MINISTRY OF EDUCATION AND TRAINING **MINISTRY OF AGRICULTURE AND ENVIRONMENT**

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STUDY ON THE PHENOMENON OF RED RIVER DIKE CRACKING AND FORECAST THE POSSIBILITY OF CRACKING OF SOME DIKE SECTIONS

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SUMMARY OF DOCTORAL DISSERTATION

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INTRODUCTION

1. Rationale of the study

Vietnam has a dike system with total length of about 13,200 km, including nearly 2,600 km of sea dikes and about 10,600 km of river dikes, mainly in Red river delta area. Last time, the dikes were built up manually without foundation treatment. Over thousands of years, the dike system have been expanded and connected continuously to become the entire system. Initially, the dike are mainly built to preventing flooding and partialy in combination with trafic. Principally, the dike width was narrow, the traffic was mainly for human and small personal transport due to the low requirement of economic development. During this period, dike failures such as sliding, erosion are main phenomenon. The problem of dike cracking has also appeared, but on a small scale and does not affect the dike stability. After that, the dike system was upgraded to satisfy the high requirements of flood rescue and relief and economic development. At this time, there were no large reservoir systems in upstream area, then the dike is often "soaked" for a long time in the rainy season. Then, the phenomenon of dike cracking still occurs, but it is very sporadic and on a small scale. In the past, the dike was built manually, so in general, there are many defects such as high void ratio and small relative density. During the process of upgrading and renovating, most of the dike crest is high enough to prevent flooding. Many dike systems are hardened with asphalt, concrete, etc. The dikes are expanded by materials mainly transported from other places. Due to the longer "dry" cycle than before, the phenomenon of dike cracking tends to increase. In addition, the diffusion and resonance of the trafic load have made the phenomenon of dike cracking threatening the safety of the dike. Therefore, it is necessary to research to find out the common causes of river dike "cracking", so that there are measures to ensure the safety of river dikes.

2. Research objectives

- To clarify the mechanism of dike cracking in the dry season through field observation, laboratory experiments on the change in the soil volume, due to the variation of moisture according to the dry-wet cycle and simulation on mathematical models.

- To explain the phenomena and incidents that have occurred to the dike in the study area.

- To explain and evaluate the process of failure development and the influence of negative factors on the river dike.

- Analyze and forecast the possibility of cracking of some dike sections in the study area, and propose appropriate treatment solutions.

3. Subjects of research

The existing earth dike; The body of the dike, especially the roof, downstream of the river dike in the Red River Delta.

4. Scope of research

- River dikes with limits on the body, the crest and the sides of Red River dyke in Ha Noi, Hai Phong, Bac Giang, Bac Ninh, Ha Nam, Hai Duong, Hung Yen, Nam Đinh, Ninh Binh, Thai Binh and Vinh Phuc.

- The cracking phenomenon occurs initially when the sides and the dike body are subjected to environmental changes at the end of the dry season. The research does not study the subsequent development of cracks during the rainy season, as well as the impacts of water infiltration into the original cracks and traffic loads.

5. Research content

- To study the effect of the clay particles content and fine particles (silt) of the soil in the embankment on the phenomenon of dike cracking, which usually occurs at the end of the dry season.

- To study the volume variation, tensile stress variation lead to the soil deformation in embankment when moisture changes due to changes in the wet-dry cycle in nature.

- To explane the phenomenon of dike cracking that occurred in history and after the reservoir system in the operation.

- To analyze and forecast a number of dike sections that are likely to generate cracks in the area of research, argue and propose appropriate treatment solutions.

6. Approaches and research methods

The thesis uses a synthesis of highly reliable advanced research methods, specifically:

Methods of collecting and synthesizing relevant documents; Field survey methods; Theoretical research methods; Numerical simulation method; Expert method.

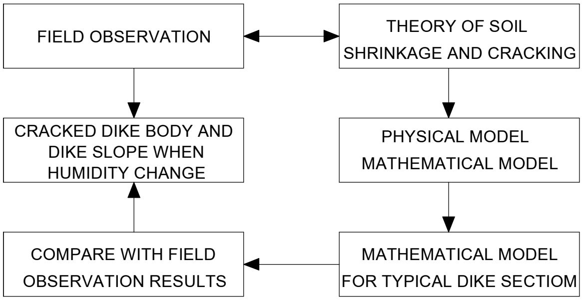

Figure 1- Flowchart of research problem-solving approaches

7. Scientific and practical significance

- The thesis contributes to supplementing the theoretical basis for the causes of dike crack. Especially the phenomenon of dike cracking often occurs at the end of the dry season. Then, it is possible to explain the phenomena and causes of dike incidents that have occurred in history. Additionally, it is possible to explain the incidents that occur during the rainy season due to rainwater entering the cracks, as well as the impact of vehicle loads, etc. Moreover, it is possible to forecast cracks for some sections of dikes on the dike system in the Red River Delta region, in order to serve as a basis for reparation, renovation and upgrading of dikes to ensure the safety.

- It is forecasted that the possibility of dike cracks at the end of the dry season of some river dike sections in the Red River Delta region is predicted. From there, the possibility of river dike incidents during the rainy season is assessed, contributing to the upgrading and repair to ensure the safety of river dikes in the study area.

8. New contributions of the thesis

- Through geological survey and field research, in combination with physical and mathematical modeling, the thesis clearly identifies that the primary cause of cracks in the dike body is due to the high content of clay and fine particles in the embankment soil (clay fraction < 0.005 mm accounting for 17.1% to 32.1%, fine particles < 0.05 mm making up 46.7% to 76%), along with chemical components that cause shrinkage, which are highly sensitive to changes in moisture. By integrating field research with physical and mathematical modeling, the study explains the phenomenon of cracking in the dike body that typically occurs at the end of the dry season.

- Cracking happens due to the reduction in the soil volume when the soil is dry, creating internal stress that lead to deformation. Initially, the main cracks are formed predominantly perpendicular to the dike axis. These cracks exhibit characteristic patterns and develop in a predictable manner, with an average width ranging from < 0.5cm to 1cm, and depths from < 0.5m to 5.7m. Secondary cracks subsequently form along the lines of the initial cracks. Based on these findings, the thesis establishes a comprehensive theoretical framework explaining the causes and mechanisms of cracking in the Red River dike in the research area during the late dry season, as well as the potential consequences.

- The study also forecasts specific dike sections within the study area that are at high risk of being cracked, thereby contributing to proactive planning, maintenance, and upgrading of the dike system.

