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SYNOPSIS Presented in this paper is the summary of two case histories using alkali liquid method to reinforce collapsible loess ground. One is the ground treatment of administration building which was not in a position of normal service because of the unequal settlement of the ground caused by collapsibility; the other is the ground improvement of the office building of a hospital before construction. The test to examine reinforcing effects is held one month after ground stabilization. It is learned from the test results that the soil compressibility characteristics within the treated aera has been changed from high grade to medium grade or low grade, and the collapsibility of loess within the treated area has been eliminated. The method of alkali liquid to improve ground has many advantages, namely, simple in construction , with obvious effects , and no vibration or contamination to be caused.

INTRODUCTION

Shanxi, P.R.China, is located in a loess plateau. It is one of the major problems to eliminate the collapsibility of loess in construction. Engineers have applied various innovative methods to the treatment of collapsible loess grounds, for instance, heaving tamping, dynamic compaction, sand cushion, soil-lime compaction pile, pile foundation, chemical stabilization. Much practical experience has been drawn from engineering performance. Presented in this paper is the summary of two case histories using alkali liquid method to reinforce collapsible loess ground.

CASE HISTORY I, THE GROUND TREATMENT OF ADMINISTRATION BUILDING IN THE FOURTH ELEMENTARY SCHOOL AT TAIYUAN STEEL COMPANY

1. Project Description and Site Conditions

The administration building of the Fourth Elementary School is a Four-story brick-concrete building constructed in natural ground with strip footings. It has rectangular plan, 52 meters in length and 12 meters in width. The site of the building belongs to grade II self-weight non-collapse loess. Soil layers within the depth of exploration include miscellaneous fill, loessial silt, loessial silty clay, and the geological profile is shown in Fig.1. The loessial silt layer, 1.4 meters to 2.6 meters in thickness, is characterized by yellow color, loose macropore structure, high compressibility, and medium collapsibility. The loessial silty clay layer is characterized by brown yellow color, macropore structure, medium compressibility, and medium collapsibility. The physico-mechanical indexes of every layer are shown in Table 1 .

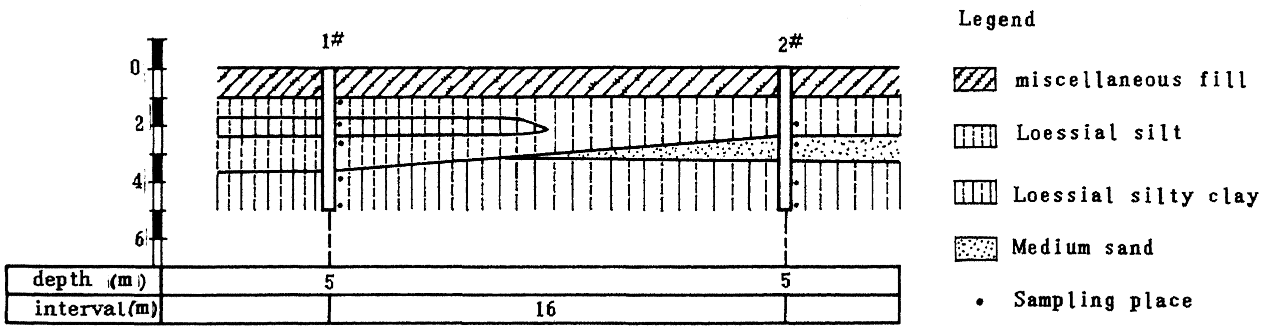

Fig.1 Geological Profile

The embedded pipes in the toilet had been broken, and thus water leaked out , and therefore caused collapsibility after the building had been put in use for two years. Many cracks appears in the longitudinal and lateral walls because of the uneqaual settlement of the ground. The building is not in a position of normal service. Finally alkali liquid method was selected to treat the deposit in order to improve the bearing capacity of the ground and prevent the ground from further settlement.

2. The Method of Improvement

The toilet is on the northern side of the building, and the embedded tubes are arranged parallel to the northern wall. Therefore, the collapsibility of the deposit happens mainly in the northern side of the building. A total of 143 holes to reinforce the ground is arranged along two sides of the footings of the northern wall in order to strengthen the ground, and also to prevent the ground from lateral pushing out when the ground is soaked and to decrease the ground settlement. The distance befween holes is 70cm.

The holes are formed by Loyang spoon. The radius of holes is 8 cm. The depth of holes is 5 meters outside the building and 5.75 meters inside the building respectively . The grouting tube is plunged into the required depth; the space between holes and tubes is filled with pebbles of diameter of 10 to 20 mm in order to prevent the hole from blocking; the holes above the bottom of foundations is filled with clay soil to keep the alkali liquid from overflowing.

