The analysis of Stability reliability of Qian Tang River seawall

Xue-Xiong Wu\textsuperscript{1,2}

\textsuperscript{1}Zhejiang Key Laboratory of Water Conservancy Disaster Prevention and Reduction, Zhejiang Institute of Hydraulics & Estuary, Hangzhou, 310020, China
\textsuperscript{2}Zhejiang Guang Chuan Engineering Consulting Co., Ltd., Hangzhou, 310020, China

Abstract: Qiantang River seawall due to high water soaking pond by foreshore scour, encountered during the low tide prone slope overall instability. Considering the seawall beach scour in front of random change, using the simplified Bishop method, combined with the variability of soil mechanics parameters, calculation and analysis of Qiantang River Xiasha seawall segments of the overall stability.

1. Introduction
Qiantang River seawall is an important defense against wind and tide estuary area for the purpose and the construction of social infrastructure, but also to prevent the invasion of the land storm surge barrier. Qiantang River seawall due to poor geological conditions, less dense, long dike by high water level and the means of soaking by erosion and other reasons, prone to overall instability, the long-term high water soaking pond by scour and foreshore in low tide the slope overall instability is Qiantang River instability of the main seawall form.

The calculation method of overall stability of seawall are the main strip method and limit equilibrium method, and a method commonly used in engineering practice, a method of Sweden method and Bishop method are the two forms of\textsuperscript{[1]}. The Bishop method is smaller than the Swedish method due to the force acting on the side of the soil bar, while the simplified Bishop method is the most common method for the calculation of soil slope stability. At present, the overall stability reliability analysis of embankment is usually calculated by the slice method, taking into account the variability of soil mechanical parameters\textsuperscript{[2,3]}.

2. Integral stability reliability analysis theory
Bishop method\textsuperscript{[5]} assumes that the slip resistant safety coefficients of the sliding surfaces at the bottom of each soil strip are the same, which is equal to the average safety factor of the entire sliding surface. Figure 1 is the Bishop method for computing the schema. It is assumed that the center of the sliding surface is O and the radius is R. Take a soil strip I, the acting force on it has the weight of the soil bar; the shear resistance, the effective normal reaction force and the pore water stress acting on the bottom of the soil bar; it is assumed that the action points of these forces are at the midpoint of the bottom of the soil strip. In addition, both normal and tangential forces are applied to both sides of the soil bar.
Take $i$ slices of the vertical force balance and the sliding mass on the center $O$ for torque balance, and the individual slices were equal to 0, can be obtained, analysis of the overall stability of seawall safety coefficient formula for simplified Bishop method

$$F = \frac{M_R}{M_S} = \sum_{i=1}^{n} M_{Ri} \sum_{i=1}^{n} M_{Si} \frac{\sum_{i=1}^{n} [bc_i + \left(W_i - u_i b\right) \cdot \tan \phi_i] \cdot \frac{1}{m_{ai}}}{\sum_{i=1}^{n} (W_i \sin \alpha_i)}$$

In the formula, $m_{ai} = \cos \alpha_i + a_i \sin \alpha_i \cdot \tan \phi_i$, $b$ for the width of each soil.;

The function of the stability analysis of embankment reliability generally used anti sliding moment and sliding torque difference\textsuperscript{[2]} or anti sliding and sliding moment logarithmic\textsuperscript{[3]} torque ratio, torque and torque due to sliding sliding ratio is the safety factor, the physical concept is strong, and the study of\textsuperscript{[6]} showed that the probability density function and the logarithm the normal distribution, which can meet the accuracy requirement of seawall stability analysis. Therefore, the function function used in this project is

$$g(X) = \ln\left(\frac{M_R}{M_S}\right) = \ln M_R - \ln M_S$$

The reliability index can be calculated by pressing type\textsuperscript{[7]}

$$\beta = \frac{\ln\left(\frac{\mu_{M_R}}{\sigma_{M_S}} \cdot \frac{\sqrt{1 + \delta_R^2}}{1 + \delta_S^2}\right)}{\sqrt{\ln\left(1 + \delta_R^2\right)\left(1 + \delta_S^2\right)}}$$

$$\delta_R = \sqrt{\text{Var}(M_R)}/\mu_{M_R}, \quad \delta_S = \sqrt{\text{Var}(M_S)}/\mu_{M_S}, \quad M_R \text{ and } M_S \text{ are the Coefficient of variation.}$$

The function of overall stability of seawall is a complicated function of the basic random variables, the distribution of soil parameters are difficult to determine and the elevation of geometric random variables as Tang foreshore conditions, simple calculation, using the mean first order two moment method to calculate\textsuperscript{[7]}:

$$Z \approx g(\mu_x, \mu_x, ..., \mu_x) + \sum_{i=1}^{n} (x_i - \mu_x) \cdot \frac{\partial g}{\partial x_i} \bigg|_{x_i=\mu_x}$$

