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SPECIAL REPORT

LIME OR CHLORIDE TREATMENT OF GRANULAR BASE COURSE MATERIALS

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The increasing structural demands on pavements have caused a trend towards use of treated (in lieu of untreated) base course materials. Common treated materials include "black base" (i.e. asphalt treated crushed stone or gravel) and soil-cement. The objectives of this study were to evaluate the effects of small amounts of calcium chloride, sodium chloride, or hydrated high-calcium lime on strength of granular base course materials. Various strength parameters were studied, including volume change of the material as it was loaded to failure, pore water pressures within the material during loading and failure, and various measures of the shear strength of the material.

Materials

Three crushed stone materials were used in this study, each being an Iowa State Highway Commission-approved crushed stone for rolled stone bases and being representative of poor to good field service records. The three stones tested include Bedford quarry stone, which is a weathered moderately hard limestone; Gilmore quarry stone, a hard limestone; and Garner quarry stone, a hard dolomite.

Mineralogical and chemical tests of the three stones are presented in Tables 1, 2, and 3. The engineering properties of each of the three materials are shown in Table 4.

The inorganic chemical additives were representative of those approved by the Iowa State Highway Commission. Anhydrous calcium chloride

Table 1. Mineral constituents of crushed stone by x-ray diffraction[a].

Stone	Calcite	Dolomite	Quartz	Feldspars	Calcite/dolomite ratio
Bedford	1	3	T	0	25
Garner	1	2	T	0	1.16
Gilmore	1	0	T	0	

[a] 1-predominant, 2-major amounts, 3-small amounts, T-trace, 0-not identified.

Table 2. Non-HCl soluble minerals by x-ray diffraction[a].

Stone	Montmorillonite	Vermiculite-chlorite	Micaceous material	Kaolinite	Quartz
Bedford	0	0	1	2	2
Garner	0	3	1	2	2
Gilmore	0	0	0	1	3

[a] 1-predominant, 2-major amounts, 3-small amounts, T-trace, 0-not identified.

Table 3. Quantitative chemical analysis of whole material.

Stone	pH	Cation exchange capacity me/100g	Non-HCl soluble minerals, %
Bedford	9.40	10.88	10.92
Garner	9.25	10.60	6.73
Gilmore	8.99	5.86	< 1.66

Table 4. Engineering properties of crushed stones.

	Bedford	Garner	Gilmore
Textural composition, %			
Gravel (> 2.00 mm)	73.2	61.6	66.8
Sand (2.00 - 0.074 mm)	12.9	26.0	23.3
Silt (0.074 - 0.005 mm)	8.4	10.2	5.9
Clay (< 0.005 mm)	5.5	2.2	4.0
Colloids (< 0.0001 mm)	1.7	1.4	0.9
Atterberg limits, %			
Liquid limit	20.0	Non-	Non-
Plastic limit	18.0	Plastic	Plastic
Plasticity index	2.0		
Standard AASHO-ASTM density			
Optimum moisture content, % dry soil weight	10.9	7.6	9.4
Dry density, pcf	127.4	140.5	130.8
Specific gravity of minus No. 10 sieve fraction	2.73	2.83	2.76
Textural classification		Gravelly sandy loam	
AASHO classification	A-1-b	A-1-a	A-1-a

was used in pellet form, No. 8 mesh, and contained more than 96% $CaCl_2$. The sodium chloride was in granular form and contained more than 94.5% NaCl. High calcium lime was obtained locally and x-ray analyzed to assure low carbonation.

Tests

Several types of tests were used in this study, the most important method being the triaxial shear test. Unconfined compression tests were used for the determination of optimum lime contents.

Chlorides were added in amounts of 0.5% of the dry weight of the aggregate, whereas lime was added at 1.0% and 3.0% levels. Further tests were conducted on Bedford and Garner stones with 10.0 and 16.0% lime.

Materials plus additives in dry form were hand-mixed to minimize degradation. Each mixture was then compacted at optimum moisture content in a vibratory compaction apparatus. This consisted of a cylindrical mold and a Syntron Electric Vibrator table operated at a frequency of 3600 cycles/min, an amplitude of 0.368 mm during compaction, with a surcharge weight of 35 lb, for a period of 2 min. This compaction procedure produced the most uniform density while minimizing degradation and segregation of the three stones tested. The densities obtained were close to AASHO-ASTM standard (Table 4).

