Stability analysis and repair of a garbage dam

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Abstract. Garbage dam is an important structure of sanitary landfill, but there is no systematic stability calculation method at present. In this paper, the present situation of a garbage dam is investigated in detail, and it is found that the local settlement of the dam body is large, and there is the possibility of instability. Then, the soil samples were collected from the dam body and the indoor geotechnical tests were carried out. Based on the test data, the GEO-SLOPE software is used to carry out the numerical simulation analysis of the garbage dam. The results of the numerical analysis show that the safety factor of the garbage dam does not meet the requirements of the code, and there is a risk of instability. In view of the problems existing in the dam body, this paper puts forward the solutions for the reinforcement of the dam body, which effectively eliminates the problems of Seepage Damage and crack damage. The results show that the numerical analysis is correct and the reinforcement effect is effective.

1. Introduction
With the rapid growth of economy, the discharge of municipal solid waste is increasing, and the construction of treatment and disposal facilities is lagging behind[1]. The environmental pollution caused by municipal solid waste is becoming more and more serious. As the main means of municipal solid waste treatment, sanitary landfill technology has been widely used at home and abroad in recent years[2]. The so-called sanitary landfill method is that the environmental sanitation department transports the collected municipal solid waste to the landfill site, paves it in the landfill area with the thickness of (2.5 ~ 3.0) m for each layer, then carries out mechanical compaction, and then paves it with (15 ~ 30) cm clay layer and compacts it again to form a complete daily landfill soil layer unit. A complete sanitary landfill site is composed of several to dozens of such layers Daily landfill unit composition.

Garbage dam is a necessary facility of domestic waste landfill. Its main function is to maintain the stability of waste heap in the landfill area, increase the effective storage capacity of the landfill area, prevent the waste from being washed out of the landfill area in case of heavy rain, orderly drain the leachate from the landfill area and act as a connecting channel inside and outside the landfill[3].

2. Project Overview
A waste disposal site occupies an area of 13 hectares, with a valley length of 400m, a width of 64m, and a storage capacity of 460,000 m3. The main landfill in the reservoir is domestic waste. The designed garbage dam type is sandy soil clay dam, which is filled in layers. The dam crest elevation is 90m, the dam bottom ground elevation is 69m, and the maximum dam height is 21m. The dam crest is 4m wide, the dam crest length is 95m, the designed upstream slope ratio is 1:2, and the downstream slope ratio is 1:2. There is a 3m wide horse track at the 82m elevation of the upstream and downstream slopes. The typical section of the garbage dam is shown in Figure 1. The dam foundation is the undisturbed fully weathered soil layer after the foundation is cleared. There is a retaining dam in the upstream of the
garbage disposal site, and a flood interception ditch is set around it. The rainwater collected in the upstream area is discharged to the downstream drainage ditch of the garbage dam through the flood drainage concealed pipe under the retaining dam. A groundwater collection pipe is laid under the anti-seepage membrane in the landfill, and its direction is basically the same as that of the flood drainage concealed pipe. The groundwater under the membrane in the landfill is collected and discharged to the downstream of the garbage dam. There is one in the upstream and downstream of the landfill Water quality monitoring wells.

Figure 1. Typical section of garbage dam (maximum dam height)

3. Investigation of the status quo of garbage dams
Through investigation, the waste disposal site has hidden environmental and safety hazards, mainly as follows:

3.1. The anti-seepage system in the reservoir area has been damaged and leaked. The current groundwater monitoring wells have detected the diffusion of leachate pollution, which has caused the pollution of groundwater, surface water and the surrounding environment.

3.2. Landfill gas is not effectively collected, guided and discharged
The gas guide wells set up in the garbage disposal site are not constructed in accordance with relevant national standards and regulations. The depth of the gas guide wells is insufficient. The biogas generated in the garbage can not be effectively collected and discharged. A large amount of smoke pollutes the atmosphere.

3.3. Uneven settlement of the main garbage dam
According to the site survey, the current garbage main dam has undergone uneven settlement and deformation, the dam crest elevation is inconsistent, the dam crest pavement is uneven, and many vertical and horizontal cracks can be seen. The settlement deformation of the main garbage dam will cause tension on the weld at the junction of the leachate through the dam pipe and the HDPE membrane. If the tensile deformation value is too large, the weld at the junction between the leachate through the dam pipe and the HDPE membrane will be destroyed and fill The anti-seepage system in the buried reservoir area failed.

