Research progress of waste retaining dam expansion project technology for large domestic waste landfills

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Abstract: In view of the problem of insufficient storage capacity of the original landfill site, it is a very economical and effective way to use the horizontal, longitudinal and composite extension of garbage dam with geotextile reinforced earth dam. In this paper, the types of garbage dam, dam extension technology, dam reinforcement method and stability of garbage dam are introduced and discusses the types and advantages and disadvantages of dam retaining, the construction technology of dam retaining, the stability analysis and influencing factors of garbage dam retaining and the safety monitoring of dam body.

Key words: garbage dam; extension technology of dam retaining; stability analysis; leachate.

1. Introduction

With the rapid development of urban construction, garbage disposal technology has gradually improved. From 1989 up to the present, it has been revised four times, and now it is used “Technical Specification for Sanitary Landfill Treatment of Domestic Waste” (GB 50869-2013)[1]. The increasing improvement of people’s quality of life has led to a sharp increase in urban garbage. From 2013 to 2019, the annual output of domestic garbage increased from 16.979 million tons to 236 million tons, as shown in Fig. 1[2, 3]. The main disposal methods of domestic waste in developed countries are landfill and incineration. For domestic waste in China, sanitary landfill is the preferred way. Therefore, landfills have entered our lives. According to incomplete statistics, China has built about 1000 landfills by 2017[4]. With the increasing number of domestic waste, the early constructed landfills have entered into a state of near saturation from the operation stage. According to the original plan, the landfills that will reach a fully saturated state will be closed. However, there are many problems in the site selection of landfills, such as difficulties in state approval of land use, large area, terrain conditions, and landfill leachate invading underground contaminated groundwater, which make the site selection of landfills difficult. Therefore, it is a feasible scheme to maximize the utilization rate of early landfills, and can effectively increase the garbage storage capacity and solve the problem of urban land use.

There are several ways to expand the capacity of landfills. The first is the excavation and sorting method, which excavates the originally landfill garbage and re-filters and uses it; the second method is compression expansion method, the original garbage compression landfill; these two methods can increase the storage capacity of landfills, but the disadvantage is time-consuming and labor-intensive with high economic cost[5]. The third is the construction of the original landfill dam, usually in the original dam horizontal extension, vertical extension and composite extension, and they are based on the early landfill garbage dam[6-8]. Many scholars have studied and applied it, Zheng et al[9] conducted numerical and experimental studies on the upgrading and expansion project of a large landfill in the south, and found that the upgrading and expansion could increase the storage capacity of the landfill. Under the action of geotextile, when the geotextile strength was 50%, the safety factor of the dam body could meet the safety specification. Zhou et al[7] conducted a comparative analysis of non-reinforced soil and reinforced soil through centrifugal test and numerical simulation, and found that compared with non-reinforced soil, reinforced soil can reduce horizontal displacement, and geotextile can significantly improve the stability of dam body. Chen et al[10] studied the expansion of Xingfeng Municipal Solid Waste Sanitary Landfill Site in Guangzhou, and found that when the original dam with horizontal displacement was expanded, special attention should be paid to the reinforcement method of the original dam, the material selection of the new dam and the connection between the new and old dam. After the construction of the existing landfill, it is also necessary to analyze the stability of the garbage dam and the garbage pile. The stability is verified by laboratory test and numerical simulation analysis, that is, the stability of the garbage dam under normal conditions is analyzed by the indoor centrifuge model test, and the simulation analysis under various sudden conditions is carried out by numerical simulation.
2. Study on Characteristics of Garbage Dam and Connection between New and Old Dams

2.1 Types and Type Selection of Garbage Dam

The main function of the garbage dam is to maintain the stability of the garbage pile, prevent the sliding of the garbage pile caused by rainwater scouring and prevent the pollution of groundwater caused by the discharge of landfill leachate. It can also improve the height of the garbage pile and increase the storage capacity[11-12]. Although landfills have been implemented on a large scale throughout the country, there is no specific industry specification for the design of landfill dams, which is considered according to the hydraulic structure specification, civil building specification and other industry specifications.

Earth-rock dams began to appear in the 1930s[13]. With the rapid development of dam engineering, from the continuous engineering practice of concrete gravity dams and arch dams, the structural design and construction of the dam body are gradually improved, and the form of dam retaining is gradually increasing[14]. In order to apply various needs, gravity dams, flexible dams, homogeneous earth-fill dams, steel dams, rubber dams, masonry gravity dams, concrete face rockfill dams, wide-wall earth-rock dams, etc. Among them, the earth-rock dam has strong foundation adaptability, simple dam construction materials and convenient construction, which makes the earth-rock dam have certain advantages in the construction of dam engineering. The common types of garbage dam are gravity dam and flexible dam. Gravity dam is represented by masonry dam and concrete dam, and flexible dam is represented by rolling earth-rock dam.

