

Research Progress on Stability of Garbage Dump in Large-scale Landfill

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Abstract. Based on the instability and failure of garbage dump in large landfill, this paper introduces the stability of landfill from theoretical research, numerical analysis, model test and laboratory test. On the basis of summarizing the previous work and combining the latest research results, the stability analysis of garbage dump is discussed, and the main influencing factors of garbage dump stability are summarized. The main factors are the leachate level, the engineering properties of garbage soil and the shear slip of liner system.

Keywords: Garbage dump; Stability analysis; Influencing factors; Leachate level; Garbage soil; Liner system.

1. Introduction

With the rapid increase of domestic waste output in China, the stability of large-scale landfill is very important for urban development and protection of human and property safety. As shown in Fig. 1, China's annual domestic waste output increases at a rate of about 4%, and the annual domestic waste output increases from 158.05 million tons in 2010 to 235.12 million tons in 2020 [1]. There are many methods of waste disposal, among which sanitary landfill is one of the most important means of domestic waste disposal in many countries, especially in developing countries. The sanitary landfill technology in China started relatively late. Until the early 1980s, the urban waste treatment in China was mainly open-air landfill, and there was no standard sanitary landfill in the country. In the middle and late 1980s, the exposed stacking of garbage brought about environmental problems such as mosquito breeding, odor diffusion, leachate pollution and so on, which were not coordinated with urban development, prompting all parts of China to plan and build standardized garbage sanitary landfills. In the middle and late 1990s, with the state's emphasis on health work, the state has increased its investment in waste treatment with national debt funds, and various large and medium-sized cities have successively built sanitary landfills for domestic waste. For example, Hangzhou Tianziling waste treatment plant built in 1991 is the first large-scale valley type waste sanitary landfill site designed and constructed in accordance with "Technical code for sanitary landfill of municipal solid waste" (cjj17-88) [2]. At this stage, the construction of sanitary landfill is mainly based on artificial seepage prevention. In the 21st century, the application of domestic sanitary landfill technology has become mature, and various standards and specifications are gradually complete.

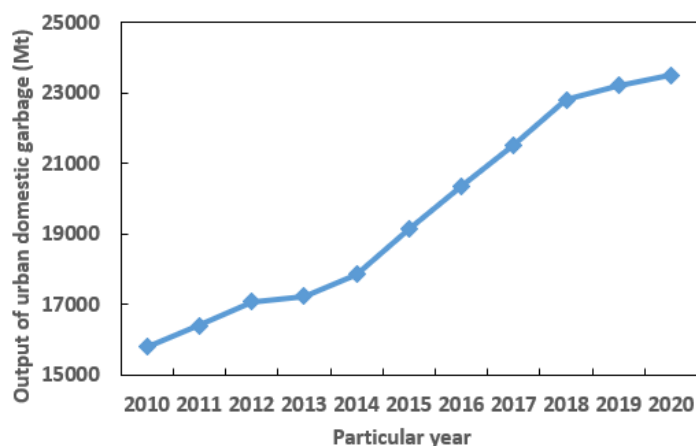


Fig. 1 Growth trend of domestic waste output in China

After more than 40 years of development, sanitary landfills in China are developing towards the trend of "centralized management, super large-scale and super high burial depth". With the development of high landfills and large storage capacity in our country, great importance has been attached to the stability design of garbage landfills. Once the garbage landfills are unstable and damaged due to improper treatment, the harm will be enormous. The instability and failure of large-scale garbage landfill brings huge soil sliding, destroys downstream buildings, and causes casualties. For example, in 2002, Chongqing Liangfengya landfill was destroyed by landslide due to rainstorm, about 400000 m³ of solid waste was dumped, engulfing the three storey dormitory building of the gravel plant, and 10 people died [3]; In 2009, due to the high water content of the sludge in Xiaping landfill in Shenzhen, about 40000 m³ of sludge gushed out of the landfill [4]; In 2010, due to improper waste disposal and the generation of leachate and landfill gas, the 30m high slope of Xerolakka landfill site in Greece was unstable and about 10000 m³ of garbage landslide [5]. Therefore, the stability of garbage dump in large landfill needs further study. In order to reduce the instability of large-scale landfill, many scholars at home and abroad have carried out a lot of research on the stability of the landfill. The research on the stability of garbage dump in large landfill mainly includes theoretical research, numerical analysis, model test and indoor test.

