$6,87*10^{-5}$	-	-
8	Poisson's coefficient	ν	-	-	0,25	-
9	Compression resistance	q_u	kPa	-	700	-
10	Distortion modulus	E	kPa	-	84.000	11.000

In addition, a additional loading plate is also used in the experiment. The loading plate has a thickness of 10 cm, the hardness corresponding to the hardness of the actual dyke foundation soil and has the modulus is E_{tnqd} = 135,000,000 kPa. Weight of loading plate is attributed to external load acting on the foundation. The external load acting on the foundation is equal to 45 kPa (corresponding to the load of the dike acting on the ground). The thickness of the soft soil of the dyke is calculated by taking the actual compressive thickness of the dyke of 6 m [9].

C. Models and computational contents

The computational contents are implemented by using the Plaxis 3D geotechnical digital model developed by the Netherlands [17]. The calculation computation sequence is as follows: (i) build a calculation model; (ii) element meshing; (iii) perform calculations; (iv) report calculation results. The calculation model is performed according to the research diagram in Figure 3, Figure 4 and Figure 5. The element mesh is divided into the appropriate size to ensure the accuracy of the calculation results. Plaxis 3D software uses a 10-node tetrahedral element. In order to ensure the highest level of accuracy for the calculated results (the calculation takes a long time due to the very large volume of particles), the author chose "very fine distribution mesh", with a largest size of a element being from 10 to 15 cm. Only one stage calculation was used to provide stress distribution in the foundation.

D. Result and Discussion

Results of under-foundation stress distribution calculating by using Plaxis3D software for 3 different wedge blocks is presented in Figure 3, Figure 4, and Figure 5. The boundary and input conditions were the same and they included the condition

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

of flat deformation problem, weak soil under the foundation and the same external load as shown in Figure 6. In order to easily compare, analyze and discuss results, the method of mapping stress distribution of 3 foundation types was used.

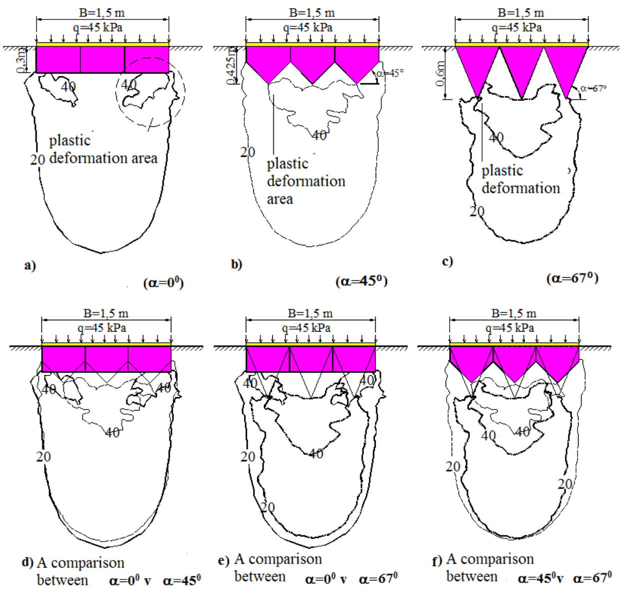


Figure 6 – Vertical stress distribution under the foundations and comparison between stress of foundation with different oblique angles.

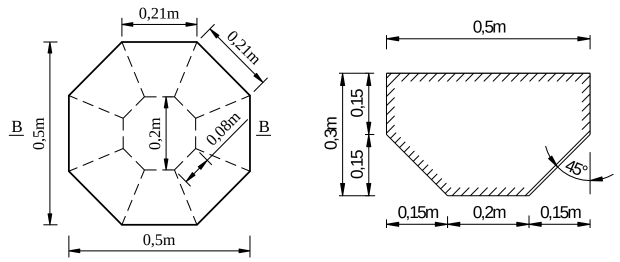
The results of the stress distribution in the foundation presented in Figure 6 show that:

- The ability to reduce stress between the different foundation shapes is unclear when the foundations have the same area, material properties, and the load applied to the foundation;
- The bottom of the foundation with a wedge shape and oblique angle of 45^0 has more advantageous stress distribution than the flat foundation bottom (conventional shallow foundation) and the bottom of the wedge block foundation with sharp oblique angle (oblique angle 670);
- The superiority of the foundation using wedge block with oblique angle of 450 is shown as follows: (1) The consolidation time is faster due to the wider range of stress distribution. This means that the weak soil under the wedge foundation is tighter and will increase unit cohesion and internal friction angle of the soft soil. As a result the foundation increases the load capacity; (2) The loading ability of a wedge block foundation with oblique angle of 45^0 is better. The reason is that the maximum stress area is located at the bottom of the foundation but does not expand to the two sides of the foundation as that of 2 the other types. In addition, when the maximum stress is located near the edge of the foundation, the ability of pushing the weak foundation soil up is higher and can damage the foundation.
- From the above-mentioned advantages, the author proposes to use the wedge block foundation with oblique angle 45^0 to for sea dikes in the Mekong Delta region. However, for construction purposes, the bottom point of the wedge is beveled (see Figure 2).

