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# Analysis of deformation characteristics of layered ground under uniform load

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**Abstract.** For the layered ground in a large area, the deformation under uniform load is analyzed numerically. Considering the work property of the concrete plane, the uneven settlement is strictly restrained using different foundation. In the process of settlement calculation, according to the linear interpolation of multiple borehole elevations, the geological profiles with different soil layer thickness are formed, and the influence of compressed soil layer thickness on the total settlement and uneven settlement is fully considered.

## 1 Project overview

According to the general plan and borehole layout, the floor of a test hall is a large-area concrete structure. Under the action of water load in the pool and model load, the foundation will produce obvious settlement, which may lead to floor cracking[1-3]. In addition, according to the geological survey report, the foundation compression layer within the test hall is large and uneven in thickness, which is easy to produce uneven settlement. In order to reduce the influence of uneven settlement on the concrete floor, the designer proposes to adopt pile foundation, and gives two types of pile foundation: cement mixing pile and prestressed concrete pipe pile[4-6]. The corresponding cost will increase by 6.245 million and 4.462 million respectively, which greatly increases the project cost.

In this paper, considering the influence of different thickness of compression layer of layered foundation, the settlement deformation of test hall foundation under large-area service load is studied, and the causes and changes of uneven settlement are mainly analyzed. The research results can provide basis for later foundation selection.

## 2 Load, soil layer distribution and soil property analysis

### 2.1 Load analysis

The elevation system in the geological exploration report takes the theoretical lowest tidal level of Tianjin Xingang as the datum, while the Dagu elevation is taken as the elevation system in the design data. The conversion relationship between the two is: Xingang elevation = Dagu elevation+1. In order to unify the elevation, Xingang elevation system is adopted in the calculation. The profile and elevation of the test hall are shown in Figure 1.

It can be seen from Figure 1 that according to the converted Xingang elevation, the average elevation of the borehole orifice within the scope of the test hall is + 4.0m, while the indoor floor elevation of the test hall is + 5.4m. Considering the depth of the pool and the thickness of the bottom plate, the concrete bottom plate elevation of the test hall is just equal to the original surface elevation. If the elevation of the concrete floor, i.e. the original ground, is taken as the analysis object, the fill on both sides, the service load and the concrete floor are regarded as the large-area uniform load:

1) The weight of the concrete floor within the pool;

The thickness of the concrete floor is 0.2m, the unit weight is 26kN/m$^3$, which is above the groundwater level, so the uniform load of the concrete floor is 5.2kpa.

2) Weight of overburden on both sides outside the pool

The filling height is 1.4m, the natural bulk density is 18kn / m3, which is above the groundwater level, so the filling load on both sides is 25.2kpa.

3) Water load, model (aggregate) load, wave maker load, etc. within the scope of the pool

The water depth in the pool is 1m, the uniform water load is 10kPa, the model load is considered as the uniform 10kPa load, and the service load is 2T; the weight of the wave maker is 2.5t, the bottom area is 2M2, and the load generated by the wave maker is 12.5kpa. In order to consider the adverse effect of the wave maker load on the uneven settlement, the wave maker load always acts on the maximum thickness of the

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compressed soil layer. The specific load action diagram is shown in Figure 2.