2. Research method of stability of large-scale landfill

2.1 Theoretical research

In terms of theoretical research, Mitchell et al. [6] carried out slope stability analysis on a landfill site in the United States in 1991 and put forward suggestions for the design and construction of the landfill site: when treating low-strength liner system, possible three-dimensional effects should be specially considered in the design process, which may have a significant impact on the stability of the whole system during the landfill period. Chen [7] carried out stability analysis on the slope of a landfill site through static and dynamic finite element calculation. The method adopts circular sliding surface and improves Newmark method, which can be used to calculate the permanent displacement of the landfill site under earthquake load.

Qian et al. [8] used the limit equilibrium method to deduce the double wedge analysis method and studied the stability of the landfill body sliding along the site bottom liner. Different from the traditional method, the new method can reveal the influence of the internal friction angle of the garbage dump on the translational failure of the garbage block. With this method, the magnitude and direction of the force between wedges can be calculated. Based on the research of double wedge theory, many scholars apply the three-wedge analysis method to the stability analysis of landfill. The three-wedge analysis method divides the landfill into three parts: active wedge, passive wedge and garbage dam, and carries out limit equilibrium analysis on them. Feng et al. [9] applied the three wedge analysis method to analyze the stability of the liner system along the bottom of the landfill, and studied the stability of the liner system along the bottom of the landfill. Gao [10] extended the limit equilibrium theory of three wedges, applied it to the dynamic stability analysis of landfill, and gave the approximate solutions of safety coefficient and yield acceleration coefficient. Ruan et al. [11] considered the randomness of garbage characteristic parameters, and analyzed the stability of the landfill site by the method of trapezoid triple wedge and reliability analysis.

2.2 Numerical analysis

At present, numerical analysis method is one of the most widely used methods for landfill stability analysis. In terms of numerical analysis, the finite element method and the finite difference method are adopted for the stability analysis of the waste filling site [12,13]. Ke et al. [14] used the finite element method to calculate the static and dynamic stability of the landfill slope, improved the Newmark method, and obtained the permanent deformation of the landfill under the earthquake. Deng et al. [15] analyzed the limit equilibrium of the landfill site with a certain slope angle by assuming that the potential sliding body along the liner layer at the bottom of the landfill site is composed of

three rigid sliders, and deduced the calculation formula of the yield acceleration coefficient of the liner layer of the landfill site; Zhang [16] adopted the limit equilibrium method to quantitatively analyze the influence of pore water pressure and pore gas pressure on the stability of landfill slope. Gao [17] used the finite difference method to analyze the instability of the double-layer interface at the bottom of the landfill, and studied the influence of the material parameters of the waste body and the geometric configuration parameters of the landfill on the shear stress and shear displacement distribution of the double-layer interface.

In the numerical method, the stability analysis of the landfill site is mostly based on the limit equilibrium and limit analysis theory, and the finite element method and finite difference method are used to describe the instability characteristics of the landfill site involving typical environmental problems. However, these grid based methods are prone to cause grid distortion and numerical oscillation when simulating extreme deformation problems, which will reduce the computational efficiency and accuracy, and even cause errors. These methods are not suitable for simulating the whole process of unstable flow slip in landfill. In recent years, the mesh free method has been regarded as an effective way to solve large deformation problems, and has gradually attracted people's attention.