III. STRESS-REDUCTION MECHANISM OF THE FOUNDATION USING A PHYSICAL MODEL

A. Experimental design

The objective of the physical experiment model is to study the effect of stress reduction at the bottom of the wedge block under the effect of external load. The shape and size of the wedge is shown in Figure 7. The installation of wedge blocks on the foundation is shown in Figure 8, Figure 9, and Figure 10.



a) Plan of the wedge b) Vertical section B - B

Figure 7 – The shape and size of the wedge [7]

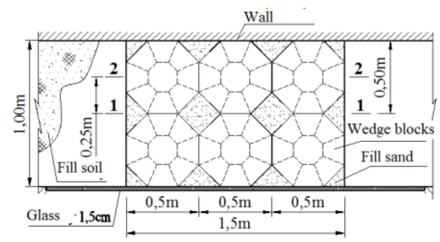


Figure 8 – Plan of the wedge blocks

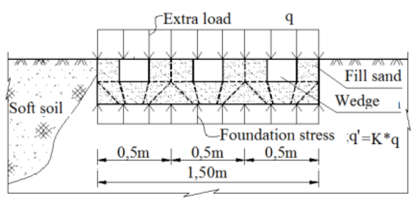


Figure 9 – Section 1 – 1

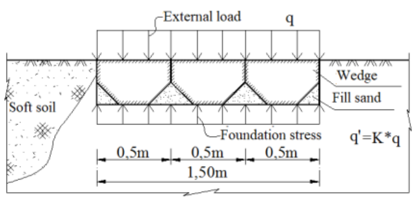


Figure 10 – Section 2 – 2

The boundary conditions of the physical model were designed and built to reflect closely to reality. These conditions depend on the slip limit of the model. Through the theory presented in [3, 8], the boundary conditions of the model on the vertical surface (cross-section of the foundation) are shown Figure 11. The lenght of the model was 1 m corresponding to the problem of plain strain dykes. The model was surrounded by a 35-centimeter M100 brick-built wall to ensure stability of the model (Figure 11). 3D perspective of the model is presented in Figure 12.

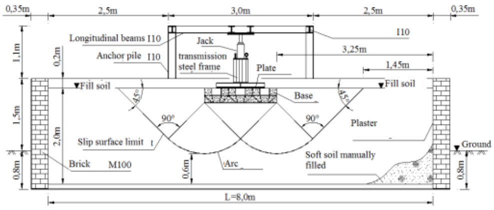


Figure 11 - Boundary conditions of the model.

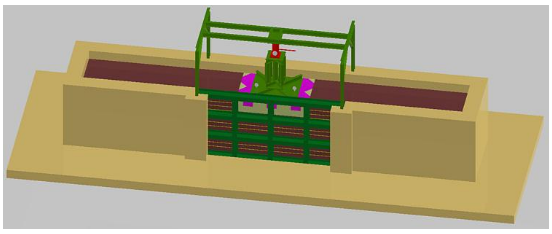


Figure 12 – 3D perspective of the physical model

Installation procedure of loading and monitoring equipment in the experimental model is following. Stress sensors S1 and S3 were installed to measure the stress at the base of the foundation with different loading levels as shown in Figures 13, 14 and 15 respectively. Loading plate and transmission frame were made of steel CT3 as shown in Figure 12. Other equipment includes device for recording data from stress sensors to transfer to computer for processing test results (Data Taker), load gauges to monitor and maintain constant load for each load level. Al the equipment has been calibrated before installation and experiment.

Corresponding the different loading levels, vertical stress at S1 and S3 was measured while the settlement of the foundation is determined. The displacement field in the dyke is measured by the PIV technique.

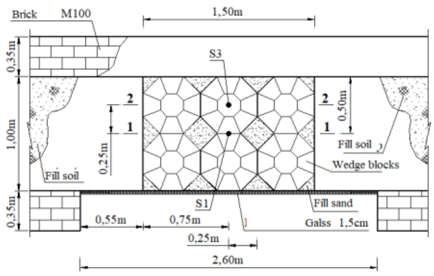


Figure 13 – The position of the stress sensor on the model plane.

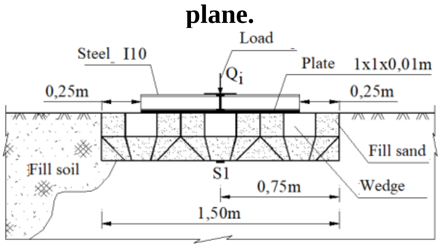


Figure 14 – Section 1 – 1 at S1 position.

