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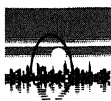
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Chinese Expansive Soil Canal Project

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SYNOPSIS This paper gives three representative expansive soil canal projects in China. The engineering geological conditions, the properties of the expansive soil, features of the slides and the measures taken for these canal projects are introduced in detail.

INTRODUCTION

Expansive soil distribution is widespread in China where many expansive soil canals have been built. The main question of expansive soil canal projects is the slide of canal slope, so the study of the canal slope stability is an important subject awaiting solution. In order to summarize its experience, this paper gives three representative expansive soil canal projects which are located in northeast, central and southern China.

A. BEIYIN OVERALL ARTERIAL CANAL IN HEILONGJIANG PROVINCE

This canal is 202 km long. There is K22 to K48 through the second terrace leading edge slope of the Nen River left bank and its slope angle is 7° to 8° . This canal was designed and built in 1970 according to the common clayey soil. Its section was the cut-and-fill type and had 16 metres wide at the bottom and the depth of water was 2.3 metres. The slope was 1:2 in the lower part and 1:1 in the upper part. The maximum depth of cut was 8 metres and none of other measures was taken. In 1974, there were continuous slides from K36 to K40 when the project was under construction. It formed a group of slide. The total length of the slide group was 1,700 metres and total volume was $140,000 \text{ m}^3$. The measures of renovation were put forward on the basis of the thorough researches on the engineering geological conditions, the engineering properties of the expansive soil and the destructive features of the canal slides. The measures were tried in the construction in 1975. Since then, no destruction have appeared. It appears very successful.

A.1 Engineering Geological Conditions of the Canal Slope

The strata structure of the canal slope as follows:

a. Q_3^{s1+p1} clay (non-expansive soil): 3 to 10 metres thick. The silt content is about 50% and clay ($< 5\mu$) content is about 30%.

b. Q_2^{s1+p1} clay (expansive soil): 20 to 30 metres thick and clay content is about 60%. According to the colour, separating it into two portions: grey-brownish grey and orange-red. The mineralogical composition, the former, is mainly montmorillonite and illite; the later, is mainly illite and montmorillonite, and the cation exchange capacity is 77.1 me/100g and 74.3 me/100g respectively. The fissure in soil body developed well and the fissure-faces are smooth, which have obvious slickensides.

c. N_2 sand gravel: about 100 metres thick.

The basic properties are shown in Table 1 and Table 2 respectively. It follows that this soil is a high plasticity clay and a strong expansive soil.

The shear strength data of the expansive soils tested by direct shear apparatus are shown in Table 3. It follows that the shear strength of the expansive soils, especially, residual shear strength decreases obviously with the increase of the water content from natural water content to saturated water content. The residual value of angle of internal friction (ϕ) decrease from 8° to 3° .

For typical slides, the backfigured data of the shear strength solved by the use of equilibrium conditions of the slide mass are shown in Table 4. It follows that the backfigured values is larger than the residual strength values from laboratory test under the conditions of saturated water content, and smaller than the values from laboratory test under the conditions of natural water content.

A.2 Analysis of Canal Slope Failure

The main form of canal slope failure was slide. It had obvious sliding surface which had a broken-line shape in analogy to circular arc. The sliding bed was gentle (generally, the slope

TABLE 1. Natural Physical and Plastic Properties of the Expansive Soil

Soil type	Natural Physical and Plastic Properties								
	Water Content	Unit Weight	Specific Gravity	Void Ratio	Degree of Saturation	Saturation Moisture Content	Liquid Limit	Plastic Limit	Plasticity Index
	(%)	(KN/M ³)			(%)	(%)	(%)	(%)	(%)
Orange - Red Expansive Soil	27.2	19.1	2.74	0.83	90.0	30.5	54	28	26
Grey - Brownish Expansive Soil	31.0	18.7	2.74	0.92	92.5	33.6	52	29	23

TABLE 2. Swell - Shrinking Properties of the Expansive Soil

Soil Type	Swell - shrinking Properties						
	Water content	Dry Unit Weight	Vertical Shrinkage	Volumetric Shrinkage	Shrinkage Limit	Volume Expansive	Swelling Pressure
	(%)	(g/cm ³)	(%)	(%)	(%)	(%)	(kpa)
Orange - Red Expansive Soil	23.4	1.45	7.3	18.1	10.1	25.7	204
Grey - Brownish Expansive Soil	27.8	1.50	8.0	23.0	11.3	8.8	116

TABLE 3. Shear Strength Data of the Natural Samples

Soil Type	States of Samples	Test Method	Shear Strength			
			Peak Values		Residual Value	
			C(kpa)	ϕ (°)	C(kpa)	ϕ (°)
Orange - Red Expansive Soil	Saturated (33% Water Content)	Consolidated Quick Shear	38	18.6		
	Natural (29% Water Content)	Consolidated Quick Shear	38	20		
Grey - Brownish Expansive Soil	Saturated (33% Water Content)	Consolidated Quick Shear	45	20.0	8	3
	Natural (29% Water Content)	Consolidated Quick Shear	48	22	16	8

TABLE 4. Backfigured Shear Strength data by Slide Mass

Conditions	Section Form	Backfigured	Shear Strength Data
		Cohesion (KPa)	Angle of Internal Friction (°)
Disregarding the Influence of Seepage	Standard Construction Section of Sliding Canal	8.6	6.4
	Section After First Sliding	8.1	3.9
Regarding the Influence of Seepage	Standard Construction Section of Sliding Canal	7.6	12.1
	Section After First Sliding	8.4	6.4

was smaller than 15°) in expansive soil, and steep (the slope reaches $30^\circ - 40^\circ$) in non-expansive soil. There often was a adverse slope on the leading edge of the sliding bed and its slope was smaller than 5° . The sliding wall was steep (dip angle is larger than 50°) and its height was different (generally, around 1.0 m). The sliding tongue of the slope heaved original surface up 0.4–0.8m (fig. 1). In plane, the length of the slide along the direction of the canal was large, and small along the direction of the slide. The slide boundary was distinct.

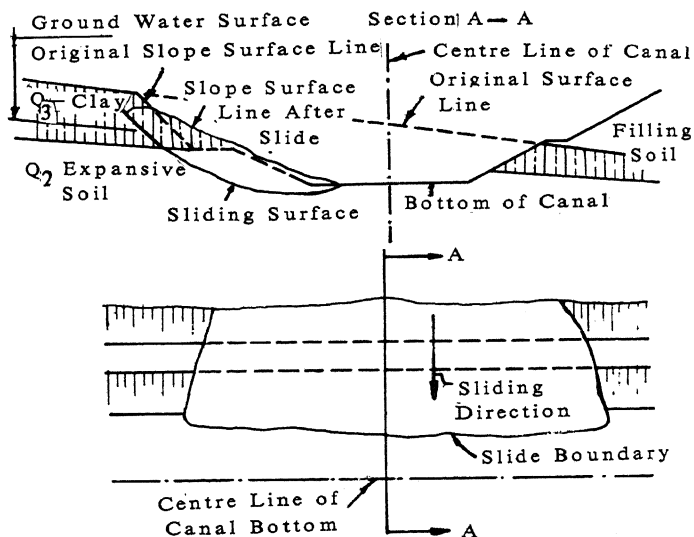


Fig. 1. A Typical Slide

The characteristics of the canal slide occurrence as follows:

a. The slides occurred only in the exposure segments of expansive soil, for example, at K25, K29 points and in K37 to K40. No slides occurred in the unexposed segments of expansive soil.

b. The slides occurred after rain. The sliding velocity down the slope increased in a rainy season, but decreased in a dry season, even stopped sliding.

c. Because the maximum depth of cut was only 7 to 8 metres and the exposure area of expansive soil was not large, and the maximum thickness of sliding mass is 4 to 8 metres, the slide belonged to the small shallow slide; but as a series of slide connected and formed a sliding groupe, it had a considerable scope.

d. Because the slides occurred in the exposure segments of expansive soil and the fissure developed well in its mid-lower part, the major sliding segment occurred in expansive soil and the slide in upper non-expansive soil belonged to a retrogressive slide.

Thought the sliding reason was the severe decrease of the shear strength of the expansive soil caused by the exposure of expansive soil and the intrusion of subsurface and surface water, in essence, the reason was the design

based on the common clayey soil in the absence of expansive soil knowledge, and no appropriate measures were taken. For example, at that time, the slope 1:2 of the canal without any measures protecting the expansive soil slope from slide was designed by checking slope stability using peak strength ($c=30 \text{ kpa}$, $\phi=20^\circ$) of saturated consolidated quick shear test and the safety factor of the slope stability was more than 2; but in fact, the residual strength values of this soil was $c=8 \text{ kpa}$, $\phi=3^\circ$ to 4° , so the occurrence of slide was inevitable. In addition, another kind of the canal slope failure was surface plastic flow slump (Fig.2) besides slide. Its scope was not large and the thickness of slump mass was generally within 1 meter. The reason producing flow slump was the swell softening of expansive soil and forming plastic flow state caused by the intrusions of surface and subsurface water from the non-expansive soil strata.

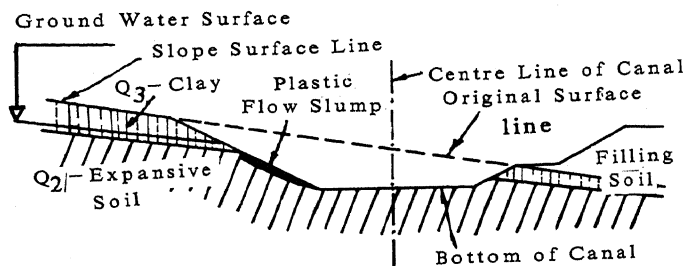


Fig. 2. A Typical Plastic Flow Slump

A.3 Measures of Renovation (Fig.3)

a. Setting up the back-compacting body: non-expansive soils were placed in the lower part of sliding mass according to the requirements of dam construction. The roof width of the back-compacting body was 6 to 10 metres and its slope is 1:3. It acted also as sealing the slope surface of expansive soils.

b. Sealing the slope surface of expansive soils: the residual part of slope surface of expansive soil which is not sealed by back-compacting body is sealed with non-expansive soil. It was placed according to the requirements of dam construction and its thickness was 1 metre.

c. Building blind drains to drain subsurface water away and drop the subsurface water level (it is not pointed out in Fig.3).

d. Building the intercepting ditch and drainage ditch to drain surface water.

e. Cutting slope and reducing loading: the slope over the back-compacting body was reduced to 1:3.

B. YINHAN TAOCHO CANAL IN HENAN PROVINCE

The length of this canal project is 4.44 km and the width at the bottom is 30 metres. The design

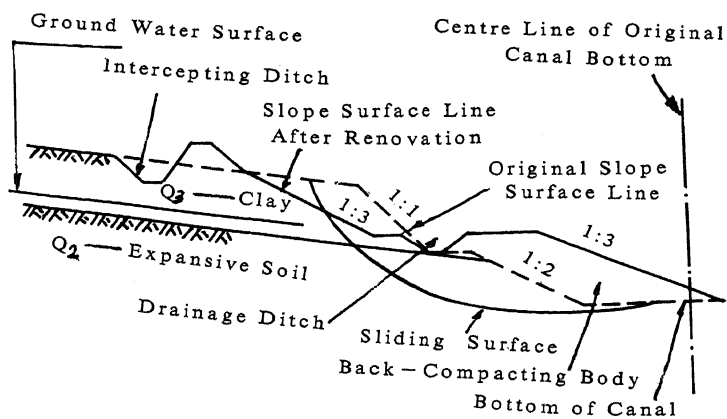


Fig. 3 Measures of Renovation

discharge is 1100 m³/sec. The general cutting depth is 20 to 30 metres and the largest cutting depth is 40 metres.

Though the construction slope was 1:4 to 1:4.5 considering the existence of the expansive soil, the slide occurred when it was excavated to the 10 metres depth in April, 1970. By the end of that year, there were thirteen slide points. Among these slides, the larger slides were No.1 slide of left bank and No.8 slide of right bank (the width of the sliding mass was more than 200 metres and 100 metres, respectively). Therefore, the thorough research on this canal project was required.