2.3 Model test

Model test refers to the corresponding test conducted on a scaled down or equal scale model. Through the model test, it can indirectly reflect the instability process and law of the landfill. Thusyanthan et al. [18] of Cambridge University artificially prepared waste soil, which mainly consists of silt, kaolin and quartz sand. Based on the prepared model solid waste, a series of centrifugal model tests were carried out to analyze the static and dynamic response of the landfill site [19]. Chen et al. [20] carried out centrifugal model test research on the deformation of geomembrane for anti-seepage of landfill site, and used corresponding model materials to simulate the geomembrane in actual projects to provide basis for the anti-seepage design of geomembrane for landfill site. Jiang [21] carried out model test research based on the deformation and failure mode of Dameishan landfill, and studied the effect of weathered gravel soil reinforced retaining dam on the actual project.

Luo [22] et al. Carried out a series of centrifugal model tests of the slope under the condition of water level drop, evaluated the reinforcement effect of geotextile and its influencing factors, and clarified the progressive failure mechanism of the slope and the reinforcement mechanism of geotextile. The results are as follows: 1) The reinforced slope and the unreinforced slope show obvious progressive failure under the condition of water level drop, and the failure develops from the top of the slope to the bottom of the slope. Progressive failure is the result of coupling of deformation localization and local failure. 2) Geotextile reinforcement significantly improves the safety limit of the slope, reduces the displacement of the slope, changes the damage characteristics of the slope, and improves the ductility of the slope. The arrangement of geotextile has a significant impact on the reinforcement effect. The reinforcement is effective only when the geotextile is long enough to pass through the sliding surface of the unreinforced slope. 3) The geotextile reinforced slope can be divided into anchorage zone and restriction zone, and the boundary is determined by the peak strain position of the geotextile regardless of the water level drop. 4) Geotextile can strengthen the slope condition by reducing and evenly spreading the deformation of the slope. The reinforcement mechanism is realized by the interaction of the reinforcement and soil in the anchorage zone and the restraint of the soil in the restriction zone.

The existing studies still have the following shortcomings: (1) the composite lining is composed of a variety of geosynthetics, clay and gravel layers. In the previous studies, the lining was mostly attached to the rigid plate at the interface, which is inconsistent with the actual situation. (2) Limited by the test instrument, the sample has size effect. Because the model test is difficult to reflect the actual engineering situation, more scholars use the numerical model to study.

2.4 Indoor test

Due to the different garbage components and landfilling processes in different regions, the shear characteristics of garbage dump are quite different, and the dispersion of the results is usually large. Garbage soil has the properties of large particle size and dispersion, and its properties can be accurately reflected by laboratory tests.

In terms of indoor tests, Zhang et al. [23] carried out routine geotechnical tests and triaxial tests on 42 barrels of undisturbed soil samples from Hangzhou Tianziling landfill. The test results show that the composition of garbage is disordered, but the physical and mechanical properties show certain laws. Through unconsolidated and non-drained tests, it is found that timely discharge of leachate is the key to accelerating the consolidation of garbage and improving the stability of the landfill. Gao et al. [24] carried out repeated direct shear tests of garbage soil according to the characteristics of garbage soil. Through the analysis of the test results, it is concluded that at the beginning of shear, garbage soil is gradually compacted and inelastic is gradually eliminated, and the stress-strain curve of garbage soil is nonlinear; When inelastic deformation is eliminated, the shear curve is linear elastic deformation. Compared with ordinary soil, the residual strength of waste soil is not significantly reduced. Hu [25] conducted shear tests on waste soil through self-made large-scale direct shear apparatus. Through the experimental study on the engineering mechanical properties of waste soil samples, it was concluded that during horizontal shear, waste soil showed obvious stress yield and plastic deformation characteristics, and its deformation and failure showed significantly different characteristics from that of ordinary rock and soil materials. The development of the whole curve is divided into four stages: 1) linear elastic stage, 2) elastic-plastic stage, 3) peak stage and 4) strain softening stage.

The indoor tests mainly include consolidation test, unconfined compression test, direct shear test and permeability test with different sample sizes. There are many kinds of waste soil with different mechanical properties, and the characteristics of each independent landfill unit are quite different. At present, the research on the stability of large-scale waste landfill mainly focuses on the selection of landfill site location, the research on landfill technology, seepage prevention and leakage detection, and the collection and drainage of leachate. There is a large research space for the design, analysis and prediction of the landfill stability system of the nature of waste soil.

