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A New Type of Solid Sand Fort Foundation Shape -- "Droplet Shape"

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Abstract

In this paper, a new type of sand castle foundation with a long service life is presented, and the optimum ratio of water and sand adapted to wave, tidal and rain erosion is calculated. The results are as follows:(1) In the process of determining the foundation model of the sand castle, the minimum sand stress should be adopted to make the foundation last the longest. We used the nonlinear programming method to determine the optimal slope Angle of 35.2 degree. (2) Using fluid simulation software (CFD), we determined the model's "water drop" streamlined structure. The structure can effectively reduce the pressure difference resistance of turbulence, and the concave structure on the side can reduce the wave erosion by centripetal force. (3) The optimal water-sand mixing ratio of 8.2% was obtained by fitting the internal mechanical relationship between the water-sand particles; This method is robust.

Keywords

TOPSIS, CFD, surface tension, nonlinear programming.

1. Introduction

Around the world, there are many artists dedicated to building and sculpting giant sand castles. They always "stick" them together with a certain amount of water and some sand, but due to the effects of waves and tides, the cohesive force is limited and they cannot last long. At the same time, a certain structure of sand castle foundation is needed to make the sand castle can exist for a long time.

To address these problems, we focus on two key points: the geometry of the base, the proportion of sand and water. In order to achieve optimal results without complicating the model, we idealize many unimportant factors and highlight the main problems.

To build an optimal model, we begin with the simplest model. Firstly, we built a relatively simple model by looking for a large number of existing models and data, as well as the necessary literature. Secondly, we establish a more complicated the optimization model via constant digging and innovation. Finally, we built an excellent model, which can effectively resist the intrusion of external forces. The internal structure is also stable.

In the end, we will pay more attention to the realistic ideal conditions and find more data and data to make our model more robust.

1.1. Modeling

In this chapter, we take the most ordinary cube as our starting point. As we all know, in order to carry more load, the base area should be increased to reduce the effect of pressure under the condition that the weight of the foundation remains the same. As a result, we turned the model into a platform. Since it is determined to be a platform, then it is necessary to find the angle between the busbar and bottom surface, in order to reach the slope by the wave impact of the minimum. α refers to the angle.

1.1.1. Model 1:The establishment of the sandcastle foundation model

In a wave period, the wave movement on the slope mainly includes three stages: incident, climb up, back up. Since the climbing stage has little effect on the movement of sand, we ignore this stage. We're just going to take the incident phase and the fallback phase.

Incident stage:

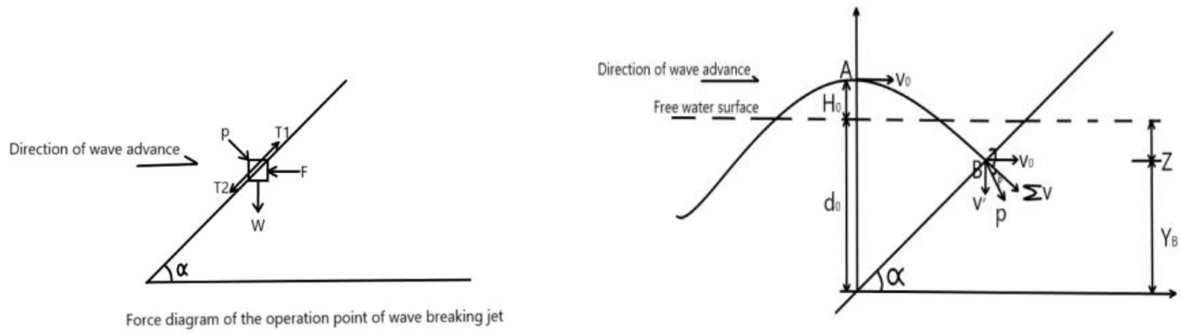

Figure 1 : Schematic diagram of force analysis of the incident

Based on the force analysis of the figure above, the following formula can be obtained:

When $\beta > 90^\circ - \alpha$,

$$T_{2i} = (m' - \tan\beta)/(1 + m'\tan\beta) \cdot p \cdot k_p; \tag{1}$$

$$\tan\beta = \sqrt{2g(H_0 + Z)/v_0}; \tag{2}$$

$$p = \frac{1}{2}\rho DC_s v^2; \tag{3}$$

$$v = \frac{\sqrt{2\pi g}}{\sqrt{L_0}}; \tag{4}$$

We know that DCs=1.1957, L_0=125 meters. And we get that ρ =1.07g/cm3, D=0.25mm.

Where, T_{1i} is the force that goes up parallel to the plane,T_{2i} is the force that downward parallel to the plane, m'= tan α,P is the positive pressure ,β is the angle between the incident angle and the positive pressure, K_p is correction coefficient, W is the vertical velocity of falling water droplets.

