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Research on Sandcastle Durability based on Dynamic Damage Function Model and Anti-Damage Model

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Abstract

Sandcastles of various shapes appear on recreational sandy beaches all over the world, from simple small houses to complex and exquisite castle models, none of them are not from a primitive prototype of sand pile. Through the study of a large number of sandcastle shape data, we can assume that a large number of sandcastle shapes are formed by cutting and shaping a three-dimensional cuboid. In order to better avoid the erosion of sandcastle by waves and tides, we set up a Dynamic damage function model of waves and tides to detect the influence of different ratio of length, width and height on sandcastle's ability to resist the erosion of waves and tides, and introduce the dynamic destructive force factor of waves and tides to find the best ratio of length, width and height of the cuboid sandcastle's prototype to resist the erosion of waves and tides. Therefore, we conclude that the sandcastle can last the longest when the ratio of length, width and height is 2:7:1. Based on the obtained failure function model of waves and tides, we further developed the water sand ratio failure prevention model. We take the different ratio of sand and water as the independent variable, and the life of sandcastle as the dependent variable, and use the failure function model to test. Through common sense, we exclude the experimental group with more water than sand. We find that the life of sandcastle increases first and then decreases with the increase of water content. When the water content is 30%, the life is the longest. Therefore, we get the best ratio of water and sand to prevent failure is 3:7. Next, we change the failure function of wave and tide into a new failure function of rainwater based on the original model. It is calculated that the life of sandcastle with different length, width and height affected by rain is the longest when the ratio of length, width and height is 2:5:3. Compared with the erosion effects of waves and tides, it can be seen from the new data that: firstly, almost all sandcastles lost about a quarter of their life, and the optimal ratio of length, width and height changes from 2:7:1 to 2:5:3, which shows that the damage of rain to flat and low foundation is more serious than the impact of waves and tides, so the foundation should be appropriately increased when affected by rain.

Keywords

Dynamic Damage Function Model; Anti-Damage Model; Sandcastle Durability.

1. Introduction

During the holiday, the activity of making sandcastle on the beach full of childlike fun also makes people relive the happy time of childhood and experience the joy between parents and children. As a result, sandcastles of different shapes appear on leisure beaches all over the world. From simple small houses to complex and delicate Castle models, they will inevitably be affected by the overturning of waves, the fluctuation of tides and the erosion of rainfall, as well as the proportion of water and sand used to build sandcastles themselves.

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However, it seems that under the influence of these factors, not all sandcastles react the same. So far, some factors affecting the life of sandcastle have been studied. For example, O'Shaughnessy, Lewis. [1] has studied the relevant changes of sandcastle in the air. Therefore, in order to extend the life of sandcastle better, we have carried out dynamic data research.

2. Failure Function Model of Wave and Tide

By studying the shape of sandcastle, we can assume that a large number of sandcastle shapes are formed by cutting and shaping a three-dimensional cuboid.

First of all, we analyze the influence of different ratio of length, width and height of sandcastle prototype on its ability to resist wave and tide erosion. Considering that the tide has a greater impact on the length and width of sandcastle prototype, but a smaller impact on the height. The wave has a greater impact on the height and a smaller impact on the length and width, so we determined the destruction coefficients of the tide T_{ijk} and the wave S_{ijk} on the length, width and height respectively.

Therefore, the following formula is obtained:

$$T_{ijk} = \frac{t\,(L + W + H)}{(0.4L' + 0.4W' + 0.2H')} \tag{1}$$

$$S_{ijk} = \frac{s\,(L + W + H)}{(0.3L' + 0.3W' + 0.4H')} \tag{2}$$

Explanation: t is equilibrium coefficient of tidal destructive force, s is equilibrium coefficient of wave destructive force, L is length of sandcastle without damage, L' is length of sandcastle after damage, W is width of sandcastle without damage, W' is width of sandcastle after damage, H is height of sandcastle without damage, H' is height of sandcastle after damage. In order to experience the characteristics that the tidal destructive force increases with the loss of sandcastle, we put the original length, width and height as a constant in the molecule, and the current length, width and height in the denominator, where {0.4, 0.4, 0.2} is a coefficient set for the purpose of experiencing the different reduction of length, width and height on the tidal destructive force. The specific weight is determined because the tide has a greater impact on the length and width of the sandcastle prototype, but a smaller impact on the height. The effect of waves on sandcastles is the opposite.

