Stability analysis and improvement of coastal soft soil foundation

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Abstract. In the construction process of coastal buildings, how to improve the stability of the soft soil foundation of coastal buildings so as to increase its service life is always a problem that needs to be paid attention to and solved in the construction process. In Qingdao sea beach, for example, according to the force of the foundation, the foundation of the wave force and tidal forces modeling analysis, and puts it into the fluid - sand erosion simulation model, the soft foundation in the best shape of certain external environment, slow down the erosion of various kinds of flow strength of foundation. Finally, we conduct sensitivity analysis and conclude that our model has good stability.

Key words: coastal building; soft soil foundation; fluid erosion; optimal shape.

1. Research background and significance
In recent years, with the booming development of China's coastal construction industry, a large number of high-rise buildings and commercial complex projects have emerged. [1] However, due to the high groundwater level in coastal areas, the foundation soil is soaked by water all the year round, and there are often soft soil layers such as silty soil, sand and gravel in the foundation. [4]

Due to the low strength and poor anti-disturbance of soft soil layer, it is easy to cause foundation collapse and slip, so that it can’t meet the relevant requirements. [3] How to improve the stability of the soft soil foundation of coastal buildings so as to increase its service life has become a problem that needs to be focused on and solved in the construction process.[2] Considering the erosion effect of various fluid forces on the foundation, we can solve the best shape of the foundation by establishing a mathematical model, so as to increase its service life.

2. Model assumes
1. In actual production and life, reinforced concrete foundation is often used in buildings. In order to simplify the model and facilitate the analysis of its force and internal structure, sand foundation is used instead of reinforced concrete structure for modeling.

2. During the modeling process, it is assumed that the density of sand remains constant.

3. Assume that poured into sand waves force $F_{in}$ and waves rising wave force $F_{up}$ is proportional to the. Assuming that poured back into the sea wave force $F_{out}$ waves to the fall in the wave force $F_{down}$ approximation is proportional to the. In order to facilitate the analysis and establishment of the model, this paper takes the data of Qingdao Golden Beach as a reference.
3. Determine the base shape of the sand-base
We all know that a triangle is the most stable shape in two dimensions, and in three dimensions, the corresponding is a tripyramid. However, if the angular bisector of the pyramid is not symmetrical, the angular bisector will not be equal, which will lead to the failure of the component force of gravity to be consistent with the friction force, and the sand pile cannot be kept in balance. In addition, the inflow of waves and the rise of tides will erode the sand base from multiple directions, making it impossible to guarantee the stability of the sand pile. All angular bisectors of the cone are equal, which ensures that the force components of gravity are consistent with the force of friction, and it is easier to maintain balance even when subjected to forces from different directions. Our research target is sand-base, so we decided to choose the circular table as the basic shape of our research to study the optimal shape of sand-base. Then, to choose the best shape of the circular table is to determine \((r, R, h)\) of the circular table (where the upper surface radius \(r\), the lower surface radius \(r\), and the height of the circular table \(h\)).

4. Stress analysis of sand base
According to the investigation data, the factors that affect the stability of sand foundation in coastal areas are: tidal force, wave force, rainwater infiltration, impact level and so on. Therefore, the following analysis is made for the force of sand under different circumstances.

4.1. The periodic characteristic equation of tidal forces
According to the information, we know that the elevation of Qingdao Golden Beach is 2m, and there are semi-diurnal tides from May to September (four tidal peaks can occur every day). Since tides are a periodic natural phenomenon, we use the sine function to express the change in tide height.

There are two sea state factors to be simulated: tidal height and mass height.

1. Simulated tide: the simulated physical quantity of tide is its water level height, that is, the water pressure on the pressure sensitive surface is different at different tide heights. By calculating the pressure on the pressure surface at different tide heights, the tides at corresponding heights can be simulated and the counterweight of different masses can be prevented to replace the water level pressure on the pressure surface.

2. Simulated waves: waves are approximately sine waves, and their effect on the pressure sensitive surface is periodic. The waves at different heights exert different periods and different sizes of forces on the pressure sensitive surface. The two main factors for the action of waves with more than one period are the wave period and the force of waves on the pressure sensitive surface.

\[
F = S \times \rho \times g \times h
\]  
(1)

the \(S = \pi R^2/4. \rho = 1.025 \text{g/cm}^2, g=9.8 \text{m/s}^2, S, \rho \) and \(g\) to the tidal stress type can get on the \(F\), thus \(F_W \propto h\).