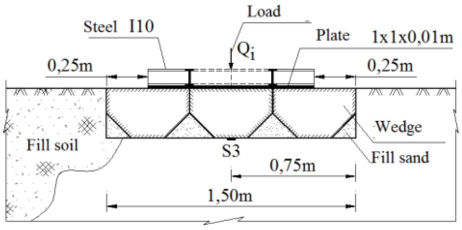


Figure 15 – Section 2 – 2 at S3 position.

- Step 1: Loading:

+ The number of levels : n=8 levels;

+ Load value per level: 4 kPa (corresponds to the gravity of 25-cm soil layer). The final load level corresponds to the gravity of two-meter soil layer

+ Time to maintain each load level: 30 minutes

- Step 2: Measure the designed parameters:

+ Measure vertical stress at stress sensors;

+ Measure settlement of compression plate;

+ Measure displacement field in the foundation by PIV technique.

B. Resutl and Discussion

Corresponding to different loading levels, the measured stress at sensors S1 and S3 are shown in Table 2 while the settlement of the compressive plates are shown in Table 3.

Table 2. Stresses at sensors S1 and S3 corresponding to load levels

Loading levels	Q_i (KN)	q (kPa)	q' (kPa)		Reduction rate (%)	
			S1	S3	S1	S3
1	6	4	1,5	2,4	62,5	40,0
2	12	8	5	7,4	37,5	7,5
3	18	12	7,3	10	39,2	16,7
4	24	16	9,2	12,8	42,5	20,0
5	30	20	13,8	16	31,0	20,0
6	36	24	18,4	20,3	23,3	15,4
7	42	28	22,3	23,1	20,4	17,5
8	48	32	26,9	25,1	15,9	21,6

Table 3. The settlement of the compression plate corresponds to the load levels

Loading levels	Q_i (KN)	q (kPa)	The settlement of the compression plate (mm)
1	6	4	0,42

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

2	12	8	3,40
3	18	12	7,69
4	24	16	12,73
5	30	20	20,78
6	36	24	33,49
7	42	28	50,49
8	48	32	76,56

Results from Table 2 show that the increased stress is significantly reduced. The degree of change at the sensor positions is different with the increased stress at S3 (position at the bottom of the wedge block) is greater than that at S1. This difference is due to heterogeneous modulus (hardness) of the wedge blocks foundation. The deformation module of sand inserted between the block gaps is smaller than that of the blocks which were made of a mixture of soil, cement and additives so that the load concentrating on the position between the wedge block may be greater than other locations. In general, the increased stress at the bottom of the wedge block foundation has decreased compared to external load on the top base with stress reduction changing from 15.9% to 62.5% (at S1) and from 15.4% to 40% (at S3) depending on the level of external load applied. This reduction has a difference from the initial assumption of 20% to 30%.

The results of the displacement field in the foundation are shown in Figure 17. It shows the ground area just below the foundation, where it is subjected to a large load, has greater displacement than that of the far-off foundation. This is also consistent with the displacement of actual buildings.

In addition, the author also compares the measured results on physical models and calculation results on numerical models. The results are quite similar and they are shown in Table 4, Figure 16 and Figure 17.

Table 4 – Bottom stresses are obtained from the physical model (PM) and numerical model (NM).

No	Q_i (KN)	q kPa	q' from PM (kPa)		q' from NM (kPa)		Decrease (%)	
			S1	S3	S1	S3	S1	S3
1	6	4	1,5	2,4	2,9	3,0	91	24
2	12	8	5,0	7,4	6,2	6,3	23	-14
3	18	12	7,3	10,0	9,7	9,9	32	-1
4	24	16	9,2	12,8	13,3	13,6	44	6
5	30	20	13,8	16,0	17,0	17,4	24	9
6	36	24	18,4	20,3	20,9	21,3	14	5
7	42	28	22,3	23,1	25,0	25,3	12	9
8	48	32	26,9	25,1	29,1	29,3	8	17

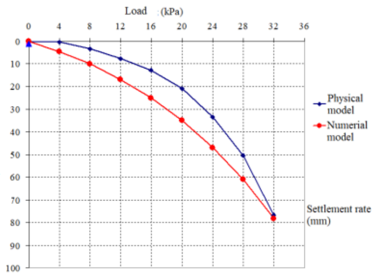
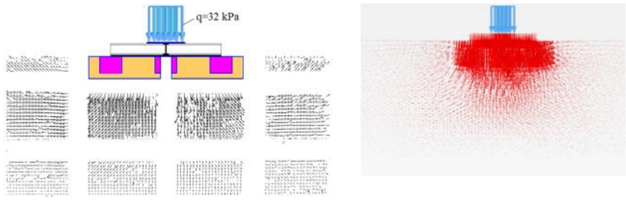


Figure 16 – The settlement of compression plate measured from physical and numerical models



a) Physical model b) Numerical models

Figure 17 – The displacement field of the soil under the wedge block foundation.

