

CERTAIN ENGINEERING ASPECTS OF SOIL STABILIZATION
WITH LIME

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PREFACE

This thesis is an investigation of the effects produced on the physical properties of several soils from Manitoba and Ontario, when admixtures of lime are used.

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CHAPTER I

INTRODUCTION

The main purpose of this thesis was to determine what effects additives of lime had on stabilizing local Manitoba soils in the construction of base and subbase courses for highways, railways, city streets, and airfields. This thesis presents the results of laboratory investigations of lime stabilization on a variety of soils obtained from different parts of Manitoba, as well as two types from Ontario.

The use of admixtures of lime for soil stabilization has been a subject of considerable interest to highway and airfield engineers in recent years, particularly in the southern part of the United States. Structural engineers are quite familiar with the phrase, "The building is only as sound as its foundations". This is also applicable to highway and airfield engineering, particularly in this day and age when we must contend with every increasing traffic loads. Stable, durable road bases are a vital necessity for the construction of good roads.

Where abundant supplies of satisfactory base materials, such as gravel and crushed stone, are locally available, the construction of road beds is easily accomplished. However, in localities where there is a deficit of satisfactory base materials, the great need arises for an economical means of converting or upgrading natural soils and soil materials into satisfactory base materials. Highway and airfield engineers

commonly refer to this method of improving the strength of this material as "soil stabilization".

CHAPTER II

Review of the Development of Lime Stabilization

Although the use of lime as a soil stabilizing agent has only recently received widespread recognition, the idea was born many centuries ago.

The ancient pyramid builders recognized the fact that lime had cementitious properties when mixed in with clayey soils. The pyramids of Shensi in the Tibetan-Mongolian Plateau, over 5000 years old, and still intact, were constructed out of compacted mixtures of clay and lime¹.

The historic Romans, famous for their advanced form of civilization centuries before the birth of Christ, are believed to have been the first users of lime in connection with road construction. Most of their principal roads radiating out of Rome were stabilized with lime.

The Romans were marvels at engineering feats. Even today we are still amazed when we think about the towering Colosseum, the mighty aqueducts, and the Appian Way. Unfortunately, their civilization was finally destroyed after a series of disastrous battles, however, the ruins of their works are still in evidence today.

According to studies made by archaeologists of ancient Roman civilization, the typical section of the Appian Way² was approximately four feet thick and consisted of five layers from the wearing surface to the

subbase. The materials used in the road were a gradation of rock, sand, and lime. In three of these lifts admixtures of lime were used to give added stability.

Crude forms of lime stabilization have been used on the rural and village roads of China for years. Lime, serving mainly as a cementitious material, has also had application in the construction of earth dams in India and China³.

A considerable amount of interest has been shown in the United States in all forms of soil stabilization for constructing roads. However, lime stabilization has been introduced only recently. Additives of lime in the hydrated form appeared to have been first used for stabilization purposes in 1924, in the State of Missouri, where short experimental test strips were laid. The U.S. Bureau of Public Roads in Iowa and Dakota followed with similar experiments. The results of these first test strips showed that the addition of from 3% to 6% of hydrated lime made earth roads on clay soils reasonably stable.

Although the test results obtained from these experiments were encouraging, it was not until the second world war that lime stabilization was used on a large scale. The first major application was in runway and taxi-strip construction on airfields in Texas. The enormous demands for satisfactory base course materials could not be met economically unless lower grades of gravels with high clay contents could be successfully stabilized. The use of lime to up-grade the plastic material proved successful, and was one of the first uses

of this method in the United States.

Shortly after the war, the Texas State Highway Department commenced using lime stabilization on civil roads. At the beginning, they employed a locally available waste lime, however, later, they began using commercial hydrated lime ranging from 3% to 8%. The results were quite satisfactory and by 1953, 250 miles of road had been constructed in Texas using soil stabilized with lime ³.

Shortly after, British road builders, hearing of the success the Americans had achieved with lime stabilization, began conducting lime-soil laboratory tests. Their first actual application was in Worcestershire, where hydrated lime was successfully used in place of stone for road base construction, the soils stabilized in these roads being sands, or light clays.

Similarly, in other parts of the British Commonwealth, soil engineers in Northern Rhodesia and Nyasaland found that they were able to up-grade clayey gravels for road bases by stabilizing or actually neutralizing the excessive amounts of clay fines in the material by adding as little as 2 to 3% of lime. They found from laboratory experiments (Road Research Laboratory), and from actual field applications, that lime did have a marked effect, particularly in stabilizing cohesive soils such as heavy clays. In the early 1950's, British engineers ⁴, like Kerr and Brooke-Bradley, used hydrated lime in conjunction with Portland cement to reduce the plasticity, alter the texture, and make cohesive soils more workable.