At present, the garbage in front of the dam has been piled up to 0.5m~1.0m above the crest of the garbage dam, and the brick drainage ditch set at the foot of the slope of the garbage pile on the upstream dam surface has also been covered, as shown in Figure 2. Due to uneven deformation near the entrance, the top of the dam has tilted toward the upstream side, with a local slope of 2.5%. When it rains, the phenomenon of local water accumulation on the top of the dam is obvious. Most of the rainwater collected at this location seeps into the garbage dam. Reduce the safety of the dam.
Figure 2. Status of garbage stacking in the warehouse

According to the on-site elevation measurement results, the settlement and deformation distribution of the dam crest is shown in Figure 3. Compared with the highest point of the dam crest at the entrance (point 1), the lowest point (point 29) on the cement pavement of the dam crest is 93 cm lower than the highest point. If you consider the pavement here in the past few years to recover the original settlement pavement foundation, the maximum settlement deformation here exceeds 100 cm. There is no obvious settlement and deformation below the horse track.

Figure 3. The results of dam crest settlement and deformation measurement

The downstream dam face of the garbage dam at the position of maximum settlement also has obvious sinking phenomenon, and there is obvious uplift of the dam face block stone at the position above the horse track, as shown in Figure 4. Based on the analysis of the above phenomena, the garbage dam at this location has obvious signs of sliding failure, as shown in Figure 5. This judgment was also verified during the drilling and sampling process where the settlement and deformation of the dam crest were obvious. The soil samples in the depth range of about 5 m were loose and saturated, and there was obvious water accumulation in the dam body in this depth range.

Figure 4. Block uplift of the dam surface above the horse track
4. Stability analysis

4.1 Stability analysis method

According to the relevant regulations in the "Technical Specifications for Sanitary Landfill Treatment of Domestic Waste" GB 50869-2013, the dam stability analysis adopts the simplified Bishop method and the Morganston-Pryce method that take into account the forces between the bars[4].

The simplified Bishop method and Morganston-Pryce method are developed based on the Swedish arc method. The basis of the Swedish circular sliding method is to assume that the potential sliding surface is a circular arc, and the soil within the sliding surface is regarded as an ideal plastic body. The stability analysis is to try a series of circular sliding on the dam or foundation (soil foundation). Cracked surface. As a plane problem, analyze the stability of the rotation of the soil in these arcs around the center of the circle. For the convenience of specific calculations, the slice method is usually used. The "equivalent moment method" is generally used to calculate the influence of seepage water pressure in sliding soil on the stability of the dam slope. The shear strength of the fractured surface of the soil is in accordance with the Mohr-Coulomb strength criterion[5].

The expression for calculating the safety factor of dam slope stability by the Swedish arc strip method is:

$$K_s = \frac{\sum b_i (\gamma h_{i1} + \gamma' h_{i2} + \gamma'' h_{i3}) \cos \alpha_i \tan \varphi_i + \sum c_i l_i}{\sum b_i (\gamma h_{i1} + \gamma' h_{i2} + \gamma'' h_{i3}) \sin \alpha_i}$$

(1)

$\gamma$, $\varphi$ are the cohesion and internal friction angle of the soil on the sliding surface;

$\gamma'$, $\gamma''$ are the natural bulk density, floating bulk density and saturated bulk density of the soil respectively;

$h_{i1}$, $h_{i2}$, $h_{i3}$ are the heights of the soil strips above the infiltration line, between the infiltration line and the downstream water level, and below the downstream water level in the ith soil strip, respectively;

$\alpha_i$ is the angle between the vertical line and the center of the sliding arc surface of the ith soil strip and the center of the instantaneous sliding arc.

In order to analyze the stability of the dam slope under the action of a 6-degree earthquake, the pseudo-static method is used to apply the horizontal seismic inertial force generated during the earthquake as a pseudo-static force to the center of gravity of each soil strip, and calculate it with other load combinations. The stability safety factor is calculated by the following formula:
\[ K_i = \frac{\sum \left[ b_i \left( \frac{Q_i}{M_0/R} + \sum c_i l_i \right) \cos \alpha_i - Q_i \sin \varphi_i \right] \tan \varphi_i + \sum c_i l_i}{\sum b_i \left( \frac{Q_i}{M_0/R} + \sum c_i l_i \right) \sin \alpha_i + M_0/R} \]  

Qi is the seismic inertial force acting on the center of gravity of the soil strip, \( Q_i = K_i C_z G_i a_i l_i \); Kh is the horizontal seismic coefficient; CZ is the comprehensive influence coefficient, with a value of 0.25; ai is the seismic acceleration distribution coefficient; Gi is the soil weight of the soil strip; M0 is the moment of horizontal seismic inertial force to the center of the circle; R is the instantaneous center radius; Ci, \( \varphi_i \) are the cohesion and internal friction angle of the soil under the action of an earthquake. The calculation uses GEO-SLOPE's SLOPE software.