The injecting equipment is shown in Fig. 2. Alkali liquid is kept in a metal barrel, and that is heated by fire directly beneath the bottom of the barrel. There is a tap with a diameter of 20 mm in the barrel's bottom, and a rubber tube of 25 mm in diameter is connected with the tap from outside. When injecting is started, the rubber tube is connected with the injecting tube, and the tap is opened, then the liquid will automatically flows into the injecting holes. 1200 liters of alkali liquid are needed for each hole. The average density of alkali liquid is 110 grams per liter. The temperature of alkali liquid is above 90 degrees centigrade. The injecting velocity is between 1.5 to 2.0 liters per minute and continuous injecting is adopted. To control the settlement of the building due to injecting alkali liquid, the injecting interval between two adjacent holes is at least 3 days, and the distance between two holes which are grouted at the same time is at least 3 meters to prevent the penetrating regions from forming a continuously penetrated area.

3. The Effect of Improvment

(1) The Comparison of Physico-mechanical Properties for Collapsible Loess Deposit before and after Improvement

The test to investigate reinforcing effects is held one month after construction. A test pit is dug in site, and at different depths samples are taken from the position which are located 35 cm and 70 cm away from the center of holes for reinforcement. These samples are tested in laboratory. The parameters of physico-mechanical properties of reinforced soil are shown in Table 2. Comparing table 1 with table 2, we can get the following results, the reinforcing effects of soil are obvious within the depth of 1.3 meters to 3.5 meters below the ground surface. In this range, the mechanical properties of soil are changed a lot, the collapssibility is completely eliminated. Again, the strata with the depth of 4.0 meters to 5.0 meters are also improved to a certain extent.

(2) The Additonal Settlement of The Builiding in the Process of Grouting Alkali Liquid

It is a common problem that a foundation will get further settlement when a method of chemical grouting liquid is applied to treat ground collapse accidents. This is because that the soil will absorb the water of chemical liquid and become softer, therefore additional settlements are caused under the action of the superimposed pressure.