9. Structure of the Thesis

In addition to the Introduction and Conclusion, 50 references, 06 published authors' documents and 04 Appendices, the main content of the thesis is presented in 04 Chapters including 130 pages, 98 drawings and 29 tables.

CHAPTER 1 OVERVIEW OF RIVER DIKES AND CRACKING OF RIVER DIKES

1.1. Cracking phenomenon of embankment chips

1.1.1. Some cracking phenomena of embankment

The phenomenon of river dike cracking is caused by the following causes: (+) Cracking due to neotectonium; (+) Cracking due to subsidence; (+) Man-made fissures; (+) Cracks due to swelling; (+) Cracking due to shrinkage. In the thesis, the author research the phenomenon of chip cracking caused by the deformation of the volume (shrinkage) according to the dry-wet cycle.

1.1.2. Research in the world

The history of Vietnam's dikes, especially the dikes in the Red River Delta area, is different from the dikes of other countries in the world. Currently, there is no research in the world with a similar nature to the dike in the Red River Delta. The research publications of countries around the world on dikes mainly focus on research in the fields of flow control, waterproofing, dike breakage, etc. However, from the perspective of viewing a dike as a embankment, on weak ground, it can also be considered that there are a number of related aspects, specifically: (+) Research on embankments, many countries in the world have had relatively methodical studies, for example: UK, Netherlands, etc. Models of stress - deformation of soil materials have been developed and used in software for simulation calculations. At present, the US-BD relationship models of soil that we are using such as Mohr-Coulomb, Hardening Soil, etc. are the results of these research processes; (+) Study on the influence of earthquakes and dynamic loads on embankments. When the vehicle runs on the road, it causes vibration of the roadbed and works along both sides of the road; (+) NDry-Wet Cycle Cracking: According to Konrad and Ayad (1977) There are many processes that take place when the soil goes through dry-wet cycles. Research of Dexter (1988) simulates the process of crack formation and development when the moisture content changes from a 100% saturated state to a 0% dry state. The most recent study by (Yliang Tu, Ruizang et al., 2022) on the durability characteristics and crack development due to changes in moisture content of clay muddy soils due to changes in dry-wet cycles, etc. proving that the strength of the soil will decrease when affected by the dry-wet cycle.

1.1.3. Research in Vietnam

Vietnam Institute of Science and Technology, Institute of Irrigation Planning, University of Irrigation, etc. mainly focusing on flood planning, flow and landslide issues, and stream correction. Doctoral dissertations on dikes are of a similar nature. There is a ministerial-level topic "Research on dike cracking and solutions to upgrade and repair to ensure the safety of dikes when combining roads", which is directly related to the content of the thesis. In the above research, in order to explain and evaluate the degree of damage caused by the consequences of dike cracking due to changes in humidity at the end of the dry season, a hypothesis was made about the mechanism of dike cracking, thereby analyzing and evaluating the consequences caused by this cracking phenomenon during operation. The thesis will prove the essence that the above topic has raised.

1.2. Characteristics and natural conditions of river dikes in the Red River Delta

1.2.1. Characteristics of formation and structure of river dikes

The typical structure of river dikes in the research area can be summarized as follows:

- The dike has a small cross-section, the largest average height is H = 10 m; River side roof $m_s = 2$; The roof on the copper side is $m_đ = 3$; The width of the top of the dike = 5 ÷ 8 m; Muscular and non-muscular type, muscular type with high $H_c = 1.5 \div 3$ m, muscle width $B_c < 5$ m.

- The dike body from the foundation upwards usually has 1 ÷ 2 layers of embankment made of on-site materials, has a very high content of clay and dust, sensitive to changes in moisture, and vibration on the dike body.

- The dike background is formed from the natural alluvial process, so it is very complicated, usually with 3÷5 layers. Geology consists of many layers of weak clay in a flowing and flowing state that are intertwined with each other. It can be generalized into 3 forms: form 2 (figure 1.5) and form 3 (figure 1.6) are forms that need technical attention when upgrading and expanding dikes combined with traffic objectives.

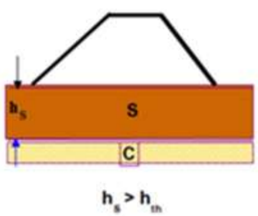

Figure 1.1 - The substrate has a thick layer with little permeability, below is a strong permeable layer of small thickness

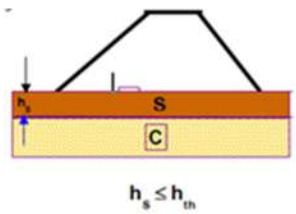

Figure 1.2- The dike bed has a thin layer of weak permeability, below is a strong permeable layer of large thickness

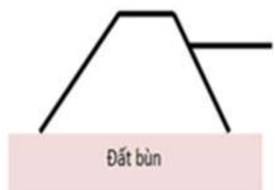

Figure 1.3 - The dike bed is weak soil (Mud, organic clay in a flowing and flowing state)

1.2.2. Characteristics of natural and social conditions

The Red River Delta is the downstream area of the Red River and the Thai Binh River, including 10 provinces and cities, with an area of about 21.3 thousand km^2 and equal to 6.4% of the country's area, with a fairly flat terrain, with an altitude of 0.4 ÷ 12m above sea level. It is the region with the highest population density in Vietnam (1450 people/km^2), with a population of 21.9 million people.

1.2.3. Climatic features

The seasons of the year are clearly divided into the rainy season from May to October and the dry season from November to April next year. The average annual temperature is about 23.8°C, summer is 35.3°C, winter is below 14.4°C. Average annual air humidity is 83%. Rainfall is concentrated and distributed seasonally, in summer there are often heavy rains and heavy storms (rainfall from 1,000 - 1,200mm accounts for about 80% of annual rainfall), prolonged dry weather in winter, little rainfall (rainfall from 200 to 300mm accounts for about 10-20% of annual rainfall.

1.2.3. Hydrological characteristics and water sources

The Mekong Delta has a dense river system, in which the Red River plays an important role in influencing the hydrological conditions of the region. The Red River has an average water level of +l.58m in the dry season and +4.7m in the flood season. In the dry season, the river water flow rate ranges from 0.2 ÷ 0.4 m/s, in the flood season 1.3 ÷ 1.5 m/s. The width of the river in the dry season is 500 - 1,000 m. The river flows into the delta to sediment, the river has a winding characteristic, creating erosion on both banks, causing flooding. Major floods usually occur around July, August, and September, coinciding with the time of inundation.