3. Factors affecting the stability of garbage dump in large landfill

The stability of garbage dump in large landfill has an important influence on the stability of retaining dam. According to the earth pressure principle of the retaining wall, if the garbage dump is unstable, the thrust of the unstable failure on the retaining dam will be significantly increased. The stability of garbage dump is affected by many factors, including leachate level, the engineering properties of garbage soil and the shear slip of the liner system. In addition, it is also affected by factors such as compaction degree, landfill method and landfill age.

3.1 Leachate level

Leachate refers to a kind of high concentration organic wastewater that comes from the water contained in the garbage in the landfill, the rain and snow water and other water entering the landfill, deducting the saturated water holding capacity of the garbage and the overburden, and passing through the garbage layer and the overburden. Too high leachate level may cause instability and damage to the landfill site. The adverse effects of leachate level on the stability of garbage dump include the following aspects: increasing the wet bulk density of garbage, reducing the effective bulk density of garbage, and reducing the overall and local stability of garbage dump. The buried depth of the leachate level in large-scale landfill is generally 9 ~ 19m, which is higher than the top of the waste retaining dam. The volume of the leachate accounts for about one fourth of the total landfill site. The leachate level significantly affects the safety factor of the landfill site. The leachate level distribution in the landfill can be divided into four categories: 1) The water level is parallel to the leachate on the

bottom slope and back slope of the landfill; 2) The water level is parallel to the leachate of the bottom slope of the landfill; 3) With horizontal water level and leachate parallel to the bottom slope and back slope of the landfill; 4) Leachate with horizontal water level [26]. It can be seen that the leachate at different water levels and positions has different degrees of influence on the garbage dump.

3.2 Engineering properties of garbage soil

The engineering properties of garbage soil are affected by many factors such as garbage type, composition, compactness, moisture content, leachate management, stacking age and overlying soil pressure, and its mechanical parameters such as gravity density, moisture content, porosity, permeability and shear strength show great dispersion [23,27]. The discreteness of the engineering properties of the garbage soil brings difficulties to the stability evaluation of garbage dump, which is manifested in the following aspects: 1) the types and components of the garbage dump are very different, and the physical and mechanical parameters are discrete; 2) The test is difficult, and the test results of small diameter and small size are difficult to reflect the macroscopic properties of the garbage dump, and it is difficult to reasonably reflect the actual physical and mechanical properties of garbage dump by using a single test method; 3) With the continuous degradation of organic matter, the physical and mechanical properties of garbage dump change with time. After 10 years of degradation, the volume change of waste soil reaches 60%, and the safety factor decreases with the extension of waste soil stacking time [28]. It is unrealistic to comprehensively evaluate the impact of the engineering properties of waste soil on the stability of the landfill, and the research focus can only be selected according to the engineering needs.

3.3 The shear slip of liner system

The liner system is located at the bottom and four sides of the landfill. Its main function is to prevent seepage and pollution, that is, to prevent the leachate from polluting the surrounding soil and groundwater. The liner system is usually composed of multiple layers of clay or geosynthetics (mainly geomembranes) to prevent the liquid from moving between the landfill and the surrounding sites. The instability mechanism of the landfill is mainly the sliding failure along the liner system, and the shear characteristics of the liner system directly affect the overall stability of the landfill [29]. In order to measure the residual strength of the shear failure surface correctly, it is necessary to carry out the large deformation shear test in the field for the shear research of the liner system, and the deformation is about 500 ~ 700mm. The test results show that in most cases, the failure surface appears at the contact surface of geosynthetics and geomembranes, but sometimes it also appears in the interior of geosynthetics [30, 31]. The location of the failure surface is affected by many factors, including the properties of geosynthetics, the hydration degree of bentonite in the geomembrane, and the normal stress applied in the test. Therefore, it is very difficult to accurately determine the shear failure surface.