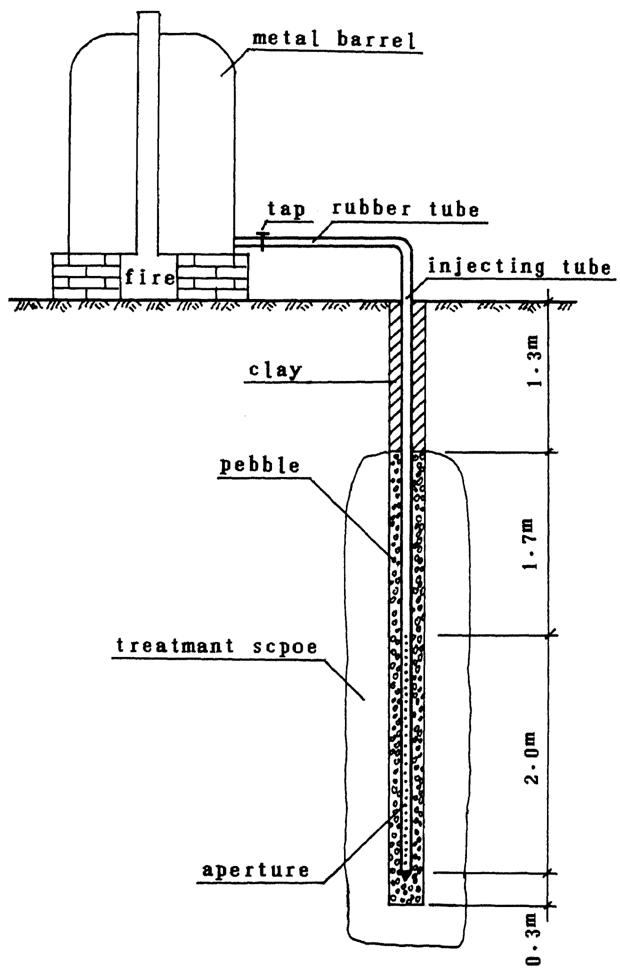

Fig. 2 Injecting Equipment

TABLE 1 The Physico-mechanical Indexes of Every Layer

No. of sample	No. of test shaft	depth (M)	W (%)	γ (KN/m³)	γ_d (KN/m³)	ds	e	Sr (%)	W (%)	Wp (%)	Ip	I_L	a_{1-2} (MPa⁻¹)	δs	δzs	Psh (KPa)	Es (MPa)	classification
1	1#	1.0	14.7	15.3	13.3	2.70	1.024	39	25.4	16.5	8.9	<0	0.70	0.049			2.78	silt
2		1.7	17.1	14.9	12.7	2.70	1.122	41	27.2	17.0	10.2	0.010	0.46	0.085	0.015	30	4.49	silty clay
3		2.4	8.7	14.8	13.6	2.69	0.976	24	23.9	15.8	8.1	<0	0.21	0.022	0.008	110	9.37	silt
4		3.7	23.1	16.8	13.6	2.70	0.978	64	25.6	16.3	9.3	0.731	0.21	0.027	0.006	135	9.34	silt
5		4.7	17.7	16.6	14.1	2.71	0.922	52	28.9	17.4	11.5	0.026	0.11	0.047	0.006	128	17.7	silty clay
1	2#	2.0	21.6	16.6	13.7	2.70	0.978	60	25.2	16.2	9.0	0.600	0.40	0.029	0.003	100	4.81	silt
2		2.6	17.0	16.3	13.9	2.65	0.902	50										sand
3		4.0	27.3	18.1	14.2	2.71	0.906	82	28.3	17.5	10.8	0.970	0.22	0.017	0.003	180	8.47	silty clay
4		5.0	24.3	16.9	13.6	2.71	0.933	66	30.1	17.8	12.3	0.527	0.57	0.028			3.78	silty clay

TABLE 2 The Parameters of Physico-mechanical Properties of Reinforced Soil

No. of sample	No. of test shaft	depth (M)	W (%)	γ (KN/M³)	γ_d (KN/M³)	ds	e	Sr (%)	W (%)	W (%)	Ip	I_L	a_{1-2} (MPa⁻¹)	δs	Es (MPa)	q_u (KPa)	q'_u (KPa)	classification
1	1#	1.0	16.5	17.5	15.0	2.68	0.784	56	26.2	19.4	6.8	<0	0.06	0.0001	29.5	554	590 578	silt
2		2.1	21.4	17.7	14.6	2.68	0.836	68	30.3	22.6	7.7	<0	0.07	0.0002	26.0	139	167	silt
3		3.0	29.6	17.8	13.7	2.68	0.951	83	29.8	22.9	6.9	0.971	0.25	0.0001	7.6	66		silt
4		4.0	28.7	17.4	13.5	2.70	0.997	78	29.7	20.8	8.9	0.888	0.57	0.0001	3.4	70		silt
5		5.0	23.4	18.3	14.8	2.69	0.814	77	24.0	16.6	7.4	0.919	0.18	0.0001	10.1	119		silt
1	2#	1.0	19.5	16.0	13.4	2.69	1.009	52	27.3	19.5	7.8	0.0	0.06	0.0002	33.6			silt
2		2.7	21.1	16.4	13.5	2.69	0.986	58	27.5	19.5	8.0	0.200	0.09	0.0001	21.6			silt
3		3.1	28.6	18.2	14.2	2.69	0.901	85	29.2	21.2	8.0	0.925	0.09	0.0003	20.1	235		silt
4		4.0	29.1	17.8	13.8	2.69	0.951	82	26.9	19.0	7.9	>1	0.47	0.0002	4.0	51		silt
5		5.0	24.6	17.7	14.2	2.69	0.894	74	25.8	17.3	8.5	0.859	0.73	0.0002	23			silt
1	3#	1.0	18.0	16.0	13.6	2.69	0.984	49	23.3	17.2	8.1	0.099	0.78	0.00	2.5			silt
2		2.0	13.0	17.6	15.6	2.69	0.727	48	25.6	17.1	8.5	<0	0.06	0.0003	27.5			silt
3		3.0	25.9	18.5	14.7	2.69	0.831	84	27.1	19.3	7.8	0.846	0.09	0.000	19.9			silt
4		4.0	25.4	17.8	14.2	2.69	0.895	76	26.0	18.3	7.7	0.922	0.59	0.0003	3.1			silt

Note, 1# is 0.35m away from the center of grouting hole.
2# is 0.35m away from the center of grouting hole.
3# is 0.70m away from the center of grouting hole.

In the course of construction, the holes which are being grouted at the same time are not adjacent so that adjacent non-penetrated ground will bear more load which the penetrated ground unloads, then further settlements will be reduced. The investigation reveals that the greatest additional settlement, 2.3 mm, is in the region in which the toilet is located, and the average additional settlement in other regions is 1.2 mm.