100 minus the total damage degree of sandcastle at present is equal to the remaining part of sandcastle. This part is divided by the whole. The product of the percentage times the original length, width and height is the current length, width and height of sandcastle. This relationship changes dynamically over time.

$$L' = \frac{(100 - D_{ijk})L}{100} \tag{3}$$

$$W' = \frac{(100 - D_{ijk})W}{100} \tag{4}$$

$$H' = \frac{(100 - D_{ijk})H}{100} \tag{5}$$

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Among them, D_{ijk} is the overall damage degree of Sandburg when the ratio of length, width and height is i: j: k.

According to the data [2], the wave is generated once in 0.5-25s on average, and the tide is generated twice a day, and the rising tide is delayed for 48 minutes in turn every day.

It is assumed that about 10% of the waves can reach the shore, with the initial time of 7:00, the first flood time of 8:00 and the second flood time of 20:24. We calculate one time of wave impact, and randomly generate a number from 5-250. Take this number as the interval time of two wave impacts, accumulate the damage caused by each wave, and accumulate the time in the time axis.

Then, we judge whether the time of rising tide is reached after the impact of this wave. If the time of rising tide is reached, add the damage value caused by a single tide, so as to cycle dynamically. When the overall damage degree of sandcastle reaches 100%, we think that sandcastle has been completely damaged. The Time_{ijk} is the survival time of sandcastle when the ratio of length, width and height is i: j: k.

$$D_{ijk} = n_1 T_{ijk} + n_2 S_{ijk} \tag{6}$$

Among them, n_1 and n_2 are the times of wave and tide impact respectively.

The overall damage degree of sandcastle prototype mainly comes from tide and wave, so we use the basic damage power of tide and wave to multiply the times of damage to sandcastle and add them to represent the overall damage degree, and the times of damage are determined by the time axis in our model.

We calculate the life span of sandcastle prototype under different length width height ratio, and find the best length width height ratio corresponding to the longest sandcastle life under the erosion of tide and wave. In order to express our conclusion more intuitively, vividly and clearly, we have made Figure 1.

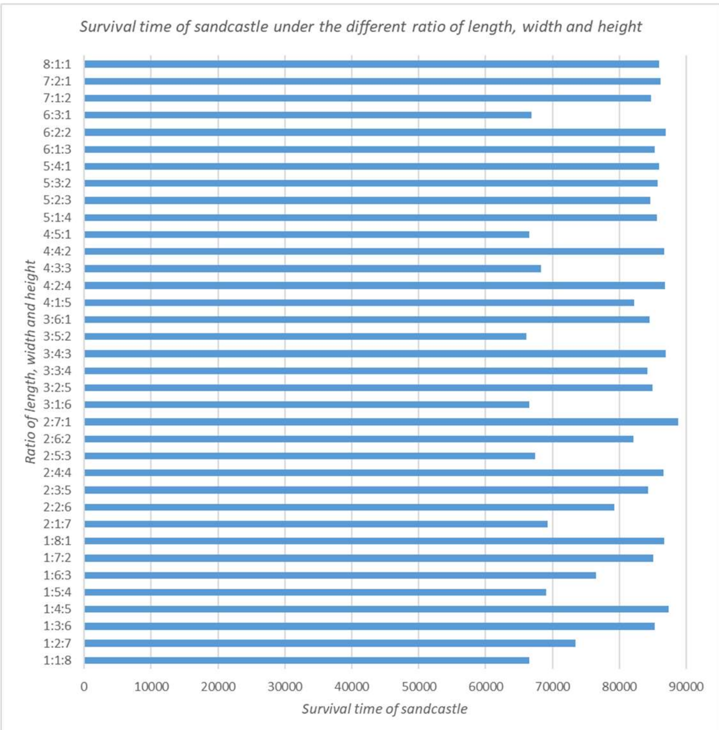

Figure 1. Survival time of sandcastle with different ratio of length, width and height

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From Figure 1, we can clearly see that when the length width height ratio of sandcastle prototype is 2:7:1, the life of sandcastle is the longest.

3. Anti-Damage Model for the Ratio of Sand to Water

In order to study the optimal sand-to-water mixture proportion, we use the optimal ratio of length, width and height to exclude the influence of different length, width and height on the research variables. We take the different ratio of sand and water as the independent variable, the life of sandcastle as the dependent variable, and use the failure function model established in the first question to test. Through common sense, we exclude the experimental group with more water than sand, and lock the range in the water content of 5%~50%, and each 5% is tested in a group. The water content is equal to the mass of water divided by the sum of the mass of water and the mass of sand. Finally, based on the obtained failure function model of waves and tides, we further developed the anti-damage model for the ratio of sand to water.