By referring to the four common tidal peaks in the Golden Beach a day, we finally obtained the expression formula of the tidal height at the Golden Beach in Qingdao:

\[
h = \begin{cases} 
420\sin\left(\frac{\pi}{3}t\right) & (0 \leq t \leq 6) \\
150\sin\left(\frac{\pi}{3}(t-6)\right) & (6 \leq t \leq 12) \\
420\sin\left(-\frac{\pi}{3}(t-12)\right) & (12 \leq t \leq 18) \\
30\sin\left(\frac{\pi}{3}(t-18)\right) & (18 \leq t \leq 24) 
\end{cases}
\]  
(2)

Since the elevation of Golden Beach is 2m, in order to more clearly study the influence of tide rise on sand base, we ignore the time when the tide height is less than zero, and get the tide change curve over time in a day as shown in the figure below:
4.2. The periodic characteristic equation of wave force

1. In terms of wave cycle theoretical calculation, there are no wave cycle calculation formulas that fully satisfy complex sea conditions at home and abroad. However, we obtained the empirical values of different wave cycles by referring to the materials. Among them, the observation data of the offshore sea waves are shown in Table 1-1.

| Wave height H/m | cycle T/s | Wave height H/m | cycle T/s | Wave height H/m | cycle T/s | Wave height H/m | cycle T/s |
|-----------------|-----------|-----------------|-----------|-----------------|-----------|-----------------|-----------|
| 0.3             | 2.1       | 2.5             | 6.4       | 5.0             | 9.2       | 7.5             | 11.5      |
| 0.5             | 2.5       | 3.0             | 7.0       | 5.5             | 9.6       | 8.0             | 11.8      |
| 1.0             | 4.0       | 3.5             | 7.6       | 6.0             | 10.2      | 8.5             | 12.3      |
| 1.5             | 4.8       | 4.0             | 8.0       | 6.5             | 10.7      | 9.0             | 12.6      |
| 2.0             | 5.6       | 4.5             | 8.5       | 7.0             | 11.0      | 9.5             | 13.0      |

2. At the same time, through the results of Zhang Song's research experiment "Fluent Simulation Calculation of Wave Force", we know that the impact pressure of waves on the pressure sensitive surface presents sinusoidal trend when waves rise and fall. However, due to the different amplitude of sinusoidal waves when rising and falling, in order to build a more realistic model, the wave impact force when rising and falling waves are independently drawn into sinusoidal curves.

3. By superimposing waves of different wave heights, we simulated the periodic relationship between wave force and time, as shown in the table below:

| phase rad | speed m/s | The acceleration m/s² | phase rad | speed m/s | The acceleration m/s² | phase rad | speed m/s | The acceleration m/s² |
|-----------|-----------|------------------------|-----------|-----------|------------------------|-----------|-----------|------------------------|
| π/6       | 0.68      | -0.62                  | 3π/4      | -0.56     | -0.88                  | 4π/3      | -0.40     | 1.07                   |
| π/4       | 0.56      | -0.88                  | 5π/6      | -0.68     | -0.62                  | 3π/2      | 0         | 1.24                   |
| π/3       | 0.40      | -1.07                  | π         | -0.79     | 0                      | 5π/3      | 0.40      | 1.07                   |
| π/2       | 0         | -1.24                  | 7π/6      | -0.68     | 0.62                   | 7π/4      | 0.56      | 0.88                   |
| 2π/3      | -0.40     | -1.07                  | 5π/4      | -0.56     | 0.88                   | 11π/6     | 0.68      | 0.62                   |

| phase rad | The pressure Pa | phase rad | The pressure Pa | phase rad | The pressure Pa | phase rad | The pressure Pa |
|-----------|-----------------|-----------|-----------------|-----------|-----------------|-----------|-----------------|
| π/6       | 235.2           | 2π/3      | -34.3           | 7π/6      | -80.8           | 5π/3      | 85.8            |
| π/4       | 160.4           | 3π/4      | -59.1           | 5π/4      | -58.8           | 7π/4      | 165.3           |
| π/3       | 85.5            | 5π/6      | -81.1           | 4π/3      | -33.9           | 11π/6     | 241.3           |
| π/2       | 0               | π         | -102.9          | 3π/2      | 0               | 2π        | 324.6           |

By superimposing waves of different wave heights, we simulated the cycle curve of wave force with time, as shown in the figure below:
4. In order to study the erosion of sand base by wave forces in the two conditions of flooding into the beach and rushing back to the sea. We divide the sand base into two parts: the seaward and the dorsal. The diagram is as follows:

![Fig. 3 Schematic diagram of sand base sea level and back sea level](image)

At the same time, the wave forces that erode the sand base are divided into the wave forces that rush toward the beach $F_{in}$ and the force of the waves rushing back out to sea $F_{out}$. For this reason, we introduce a correction factor $\zeta = 0.6$ and the force of the waves on Shakki:

\[
\begin{align*}
F_{in} &= \zeta_1 F_{up} \\
F_{out} &= \zeta_1 F_{down}
\end{align*}
\]

5. Establishment of fluid-sand erosion model

5.1. The correlation between erosion rate and fluid strength of sand pile was studied

In order to study the relationship between sand erosion and fluid force, we established the first kinetic equation of sand erosion by referring to the first kinetic equation of gypsum dissolution as follows.

\[
\frac{dm}{dt} = KA(cs-c)
\]

$m$ (kg) on behalf of t(s) for the quality of the grains of sand to dissolve, $K$ (m/s) said the first kinetic constants, $A$ ($m^2$) contact with the fluid surface area of the sand, $cs$ (kg/m$^3$) fluid saturated sand concentration (we approximate assumption of sand density remains constant), $c$ (kg/m$^3$) the concentration of the fluid in the sand in time, is the first kinetic constant $K$.

Different environmental conditions (temperature, flow rate, etc.) affect the dissolution of sand by affecting one or more of the parameters in the above equation. The increase of fluid velocity mainly leads to the decrease of boundary layer thickness and thus accelerates the loss. The magnitude of the wave force is proportional to the velocity. Therefore, we conclude that the erosion rate of sand castle foundation is positively correlated with the size of fluid force. A sand erosion rate $\nu(cm^3/s)$, and the flow of physical $F(N)$, flow energy loss coefficient, $\zeta$ the available formulas:

\[
\nu = F \times \zeta
\]

5.2. Fluid-sand erosion simulation model

(1) According to the information, the general radius of the low surface of a sand castle is about 0.5m. In order to ensure the bearing capacity of the circular platform, we assume that when the upper surface
radius of the circular platform is less than 0.5m, the default is that the circular platform cannot bear the sand castle and the sand base collapses. \( r \geq 0.5 \text{m} \)

(2) Taking into account the erosion of the bottom of the sand castle foundation by tidal and wave forces, we assume that the height of the soft soil foundation will gradually decrease, and when the height is zero, the sand foundation will collapse, \( h > 0 \). Therefore, we use Java to build a simulation model of fluid-soft soil foundation erosion as follows:

![Flow chart of soft soil foundation simulation](image)

**Fig. 4** Flow chart of soft soil foundation simulation

### 5.3. Java simulation based on tide-wave model and rainwater infiltration impact dynamic model

Then on the basis of the first question, combined with the tidal wave model and the rainwater infiltration and impact dynamic model, the two models were used to accurately test the structure's anti-destruction performance, and the sand castle foundation model with the longest persistence time or the least damage degree was found.

![Schematic diagram of input data of fluid-sand erosion simulation model](image)

**Fig. 5** Schematic diagram of input data of fluid-sand erosion simulation model

Finally, the optimal solution is obtained:

![Evolution diagram of optimal multi-force combination model](image)

**Fig. 6** Evolution diagram of optimal multi-force combination model
6. Conclusion
According to the sensitivity analysis and the tidal-wave model dynamic model established meet the following performance:

(1) Through the analysis of the compressibility and bearing capacity of soft soil foundation, when similar problems are encountered in the project, the conclusions obtained in this paper can be fully and reasonably used, so as to effectively improve the strength of soft soil foundation.

(2) The tide-wave model dynamic model is used as the prototype of the foundation to effectively solve the problem of poor anti-disturbance, and it can greatly improve the permeability of the original soft soil foundation.

References
[1] Jiang zengjie, Fang jianguang, Menqiang. Determination of seawater velocity by gypsum method [C]. China Marine limnology society, shellfish science branch of Chinese zoological society.
[2] Zhang song. Research on flexible fixation system for buoy wave power generation device [D]. Harbin Institute of Technology, 2013.
[2] Lu yehong. Test simulation of damage resistance of building roof structure in rainy season [J]. Computer simulation, 2008, 35 (12): 176-180. (in Chinese)
[3] Liu lu, Sun jian, Yuan bing, Lin binliang. Study on surface water accumulation in urban rainstorm: a case study on the campus of tsinghua university [J]. Journal of hydroelectric power, 209,38 (08): 98-109. (in Chinese with English abstract)