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Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 3.44

A Case Study of Success to Structures Founded on Expansive Soils

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SYNOPSIS: Since 1979, in accordance with the design program given by the author, no more than 3 storied buildings with an area of more than 200,000 square metres have been built in the expansive soil area of Guangxi Zhuang Autonomous Region and Guangdong Province in South China. The different measures have been adopted according to specification of light, medium and heavy expansive soil. Through the test of special weather and the deformation observation for 3 to 7 years, it has been proved that the intact rate of the buildings has reached 90-98 percent.

This paper mainly expounds three cases and has summed up very effective treatment methods from the practice.

INTRODUCTION

In China, the expansive soil is distributed broadly over almost every province except northwest area, and especially widespreaded in the provinces of Guangdong, Hubei, Hunan, Yunnan, Shichuan and Guangxi Zhuang Autonomous Region. Because of the natural geographical distribution, these areas are rich in rainfall with an annual average between 1,000 and 2,000mm, about 70 percent are concentrated in the two seasons of summer and autumn, i.e. from April to September. In these two seasons, there're many storms and heavy flow,and the monthly average temperature is from 20 to 25 degrees centigrade. It's the main typical characteristics to have frequent rain and high temperature in the same seasons, so as to reduce a lot of rainfall seeping into the ground.

In winter and spring, the monthly rainfall would be only 300mm or even less. But the monthly average temperature remains 10 to 20 degrees centigrade. Therefore, during this period, the foundation soil becomes drying shrinkage, and at the same time, most of the buildings and houses begin to sink and crack. According to the result of moisture content observation for long time in South China, the weather-influenced depth may reach 5m, but the serious influenced depth by weather is bout 1.5 to 2.5m (Figure 1).

Fig. 1 Two Storied-Building Damaged in South Yunnan

Due to the transverse movement of the soil, usually, the crack with 1 to 10cm in width, 1 to 3m in depth and 30 to 300m in length would appear on the ground. When the ground crack goes through the buildings, the fracture or crack on the wall and floor would emerge.

As known to all, the swelling and contracting deformation of expansive soil comes from the change of the moisture content in the soil. The moisture shift of foundation soil is a rather complicated matter which may be expressed by the moisture balance formula as follows:

$$W = Wo+[P(1-r)+L+e]-(E+T+u)$$

Where: W = The moisture content in a certain soil layer after the moisture migration

Wo= The initial moisture content before the moisture migration

P = Precipitaion

r = Coefficient of surface run-off

L = The moisture shifted up from the subsoil by capillary

e = The water condensed from water gas

E = Evaporation

T = The moisture transpired from plants

u = The moisture migrated or infiltrated down into the ground

According to the weather condition in China and the moisture balance formula as mentioned above, a program of the comprehensive protection measures has been put forward by the author for the

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treatment of the foundation on expansive soil. Here, the program of the comprehensive protection and management dosn't mean that all the measures must be adopted all together. It's required that engineers should not only have a correct design for the houses, i.e. usually, the foundation soil and foundation management would be taken as the main, and the upper-structure's strengthening as the second, but also the treatment of the surroundings of the houses such as building retaining wall, slope protection, drainage, vegetation, and so on should be put into the detailed consideration of design, so as to keep the relative balance of the moisture content in foundation soil, only in this way can the deformation range be shortened. On the other hand, whether the design can be succeeded and whether the desired result of the management measures can be obtained, it's not only by the design unit itself, but also the close co-operation come from the unit in charge of construction and the house management or house owner. In accordance with the characteristics of expansive soil such as that it would swell when the moisture increase and it'd contract when the moisture decrease, therefore the protection and management work in all fields must be done well.

For recent 10 years, the buildings with an area of 200,000 square metres have been built up in the expansive area of Guangxi Zhuang Autonomous Region and Guangdong Province. The author has conducted observation on foundation soil and buildings for many years. Through the test of special weather, the building intact rate has reached 90-98 percent. Here are the three successful cases specified by light, medium and heavy grades.

CASES STUDY

Case 1 Medical Ward Building of a Hospital in North Guangdong

Basic Condition
This is a three storied-building with 102m long, which is divided into 3 sections by deformation joints, and observation post is in the middle section (Figure 2B).

Figure 2A means the observation poles to observe the deformation for different layers in foundation soil, their depths are specified by 0.5, 1.0, 1.5, 2.0, 3.0, 4.0m.

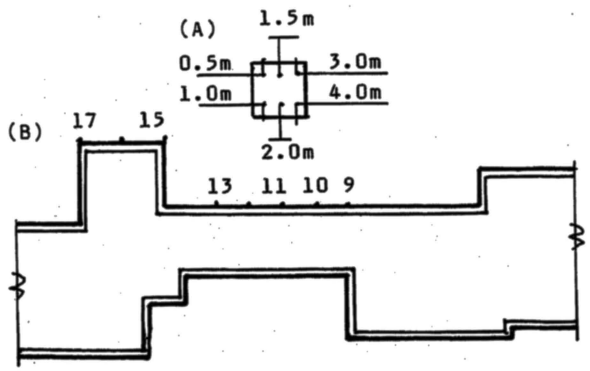

Fig. 2 Plan Figure of Experimental Site

In Figure 2B, the numbers of 9, 10, ... 17 are observation posts of building deformation. The characteristics of the ground features of the observation field are eroded hilly land, and terrain is a slight slope. The depth of foundation soil layer is between 10 and 15m. Above 5m is residual clay by shale with brown and yellow colours as the main mixed up with light yellow and greyish stripes, hard to plasticity, soil test results shown as Table 1.

TABLE 1. Soil Test Results

d (m)	W(%)	WL(%)	Ip	D(%)	e(%)	Ls(%)
1.1-1.25	27	49	23	39	1.195	1.12
2.1-3.25	26	47	22	44	3.505	1.94
3.0-3.15	29	50	24	52	2.155	1.26
4.0-4.15	27	54	30	43	4.06	0.66
4.85-5.0	27	46	23	40	2.13	1.18

In Table 1: d = Embeded depth of soil sample
W = Initial moisture content
WL= Liquid limit
Ip= Plasticity index
D = <0.005mm grain composition
e = Expansive rate
Ls= Linear shrinkage

Management Measures
1. Strip foundation have been buried into 1m deep with sand cushion (Figure 3) and the two sides of foundation trough are filled with sand.

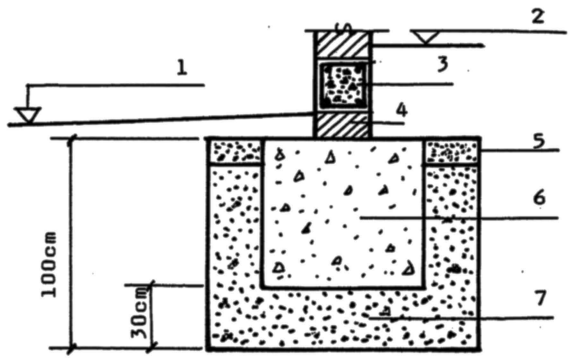

Fig. 3 Sand Cushion
In Figure3: 1 = Outer ground surface
2 = Interior ground surface
3 = Periphery beam
4 = Brick wall
5 = Lime clay
6 = Footing
7 = Filled with sand

The sand diametre is from 0.25 to 0.5mm, and the moisture content is from 15 to 20 percent.

The unit weight is 14KN/m^3 about.

2. The pour-in-placed reinforced concrete floor and periphery beam.

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3. The width of drainage slope is about 1.5-2.5m.

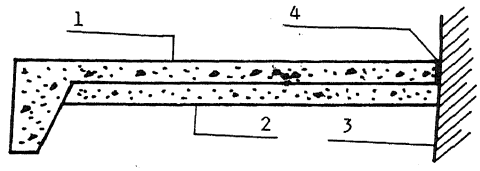

Fig. 4 Drainage Slope

In Figure 4: 1 = Concrete surface layer
2 = Cushion by lime clay, etc.
3 = Surface of outer wall
4 = Expansion joint

The drainage slope around the building is divided by the expansion joint at intervals of 3 to 5m.

In order to prevent the crack of the concrete surface layer on the slope, the building-slope link should be divided by expansion joint, so as to prevent water infiltration into the ground.

The drainage slope's surface layer is made of concrete with its thickness of 80 to 100mm. And the cushion is made of native cement (lime, sand , broken stone), lime soil or sand-stone material.