After querying the data [3], we get the following contents: Generally speaking, the soil is composed of three phases: solid phase (soil particles), liquid phase (soil water) and gas phase (soil gas). When the soil particle gap is completely filled by liquid phase, that is, when the proportion of water to soil gap is 100%, the soil is called saturated soil. On the contrary, the soil pores are filled by water and air, that is, when the saturation is less than 100 but more than 0, the soil is unsaturated.

It can be concluded that the sand water mixture belongs to unsaturated soil. We can think that the strength of sand Fort depends on the strength characteristics of unsaturated soil.

In the paper "interpretation and analysis of effective stress and related concepts in unsaturated soil" [4], we get that effective stress is the only state of stress that controls the deformation and strength change of soil. In the paper "study on the quantitative relationship between moisture absorption and moisture content of unsaturated soil" [5], we get that the moisture absorption is determined by the saturation angle and contact angle, which are the angle between soil particles in the micro state. And the saturation angle is related to the water content, which is the proportion of sand water mixture we need to find. Let the radius of soil particles be r, the contact angle be θ, the saturation angle be φ, the wet suction in macro state be p, the surface tension coefficient of water be σ, and the water content be ω.

Therefore, the following formula is obtained:

$$p = (\sigma/R)\sin(\theta+\varphi)(1-\cos\varphi)/\sin\varphi \tag{7}$$

$$w = 5(1-\cos\varphi)^2\,(2\cos\varphi+1)/3 \tag{8}$$

When the surface tension coefficient σ of water is equal to 73 × 10-3n/M and the radius of soil particle r = 0.1mm (sand), the quantitative relationship between moisture absorption and water content can be obtained by combining the above formula. Since the value of contact angle does not affect the change of final result, we might as well take θ = 10°. In this case, the relation of quadratic polynomial function corresponding to P is the following equation:

$$P = -0.0456w^2 + 2.7665w + 13.618 \tag{9}$$

In order to express the influence caused by different sand water ratio, we introduce P as the anti-damage coefficient, which mainly affects the destructive force of tides and waves. P depends on the moisture content.

The following new failure functions are obtained:

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$$T = \frac{tp\,(L + W + H)}{(0.4L' + 0.4W' + 0.2H')} \tag{10}$$

$$S = \frac{sp\,(L + W + H)}{(0.3L' + 0.3W' + 0.4H')} \tag{11}$$

After considering the ratio of sand to water, we multiply the calculated anti failure coefficient before the original formula to form a new calculation method.

$$D = n_1 T + n_2 S \tag{12}$$

We calculate the life of sandcastle prototype under different sand water ratio, so as to find the best water content corresponding to the longest life of sandcastle. In order to show the source of our conclusion more intuitively, vividly and clearly, we have made Figure 2.

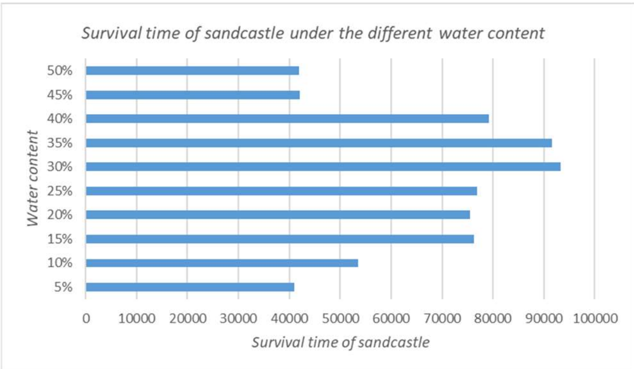

Figure 2. Survival time of sandcastle under the different water content

From the histogram, we can clearly see that with the increase of water content, the life of the sandcastle prototype increases first and then decreases. When the water content is 30%, the life of the sandcastle is the longest. The survival time is the longest, so we get the best water sand ratio of 3:7.

4. Failure Function Model of Rain

Compared with the failure function of the tide and wave, we think that the influence of rainfall on the length, width and height of the sandcastle prototype is approximately the same, so we get the failure coefficient of rainfall as follows:

$$R = \frac{r\,(L + W + H)}{(0.33L' + 0.33W' + 0.33H')} \tag{13}$$

R is the basic destructive force of tide. In order to reflect the characteristics that the destructive force of rainfall increases with the loss of sandcastle, we put the original length, width and height as a constant in the molecule, and the current length, width and height in the denominator. We believe that the reduction in length, width, and height have the same effect on the destructive power of rainfall, and therefore set the coefficient to 0.33.