1.3. Current status of river dike cracks in the study area

1.3.1. Field survey results

- Dikes of grade III or higher have 2,050.4 km of dikes, including 1,072.6 km of concrete reinforced dikes, 450 km of paved reinforced dikes, 463 km of dikes of distribution level, and the rest of which are earthen dikes. The length of the damaged dike is 454.98 km, accounting for 23.28% of the total length of the dike. Concrete surface damage of 242.86 km accounted for 23% of the total length of concrete reinforcement; damage to asphalt pavement is 154.52 km, accounting for 34% of the total length of plastic reinforcement; damage to the distribution surface of 57.6 km, accounting for 12% of the total length of reinforcement of the distribution level.

- The phenomenon of cracking of the roof of the upper, downstream and subsidence, cracking of the dike surface mostly occurs in the dry season (> 95%). In particular, the phenomenon of cracking the dike roof usually begins to occur from the beginning of the dry season. The phenomenon of subsidence and cracking of the face usually occurs in the middle or end of the dry season.

1.4. Conclusion of Chapter 1

- The phenomenon of cracking of the dike roof and dike surface of the dike system in the Mekong Delta is a phenomenon with a specific regional nature, which usually occurs at the end of the dry season and causes incidents during the rainy season.

- The structural characteristics of the dike body and river dike bed in the study area have been analyzed and clarified, in order to demonstrate the selection of typical dike sections for study in the following chapters.

- Analyzing the research results of previous consultants when assessing the incident, it is found that these studies have pointed out specific causes. However, it does not explain the causes and mechanisms of formation, nor can it explain the phenomena that have occurred in reality.

CHAPTER 2 CAUSES AND MECHANISMS OF RIVER DIKE CRACKS IN THE RED RIVER DELTA

2.1. Shrinkage phenomena in soils

-When soil moisture decreases, capillary stress causes shrinkage and volume decreases.

- Based on the theoretical basis of soil shrinkage, the author orients the research.

2.2. Argument for selection of dike section case study

Typical river dike locations for the Red River Delta dike system need to meet the following criteria:

- The selected dike location belongs to the Red River Delta dike system.

- The structure of the height and width of the dike surface and the construction method are representative of the Red River Delta dike system.

- Dike body embankment land means on-site land other than embankment land taken from other places, and the dike foundation has not been treated.

- There is a phenomenon of dike chips cracking at the end of the dry season in history.

Choose the dike section from K81 ÷ K82.5 on the Hong left dike through Hung Yen as a typical example because it satisfies the above criteria for research.

2.2.1. Drilling location for sampling to perform the experiment

Choose to survey at K81+813 and K84+005, each with 3 boreholes at the top of the dike and upstream - downstream of the dike.

2.2.2. Topographic and geological conditions

2.2.2.1. Terrain conditions

The topography of the construction area is relatively flat. On the river side, there is a wide river bank with an average elevation of about + 6.90 m and is flat, but along the foot of the river dike are ponds, lakes and lagoons with an average elevation of about +4.00 ÷ +5.30 m. Inside the plain, the average elevation is about +5.80 ÷ +6.30 m.

2.2.2.2. Quaternary Geological Features of the Red River Delta

Characteristics of the Quaternary sedimentary stratigraphy (District 2) of the Red River Delta, including the following strata: Le Chi, Hanoi, Vinh Phuc, Hai Hung and Thai Binh:

- Le Chi Formation (District 11lc) - Hanoi Formation (District 12-3hn) - Vinh Phuc Formation (District 13vp) - Hai Hung Formation (District 21-2hh). These strata are dike beds.

- Thai Binh Formation (Q23tb) includes: (Q23tb1) and (Q_{23TB2}). (Q23tb2) is a sediment in the alluvial field outside the dike with a small thickness. (Q23tb1) is the sediment in the alluvial ground in the dike, used as the dike foundation and dike embankment material. The entire river dike in the Red River Delta is basically built on the foundation of this sediment and uses soil according to this stratum as embankment material. The source soil of the river (a) in the Thai Binh stratum is the object of the author's study (aQ23tb1).

2.2.2.3. Geological conditions of Ta Hong dike

The strata of the dike route are distributed in the order from top to bottom as follows:

Class 1A: Mixed soil and asphalt, hard compacted state; Grade 1B: Embankment, clay mixed with gray-brown, mahogany brown, hard plasticity; Grade 1C: Embankment, clay mixed with gray-brown, mahogany brown, soft plasticity.

Grade 2: Lightning mixed with gray-brown, blue-gray, soft plasticity; Grade 2B: Gray-brown, dark gray, and organic clay, flowing plastic, sand-sanded in some places; Grade 2C: Lightning mixed with blue-gray, gray gray, black, and organic, soft state.

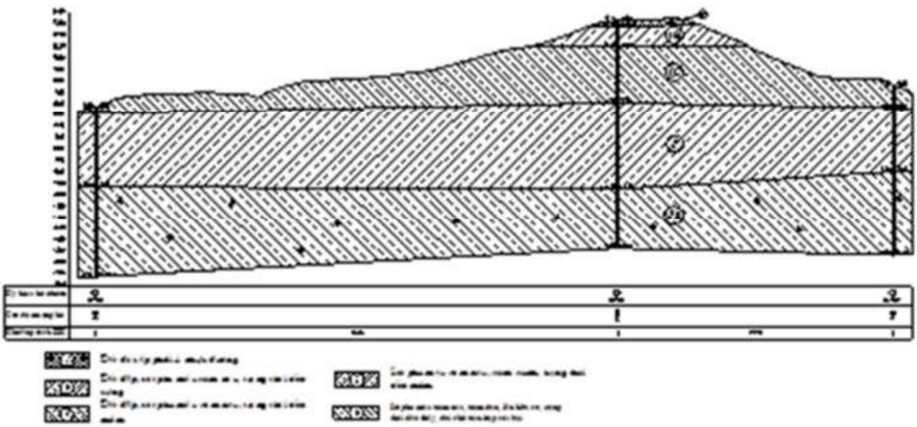

Figure 2.1 - Geological cross section of dike km 81+813

Table 2.1 - Results of experiments to determine the mechanical and physical indicators of soil bodies and dike beds