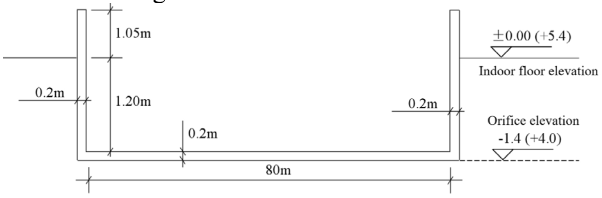


**Fig. 1** Elevation and dimension diagram of hydraulic test hall

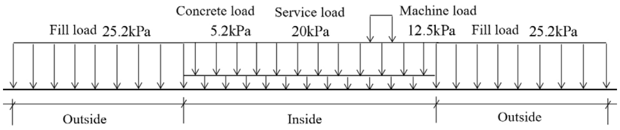


**Fig. 2** Schematic diagram of foundation action load of hydraulic test hall

### 2.2 Soil distribution

According to the drilling data, it can be divided into ten layers from top to bottom, mainly including plain fill 1, muddy clay 2a, silty clay 2b, muddy clay 2c, silty clay 2D, silty clay 3, silty clay 4a, silty clay 4b, silty clay 4c and clay 5a. The thickness of soft soil mucky clay 2c and silty clay 2d in the hydraulic hall is the most uneven, while the thickness of soft soil mucky clay 2a, silty clay 2b and mucky clay 2c in the reservoir is the most uneven.

### 2.3 Soil property analysis

The soil parameters have great discreteness, and the indexes are greatly affected by the drilling method, disturbance degree, test method and result statistics. The uncertainty of geotechnical parameters mainly comes from two aspects: one is the inherent variability of soil. Due to the changes of mineral composition, soil depth, stress history and other factors in the formation process of soil layer, the properties of soil at each point may be quite different; the other is the uncertainty of system environment, including test uncertainty, model uncertainty and statistical uncertainty. In order to get more reliable indexes, a large number of physical and mechanical tests are needed to classify the test results, eliminate the obvious error values, and get the average value of each index. Refer to the code for design of building foundation (GB 5007-2011), the unit weight, compression modulus and compression coefficient are taken as the arithmetic average value, and the shear index is taken as the standard value.

## 3 Foundation settlement calculation of test hall

### 3.1 Calculation conditions

The software used in this calculation is "port engineering foundation calculation system 2008 edition", which is based on the latest specifications and has unique advantages in foundation settlement calculation, consolidation analysis and stability calculation. According to the borehole profile, the required block division is shown in Figure 3, and the load distribution is shown in Figure 2. The bottom elevation of the calculation depth is - 35m, the elevation of each soil layer is given according to the actual drilling depth, and the linear interpolation is used between the drilling holes. In this way, the influence of different compressed layer thickness on the surface uneven settlement can be effectively considered. The physical index of each "block" is the arithmetic average value of each layer, and the mechanical index is the standard value. The pool is about 80m long and 60m wide. The stratigraphic profile along the length of the pool is shown in Figure 3. In order to calculate the settlement value of the surface and stratum in the depth direction, the coordinate origin (0,0) is set at the midpoint of the length of the surface floor, which is the x-axis along the surface and the Z-axis in the depth direction.

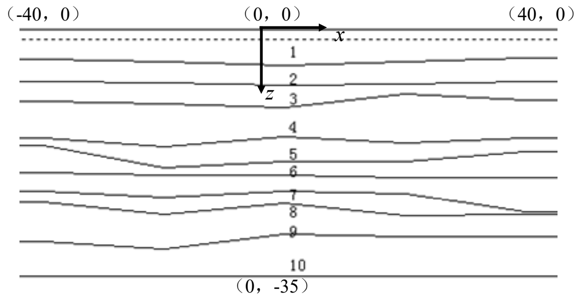


**Fig. 3** calculation of soil layer and "block" division

As mentioned above, in order to consider the influence of wave maker on the uneven settlement of foundation, the wave maker load acts on the place with the largest thickness of compressed soil layer. It can be seen that the thickest part of muddy clay 2c (block No. 4) is located at (20,0), while the action width of wave maker is 2m, so the action range of wave maker is between (19,0) and (21,0).

In addition, in order to consider the consolidation degree of foundation at different time, the consolidation degrees of 50d, 100d, 200d, 300d, 10y, 20y, 30y, 40y and 50y are calculated respectively. In the calculation process, considering the impermeability of the foundation base, the single-sided drainage calculation is adopted. There is no permeable layer with large permeability coefficient in the layered soil, so there is no intermediate permeable layer. Considering the influence of layered soil layer and referring to relevant data, the vertical weighted average value of consolidation coefficient of foundation is calculated according to CV = (∑ HI) / (∑ hi / CVI), that is, the vertical consolidation coefficient of layered soil is determined by the soil layer with the smallest consolidation coefficient.

### 3.2 Calculation results and analysis

In order to clarify the compression amount in each soil layer and provide effective guidance for later foundation selection, Table 1 lists the final compression amount of corresponding soil layer at different positions of pool foundation when the service load is 2t, the soil layer with the largest compression amount, the final settlement of surface and the uneven settlement of surface, among which the empirical coefficient of foundation settlement is 1.3. Figure 4 shows the single-layer compression of each layer at different coordinates, and Figure 5 shows the total surface settlement at different coordinates before and after the application of wave maker load.

**Table 1** Compression of each layer and total surface settlement at different coordinates when the service load is 2t

| Coordinate *x* / Block NO. | -40 | -30 | -20 | -10 | 0 | 10 | 20 | 30 | 40 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.068 | 0.056 | **0.057** | **0.059** | **0.061** | **0.059** | 0.060 | 0.056 | 0.067 |
| 2 | 0.050 | 0.039 | 0.037 | 0.035 | 0.034 | 0.036 | 0.042 | 0.042 | 0.052 |
| 3 | 0.017 | 0.014 | 0.014 | 0.014 | 0.014 | 0.011 | 0.009 | 0.009 | 0.014 |
| 4 | **0.069** | **0.061** | **0.057** | 0.049 | 0.041 | 0.054 | **0.071** | **0.072** | **0.074** |
| 5 | 0.012 | 0.016 | 0.020 | 0.021 | 0.022 | 0.020 | 0.019 | 0.017 | 0.017 |
| 6 | 0.015 | 0.008 | 0.004 | 0.006 | 0.007 | 0.008 | 0.009 | 0.011 | 0.016 |
| 7 | 0.013 | 0.012 | 0.012 | 0.010 | 0.009 | 0.009 | 0.009 | 0.013 | 0.020 |
| 8 | 0.008 | 0.008 | 0.009 | 0.007 | 0.006 | 0.008 | 0.011 | 0.009 | 0.004 |
| 9 | 0.023 | 0.019 | 0.017 | 0.016 | 0.016 | 0.014 | 0.012 | 0.012 | 0.013 |
| 10 | 0.022 | 0.019 | 0.017 | 0.021 | 0.024 | 0.024 | 0.025 | 0.026 | 0.028 |
| Max. layer | 4 | 4 | 1, 4 | 1 | 1 | 1 | 4 | 4 | 4 |
| Total settlement | 0.296 | 0.253 | 0.244 | 0.238 | 0.234 | 0.244 | 0.266 | 0.267 | 0.305 |
| Uneven disp. | Max. settlement 0.305m, located 40m, Min. settlement 0.234m, located 0m, uneven settlement 7.1cm. | | | | | | | | |

It can be seen from Table 1 and Figure 4 that when the service load is 2T, most of the soil layers with the largest compression are plain fill layer and silt layer, followed by muddy clay layer, and the total compression of the three layers accounts for more than 60% of the total settlement. The plain fill layer, the muddy clay layer and the muddy layer all have obvious uneven settlement, among which the silt layer has the largest uneven settlement, which also causes large uneven settlement on the surface. It can be seen from Figure 5 that after the wave maker load is applied, a settlement of about 1.5cm is generated at the load center. It can be seen that the main factor affecting the uneven settlement of the surface is the uneven thickness of the stratum compression layer. The maximum settlement of 0.305m is at 40m, the minimum settlement of 0.234m is at 0m, and the uneven settlement is 7.1cm.

Figures 6 and 7 show the total settlement at the surface and the average degree of consolidation in the foundation at different times. It can be seen that the permeability coefficient of each layer of soil is small due to the unilateral drainage of foundation, which leads to the small average consolidation coefficient of foundation and slow consolidation of foundation. It can be seen from Figure 6 that after 300 days of consolidation, the total surface settlement is only about 7cm, far less than the final settlement, and the uneven settlement at the surface is only 1.3cm. With the increase of consolidation time, the surface settlement also increases. After 50 years, there is still a big gap between the surface settlement and the final settlement, and the uneven settlement is about 4.6cm. It can be seen from Figure 7 that after 300 days of consolidation, the average degree of consolidation in the foundation is only about 24%. With the increase of consolidation time, the average degree of consolidation in the foundation also increases. After 50 years, the average degree of consolidation in the foundation is about 65%, and it will take a long time to complete the consolidation process.

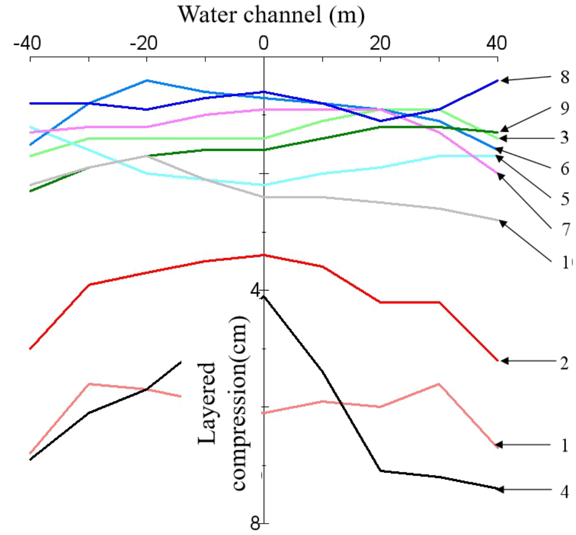


**Fig. 4** Layered compression of each soil layer at different coordinates

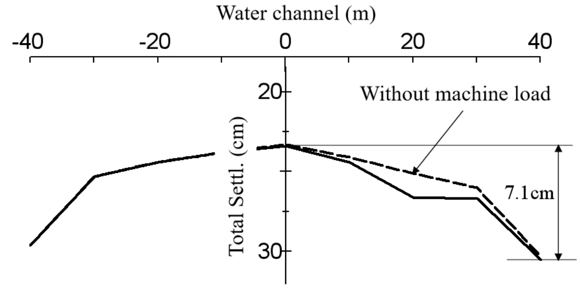


**Fig. 5** Total settlement at different coordinates

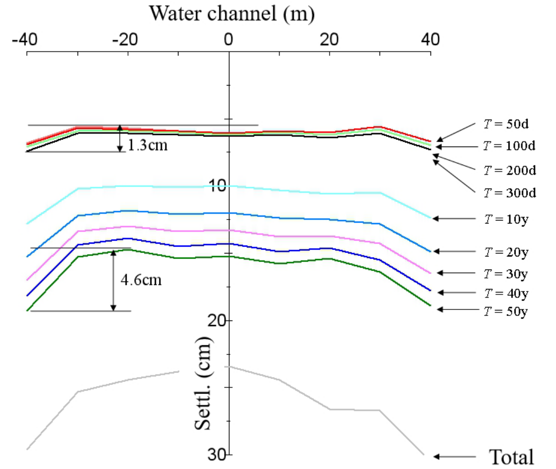


**Fig. 6** Total surface settlement at different coordinates at different times

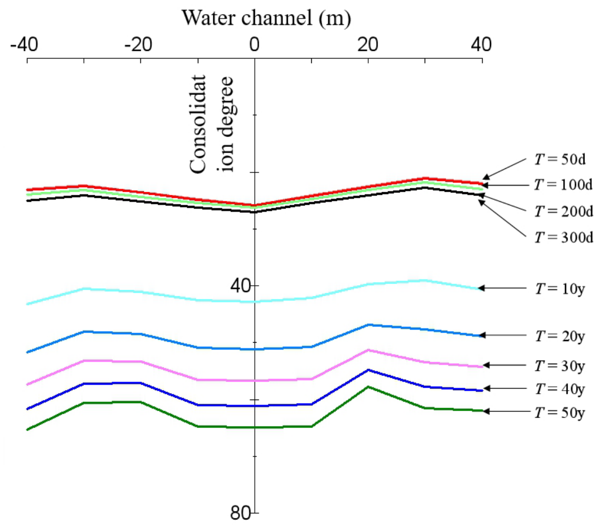


**Fig. 7** Average consolidation degree of foundation at different time and coordinates

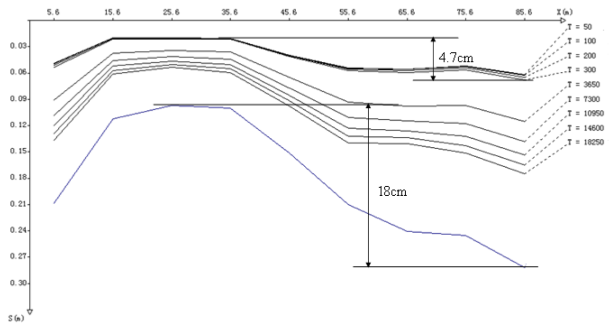


**Fig. 8** Settlement of water tank with uneven sand load

In the above calculation, only the case of uneven distribution of soil layer is considered, which can be defined as the general case. In addition, it is necessary to consider the extreme case, that is, the uneven settlement of the surface when the load is uneven and the soil layer is uneven. Therefore, it is necessary to remove the model load in (- 20,0) area, that is, there is no model load in the better soil layer, but there are model load and wave maker load in the poor soil layer. The calculated surface settlement results are shown in Figure 8. It can be seen that the uneven settlement of the ground surface increases obviously from 1.3cm to 4.7cm after 300 days of consolidation, reaches 12.1cm after 50 years of consolidation, and finally increases to 18cm.