4. Surrounding Management
The slope nereby the building may be protected by building up the stone. At the foot of the slope, a retaining wall with 1 to 2m high should be built. At the middle of the slope, a drainage ditch should be excavated so as to complete the drainage system at the construction site.

The lower and easier trim away unwanted branches and twigs trees may be selected for scientific vegetation such as fruit and flower trees. It's prohibited to plant quick growing or heavy transpiring trees such as eucalyptus, poplar etc. The distance from trees to buildings shoud be about 5m. The spare ground should be covered by grass and bush as more as possible, but the irrigation must be controlled.

5. The special requirements to the building construction.
To work out a construction plan is a special importance. The foundation must be laied quickly by continuous construction. The trough or pit should be prevented from heavy sunshine or soaked by water. In the construction site, used water must be controlled strictly and pay a good attention to the drainage of the construction site.

Results of Deformation Observation

Since September 1979 to May 1978, the author has conducted deformation observation of different layers of foundation soil with precise leveling instrument Wild N3.

The deformation curves are as Figure 5.

In Figure 5, it's clear to see that with the deepening of the foundation soil layer, the verticle deformation magnitude would be reduced gradually. It's very evident that they'll go up and come down in synchronism.

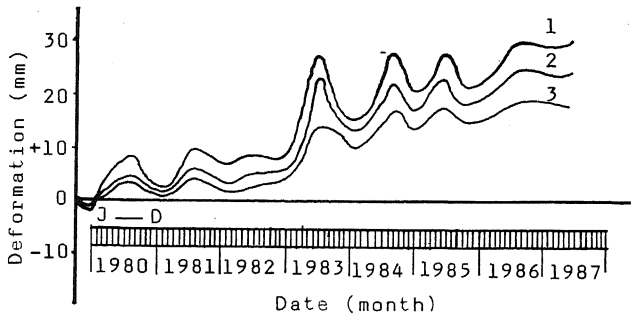

Fig. 5 Deformation Curves of Different Layers of Foundation Soil

In Figure 5: 1 = 0.5m Depth under ground
2 = 1.5m Depth under ground
3 = 3.0m Depth under ground

Besides it, the up and down deformation of the foundation soil coincides very much with the changes of the weather at the building area. In rainy season, the foundation soil rises up, and in dry season, it would subside. In 1983, it was a rain-rich year, the rising magnitude was beyond 20mm.

The comparison of the deformation curve of the foundation soil in 1m deep with the deformation curve of building observation post 11 shown in Figure 6.

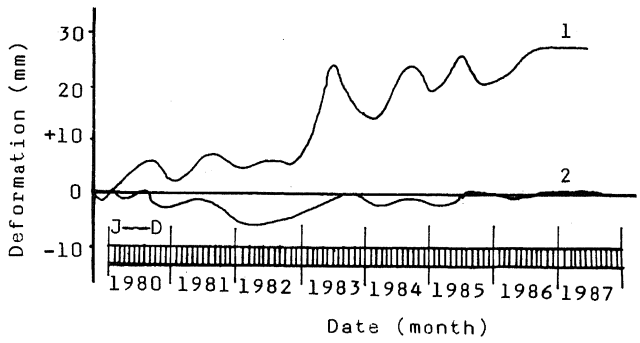

Fig. 6 Comparison of the Foundation Soil Deformation with the Building Deformation

In Fig. 6: 1 = Deformation curve of the foundation soil
2 = Deformation curve of the building

It's clear in Figure 6:

1. In the same depth, the building deformation range is only the 23 percent of the foundation soil deformation range.

2. In the spring of 1984, the foundation soil was subsided 11mm, but the building was subsided only 2.5mm.

Analysis of Management Results

The building was used and observed for deformation for 8 years. Through the test of the very special weather in the summer of 1983 and the spring of 1984, the building remained well. It shows that the management was successful.

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The sand cushion for the foundation soil management is different from the function of the exchange of soil by sand cushion on normal foundation soil. Here it's a part of the buffer area between the foundation soil and footing, and plays role together with upper_structure for the adjustment of the uneven swelling and contracting deformation of the foundation soil. On the basis of scale-down test and abundant observation data, it improves that on unit-weight about 14KN/m^3 condition, the sand cushion layer is in a state of medium density, which has an evident feature of elastic deformation. This feature can adjust or redistribute internal force transmited by the deformation of foundation soil. The adjustable value is the 2 percent of the sand cushion thickness, or 5 to 10mm. The two flanks of foundation trough are filled with sand in moderate and fine size, which may prevent crevice and shift of the foundation and wall caused by ground crack when it goes through the buildings, this function has been improved by broad investigation.

The function of drainage slope may reduce the influence of the moisture content of the foundation soil caused by weather elements such as rainfall, temperature of atmosphere and earth's interior, and evaporation. So as to make the covering condition of both outside and inside building similar and reduce the deformation difference from inner and outer walls. Through the test and observation, it's improved that with the increasing of the width of the drainage slope, the deformation range of the foundation soil would be reduced evidently (Figure 7).

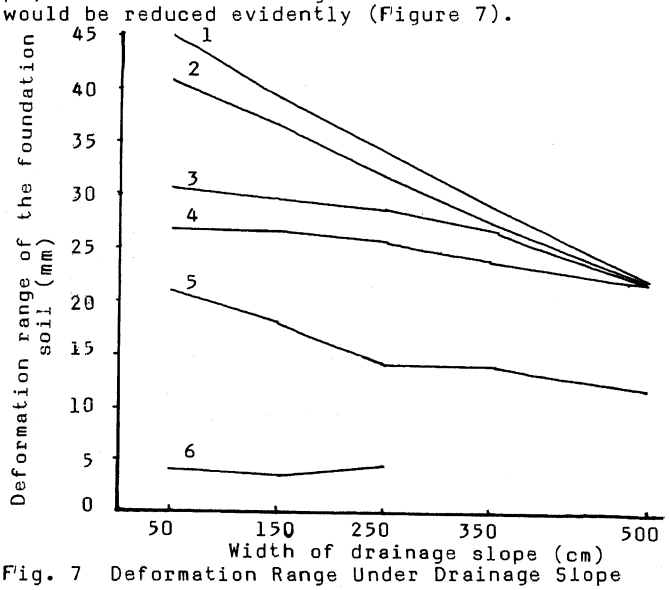

Fig. 7 Deformation Range Under Drainage Slope

In Figure 7:

Curve 1 = Deformation of the foundation soil 0.5m under the ground surface

Curve 2 = Deformation of the foundation soil 1.0m under the ground surface

Curve 3 = 1.5m deep Curve 5 = 3.0m deep

Curve 4 = 2.0m deep Curve 6 = 4.0m deep

In Figure 7, it shows that it's obvious to reduce the deformation range of the foundation soil between 1 to 2m under the ground surface by drainage slope. Thereafter, the buried depth of the foundation can be reduced by widening the drainage slope.

The results of the other measures couldn't be introduced and analysed detailedly because of the limited paper space.

Case 2 A Hospital Dispensary in South Guangxi Zhuang Autonomous Region

Basic Condition

This is the two-storied building with a floor space of 282 square metres built on slight slope. Nereby the building, there're some originally built buildings which have cracked and damaged already.

The overburden soil stratum on the building construction site is the residual clay with thickness of 4 to 5m. The colour of soil is greyish mixed up with light red and grey-green stripes. The bedrock is weathering mudstone.

The results of soil test shown as Table 2.

Table 2. Soil test Results

d (m)	W(%)	WL(%)	Ip	D(%)	e(%)	Ls(%)
1	30	48	19	49	3.22	5.03
2	30	58	26	64	3.93	3.83
3	26	44	16	58	1.30	6.35
4	27	57	29	/	3.37	3.65

The means of the symbols: d,W, ... as Table 1

The Following Measures Taken for the Buildings:

1. Strip foundation laid in 1.5m deep with sand cushion in 50cm thick.
2. The pour-in-placed reinforced concrete floor and periphery beam.
3. Width of drainage slope is 2.5m.
4. Reinforced concrete colums constructed in the four corners of the outer wall.
5. The surrounding management is the same as Case 1.

Management Results

Since the end of 1981, the author had begun to conduct deformation observation untill March 1987. Figure 8 shows the comparison of the deformation of managed and damaged old buildings.