IV. CONCLUSION

The authors have proposed a wedge foundation solution for sea dykes in the Mekong Delta region. The results showed that the wedge block had a beveled angle α = 450 more advantages than that of the wedge block with beveled angle α = 670 and α = 00 (traditional flat bottom foundation).

The wedge foundation has the ability to reduce stress under the foundation and quickly increase the drainage capacity. Experimental results are reliable based on both the large-scale physical and numerial models and all used equipment were tested before being installed.

Applying the foundation of wedge block to build sea dykes is very positive. However, further research is needed to optimize the wedge blocks shape.

V. ACKNOWLEDGEMENT

The author would like to thank Mr. Nguyen Cong Man for lending the Plaxis 3D software license to be used in the study of selecting the appropriate shape of the wedge block; Thank you to the Ministry of Agriculture and Rural Development of Vietnam for funding the experiments of the physical model in the study.

REFERENCES

1. Phung Vinh An: Research on some factors affecting bearing capacity of cement-soil pile constructed by Jet-Grouting technology for some weak areas in Vietnam, Dissertation, 2012, Vietnam Institute of Forestry Science, Hanoi
2. Ministry of Transport, 22TCN 262-2000 - Process of surveying and designing motorway roads on soft soil - Design standards, Hanoi. (2000).
3. Cao Van Chi and Trinh Van Van, Soil Mechanics, Construction Publishing House, Hanoi. (2003)
4. TBS Vietnam Joint Company, TCCS 001: 2011 - Reinforced concrete block foundation (Top-base technology) - Design, construction and acceptance standards, Hanoi . (2011)
5. Le Thanh Chuong. Summary report of ministerial level project: Proposing research on sea dike cross-section suitable to conditions of each region from Ho Chi Minh City to Kien Giang,. (2012)
6. Nguyen Quoc Dung . Reinforce the foundation of Irrigation Works, Lecture Course, University of Water Resources. (2012)
7. Nguyen Quoc Dung, Phung Vinh An and Do The Quynh. Ministry-level project documents: Research on technological solutions for improving soft ground by on-site soil mixing equipment with inorganic adhesives for public construction Irrigation Program, 2016.
8. R.withlow (1996), Soil mechanics, volume II (translation), Education Publishing House, Hanoi. (R.withlow (1996).
9. Tran Thi Thanh and Nguyen Viet Tuan, "Determining the compressive zone in saturated soft soil under the embankment of dykes in the Mekong Delta", Collection of the results of science and technology in 2003 on the occasion of the 25th anniversary of the Southern Institute of Forestry Science (1978-2003), p. 421-429, Vietnam Institute of Science and Technology, 2003, Hanoi.
10. Tran Thi Thanh and Nguyen Viet Tuan (2003), "Method of calculating embankment segments to ensure stability of soft soil under the dyke in the Mekong Delta", Collection of 2003 Science and Technology results on the occasion of the 25th anniversary of the establishment of the Institute Southern Planning Center (1978-2003), p. 406-413.
11. Nguyen Van Tho, Tran Thi Thanh (2002), Construction of dykes, dams, and embankment of residential routes on soft soil in Mekong Delta, Agriculture Publishing House, Ho Chi Minh City .
12. Prime Minister, Decision No. 2139 / QD-TTg dated December 5, 2011 on Approving the National Strategy on Climate Change,. Hanoi..(2011)
13. Prime Minister, Decision No. 1397 / QD-TTg dated September 25, 2012 on Approving the Planning on Irrigation of the Mekong River Delta in the period of 2012-2020 and orientation to 2050 in the context of climate change and sea level rise, Hanoi. (2012)
14. WRU, Southern Institute for Water Resources Research, Southern Institute of Water Resources Planning: The integrated management report of UNDP research project: Integrated management of water resources in terms of climate change, sea level rise and generation rapid economic and social development in the Mekong Delta, Vietnam, 2016, Hanoi. (2016)
15. Nguyen Xuan Truong, Design of earth dam, 1972, Science and Technology Publishing House, Hanoi. (1972)
16. ALLU, Mass Stabilisation Manual, Finland.
17. Delf University of Technology & Plaxis bv, Plaxis3D2013, 2013, The Netherlands.
18. Banseok Top Base Co., ltd, In-place Top base method – New foundation method on soft ground, Korea.
19. Delt University of Technology & Plaxis bv, Plaxis 3D – Reference Manual, The Netherlands. (2013)
20. Japanese material institute, Top-base method of ground improvement handbook, Japan. (1991)

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication