Research Article

Research on Seepage Field and Slope Stability Considering Heterogeneous Characteristics of Waste Piles: A Less Costly Way to Reduce High Leachate Levels and Avoid Accidents

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Due to the characteristics of high heap and large volume, the complex layers of waste, high-water level of leachate, environmental pollution, and slope instability are easily produced. Although many researchers have studied landfill two-dimensional leachate migration law, three-dimensional seepage and stability of landfill sites have been rarely studied. This paper focuses on the heterogeneous characteristics of the landfill piles and analyzes the seepage field and slope stability of the landfill using statistical and numerical analysis methods. The calculated results are compared with the field measurement and literature research data to verify the reliability of the model, which may provide the basis for the design and safe and eco-friendly operation of the landfill. Taking an actual landfill as the research object, the saturated–unsaturated transient model of heterogeneous waste is applied to practical engineering. Considering the landfill process and heterogeneous permeability, the calculated maximum water level is higher. Compared with the homogeneous material, the difference in the water level of each waste layer is about 0.08–1.88 m, which is not good for the stability of the landfill. Combined with the engineering characteristic distribution of a landfill, the heterogeneous stability model is applied to the actual project to study the influence of different unit weight and shear strength distribution on landfill stability. The established model is suitable for the study of two-dimensional and three-dimensional slope stability of landfill sites. Through the slope stability analysis of the three-dimensional landfill site, it is found that the bank slope of the reservoir is steep and prone to instability failure. In most studies, only the instability of the landfill is of concern, but the bank failure is ignored. In the process of landfill operation and management, while considering the capacity of the landfill, the stability of the bank slope should also be paid attention to, and if necessary, bank slope reinforcement or slope ratio improvement should be carried out.

1. Introduction

1.1. Research Background and Significance. Municipal solid waste is the waste generated by urban residents in the process of daily life or activities providing services for day-to-day life, mainly including food and fruit, wood, paper, textiles, plastics, and dust [1–3]. The main body of the landfill sites is a pile made of domestic waste paved and rolled in layers, which is composed of waste dam, leachate guidance, drainage system, anti-seepage system, intermediate overburden, final overburden, gas collection system, etc. With the improvement of economic level and the increase of urban population, the production of urban domestic waste has increased sharply, which has great harm to the surrounding air, soil, and water and the life safety of residents.

According to research worldwide, under the action of rainfall infiltration, the leachate of most landfill sites cannot be discharged from the pile in time due to the blockage of the
guide and drainage system [4, 5]. The leachate accumulates at the bottom of the landfill sites, resulting in high-water levels and excess pore water pressure, which seriously threatens the safety of the landfill sites. The difference between seepage in landfills and seepage in the soil is that there is a dominant flow in addition to the main Darcy seepage mode. Due to the complex composition and filling mode of the waste landfill, there is a preferential leakage channel in the seepage. The leachate percolates along the larger pores to form a dominant flow. With the increase of the compaction degree of the waste, the macropores gradually decrease, and Darcy seepage is the main seepage form of the landfill [6, 7].

The water level of leachate is an important factor affecting the stability of landfills, and the leachate of landfills mainly comes from rainfall, water content of waste itself, degradation, and surface water [8, 9]. The landfill is generally built above the groundwater level, and anti-seepage systems are set at the bottom and around the landfill, so the groundwater has little impact on the leachate [10, 11]. Due to the characteristics of high heap, large storage capacity, and high-initial water content of the landfill, as well as the silting of the guidance and drainage system and the effect of rainfall, the leachate transport law, safety, and stability of the landfill are particularly important [12]. With the continuous degradation of solid waste and the effect of upper pressure, the void ratio of the landfill gradually decreases. The bottom is mainly composed of small particle materials such as plastic and residue that are difficult to degrade, which gradually silts up the drainage layer. The leachate accumulates at the bottom due to untimely drainage, resulting in the rise of leachate water level, slope instability, and damage [12].

The research on landfill leachate water levels mainly includes field tests and numerical analysis methods. Because the traditional hydrogeological survey method is adopted in the landfill, the waste is prone to shrinkage after drilling, and the methane produced by the degradation of the waste mixes with the leachate to form foam, which affects the measurement of the water level of the leachate. The numerical analysis method is a widely used landfill stability analysis method [13–15]. Considering the relationship between waste characteristics and degradation, Hossain and Haque [16] divided the landfill into four ages and applied PLAXIS FEM software to analyze the stability of landfill slopes with different slope ratios.

Due to the rapid increase of municipal solid waste produced in cities, the research on the safety and stability of municipal solid waste landfills is very important for the protection of personal and property safety. Through the statistics and analysis of many landfill accidents around the world, it is found that one of the main factors causing the instability and destruction of landfill sites is the high leachate water level [17–19]. The well-known sites include Dona Juana Landfill (Columbia), where nearly 1,200,000 m³ of waste accumulated within 20 minutes [20, 21]; Payatas Landfill (Philippines), where approximately 278 persons died and 100 others were lost [22]; and Chongqing Landfill (China), where about 400,000 m³ of waste slid down and killed 10 persons [23]. In addition, earthquake action and unfavorable waste characteristics also have a great impact on the stability of landfills [24–27]. On December 20, 2015, a landslide occurred in a landfill in Shenzhen. Yin et al. [28] analyzed the accident and found that the main influencing factors included waste composition, rainfall, and mechanical properties. Through the analysis of geological conditions of unstable landfill sites, it is concluded that the main factors affecting the stability of landfill sites are rainfall, earthquake, and human factors [29]. To reduce the occurrence of landfill accidents, many scholars have researched its stability.

The stability of landfill sites is particularly important during the construction period and operation period and after closure [5, 30]. The stability analysis mainly includes several aspects of calculation, such as reservoir bank slope stability, waste dam stability, waste dump stability, and site closure coverage system stability [20, 21]. In recent years, with the rapid increase of municipal solid waste, landfill tends to develop to high-pile and large storage capacity, which leads to many landfill instability accidents and serious losses [31]. During the gradual compaction and degradation of waste, the important parameters (weight and shear strength) affecting the stability of landfill sites are constantly changing. Experience showed that the characteristics of the waste dump are closely related to the physical composition, buried depth, compaction, and degradation of waste, and its unique distribution law is very different from the traditional parameters.

Through analysis of accident causes of several landfill sites, it is found that characteristics of landfill and leachate level are important factors causing slope instability of landfill sites. Many researchers have studied landfill two-dimensional leachate migration law, but research of three-dimensional seepage and stability of landfill sites is rare. Aiming at the problems of seepage field and slope stability in heterogeneous landfill, the main work of this paper includes the following: firstly, the temporal and spatial distribution law of landfill characteristics is analyzed from the perspective of statistics, and the interaction between the characteristics is studied; secondly, the siltation model of guide and drainage layer is established, and the formation law and influencing factors of seepage field of the heterogeneous waste unit are studied; a heterogeneous stability model is established to quantitatively analyze the effects of slope geometry, strength characteristics, and leachate level on the stability of heterogeneous waste dump slope; finally, the waste heterogeneity model is applied to practical engineering and the reliability of the model is verified.

1.2. Engineering and Concealed Hazards. The studied landfill is a valley-type landfill and covers approximately 687,333 m². The total capacity is 49 million m³. The design’s maximum altitude is 120 m, and the total length is 1.5 km. The minimum width is 30 m at the base of the landfill, and the maximum width is 500 m at the top. The average altitude is 65 m, and the highest is at 80 m. The maximum height increased up to 70 m. The research area has more rainfall in summer and autumn, and the seepage coefficient of domestic waste landfills is large. A large amount of water seeps...
into the landfill and cannot be discharged in time. Therefore, the pore water pressure and waste weight of the landfill increase significantly, resulting in a landslide of the landfill. In 2000, the upstream waste dam collapsed, and in 2001, dry masonry was used to strengthen the slope. Therefore, high leachate levels and uneven settlement of waste are the main factors causing leachate leakage and waste dam cracking. During the continuous rainfall in 2007, due to the high pore water pressure, the downstream slope of the landfill site was unstable, and the downstream waste dam collapsed. The solution was to modify the downstream slope ratio of the waste dam from 1:2 to 1:3 and strengthen the slope. After the flood season in 2011, the waste on the 5th and 6th layers of the landfill site caused local landslides due to the untimely drainage of leachate, and the collapsed waste was about 20,000 m$^3$. In April 2016, a local landslide occurred on the upstream slope with an elevation of 580–600 m. The produced leachate reached almost 1,200 t/day, and the evacuation of leachate was about 300 t/day at the bottom of the landfill. Therefore, studying the distribution of leachate in this landfill and establishing a heterogeneous slope stability model to calculate the slope stability of the waste landfill based on the relationship between the characteristics of the waste landfill and the buried depth are of scientific significance.

2. Material and Methods

2.1. Material Seepage Characteristics and Research Scheme Design

2.1.1. Material Seepage Characteristics. Through the statistical analysis of the research on waste characteristics [32], it can be found that the seepage characteristics of waste have obvious heterogeneous characteristics in the direction of buried depth. When calculating the seepage field, many researchers divide the landfill into shallow waste, middle waste, and deep waste [19, 33]. As the landfill age gradually increases from shallow to deep, the saturated water content gradually decreases. This paper refers to the soil-water characteristic curve of waste (Dang et al.) [33]. The average annual precipitation in the studied area is about 582.5–752.8 mm. Combined with the physical composition of waste and referring to specification (2012), the volume water content during initial waste filling is taken as 50% [34]. According to the soil-water characteristic curve of shallow waste, the corresponding initial pore water pressure, $-2$ kPa, can be taken as the initial condition for calculation (Dang et al.) [33]. The material characteristics of each landfill area are depicted in Table 1.

Based on the research on the seepage test of similar landfill [35], this paper divides the waste body with a depth of 0–60 m into six layers and gives the saturated seepage coefficient ($K_1$–$K_6$) from shallow to deep. At the same time, the distribution of the saturated seepage coefficient function is also considered. The correlation between the saturated seepage coefficient and the buried depth is given in (1).

### Table 1: Seepage characteristics of the local material in landfill

| Landfill area      | Saturated seepage coefficient $k_{sat}$ (m/s) |
|-------------------|---------------------------------------------|
| Landfill body     | $K_1$, $K_2$, $K_3$, $K_4$, $K_5$, $K_6$    |
| Equation (1)      |                                             |
| Waste dam         | $1.0 \times 10^{-9}$                        |
| Clay foundation   | $1.0 \times 10^{-9}$                        |
| Overburden layer  | $8.37 \times 10^{-10}$                     |

Note. $K_1$, $K_2$, $K_3$, $K_4$, $K_5$, and $K_6$ are the values of saturated seepage coefficient $k_{sat}$ when $H$ is 5 m, 15 m, 25 m, 35 m, 45 m, and 55 m, respectively, in (1).

The relationship between the saturated seepage coefficient of waste and the buried depth is as follows:

$$
\lg k_{sat} = -4.024 - 1.018 \times 10^{-4}D - 2.815 \times 10^{-5}D^2
+ 7.077 \times 10^{-6}D^3.
$$

In the formula, $k_{sat}$ is the waste saturated seepage coefficient (m/s) and $D$ is the waste buried depth (m).

2.1.2. Research Scheme Design. There is a drainage layer at the bottom of the third stage landfill waste, and the landfill leachate often escapes from the slope. In the later stage, a drainage pipe is added near the slope of each layer of waste. Therefore, a drainage boundary is set at the corresponding position of the model, and a flow boundary is set at the top of each layer of waste to simulate the rainfall during the landfill of this layer of waste. Assuming that the rainfall is evenly distributed, the rainfall intensity at the slope needs to be reduced according to the slope ratio. This paper uses the secondary development of finite element software to establish a saturated–unsaturated heterogeneous transient seepage model to study the seepage field of the landfill during the process of landfill. When filling the first layer of waste at the bottom, the upper units are all inactivated, then the top of this layer is loaded with rainfall, and the seepage field of this layer of waste is calculated; when the second layer of waste is filled, the unit of this layer is re-“activated,” and the units above this layer remain inactivated. The results of the previous calculation are used as the initial seepage field of this stage, and the rainfall loading is carried out on the top of the waste of this layer to calculate the seepage field. Then, the seepage situation of the whole landfill is calculated by analogy. In the process of layered filling, the seepage coefficient of waste decreases gradually under the action of compaction and degradation with the increase of the landfill.

During the operation of the landfill, the drainage system will gradually become blocked, which will affect the discharge of leachate inside the landfill. The saturated seepage coefficient of gravel is generally greater than 0.005 m/s. For the design of silting and blocking conditions of the discharge layer, there are two schemes as follows: (1) the seepage coefficient of discharge layer $k_{d1} = 6.64$ m/day; (2) the seepage coefficient of discharge layer $k_{d2} = 4.80 \times 10^{-3}$ m/day. Considering the influence of discharge system blocking degree, landfill process, and vertical heterogeneity of seepage coefficient on landfill seepage field, the research scheme design in this paper is given in Table 2.
In Figure 1 is as follows:

The fitting equation of waste density \( D \) in Figure 1 is as follows:

\[
\gamma = 8.125 + 0.133333D - 0.000556D^2.
\]  

The fitting formulas of waste shear strength \( c, \phi \), and buried depth \( D \) are as follows:

\[
c = 21.25 - 0.43611D + 0.00111D^2 + 0.00001D^3,
\]

\[
\phi = 0.65222D + 0.00178D^2 - 0.00005D^3.
\]

2.2. Characteristics and Research Scheme Design of Waste Materials

2.2.1. Strength Characteristics of Waste Materials. Through the review of waste characteristics [32], it can be found that the physical compositions of waste have a very important impact on the engineering characteristics of waste landfills. According to the test data of material properties of the project and the material properties of other landfills [36,37], the distribution law of material density and shear strength characteristics in each area of the landfill site is given in Table 3. Since the density, cohesion, and internal friction angle of the waste in the actual landfill gradually change with the buried depth, as depicted in Figure 1, the fitting curve of the characteristics of the landfill is carried out. With the increase of landfill age, the organic matter in the waste with a larger buried depth will gradually degrade. Therefore, the inorganic matter content will be higher, which makes the waste density increase (Figure 1(a)). As the landfill age gradually increases from shallow to deep, the decrease of the strengthened phase directly results in the decrease of cohesion force of the waste (Figure 1(b)).

The fitting equation of waste density \( \gamma \) and buried depth \( D \) in Figure 1 is as follows:

\[
\gamma = 8.125 + 0.133333D - 0.000556D^2.
\]  

The fitting formulas of waste shear strength \( c, \phi \), and buried depth \( D \) are as follows:

\[
c = 21.25 - 0.43611D + 0.00111D^2 + 0.00001D^3,
\]

\[
\phi = 0.65222D + 0.00178D^2 - 0.00005D^3.
\]

2.2.2. Scheme Design of Waste Materials. According to the heterogeneity of landfill waste, the density of waste and the distribution of shear strength are considered in the calculation of slope stability, as given in Table 4.

2.3. Heterogeneous Seepage Model of the Landfill Site

2.3.1. Finite Element Model. According to the actual survey topographic chart (Figure 2(a)) of the landfill site, section 1–1 is intercepted (Figure 2(b)). The elevation of the downstream waste dam is 509 m. Phase I and II landfills in the early stage are one layer of waste every 15 m height. The top part is covered with about 0.3 m thick clay for rolling. To reduce the amount of leachate inside the landfill, a leachate discharge layer is buried at an elevation of 543 m at the bottom when the waste is filled to phase III. Then, landfill and soil are covered in a layer of 10 m height until 603 m above the top of phase III landfill.

Considering the landfill process, the finite element transient seepage model of the landfill is established. The mesh is divided into eight-node quadrilateral form and pore fluid/stress coupling element type (Figure 2(c)). The thickness of the intermediate overburden is taken as 0.3 m. Because the thickness of the intermediate overburden and the guide layer is relatively small, the mesh is encrypted to ensure the quality of the mesh division of the whole model, and the model is divided into 4,269 units and 13,122 nodes.

2.3.2. Numerical Model of the Landfill Filling Process. USDFLD secondary development subroutine is used to establish the numerical model of the landfill filling process (Schemes 1, 2, 4, and 5); establish the functional relationship between saturated seepage coefficient and filling time; set the material properties, boundary conditions, and load; and calculate and output the cloud chart of saturated seepage coefficient distribution of landfill as shown in Figure 3. It is found that with the increase of waste, the seepage coefficient of each layer changes constantly and decreases with the increase of buried depth. The final seepage coefficient ranges from \( 1.200 \times 10^{-4} \) to 2.540 m/day, which is consistent with the actual situation.

2.3.3. Numerical Seepage Model for Heterogeneous Waste Landfills. According to the relationship between the seepage coefficient and the node location, USDFLD subroutine written in FORTRAN is used to establish the variation relationship between the saturated seepage coefficient of waste and the landfill depth (Schemes 2, 3, 5, and 6); then set the material characteristics, boundary conditions, and loads; and calculate and output the distribution cloud chart of the saturated seepage coefficient of the waste landfill. When considering the landfill filling process, i.e., the change of landfill seepage coefficient with time, the relationship between seepage coefficient and landfill depth and landfill time needs to be constructed at the same time. Then, the change cloud chart of landfill saturated seepage coefficient is output through seepage calculation (see Figure 4).

With the increase of pile height, the saturated permeability coefficient of waste changes continuously. Compared with Figure 3, the biggest difference is that the permeability coefficients at different landfill depths are different, and the permeability coefficients at the slope in each landfill stage

| Blockage degree of the discharge system | Distribution of waste seepage coefficient | Consideration of the landfill process | Scheme |
|---------------------------------------|------------------------------------------|--------------------------------------|--------|
| \( k_{d1} \)                           | Interlayer homogeneity                  | Yes                                  | 1      |
|                                       | Interlayer heterogeneity                | No                                   | 2      |
| \( k_{d2} \)                           | Interlayer homogeneity                  | Yes                                  | 3      |
|                                       | Interlayer heterogeneity                | No                                   | 4      |
|                                       | Interlayer homogeneity                  | Yes                                  | 5      |
|                                       | Interlayer heterogeneity                | Yes                                  | 6      |
follow the same distribution law. The cloud chart shows that the saturated permeability coefficient of the waste landfill is $1.178 \times 10^{-4} \sim 8.175$ m/day, which is consistent with the actual situation, and the heterogeneous model is reasonable.

### 2.4. Two-Dimensional Slope Stability Analysis of Landfill

#### 2.4.1. Two-Dimensional Model and Boundary Conditions.

A two-dimensional finite element model is established based on the size and shape of the landfill section. In addition, plane strain elements are used to calculate the stability of the landfill. To optimize the mesh quality of the model, a four-node quadrilateral structure is used for structural meshing. When calculating the stability of a two-dimensional slope, it is assumed that the displacement of the two sides of the model along the horizontal direction is zero and the displacement of the bottom surface of the model along the horizontal and vertical directions is zero. The two-dimensional model waste landfill site is established as follows:

1. Homogeneous model (Scheme 1)
   The waste landfill is divided into three layers according to the order of landfill time, and the

| Material | Unit weight ($\text{kN/m}^3$) | Cohesion $c$ (kPa) | Internal friction angle $\phi$ (°) |
|---|---|---|---|
| Landfill (heterogeneity between layers) | Equation (2) | Equation (3) | Equation (4) |
| Phase I and II landfill | 15 | 0 | 36 |
| Phase III landfill (part 2) | 13 | 5 | 28 |
| Landfill (homogeneity between layers) | Phase III landfill (part 1) | 10 | 15 | 10 |
| Waste dam | 19 | 10 | 28 |
| Clay foundation | 19 | 40 | 24 |

### Table 3: Reference values for engineering properties of the landfill.

#### Figure 1: Variations in the landfill engineering properties with buried depth. (a) Density. (b) Shear strength.
(2) Heterogeneous model

Scheme 2: establishment of heterogeneous weight model (Schemes 2, 4-1, 4-2).

According to the relationship between waste weight and buried depth, the USDFLD subroutine is used to establish a numerical model of heterogeneous weight. Then, material properties, boundary conditions, and loads are set. The cloud chart of waste weight distribution as shown in Figure 5(b) is calculated and output. The difference from Scheme 1 is that the waste weight near the slope is relatively small and there is no obvious stratification with the elevation direction. Since the maximum landfill depth
of waste is about 75.77 m, the figure shows that the weight range of the waste pile is 8.104~15.08 kN/m³, which conforms to the law of Figure 1(a), so it is closer to the actual situation.

Scheme 3-1: establishment of heterogeneous shear strength model (Schemes 3-1, 3-2, 4-1, 4-2).

UTEMP subroutine is written, to establish the functional relationship between landfill depth and model node coordinates, and to set the shear strength parameters of waste. According to (2) and (3), the relationship between cohesion, internal friction angle, and landfill depth is established. Then, other material characteristics, boundary conditions, and loads are set for stability calculation. The distribution nephogram of landfill depth in Schemes 3-1 and 4-1 (see Figure 5(c)) and that in Schemes 3-2 and 4-2 (see Figure 5(d)) are output.

Scheme 4: establishment of heterogeneous weight and shear strength model.

Using USDFLD and UTEMP subroutines, the functional relationship between the three parameters of waste weight, cohesion, and internal friction angle and the landfill depth is constructed. Combined with the relationship between the buried depth and node coordinates, three field variables are defined, and one of them is the strength reduction coefficient, to set the variation law of cohesion and internal friction angle with the reduction coefficient. Then, according to the above process, the heterogeneous model of Scheme 4 is obtained, and
|       | FV1          | TEMP         | TEMP         |
|-------|--------------|--------------|--------------|
| (Avg: 75%) | +1.508e+00 | +1.070e+02  | +7.577e+01  |
|       | +1.450e+00  | +8.820e+01  | +6.954e+01  |
|       | +1.392e+00  | +8.942e+01  | +6.331e+01  |
|       | +1.334e+00  | +8.065e+01  | +5.708e+01  |
|       | +1.276e+00  | +7.187e+01  | +5.084e+01  |
|       | +1.217e+00  | +6.309e+01  | +4.461e+01  |
|       | +1.159e+00  | +5.432e+01  | +3.838e+01  |
|       | +1.101e+00  | +4.554e+01  | +3.215e+01  |
|       | +1.043e+00  | +3.677e+01  | +2.591e+01  |
|       | +9.848e-01  | +2.799e+01  | +1.968e+01  |
|       | +9.267e-01  | +1.922e+01  | +1.345e+01  |
|       | +8.685e-01  | +1.044e+01  | +7.219e+00  |
|       | +8.104e-01  | +1.667e+00  | +9.865e-01  |

Figure 5: (a) Two-dimensional model of the landfill site. (b) Distribution cloud chart of waste unit weight (unit: ×10 kN/m²). (c) Simulated cloud chart of buried depth in Scheme 3-1 and Scheme 4-1 (m). (d) Simulated cloud chart of buried depth in Scheme 3-2 and Scheme 4-2 (m).
2.5. Three-Dimensional Slope Stability Analysis of Landfill

2.5.1. Three-Dimensional Model and Boundary Conditions. A three-dimensional finite element model is established according to the landfill topographic chart (Figure 2(a)), and the stability of the landfill is calculated by three-dimensional stress element. To optimize the mesh quality of the model, a three-dimensional eight-node hexahedral reduced integral element is used for mesh generation. The three-dimensional model and mesh generation of the landfill are shown in Figure 6(a), including 23,642 nodes and 20,208 units. The foundation requires nearly one-time the height of the pile body toward the bottom and downstream range, and about three times the height of the pile body to the upstream range. In the calculation of three-dimensional slope stability, it is assumed that the displacement of the upstream and downstream sides of the model along the $X$ direction is zero; the displacement of the front and rear sides along the $Y$ direction is zero; the displacement of the bottom surface along the $X$, $Y$, and $Z$ directions is zero; and the other surfaces are free boundaries. The dimensions and boundaries of the three-dimensional model are shown in Figure 6(b). In the actual survey, it is found that the landfill site is in a U-shaped valley, with high and steep slopes on both banks, most of which are formed by manual excavation and slope cutting based on natural bank slopes. According to the field investigation and measurement, the bank slope rate of the reservoir area is about $1:0.8$–$1:0.7$.

2.5.2. Research Scheme Design. The slope stability is calculated by considering the characteristic distribution of homogeneous waste and heterogeneous waste, respectively. When calculating the stability of a three-dimensional landfill, the slope stability of a three-dimensional landfill is analyzed. The selection of material parameters for each part of the landfill site is depicted in Table 5. The heterogeneous characteristics are considered as the functional relationship between the waste weight, cohesion, and internal friction angle with the landfill elevation.

For Scheme 4-1, the establishment method is the same as that of the two-dimensional heterogeneous model. At this time, the model coordinates are $X$, $Y$, and $Z$ variables. USDFLD and UTEMP subroutines are compiled to establish the functional relationship between the three parameters of waste weight, cohesion, internal friction angle and the depth of the waste landfill. At the same time, the relationship between the two strength parameters of cohesion and internal friction angle and the strength reduction coefficient is established according to the strength reduction formula.

Then, the load and boundary are applied to analyze the stability of landfill slope. After postprocessing, the three-dimensional cloud chart of the landfill depth distribution of waste landfill is output as shown in Figure 7. The vertical $Y$-axis section has the same effect as the two-dimensional simulation in Figure 5(d).

3. Result Analysis and Discussions

3.1. Heterogeneous Seepage Model of the Landfill Site

3.1.1. Saturated-Unsaturated Seepage Mechanism. Based on the saturated–unsaturated seepage mechanism, the numerical analysis method is used to calculate the leachate movement in the landfill under various schemes. Figure 8 depicts the distribution of leachate and pore water pressure in the landfill at the end of the ninth layer landfill under Scheme 4. As depicted in the figure, when the pore pressure is 0 kPa, it is the leachate level line; the white area less than 0 kPa is the unsaturated area of the landfill; the colored area below the water level line is the saturated area. Except for the first layer of waste at the bottom, there are stagnant leachate levels in the top of the intermediate overburden of each waste layer. It can be concluded that the intermediate overburden is the main reason for the stagnant leachate level, which is the same as the actual survey results.
Duetothedischargeboundaryateachlayerofthewasteslope,assumingthenormaloperationoftheslopedischarge system,thestagnantwaterlevelofeachlayerdecreasesnear the slope. Because of the rainfall seepage on the landfill surface and slope in phase I and II landfill and a lack of dischargesystematthebottom,thefirstlayerofwasteatthe bottomhasaconfinedwaterhead(Figure8(b)).Underthe influenceoftoprainfallseepageandtopographical condi-tions, the upstream sections of the fifth and sixth layers of wasteallproduceconfinedwaterheads,whichareconsistent withtheresults calculatedbyDangetal.[33].

3.1.2. Silting Degrees of Discharge Layers. According to differentsiltingdegreesofdischargelayers,thedistribution ofleachateinSchemes1and4within two years of laying the discharge pipe is depicted in Figure 9. When the discharge layer is silted, the leachate in the wastelayercannotbedischargedinitime andaccumulatesin the toph of the dis-chargelayer,resultinginas stagnantwater level. In Scheme 1, the degree of silting of the discharge layer is relatively small, and part of the leachate in the fourth layer of waste is dischargedfromtheoutletoftheslopedischarge layer.

Itcanbeseenthethestagnantleachatelevelnear the outlet of the discharge layer obtained by Scheme 1 is rela-tively low(Figure 9(a)). Since the fifth layer of waste is buried, the fourth layer of stagnant water level continues to decrease until it reaches an equilibrium state under the combined effects of rainfall seepage, drainage layer dis-charge, and seepage of intermediate overburden layer.
In Scheme 4, because the seepage coefficient of the drainage layer is small, the stagnant leachate level is high after landfilling the fourth layer of waste. There is still a saturated area at the fourth layer of the waste slope when the next layer of waste landfills is completed until the seventh layer of waste landfilling becomes unsaturated at the initial stage.

The results reveal that burying the discharge layer is one of the important measures to reduce the stagnant leachate level inside the landfill. However, due to the interception effect of the intermediate overburden layer on the top landfill leachate, the discharge layer has little effect on the stagnant leachate level of other landfill layers. Assuming that the discharge layer is completely silted, the leachate will be difficult to discharge, consequently generating an everlasting stagnant leachate level.

3.1.3. Influence of Discharge Layers. To analyze the influence of discharge layers on leachate under different boundary conditions, Figure 10 depicts the leachate level distribution when the fourth layer of landfill is completed under Schemes 2, 3, 5, and 6. When the landfill process is not considered, the rainfall gradually seeps into the landfill from the surface and the slope. Figures 10(a) and 10(c) reveal that the stagnant leachate level of the landfill layer near the surface decreases layer by layer from top to bottom. At first, the stagnant water level of each layer near the slope occurs and gradually spreads to the interior with the increase of rainfall duration.

In Scheme 2, due to the relatively large seepage coefficient of the discharge layer, the leachate seeps from the slope and flows along with the drainage layer to the fourth layer of waste. Therefore, the stagnant leachate level of the fourth layer in Figure 10(a) extends more into the waste layer.

When considering the landfill process and the heterogeneous distribution of the seepage coefficient of the waste, the stagnant water level is generated layer by layer from bottom to top with the landfill height. The silting of the discharge layer in Figure 10(d) is more serious than that in Figure 10(b). The difference of the fourth layer’s stagnant leachate level is about 0.7 m under the two schemes at the #3 observation point.

The results show that the reasonable setting of boundary conditions, the clogging degree of the discharge layer, and the distribution law of the landfill seepage characteristics are the key to calculating the landfill seepage field.

3.1.4. Variation of Leachate Level. To compare the variation of leachate level in the landfill under each calculation scheme, five observation points are selected to monitor the leachate level as depicted in Figure 11. Observation point #1 is used to obtain the height of the first stagnant leachate level in different landfill stages; the height of stagnant leachate level in the second and third layers is monitored at observation point #2; to reflect the sensitivity of discharge layer to rainfall, observation point #3 used to obtain the fourth stagnant leachate level is selected near the discharge outlet; observation point #4 is used to obtain the height of the fifth layer of stagnant leachate; observation point #5 monitors the sixth to the ninth layer of stagnant leachate level.

According to the seepage numerical calculation, Figure 12 depicts the variation law of the stagnant leachate level of each layer in the landfill process under Scheme 4. The stagnant leachate level number in the figure is the observation point number + L number of waste layers. For example, the stagnant leachate level of the first layer is expressed as # 1 + L. Due to the low seepage coefficient of the discharge layer at the bottom of the fourth layer of waste, the rainfall seeps from the landfill surface and slope to the top of the discharge layer and accumulates to form a stagnant leachate level of about 3.2~5.6 m. Only a small amount of leachate is discharged from the slope outlet, but it has little impact on the stagnant leachate level of other waste layers.

It can be seen from the figure that there are 9 layers of stagnant leachate level in the landfill site. Because the seepage coefficient of the intermediate overburden is small, it hinders the leachate seepage and makes it accumulate in the top of the intermediate overburden, which is consistent
with the research results of the literature (Dang et al.) [33]. When landfilling the first layer of waste, the stagnant water level gradually increases with the increase of rainfall duration, and the maximum confined leachate head reaches 17.6 m. This is because there is no discharge device at the initial stage of the landfill process of the first and second stages of waste at the bottom. With the continuous increase of waste, the number of stagnant leachate levels gradually increases. Under the effect of the discharge layer, the third layer of waste at the bottom is less supplied by the upper leachate, which makes the leachate seep into the first and second layers of waste; consequently, the stagnant leachate level of the third layer gradually decreases.

For other schemes, Figure 13 depicts the distribution of landfill leachate under the effect of rainfall in the previous five years. Schemes 1 and 3 have the same degree of silting. When the seepage coefficient of waste is heterogeneously distributed with the buried depth, the seepage coefficient of top waste is larger. The initial rainfall seepage rate is relatively larger. Therefore, the maximum stagnant leachate level generated by Scheme 3 is relatively higher. Similarly, the maximum stagnant leachate level of Scheme 6 is higher than that of Scheme 4. Due to the serious silting in Scheme 6, the stagnant leachate level of each layer is higher than that in Scheme 1 and Scheme 3. When the landfill process is not considered, the rainfall seeps into the landfill from the top and the slope to produce leachate. Firstly, the stagnant leachate level is formed on the slope and top of the landfill. Then, with the increase of rainfall duration, it gradually extends to the landfill. This scheme is suitable for knowing the initial leachate level of the landfill and analyzing the impact of rainstorms on the seepage field in a certain period.

The maximum stagnant leachate level of each layer of the six schemes is compared, as shown in Table 6. It can be seen that the stagnant leachate level of each layer is high, especially in the waste layer at the bottom of the landfill. According to the field investigation of several large landfills carried out, most of the leachate in the top landfill layer is about 3–5 m away from the landfill surface, which is higher than the leachate level of landfills in other countries [38].

When considering the landfill process, the height of the stagnant leachate level of the ninth layer calculated in this paper is about 6.24–7.13 m, which is consistent with the above survey results. For the calculation results of Schemes 1–3, the fourth layer’s stagnant leachate level is lower due to the larger seepage coefficient of the discharge layer. When the landfill process is not considered, the rainfall seepage from the top of the landfill site makes the stagnant leachate level calculated in Scheme 2 and Scheme 5 rise and decrease layer by layer. Considering the heterogeneity of the seepage coefficient, the maximum stagnant leachate level calculated by Scheme 3 and Scheme 6 is slightly higher than that calculated by Scheme 2 and Scheme 5, which is in agreement...
Figure 13: Leachate level distributions of the landfill in the first five years. (a) Scheme 1. (b) Scheme 3. (c) Scheme 5. (d) Scheme 6.

Table 6: Max. perched levels of all the schemes (m).

| Observation point | #1     | #2     | #3     | #4     | #5     |
|-------------------|--------|--------|--------|--------|--------|
| Waste layer       | 1st layer | 2nd layer | 3rd layer | 4th layer | 5th layer | 6th layer | 7th layer | 8th layer | 9th layer |
| Scheme 1          | 17.60  | 8.94   | 6.82   | 4.90   | 5.18   | 5.52   | 6.23   | 6.67   | 6.24   |
| Scheme 2          | 11.75  | 6.33   | 5.35   | 2.63   | 3.13   | 6.91   | 7.61   | 7.95   | 8.23   |
| Scheme 3          | 17.60  | 8.71   | 7.92   | 5.32   | 7.06   | 7.32   | 7.44   | 7.92   | 6.96   |
| Scheme 4          | 17.60  | 8.86   | 6.72   | 5.67   | 5.53   | 5.83   | 6.37   | 6.80   | 6.43   |
| Scheme 5          | 11.72  | 6.38   | 5.38   | 4.01   | 3.10   | 7.16   | 7.85   | 7.92   | 8.36   |
| Scheme 6          | 17.60  | 8.94   | 8.24   | 5.84   | 7.33   | 7.56   | 7.48   | 7.93   | 7.13   |
with the data of field observation and literature investigation [35,38–40].

3.1.5. Influence of Leachate Water Level on Slope Stability of the Landfill. Due to rainfall and waste degradation, a large amount of leachate is produced in landfills. To analyze the influence of the leachate level on the stability of the landfill, the main leachate water level is assumed to be $h$, and the stagnant water level is ignored. The slope ratio of the landfill is taken as 1 : 3, and the slope height is taken as $H = 20$ m, 40 m, and 60 m. The calculation schemes are as follows: For the same homogeneous slope with $H = 60$ m, $T/H = 1$, $\gamma = 11$ kN/m$^3$, $\epsilon = 20$ kPa, and $\varphi = 22^\circ$. A set of varying leachate water levels is designed. That is, $h/H1 = 0$, 0.15, 0.25, 0.35, 0.45, 0.55, 0.65, 0.75, 0.85, and 0.95. The strength reduction method is used to calculate the 2D and 3D slope safety factors at different leachate water level heights. When $h/H1 = 0.65$, the leachate water level distribution and pore pressure cloud chart are depicted in Figure 14(a), and the plastic zones of 2D and 3D slope critical instability under this water level are calculated as Figures 14(b) and 14(c), respectively.

It can be seen that the two sliding surfaces slide out from the top to the toe of the slope, and the calculated safety factor of the 2D slope is smaller than that of the 3D slope. Through the finite element analysis, the relationship between the leachate water level and the slope safety factor is depicted in Figure 14(d). It can be seen from the figure that the safety factor is larger when there is no water in the slope, and the safety factor gradually decreases with the increase of the leachate water level. For the same leachate water level, the safety factor of the 3D slope calculated is higher than that of the 2D slope, which can be seen as a result of the influence of slope thickness. When the leachate water level is high, the difference between the two is small, and the height of the water level has a greater effect on the safety factor than the thickness of the slope.

3.2. Heterogeneous Stability Model for Landfill Site

3.2.1. Analysis of Two-Dimensional Slope Stability of Landfill Site. Figures 15(a) and 15(b) show the plastic zone and corresponding deformation of the landfill slope in critical instability (Scheme 1). The minimum safety factor of the slope is calculated as 1.473. Scheme 2 is the same as Scheme 1, stratified and homogeneous distribution of refuse shear strength are considered, and slope stability is calculated only when the weight distribution is changed. Due to the large difference in shear strength between the two layers of landfill waste in phase III project, there is a weak structural plane at the junction of the two layers, and a local landslide occurs at the top of the slope. The sliding point is located at the slope toe of the (upper) part of the landfill waste in phase III. The displacement and deformation in the plastic zone increase sharply, which is mainly manifested in sliding to the left and lower. Figure 15(b) shows the effect chart of the deformation magnified by 15 times when the waste slope is critically unstable.

The plastic zone of the critical instability of the landfill slope in Scheme 3-1 is depicted in Figure 15(c). It can be seen that there is a sliding surface similar to the position of Scheme 1, which slides out from the top of the slope to the toe of the sixth layer of the waste slope. In addition, another sliding surface slides out from the toe of the seventh layer of the waste slope. When the shear strength of the waste is distributed with the elevation, the minimum safety factor of the slope is larger due to the larger cohesion and density of the waste at the top.

For Schemes 3-2 and 4-2, the distribution of the shear strength of waste with the depth is considered as a function of heterogeneity. However, the density range is small, i.e., 8.125–15.080 kN/m$^3$, and there is no sudden change in the strength of the whole landfill. Therefore, the overall landslide occurs on the slope. The sliding point is at the angle between the waste dam and the landfill (Figure 15(c)). The reason is that there is a large difference in shear strength and density between the waste near the slope and the waste dam, creating a weak structural plane. In Scheme 3-2, the displacement and deformation of the waste slope during critical instability are depicted in Figure 15(e). The displacement and deformation of the waste body above the sliding surface increase unexpectedly, which is mainly manifested as horizontal displacement and waste sliding to the lower left.

Through the finite element model calculation, the safety factor of landfill slope with critical instability under four schemes is depicted in Table 7. It can be found that the weight and shear strength distribution have a great influence on the stability of the landfill slope, especially the shear strength, and change the instability type and sliding surface position of the slope. Because the weight of waste along the slope and landfill surface in Scheme 2 is smaller than that in Scheme 1, the calculated safety factor is larger. Because the change range of waste weight is small, the influence of this parameter on stability is small, and the instability type and sliding surface position are not changed. The results conform to the law of the influence of weight and shear strength on the safety factor.

For Schemes 3-1 and 4-1, the shear strength of the waste presents heterogeneous distribution with the landfill elevation. That is, the cohesion and internal friction angle of the waste at the same elevation are the same. Consequently, the shear strength of each elevation near the slope varies greatly, resulting in local slope instability.

For Schemes 3-2 and 4-2, the difference between the weight and shear strength of the slope near the waste and the landfill surface is small, both of which are shallow waste characteristics. Therefore, the overall instability of the slope after strength reduction is calculated.

According to the code for the design of landfills, the slope safety factor of grade I landfill site should be greater than 1.35 under normal conditions. It can be seen that, without considering the effect of pore pressure, the landfill site does not lose stability under all four schemes. When considering the leachate in the landfill, the pore pressure results calculated in Scheme 6 are taken as the boundary conditions for stability calculation. The waste weight and shear strength are selected according to Scheme 4-1.

When
the strength reduction coefficient is 1.109, the calculation does not converge and the calculation stops. At this time, the circular-slip surface appears on the downstream waste dam slope, and the plastic zone appears along the slope at the bottom of the landfill.

Due to the deficiency of anti-seepage facilities at the bottom of the landfill, the leachate in the downstream waste dam is very high, and the slope of the landfill is saturated due to rainfall, which is unfavorable to the stability of the slope and leads to critical failure. The calculation results are close to those in the literature [19]. The landslide occurs at the waste dam, which is quite different from the safety factor (1.794) of the critical failure of the slope without water. Therefore, in the process of landfill design and management, special attention should be paid to the landfill downstream dam strength, drainage design, and landfill slope protection.

To sum up, it can be seen that the waste weight, shear strength, and distribution of leachate have a great influence on the slope stability of the landfill. The characteristics of waste are closely related to many factors such as the depth, age, degradation, and physical composition of the landfill. Therefore, the reasonable setting of model strength parameters and leachate level distribution is still an important issue in the calculation of landfill stability.

Through the literature research, the following is found: (1) the slope thickness-height ratio has a certain impact on the slope stability of the landfill; (2) it is necessary to cut the slope on both sides of the reservoir before the landfill process; (3) the slope instability of the reservoir bank also has great harm to the landfill. Therefore, it is necessary to analyze the three-dimensional finite element method stability of the whole landfill site.

3.2.2. Analysis of Three-Dimensional Slope Stability of Landfill Site. Through the finite element method calculation, the safety factor of landfill slope with critical instability under four schemes is obtained in Table 8. For the safety level of the bank slope in the landfill area, the safety factor should be greater than 1.25, and it can be found that no slope instability occurs. Because of the steep bank slope, the stability of the downstream front bank slope of the landfill is poor, and the critical safety factor is the smallest. The order of bank slope instability is downstream front bank slope, downstream back bank slope, upstream front bank slope, and upstream back bank slope. In the actual project, because of the steep cut slope and poor stability, the slope is slowed down in the later landfill process.
When the waste material is taken as shallow homogeneous, the safety factor of the landfill slope is 1.077. At the same time, the slope is damaged by the landslide. The plastic zone of the critical failure of the slope at each position of the landfill is calculated according to the scheme as depicted in Figure 16(a). Both the upstream and
downstream bank slopes and the landfill slope form the thorough plastic zone.

Three sections in the model are selected to obtain the sliding body shape of bank slope and landfill slope as shown in Figures 16(b) and 16(c). At the four locations, the soil mass slides towards the bottom of the slope, and the sliding surface slides out from the top to the bottom of the slope, showing a circular shape. The instability of the downstream bank slope is serious, mainly manifested by the sudden change of the displacement in $Y$ and $Z$ directions. When considering the homogeneous characteristics of waste, the overall instability of the slope of waste landfill occurs, and the sliding surface slides out from the top of the slope to the foot of the slope in contact with the downstream waste dam, presenting an arc shape, which is mainly manifested as the abrupt displacement of $X$ and $Z$ directions. To reflect the sliding form of the slope, the landslide deformation is shown in the figure by 2 times.

When the waste weight, cohesion, and internal friction angle continue to change with the elevation of the landfill, the plastic zone of critical failure of the landfill slope is depicted in Figure 17(a). When the overall strength reduction factor of the landfill is 1.507, the plastic zone appears on both sides of the upstream and downstream bank slopes, and the thorough plastic zone does not appear on the slope of the landfill.

As shown in Figure 17(b), two sections of the model are selected to provide the morphology profile of the slope slide body. In the four locations, the soil on the bank slope slides to the bottom, and the sliding surface slides out from the top to the bottom, presenting a circular-arc shape. The instability of the bank slopes on both sides of the downstream is serious, which is mainly manifested by sudden changes in displacements in $Y$ and $Z$ directions.

Based on the above analysis, the bank slope of the landfill should be slowed down appropriately in combination with
the storage capacity and slope stability. In the finite element analysis of the landfill, the density, cohesion, and internal friction angle distribution of the waste have a great impact on the stability of the landfill. Therefore, it is very important to study the three-dimensional distribution of the characteristics of the landfill, which is the basis of the accurate calculation of the slope stability of the landfill.

4. Conclusions, Recommendations, and Potential Future Studies

4.1. Conclusions and Recommendations. In this paper, a series of studies on the heterogeneity of landfills are carried out, and the heterogeneity, seepage field, and stability of landfills are deeply studied by using the methods of statistical analysis and numerical analysis. The main conclusions of this paper are as follows:

1. Based on the principle of saturated–unsaturated seepage of heterogeneous soil, a method of establishing a seepage model considering the characteristics of heterogeneous seepage and the process of filling is proposed. At the same time, the model of silting and blocking the drainage layer is established, which can not only calculate the water level distribution of the seepage liquid in the actual process of silting and blocking the drainage layer of the landfill, but also be applied to the distribution of the permeability coefficient of the drainage pipe on the sand ground and the drainage of the tailings pond pipe silting and other similar projects. The influence of rainfall intensity, guide layer, middle cover layer, and garbage permeability coefficient distribution on the seepage field of landfill unit has been studied, and the formation reason of the stagnant water level and the factors affecting the stagnant water level height are obtained. Considering the heterogeneity of waste, it can be regarded as dividing waste piles into infinite layers. The maximum perched water level is large, which is unfavorable to the stability of landfills. Therefore, the selection of permeability coefficient and distribution of landfill permeability is the key to the analysis of the landfill seepage field.

2. Combined with the distribution law of shear strength of landfill, a method of building heterogeneous finite element model about the unit weight and shear strength of garbage is put forward. Through research, it is found that the distribution of unit weight and shear strength of waste has a great influence on the stability of the slope; especially in the early stage of the landfill, the unit weight change rate of waste is large. The effects of slope height, ratio of slope thickness to height, ratio of slope thickness to height, unit weight, shear strength, and water level of leachate on slope safety coefficient are studied. When the ratio of slope thickness to height is large, three-dimensional slope can be simplified as a two-dimensional plane strain problem. Under the same conditions, the safety factor of the three-dimensional slope is slightly larger than that of the two-dimensional slope. When the water level of leachate increases to a certain height, the difference between the two is small, and the water level has a greater impact on the safety factor than the slope thickness. A series of safety coefficient charts are given through calculation. Under the condition that each parameter is determined, the range of safety coefficient of landfill slope can be predicted preliminarily, which provides the basis for the early design of landfill.

3. Taking an actual landfill as the research object, the saturated–unsaturated transient model of heterogeneous waste is applied to practical engineering. Considering the landfill process and heterogeneous permeability, the calculated maximum water level is higher. Compared with the homogeneous material, the difference in the water level of each waste layer is about 0.08–1.88 m, which is not good for the stability of the landfill. At the same time, the development law of the heterogeneous waste unit leachate is verified, which provides a basis for the design of the landfill dewatering and safe operation. In the landfill, the water level of leachate is high and there is a multilayer stagnant water level. The guide and drainage layer can only reduce the stagnant water level of the current garbage layer better, and the stagnant water level drops about 0.52–1.38 m, while the other garbage layers have less impact due to the barrier of the covering layer. In the actual landfill, guide and drainage pipes should be set at the bottom of each layer of garbage, or vertical wells should be used to reduce the stagnant water level.

4. Combined with the engineering characteristic distribution of an actual landfill, the heterogeneous stability model is applied to the actual project to study the influence of different unit weight and shear strength distribution on landfill stability. The model is also applicable to complex terrain, geomembrane, or multiple strata. It is found that the mechanical properties of refuse have a great influence on the stability of landfill slope; the shear strength distribution especially plays an important role in determining the type of slope instability and the position of the sliding surface. Considering the water-free condition, the calculation results show that the landfill has no instability under various weight and shear strength distributions, and the safety factor is 1.363–1.794. Considering the perched water level of the landfill, the downstream waste dam has a landslide, and the safety factor is 1.109, which needs to be reinforced. Through the analysis of the slope stability of the three-dimensional landfill, it is found that the slope of the reservoir bank is steep and prone to instability. During the operation and management of the landfill site, the stability of the slope of the reservoir bank should be paid attention to while considering the capacity of the landfill. If necessary,
the bank slope should be strengthened or the slope ratio improved.

4.2. Potential Future Studies. Combined with statistical analysis and secondary development of finite element software, this paper puts forward heterogeneous seepage model, stability model, and siltation model of guide and drainage layer of the landfill and studies the seepage field and slope stability of landfill. Due to the limitation of the authors’ time and energy, some research work in this paper is still worthy of further research and improvement. The heterogeneous model and stability of landfills can be deeply studied from the following aspects: (1) This paper studies the relationship between the physical composition, weight, permeability coefficient, shear strength, and buried depth of waste in landfills from the perspective of statistics. Through the model test, the interaction between the characteristics can be monitored in real time, and the change law can be analyzed quantitatively. Therefore, the model test research of waste characteristics needs to be further carried out. (2) In this paper, the Darcy flow theory is used to analyze the seepage field of landfills. In practice, due to the influence of landfill components and landfill methods, the dominant flow is also an important form of leachate migration in a landfill. Considering the Darcy flow and the dominant flow at the same time is an important further work, which can be started from a combination of laboratory experiments and numerical analysis. Due to the complexity of waste components and the randomness of the landfill, there is uncertainty in the priority channel, so the study of dominant flow still needs a long time. (3) Rainfall and garbage degradation are important sources of leachate levels in a landfill. This paper only studies the seepage field under the action of rainfall, and the research on the garbage degradation process is the work that needs further research [41,42].

Data Availability

The data used to support the findings of this study are included in the article.

Disclosure

The abstract of this paper has been published in a conference proceeding [43].

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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