Design and Analysis of Foundation Detection in Collapsible Loess Area

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Abstract

In China, there are a large number of collapsible loess areas, especially in the northwestern cities of China. A large number of collapsible loess has caused some problems for the construction of the project. At present, there are many ways to deal with the foundation in the collapsible loess area. It can detect the ground treatment results in an all-round way. This paper combines the actual engineering cases of a provincial capital city in northwestern China to test the foundation after the collapsible area treatment in various ways, which will provide reference for similar projects in the future.

Keywords

Collapsible loess, Ground treatment, Detection.

1. Introduction

After the collapsible loess is immersed in water, the soil structure is destroyed and deformed. The collapsible loess is immersed in water and the soil structure is destroyed and deformed. In the project, the collapsible loess is generally treated by refilling and compacting, in order to ensure the engineering. Quality, the treated foundation must be tested, and only the test results meet the relevant specifications, can be used as the foundation of the building.At present, methods for ground detection include flat load test, core drilling method, standard penetration test, geotechnical test, and low strain method. Usually a combination of several methods is used to form a comprehensive solution.

In China, a large number of scholars have studied the collapsible loess. Some scholars have studied the settlement of loess under different load conditions of highway test pavement by combining the viscoelastic theory and curve simulation of material creep. It is proposed that loess has nonlinear viscoelastic characteristics, which can help analyze different secondary settlements[1].Some scholars have carried out large-scale water immersion tests on Q_2 loess. According to the test results, the Q_2 loess and paleosol exchanged soils are very different from the collapsibility of general self-weight collapsible loess. The actual test results have a collapsibility and calculation. Great difference[2], which is very vigilant for engineering construction.

2. Project Overview

The project is located in a provincial capital city in northwestern China. It is planned to build two commercial buildings (A, B). The building category is Class C, with a total construction area of 3,560.60 m^2. The structure type is frame structure, the basic form is independent foundation, and the foundation type is plain soil. , 1:7 cement soil cushion, the top surface elevation of the cushion: -2.00m (commercial building A, B), the ground treatment area: 2790.08m^2 (commercial building A 1313.14m^2, gate 172.80 m^2, commercial building B 1313.14m^2), The schematic diagram of the detection point is shown in Figure 1:

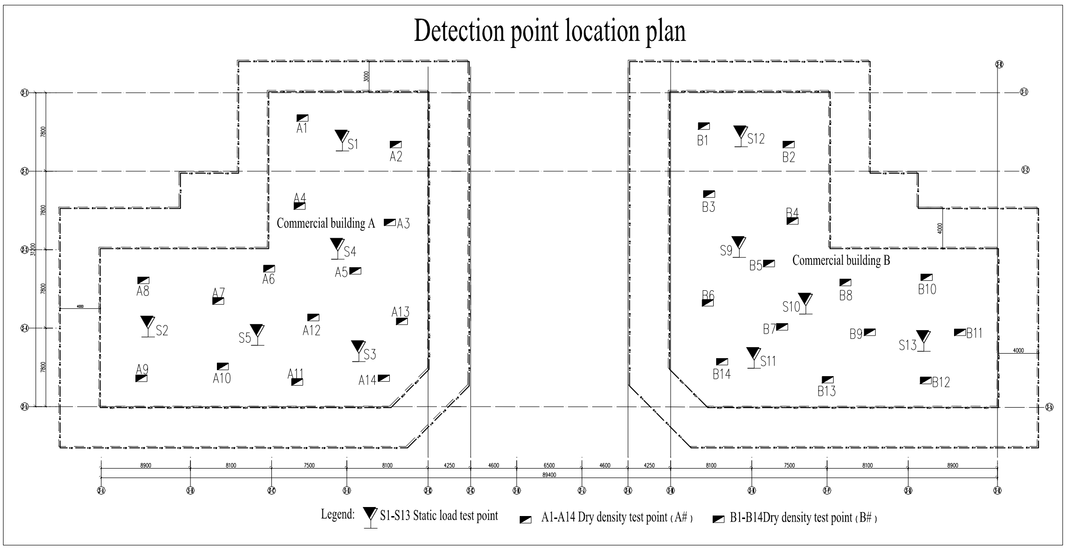


Figure 1 Inspection point layout plan

3. Engineering geological conditions

3.1 Topography

The proposed site has a relatively flat terrain with a ground elevation ranging from 352.88 to 354.40 m and a relative height difference of 1.52 m. The site geomorphology unit belongs to the Weihe I level terrace.

3.2 Stratigraphic structure

The distribution of strata in this area can be seen from the engineering geological survey data, see Table 1.

Table 1 Stratigraphic structure information table

Stratigraphic structure information table			
Formation number	Formation thickness	Stratum depth	Stratigraphic elevation
1Layer filling（Q4ml）	0.90～3.70m	0.90～3.70m	349.72～352.50m
2Layer filling（Q4ml）	0.50m	0.50m	352.38～353.90m
Loess soil（Q4al）	7.00～13.00m	7.50～13.50m	339.94～345.97m
Layer fine sand（Q4al）	1.30～1.80m	12.70～16.70m	337.01～340.94m
Thick sand in the layer（Q4al）	6.70～11.70m	21.00～26.00m	327.47～332.91m
Thick sand in the layer（Q3al）	15.60～22.10m	40.00～43.90m	309.43～313.22m
Layered clay（Q3al）	5.60～8.30m	47.40～51.10m	302.21～305.71m
Coarse sand（Q3al）	3.60～9.10m	54.00～57.30m	295.87～299.91m
Silty clay（Q3al）	2.90～9.00m	59.80～64.50m	289.27～293.58m
Coarse sand（Q3al）	5.80～11.50m	68.30～71.60m	281.30～285.75m
Silty clay（Q3al）	5.20m	-	-
Coarse sand（Q3al）	3.00～5.80m。	-	-

3.3 Groundwater

During the survey, the groundwater level is in the flat water level, and groundwater is seen at all exploration points. The stable water level depth is 16.40~17.80m, and the corresponding elevation is 336.29～336.70m, which is a type of diving. According to regional data, the annual variation of groundwater level is 1.00~2.00m.

3.4 Site collapsibility evaluation

The proposed site is a self-weight collapsible loess site, and the foundation collapsibility level is Grade II (medium) to Grade IV (very severe). According to the geotechnical conditions of the site: 1# floor foundation can be designed according to general area regulations; 2~8# floor foundation damp level is considered according to level II (medium); property office building foundation level is grade III (serious) Kindergarten and underground garage foundations are grade IV (very serious).

The scheme of dealing with collapsibility: the buried depth of the foundation is -8.5m, and the underlying collapsible soil layer can be replaced by a thick soil cushion of not less than 1m.

4. Foundation treatment design and construction overview

4.1 Design requirements

The purpose of foundation treatment is to increase the bearing capacity of the foundation and eliminate the partial collapse of the foundation. Foundation treatment method: the foundation treatment is treated by plain soil and 1:7 cement soil cushion replacement method. The thickness of the cushion layer is 3.00m for commercial building A, 3.50m for main gate, 3.20m for commercial building B, and the top surface of cushion. The elevations are -2.00m, -1.60m, -2.00m, the bottom elevations of the cushion are -5.00m, -5.10m, -5.20m, respectively. The bearing layer has a bearing capacity characteristic value of 150kPa on the 2 layers of foundation soil. The width of each side of the top surface of the layer beyond the base bottom edge is not less than 1/2 of the thickness of the treated soil layer and not less than 2 m. Design requirements: the bearing capacity of the cushion foundation is $f_{ak} \geq 200$ kPa, and the mat lamination coefficient is $\lambda_c \geq 0.97$.

4.2 Construction overview

The construction method and technology of the cushion foundation shall be implemented in accordance with the relevant regulations and requirements in the Technical Specifications for Building Foundation Treatment (JGJ 79-2012) and the Building Code for Collapsible Loess Area (GB 50025-2004). The commercial A building of the cushion is divided into 18 pieces (including 12 pieces of plain soil and 6 pieces of cement soil of 1:7). The thickness of the cushion is 3.00m (including 2.00m of plain soil and 1.00m of cement soil of 1:7); 19 pieces (including 12 pieces of plain soil and 7 pieces of cement soil of 1:7) were constructed with a cushion thickness of 3.20 m (including 2.00 m of plain soil and 1.20 m of cement soil of 1:7). The construction process of the entire cushion is carried out by mechanical sieving, mechanical mixing, loader + manual filling, manual leveling and mechanical rolling, and crushing 8 times with an 18-ton road roller.

5. Ground detection

5.1 Ground-based inspection

The ground treatment area of the project is 2790.08m^2, and the thickness of the cushion is 3.00m for commercial building A and 3.20m for commercial building B. The testing methods and workload are determined according to the design requirements and testing contract:

Number of load tests: according to the ground treatment area of 1000m^2 or more, increase by at least 1 point per 300m^2, less than 300m^2 according to 300 m^2; or according to the ground treatment area of not less than 1 point per 500m^2, and the single project is not less than 3 points . A total of 13 points were tested in this test to evaluate whether the characteristic value f_{ak} of the bearing foundation bearing capacity meets the design requirements;

Number of compaction coefficient test: The compaction coefficient of the cushion layer is detected by the ring cutter method. The base treatment area is taken at 1 point per $100m^2$, and the single project is not less than 3 points. In this test, the commercial building A was divided into 18 pieces, each of which was sampled by 14 pieces, and a total of 252 pieces were sampled; the door was divided into 21 pieces, each of which was sampled by 3 pieces, and a total of 63 pieces were sampled; the commercial B building was divided into 19 pieces, and each sample was sampled by 14 pieces. A total of 266 samples were sampled; a total of 581 samples were sampled in Commercial A and Commercial Building B for dry density test to assess whether the foundation compaction level meets the design requirements.

5.2 Detection method

Load test: The slow-maintenance load method is adopted. According to the design and related specifications, the bearing plate area is 1.00m2, the diameter is 1.129m, and the 20mm medium coarse sand is laid under the bearing plate. The test is to provide the reaction force by the heavy-duty platform I-beam. The 1000kN jack is manually loaded. The jack joint center is consistent with the center of the bearing plate. The pressure measurement adopts the load cell and the settlement of the bearing plate is carried out by 4 dial gauges. 4 A displacement measuring instrument is installed symmetrically with the edge of the bearing plate 25-50 mm. During the test, the pressure and displacement measuring instruments and loading equipment are working normally and within the valid period of identification.

Before loading, press 5% of the maximum load for 5 minutes, then unload to zero, and record the initial reading of the displacement measuring instrument. The maximum load of the load test is twice the design requirement, that is, 360 kPa, which is loaded in 8 stages. Each stage load is 1/8 of the maximum load, that is, 45 kPa. After the stage is stabilized, the next stage is added, and the unloading is twice the loading. The time interval for settlement observation, the stability standard and the termination test conditions shall be carried out in accordance with the regulations and the relevant provisions of the provincial quality inspection general station.

Compaction coefficient test: stratified sampling by ring knife method, the sampling point is located at 2/3 of the thickness of each layer of the mat; the water content and dry density are determined by the drying method, and then the maximum dry density is reported according to the compaction test. Calculate the compaction factor of the mat.

During the test, the equipment was running normally. The equipment used for the test was: ring cutter, volume 200cm3; electronic balance, measuring range 2000g, minimum score 0.01g; sample box, constant mass; electric heating constant temperature drying oven, temperature 0°～300°±1.0° A set of homemade samplers.

5.3 Comprehensive analysis and evaluation

5.3.1 Load test result

The load test parameters are shown in Table 2 below. The data summary table and p-s and s-lgt curves for each load test point are shown in Figure 2.5. It can be seen from the ps and s-lgt curves in Figure 2.5 that the ps curve is slowly changing, and the total settlement of the bearing plate is between 4.30 and 5.61 mm, which does not exceed the settlement value required for the termination of the test conditions (s0/ b=0.06, s0=67.74mm);The settlement of the s-lgt curve is uniform, and there is no obvious steep drop, and the bearing capacity has not reached the limit state. When the load is 200 kPa, the settlement of each test point is between 1.93 and 2.54 mm. According to the fourth paragraph of Article 4.4.3 of JGJ 340-2015 of Technical Specifications for Building Foundation Testing, take the pressure corresponding to s0/b=0.010, ie s0=11.29mm, but its value should not exceed half of the maximum test load. The principle is to determine that the bearing capacity of each test point is 200 kPa, the range is zero and does not exceed 30% of the average value, and the characteristic value of the foundation bearing capacity can be taken as the average value of 200 kPa;According to the provisions of Article 4.4.4, paragraph 1 of JGJ 340-2015 of Technical Standards for Building Foundation Testing, the average value of 200 kPa is taken as the characteristic value of the bearing capacity of the project, which meets the design requirements of $f_{ak} \geq 200$ kPa.

Table 2 S1-S13 load test parameter information table

Test point number	Platen diameter (m)	Pressurization level (kPa)	Termination of pressure (kPa)	Settlement(mm)	
				200kPa	400kPa
S1	1.129	50	400	2.47	5.58
S2	1.129	50	400	2.00	4.55
S3	1.129	50	400	2.46	5.61
S4	1.129	50	400	2.48	5.41
S5	1.129	50	400	2.26	5.10
S6	1.129	50	400	2.33	5.30
S7	1.129	50	400	1.93	4.30
S8	1.129	50	400	2.19	4.80
S9	1.129	50	400	2.48	5.54
S10	1.129	50	400	2.54	5.05

5.3.2 Mat lamination factor test results

In order to detect the replacement effect of collapsible loess, the relevant parameters of the compaction coefficient of the foundation are obtained by means of ring knife sampling, etc., taking $A^{\#}$ commercial building as an example, the test results are shown in Table 3.

Table 3 Ground compaction coefficient parameter table

Sample number	Wet density (g/cm3)	Average moisture content (%)	Dry density (g/cm3)	Compaction coefficient (λc)	Sample number	Wet density (g/cm3)	Average moisture content (%)	Dry density (g/cm3)	Compaction coefficient (λc)
1-1	1.96	17.6	1.67	0.97	1-2	1.93	15.5	1.67	0.97
1-3	1.97	18.0	1.67	0.97	1-4	1.94	15.2	1.69	0.98
1-5	1.95	15.7	1.69	0.98	1-6	1.97	18.2	1.67	0.97
1-7	1.99	15.3	1.72	1.00	1-8	1.95	15.6	1.69	0.98
1-9	1.97	17.7	1.67	0.97	1-10	1.99	18.1	1.69	0.98
1-11	2.01	18.1	1.70	0.99	1-12	1.93	15.4	1.67	0.97
1-13	1.97	18.2	1.67	0.97	1-14	1.97	17.7	1.67	0.97
2-1	1.99	15.6	1.72	1.00	2-2	1.97	17.8	1.67	0.97
2-3	1.97	15.6	1.71	0.99	2-4	1.95	15.5	1.69	0.98
2-5	1.96	17.6	1.67	0.97	2-6	1.93	15.4	1.67	0.97
2-7	1.94	15.2	1.69	0.98	2-8	1.95	15.3	1.69	0.98
2-9	1.96	17.6	1.67	0.97	2-10	1.93	15.6	1.67	0.97
2-11	2.03	18.1	1.72	1.00	2-12	1.93	15.5	1.67	0.97
2-13	1.99	18.1	1.69	0.98	2-14	1.98	18.3	1.67	0.97
3-1	1.95	15.7	1.69	0.98	3-2	1.93	15.6	1.67	0.97
3-3	1.99	15.5	1.72	1.00	3-4	1.93	15.8	1.67	0.97
3-5	1.95	15.6	1.69	0.98	3-6	1.98	18.3	1.67	0.97
3-7	1.99	15.4	1.72	1.00	3-8	1.99	17.7	1.69	0.98
3-9	1.97	15.7	1.70	0.99	3-10	1.97	18.1	1.67	0.97
3-11	2.03	17.8	1.72	1.00	3-12	1.94	15.2	1.69	0.98
3-13	1.96	17.6	1.67	0.97	3-14	1.92	15.2	1.67	0.97
4-1	1.93	15.3	1.67	0.97	4-2	1.95	15.7	1.69	0.98

4-3	1.97	18.0	1.67	0.97	4-4	2.00	18.3	1.69	0.98
4-5	1.95	15.3	1.69	0.98	4-6	1.99	18.1	1.69	0.98
4-7	1.99	15.6	1.72	1.00	4-8	1.95	15.4	1.69	0.98
4-9	1.97	15.6	1.71	0.99	4-10	1.95	15.5	1.69	0.98
4-11	2.03	17.8	1.72	1.00	4-12	1.97	18.0	1.67	0.97
4-13	2.02	18.2	1.70	0.99	4-14	1.94	15.2	1.69	0.98
5-1	2.03	17.8	1.72	1.00	5-2	1.99	17.9	1.69	0.98
5-3	1.93	15.6	1.67	0.97	5-4	1.94	15.9	1.67	0.97
5-5	2.01	18.0	1.71	0.99	5-6	2.00	18.3	1.69	0.98
5-7	2.02	18.3	1.70	0.99	5-8	1.95	15.8	1.69	0.98
5-9	2.03	18.0	1.72	1.00	5-10	1.96	17.6	1.67	0.97
5-11	1.97	17.9	1.67	0.97	5-12	1.93	15.3	1.67	0.97
5-13	1.98	18.4	1.67	0.97	5-14	1.99	17.7	1.69	0.98
6-1	1.98	18.3	1.67	0.97	6-2	1.97	17.8	1.67	0.97
6-3	1.93	15.7	1.67	0.97	6-4	1.99	18.1	1.69	0.98
6-5	2.03	18.0	1.72	1.00	6-6	1.96	17.6	1.67	0.97
6-7	1.92	15.2	1.67	0.97	6-8	1.93	15.6	1.67	0.97
6-9	1.99	17.8	1.69	0.98	6-10	1.99	17.7	1.69	0.98
6-11	1.99	15.3	1.72	1.00	6-12	1.93	15.8	1.67	0.97
6-13	1.97	15.8	1.71	0.99	6-14	1.99	17.7	1.69	0.98
7-1	1.93	15.5	1.67	0.97	7-2	1.95	15.3	1.69	0.98
7-3	1.95	15.3	1.69	0.98	7-4	1.93	15.5	1.67	0.97
7-5	1.93	15.5	1.67	0.97	7-6	1.97	18.2	1.67	0.97
7-7	1.99	17.6	1.69	0.98	7-8	1.97	17.7	1.67	0.97
7-9	1.95	15.8	1.69	0.98	7-10	1.97	18.2	1.67	0.97
7-11	1.99	17.7	1.69	0.98	7-12	1.95	15.8	1.69	0.98
7-13	1.95	15.6	1.69	0.98	7-14	1.95	15.6	1.69	0.98
8-1	2.01	17.8	1.71	0.99	8-2	1.97	18.2	1.67	0.97
8-3	2.04	18.3	1.72	1.00	8-4	1.97	18.0	1.67	0.97
8-5	1.96	15.9	1.69	0.98	8-6	1.96	15.9	1.69	0.98
8-7	2.01	17.6	1.70	0.99	8-8	1.95	15.6	1.69	0.98
8-9	1.93	15.4	1.67	0.97	8-10	2.00	18.2	1.69	0.98
8-11	1.97	18.0	1.67	0.97	8-12	1.95	15.5	1.69	0.98
8-13	1.99	15.8	1.72	1.00	8-14	1.99	17.8	1.69	0.98
9-1	1.93	15.5	1.67	0.97	9-2	1.97	18.2	1.67	0.97
9-3	1.96	17.6	1.67	0.97	9-4	1.97	18.0	1.67	0.97
9-5	1.97	17.8	1.67	0.97	9-6	1.95	15.4	1.69	0.98
9-7	2.03	17.9	1.72	1.00	9-8	1.95	15.5	1.69	0.98
9-9	1.98	15.2	1.72	1.00	9-10	1.95	15.4	1.69	0.98
9-11	1.99	15.8	1.72	1.00	9-12	1.93	15.7	1.67	0.97
9-13	2.03	18.1	1.72	1.00	9-14	1.93	15.3	1.67	0.97
10-1	1.97	18.1	1.67	0.97	10-2	1.96	15.9	1.69	0.98
10-3	1.97	18.0	1.67	0.97	10-4	1.97	17.8	1.67	0.97
10-5	1.99	17.9	1.69	0.98	10-6	1.99	17.7	1.69	0.98
10-7	2.01	18.0	1.71	0.99	10-8	1.97	18.0	1.67	0.97