Through practical application and economic benefits: masonry dam and concrete dam are gravity dam, mainly rely on self-weight to provide anti-sliding force. Compared with earth-rock dams, masonry dams have smaller volume and will not affect the storage capacity of landfills; when the dam foundation condition is good or the stone transportation distance is close, the masonry dam with small volume is the most suitable for the valley landfill site limited by the site. Concrete dams are also available in areas lacking stone; compared with concrete dam, masonry dam consumes less cement and steel, and has good economy; concrete dam has the advantages of high strength and good waterproof, and the disadvantages of poor economic applicability and high cost. Compared with concrete dam, gravel earth dam has the advantages of good economic applicability, local materials and low cost. However, the slope slope of earth-rock dam should reach 1:2~1:3. The slow slope will cause the volume of garbage dam to increase. When the original dam is upgraded and expanded, it will affect the storage capacity of landfill. Compared with concrete dam and gravel dam, reinforced earth dam has strong economic applicability, low comprehensive cost, steep slope about 1:1~1:1.5, which can reduce the volume of the dam and increase the storage capacity. Roller compacted earth-rock dam is compaction by rolling machine to improve the shear strength of filler, so as to ensure the stability of the dam. The unit price of roller compacted earth-rock dam is relatively low, but its volume is relatively large, so the overall cost is high. Compared with the gravity garbage dam, the roller compacted earth-rock dam has the advantages of low process requirements, simple construction and short construction period. The roller compacted earth-rock dam has the disadvantages of relatively complex construction technology and long construction period. In comparison, the advantages and disadvantages of refuse dam determine that gravity dam is commonly used in refuse dam. According to the construction requirements of landfill, comprehensive comparison of geotextile reinforced earth dam is the best way to build old landfill dam.

2.2 Research on construction technology of garbage dam

(1) Transverse extension

Transverse extension of the original landfill usually requires sufficient transverse space[15]. Transverse extension has two ways: the first one extends outward from the original landfill body, as shown in Fig. 2 (a); the second is to build a new landfill next to the original landfill, which is equivalent to the design of a new landfill, as shown in Fig. 2 (b) and Fig. 2 (c). Both methods increase the working area of the garbage pile to achieve the purpose of increasing the storage capacity. According to the terrain conditions, it can also be divided into plain horizontal expansion and valley horizontal expansion. As shown in Fig. 3, the expansion projects of Hangzhou Tianziling Second Landfill and Guangzhou Xingfeng Landfill in China are both valley horizontal expansion landfills.
Vertical expansion
For the insufficient horizontal space and insufficient storage capacity of the original landfill site, two ways of vertical expansion and vertical expansion can be adopted, the first is to increase the slope of the pile on the external surface of the original landfill site when the stability requirements are met, as shown in Fig. 4 (a); the second is the heightening design on the original garbage retaining dam, as shown in Fig. 4 (b). Both methods are expanded by increasing the height of the garbage pile, but the vertical expansion by changing the slope of the garbage pile will have a certain impact on the stability of the slope. According to the terrain conditions, it can be divided into plain vertical expansion and valley vertical expansion. As shown in Fig. 5, the expansion project of Pudong Dawn landfill belongs to the plain vertical expansion landfill[18].

(3) Composite expansion
When the landfill space is sufficient, the composite expansion technology extends both horizontally and vertically, as shown in Fig. 6. According to the terrain conditions, it can also be divided into plain-type composite expansion and valley-type composite expansion. As shown in Fig. 7, the expansion project of Suzhou Qizishan landfill belongs to valley-type composite expansion landfill mainly with vertical expansion[16].
2.3 Connection between original dam body and new dam body of refuse dam

The original dam reinforcement methods are:
(1) The dam is heightened and thickened. For the dam project with better quality, the original dam is heightened and thickened. (2) The anti-seepage layer and protective layer are added on the dam body, and the original dam body cannot be reinforced by large-scale excavation. The anti-seepage wall can be constructed in the dam body by cement mixing pile, high-pressure jet grouting, and vertical membrane laying. The anti-seepage geomembrane can also be laid or the anti-seepage panel can be constructed by concrete. (3) To enhance the anti-sliding performance of the dam, a row of anti-sliding piles can be set at the foot of the dam. (4) Consolidation grouting. If holes appear in the original dam, cement slurry grouting reinforcement should be carried out for the original dam.

