PROGRESS REPORT

FACTORS INFLUENCING STABILITY OF GRANULAR BASE COURSE MIXES

1 April 1964

Project HR-99 of the Iowa Highway Research Board
Project 516-S of the Iowa Engineering Experiment Station, Iowa State University, Ames, Iowa

This report presents the progress made during the four-month period December 1, 1963 to March 31, 1964 on the project entitled "Factors Influencing Stability of Granular Base Course Mixes." During this period work has been started on all three of the problem areas detailed in the project.

Staff and Equipment

Following approval of the project, an Engineering Experiment Station project number was assigned (516-S) and staff appointments were made as follows:

Prof. J. M. Hoover, director,	50% time
Dr. R. L. Handy, coordinator	17 1/2%
Dr. Turgut Demirel, Physical Chemist	25%
Mrs. Clara Ho, Soil Chemist	50%
Mrs. Annetta Schreiner, secretary	25%
Malati Charyulu, grad. asst.	50%
Mr. S. B. Kumar, grad. asst.	50%
Mr. Fernando Tinoco, grad. asst.	50%
Mr. J. W. H. Wang, grad. asst.	50%

Adjustments of the above staff will occasionally be made during the conduct of the project.

No major additional equipment has been purchased as of date of this report; the major basic apparatus being transferred from Iowa Highway Research Board Project HR-81 in addition to that apparatus owned by the Engineering Experiment Station.

A twin unit triaxial shear test machine is under fabrication in the Engineering Shop. This unit, when completed, will be capable of axial loads up to 12,000 lb under variable load rates from 0.0002 to 0.1 inch per minute, controlled to within 1% of the preset loading rate, and cell pressures up to 200 psi on 4 inch diameter by 8 inch high compacted granular cylinders. Completed thus far is the double load frame, counterbalanced loading yokes, calibrated proving rings, and the triaxial cells. Quotations are now being received on the variable speed motor drive and control unit. Total parts and fabrication costs of the unit is estimated at under $3000.00. Equivalent commercial units are $6500.00 and up.

In March, over $19,000.00 was allocated by the Board of Regents and approved by the Legislative Interim Committee for remodeling of the ground floor of an adjoining building for additional soil engineering research laboratories. An additional $12,000.00 has been allocated by the Engineering Experiment Station to supplement and add to the laboratory furniture requirements. University Physical Plant personnel have started the remodeling but formal occupancy is not expected for about 60 days. Included in the remodeling will be facilities for soil processing, and routine testing such as classification, density, etc. All physical property testing including the bulk of the problems areas of this project will be conducted in the new laboratory under controlled temperature conditions.

Problem 1. Determination of a suitable and realistic laboratory method of compaction.

1. Introduction.

The purpose of this study was to obtain a laboratory compaction method which would give uniform, controllable density while minimizing degradation and segregation of compacted crushed stone samples. Three methods of compaction, normally available in a materials laboratory were to be used; ie, drop hammer, static and vibratory.

2. Progress.

The crushed rock material selected for this study is geologically a weathered limestone, fine to medium grained, and moderately hard. It is part of the Pennsylvania System of which the outcrop pattern covers nearly half the state of Iowa. The sample was obtained in Taylor County which has one of the few locations where workable limestone of the Pennsylvanian is exposed in the state. The engineering properties of the sample are given below.

Textural composition, %	
Gravel (>2.00 mm)	70.9
Sand (2.00-0.074 mm)	17.1
Silt (0.074-0.005 mm)	6.0
Clay (<0.005 mm)	6.0
(<0.002 mm)	4.0
Effective size, mm	0.025
Uniformity Coefficient	296.
Dust ratio, %	66.5
Atterberg Limits, %	
Liquid limit	20.0
Plastic limit	18
Plasticity index	2
Specific Gravity of minus No. 10 fraction	2.73