The compacted specimen size for all three stones was 4 in. in diameter by 8 in. high. The specimens were extruded with a hydraulic jacking arrangement, immediately wrapped to prevent evaporation, and weighed. Lime-treated specimens were placed in a controlled atmosphere of 75^{o}F and near 100% relative humidity, and cured for periods of 0, 7, 28, 60, or 90 days. All test specimens were found to be within $\pm$ 2.3% of the average density for each design mixture.

Lateral pressures for triaxial testing ranged from 10 to 100 psi. Prior to loading, specimens were allowed to consolidate to a constant volume under the applied lateral pressure. The specimens were then sheared under axial loading at a deformation rate of 0.01 in. per min. Volume change and pore water pressure readings were recorded at 2.5 and 5 min intervals during shearing.

Optimum Lime Content

To determine optimum lime contents for the three crushed stones, unconfined compression tests were made on 2 in. diameter x 2 in. high specimens. Only that fraction of each material passing the No. 10 U.S. standard sieve was used in this test. Optimum moisture contents at each percent of lime for all three materials were determined, and two test specimens for each lime content were then molded by drop hammer compaction. Moisture content samples for each mixture were taken before and after compaction. Each test specimen was weighed, measured for height, and immediately wrapped and placed in a controlled atmosphere at 75°F, and near 100% relative humidity. After a 28-day curing period the specimens were again weighed and then tested in unconfined compression at a rate of deformation of 0.1 in. per min.

A plot of load versus calcitic lime content was made to indicate optimum lime content for the minus No. 10 fraction materials. Knowing this lime content and the percent of the whole material passing the No. 10 sieve, optimum lime content for the whole material was determined. For example, if 25% of the whole material passed the No. 10 sieve and the optimum lime content for this material was 8%, the optimum lime content for the whole material would be 8 x 25/100 = 2%.

Analysis of Triaxial Tests

Maximum Stress Ratio

To evaluate the angle of internal friction φ and cohesion c from the triaxial compression test, a point of failure for each specimen was defined as that stress at which the effective stress ratio, $(\bar{\sigma}_1 - \bar{\sigma}_3)/\bar{\sigma}_3$, had reached its maximum value. Maximum and minimum principal stresses, σ_1 and σ_3, were corrected for water pressure to give effective principle stresses, $\bar{\sigma}_1$ and $\bar{\sigma}_3$ for this calculation which was done with an IBM 650 computer. Effective shear stress strength parameters φ' and c' were then determined.

Methods of analysis used for triaxial compression tests were the Mohr envelope, Bureau of Reclamation, and stress path methods. All follow Mohr failure theory, the last two essentially being methods of curve fitting. Values of φ' and c' from the three methods for all materials are given in Tables 5, 6, and 7. Maximum ordinate points for the stress path method conformed very closely to straight lines for all series of tests, and the stress path method was used in subsequent analyses.

Table 5. Triaxial test results for Bedford stone.

Additives used	Curing period (days)	No. of tests	Lateral pressures (psi)	Dry density (pcf)	Mohr envelope		Bur. of Reclamation		Stress path	
					φ' (degrees)	c' (psi)	φ' (degrees)	c' (psi)	φ' (degrees)	c' (psi)
No additive	None	5	10,20,30,40,60	126.5	45.8	9.0	44.8	16.5	44.7	9.6
0.5% NaCl	None	8	10,20,30,40,60,80	127.2[b]	44.0	11.5	43.9	11.5	43.9	11.2
0.5% $CaCl_2$	None	6	10,20,30,40,60,80	127.7[b]	45.0	9.5	45.4	8.8	46.3	7.2
1.0% $Ca(OH)_2$	7	7	10,20,30,40,60,80,100	124.4	46.3	8.5	45.7	9.1	46.6	8.6
	28	7	10,20,30,40,60,80,100	123.8	43.8	15.0	44.2	12.9	45.0	10.0
	60	6	10,20,30,40,60,80	123.6	(a)	(a)	45.4	14.1	45.9	13.8
	90	7	10,20,30,40,60,80,100	122.5	(a)	(a)	43.1	18.9	43.7	16.2
3.0% $Ca(OH)_2$	7	7	10,20,30,40,60,80,100	122.5	46.3	7.0	44.3	9.5	45.2	7.0
	28	7	10,20,30,40,60,80,100	121.5	44.7	10.0	45.0	9.0	44.6	9.2
	60	7	10,20,30,40,60,80,100	121.8	44.7	15.0	45.5	11.4	44.3	14.6
	90	6	10,20,30,40,60,80,100	122.8	45.5	14.0	45.9	11.0	46.7	11.6[c]
10% $Ca(OH)_2$	28	3	20,40,60	118.9	–	–	–	–	39.6	24.6

[a] Mohr envelope concave downward; straight line could not be plotted

[b] Dry density was not corrected for chloride in solution

[c] Anomalous series

Table 6. Triaxial test results for Garner stone.

Additives used	Curing period (days)	No. of tests	Lateral pressures (psi)	Dry density (pcf)	Mohr envelope φ' (degrees)	Mohr envelope c' (psi)	Bur. of Reclamation φ' (degrees)	Bur. of Reclamation c' (psi)	Stress path φ' (degrees)	Stress path c' (psi)
No additive	None		40, 60, 80	144.5	–	–	43.2	31.0	47.9	14.4
1.0% $Ca(OH)_2$	7	5	10, 20, 40, 60, 80	140.3	(a)	(a)	46.1	23.9	48.8	12.0
	28	4	20, 40, 60, 80	140.2	49.7	14.0	50.7	10.4	50.5	10.2
3.0% $Ca(OH)_2$	7	4	20, 40, 60, 80	140.9	46.2	21.0	46.1	19.7	46.7	21.0
	28	4	20, 40, 60, 80	138.8	45.7	12.5	47.0	13.5	48.1	10.4
16% $Ca(OH)_2$	28	3	20, 40, 60	122.8	–	–	–	–	43.8	8.3

[a] Mohr envelope concave downward; straight line could not be drawn

Table 7. Triaxial test results for Gilmore stone

Additives used	Curing period (days)	No. of tests	Lateral pressures (psi)	Dry density (pcf)	Mohr envelope φ' (degrees)	Mohr envelope c' (psi)	Bur. of Reclamation φ' (degrees)	Bur. of Reclamation c' (psi)	Stress path φ' (degrees)	Stress path c' (psi)
No additive	None	3	40, 60, 80	135.0	44.5	20.0	43.8	22.1	43.8	26.1
1.0% $Ca(OH)_2$	7	4	20, 40, 60, 80	133.7	46.0	14.5	45.5	14.5	45.9	13.0
	28	4	20, 40, 60, 80	133.4	46.9	12.5	47.1	12.8	48.1	10.4
3.0% $Ca(OH)_2$	7	4	20, 40, 60, 80	133.7	46.8	9.0	46.5	10.1	46.3	10.2
	28	4	20, 40, 60, 80	134.1	44.7	19.0	45.3	16.9	44.8	16.2

Effects of Chlorides

Because of the mixed service record of the Bedford stone, it was selected for treatment with calcium or sodium chloride. The amount of chloride added, 0.5% by weight, coincides with NaCl content recommended by the Salt Institute. Following molding and moist curing, each specimen was tested in consolidated-undrained triaxial compression with lateral pressures ranging from 10 to 80 psi. Data are presented in Table 5.

Possible changes expected in the physical properties of the chloride-treated stone are: (1) an increase in the dry density of the material due to an increase in surface tension and lubrication which may aid compaction, (2) an increase in moisture retention, (3) flocculation of the clay particles, improving permeability, (4) an improvement in interlocking due to recrystallization of the sodium chloride, and (5) lowering the freezing point of the treated material.

The effective shear strength parameters, φ' and c' values for the untreated material, were 44.7° and 9.6 psi. For the sodium-chloride treated stone the values were 43.6° and 11.2 psi, for the calcium-chloride treated, 46.3° and 7.2 psi.

The addition of sodium chloride therefore caused a very slight decrease in effective friction angle and a slight increase in cohesion, whereas the opposite effect was noted with calcium-chloride treatment, i.e., increased friction and decreased cohesion. These changes are considered to be of negligible proportions.