If the original dam body is earth-rock dam and the new dam body is concrete dam, due to the rigid structure of the concrete structure, the deformation of the new and old dam body will not be coordinated and the gap will be generated. The excessive weight of the concrete structure will also lead to the collapse of the original dam body due to the lack of bearing capacity. The connection between the original dam body and the new dam body is as follows:
(1) When the sliding surface is located at the connection between the original dam body and the new dam body, the safety factor here will be low and do not meet the requirements of the specification. Therefore, it is necessary to insert the anchor into the original dam body and establish a connection with the new dam body through the steel pipe, so as to increase the tension and anti-sliding force of the original dam body and the new dam body. (2) Since the original dam body and the new dam body are not constructed at the same time, the original dam body will be deformed due to the influence of rainfall and weathering and the load of the new dam body, thereby reducing the strength. Therefore, in the extension project of the garbage retaining dam, the construction cushion of the new dam body can improve the bearing capacity of the original dam body and increase the stability of the dam body[17]. (3) The appropriate dam form is selected. Although the concrete dam has the advantages of high strength and good waterproof, it is not suitable for all the new and old dam reinforcement. Geotextile reinforced earth dam is the best form for the construction of the old landfill.

3. Factors Affecting Stability of Landfill Waste Dam

3.1 Leachate

Leachate is a kind of high concentration wastewat produced by rainwater erosion and groundwater immersion in the process of landfill and landfill. It has the characteristics of complex substances, high ammonia nitrogen concentration and organic pollutants. For landfill dams, the water level of landfill leachate directly affects the anti-sliding stability of landfill dams. When the water level of landfill leachate is low, the anti-sliding stability of landfill dams is better. With the gradual increase of leachate water level, the overall stability of the dam body will also be affected, resulting in the deepening of the potential sliding surface position. The anti-seepage measures of landfill leachate are as follows: (1) Do a good job of bottom liner system, adopt single layer, double layer or composite liner system, choose high strength and grand tensile properties of geomembrane or other geosynthetics. (2) The leachate can be collected by setting up a leachate drainage well to prevent the rise of water level. Therefore, it is necessary to monitor the height of leachate water level for the overall anti-sliding stability of landfill dams.

3.2 Waste dump landslide

The rise of leachate will not only affect the overall stability of garbage dam, but also cause slope instability, resulting in garbage dump landslide. Generally, when the leachate level is low, the refuse pile has a certain shear strength, and the load generated by the liquid on the pile slope is also relatively small, which has little harm to the slope stability and dam stability. When the leachate level is high, the heap slope will have a large load due to the effect of leachate. When the leachate overflows, the garbage heap will produce a large area of tensile stress, and there will be a potential instability area. This area will reduce the safety factor of the heap slope, leading to the landslide of the heap and affecting the overall stability of the garbage dam. Therefore, it is necessary to ensure that there will be no sliding and tilting problems under the influence of the external load of the garbage and its own gravity, so as to effectively improve the overall stability of the garbage dam and ensure the safety of the landfill.

3.3 Other factors

Combined with practical engineering, it is found that hydrogeological conditions, appropriate dam form, uneven settlement of garbage pile, slope ratio of outer slope of dam body, compactness of dam body, local collapse of flood intercepting ditch and dam abutment all affect the safety and stability of dam body.
4. Study on the stability of landfill waste dam

4.1 Analysis method of landfill stability
The factors affecting the stability of landfills should be considered from the slope stability of landfills, the stability of landfills, the overall anti-slip and anti-dip stability of landfill dams, and the stability under earthquake [17-19]. Through centrifuge model test and numerical simulation analysis. Centrifuge model test simulates the deformation and failure process of prototype by increasing centrifugal force to simulate gravity. At the same time, the rationality and reliability of theoretical analysis and numerical calculation can be verified, and the effect of field test can be reflected intuitively[20].

(1) Slope stability of landfills: Arc sliding method is often used in slope stability analysis of landfills[21]. Wedge limit equilibrium method[22-23] and finite element analysis method[24]; the strength of the slope model is calculated and analyzed according to the Mohr-Coulomb strength formula and the total stress formula; stability Analysis of Slope Engineering by Finite Element Method[25]; study on failure mechanism of reinforced soil slope by centrifuge model test[26-27].

(2) The stability of garbage pile: Geostudio-Slope finite element calculation software or Lizheng geotechnical software is used to analyze the overall stability of the dam and garbage pile. The safety factor of non-circular sliding surface is calculated by Morganstein-Price method. The Mohr-Coulomb strength formula is used as the calculation criterion, and the total stress method is used to calculate[28].

(3) The overall anti-sliding and anti-overturning stability of refuse retaining dam: the anti-sliding and anti-overturning stability of refuse retaining dam are calculated by Lizheng software and Geo studio-Slope finite element software[29].