10-9	1.99	17.7	1.69	0.98	10-10	1.95	15.5	1.69	0.98
10-11	1.99	15.7	1.72	1.00	10-12	2.00	18.3	1.69	0.98
10-13	1.97	18.1	1.67	0.97	10-14	1.93	15.6	1.67	0.97
11-1	1.99	15.5	1.72	1.00	11-2	1.95	15.4	1.69	0.98
11-3	1.99	15.5	1.72	1.00	11-4	1.93	15.4	1.67	0.97
11-5	1.99	15.7	1.72	1.00	11-6	1.99	17.6	1.69	0.98
11-7	1.93	15.4	1.67	0.97	11-8	1.94	15.9	1.67	0.97
11-9	1.95	15.5	1.69	0.98	11-10	1.97	17.8	1.67	0.97
11-11	2.01	17.7	1.70	0.99	11-12	1.99	17.9	1.69	0.98
11-13	2.03	17.7	1.72	1.00	11-14	1.96	17.6	1.67	0.97
12-1	1.99	18.0	1.69	0.98	12-2	1.99	17.7	1.69	0.98
12-3	2.04	18.4	1.72	1.00	12-4	1.99	17.8	1.69	0.98
12-5	1.99	17.7	1.69	0.98	12-6	1.95	15.5	1.69	0.98
12-7	1.95	15.8	1.69	0.98	12-8	1.94	15.2	1.69	0.98
12-9	1.93	15.8	1.67	0.97	12-10	1.97	18.2	1.67	0.97
12-11	1.96	15.2	1.70	0.99	12-12	1.96	15.9	1.69	0.98
12-13	1.97	17.7	1.67	0.97	12-14	1.96	17.6	1.67	0.97

5.3.3 Summary of test results of pad lamination coefficient

Similarly, taking the $A^{\#}$ commercial building as an example, the test results of the mat lamination factor are summarized, as shown in Table 4.

Table 4 Mat lamination factor test result table

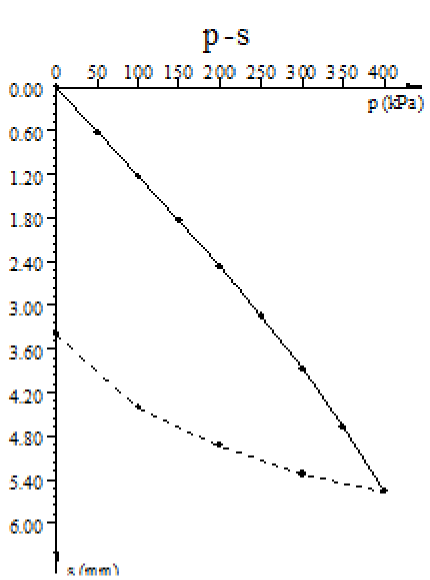
Layer number	Number of data	Minimum compaction coefficient	Maximum compaction coefficient	Average pressure Real coefficient	Layer number	Number of data	Minimum compaction coefficient	Maximum compaction coefficient	Average pressure Real coefficient
1	14	0.97	1.00	0.98	7	14	0.97	0.98	0.98
2	14	0.97	1.00	0.98	8	14	0.97	1.00	0.98
3	14	0.97	1.00	0.98	9	14	0.97	1.00	0.98
4	14	0.97	1.00	0.98	10	14	0.97	1.00	0.98
5	14	0.97	1.00	0.98	11	14	0.97	1.00	0.98
6	14	0.97	1.00	0.98	12	14	0.97	1.00	0.98
Plain soil（Commercial building A）					Total statistics	168	0.97	1.00	0.98

5.3.4 In situ test results chart

Through the static load test of the $A^{\#}$ commercial building S1-S13 monitoring point, the ground bearing capacity of the area can be effectively obtained, combined with the compaction coefficient, etc., can make a comprehensive evaluation of the foundation, by drawing the ps curve and s-lgt curve. It can be seen that the displacement map of settlement under different pressures and the relationship between displacement and time at different time periods.Taking the S1 and S2 monitoring points as an example, the pressure-displacement curve and the displacement-time curve are plotted, as shown in Fig. 2 and Fig. 3. See Table 5 and Table 6 for settlement data.