4. Damage forms of waste dump in large-scale landfill and prospect

According to the study of typical cases of instability and failure of garbage landfills, it is found that the failure forms of garbage dump are mainly rotational failure and lateral displacement failure [3-9].

4.1 Damage forms of waste dump in large-scale landfills

(1) Rotation failure of garbage dump

The schematic diagram of the rotation failure of the garbage dump is shown in Fig. 2. Fig. 6 (a) and (b) show that circular arc sliding occurs inside the garbage dump, which may occur when the dump is very steep. The method of slope stability analysis of the landfill can be used for analysis. However, when selecting the shear strength parameters of the garbage dump, it should be noted that the friction angle in the garbage dump is usually high and the range of change is large, which may be in the range of $30^{\circ} \sim 60^{\circ}$.

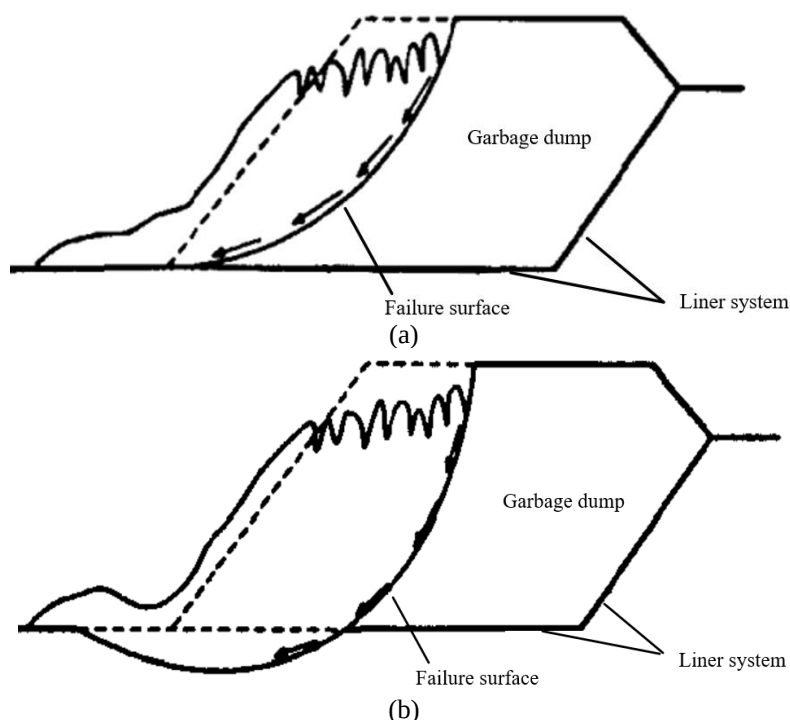


Fig. 2 Schematic diagram of rotating failure of garbage dump

(2) Lateral displacement damage of garbage dump

Fig. 3 (a) and (b) show the lateral displacement failure forms that may occur when there is a low friction surface in the multi-layer composite liner. For example, the contact surfaces between the garbage dump and the geomembrane, the sand layer and the geomembrane, the geomembrane and the geonet, and the geomembrane and the wet clay may all be subject to sliding failure. When the landfill is not filled, the double wedge analysis method can still be used to analyze the stability of the garbage dump sliding along the contact surface of the liner. When the landfill is not filled, it can be divided into two discontinuous parts. The active wedge causing sliding failure is on the slope, and the passive wedge preventing sliding is on the bottom of the slope.