(4) Stability under seismic action: pseudo-static method was used to simplify the seismic load, and a five-wedge analysis model was established to solve the safety factor under seismic action, and the stability and failure mechanism of landfill under seismic load were analyzed[22].

(5) Specification for earth-rock dams in China[30] usually adopts rigid body limit equilibrium analysis method, and simplified Bishop method is recommended for homogeneous earth dams; for the stability calculation of complex conditions, numerical algorithms such as slice method and finite element method are needed. For the stability analysis of reinforced earth dams, the arc sliding surface limit equilibrium method is usually adopted[7].

4.2 Study on the stability of refuse dam
The constructed landfill site should not only meet the requirements of no landslide, no sliding and tilting of the dam body, normal settlement and good slope stability[31-32], but also meet the stability requirements of numerical simulation under various working conditions, such as considering the influence of seismic load, considering hydrostatic pressure in saturated state or considering hydrodynamic pressure. The minimum safety factor obtained by simulation calculation should meet the requirements of the specification. With the increase of landfill, there will be landfill leachate in the landfill, which needs to be guided and discharged in time to ensure that the leachate level does not cause the head difference before and after the dam body, resulting in seepage failure of the dam body. Low leachate level can also ensure the anti-sliding stability of the garbage dam.

The stability of the garbage dam is very important, which affects the operation and use of the garbage landfill. In order to avoid the instability of the garbage dam, we can observe the dam deformation, settlement and safety monitoring of the garbage dam and garbage pile, and the slope monitoring method can be used for monitoring[33]. Slope deformation monitoring methods mainly include slope surface measurement (range finder, total station, leveling, theodolite, etc.), multi-point displacement meter, GPS measurement, SAR interferometry, microseismic monitoring, distributed optical fiber displacement measurement (OTDR and BOTDR) and time domain reflection test (TDR). Centrifuge test, theoretical analysis and numerical analysis can be used to analyze the slope and dam stability, and long-term monitoring of landfill dam deformation, slope displacement, leachate water level and settlement can be carried out. Artificial intelligence algorithms such as neural network, grey algorithm and support vector machine can be used to predict.

5. Conclusions and outlook
Due to the rapid growth of urban garbage, the storage capacity of landfill can no longer meet people’s needs. It is necessary to carry out the construction on the basis of the existing landfill. This paper refers to the current situation of the storage capacity of the landfill, how to select the form of the garbage dam, introduces three ways of extension on the original dam, and summarizes the analysis method of the stability of the garbage dam.

(1) The garbage dam is designed with reference to water conservancy projects. The common garbage dam is gravity dam and flexible dam, which are represented by masonry dam or concrete dam and rolling earth-rock dam respectively. Geotextile reinforced earth dam is often used in dam extension projects. Concrete, gravel soil, reinforced soil, stone chips or gravel are generally used as the filling materials of waste dam. Geomembranes, geotextiles, HDPE geogrids and high toughness polyester geotextiles with high strength and good tensile properties are used as the reinforcement materials.

(2) The construction methods of garbage retaining dam include horizontal expansion, vertical expansion and composite expansion. According to the terrain conditions, there are plain expansion and valley expansion. The connection between the original dam and the new dam should be well protected.

(3) The factors affecting the stability of waste dam include leachate level, displacement and settlement of waste pile, hydrogeological conditions, dam form and slope ratio,
dam compactness, local collapse of flood intercepting ditch and dam abutment.

(4) The stability of refuse retaining dam is analyzed by centrifuge test and numerical simulation. The displacement of refuse pile, slope stability, sliding and tilting of dam body, leachate level and settlement displacement should be analyzed.

Through the above research combined with Hangzhou Tianziling Second Landfill, Guangzhou Xingfeng Landfill, Pudong Liming Landfill Extension Project, Suzhou Qizishan Landfill Extension Project and other practical projects, it is proved that the dam retaining construction project can increase the storage capacity of the landfill and save the cost without relocating the site. Through the study found and put forward the following points: (1) Leachate has a great influence on the stability of the dam, usually through the laying of leachate drainage wells to collect and discharge the filtrate, when the drainage well clogging occurs, what way can be drainage wells to collect and discharge the filtrate, when of the dam, usually through the laying of leachate points: (1) Leachate has a great influence on the stability of the landfill and save the cost without relocating the site.

(2) The refuse heap has a certain shear strength, and what kind of material can be added to enhance the strength of the heap and reduce the harm of landslide; (3) Whether there is a more convenient and higher connection strength method between the original dam and the new dam. In short, it is hoped that this study can provide certain theoretical basis and guidance for the future construction of waste dam.

References

1. GB 50869-2013, Technical code for municipal solid waste sanitary landfill[S].