Maximum pore water pressures occurred near failure in all untreated samples. In general (Fig. 1), maximum pore pressures were consistently

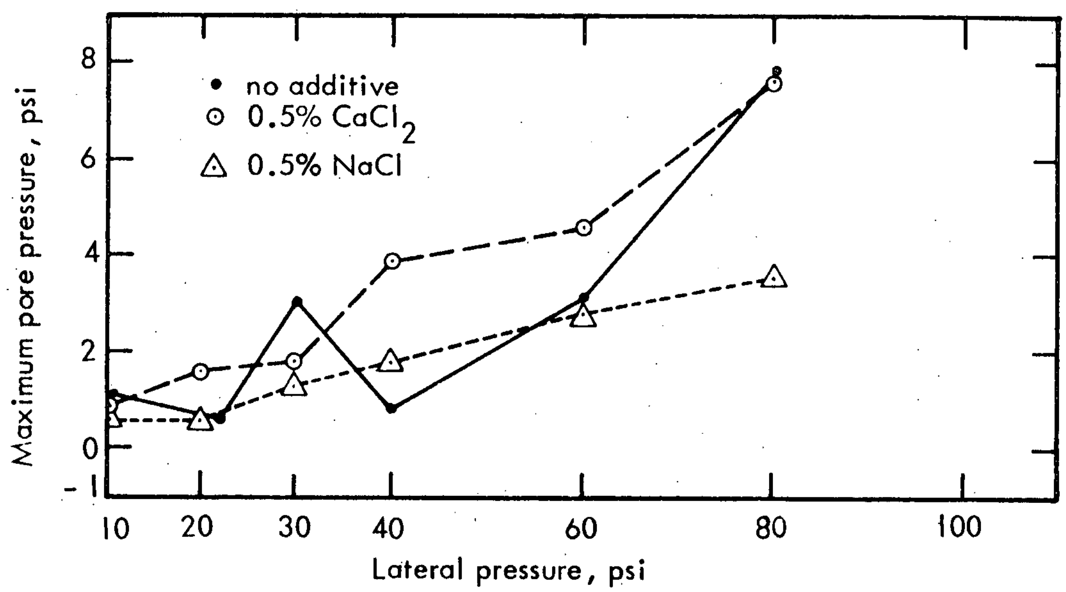

Fig. 1. Maximum water pressure vs lateral pressure for Bedford stone, untreated and 0.5% chloride treated.

lower in the NaCl treated specimens and tended to be lower in the $CaCl_2$-treated specimens. Since c' and φ' were calculated on an effective stress basis this does not directly influence the previous conclusions. However, if we extrapolate to the much higher rates of loading in actual highways, the reduction in pore pressure by use of chlorides might be significant.

Stresses at Minimum Volume

Instead of using the peak stress ratio as the failure point, an argument can be made for using the stresses at minimum volume, presuming that when the specimen starts to expand it starts to fail. Use of this failure criterion does not materially alter c' and φ'.

Another method proposed by Best and Hoover (1966) is to define a "stress modulus," defined as the deviator stress $(\overline{\sigma_1} - \overline{\sigma_3})$ divided by the unit strain at minimum volume. This is an approximate modulus of elasticity, in that the higher the stress modulus the more rigid the material.

Figure 2 presents stress moduli vs lateral pressure for Bedford stone with and without chloride treatment. For comparison, Best and Hoover's (1966) data for untreated Bedford with modified and standard Proctor compaction are also presented. Lines fitted by the method of least squares are shown, and correlation coefficients are indicated.

Figure 2 indicates that modified Proctor compaction increases rigidity of the Bedford stone, being far more effective for this purpose than the use of chloride additives. With standard compaction the stress modulus is higher with lateral pressure, indicating consolidation, whereas after modified compaction the samples apparently resist further consolidation.

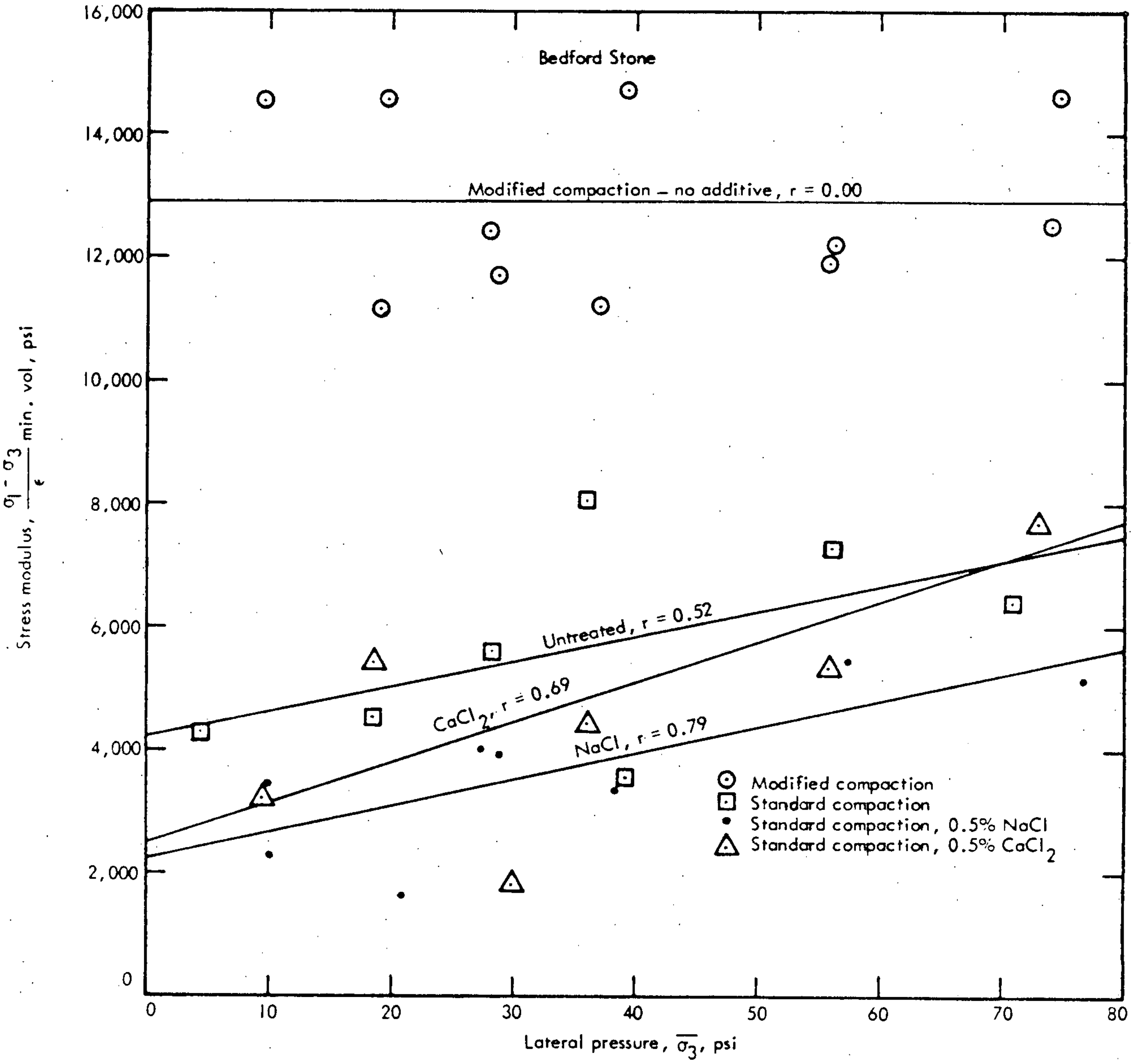

Fig. 2. Stress modulus indicating rigidity of compacted Bedford stone with and without chloride treatments. Correlation coefficients (r) are for the relationship to lateral pressure.

Additions of chlorides caused minor decreases in the stress modulus, and therefore were of no benefit.

Lime Treatment

Based on plasticity and clay mineralogy of the stones, lime treatment was expected to be most effective with the Bedford stone, which had the poorest service record. However, lime also was tried with the other two stones for comparison.

The action of hydrated lime is first to improve flocculation of clay into silt-size aggregates. If this occurs, it should be reflected in an increase in φ' and a decrease in c'. Second, lime and clay participate in a long-term cementitious reaction called a pozzolanic reaction; this should increase c'.

Figure 3 shows 28-day unconfined compressive strengths of No. 10 sieve materials stabilized with various percentages of lime expressed on a whole-soil basis. No clear-cut optimum lime contents exist, since with longer curing such curves usually level off at higher lime contents as more lime is used in the reaction. However, based on these results, 1% and 3% lime were selected as trial percentages for triaxial testing, with a few additional tests with 10% and 16% lime to insure a maximum pozzolanic reaction.