Falling phase:

When the wave falls down, the slope particles are mainly dragged down parallel to the slope by the action of the slope flow, upward lift perpendicular to the slope face, the decrease of surface water level on the bank slope results in dynamic water pressure and its own gravity caused by head difference.

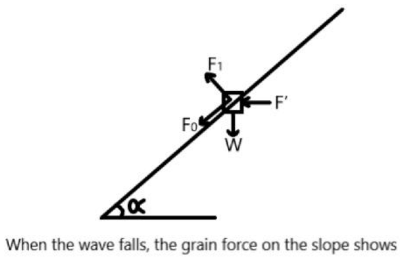

Figure 2 : Schematic diagram of force analysis of the falling

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According to the stress analysis diagram, we derive

$$F_D = C_D \pi D^2/4 \cdot \rho v^2/2; \tag{5}$$

$$F_L = C_L \pi D^2/4 \cdot \rho v^2/2; \tag{6}$$

Finally, we determined the model of sand heap collapse and use the least stress on the sand to ensure that the sand castle lasts the longest. And we use the method of nonlinear mathematical programming to determine the angle.

$$\begin{aligned} \min \quad & \sum T_{i2} + (F_D + F_L)0.5 + W\cos\alpha \\ \text{S.t} \quad & 0 \leqq \alpha \leqq 90°; \\ & \beta > 90° - \alpha \end{aligned} \tag{7}$$

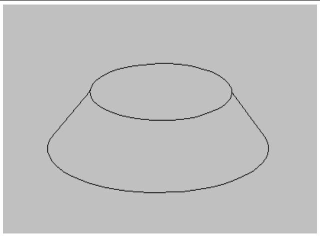
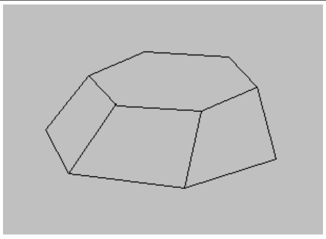
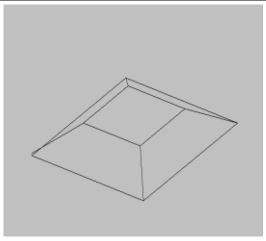
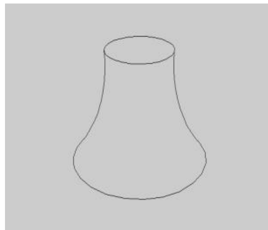
Through the MATLAB, we determine that α is 35.2°. Aiming to verify our results, the safety coefficient is calculated according to the empirical formula

$$\text{safety} = \frac{\tan\phi}{\tan\alpha}; \tag{8}$$

Φ is the internal friction angle. Sea sand is usually 38°. And we calculate that safety is equal to 1.12, which is greater than 1 and compliance with engineering specifications [2].

In addition to the angle, we considered several other factors: the ratio of height to base area①, slope surface curvature②, the number of stare blankly③. We utilize AHP to evaluate the three features and we consider the following four models and every model has the same weight of sand. According to the weight of AHP, we find the optimum model estimated by TOPSIS.

Table 1 : The result of TOPSIS

			
0.3396	0.1243	0.0928	0.4433

Thus, we establish the following model: The angle between the generatrix and the bottom is 35.2°. Each side is recessed with a certain radian. Also, each strand is ground into an arc.

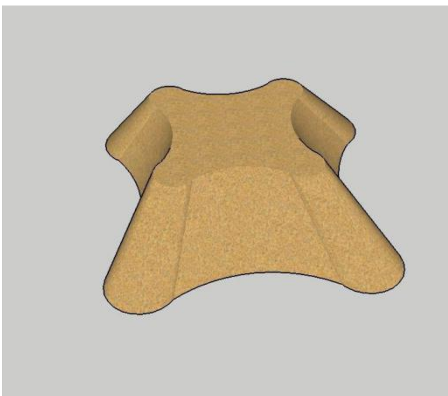


Figure 3 : The preliminary model

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The front side is affected by the impact, and both sides receive the drag force from sea water. Thus, in this section, we consider a model of forces operating in both sides and forces acting on the front.

In the previous section, we assumed that the flow of seawater was laminar, while the literature we found shows that the flow of seawater should be turbulent. According to the knowledge of fluid mechanics, the resistance mainly consists of friction resistance and differential resistance. When a fluid reaches turbulence, resistance is mainly differential pressure resistance.

To reduce the pressure differential resistance, we use the "droplet shape" streamline body. The streamline body is smooth at the front, gently at the back and slender in shape, which can effectively reduce the reverse pressure gradient at the back.

