The Applications of Non-Standard Stabilizers to the Base Course of Rural Roads

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Abstract

China is now paying more and more attentions to rural roads and township roads in order to improve the road networks, living standards and working conditions in the countryside. Thousands mileages of rural roads are under construction every year and the financial burden is evident. To fulfill such tasks with low costs, the local or in-situ soils have to be used as the primary construction materials for the base and sub-base courses of the rural roads especially for the areas where there are lacking in stones or quarry materials. Generally the engineering properties of the soils are weak and cannot meet the requirements and standards of the road construction. Soil stabilizations with both standard or conventional stabilizers (or commonly called as the stabilizing agents) and non-standard stabilizers such as various chemical stabilizers either in powder form or in liquid form have been studied in order to solve the problems caused by the utilizations of natural soils. This paper presents the preliminary results from a national research project on “Construction Technologies of Low-Cost Rural Roads in Western China”, including the laboratory test results of different types of soils stabilized by the selected stabilizers, the executions of trial roads located at both South-West and North-West regions of China, and the comparisons between non-standard stabilizers and the standard inorganic binders such as cement and lime. The laboratory results have been summarized from the tests of compressive strength, indirect tensile strength, drying-shrinking and thermo-shrinking properties and etc.. The field tests have also been introduced mainly in both aspects of the procedures of mixing and compaction by simple machinery or tools and of some key field test results achieved after the stabilization.

Keywords: *Rural Road, Non-Standard Stabilizer, Soil, Stabilization.*

1. Introduction

After high intensive investments to the national truck roads in past years all over China, more attentions have been paid to the rural roads and township roads in the countryside while the national truck road construction projects are continuously carried out. As executions of great development strategy for the Western China, the large-scale construction of road infrastructure in the western region is on the way. However, large number of roads to be constructed but with lesser funds is the current situation. In order to construct more low-cost rural roads the local materials have to be used and furthermore the in-situ soils have to be utilized as the primary construction materials for roads in many areas where there are lacking in good quarry materials. Thus the current research project has been conducted to study how to use the soil stabilization with chemical stabilizers for the base course of rural roads.

For past ten years the studies and applications of the non-standard chemical stabilizers have been concentrated. Based on the statistical data, about a thousand technical papers on the non-standard stabilizers were published in a five-year period from 1992 to 1996 in China. Furthermore a lot of local-made non-standard stabilizers have been invented and applied. The so-called “non-standard stabilizers” are these materials that are different from the standard or conventional stabilizers or inorganic binders such as cement and lime. The typical non-standard stabilizers can be categorized in groups according to their chemical basis, such as the chemical types in powder form and the enzyme-type in liquid form. The modified cement-base or lime-base stabilizers with additives inside to improve the properties of cement or lime are normally regarded as the non-standard stabilizers or stabilizing agents.

Though a lot of the studies on non-standard stabilizers have been carried out in China, it is still very necessary to further study how to use them for the rural roads on a large scale, how to use the stabilized soils to replace the quarry materials as the base course and how to select the proper stabilizers for different types of soils. Therefore the study on the non-standard stabilizers for rural roads has become an important part of the currently on-going national transportation research project on construction technologies of low-cost rural roads in the Western China. The purposes of this project are to develop the design and construction methods for rural roads in the Western China. The project has been carried out by the Research Institute of Highways of the Ministry of Communications of China in collaboration with Chongqing Institute of Communications and other four Highway Administration Bureaus. In addition to comprehensive laboratory tests on the properties and performances of soils stabilized by the non-standard stabilizers, four trial roads have been constructed with the stabilized soils as the base in Sichuan, Inner Mongolia and Xinjiang Uigur Autonomous Region in western China.