The corresponding mean and variance are
\[
\mu_Z = g(\mu_{x_1}, \mu_{x_2}, \ldots, \mu_{x_n})
\]

\[
\text{Var}(Z) = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\partial g}{\partial x_i} \left. \frac{\partial g}{\partial x_j} \right|_{x_i=\mu_{x_i}, x_j=\mu_{x_j}} \cdot \text{Cov}(x_i, x_j)
\]

\[
= \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\partial g}{\partial x_i} \left. \frac{\partial g}{\partial x_j} \right|_{x_i=\mu_{x_i}, x_j=\mu_{x_j}} \cdot \rho_{x_i,x_j} \cdot \sqrt{\text{Var}(x_i) \cdot \text{Var}(x_j)}
\]

For any soil bar

\[
\mu_{\text{M}_S} = \mu_w \sin \alpha = \mu_f \cdot \mu_v \cdot \sin \alpha
\]

\[
\text{Var}(M_S) = \mu_f^2 \cdot \sin^2 \alpha \cdot \text{Var}(\gamma) + (\mu_f \cdot \sin \alpha)^2 \cdot \text{Var}(h)
\]

The most dangerous slip surface is determined by layer 0.618 optimum method [8]. The selected coordinate Y two initial \([y01 \text{ first, } y02] \) arc and cut into the soil to calculate reliability index and initial value, then \(y1 = y01 + 0.618 \cdot (y02 - y01)\), the reliability index can be calculated using the same method to determine the reliability index corresponding to small interval where the center point of the sliding surface. Repeat the above calculation process and gradually reduce the ordinate search range until the minimum Y value and the arc arc corresponding to the minimum reliability index value are found.

In order to achieve the overall stability of the reliability calculation of the elevation of random variables after the Tang foreshore seawall, the Tang Foundation (or pile lateral caisson) as a soil bed alone in calculation, calculate the depth range is determined by the most dangerous sliding arc to cut the depth of the pond foreshore. Qiantang River seawall riverbed is generally thick silt depth, small change of soil parameters can be combined with the distribution of soil should be based on the deep range in consideration of actual calculation.

3. The analysis of Overall stability reliability

According to 1/50000 in the past 40 years Daoshui River topographic map and several 1/10000 topographic map statistics, and the movable bed mathematical model calculation results, the correlation analysis of elevation and elevation of main foreshore pond, the pond before the final recommendation for the elevation of [4]: Tang foreshore elevation is 2.0m in average, \(p=1\% \) height is 0.1M, height \(p=0.2\% \) -1.5m. Calculation parameters are shown in table 1.

| Number | soil layers         | \(\gamma/\text{kN/m}^3\) | \(C/\text{kPa}\) | \(\varphi(\degree)\) |
|--------|---------------------|---------------------------|-----------------|-----------------------|
| 1      | silty clay fill     | 18.4 (0.061)              | 8.4             | 20.09                 |
| 2      | sandy silt, clayey | 19.2(0.026)               | 8.4(0.160)      | 21.07(0.032)          |
| 3      | sandy silt         | 19.7(0.013)               | 8.4(0.202)      | 23.59(0.038)          |
| 4      | silt sand, sand    | 19.7(0.028)               | 9.8(0.262)      | 23.52(0.074)          |
| 5      | clay containing silt| 19.0(0.020)            | 9.1(0.196)      | 21.98(0.085)          |
| 6      | silty silt clay    | 18.2(0.023)               | 12.6(0.245)     | 16.73(0.257)          |
| 7      | silty clay         | 17.6(0.132)               | 14.7            | 12.53                 |

Note: the numbers in a table represent the mean of a variable (coefficient of variation)

The correlation coefficient of each soil parameter calculation assumed respectively, and the elevation of the foreshore, take the Tang standard deviation is 4.38, and consider two different level combinations: (1) the water level from 10.18m to 5.58m, the average low tide, the water level in the underground water level 6.50m; (2) the water level by the mean high tide 6.27m fell.
to 20 year low tide 3.43M, the water level of underground water from 6.50m; and different elevation of Tang foreshore: 3.0m, 2.0m, 0.1m, -1.5m. The calculation results are shown in table 2.

The factors of influence on overall stability of seawall reliability, of these factors (mainly the variability of each variable) by sensitivity test. With the combination of water level (2), the mean elevation of the Tang foreshore take 1.5m as an example, the safety factor with the Swedish law and law obtained were 1.36, 1.47.