TT	**Indexes**	**Unit**	**Class 1B**	**Class 1C**	**Grade 2**	**Class 2B**	**Class 2C**
1	Particle composition						
	- Sand (0.25÷0.05)	%	33	28	29	25	26
	- Silt particles (0.05÷0.005)	%	45	48	45	53	47
	- Clay (<0.005)	%	22	24	26	22	27
2	Moisture content	%	31,5	35,2	37,6	43,5	37,2

TT	Indexes	Unit	Class 1B	Class 1C	Grade 2	Class 2B	Class 2C
3	Density	g/cm^3	1,89	1,85	1,82	1,76	1,82
4	Dry density	g/cm^3	1,44	1,37	1,32	1,23	1,33
5	Porosity	-	47	50	51	55	51
6	Saturation	%	96	97	97	98	96
7	Liquid Limit	%	40,5	41,9	42,6	45,6	42,9
8	Plastic Limit	%	24,6	25,6	27,7	30,1	27,0
9	Liquid index	-	0,44	0,59	0,67	0,88	0,65
10	Cohesion	KG/cm^2	0,18	0,20	0,18	0,09	0.19
11	Friction Angle	Degree	15^{o}09	12^{o}26	07^{o}13	04^{o}21	06^{o}17
12	Permeability coefficient	cm/s	1.2*10-4	1.7*10-4	2.9*10-4	4.3*10-4	1.8*10-4
13	Modulus	KG/cm^2	100	87	66	19	67

2.3. Research on the mechanism of dike fractures in the laboratory

2.3.1. Selection of experimental specimens

The soil samples used in the experiment to determine the correlation of variation between volume and moisture are samples of intact body soil taken in boreholes. The temperature used to simulate the experiment was taken according to the highest temperature of the temperature at the beginning of the dry season from 20 ÷ 30 degrees Celsius.

2.3.2. Experiment process

- Sequence of experiments to evaluate volume and humidity variation

Step 1: Saturate the high gas intake plate. First, fill the chamber below the dish with water through the duct and push out all the air bubbles in the chamber. Then place the plate in a large stainless steel tray, pour water into the tray so that it is covered on the surface of the plate, soak the plate in water for 3 to 5 days until the ceramic plate is saturated. When the disc is saturated, the water in the cavity of the disc circulates with the water in the chamber. The water pressure in the chamber is always maintained at zero (Uw = 0) by opening the water hose out into the air.

Step 2: The intact soil samples after being transferred to the laboratory are put into ring knives with a height of 2.0 cm and a volume of 60 cm^3. Then the soil sample is saturated by placing a ring knife containing the soil sample in a triple compressor, above and below the sample with absorbent stone and absorbent paper. Pour water gradually into the compression box until the sample is flooded so that the soil sample is saturated slowly, and at the same time put a compressive load on the sample with a force level of 0.05kG/cm^2 so that the sample does not expand.

Step 3: Place the soil sample in the drying oven set at a constant temperature of 30°C. Then weigh the soil volume after the steps, the customary time is 1 hour to determine the soil moisture.

Figure 2.2 - Cracked and shrunken test soil sample

Figure 2.3 – Determination of sample volume

- Results of experiments to evaluate volume and humidity variation

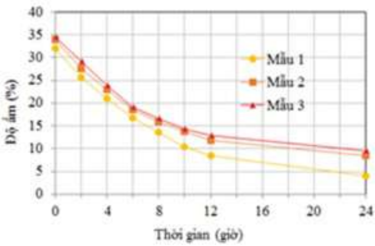

Figure 2.4- Variation of humidity according to T 30°C

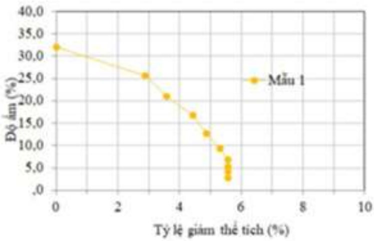

Figure 2.5-Volume-moisture reduction relationship M_1

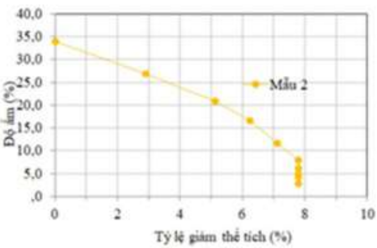

Figure 2.6-Volume reduction-humidity relationship M_2

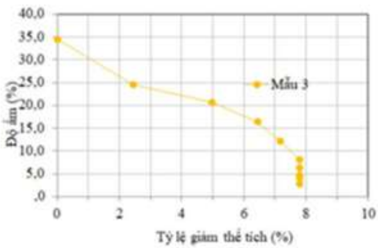

Figure 2.7-Volume-moisture reduction relationship M_3

Sequence of experiments to evaluate the deformation of cracks and deformations with moisture

The main purpose of this is to control the total deformation in the experimental sample, since it is not possible to know exactly where the crack appears or the area of shrinkage is initially known. The implementation steps are carried out as follows:

- Deformation assessment: (+) Step 1: Prepare a sample box with a height, width, and length of (100 x 200 x 300) mm, KL 2748g; (+) Step 2: Mix the soil with water at the optimum humidity, then compost the soil for about 1 day; (+) Step 3: Compacting the soil into the sample box with tightness K = 0.93; (+) Step 4: Use the positioning pile system arranged in the shape of an apricot flower with a distance of 10 cm, with buttons attached to fix it with the deformation measuring device to perform the deformation measurement work; (+) Step 5: Put the soil sample into the drying oven, set the temperature of the drying oven to 30^{o}C;

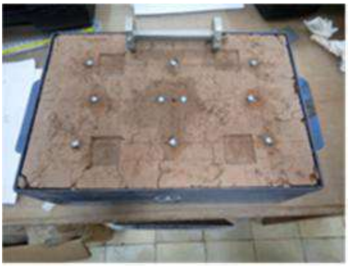

Figure 2.8 - Layout of the gauges on the sample

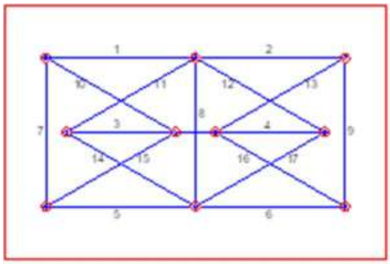

Figure 2.9-Deformation measurement diagram on the sample

(+) Step 6: After a period of 2 hours, 4 hours, 6 hours... take soil samples out of the drying oven; (+) Step 7: Weigh the volume of the soil sample, calculate the moisture content of the soil sample; (+) Step 8: Measure the crack size with a crack measuring glass; (+) Step 9: Measure the deformation size of the sample with a strain gauge.