2. Brief Review of Soil Stabilizing Materials

Lime and cement are still commonly used as the standard stabilizers in road construction. Lime is the oldest stabilizing agent used in the world. In China the earliest example is that the mixed soils with lime content were used to construct the great wall thousands years ago. As early 1954, the lime-stabilized soil was used as the base course in road engineering. Cement is the most commonly used and successful soil stabilizer. Since early 1970, cement stabilized soil or called as cement-soil has been used for road construction in China. Currently in China cement and lime as the standard and conventional stabilizers are still popularly used for soil stabilizations.

The use of non-standard soil stabilizers has a quite long history too ([1], [2]). In 1913 the application of calcium chloride or magnesium chloride to the unpaved road was tried for dust control. In 1944 in France, a furfural resin was first and successfully used to stabilize the sea sands on the beach. During the second war period, cement-soil and lime-soil were, on a very large scale, used to construct the roads and airports for military purposes in many involved countries. A lot of problems were thus found from these applications with cement and lime stabilizations and in return, the non-standard stabilizers were proposed and studied in order to overcome the difficulties and disadvantages of standard stabilizers. Since the late of 1970s, the studies on the modification of the standard stabilizers have been concentrated and a lot of results on different types of soil stabilizers have been achieved in China.

3. Basic Stabilizing Mechanism of Non-Standard Stabilisers

The non-standard stabilizers in powder form mainly contain cement or lime and other active materials like mining slag, coal fly ash and etc. with additives such as salt, high alkaline stimulating agents and water retention agents, whose mineral contents mainly include the chemical compounds of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO and SO_3. The stabilizer as the active additive has a series reactions when mixed with soils. These reactions include chemical reactions, physical-chemical reactions and physical-mechanical reactions so that soil structures are changed and then the engineering properties of soils are significantly improved. (1) The chemical reactions include the reactions of the particulars of the stabilizer with water and between the particulars of both the stabilizer and the soil. These chemical reactions result in forming new crystallized bodies so as to establish a new net-space with complicated crystallization-condensation structures. Such structures with chemical reactions among the crystallized bodies increase the strengths and rigidities of the soil, which is similar to the result from the reactions of ions exchanges and then particulars grouping of cement-soil and lime-soil. (2) The physical-chemical reactions mainly refer to the adsorptions between particulars of both the stabilizer and the soil, where these adsorptions are in physical type, physical-chemical type and chemical type. The reactions of these adsorptions not only enable the particulars of the stabilizer to tightly stick on the surface of particulars of the soil so as to reduce their freedom energies on the surface and increase the strengths, but also improve the cation exchanges between the particulars of the stabilizer and the surface of particulars of the soil so as to increase the stabilities, which is similar to the solidification of cement or the crystallization of lime. (3) The physical reactions mainly include the processes of breakdown of soils, mixing the soil with the stabilizer and the compaction of the chemical-soil mixture. These physical-mechanical effects speed up the reactions between the stabilizer and the soil, which is similar to the effects of volcanic fly ash for cement or the carbonating effects for lime. The analyses as mentioned above provide an understanding on the main mechanism of soil stabilization by the non-standard stabilizers.

The non-standard stabilizers in liquid form at least contain surfactants, bio-enzymes and organic cotton-shape materials, where three of them have similar working mechanism. The stabilization mechanism for the non-standard stabilizers in liquid form generally includes four processes as follows. (1) The changing of surface energy enables the stabilizer to easily go into the diffusion layer so as to improve the property of electric charges on the surface of particulars of the soil. (2) The improvement is beneficial for the exchange of irons in order to reduce the inter-repelling energy between particulars of the soil and thus to obtain the denser compacted soil mass. (3) Normally the stabilizer in liquid form contains long-chain high polymers and each polymer connects with the surrounding particular of the soil through the bridge of their long-chain so as to establish net-shape structure. Under such net-shape structures the stabilized soil gains stable strengths, because this process is in one-direction and cannot return back to the original status. It should be one of the major reasons of why the stabilized soil is stable in strengths. (4) The water-repellent materials have been formed during and after the third process and furthermore a lot of coagulated gluey bodies and crystallized bodies of the said water-repellent materials have left in the capillaries so as to block the internal water channels of the soil. This could be a major reason of the water- and antifreeze-stabilities. These overall reactions during the four process and the physical, physical-chemical and chemical interactions between the stabilizer and the soil and among their selves during each process have established the basic mechanism and principle of soils stabilized by the non-standard stabilizers in liquid form.