According to published literature ⁴, it is believed that the first experiments in the Soviet Union, in connection with lime-soil mixtures for roadways, were made by Okhotina in 1926. These experiments were conducted on Cambrian clays, and it was found that an additive of 5% hydrated lime greatly reduced the plasticity of such clays. Okhotina's findings were later confirmed by other Russian workers on a variety of soils (Groditskaya and Ipatova, 1932; Bykovskii, 1937; Volkov, Gelmer Zasobin and Panteleev, 1948.) It is unknown whether the Soviet Union has any lime stabilized roads as yet, however, tentative specifications have been prepared for the construction of roads using lime-stabilized soil. The results of laboratory tests on Russian soils reveal that there is an optimum percentage of lime for successful stabilization. Although the principle by which this is judged is unknown, they have concluded that the range is within 5 to 12% by the weight of the soil ⁴.

CHAPTER III

Chemical and Physical Properties of Lime in Relation to Soil Stabilization

The widespread production, low cost, and abundant supply of lime has made it one of the most widely used chemicals in industry today.

The raw material, limestone, occurs in numerous surface deposits across Manitoba⁵. One of the largest areas lies in a great belt 100 miles wide, extending northwesterly across the province, from near Winnipeg to The Pas.

At present, however, there are only two major locations where lime is produced on a large scale. Stonewall⁵, which is located approximately 25 miles northwest of Winnipeg, has long been an important centre for the production of white dolomitic lime. Spearhill⁵, located approximately 120 miles northwest of Winnipeg, is known as the only location in Manitoba where high-calcium lime is produced.

The proper "burning" of lime is a fairly complex process. In general, however, lime is produced by the controlled calcination of limestone at temperatures in the vicinity of 2500°F. The limestone is prepared by first drilling and blasting the deposit. The product of the blast is then classified so that only the satisfactory size of stone is burned. During the burning process a careful control is kept on the temperatures in the hot zone, the flow of material through the kiln,

and the removal of the end product from the bottom of the kiln to ensure the production of a pure homogeneous chemical.

Quicklime, the product of calcination, consists of the oxides of calcium and magnesium, and in this locality it is available in two forms:

High calcium quicklime, produced at Spearhill, usually contains over 97 per cent calcium oxide (CaO), the magnesium oxide (MgO) content varying from 0.5 to 2.5 per cent.

Dolomitic quicklime, a product of the Stonewall deposit, usually contains from 45 to 50 per cent of calcium oxide and from 35 to 40 per cent of magnesium oxide.

Both of these types of quicklime have a considerable affinity for water. High calcium hydrated lime contains generally from 72 to 74 per cent calcium oxide and from 23 to 24 per cent water. Under normal hydrating conditions only the calcium oxide fraction hydrates. The resulting chemical composition is as follows: 46 to 48 per cent calcium oxide, 33 to 34 per cent magnesium oxide, and 15 to 17 per cent water. Under steam and pressure it is possible to hydrate almost all of the magnesium oxide as well as all of the calcium oxide, however, according to published literature, pressure hydrated dolomitic lime has had no application in soil stabilization.

Chemical lime is a white solid having a crystal

lattice structure. The product of calcination, quicklime, reacts highly with water, generating a considerable amount of heat in the hydration process. In the presence of moisture, the lime reacts slowly with the carbon dioxide of the air, forming water insoluble carbonates. Although commercially, quicklime is available in a variety of sizes ranging from lump to a finely pulverized powder, it tends to react more favourably and the most efficient utilization is made of the chemical when it is in the pulverized form. Quicklime is commercially available by the carload, in bulk, or in moisture proof paper bags. Hydrated lime can be purchased as a dry powder either in bulk or bagged. On some projects it has been found more convenient to obtain the lime in the form of a suspension in water or a slurry⁸.

CHAPTER IV

Theory of Lime Stabilization

According to published literature, no specific answer has been given on exactly how lime reacts with a soil. The theory behind the behaviour of a mixture of soil and lime is rather complicated. It did appear, however, that the reaction was chemical in nature. The first apparent change in the soil's properties was noticed immediately after mixing a small quantity of lime with a moist soil. Particularly when the lime was mixed in with a clay, there was a sharply defined drop in the soil's stickiness. It appeared that an agglomeration of the finely divided clay particles occurred and the soil then exhibited properties similar to those of a silt or a sand.