Predominant non-clay mineral	Calcite
Predominant clay minerals	Illite Kaolinite
Other clay minerals	Chlorite Vermiculite Montmorillonite
Cation Exchange Capacity, m.e./100 gms of soil	0.314
AASHO classification	A-1-a

Triplicate representative samples of the Taylor County material were removed from the supply sample and divided into six equal portions, each portion large enough to produce one (1) standard Proctor density specimen. The first portion of each sample was set aside (not compacted) to be used for Mechanical Analysis. Increasing increments of distilled water were added to each of the remaining portions to produce one point on the moisture-density curve. Mixing was accomplished entirely by hand to minimize degradation during mixing. Following compaction each specimen was extruded and examined for visual segregation. Duplicate representative moisture samples were then removed from each Proctor specimen and the remainder of the specimen was retained for Mechanical Analysis.

The results of the standard Proctor moisture-density study are noted below:

Sample No.	Optimum Moisture Content, % dry soil weight	Dry density, pcf
A	10.4	126.9
B	10.8	128.2
C	11.5	127.1
Average	10.9	127.4

No visual segregation occurred in any specimen.

Complete Mechanical Analysis is being run on each portion in order to note the degradation of the material during the drop hammer compaction. As of date of this report the gravel and hydrometer sizes have been completed and the sand size fraction is being run. A complete analysis of the degradation will be available in the next report. The vibratory method of compaction will be started upon completion of the present phase in order to aid the progress and response of Problems 2 and 3.

Problem 2. Effect of gradation and mineralogy of the fines on cohesion and angle of internal friction, before and after saturation.

1. Introduction.

The purpose of this study was to determine the relation of cohesion (c) and angle of internal friction (ϕ) to the variation of the quantity of fines and the dominant minerals identified in the fines in each of several crushed stones ranging from good to poor in quality. Changes of the mineralogical characteristics of the clay size fractions will aid in the research noted in Problem 3.

2. Progress.

Good and poor quality stones are to be checked for c and ϕ using several gradation ranges of coarse and fine materials. From this preliminary study one coarse range gradation is to be adopted as the standard control of coarse gradation without any material passing the No. 200 U.S. Standard sieve. Varying quantities of minus 200 material will then be added to the coarse standard, compacted, and triaxially tested to determine the effect on c and ϕ by analysis of:

a. Modification or changes of internal pore water pressure including that developed during normal rates of axial loading and that developed and dissipated during relatively rapid load-unload cycling.

b. Changes or influence of variable stress-strain rates.

c. Variation of degree of saturation by moisture.

d. Modification of the mineralogical properties of the fines using various salts and alkalis.

As may be noted, the number of variables are many and the amount of laboratory testing is directly dependent on the quantity of variables. As a result, the variables are in process of being defined, and hopefully limited, and assistance is being obtained from the University Department of Statistics in establishing the experiment.

Problem 3. Improvement of the shear strength of crushed stone materials with organic and inorganic chemical additives (stabilization).

1. Introduction.

The purpose of this study was to investigate the effects of economically feasible stabilization additives on the shearing resistance of compacted crushed stone base materials, particularly those of poorer quality. Additives included in this study are cationic waterproofers, Portland and Asphalt cements, asphalt emulsions and possibly others.

Knowledge gained in Problems 1 and 2 is assisting in direction of the efforts of this study as the former relates to investigation of the stability mechanism(s).

2. Progress.

In cooperation with Project HR-97 (IEES No. 505-S), directed by Prof. Demirel, a study of the stabilization of the Taylor County crushed stone with a quaternary ammonium chloride waterproofer has been completed. A copy of the M.S. thesis prepared on this study by Mr. M. H. Farrar is being supplied the Director of Research, Iowa State Highway Commission. A summary of the results and conclusions are presented below.