We used FLUENT to draw the velocity cloud diagram, and found that the model in FIG. 4 was optimal. So we determine the final model:

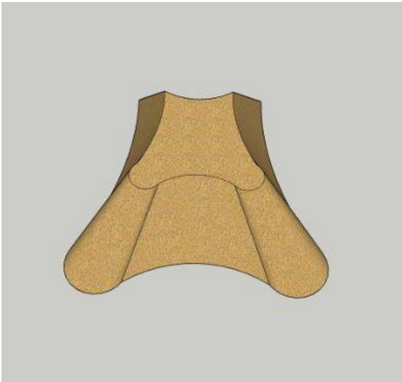

Figure 4 : The streamlined model is added to figure 8

1.2. Model 2: The best proportion of sand water

Here we discuss the water-to-sand proportion to make the model last longer.At first, we are ought to know the action mechanism of sand and water.

Principle:

As we know, sand is not cohesive, so only the action between the sand is not "bonding" up. At that time, we need water to "bond" grains of sand to grains of sand.

There are many pores of different sizes in the sand, which are connected into tiny channels (capillaries). And the surface tension is caused by the interface between water and air. Surface tension is the main force of particle "cohesion".

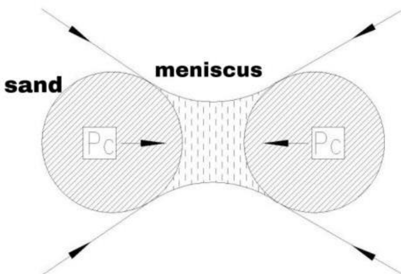

Figure 5: Mechanism of the figure

When the water content reaches saturation, the more water, the greater the surface tension. And then,with more and more water exceeding the saturation value, the liquid film formed by the surface tension will become thicker and the curvature will decrease, resulting in the decrease of the surface tension.

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However, the bridging force is a powerful combination of two particles (viscous force, surface tension).So, here we're thinking about the liquid bridging force.

Before saturation:

There are many forms of accumulation in the sand, such as cubes, positive rhomboids, the densest hexagons, and so on. We made a figure based on the data of literature [4].

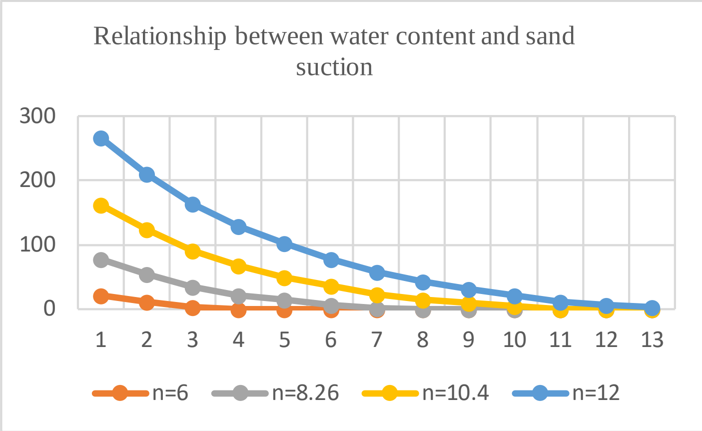

Figure 6 : The relationship between different coordination number and water content

We can see that the suction between the sand is greatest when the sand coordination number is 12. We can interpret it as: the more the number of coordination, the closer the sand is, and the most liquid bridges are contained, so the suction is larger.

Thus, we adopt the arrangement where the coordination number is 12.