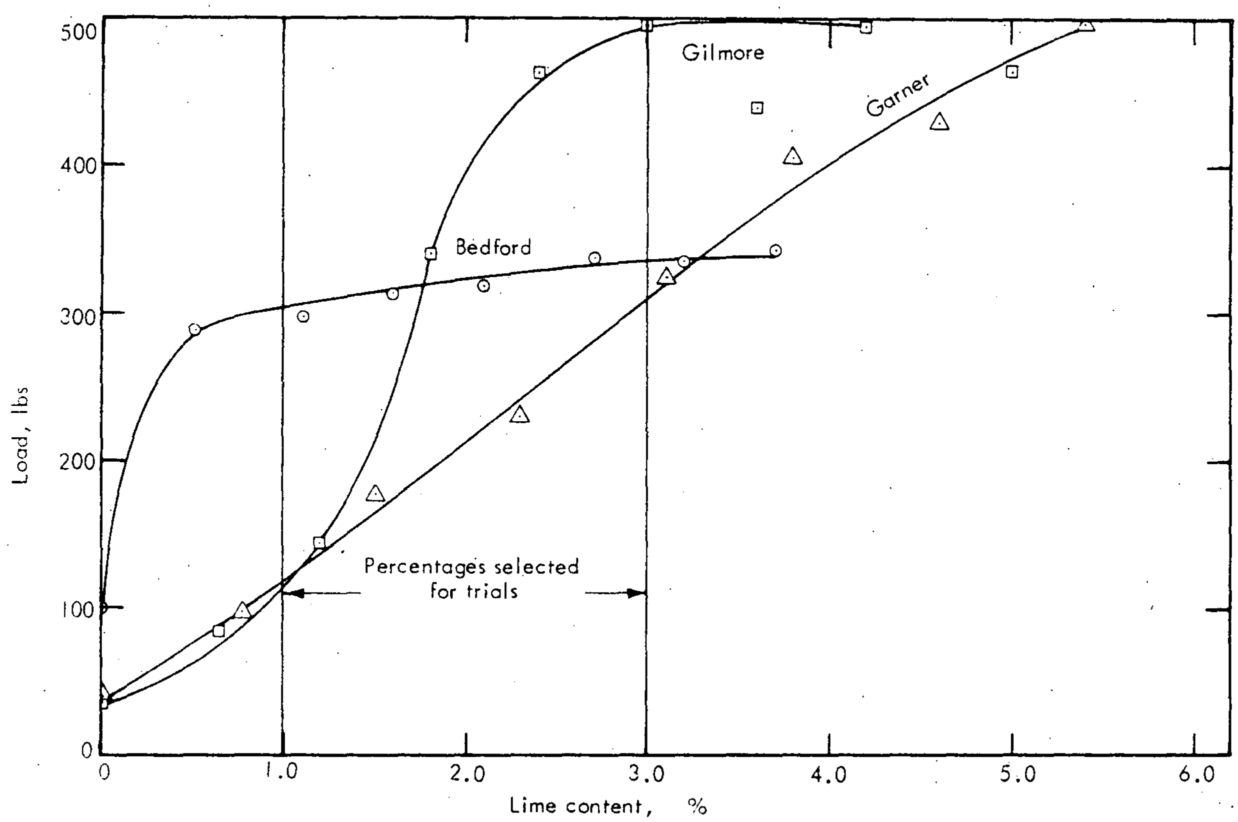

Fig. 3. 28-day unconfined compressive strength of 2 in. x 2 in. diameter cylinders molded from material passing No. 10 sieve. Lime contents are corrected to a whole soil basis.

Maximum Stress Ratio

Lime produced the anticipated results on c' and φ' of the Bedford stone (Table 3), decreasing c' at 7 days and increasing it at 90 days, indicative of flocculation followed by cementation. With only 1% lime, c' almost doubled, going from 9.6 to 16.2 psi. Simultaneously the reverse occurred in values of φ', but these effects were relatively minor (less than 2^{o}). With 3% lime the effects were somewhat more noticeable (Table 5), and 10% lime produced a c' of 24.6 psi after only 28 days.

Lime decreased the compacted density of the Bedford stone, another indication of flocculation, and at the 3% level greatly increased pore pressures during testing (Fig. 4), suggesting reduced permeability due to plugging of pores by unreacted lime. This could be detrimental in a road base. However with longer curing the effect diminishes presumably as the lime is used in pozzolanic reactions.