Immediately after a soil had received an admixture of lime there was a pronounced change in the plasticity properties of the soil. (The plasticity properties illustrate the soils behaviour in relation to its moisture content). Generally, a reduction of the plasticity index occurred by either a decrease of the liquid limit, or an increase of the plastic limit. In highly plastic soils, a combination of both was experienced. With some soils, the liquid limit was actually raised, however, in general, the net effect was a lowering of the plasticity index. A study⁶ of the effect of lime on the Atterberg Limits for a variety of soils with plasticity index values ranging from 15 to 50, showed that, with 3 percent lime, the plasticity index values were reduced to from 2 to 15 respectively. A lowering

of the plasticity index signified that a lime addition to a fine grained soil makes it increasingly difficult for the soil to become plastic.

K. A. Gutschick ⁷, stated that the agglomeration of clay particles, and the plasticity index reduction are explained primarily by base exchange. The base exchange reaction involves the replacement of the smaller weaker sodium and potassium ions of the clay by the larger calcium ions from the lime. Gutschick stated that this base exchange in the soil had another significant effect, in that it reduced the thickness of the absorbed moisture films or envelopes surrounding the clay grains, thereby reducing the plasticity. Thick water films shield the particles, so that they do not come into intimate contact with their neighbours; the mass they form under this circumstance possesses low stability and a very plastic state prevails ⁷.

Test results ⁹ at the Texas Engineering Station on clayey soils showed that the reaction of a soil and lime increased as the plasticity index and the capacity to absorb ions increased. Expressing the reactivity in terms of clay minerals, montmorillonite reacted the best with lime, illite next, and kaolinite the poorest, since the base exchange capacity of these types is the largest for montmorillonite clays.

Dr. R. L. Handy ² explained that the plasticity index of a soil is a function of the surface area of individual grains of soil. If the surface area of the soil grains is large, (for example, in the case of minute flaky clay particles), the capacity to hold water by the

phenomenon of electrostatic attraction is extremely large. On the other hand, soils with larger grains, having a shape between that of cubical and spherical, have a lesser capacity to absorb water since there is less available surface for wetting. This force of electrical attraction is of tremendous magnitude when compared to the force used to compact a soil. Hence, a clay material, even though well compacted, will absorb water and become plastic. Ultimately, if enough water is absorbed by the clay particles, the water "chains" bonding the particles together become so extended they lose much of their strength.

The fact that the addition of lime to a clayey soil reduced the plasticity index means that the reaction between the lime and the soil causes the clay particles to flocculate, or to stick together and behave like a silt. The clay no longer exhibits its tremendous ability to hold water between particle cleavage planes, but now occurs in larger grains and of shapes near that of cubes or spheres.

Clare and Cruchley⁴ obtained results in the calcium and pH determinations which proved that stabilization was associated with the phenomenon of base exchange. Their results were in general conformity with the suggested mechanism of base exchange. They stated that the variation in the rate at which calcium is removed from the solution in the mixture was probably a complex function of the initial surface area (or edge area) of the clay particles and the extent to which this was altered by reaction with the lime. Their report indicated that no investigations had yet been made on the shear strength development of soil-lime mixtures,

however, they felt that it was unlikely that the measurement of base exchange capacity, and the pH of the soil or the determination of the plasticity characteristics of the freshly prepared soil-lime mixtures alone would prove satisfactory means for determining whether a soil could be stabilized with lime.

Another but slower reaction is believed to take place when a soil is stabilized with lime. This reaction causes an increase in the unconfined compressive strength of a lime stabilized soil. The unconfined compressive strength is determined in the laboratory with a test machine which subjects a soil specimen (without any lateral support) to a compressive stress. Soils treated with lime increase on the average from 30 p.s.i. to 100 p.s.i., and after one to two years the strength gain is considerable, usually in the range of from 300 to 1500 p.s.i.⁶.

In the early portion of the road-building era in Rome, lime was used primarily as a mortar. This mortar usually consisted of two parts locally derived sand and one part lime. It was used either to make lime-concrete, when nine parts of gravel were added, or to fill in the voids around stone chips or slabs in the road.

However, about 150 B.C., the Romans found that they could vastly improve their mortars by using a volcanic ash additive from Pozzonli (a town near Naples). The word pozzolan, after this Roman town, was used to describe a material exhibiting properties of volcanic ash.

A pozzolanic material is defined in A.S.T.M. Specification 129 as " . . . a siliceous or siliceous and aluminous material which in itself possesses little