B.1 Engineering Geological Conditions of the Canal

The composition of Quaternary system clay strata as follows:

- a. Q₄ — clay (non-expansive soil): it is very thin in hillock and < 5 μ soil particle content is 36% to 43%.
- b. Q₃ — expansive clay: 3 to 20 metres thick and < 5 μ soil particle content is 54%.
- c. Q₂² — expansive clay (upper part of mid-pleistocene series): 0 to 12 metres thick and < 5 μ soil particle content is 54%.

TABLE 5. Basic Engineering Properties of Soil Strata

Soil Strata	Water Content (%)	Unit Weight (KN/M ³)	Dry Unit Weight (KN/M ³)	Void Ratio	Degree of Saturation (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Q ₄ - Clay	23.9	1.97	1.59	0.73	90	39.2	21.3	17.9
Blacking - Grey	24.5	1.95	1.57	0.72	92	30.2	17.7	12.5
Q ₃ - Expansive Soil and Q ₂ ² - Expansive Soil	24.9	2.00	1.60	0.72	95	55.4	28.7	26.7
Q ₂ ¹ - Expansive Soil In Clay	24.0	2.00	1.61	0.71	93	56.5	29.8	26.7

d. Q₂¹ — clay (lower part of mid-pleistocene series): very thick. Several expansive soil strata (0.5 to 0.8 metres thick) are intercalated in it and < 5 μ soil particle content is 58%.

The fissures of the expansive soil strata above developed well and the fissure face is smooth.

Most cracks are filled by the grey colour or greenish-grey colour clay (one millimetre to several millimetres thick). The fissures are distributed in a netty form. Most of the mineralogical composition are illite and with the addition of some montmorillonite and kaolinite. All cation exchange capacity are over 55 me/100g. The basic engineering properties of soil strata above are shown in Table 5.

The shear strength values of soil strata expressed by effective stress are c' = 20 kpa, ϕ' = 22°.

B.2 Sliding State of the Canal Slope

The sliding surface had generally broken-line form and its dip angle was 6° to 10°. The minimum thickness of the slide mass was 2 metres and maximum was 7 metres. All of slides belonged to a retrogressive slide, that is, the sliding occurred first in small lower scope, and then, developed gradually up. In other words, the sliding tension crack occurred first in the waist of slope and then, developed gradually up to the top of slope with the obvious growth of tension crack and a break wall occurred. The sliding tongue extruded in front of slope heaved (Fig.4).

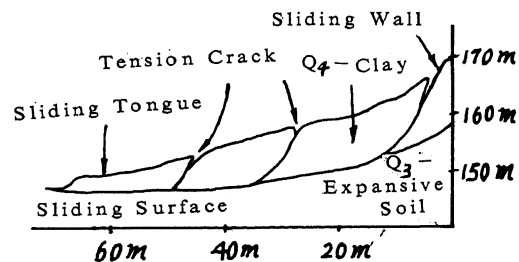


Fig. 4 A Retrogressive Slide

The slide occurred in a rainy season, and then, the slide stopped in dry season. The maximum sliding velocity given by observation was 10 cm per day. During the three years of the construction, all of the slides went slowly on

sliding down. All of several large slides of them had slid for several metres before they were treated.

After the investigation on the sliding reason, it was found that there was a very strong expansive soil intercalation between Q_4 — clay stratum and Q_3 — expansive soil stratum. The upper part of the intercalation was grass yellow colour and 10 to 20 cm thick, and the lower part was grey colour and 1 to 10 cm thick (Fig.5)

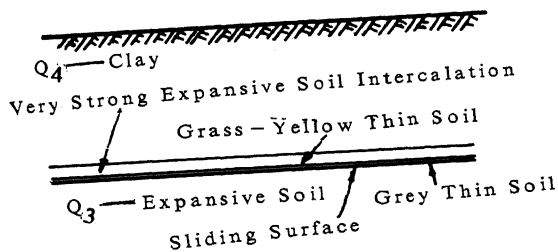


Fig. 5 Very Strong Expansive Soil Intercalation

The grey soil in intercalation: $W_L = 62$ to 64% , $<5\mu$ soil particle was more than 60% and main mineralogical composition was montmorillonite which had very strong swell-shrinking properties.