- Evaluation of crack modification: From the first drying hours, primary cracks have formed on the surface of the sample within the soil sample, longitudinal and horizontal cracks, and cracks appear on the edges of the edges with a tendency to crack the soil and the sample box. Continue to dry the soil samples, until the end of the experiment. It is found that the soil sample tends to deform and shrink compared to the mold. The cracks grow from the original both in width and length. The cracks at the edges between the soil and the mold grow strongest, completely separating the soil and the mold. There are secondary cracks, but they are few in number.

Figure 2.10 – Crack development and shrinkage of the sample

Sample drying and sample measurement experiments are carried out until the sample volume does not continue to change, then stop. When stopping sample drying, take the sample out of the mold to observe the inside of the mold and sample. On the adjacent surfaces between the mold and the sample, secondary cracks appear in large quantities. In the experiment, it was observed that there were 6 locations characteristic of the primary crack of the sample, including: 4 edges adjacent to the mold and the sample and longitudinal and horizontal cracks of the sample. Longitudinal cracks, upper margins, and lower margins represent longitudinal cracks in the sample. The horizontal crack, left edge, and right edge represent the horizontal crack of the sample. Secondary cracks can be observed and evaluated when the sample has been removed from the mold at 4 characteristic positions: Upper margin, lower margin, left margin, right margin.

- Experiment results:

The measurement results are presented in Table 2.2 and Table 2.3 as below:

Table 2.2 - Secondary crack width measurement of soil samples

Date, Time	Humidity (%)	Crack width (mm)			
		Upper Margin	Lower Margin	Left Margin	Right Margin
6pm on 9/10/2020	0	0,80	1,00	1,30	1,10

Table 2.3 – Primary crack width measurement of soil samples

TT	Date, Time	Humidity (%)	Crack width (mm)					
			Upper Margin	Lower Margin	Template Vertical	Left Margin	Right Margin	Horizontal Sample
1	8 a.m. on 28/9/2020	20,55	0,00	0,00	0,00	0,00	0,00	0,00
2	11 a.m. on 28/9/2020	20,11	0,08	0,09	0,01	0,11	0,11	0,02
3	3 p.m. on 28/9/2020	19,29	0,25	0,27	0,06	0,29	0,23	0,05
4	13h on 29/9/2020	17,72	0,50	0,53	0,11	0,68	0,56	0,13
5	11 a.m. on 30/9/2020	16,34	0,71	0,83	0,15	1,11	0,79	0,22
6	5 pm on 30/9/2020	15,28	0,98	1,11	0,22	1,18	0,98	0,27
7	15h on 1/10/2020	14,15	1,18	1,33	0,25	1,46	1,33	0,35
8	13h on 2/10/2020	12,93	1,31	1,51	0,32	1,85	1,46	0,43
9	11 a.m. on 3/10/2020	11,74	1,56	1,68	0,34	2,22	1,77	0,46
10	17h on 3/10/2020	10,76	1,66	1,98	0,38	2,36	2,13	0,53
11	14h on 5/10/2020	9,92	1,85	2,18	0,41	2,48	2,19	0,55
12	14h on 6/10/2020	8,65	2,18	2,38	0,47	2,79	2,38	0,66
13	13h on 7/10/2020	7,44	2,31	2,63	0,49	3,23	2,75	0,69
14	11 a.m. on 8/10/2020	6,21	2,52	2,88	0,58	3,38	2,98	0,75
15	5 pm on 8/10/2020	5,37	2,66	3,13	0,64	3,66	3,06	0,79
16	9 am on 9/10/2020	2,00	3,28	3,65	0,74	4,33	3,89	0,98
17	11 a.m. on 9/10/2020	1,72	3,45	3,85	0,77	4,45	3,98	1,07
18	6pm on 9/10/2020	0	3,66	4,16	0,83	4,96	4,28	1,11

The results of soil sample measurement are mainly qualitative, relatively difficult to quantify due to the complex shape of the crack. In terms of trend, the crack first develops in the short side then in the long side, the crack is extended into the center and expands during the drying process. The width of the largest crack in the soil sample at the outer edge is about 1 mm and is reduced to the center. Secondary cracks are not measured and are only observed when destroying soil samples.

2.4. Simulate experiments in the room on a numerical model

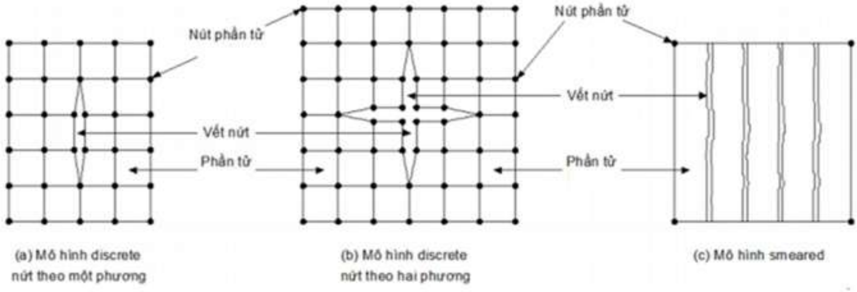

Figure 2.11 – Simulation of cracks in the model

Using digital models as an alternative to physical models is a trend to reduce research time, as well as funding. Specifically, software to simulate and analyze the working of the model. The results are shown on the image, the results are output at 16% humidity

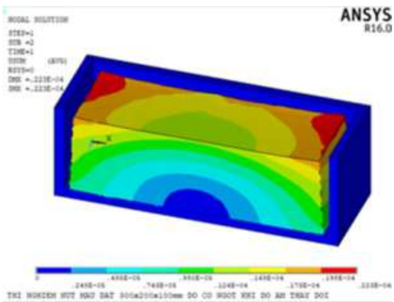

Figure 2.12 – Shrinkage of soil sample

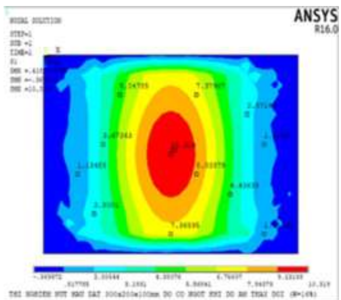

Figure 2.13 – Stress of soil sample

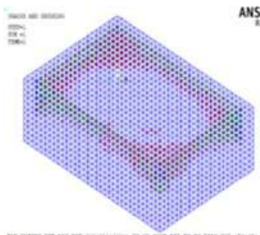

Figure 2.14 – Distribution of cracks on soil samples

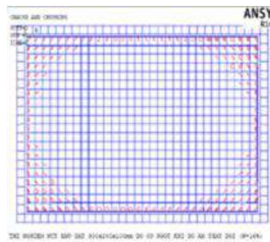

Figure 2.15 – Surface crack distribution

Table 2.4-Results of calculation and analysis of the embankment of the Hong left dike K81+813

T	Quota	Crack distribution (Phase)			Crack distribution (Phase)			Deformation	Deformation	Deformation	MAIN DEPRESSION	
	Humidity	Short Side (m)			along the long side (m)			Short edge (m)	long edge (m)	sum (m)	on the surface (kN/m²)	
	%	1	2	3	1	2	3				□max	□min
1	20	1	1	0	2	2	0	2,16E-05	2,85E-05	3.50E-05	12,16350	-1,70068
2	18	2	2	0	3	3	0	2,36E-05	3,14E-05	3,86E-05	9,87642	-1,12128
3	16	4	3	0	4	4	0	2,57E-05	3,44E-05	4,18E-05	10,31900	-0,36987
4	14	5	4	0	5	5	0	2,78E-05	3,71E-05	4.45E-05	11,10670	-1,63534
5	12	6	7	2	6	5	0	2,94E-05	3,77E-05	4.40E-05	8,73864	-3,96400
6	10	7	7	5	6	6	1	3,09E-05	3.59E-05	4,16E-05	8,31123	-0,78072
7	8	7	7	6	6	6	2	3,35E-05	4,32E-05	5,35E-05	9,36891	-11,6789
8	6	7	7	6	6	6	5	3,35E-05	3,78E-05	4,67E-05	23,45100	-2,94595

Comparison of results between physical and mathematical models

The qualitative and quantitative results between the model and the experiment are quite similar. In the physical model there are some cracks that do not follow the rules. In the mathematical model, the law of crack appearance is clear according to the law.

2.5. Conclusion Chapter 2

- The results of experiments in the room show that the largest expansion is 1.8%, the smallest is 0.1%, so compared to the prescribed standards, the dike embankment soil is not a type of expansion. The view that the land is expanding does not explain the phenomenon of dike cracking. The largest measured shrinkage is 30.60%, the smallest is 9%, so the soil is shrinkable.

- Results from physical and mathematical models show that there are many processes that take place when going through dry-wet cycles in nature. As the soil dries, the soil shrinks and decreases in volume, cracks form due to increased intrinsic tensile stress in the soil. Physical models and mathematical models both show the same law and crack magnitude. However, the image of the distribution of cracks on the physical model does not give uniform results like the mathematical model, the reason is that the soil is not a completely homogeneous environment.

CHAPTER 3 RESEARCH ON THE PROCESS OF FORMATION AND DEVELOPMENT OF CHIP CRACKS ON TYPICAL DIKE SECTIONS

3.1. Calculation to determine the formation of cracks

3.1.1. Development of calculation models and data for calculation

Using the APDL parameter programming language to build a spatial model (3D) for typical dike sections K81+299.5 ÷ K81+360.1.

Input data: Mechanical and physical indicators of the soil body and dike foundation of a typical dike section are used as calculation data for the model. For the structure of river dikes with curved and geological changes with the length of the dike, in order to properly reflect the working state of the dike, it is necessary to use the spatial model of the "Dike Body - Foundation" system.

Figure 3.1 - Model of the dike body with the foundation

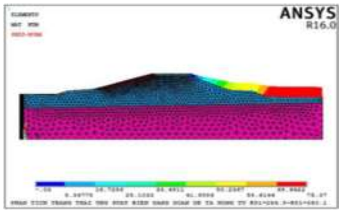

Figure 3.2 – Model boundary conditions

3.1.2. The process of calculating the formation of cracks on typical dike sections

The process of performing numerical simulation of a typical dike section of stress-deformation and the cracking process of the dike due to moisture changes. Cracks appear on the downstream dike body due to the process of changing the humidity in accordance with the law.

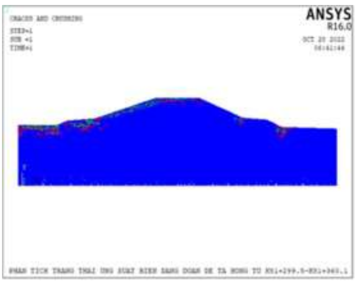

Figure 3.3 – Chip cracking on the dike cross section

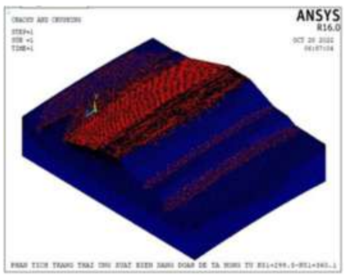

Figure 3.4 – Cracks in chips on the surface of the dike body

3.1.3. Calculation results

The process of performing numerical simulation of soil samples in terms of stress-deformation and cracking process of the sample due to changes in moisture. The distribution of cracks of the model is in 3 stages, in all 3 stages, the development of cracks and deformations continues at the same time: (+) Stage 1: The first crack appears horizontally and perpendicular to the surface of the dike; (+) Stage 2: The second crack appears vertically and perpendicular to the dike surface; (+) Stage: The third crack is parallel to the roof surface perpendicular to 2 cracks.

3.2. Determination of the mechanism of crack formation due to volume variation

3.2.1. Dike body volume variation

The dike body decreases in volume according to moisture: The experimental results of the dike body embankment soil with moisture decreased by 30% => volume decreased by 0.58% and 20% => 4.7%, 10% => 6.66%.

3.2.2. Variation of stress - deformation

Calculation analysis with 3 humidity levels of 30% - 20% and 10%, the calculation results below correspond to 20% humidity.