Table 5 S1 settlement data sheet

Test point number：S1									
Load(kPa)	0	50	100	150	200	250	300	350	400
Subgrade settlement(mm)	0.00	0.62	0.60	0.61	0.64	0.68	0.74	0.79	0.90
Cumulative settlement(mm)	0.00	0.62	1.22	1.83	2.47	3.15	3.89	4.68	5.58



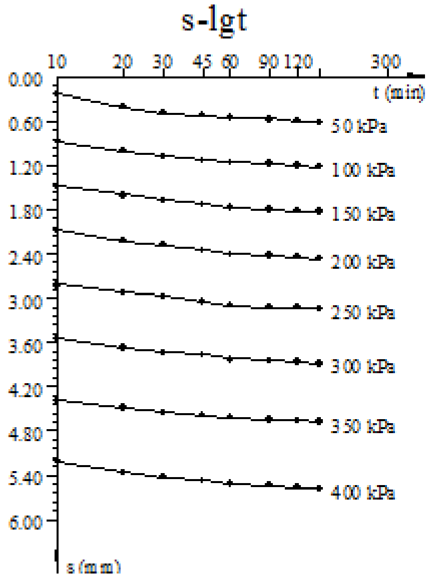
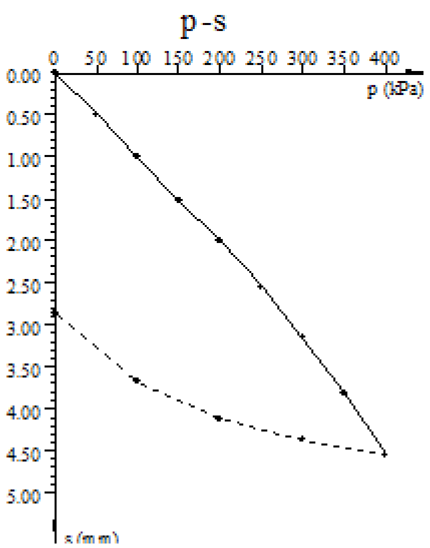


Figure 2 S1 pressure-displacement curve Figure 3 S1 displacement-time graphe

Table 6 S2 settlement data sheet

Test point number：S2									
Load(kPa)	0	50	100	150	200	250	300	350	400
Subgrade settlement(mm)	0.00	0.50	0.51	0.51	0.48	0.54	0.61	0.66	0.74
Cumulative settlement(mm)	0.00	0.50	1.01	1.52	2.00	2.54	3.15	3.81	4.55



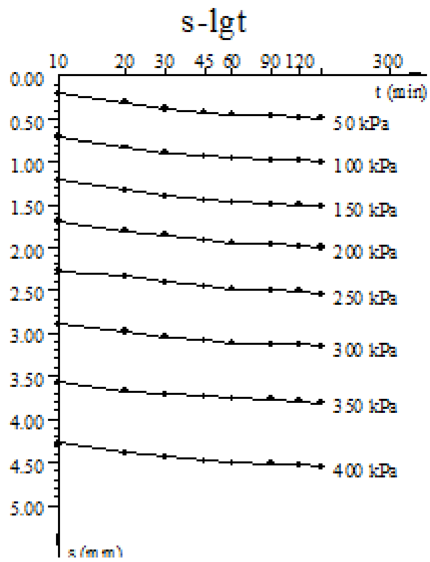


Figure 3 S2 pressure-displacement curve Figure 4 S2 displacement-time graphe

6. Conclusion

The foundation treatment in the collapsible loess area needs to consider more factors than the normal area. Therefore, the detection of the treatment result needs scientific test and method demonstration. After testing, the bearing capacity characteristic value of the cushion foundation in the project is

f_{ak}≥200kPa.Meet the design requirements. The mat lamination factor is λ_c ≥0.97, which meets the design requirements. Considering that the rainy season has a certain impact on the foundation, in construction and use, waterproof measures should be made in accordance with the specifications to ensure the safety of the overall project.

References

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