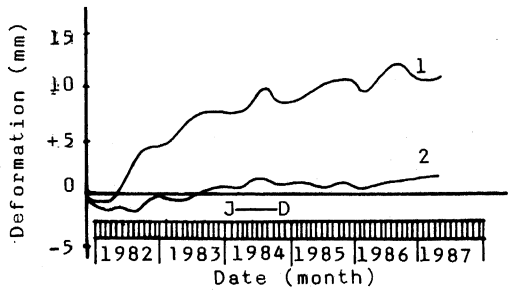

Fig. 8 Comparison of the Deformation

In Fig. 8:

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Curve 1 = Damaged buildings with deformation range of 13mm.

Curve 2 = Managed dispensary with deformation range of 3.4mm.

In the rainy season of 1986 (from April to September), the rainfall was 22 percent higher than that of the annual average rainfall. The river was in flood, but the newly built dispensary was still in good condition, which stood up to the tests in special weathers.

Case 3 A Dormitory Building in South Guangxi Zhuang Autonomous Region

Basic Condition

The building covers an area of 150 square metres, which is a single-storied house and built on the middle section of the slope covered by hard-to-plasticity clay with a thickness of 3 to 4m. The colour of soil is grey-green and yellowish white. The bed-rock is mudstone. The results of soil test shown as Table 3.

Table 3. Soil Test Results

d (m)	W(%)	WL(%)	Ip	D(%)	e(%)	Ls(%)
1	25	56	24	/	12.16	6.275
2	26	52	20	59	8.87	6.15
3	22	52	18	/	2.94	7.725
4.5	23	56	29	/	/	6.68

The means of the symbols: d,W, ... as Table 1

The Following Measures Taken for the Buildings

1. The pier foundation laid in 2.5m under the ground surface.
2. The width of drainage slope, 1.2m.
3. The pour-in-placed reinforced concrete roof-slab and periphery beam.
4. The surrounding management is the same as Case 1.

Management Results

The observation was begun in the January of 1984 and untill the March of 1987, the maximum deformation range was 9.91mm and the building remains well (Figure 9).

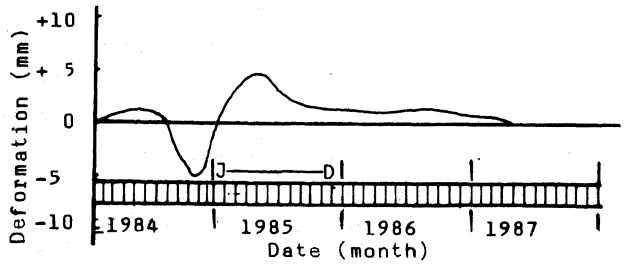

Fig. 9 Deformation Curve of the Building

CONCLUSION

The practice improves that in the management of the buildings on expansive soil, it's the only way to reach the previous result by comprehensive management with different measures according to the condition of geology, terrain, weather, etc.

The observation data show that the swelling and contracting deformation of foundation soil is mainly influenced by weather elements such as rainfall, evaporation of atmosphere and earth's interior temperature. The influenced depth of 2m is usually most obvious in South China. Therefore, the foundation's embeded depth would be 1-1.5m in light expansive soil area, 1.5-2m in medium expansive soil area, more than 2.0m in heavy expansive soil area. Besides it, the foundation soil must be managed with the measures such as sand cushion layer, replacement method, lime slurry injection process and so on. In architectural design, it's should be tried to reduce the corner of outer wall, because it's the severe-shifting area of moisture. When to determine the outdoor elevation, it should be tried to reduce the digging and filling, especially the measure to stabilize the slope must be taken for the buildings on hill-side field. The engineers must keep them in mind that : to manage slope should be stressed first, then follow after to build houses. In surrounding design, the stress should be laid to water drainage, scientific vegetation, so as to reduce the influence of foundation soil content caused by human element. In building construction, something must be stressed such as high-speed, soaking and sunshine prevention. During the usage of the buildings, it should be done to check whether the waterpipes, buildings and other facilities have been damaged, prune away unwanted branches and twigs in time, maintain the sod and so on.

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In the acknowledgement of the following gentlemen for their kind and great assistance in the research work:

Engineer Huan Guangxiang

Engineer Xie Shiqi

Engineer Wang Xianwen

Engineer Wu Shupin

(END)

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