The bedding surface of the thin grey soil stratum was the potential soft texture surface, which was the basic reason for causing slide. The explanation as follow:

a. The main mineralogical composition of the grey thin stratum was montmorillonite. Its clay content and water content were high ($W = 35\%$ to 38% which was 10% higher than that of upper or lower layer). Its perviousness was very weak. It was comparatively a clay pan, so the permeation of surface water was arrested and the permeability pressure increased. At the same time, the stress relaxation caused by excavation and decompression made texture fissure open, so the texture surface was softened by water and the strength decreased. The effective stress strength values given by slow shear test were only $c' = 2$ to 8 kpa, $\phi' = 10^\circ$ to 12° which approached to the residual strength of the sliding surface.

b. Because the thin grey stratum inclined to the centre of the canal and its dip angle was more than 5° (generally, 6° to 8°), down sliding force of soil mass increased.

In addition, in a rainy season, the subsurface water level existing in Q_4 — clay went up and dynamic water pressure increased. The spoil in the course of cut were piled on the roof of the slope and the slope loading was artificially increased. It was also a reason for causing slide.

B.3 Measures of Renovation and Effect

According to the analysis of sliding reasons given above, the supporting-retaining as main measure and the drainage as supplementary measure were taken. Two specific methods used as follow:

a. Grouted rubble arch—adopting circular-shape arch for shallow slides; $R = 5$ m and arch thickness $b = 1$ m. The height of arch body was 2.5 to 3.0 m and the depth below the sliding surface was not less than 0.5 m. The horizontal drainage conduits were placed at the bottom of the arch to drain the water on the sliding surface away (Fig.6). If the arch was not able to resist the sliding thrust, the anti-slide piles added would be placed at the arch foot.

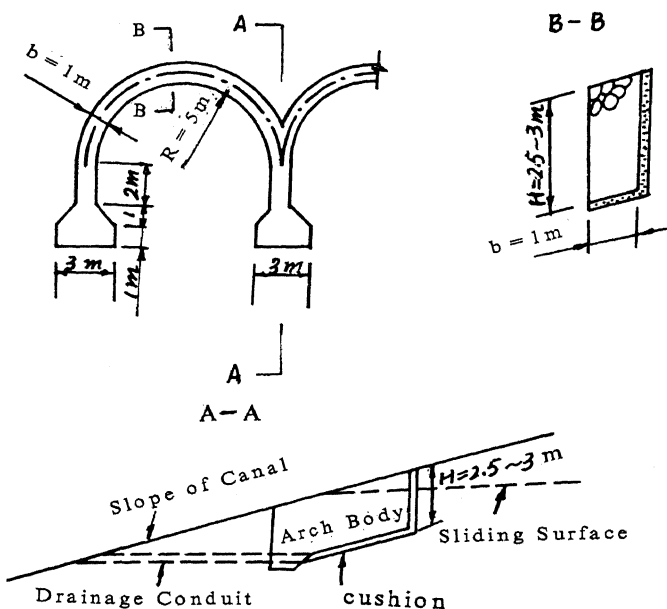


Fig. 6. Grouted Rubble Arch

b. Concrete anti-slide pile for deep slides to anchor the sliding mass with the immovable soil mass (Fig.7): the pile diameter was 1 metre. A few of reinforcements were disposed in the pile. The interval of pile in length and breadth was 5 metres. The piles were placed at the depth of 5 metres below the sliding surface and arranged as the plum-blossom shape using two or three rows piles (determined by calculating the sliding thrust).

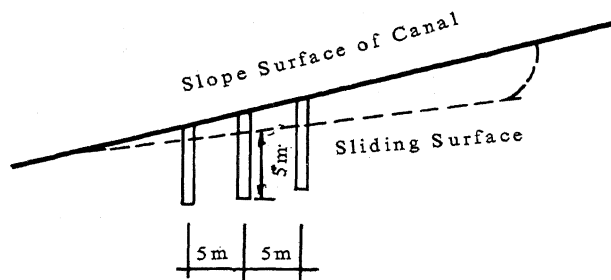


Fig. 7. Concrete Anti-slide Piles

In addition, the slope was appropriately made gentle. The slope surface was grassed, and the drainage blind ditches were placed in the some segments of the canal.

Since the slides were treated in 1973, the canal has been used normally.

