Influences of Beach Replenishment on Seawall Engineering

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Abstract. At present, the number of natural beaches is decreasing due to the damage caused by coastal development of coastal cities. At the same time, the influence of beach replenishment on seawall engineering becomes clear. There are several kinds of analysis on stability, subsidence, seepage, structure of the seawall engineering and analysis on safe operation and daily management of the sluice engineering based on a beach replenishment project in this paper. Some compensation measures are proposed based on the influence mentioned earlier.

1. Introduction
Higher requirements for tourism space are proposed with the economic development in coastal areas in recent years. The coastal coast is mainly muddy beach which can not meet the needs of tourists for leisure and recreation due to the influence of suspended sediment entering the sea and the destruction of natural beaches caused by human activities. More and more coastal cities commitment to improve grade of beach to enhance the coastal tourism and leisure functions. There is a closed circle against the tide along the coast to protect public safety at present, and the beach replenishment will affect the coastal seawalls engineering inevitably.

This paper is mainly about influences of beach replenishment on seawall engineering and compensation measures needed to be adopted due to these influences[1].

2. Theoretical analysis methods
2.1. Stability analysis method
Sweden slice method is advocated in the stability analysis. The penetrability in seepage zone is simplified as an alternative unit weight based on Code for design of sea dike project. The formula is as follows:

\[ K = \frac{2R[(r_0 - \lambda_y)\theta + \lambda b] + \sum(c_i L_i + W_i \cos \alpha_i tg \phi_i)}{\sum W_i \sin \alpha_i} + T \]  (1)

In the formula:
- \( L_i, W_i \) — Length and weight of the soil strip;
- \( C_i, \phi_i \) — Shearing strength of the soil;
- \( \alpha_i \) — The intersection of normal and vertical lines;
- \( T \) — Design strength of geotextiles;
R——Radius of the sliding arc;  
τ₀——Intercept of the intensity curve;  
λ——Slope of the intensity curve.

2.2. Calculation conditions
The calculation condition is divided into the construction period and the normal running period. Natural four-bladed vane index is adopted as the strength of foundation in the different calculation conditions. Reserved settlement and construction load of filling sand in front of bank should be considered in the calculation.

2.3. Shear strength index
1. Filling material of the seawall engineering which is mainly composed of block stone and gravel: 
\[ r=18.6\text{KN/m}^3, \quad r_{sat}=21\text{KN/m}^3, \quad r'=11\text{KN/m}^3, \quad C=0\text{KPa}, \quad \varphi=40^\circ. \]
2. New filling material for scaling and strengthening which is mainly composed of clay: 
\[ r=16.6\text{KN/m}^3, \quad r'=6.6\text{KN/m}^3, \quad C=8\text{KPa}, \quad \varphi=2.5^\circ. \]

3. The engineering example
Artificial backfill sand is used to expand beach scale through setting some hydraulic structures to adapt the evolution characteristics of coastal beach dynamic geomorphology combined with construction requirements in a beach restoration project. The form of new shoreline is built by beach reclamation combined with hydraulic structures and drain culverts based on artificial revetment. Total length of repair shoreline is 1165m. Layout of beach restoration is shown in Fig. 1:

![Figure 1. Layout of beach restoration](image)

Width of beach shoulder is about 45m. The top elevation of the beach shoulder is set to 4.60~4.00m and the slope of the beach faced to sea is set to 1:10. Typical beach section is shown in Fig. 2:

![Figure 2. Typical beach section](image)
4. Influences of beach replenishment on seawall engineering

4.1. Stability influences of beach construction

Sweden slice method is advocated in the stability analysis. Present safety factor $K_1$ and finished safety factor $K_2$ of seawall are shown in Table 1:

| Position          | $K_1$ | $K_2$ | Remarks                                                  |
|-------------------|-------|-------|----------------------------------------------------------|
| Inside completion | 1.15  | 0.93  | Stability factor is reduced after the completion of the beach, cannot meet the requirements. |
| Operation         | 1.28  | 0.99  |                                                          |
| Outside completion| 1.38  | 2.06  | Stability factor is improved after the completion of the beach, can meet the requirements.      |
| Operation         | 2.41  | 2.53  |                                                          |

Beach construction is beneficial to the stability of the outside embankment. The safety factor of inside stability decreases after beach construction and the safety factor is less than value required in the standard.