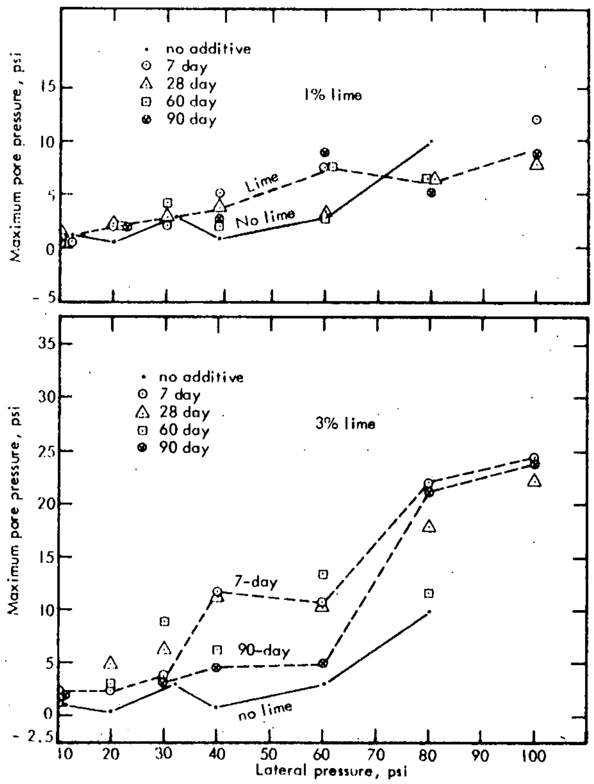

Fig. 4. Maximum pore water pressure vs lateral pressure for Bedford stone, untreated and lime treated.

In the Garner stone 1% lime decreased density, reduced c', and slightly increased φ', but not very much (Table 3). Higher percentages of lime generally further decreased c' and also φ', suggesting that lime acts as an inert lubricant (Table 6). Lime still resulted in higher pore pressures, reinforcing the conclusion of pore plugging of unreacted lime.

The Gilmore stone behaved much like the Garner stone, probably because of its similar clay mineralogy (Table 7).

Stresses at Minimum Volume

Stress moduli were calculated as before to indicate rigidity of the treated vs untreated Bedford stone. As shown in Fig. 5 addition of 1%