C. NORTH ARTERIAL CANAL OF SHANGSI IN GUANGXI PROVINCE

This canal is 65 km long and 8 metres wide at its bottom. Its design discharge is 8 m³/sec, and 46.2 km are through expansive soil areas. Half of the canal need to excavate and the deepest cut is 8 metres.

The slope was 1:1.5 to 1:2 when built in 1974 and no other measures were taken. So the slope of the canal had slided in succession since its construction began. At that time, though two measures (making the slope gentle and structuring the retaining wall) were taken, they were not effective. The sliding went on and in some slides, the retaining wall was slided out.

The slides had the obvious sliding surface, sliding wall and sliding tongue, but all of them were small scale. The width of sliding mass was 10 to 30 metres and its thickness was 2 to 3 metres. The height of the sliding wall was not over 1 metres. several small slides were composed and formed a groupe of slides. Though the slides were small scale, there were 155 sliding points in about 4 km segment of the canal, so the canal could not be used normally.

The reason why such serious failure occurred in such a small canal was the absence of expansive soil knowledge: regarding the soil in the canal as a common clayey soil at that time. In fact, the expansive soil there is the most strong expansive in China. It is formed by Tertiary system mudstone weathered and some are exposed to surface. Its thickness is very large (several metres) and fissure developed well. The main mineralogical composition is montmorillonite and illite.

TABLE 6. Shear Strength Values of Natural Soil (Quick Shear and Peak Value)

Sampling Sites	Value Type	Cohesion (kpa)	Angle of Internal Friction (°)
Kuzhang	Value Scope	15-84	0.2-6.0
	Averaged Value	56.7	3.0
	Peak Value	40	0.2
Nongzhong	Value Scope	7-67	1.4-7.0
	Averaged Value	26	3.3
	Peak Value	34	1.4
Nonghua	Value Scope	16-93	4.5-9.0
	Averaged Value	58.2	7.8
	Peak Value	48	4.5

Table 6 shows that the shear strength of expansive soil of the canal in natural state was very low. Some ϕ values were only 0.2° and C were 40 kpa, so it can be consider that its strength was still lower after the water entered the expansive soil through its fissure and some almost lost completely strength. It is also the essential reason why the serious slides occurred in the canal.

After the repeating tests and research were made by Qinzhou Exploration Survey And Designing Team Of Guangxi and Shangsi Water Power Office of Guangxi, measures of renovation were given. Since the measures were carried out, the canal have been stable.

a. For the canal Segment excavated to 6 to 8 metres depth, constructing a grouted rubble arch-type culvert with filling (Fig.8) and a double-curved arch-type culvert with filling with the grouted rubble anti-arch floor or concrete anti-arch (40 cm thick).

b. For the canal segment excavated to 4 to 8 metres depth, Constructing a single-face retaining wall with anti-arch floor or double-face retaining wall with anti-arch floor.

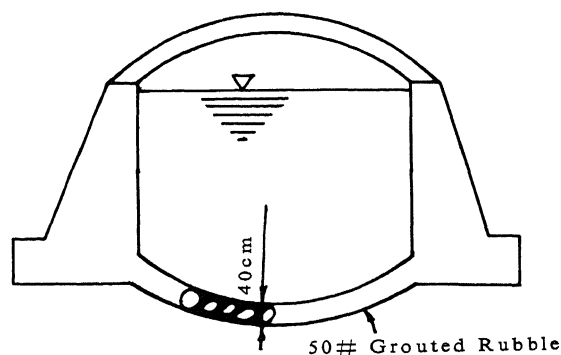


Fig. 8 A Single-Arch With Anti-Arch Floor Culvert With Filling

c. For the canal segment excavated to less than 4 metres depth, paving the section of the canal with cement soil. The bottom was anti-arch-type and its radius was 1.1 times as large as the width of the bottom. The cement soil is made by mixing the 10% cement and local expansive soil. First, Paving 10 cm thickness and then, Paving again above the cement soil with 35 × 35 × 3 cm³ cement mortar precast block to form a revetment

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Xu Zongru (1986), "The Test Study on Properties of Swell-Shrink Soil and Measures of Treatment in the North Arterial Canal of Neban Reservoir", Water-Conservancy and Water-Power Technology of China.