4.2. Settlement influences of beach construction

New settlements of embankment on each section after beach construction are shown in Table 2.

| Sections                | A  | B  | C  |
|-------------------------|----|----|----|
| Outside of beach shoulder| 137| 173| 102|
| Center of beach shoulder | 123| 167| 101|
| Inside of beach shoulder | 110| 128| 92 |
| Seawall top              | 36 | 49 | 28 |
| Inside first stage platform | 6  | 15 | 4  |

After beach construction, the maximum settlement of the seawall top is 49cm, the maximum settlement of the inside first stage platform is 15cm, the maximum settlement of the inside of beach shoulder is 128cm, the maximum settlement of the center of beach shoulder is 167cm, the maximum settlement of the outside of beach shoulder is 173cm. The difference between the elevation after settlement and the design value is large, which is unfavourable to the dampproof.

4.3. Seepage influences of beach construction

The height of the anti-seepage body should be higher than 5% high tide level 0.5m to ensure seepage stability of the seawall according to specification. Considering the settlement of the seawall and the additional settlement caused by the beach load, the top height of the wall is 6.55~7.26m, the top height of the dam is 5.55~6.26m, the top height of the anti-seepage body is 5.10~5.81m. The top height of the anti-seepage of each section meets the requirements after the settlement.

4.4. Structural influences of beach construction

Concrete protective surface and top pavement will crack due to new settlements, and dyke scouring is unfavorable to the safety of the seawall structure. Cracks on the top of the embankment may aggravate if traffic volume increases after beach construction. In addition, the construction vehicle needs to break wall of the seawall which will destroy embankment structure.
4.5. Sluice operation influences of beach construction
There will be serious siltation before sluice because the sand bar is close to the sluice after beach construction. The outflow submergence degree will be affected accordingly at the same time of siltation. Siltation will weaken the flow capacity and drainage of the sluice.

The siltation of the sluice will raise the downstream water level, and the most unfavorable condition is no water under the sluice. Downstream of the sluice will be raised to the depth behind the sluice if the offshore side is silted up to 0.8~0.9m. The current energy dissipation and erosion control facilities of the sluice can meet the requirements after the siltation of the sluice. [5-6]

5. Design of compensation engineering

5.1. Mixing Pile method to reinforced foundation at the foot of seawall
Stability of the seawall is reduced after beach construction. Stability of the seawall should be increased to meet the specifications by setting mixing pile (diameter 0.6m, spacing 1.1m, depth 12m). After reinforcement, Safety factor in completion period is 1.09 and finished safety factor in operation period is 1.19, both meet the specifications. Reinforcing section of mixing pile is shown in Fig. 3:

![Figure 3. Reinforcing section of mixing pile](image)

5.2. Restoration of revetment and drainage system
Concrete protective surface and top pavement will crack due to new settlements. Re-pouring of concrete face protection structure is implemented after removing cracked concrete face slabs along cracks in order to prevent levee from being washed away. Observation and maintenance should be strengthened during the operation period. In addition, the opening of the breakwater wall must be repaired according to the original design before the flood season after beach construction.

5.3. Seawall heightening
The maximum settlement of the seawall top is 49cm after beach construction. The top of seawall should be heightened according to the original design due to the new settlements of embankment. In addition, it is necessary to restore the upstream compression layer according to the original design because the settlement of seawall which is very disadvantageous to the anti-sliding stability of the water-facing side.

5.4. Silt cleaning outside the sluice
Both sluices have silting tendency outside the sea after beach construction. Sluices should take steps to prevent siltation and discharge sediment to ensure safe operation. The construction unit shall clear silt at the offshore side of the sluice every six months from the beginning of beach construction to completion.

6. Conclusions
(1) The safety of anti-sliding stability at the back of the seawall decreases after beach construction. Additional settlement of seawall caused by beach load is harmful to damp-proof. There will be adverse effects on the seawall structure after beach construction.

(2) Siltation is unfavorable to the safe operation of sluices after beach construction.
(3) The seawall and sluice are running well after the compensation project mentioned is implemented, in view of the above influence of the observation data.

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