(2) The Situation after Two Years of Ground Reinforcement

Since the ground reinforcement was performed two years ago, the settlement of the building had been basically stable, and no new cracks happened in longitudinal and lateral walls.
The unconfined compression strength (q'_u) of two samples which have been put in water since they were taken from the site two years ago, as shown in Table 2, is almost as the same as that of samples before they were put into water.

CASE HISTORY II. THE GROUND TREATMENT OF THE OFFICE BUILDING OF A HOSPITAL IN TAIYUAN

1. Project Description And Site Conditions

The site of the hospital is collapsible loess deposit within a depth of 8 meters. It belongs to the type of grade Ⅲ self-weight non-collapse loess. According to the design requirements, the method of alkali liquid to treat the ground was adopted in order to eliminate the collapsibility of loess. The followings are the tests conducted before construction.

The tests are run in two regions, region I and region II. There are four grouting holes A, B, C and D. The density of alkali liquid is 110 grams per liter. The test is held one month after alkali liquid is grouted. Test shaft in region I, 4.5 meters in depth, 2.5 meters in length, covers grouting holes A and B. At different depths samples are taken from the positions which are 0.25 meters and 0.35 meters away from the center of the grouting holes A and B. Test shaft in region II, 5.0 meters in depth, 2.6 meters in length, covers grouting holes C and D. At different depths samples are taken from the position which are 0.4 meters and 0.8 meters away from the centers of grouting holes C and D. In addition, the percolating scope of alkali liquid is tested by phenolphthalein. The indexes of physico-mechanical properties of samples are given by laboratory tests.

2. The Effect of Reinforcement

The indexes of physico-mechanical properties of samples taken from region I and region II are shown in Table 3. The coefficiencies of compressibility and those of collapsibility and the statistical mean values of unconfined compression strength for samples at different distances from the centers of grouting holes are shown in Table 4.

From Table 4 we can see that the effect of reinforcement within a circular region with radius of 0.4 meter from the center of grouting holes is obvious. The collapsibility of loessial silt is completely eliminated and the compress-