Table 3.1 - Results of calculation of stress and deformation of Hong left dike

TT Indicators	Taste (m)	Deformation (m)	Maximum crack depth (m)	Greatest Major Stress (kN/m^2)		Smallest Major Stress (kN/m^2)	
Humidity %	Overall	Overall	Overall	Min	Max	Min	Max
30	0,010898	0,010898	2.2	-228,349	62,2122	-424,808	3,71E-05
20	0,011770	0,011770	3,9	-225,411	38,6555	-419,015	2,99E-03
10	0,013490	0,013490	5,7	-228,451	120,716	-425,055	17,0059

3.2.3. Mechanism of crack formation

The results of the calculation and analysis of the model of the Ta Hong dike section show that: The embankment soil has a high content of clay and dust, when the moisture content of the embankment soil changes, the volume changes accordingly, and at the same time, the soil mass is deformed and generates internal stress in the soil mass and causes cracks. Thus, the mechanism of crack formation is due to the decrease in moisture content of the dike body, leading to shrinkage and deformation of the volume, generating tensile stress within the dike body and causing chip cracks on the surface and roof of the dike.

3.2.4. Explanation of some historical dike cracking phenomena

The mechanism of dike cracking can be explained as follows: because the soil of the dike body has a large fine grain content, in the dry season when the groundwater level under the dike is lowered, the dike body reduces moisture, causing the dike body soil to shrink, leading to a decrease in volume, the decrease in volume causess primary and secondary cracks.

3.3. Chapter 3 Conclusion

- The results of research on physical and mathematical models have determined that the cause of cracks is caused by the decrease in moisture content of the dike body, leading to shrinkage of the volume, generating tensile stress within the dike body and causing chip cracks on the surface and roof of the dike. There are three stages of crack formation, the first is the stage of tensile stress, followed by the stage of primary cracking, and then the stage of secondary cracking.
- The results of the study on the mathematical model show that the calculation with 3 humidity levels is 30% - 20% and 10%. When the humidity decreases to 30%, the largest main stress is: 62.2122 kN/m^2, the smallest main stress is: 3.71E-05kN/m^2, the deformation causing cracking is: 0.010898 m.
- It is possible to use a mathematical model with boundary conditions similar to a physical model to research the cracking phenomenon of a dike section.

CHAPTER 4 FORECAST OF THE POSSIBILITY OF FRACTURE FORMATION FOR SOME SECTIONS OF DIKES IN THE RED RIVER DELTA

4.1. Introduction of some dike sections in the research area

The author selects each province and city in the Red River Delta a section of dike to study.

4.1.1. Geological conditions

The study dike routes are located in the area with the Quaternary sedimentary strata (District 2) in the Red River Delta, the dike body is covered with soil in situ with high clay dust particles.

4.1.2. Dike form and structure

The general characteristics can be summarized as follows:

- The dike has a small cross-section, the largest average height is H = 10 m; River side roof m_s = 2; The roof on the copper side is m_d = 3; The width of the top of the dike = 5 ÷ 8 m; Muscular and non-muscular type, muscular type with high Hc = 1.5 ÷ 3 m, muscle width B_c < 5 m.

- The dike body from the foundation upwards usually has 1 ÷ 2 layers of embankment made of on-site materials, has a very high content of clay and dust, sensitive to changes in moisture, and vibration on the dike body.

- The dike background is formed from natural alluvium, so it is very complicated, usually has 3÷5 layers, the most common is the geological structure consisting of many layers of weak clay in a flowing and flexible state interspersed with each other.

4.2. Determination of volume variations, deformations, and cracks

4.2.1. Input data for calculation

Using the data on the physical and mechanical indicators of the dike body soil of the dike lines in the study area, on the basis of the authors of the field survey collected in the provinces and cities and additional geological surveys.

Table 4.1 - Mechanical and physical indicators of dike body soil of dike lines

Table 4.1 - Mechanical and physical indicators of dike body soil of dike lines

TT	Physical Indicators	Unit	Hung Yen	Ha nam	Bac Ninh	Nam Dinh	Thai Binh	Hai Duong	Vinh Phuc	Ha noi
1	Particle composition		Ta Hong	Huu Hong	Huu Duong	Ta Day	Hong Ha	Huu Thai	Pho Day	Huu Cau
	- Sand 0.25÷0.05	%	33	26	36,8	35	35,06	33	37,6	14,8
	- Silt 0.05÷0.005	%	45	38	26	33	36,66	43	35,3	30,5
	- Clay <0.005	%	22	25	27,1	23	24,87	24	22	17,1
2	Moisture content	%	31,5	24,3	24	28,5	29,21	33,9	23,1	20,5
3	Density	g/cm^3	1,89	1,83	1,94	1,85	1,88	1,87	1,94	1,98
4	Dry density	g/cm^3	1,44	1,47	1,56	1,44	1,46	1,4	1,57	1,64
5	Mass unit volume	g/cm^3	2,72	2,69	2,7	2,71	2,72	2,72	2,69	2,67
6	Void ratio	%	0,892	0,831	0,73	0,875	0,863	0,948	0,715	0,63
8	Liquid Limit	%	40,5	34,1	33,9	38,3	37,69	40,6	31,8	27,85
9	Plastic Limit	%	24,6	22,8	19,9	23,3	22,88	26,2	18,8	18,55

TT	Physical Indicators	Unit	Hung Yen	Ha nam	Bac Ninh	Nam Dinh	Thai Binh	Hai Duong	Vinh Phuc	Ha noi
10	Cohesion	Kg/cm^2	0,18	0,12	0,23	0,198	0,248	0,17	0,19	0,26
11	Friction angle	Degree	15°09	12°32	12°56	12°34	12°46	13°02	14°31	18°45
12	Permeability*$^{10-6}$	Cm/s	1.2*10-4	4,4	2,28	7,24	2,7	1,8	2,9	
13	Modulus	Kg/cm^2	100	84	133,2	116	100,8	85	164	

4.2.2. Calculation results

The results of calculation and analysis of dike body soil samples of dike lines show indicators of cracks, deformations, displacements and main stresses that change according to the moisture content of the dike embankment soil.

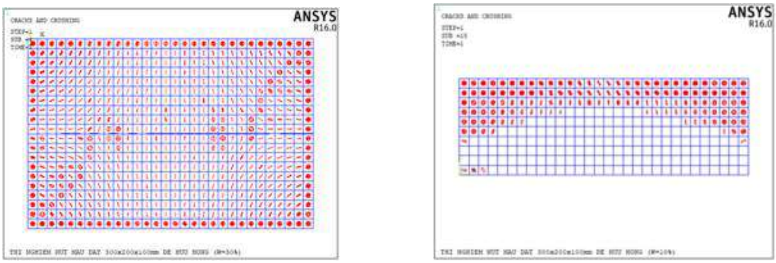

Figure 4.1 – Cracks of soil samples

Remarks: From the geological survey data on the study dike sections, it is shown that the embankment soil has a fine particle content, high clay particles, particle composition < 0.005 (17.1 ÷ 32.1)%, particle composition < 0.05 (46.7 ÷ 76)%. The results of the calculation and analysis of the soil samples of the dike bodies of these dikes, when reducing the moisture, are deformed and produce cracks on the samples similar to the laboratory results.

