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Experiment on stability of dike piled with flat geotube

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ABSTRACT: A small-scale experimental study was performed to investigate wave attack on dike piled with flat geotube under regular sea conditions. The stability of dike under wave attack with a series of wave heights was studied, in which wave steepness, slope ratios of dike and four kinds of water level were taken into account. And then, the distribution of wave pressure on the slope surface of the sea side and uplift of the tube had been obtained in the flume experiment, so as to analyze the critical stability of dike body with calculating a factor of safety. This paper is also concerned with the displacement of tube under wave impact. It demonstrates that displacement is a more rational criterion to design tube dike as well as to assess its performance when compared to merely a factor of safety. According to the experimental result, three types of stability are defined as stability, critical stability and destruction. In the end, some suggestions have been presented in the paper, while some conclusions are obtained.

1 INTRODUCTION

With the extensive use of geotextiles, coastal and hydraulic engineering problems are the starting point of the technical development of geotextiles. Over 50 years ago, first trials with sandbags made of synthetic textiles were realized in the USA, the Netherlands and in Germany. Following, geotube had been extensively adopted in breakwater construction. In recent years, theory and practical technology about geotube have experienced great success and highly visible projects. But now in China, laggard geotube theory doesn't correspond to practical projects, though geotube has been applied in various fields, especially in coastal protection engineering and in enclosing tideland for cultivation engineering along the estuary and the sea. Additionally, there is a difference: abroad, the shape of tube adopted in dike construction is nearly round, but it is usually flat shape in China. The dike is piled with tube layer by layer, as shown in Photo 1.

This experiment examined the stability of tube dike against wave attack. In order to obtain the critical wave heights which started to make the dike unstable, a series of wave heights was studied, in which wave steepness, slope ratios of dike and four kinds of water level(14cm, 18cm, 22cm and 26cm) were taken into account. And the distribution of wave pressure on the slope surface of the sea side under critical stability and displacement of tube had been obtained in the test.

All that do is trying to expect some theoretical progress in dike structure piled with tube, so as to do duty for practical engineering.

Photo 1. Panorama of the filled flat geotube embankment in practical engineering

2 HYDRAULIC MODEL EXPERIMENT

The model scale of the dike was 1/35. The experimental wave flume was 130cm depth, 50cm width and 35m length. Photo.2 shows the model tube dike. Flat geotube was made in filling sand into the fabricated geotextile units. The height of the model tube: each layer tube was 2cm and the total height was 28.6cm. One of mainly problems was to determine the critical wave heights which lead to the unsteadiness of the dike. Experiments were carried out by using regular waves. The water depth was 4cm, 18cm, 22cm and 26cm.

Photo.2 View of model dike piled with flat geotube

The design wave heights and corresponding periods are shown as Table.1.

Table 1. The Element of Regular Wave

Stee-pness	Ele-mtnt	1	2	3	4	5	6
1/20	*H*	6.5	7.5	8.5	9.5	10.5	11.5
	T	0.99	1.09	1.21	1.32	1.44	1.55
	H	5.5	6.5	7.5	8.5	9.5	10.5
	T	0.91	1.03	1.15	1.27	1.40	1.53
	H	4.5	5.5	6.5	7.5	8.5	
	T	0.82	0.95	1.09	1.23	1.37	
	H	3.5	4.5	5.5	6.5		
	T	0.73	0.88	1.03	1.19		
1/15	*H*	6.5	7.5	8.5	9.5	10.5	11.5
	T	0.82	0.90	0.98	1.06	1.14	1.22
	H	5.5	6.5	7.5	8.5	9.5	10.5
	T	0.75	0.84	0.92	1.01	1.10	1.20
	H	4.5	5.5	6.5	7.5	8.5	
	T	0.68	0.78	0.87	0.97	1.07	
	H	3.5	4.5	5.5	6.5		
	T	0.60	0.71	0.82	0.93		

Note: units of element of wave H and T are cm and s respectively.

In the wave test, changing first factor with fixing the others and then changing the second factor with fixing the rests and so on, it helped to find the influencing factors.

3 EXPERIMENT RESULTS AND DISCUSSION

3.1 *Definition of Stability*

Based on the result of wave flume experiment, we defined the stability of tube dike attacked by wave loading as three types of state as following.

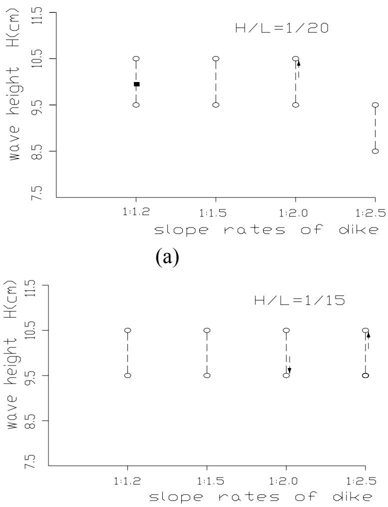
Stability: means that the dike keeps stationary; there is no sliding and no displacement; and meantime tube doesn't be churned.