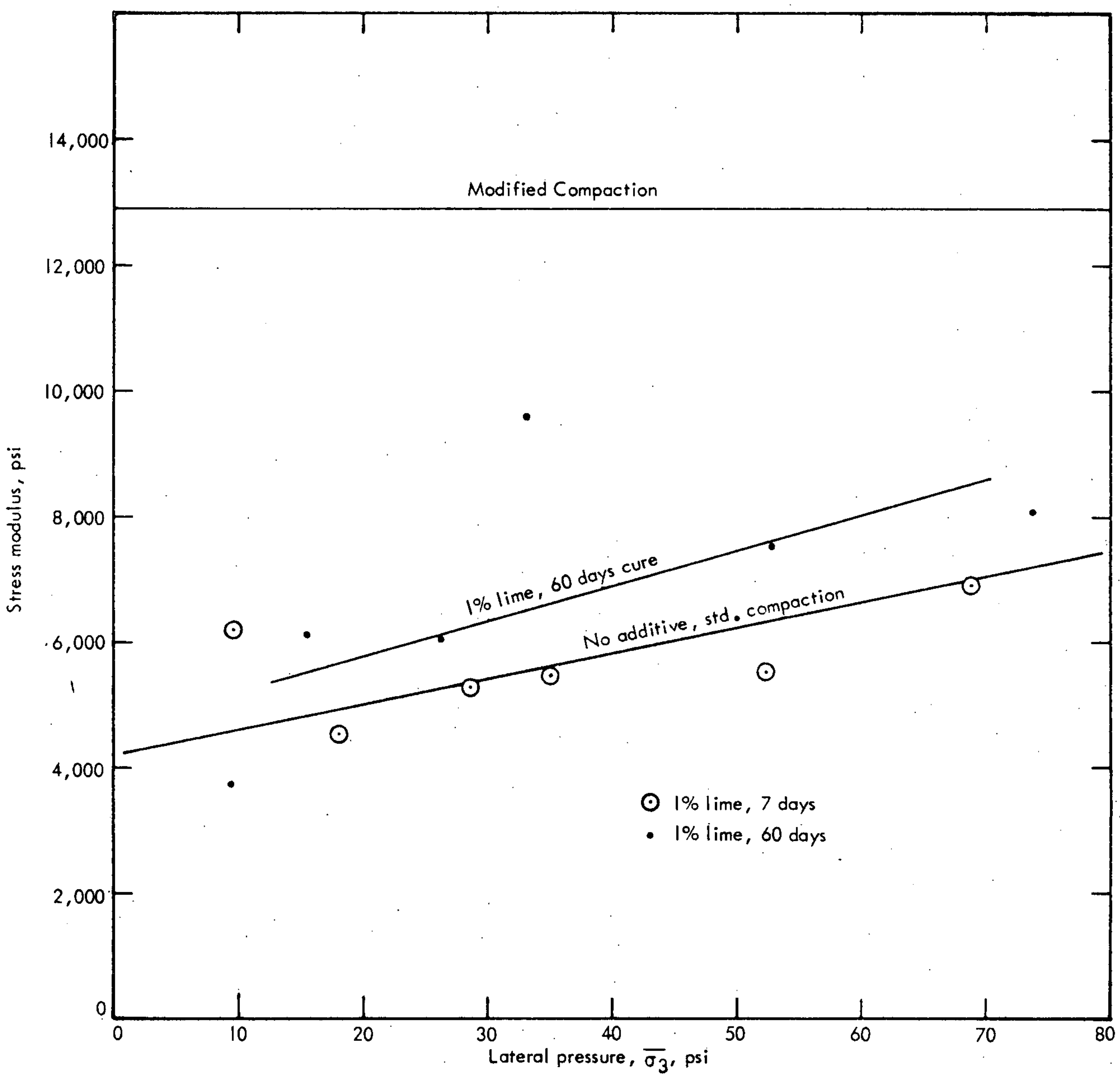

Fig. 5. Stress moduli for selected lime-Bedford stone mixes.

lime had no influence on stress moduli after 7 days curing. However after 60 days curing the modulus was appreciably higher, suggesting greater rigidity as a result of pozzolanic reaction. Similar calculations with 3% lime gave moduli about the same as in untreated stone, probably because the benefit from pozzolanic reaction was offset by higher pore pressures caused by the excess lime.

CONCLUSIONS

1. Three stones selected for variable service records in rolled stone base courses were found to differ in composition, particle size, and mineralogy as follows:

a. The Bedford (questionable service record) stone is a limestone with about 11% acid-insoluble residue consisting of kaolinite, quartz, and mica. Texturally it contains 5.5%, 5 micron clay, has a plasticity index of 2.0, and classifies by the AASHO system as A-1-b.

b. The Gilmore (intermediate record) stone is a limestone with less than 2% acid-insoluble residue consisting primarily of quartz and kaolinite. It contains 4% clay, is nonplastic, and classifies as A-1-a.

c. The Garner (good service record) stone is a dolomite with about 8% acid-insoluble residue consisting of chlorite, kaolinite, quartz, and mica. It contains only 2.2% clay, is nonplastic and classifies as A-1-a.

2. The three stones differ in standard AASHO-ASTM compacted density: 127 pcf for the Bedford, 131 pcf for the Gilmore, and 140 pcf for the Garner. The service record thus directly correlates with density, and density inversely correlates with the percent clay-size material.

3. The three compacted stones differed somewhat in static strength characteristics: φ' was 44.7°, 43.8°, and 47.9° for the Bedford, Gilmore, and Garner stones, respectively, and c' was 9.6, 26.1, and 14.1 psi, respectively. The service records thus do not correlate with these values, which are presently being reexamined by means of repetitive load testing.

4. An attempt to improve the Bedford stone with additions of 0.5% NaCl or $CaCl_2$ gave the following results:

a. NaCl decreased φ' slightly and increased c' about 17%.

b. $CaCl_2$ acted oppositely; it increased φ' slightly and decreased c' about 25%.

c. Both additives tended to decrease rigidity of the compacted stone.

Since the strength benefits are small, use of these additives in the proportions investigated is not recommended where the goal is an increase in strength.

5. Treatment of the stones with hydrated lime benefited only the Bedford stone, probably because of its higher content of clay, primarily kaolinite.

a. A curing time of 28 days or longer was necessary to gain a beneficial reaction.

b. Shorter curing times and/or excess unreacted lime caused significantly higher pore pressures, perhaps due to plugging of pores by lime.

c. The main benefit from lime was to increase cohesion. Addition of 1% lime increased c' as much as 70% after 90 days curing. The friction angle was not significantly affected, even though compacted density was reduced somewhat.

d. With low lime content and long curing, lime treatment increased rigidity. Otherwise there was no effect.

Again because of marginal strength benefit and the imperfect correlation between strength and service record, use of lime to improve the strength characteristics of crushed stone does not appear justified at this time. Two potentially deleterious side effects are lower compacted density and higher pore water pressures.

Acknowledgements

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