4.3. Forecast of cracking potential for some dike sections in the study area

4.3.2. Figures for calculation

4.3.2. 1. Geological data

Using geological data collected at: (+) Hung Yen**:** Hong left dike; (+) Ha Nam: Hong right dike; **(+)** Bac Ninh: Duong right dike, Thai Binh right dike; (+) Thai Binh: Hong Ha dike; (+) Hai Duong: Thai Binh right dike; (+) Vinh Phuc: Pho Day right dike; (+) Hanoi: Huu Cau dike; (+) Nam Dinh: Day left dike

4.3.2. 2. Data on hydrometeorology of the Red River in the Northern Delta

The author has collected hydrological documents on the Red River with daily water level measurement at Long Bien - Hanoi hydrometeorology station from 1956 to 2018 for analysis.

4.3.3. Research results

The results of calculation and analysis show that on the dikes in the study area, the embankment soil has a high content of clay particles, clay particles, particle composition < 0.005 (17.1 ÷ 32.1)%, particle composition < 0.05 (46.7 ÷ 76)%, susceptibility to vibration and danger to cracking.

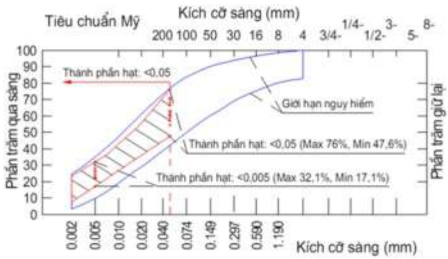

Figure 4.2 - Range of soil particle composition of embankment bodies dangerous for cracking

4.4. Chapter 4 Conclusion

- The results of the study show that there is a great similarity to J.L. Sherard's Particle Composition Chart. If the dike sections have particle components located in the fracture-sensitive zone, the calculation results show that when there is a change in humidity, chip cracking occurs.

- The analysis shows that the dike sections in the study area are likely to be fractured, including: 1. Hong left dike - Hung Yen, 2. Hong right dike - Ha Nam, 3. Duong - Bac Ninh, 4. Hong Ha dike - Thai Binh, 5. Thai Binh right dike - Hai Duong, 6. Day left dike - Nam Dinh, 7. Pho Day dike - Vinh Phuc, 8. Huu Cau dike - Hanoi. These are dike sections that need to be considered and have appropriate solutions to limit the phenomenon of chip cracking, which can cause unsafety for the dike in favorable conditions due to stimulating factors that expand the crack.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions of the thesis

- Based on the research conducted on the following aspects: (i) Overview of river dikes river dikes and the phenomenon of cracking in river dikes; (ii)

Investigation into the causes and mechanisms of cracking in river dikes in the Red River Delta; (iii) Study of the formation and development process of cracking in a typical dike section; (iv) Prediction of crack formation potential in several dike sections within the Red River Delta region. The thesis focuses on the issue of cracking in dike bodies, a pressing concern amid climate change, prolonged droughts, and upstream water control of the Red River.

- Through field surveys, laboratory experiments and modeling, the thesis identifies that the primary cause of cracking is the high content of fine and clay particles in the dike body soil, which is sensitive to moisture changes. As moisture decreases, the soil shrinks, generating internal stress that result in the formation of cracks. The thesis also provides a detailed description of the spatial and temporal development of cracks, from primary to secondary cracks. These findings also help explain historical occurrences of dike cracking.

- Based on this foundation, the thesis identifies dike sections in the Red River Delta that are highly susceptible to cracking. findings are practically significant for the maintenance, upgrading, and risk prevention of the dike system. This is an important scientific and technical contribution to ensuring dike safety in Vietnam.

2. Recommendations

- Based on these research results, the thesis recommends that management agencies and technical units should promptly incorporate criteria for assessing fine particle content, chemical composition, and moisture sensitivity of dike soil into the process of surveying, designing and quality inspection of dike systems, particularly in areas with a history of dike cracking at the end of the dry season. At the same time, it is necessary to widely apply the method of predicting the risk of dike cracking based on the field indicators developed in the thesis. This will serve as a scientific basis for zoning, planning for maintenance and upgrading of the dike system.

- In addition, expanding the application of the thesis results to other dike areas with similar geological conditions is encouraged in order to enhance proactive coping capacity to climate change and prolonged drought conditions.

- Developing a real-time monitoring system for soil moisture and deformation should also be prioritized, aiming to provide early warning of potential risks and ensure the sustainable safety of critical dike lines.

LIST OF ANNOUNCED WORKS

1. Phung Vinh An, Tran Quoc Linh, Tran Van Nguyen (2019), *"Methods for early detection of the risk of river dike and sewer incidents under dikes"*. Collection of science and technology for 60 years of construction and development (1959 - 2019) - Vietnam Institute of Irrigation Sciences, pp. 626-636.

2. Tran Van Nguyen, Phung Vinh An (2021), *"Mechanism of formation of subsidence and cracking of the road surface on the dike when combining the dike surface to make a traffic road"*. Journal of Irrigation Science and Technology (ISSN:1859-4255) - Vietnam Institute of Science and Technology, ($\frac{64}{02\text{-}2021}$), pp. 80-87.

3. Phung Vinh An, Nguyen Dinh Hai, Tran Van Nguyen (2022), *"Research and proposal of a reasonable road traffic cross-sectional structure on the river dike section through the urban area"*. Journal of Irrigation Science and Technology (ISSN:1859-4255) - Vietnam Institute of Science and Technology, ($\frac{70}{02\text{-}2022}$), pp.110-116.

4. Phung Vinh An, Tran Van Nguyen et al. (2018-2020), *"Research on dike cracking and solutions to upgrade and repair to ensure the safety of dikes when combining roads"* Ministerial project (NT 2022).

5. Tran Van Nguyen, Nguyen Tiep Tan (2024), *"Experimental results to determine the cause of river dike body cracks in the Red River Delta due to the variation of soil moisture in the dike embankment according to the dry-wet cycle"*. Journal of Irrigation Science and Technology (ISSN:1859-4255) - Vietnam Institute of Science and Technology, ($\frac{86}{10\text{-}2024}$), pp. 10-19.