4. Laboratory Test Results

In the project, three types of soils are selected for laboratory tests and their properties are given in Tables 1 and 2.

Table 1. Physical Properties of Tested Soil Samples

Sample No	Name	Location	LL	PL	PI
S1	Silt	Nei Monggol	21.4	17.5	3.9
S2	Clay	Beijing	34	21	13
S3	Sand	Beijing	0	0	0

Table 2. Physical Properties of Tested Soil Samples

Sample No	Grain Size Distribution (%)				
	2 ~ 5 mm	0.5 ~ 2 mm	0.25 ~ 0.5 mm	0.074 ~ 0.25 mm	< 0.074 mm
S1	0.2	0.2	0.4	4.5	94.5
S2	1.2	0.4	2.9	7.9	84.8
S3	0	0	0.2	57.5	47.3

After comprehensive review and evaluation of various chemical stabilizing agents and their application records, the following several typical stabilizers are selected for the laboratory tests (Table 3).

Table 3. Selected Soil Stabilizers and Their Codes

Category	Product Name	Country of Origin	Chemical Base/Grade	Code Name
Non-Standard Stabilizer In Powder form	Chemilink SS-108 Soil Stabilizing Agent	Singapore	Modified cementitious	SS
	LG Stabilizers*	China	Lime-cement Lime	CZN CZH
Non-Standard Stabilizer In Liquid Form	ISS Stabilizer	Australia	Surface active agent	IS
	Perma-Zyme Stabilizer	USA	Organic bio-enzyme	PM
	Better-Base Stabilizer	USA	Organic salt	SB
Standard Stabilizer	Lime	China	Grade 3	SH
	Ordinary Portland Cement	China	Grade 325	SN

* Note: The specific formulas of LG Stabilizers were especially designed for the particular tested soils.

It should be noted that most of selected stabilizers are in general version except that the both LG Stabilizers were especially designed to the tested soil samples after receiving them and thus they are not in general version so that the comparisons between LG and others may not be fair and even not comparable. The mixing ratios and the corresponding compaction test results of the selected stabilizers are shown in Table 4.

Generally the combinations of the stabilizers in liquid form together with cement or lime (hereafter called the combined stabilizers) are recommended to stabilize coarse-grained soils or quarry materials because of their poor stabilities under water and limited strength increments if stabilizers in liquid form are used alone for the fine-grained soils. The above-mentioned eleven (11) stabilizing agents or the combined stabilizers have been used to stabilize the three (3) types of soils, i.e. the silt with lower liquid limit (S1), the clay with lower liquid limit (S2) and the very fine sand (S3). According to the relevant Chinese testing specifications, various laboratory tests have been conducted before the site trials.

Table 4. Mixing Ratios and Compaction Test Results

Stabilizer Code Name	Mixing Ratio		Compaction Test Results					
			For S1		For S2		For S3	
	Powder Form	Liquid Form	MDD (t/m³)	OMC (%)	MDD (t/m³)	OMC (%)	MDD (t/m³)	OMC (%)
SS	3%	0	1.87	14	1.89	16	1.75	14
CZN	3%	0	1.84	15	1.85	16	1.80	16
CZH	3%	0	1.80	16	1.87	15	1.72	16
PM+SH	3%	1:1000	1.81	16	1.84	17	1.74	14
PM+SN	3%	1:1000	1.87	14	1.89	14	1.77	13
SB+SH	3%	0.5L/m³	1.81	16	1.84	17	1.74	14
SB+SN	3%	0.5L/m³	1.87	14	1.89	14	1.77	13
IS+SH	3%	1:100	1.81	16	1.84	17	1.74	14
IS+SN	3%	1:100	1.87	14	1.89	14	1.77	13
SH	3%	0	1.81	16	1.84	17	1.74	14
SN	3%	0	1.87	14	1.89	14	1.77	13