Critical stability: There is a slight slip occasionally between two tubes, however, there is no evident relative displacement between them and the dike structure still keeps its integrity under action of the durable wave.

Destruction: There is violent sliding between two tubes, and there is evident relative displacement between them, even a layer or several above layers of tube rushed out of the dike, the dike can't keep its integrity; it is destructed.

3.2 *Critical Wave Height*

Fig.1 shows the result of stability of the tube dike. From the experimental result, we can obtain the scope of the critical wave height. The arrows in the figure indicate that the pointed critical wave height is more tend to make the dike unstable firstly. Meanwhile, the critical wave height is mostly between 9.5cm and 10.5cm, while the water depth is 26cm in the model test.



(b)

Hint: o----o : meaning the quantity of critical wave height between the two numbers.
○ : water depth d=26cm .
■ : water depth d=22cm.

Fig.1 Relation of steepness(H/L),slope rates of dike and critical wave height(H)

From the test, it can be conclude that the deeper of water depth, the more unstable of the dike. When water depth was 14cm and 18cm, the model tube dike was no displacement. And also, when the slope ratio was 1:2.5, the critical wave height was between 8.5cm and 9.5cm, which was less than the others. Thus, we deduce that the more gentle slope rates of the dike, is not necessarily the more superior choice when tube dike is to be constructed.

3.3 *Stability Analysis*

About the stability of flat geotube, the mostly unstable type is direct sliding among the tubes when dike is attached by wave loading. In the wave attach, forces acting on the tube is shown as Fig.2.

The stability of the tube against direct sliding along the tube-tube interface is expressed in a factor of safety F_s, which is indicated as the ratio of total resisting force to disturbing wave force acting on the tube.

$$F_s = \mu \frac{W' - U}{P} \tag{1}$$

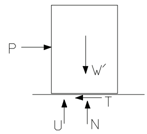


Fig. 2. External forces acting on the simplified flat geotube under wave loading

Where W' is the effective weight of the geotube, composed of the portion of filled(sand) tube below and above water table; μ is the coefficient weight of friction, which is related to the angle of friction ϕ between the two tubes: $\mu=\tan\phi$; P is the total horizontal wave force and U is the total uplift force acting on the tube dike.

Table 3. The Validating Chart of Factor of Safety

Element / parameter		26				22	
		1/20		1/15		1/20	1/15
		9.5	10.5	9.5	10.5	9.93	9.26
1 : 1.2	*W'*	32.6	32.6	32.6	32.6	32.6	32.6
	P	4.97	6.01	4.9	5.73	4.91	3.92
	U	23.6	25.2	19.2	21.8	24.7	17.9
	Fs	0.54	0.37	0.82	0.57	0.48	1.13
1 : 1.5	*W'*	200	200	200	200	200	200
	P	167	228	132	154	48.0	46.0
	U	42.9	46.2	48.7	60.0	37.3	30.8
	Fs	0.28	0.20	0.34	0.27	1.01	1.10
1 : 2.0	*W'*	86.4	86.4	86.4	86.4	86.4	86.4
	P	42.2	68.4	41.3	59.8	9.54	6.65
	U	42.6	57.6	40.2	43.5	47.3	39.1
	Fs	0.31	0.13	0.34	0.22	1.23	3.14
1 : 2.5	*W'*	246	246	246	246	246	246
	P	152	203	146	183	45.5	41.1
	U	50.8	63.9	47.2	57.1	51.9	23.7
	Fs	0.39	0.27	0.41	0.31	1.28	1.63

Note : water depth d is 26cm and 22cm; steepness is 1/20 and 1/15; wave height H is 9.5,10.5,9.26 and 9.93; the unit of *W, P* and *U* is N. F_S is the factor of safety.

The coefficient of friction can be easy to quantify under laboratory. In this experiment, μ is taken as 0.30 based on the Direct Shear Tests.

At the end of test, we analyze the experimental data partly and calculate the factor of safety F_s when the dike attains to the critical stability state. It is shown as Table.3. F_s can be used to preliminary check up the stability of tube dike.

From the chart, we include that factor of safety is small(mostly below 0.50) when displacement is happened in the dike; but it is corresponding large (above 1.0) when there is no displacement. Therefore, once there is displacement happened in the tube dike, it is easy to make dike sliding further and lead to destroy at last when dike has being attacked by wave loading in the phase of construction.

In addition, when attacked by wave loading, in the critical unstable state, the height of the displaced flat geotube was varied with slope rates of the dike. experiment has proved that the steeper of the slope ratio, the more unstable of the dike.

3.4 *The Displacement of Flat Geotube*

3.4.1 *The Principle of Displacement*

In the experiment, once the tube dike was at critical unstable state, there would be displacement between the flat geotube.