## 4 Conclusions

The settlement and deformation of foundation under large area concrete floor, especially the uneven settlement, are studied in detail. Taking the soil layer below the floor as the research object, the concrete floor is regarded as a large area uniform load, and different service loads are assumed according to the service conditions, which is regarded as a large area uniform load. In addition, according to the design elevation, the additional stress outside the scope of the pool is analyzed in detail, which is also regarded as a large area uniform load. In the process of settlement calculation, according to the linear interpolation of multiple borehole elevations, the geological profiles with different soil layer thickness are formed, and the influence of compressed soil layer thickness on the total settlement and uneven settlement is fully considered.

(1) When the service load is 2t, most of the soil layers with the largest compression are plain fill layer and silt layer, followed by muddy clay layer, and the total compression of the three layers accounts for more than 60% of the total settlement. The plain fill layer, the muddy clay layer and the muddy layer all have obvious uneven settlement, among which the silt layer has the largest uneven settlement, which also causes large uneven settlement on the surface.

(2) After the wave maker load is applied, only about 1.5cm settlement occurs at the load center, which has little effect on the uneven settlement of the surface. It can be seen that the main factor affecting the uneven settlement of the surface is the uneven thickness of the stratum compression layer. The maximum settlement is 0.305 at 40 m, the minimum settlement is 0.234 m at 0 m, and the uneven settlement is 7.1 cm.

(3) Because of the single side drainage of the foundation, the permeability coefficient of each layer is small, which leads to the low average consolidation coefficient and slow consolidation of the foundation. After 300 days of consolidation, the total surface settlement is only about 7cm, which is far less than the final settlement. The average degree of consolidation in the foundation is only about 24%, and the uneven settlement on the surface is only 1.3cm. With the increase of consolidation time, the surface settlement also increases. After 50 years, there is still a big gap between the surface settlement and the final settlement. The average degree of consolidation in the foundation is about 65%, and the uneven settlement is about 4.6cm. Considering the extreme case of uneven distribution of sand load, the uneven settlement is 4.7cm after consolidation for 300d and 12.1cm after consolidation for 50 years.

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