4.2 Calculation model and material parameters

According to the site conditions, select a typical section: the maximum settlement section, establish a calculation model, and divide the dam material into two layers according to the results of the field drilling and soil test, as shown in Figure 6. The summary of each material parameter is shown in Table 1. The stability analysis and calculation conditions are normal conditions and abnormal conditions (normal + earthquake).

According to the relevant regulations of the "Technical Specifications for Sanitary Landfill Treatment of Domestic Waste" GB50869-2013, the construction level of the garbage dam of the garbage disposal site is Class I. According to the relevant regulations of the "Code for Seismic Design of Buildings" GB50011-2010, the design seismic fortification intensity of the area where the garbage dam is located is 6 degrees, and the design basic seismic acceleration value is 0.05g. The design seismic group to which it belongs is the first group, and the site design characteristic period is 0.45s. Using the pseudo-static method, the seismic load factor is multiplied by 0.25.

Figure 6. Calculation model of the maximum settlement section

| Variable          | Density (g/cm³) | Cohesion (kPa) | Internal friction angle (degree) |
|-------------------|----------------|----------------|---------------------------------|
| Dam body (above)  | 2.20           | 5.0            | 18.0                            |
| Dam body (below)  | 2.10           | 10.0           | 26.0                            |
| Garbage Dump      | 1.10           | 12.0           | 17.0                            |
| Foundation        | 2.20           | 10.0           | 32.0                            |
4.3 Calculation results
According to the different sliding positions, the sliding form of the dam can be divided into the sliding of the dam above the horse track and the sliding of the entire dam. The construction level of the garbage dam is Class I. According to the "Technical Specification for Sanitary Landfill Treatment of Domestic Waste" GB 50869-2013, the minimum safety factor of the dam body's anti-sliding stability is calculated when the force between the blocks is used. It should not be less than the specified value in Table 2.
Table 3 shows the anti-sliding stability safety factor of the dam under various calculation conditions, and Figure 7~Figure 14 show the corresponding sliding positions.
The calculation results show that the stability safety factor of the dam above the horse track at the maximum settlement section under normal working conditions and seismic working conditions does not meet the requirements of the code.

| Condition                       | I   | II  | III |
|---------------------------------|-----|-----|-----|
| Construction period             | 1.30| 1.25| 1.20|
| Landfill Operation Period       | 1.20| 1.15| 1.10|
| Closure Period                  | 1.25| 1.20| 1.15|
| Earthquake in normal operation | 1.15| 1.10| 1.05|

Table 2. The minimum safety factor for the anti-sliding stability of the dam body specified in the code

| Condition | Section | Sliding | Calculation Method | Normative | Whether |
|-----------|---------|---------|--------------------|-----------|---------|
| Normal    | Maximum | Above track | 1.187 | 1.186 | 1.20 | No |
| Normal    | Maximum | Whole Dam   | 1.582 | 1.593 | 1.20 | Yes |
| Normal    | +Earthquake | Maximum Above Track | 1.149 | 1.148 | 1.15 | No |
| Normal    | +Earthquake | Maximum Whole Dam | 1.535 | 1.546 | 1.15 | Yes |
Figure 7. Simplified Bishop Method

Figure 8. Morganston-Pryce Method

Figure 9. Simplified Bishop Method

Figure 10. Morganston-Pryce Method
5. Reinforcement of garbage dam

Reinforcement methods for garbage dams can generally be classified according to the reasons, principles, purposes, and properties of the garbage dam reinforcement. Among them, the main reasons for the reinforcement are: seepage damage, cracks, landslides, earthquake damage, and liquefaction. According to the current investigation, the danger elimination and reinforcement measures of the garbage dam of this project are divided into penetration damage reinforcement and crack reinforcement.
5.1 Reinforcement of penetration failure
Reinforcement of the seepage damage of the garbage dam of this project adopts the anti-seepage measures of the slope surface geomembrane. The anti-seepage structure layer is as follows (from bottom to top): slope compaction foundation layer; under-membrane protection layer: 600g/m^2 geotextile; secondary anti-seepage layer: 4800g/m^2 GCL; main impermeable layer: 1.5mm single-rough HDPE film; on-membrane protection layer: 400g/m^2 geotextile; leachate drainage layer: 6.3mm geocomposite drainage net; landfill protection layer: bagged soil.