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Since the damage coefficient of rainwater is added, we improve the judgment method of damage degree in the model based on the original damage model as follows:

$$D = n_1T + n_2S + n_3R \tag{14}$$

After the calculation method of rainfall destructive force is put forward, the overall damage degree of sandcastle prototype increases the damage caused by rainfall, so we still use the basic damage degree of tides, waves and rainfall multiplied by the number of damage to sandcastle respectively to represent the overall damage degree, and the number of damage caused is determined by the time axis in our model.

As shown in Figure 3, we calculate the life span of sandcastle prototype under different length width height ratio, and find the best length width height ratio corresponding to the longest sandcastle life under the erosion of tide, wave and rain.

$$max(Time_{ijk}) \tag{15}$$

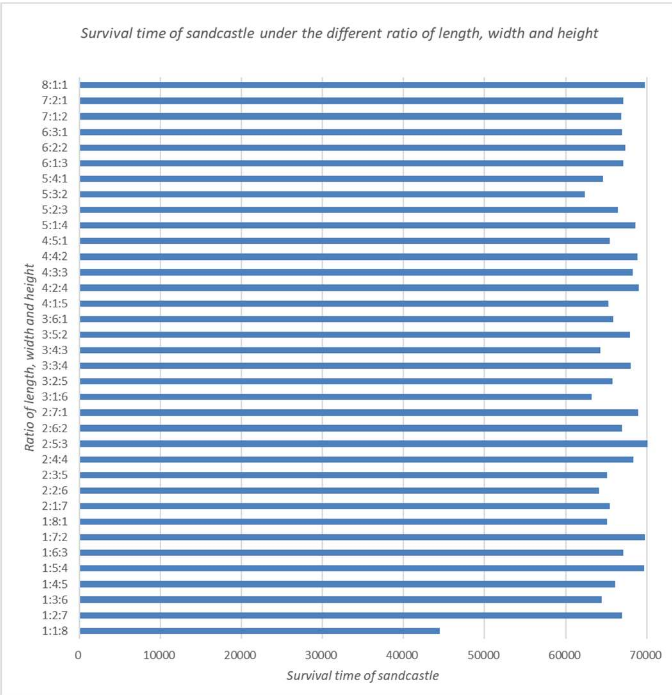

Figure 3. Survival time of sandcastle under the different ratio of length, width and height

From the new data, we can see that the overall survival time of sandcastle is reduced by about 1/4, and the optimal ratio of length, width and height is changed from 2:7:1 to 2:5:3, which shows that although the flat and low foundation can reduce the impact of waves and tides, it can promote the damage of rain, so the foundation should be appropriately increased when affected by rain.

5. Conclusion

In this paper, through the study of the shape data of sandcastle, we assume that a large number of sandcastle shapes are made of a three-dimensional cuboid by cutting and shaping. In order to avoid the erosion effect of waves and tides, we need to study the ability of sandcastle to resist the erosion of waves and tides, which is related to its own length, width and height. Therefore, we have established a dynamic model of wave tide failure function, introducing the dynamic damage factors of waves and tides respectively, and at the same time, using wave impact to push the time axis to roll, in order to find the best anti erosion ability of waves and tides.

Then, based on the obtained dynamic model of wave tide failure function, we further develop a water sand ratio model for preventing damage. The anti-damage coefficient is determined by the water sand ratio, so as to reduce the single attack power of waves and tides. In order to reduce the influence of the shape and volume of sandcastle on the study of the new model, we use the best length width height ratio, take the water sand ratio as an independent variable, compare the life of sandcastle, and finally get the best water sand ratio to extend the life of sandcastle.

Finally, in order to study the influence of rainfall on the prototype of sandcastle, we have determined a new damage coefficient of rainwater and improved the damage function. Then we use the optimal water content to eliminate the influence of different water content on the research variables. Compared with the failure function model of wave and tide, we use different length, width and height as independent variables, sandcastle life as dependent variables, and use the new damage function model to detect. The destructive force of waves, tides and rainfall on sandcastle is not constant. We have carried out dynamic analysis on it, so that the destructive force changes with the damage degree of sandcastle, which is more appropriate to the actual situation.

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