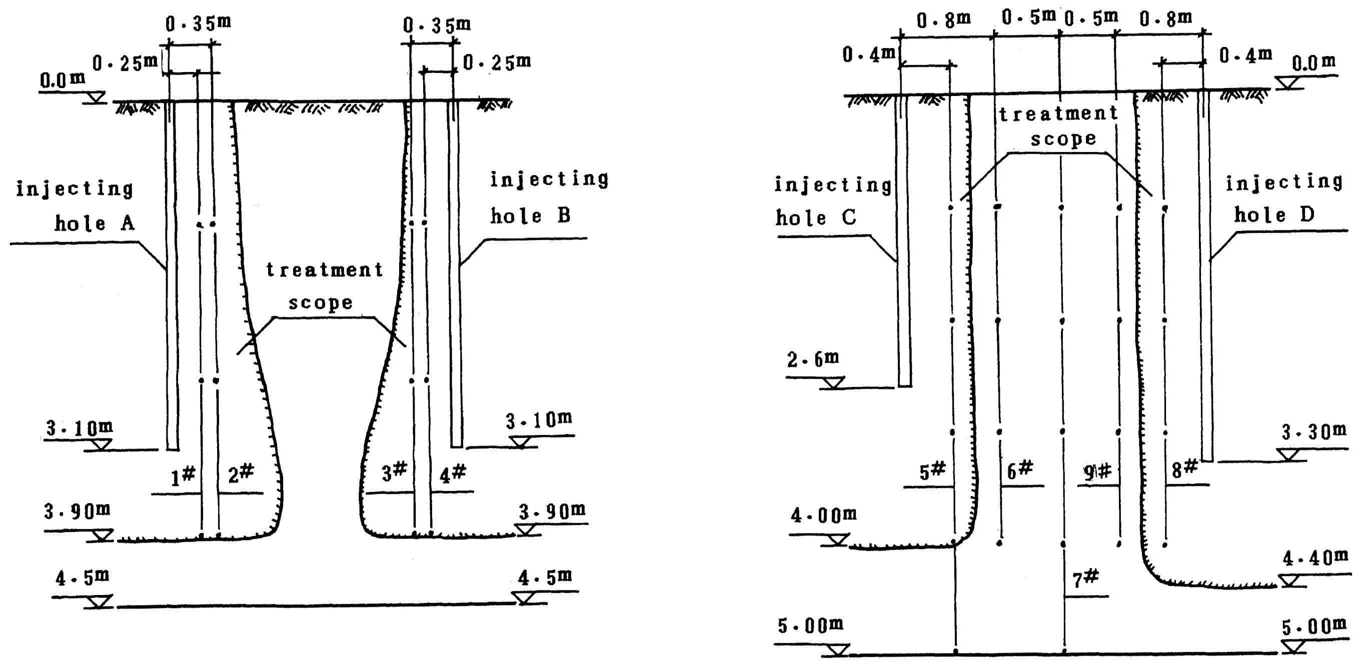

Fig. 3 Percolating range of alkali liquid

TABLE 3 The Parameters of Physico-mechanical Properties of Reinforced Soil

No. of sample	No. of test shaft	depth (M)	W (%)	γ (KN/m³)	γ_d (KN/m³)	ds	e	Sr (%)	W (%)	Wp (%)	Ip	I_L	a_{1-2} (MPa⁻¹)	δs	δzs	q_u (KPa)	classification
1	1#	1.10	23.3	15.8	12.8	2.69	1.099	57	36.7	29.7	7.0	<0	0.04	0.001	0.0006	266	silt
2		2.50	17.4	16.2	13.8	2.68	0.947	49	33.2	28.1	5.1	<0	0.04	0.002	0.001	281	silt
3		3.90	13.4	15.1	13.3	2.69	1.020	35	28.7	20.4	8.3	<0	0.20	0.009	0.001	115	silt
1	2#	1.10	17.1	15.1	12.9	2.68	1.078	42	29.4	24.0	5.4	<0	0.26	0.012	0.006	37	silt
2		2.50	16.3	15.6	13.4	2.68	0.998	44	30.1	26.2	3.9	<0	0.05	0.001	0.0004	45	silt
3		3.90	13.3	15.4	13.6	2.68	0.972	37	28.8	22.7	6.1	<0	0.30	0.001	0.007	82	silt
1	3#	1.10	16.9	15.2	13.0	2.69	1.069	43	34.2	26.5	7.7	<0	0.08	0.001	0.0003	184	silt
2		2.50	17.4	16.3	13.9	2.68	0.930	50	32.2	27.4	4.8	<0	0.04	0.001	0.0003	307	silt
3		3.90	11.0	15.3	13.8	2.68	0.944	31	29.7	23.7	6.0	<0	0.06	0.002	0.0007	187	silt
1	4#	1.10	16.1	14.3	12.3	2.69	1.184	37	26.8	17.3	9.5	<0	1.30	0.001	0.0005	42.1	silt
2		2.50	13.1	15.4	13.6	2.68	0.968	36	29.3	24.0	5.3	<0	0.12	0.001	0.0006	101	silt
3		3.60	13.4	15.0	13.2	2.69	1.034	35	28.0	19.3	8.7	<0	0.98	0.011	0.0009	138	silt

ibility reduces to medium grade or low grade. The unconfined compression strengths are 230 kpa within a circular area, 0.25 meter from the center and 80 kpa for the area within 0.25 meter to 0.4 meter from the center respectively. The ground beyond a circle with a radius of 0.5 meter which is concentric with the grouting hole is not improved very well and the compressibility belongs to high grade and the collapsibility still exists.

The percolating range of alkali liquid is shown in Fig.3. The holes, i.e. hole A & hole B, of 3.1 meters in length in region I will result in a circular percolating region around the hole with radii of 0.4 to 0.55 meter respectively at the upper soil layer, but with radius of 0.9 meter at the lower soil layer. That is to say, the penetrating scope at the lower soil layer is larger than that at the upper soil layer. Moreover, the alkali liquid penetrated to a depth of 0.5 to 0.8 meter beneath the bottom of the hole. Both the hole C of 2.6 meters in length and the hole D of 3.3 meters in length will result in a cylindrical percolating region around the hole with radius of 0.6 meter both at the upper soil layer and at the lower soil layer. While the alkali liquid penetrated to a depth of 1.1 to 1.4 meters beneath the bottom of the hole.

TABLE 4 The Statistical Mean Values of Unconfined Compression Strength for Samples at Different Distances from the Center of Grouting Hole

distance (m)	a_{1-2} (MPa⁻¹)	δs	q_u (KPa)
0.25	0.08	0.003	225
0.35	0.18	0.005	74.5
0.40	0.20	0.007	85.3
0.80	0.77	0.029	55.9
1.30	0.84	0.027	50

SUMMARY

The method of alkali liquid to reinforce collapsible loess ground has many advantages, namely, simple in equipments, easy to operate, construction period being short and effects obvious. In addition, there are no vibration and noise, no chemical liquid contamination to be caused. In a word, it is really a practical and reliable method to improve collapsible loess deposit.

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