5.2 Crack reinforcement
Reinforcement of garbage dams follows the principle of “shallow excavation and construction, deep cracks grouting and backfilling, and restoration of dam crest elevation”.

5.2.1 For rubbish dams above the road elevation, direct excavation and rebuilding shall be adopted. The matters that should be paid attention to during excavation are as follows: (Before excavation, the storage site and transportation route of excavated soil and garbage should be planned, and the excavation slope and stacking slope should be controlled to avoid landslide accidents)
   ① Clean up the rubbish pile in front of the rubbish dam before excavation in order to grasp the excavation boundary
   ② Excavation in layers, the thickness of the excavation layer should be controlled within 2.5m, and the excavator and transport vehicle should be on the same plane as far as possible to facilitate excavation and safe construction. The excavated soil should not be piled up around the pit for safety. Different soil materials should be stored separately for easy use.
   ③ After excavation to the design elevation, the excavation surface should be protected to avoid rain, dryness, freezing, and water ingress.
   ④ Soil backfill

5.2.2 Deep cracks below the road elevation shall be backfilled with deep crack grouting.
When the cracks are deep or there are many cracks, the excavation is difficult or the excavation endangers the stability of the dam slope or the engineering volume is too large, the grouting method can be used, especially the internal cracks, only the grouting method should be used.

Grouting mainly has the following two aspects. ① Filling effect. Appropriate grout has good filling capacity for cracks, pores or caves in the dam body. The slurry can not only tightly fill wide and simple cracks, but also fill small cracks with a width of about 1 mm and a complex shape. The results of the test and the excavation inspection after grouting of the dam proved that the grout and the soil particles on the crack wall can be closely combined regardless of the size of the crack. After the solidified slurry, no matter the slurry itself or the joint surface between the slurry and the fracture wall, no new cracks are generated. ② Compaction effect. Under the action of grouting pressure, the grout can squeeze open the soil in the dam on the one hand to form a grout path and grouting into the grout. At the same time, under the action of higher grout pressure, the soil in the dam on both sides of the crack can be connected to the unconnected. The gap is also compacted or closed due to the squeezing action of the soil.

6. Conclusion
The investigation on the site of the dam shows that there are significant safety hazards and the possibility of instability is very high. Through collecting soil samples from settlement site, the soil tests in laboratory are carried out, and the relevant test data are obtained, which provides accurate parameters for the subsequent numerical simulation analysis. Geo slope rock soil stability analysis software analyzes the stability of the waste dam body under normal and seismic conditions according to the parameters of indoor geotechnical test, and compares it with the requirements of the specification. The analysis results show that the dam has the risk of instability. The results of field investigation are in good agreement with the numerical simulation. Therefore, it is necessary to strengthen the dam in time
and effectively. In view of the seepage failure and fracture damage of the dam, the seepage prevention measures of geomembrane and grouting backfill measures for deep cracks are proposed. The treatment results show that the dam crest elevation has no settlement and deformation, the seepage control system in the reservoir area has been effectively repaired, and the groundwater monitoring well has not monitored the percolate pollution and diffusion.

After two years of use and monitoring, it is proved that the restoration scheme of the dam is economical and feasible, which can provide reference for other similar projects.

References
[1] Zhan Liangtong, Guan Renqiu, Chen Yunmin, et al. Monitoring and back analysis of slope instability process of a landfill site. [J]. Journal of rock mechanics and engineering, 2010,29 (08): 1697-1705
[2] Deng Xuejing, Kong Xianjing, Liu Jun. Seismic response and stability analysis of municipal solid waste landfill [J]. Geotechnical mechanics, 2007 (10): 2095-2100
[3] Wang Rui. Stability analysis of a garbage dam and suggestions on treatment measures [J]. Natural resources of North China, 2020 (05): 105-108
[4] Gao Zhenxing, Tian Yuan. Stability evaluation of a landfill dam [J]. Journal of Yangling Polytechnic, 2019,18 (03): 17-19
[5] Ma Juan, Liu Zhibin, Li Jingming. Slope stability analysis of municipal solid waste sanitary landfill [J]. Journal of Liaoning University of technology, 2009,28 (S2): 149-151