Table 2 overall stability safety factor, reliability index and failure probability

| Working condition | h/m | F algorithm of Safety factor | \( \beta \) | \( P_f \) |
|-------------------|-----|-------------------------------|-----|-----|
|                   |     | Swedish law | BISHOP |     |     |
|                   | 3.0 | 1.62 | 1.77 | 5.52 | 0.17 \times 10^{-7} |
| Water level       | 2.0 | 1.53 | 1.65 | 5.34 | 0.48 \times 10^{-7} |
| combination (1)   | 0.1 | 1.38 | 1.45 | 4.83 | 0.69 \times 10^{-6} |
|                   | -1.5| 1.26 | 1.33 | 4.07 | 0.24 \times 10^{-4} |
|                   | 3.0 | 1.50 | 1.62 | 5.18 | 0.11 \times 10^{-6} |
| Water level       | 2.0 | 1.40 | 1.53 | 4.91 | 0.46 \times 10^{-6} |
| combination (2)   | 0.1 | 1.25 | 1.33 | 4.22 | 0.12 \times 10^{-4} |
|                   | -1.5| 1.13 | 1.18 | 3.22 | 0.64 \times 10^{-3} |

The water level in the combination (2) conditions, when the Tang foreshore with the same variance of 29.9, with the mean elevation of Tang foreshore improved, stable and reliable index of the overall change of seawall as shown in table 3.

Table 3 the overall stability coefficient and reliability index

| h/m | Safety factor F algorithm | \( \beta \) |
|-----|---------------------------|-----|
| 3.0 | 1.50 | 1.62 | 4.148 |
| 2.0 | 1.40 | 1.53 | 3.931 |
| 0.1 | 1.25 | 1.33 | 3.369 |
| -1.5| 1.13 | 1.18 | 2.559 |

Table 4 the overall stability coefficient and reliability index

| Multiples of the mean of the original friction angle | Safety factor F algorithm | \( \beta \) |
|----------------------------------------------------|---------------------------|-----|
| 0.1 | 0.45 | 0.50 | -8.287 |
| 0.3 | 0.75 | 0.85 | -1.579 |
| 0.5 | 1.06 | 1.13 | 2.191 |
| 0.7 | 1.36 | 1.47 | 3.983 |
| 0.9 | 1.68 | 1.82 | 4.616 |
| 1.1 | 2.05 | 2.22 | 4.628 |
4. conclusion
Based on the analysis of overall stability of embankment on the previous reliability, combined with the characteristics of Qiantang River, by introducing a flat level in front of the seawall as random variables and established the overall stability of seawall safety analysis model, analyzes the factors of Xiasha seawall overall stability reliability and its influence. The following conclusions can be obtained:

(1) when the elevation of Tang foreshore mean 2.0m standard deviation is 4.38M, the whole of Xiasha seawall stability index beta value is 4.91, the failure probability is 0.46 * 10^-6.

(2) with the same standard deviation, with the elevation of Tang foreshore (mean) to reduce the overall stability coefficient will decrease, the reliability index also decreases.

(3) to take measures to improve the foreshore of seawall elevation, increasing the overall stability of seawall is the most important measure.

Reference
[1] Gao Dazhao. Reliability principle of soil mechanics [M]. Beijing: China Construction Industry Press, 1989.
[2] Fan Kexu, Zhu Yonghua. The middle reaches of the Yangtze River flood control dike typical slide instability risk analysis of water conservancy and Hydropower [J]. letters, 2002 (21): 15-17.
[3] he Da Wan, Yang Bin. Probabilistic analysis of seismic stability of sea wall [J]. marine engineering, 1995, 13 (1), 62-69.
[4] Qian Tang River, three fort to Shore Beach stability analysis, Zhejiang estuary and Coastal Research Institute technical report, 1998.
[5] Qian Jia Huan [5]. Soil mechanics [M]. Nanjing: Hohai University press, 1988.
[6] R.N.Yong, E.Alonso, and, M.M., Tabba., Application of Risk Analysis to the Prediction of Slope Instability, [J].1977,14., Canadian Geotechnique
[7] Wu Shiwei. Structural reliability analysis [M]. Beijing: People's Communications Press
[8] Zhang Nailiang, Sun Li. Optimization method [M]. Ji'nan: Shandong University press, 1995.
[9] Wang Zhuofu, Zhang Zhiquiang, Yang Gaosheng. Discussion on structural risk calculation model of flood control [J]. Chinese Journal of water conservancy, 1998 (7): 64-67.
[10] Wu Xingzheng, Ding Liqian, et al. Discussion on reliability design method of levees [J]. Journal of hydraulic engineering, 2003 (4): 94-100.
[11] Wang Weibiao [11], South Korea had extracted, Jin Weiliang. Qiantang River seawall reliability analysis of overall stability [J]. Journal of Zhejiang University, 2002 (4), 366-370.
[12] Wang Weibiao, Liang Guoqian, Han had extracted. The overall stability of seawall on estuary. The Qiantang River national environmental geotechnical engineering and geosynthetics technology seminar set, 2002.11323-329.
[13] Weibiao Wang, Zengcui Han&Guoqian Liang., Safety Analysis of Overall Stability of Qiantang Estuaty Seawall, ICEC-2003471-475.