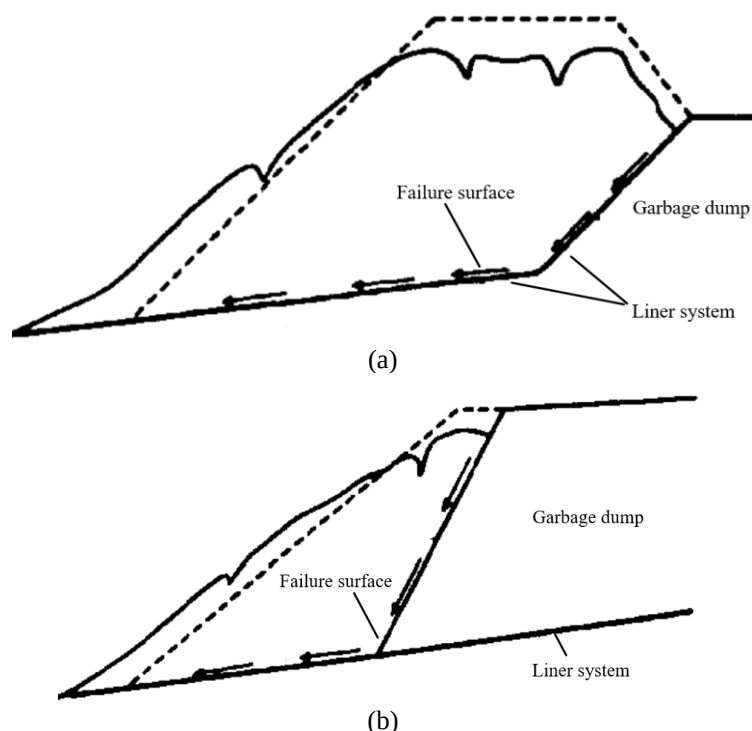


Fig. 3 The lateral displacement failure forms

4.2 Prospect of stability of garbage dump in large-scale landfill

(1) Whether it is realistic to comprehensively evaluate the impact of the engineering properties of garbage soil on the stability of garbage dump in landfill, and whether the research focus can be selected according to the engineering needs;

(2) The garbage dump has a certain shear strength. How to enhance the strength of the dump and what kind of curing agent can be added to improve the strength of the dump;

(3) Timely discharge of leachate is the key to accelerating the consolidation of garbage and improving the stability of landfill. What methods can be adopted to accelerate the discharge of leachate;

(4) Centrifugal model test is expensive, and there are few studies on centrifugal model of reinforced soil slope. The test data are precious and rare. Can more numerical models be used to study the stability of landfill site.

In a word, it is hoped that this study can provide a certain theoretical basis and guidance for the future study on the stability of garbage dump.

5. Conclusion

The process and influence factors of the instability and failure of the garbage dump are very complex. This paper introduces the research methods of the stability of the garbage dump and summarizes the failure forms of the garbage dump. The following conclusions are obtained:

(1) There are theoretical research, numerical analysis, model test and laboratory test for the stability of garbage dump in large-scale landfill. Through theoretical research, the garbage dump can be divided into three parts: active wedge, passive wedge and garbage dam, and their limit equilibrium analysis is carried out; The effects of earthquake, leachate level and pore water pressure on the landfill are analyzed by numerical simulation; The influence of retaining dam on the stability of garbage dump is studied by model experiment; The mechanical properties of garbage soil are studied through laboratory tests.

(2) The main factors that affect the stability of garbage dump in landfill are the leachate level, the engineering properties of the waste soil, and the shear slip of the liner system. In addition, it is also affected by factors such as compaction degree, landfill method and landfill age. The leachate increases the wet bulk density of the garbage dump, reduces the effective bulk density of the garbage, and reduces the overall and local stability of the garbage dump. The mechanical parameters of garbage soil, such as gravity density, moisture content, porosity, permeability and shear strength, show great discreteness. It is unrealistic to comprehensively evaluate the impact of the engineering properties of garbage soil on the stability of garbage dump in landfill, and the research focus can only be selected according to the engineering needs. The instability mechanism of the landfill is mainly the sliding failure along the liner system. The shear characteristics of the liner system directly affect the overall stability of the landfill.

(3) The main failure forms of garbage dump in large-scale landfill are rotation failure and lateral displacement failure. In order to explore the mechanism of instability and failure of garbage dump, the stability of garbage dump can be comprehensively analyzed by combining theoretical analysis and numerical simulation according to the failure form of garbage dump.

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