Based on the sliding block theory, in this study, a simplistic formula is used to determine the displacement of the tube dike subject to wave loading. In this formula, we take flat tube(despite of one layer or several layers together) as a rigid block. While its damping and stiffness properties are neglected. Thus, the sliding conforms a rigid-plastic law: the Coulomb Criterion. In the horizontal direction, the equation of motion is expressed as:

$$\frac{W + W_t}{g} x'' = P - \mu(W' - U) \tag{2}$$

Where W, W_t, x'' and g signify total weight, added weight, horizontal acceleration of the tube and earth gravity acceleration, respectively. As to the added weight W_t, in this test, we consider added mass by increasing the unit weight of tube, giving about 15% additional weight according to test materials.

Additionally, the effective weight of tube is used to express the horizontal and uplift force as follows:

$$P = C_h W' \tag{3}$$

$$U = C_u W' \tag{4}$$

Where C_h and C_u are called as wave coefficients.

Using above coefficients, the horizontal acceleration of tube is rewritten as:

$$x'' = \frac{W'}{W+W_t} \iint [C_h - \mu(1 - C_u)] g \tag{5}$$

Sliding is beginning in tube when the factor of safety F_s is equal one. At the moment of sliding, the wave coefficient calculated from the horizontal wave force is defined as the yield wave coefficient C_{hf}. There is a next expression:

$$C_{hf} = \mu\ (1-C_u) \quad (6)$$

When tube slides, Comparison of C_h and C_{hf}, the acceleration of tube can be simplified as:

$$x'' = \frac{W'}{W+W_t} \iint (C_h - C_{hf})g \quad (7)$$

Further, during the duration of wave loading, the acceleration is double integrated to yield displacement that is taken place because of excessive wave loading making tube unstable.

$$x = \frac{W'}{W+W_t} \iint (C_h - C_{hf})g\, d_t d_t \quad (8)$$

3.4.2 *Illustrative Example*

In this experiment, the tube dike was unstable attacked by the durable critical wave loading. We choose one group of wave coefficient to study its displacement.

Model water depth: d=26cm; wave height: H=9.5cm; the period time: T=1.32s;slope rates of dike: 1:2.5 and the steepness: H/L=1/20.

In terms of the data of test, we calculate the wave coefficient such as: $\frac{W'}{W+W_t} = 0.490$, C_{ho} =0.618, $C_{uo} = 0.206$, in which C_{ho} and C_{uo} are the wave coefficient when the dike is being the critical state.

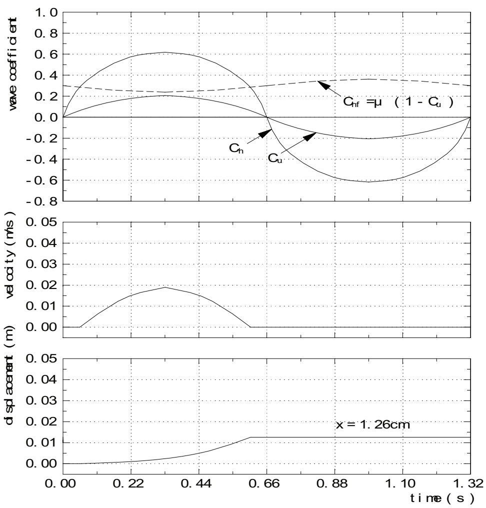


Fig. 3. Illustrative Example——Response of filled flat geotube Subject to Sinusoidal Wave

Supposing the variation of wave force with time is sinusoidal, and given$\omega = 2\pi / T$, the horizontal and vertical wave coefficients are expressed as:

$$C_h = C_{ho} \times \sin(\varpi t)$$

$$C_u = C_{uo} \times \sin(\varpi t)$$

Then, from (6), calculating the yield wave coefficient C_y, dike slides since C_h is larger than C_{hf}.

The wave coefficients, velocity and displacement of tube are shown as Fig.3.

Fig.3 characterizes the wave coefficients, velocity and displacement of tube in a particular wave cycle. When the horizontal coefficient C_h is larger than the yield coefficient C_{hf}, tube slides. The horizontal wave force increases to a peak value, and then decreases to less of the yield coefficient; corresponding, the velocity of the tube starts to increase to a peak value and then decreases to keeping zero. In the wave cycle, the displacement is calculated as 1.26cm. If there are 10 wave cycles of wave in a form, it would be 12.6cm.

4 SUGGESTIONS AND CONCLUSIONS

Suggestions and conclusions are obtained from the analysis of the experiment.

(1) The destroy energy of long wave(H/L=1/20) to the tube dike is greater than that of short one (H/L=1/15).
(2) The critical wave height making dike unstable seems decreasing due to decreasing of the slope ratio of the dike.
(3) The critical wave height is between 3.325m and 3.675m mostly whatever water levels or slope rates.
(4) In the model of tube dike, the height of bottom of the displaced tube layer varies with different ratios of slope at the critical stable condition.
(5) Based on the test, it is suggested that the slope ratio of the dike should not be steeper than 1:1.2.

Currently, flat geotube has extensively been used in coastal engineering, located in the Southeast of China. The feasibility has already been proved by the quantities of successful practical engineering, but theory of tube should be deeply studied.

This experimental study is to be taken as a preliminary investigation of the stability of the tube dike, limited in test condition. A supplementary study should be proceeded in order to deep understand all kinds of factors of impact to the stability of the dike.

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