The results of the unconfined compressive strength (UCS) tests and the indirect tensile strength (ITS) tests are shown in Figs. 1 and 2 respectively, where the chemical-soil mixture specimens with the standard dimensions were tested after six (6) days at air-curing and then one (1) day at soaking-curing. Furthermore the testing results on the drying-shrinkage index due to the loss of water and on the thermo-shrinkage index as temperature changes are presented in Figs. 3 and 4 respectively, where the samples with dimensions of 5x5x24cm were tested at the 7-day curing conditions that are the same as those for the strength tests.

Fig. 1. Test Results of Unconfined Compressive Strength (UCS) after 7-Day Curing

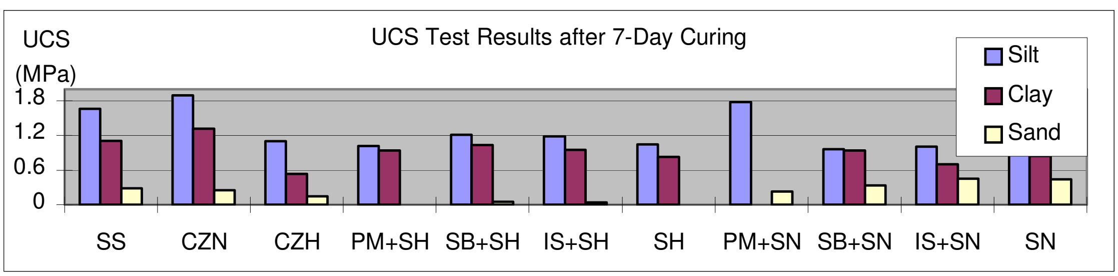


Fig. 2. Test Results of Indirect Tensile Strength (ITS) after 7-Days Curing

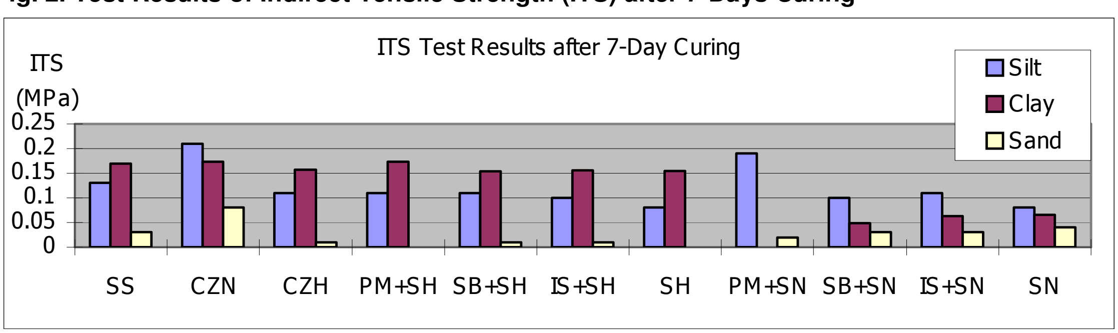


Fig. 3. Relationship between Drying-Shrinkage Index and Loss of Water

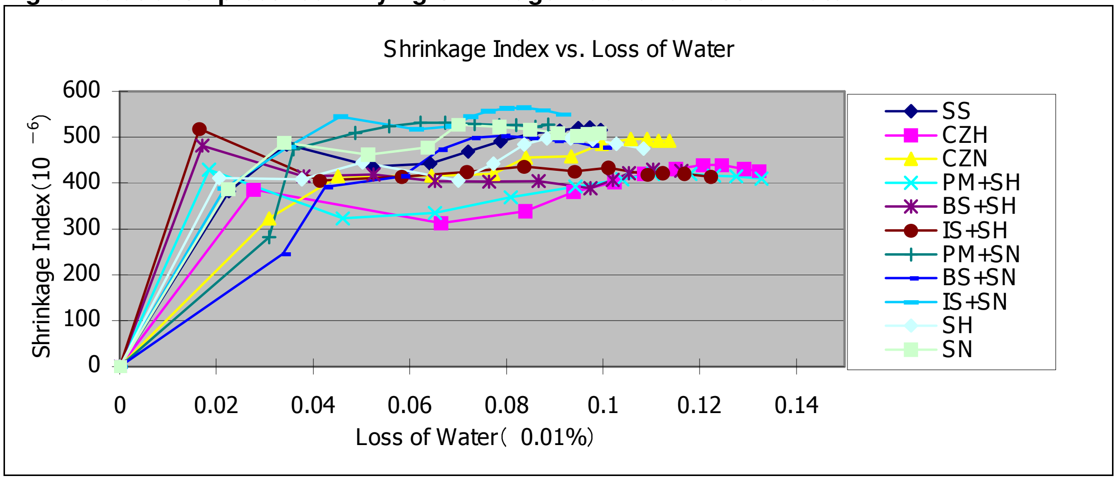
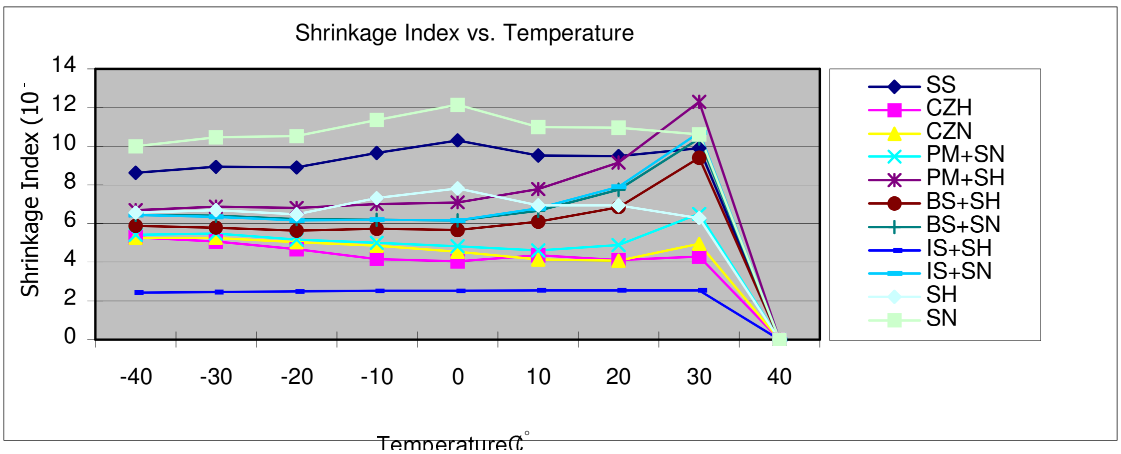


Fig. 4. Relationship between Thermo-Shrinkage Index and Temperature



According to the comparisons between the two test results as shown in Figs 1 and 2, the tendency and regulations of both strength tests are similar and thus some important conclusions can be derived from the both strength test results as follows:

- The non-standard modified cement-base stabilizers in powder form have outstanding performances in strengths among the whole stabilizer family which includes the standard ones and non-standard ones;
- The strengths of the non-standard stabilizers in powder form with three types of soils are much higher than those of cement-soils or lime-soils and generally better than those of the combined stabilizers; and
- To add the stabilizers in liquid form into cement-soils or lime-soils cannot significantly improve their compressive strengths and even make them worse (except the case of PM stabilizer with cement-silt with surprising), while the

adding of the stabilizers in liquid form looks partially useful for increasing of the elasticity of the mixtures;

Fig. 3 shows the relationship between the drying-shrinkage index and the loss of water. During the initial stage of the tests the drying-shrinkage indexes increase quite fast. The maximum shrinkage indexes corresponding to the maximum loss of water of different mixtures are quite different, which indicates that the same soil stabilized with different stabilizers may have different drying-shrinkage properties and their developing tendencies may also be different. Normally the drying-shrinkage indexes of the soil stabilized by the cement-base stabilizers are higher that those stabilised by the lime-base stabilizers. The adding of the some stabilizers in liquid form may have a little help to reduce the drying-shrinkage index of the cement-soil or lime-soil.