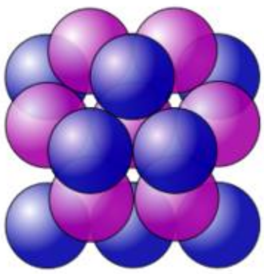

Figure 7: Diagram of the densest accumulation in six sides

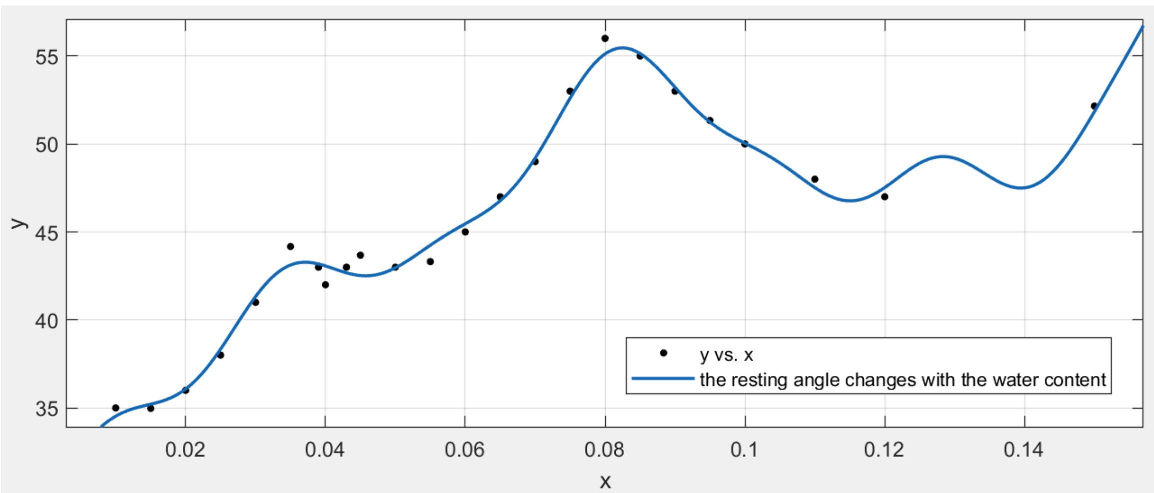

Figure 8 : The fitted image

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As can be observed in figure 7, the shaded area between the two spheres is called the liquid bridge. In the 'bridge', the repose angle is an important index to describe the stability of sand. In the reference[4],we derive

$$F = 2\pi\gamma R\cos\theta[1-(1+\frac{2V}{\pi D^2 R})^{-0.5}]; \tag{9}$$

we learn about that the repose angle is positively related to the fluid bridging force.

Through a large number of data and cubic spline interpolation, we finally use the method of fitting to make figure 8.

From figure 8, it is easy to see that there is not a linear relationship between repose angle and water content. At the beginning, with the increase of water content, the repose angle is also increasing. Although there is some fluctuation during the process, the repose angle is generally increased.

When the water content reaches 8.2%, the repose Angle reaches the maximum (ignoring the outlier in later period).The relation formula of water content and repose angle is obtained by MATLAB.

$$\begin{aligned}\theta &= 87.76\sin(18.44w-0.2979)+217.3\sin(40.91w+0.8958)\\ &+2.174\sin(137.7w+2.806)+183.1\sin(43.76w+3.815)\\ &+0.7671\sin(265.3w-1.055)\end{aligned}$$

$$R = 0.9919$$

Where: θ is the resting angle; w is the water content.

After reaching saturation:

In reference 5, we found data on the relation between bridge force and water content after saturation. The water content and suction are fitted. The result is

$$F = 759.9w^{-0.9584}; \tag{10}$$

$$r=0.975$$

$$SSE= 1.581e+04.$$

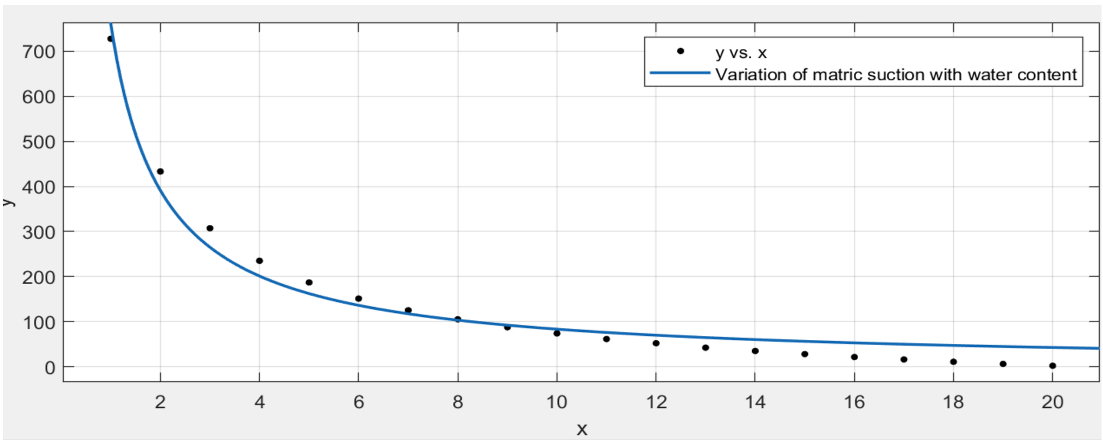

Figure 9 The relation between water content and bridge force

We can see that as there is more and more water, the bridging force becomes less and less important. Eventually, it causes the sand foundation to collapse.

As a result, we select 8.2% as the optimal ratio of sand to water.

2. Conclusion

In our paper, we have done a lot of searching work, such as searching for reference, searching for data and so on. Through the work, we finally find the best model to make the sandcastle last longer.

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The "droplet shape" model in FIG. 7 is adopted.

We determined that the optimal water-sand ratio is 8.2%.

We find that the model in model one can resist the erosion of rain.

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