As shown in Fig. 4, the thermo-shrinkage indexes for different mixtures are quite stable as temperature decreases except that there is a sudden change of the index when the temperature is around 0°C to -10°C. Generally the indexes of soils stabilized by the non-standard stabilizers are lower than those of the cement-soil and lime-soil and the introducing of stabilizers in liquid form will significantly reduce the indexes of the cement-soil and lime-soil. It is very important to notice that average value of the thermo-shrinkage index is only about 1% to 2% of that of the drying-shrinkage index for the every tested mixture if comparing Fig. 4 with Fig. 3. This finding indicates that the temperature effect on the shrinkage can be ignored when considering the effects on the shrinkage of the stabilized soils from the both factors of the temperature and the loss of water, which is very meaningful for the engineering practice.

5. Field Trial Roads with Various Stabilizers

5.1. **S**tabilization **M**ethods

Based on the laboratory test results and comprehensive studies/reviews, several typical non-standard stabilizers in both powder and liquid forms as well as cement and lime have been selected to be used for the four (4) trial roads with 3 to 5km long each in the provinces of Sichuan (2 trial roads at different locations), Inner Mongolia and Xinjiang respectively. It should be noted that SS-108 soil stabilizer has popularly used in South East Asia for past ten over years and it has technically and economically been proven to be effective especially in swampy and soft ground areas ([3], [4]). The general version of SS-108 has thus selected to be used to stabilize different soils as the base course in the three trial roads, i.e. the stabilized sandy clay for Longquan road (200mm thick base), the stabilized clayey silt for Jintang road (150mm thick base) and the stabilized silt for Aohan road (200mm thick base) respectively, and these three trial roads with SS-108 have been successful so far. The construction methods using SS-108 are typical and practical, which are thus briefly introduced in this paper as the example.

Generally construction methods for the stabilization have two major ways: in-situ mixing and central plant mixing. For rural road constructions, the in-situ mixing method is most popularly used due to its advantages such as easy handling, simple equipment required, lower construction cost, longer application history with more experience and easy to be promoted in China. This method has been used for the three trial roads, while the central plant mixing method has been used for Longquan road. The in-situ mixing method includes the following major construction steps:

1) Preparation: to prepare soils to be stabilized with proper water contents;

2) Spreading: to manually put the stabilizer in powder on the levelled ground bag by bag per the designed dosage and then spread the powder on the surface homogenously (Photo. 1-a); or, to homogenously spread the stabilizer in liquid form per designed dosage by a proper water truck.

3) Mixing: to homogenously mix the stabilizer in either powder or liquid form with soils up to the designed depth by different proper machines (such as rotorvator) and/or tools (Photos. 1-b and 1-c). It should be noted that two or more mixing machines could be used together in order to increase the quality and shorten the construction time (Photo. 1-b).

4) Compaction: to compact the well-mixed mixture after levelling and shaping.

5) Curing: to regularly spray water on the surface for the required days in order to gain higher strengths and minimize the surface cracking.

Photo. 1. In-Situ Mixing Method for Stabilization

1-a Spreading of the Powder

1-b Mixing of the Powder

1-c Spreading & Mixing of the Liquid

1-d Stabilized Base after Curing

5-2. **F**ield **T**est **R**esults

A lot of field tests and measurements per the relevant Chinese national standards and specifications have been conducted for the trial roads after the completion of the roads. Due to the limitation of the paper length, only the deflection data measured by Benkelman beam on the trail road of Aohan in Inner Mongolia are discussed here. The deflection value is a comprehensive and overall index that directly reflects the resilient modulus of the whole pavement of the road.

The measured deflection values of the natural sub-grade and the base course stabilized by seven (7) types of stabilizers or the combined ones for each road section are given in Table 5. From the overall average data of both the natural sub-grade before stabilization and the base course after stabilization for the whole trail road, it can be found that the deflection value has been improved from 113 to 46, which means that the stabilization is significantly effective to increase the bearing capacities of roads.

In order to fully understand the actual engineering meaning of the measured deflections, the designed deflection value from an actual design of an expressway in Northeast China region is presented as an example ([5]). The designed deflection value is 21.8 (unit: 1% mm) for the designed expressway, where the designed working life is 15 years and the total pavement thickness is 720mm. If a high-grade road is assumed with 50% of the traffic volume of this expressway and with the same other conditions, the designed deflection value for the assumed high-grade road will be 39.04 (1% mm). It is very surprised to find that the measured deflection values of the trial road with a base of the gravels stabilized by cement and lime and with a base of the silty soils stabilized by SS-108 can meet the designed requirement on the deflection value for this assumed high-grade road. It should be highlighted that it is not easy for a road, only with a single pavement layer formed by a 200mm thick base of the silty soils stabilized by SS-108, to obtain such good performance on the resilient modulus of the whole pavement. Of course, the performances of the road does not only limit to this deflection index though this index is the major design criteria. This example has repeatedly proven the conclusion that the non-standard stabilizer can be used to effectively strengthen the soils for the road pavement.

Table 5. The Measured Deflection Values of Aohan Trial Road in Nei Monggol, China

Foundation Type*	Test Nos.	Ave. BS Value (1% mm)	Max. BS Value (1% mm)	Min. BS Value (1% mm)	Cv (%)	Representing BS Value** (1% mm)	Remarks
Lime+Gravel	84	28.63	70	0	37	44	Fair
Natural sub-grade	102	66.73	122	10	34	101	
Cement+Lime +Gravel	118	20.08	48	0	42	33	Good
Natural sub-grade	148	64.37	138	0	45	108	
SS+Silt	16	22.25	32	12	26	31	Good
Natural sub-grade	20	58.40	103	0	40	94	
CZH+Silt	44	24.61	72	8	45	41	Fair
Natural sub-grade	52	64.08	121	25	28	91	
CZN+Silt	42	27.19	48	8	34	41	Fair
Natural sub-grade	44	59.00	181	0	57	110	
PM+Lime+Gravel	74	32.27	70	10	27	45	Fair
Natural sub-grade	74	63.84	176	0	61	123	
PM+Gravel	58	39.71	89	15	40	64	Poor
Natural sub-grade	62	71.02	176	0	68	144	
Stabilized base for whole trial sections	436	27.63	89	0	44	46	Overall average
Natural sub-grade for whole trial sections	502	64.85	181	0	49	113	

Note: *-- 200mm thick for all stabilized bases and **-- weighted average value

6. Conclusions

- A national research project on construction technologies of low-cost rural roads for Western China has been carried out and the non-standard soil stabilizers have been studied, as a part of this project, from the development history, basic stabilizing mechanisms, comprehensive laboratory tests to the large-scale field road trials with a lot of rich results.

- The laboratory and field tests results have proven that the non-standard stabilizers in powder form are generally more effective than the standard stabilizers for soil stabilizations. The non-standard stabilizers in liquid form are generally ineffective in improving the strengths of the stabilized sols but they may have some effects on improving some properties of cement-soil and lime-soil.

- The soil stabilization with the non-standard stabilizers in powder form is a technically reliable and practically applicable construction method for rural roads and it could be cost-effective for those areas where there are lacking in good quarry materials.

- In order to achieve better and cost-effective results, it is very important to select the proper soil stabilizer based on various stabilization mechanisms, different types of soils and localized conditions.

7. References

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