It was the purpose of this study to determine the value of Arquad 2HT* as a waterproofing agent for the Taylor County crushed rock with only enough fines to meet AASHC specifications as a base course material. Since the chemical is a surface active agent, a relatively small amount would be required to produce adequate waterproofing for the coarse textured material. The crushed stone was considered unsuitable for use in a pavement under adverse moisture conditions. The Arquad 2HT was thus added to improve the immersed shearing resistance of the stone. Two minor objectives were also included:

a. To determine the effects of variable amounts of Arquad 2HT on the standard Proctor density and optimum moisture content of the crushed stone material.

b. To determine the effects of air-dry curing on the immersed shear resistance of the Arquad 2HT treated material.

The triaxial shear test was used as it is more representative of actual field conditions, if conducted under approximate pressure and density conditions normally existing in the field. The field conditions considered for this study were that a layer of partially saturated,

*Commercial trade name of a dioctadecyl dimethyl ammonium chloride produced by Armour Industrial Chemical Company, Chicago, Illinois.

compacted, granular material was used as the base component of a flexible pavement. Since loads for pavements are transient, it is doubtful whether any drainage of the material takes place during the loading-unloading cycle. Thus a quick (unconsolidated-undrained) triaxial shear test was used to measure the cohesion and angle of internal friction of the untreated and treated material.

The first preliminary phase of the investigation, was to determine the properties of the crushed stone by standard tests. These are noted in Problem 1 of this report. In general, the material met AASHO specifications for use as a pavement base.

For each succeeding phase, standard solutions of Arquad 2HT were prepared as a dispersion in distilled water previously heated to a temperature of 60 degrees centigrade. The solution was brought to room temperature before using; thus prepared, it contained 7.5 percent of active Arquad 2HT on a weight basis. The desired quantities of the Arquad 2HT, as a percentage of the total weight of the mix, was then added to the crushed stone. Additional distilled water was also added to provide the desired moisture content. All mixing was accomplished by hand to prevent degradation of the stone.

The second preliminary phase consisted of performing the standard Proctor density test with various Arquad 2HT contents. There was a general decrease of density and optimum moisture content with increasing amounts of Arquad 2HT. The data are summarized below:

Arquad 2HT Content, % oven dry soil wt.	Maximum Dry Density, pcf	Optimum Moisture Content, % oven dry soil wt.
0.00	130.5	10.7
0.02	128.5	10.7
0.05	128.5	10.6
0.10	127.5	10.1

One possible explanation for the decrease in density and O.M.C. is that the Arquad 2HT causes aggregation of the small size particles on the larger aggrgates; giving a slightly poorer gradation and resulting in lower density.

The third preliminary phase determined the moisture content range to which the treated crushed stone should be air-dried to obtain the highest immersed shear strength. Each specimen was molded at standard Proctor density in a CBR mold and air dry cured for varying periods of time. All molded specimens contained 0.05 percent Arquad 2HT treatment. Following determination of the air-dry moisture content, each specimen was tested using the soaked CBR test. The length of air-drying based on maximum practical moisture content loss during curing and highest soaked CBR value was selected as the curing period for treated samples in the major phase of the investigation. The following table summarizes the data obtained:

Moisture loss during curing, % dry soil wt.	Soaked CBR at 0.1 inch penetration	Soaked CBR at 0.2 inch penetration	Saturation %	Vol. change during immersion[a], %
0.00	29.7	38.2	85.1	-0.02
1.22	42.0	45.3	81.7	-0.04
2.40	26.7	33.0	91.4	-0.36
3.84	37.2	47.3	90.6	-0.28
5.30	48.2	55.7	90.7	-0.14
5.75	41.0	44.5	92.3	+0.88
6.27	31.5	36.7	83.9	-0.12

[a]Based on the change in height as a percent of the original height, (-) indicates shrinkage and (+) indicates expansion.

The maximum immersed CBR value indicated a necessary period of drying to produce a moisture content loss of about 4.5 to 5.8 percent by dry soil weight. All major investigation specimens were thus air-dried to within this moisture loss range.

The maximum saturation during immersion ranged from 81.7 to 92.3 percent, increasing to the maximum (at a moisture loss during prior curing of less than 6 percent), then rapidly decreasing due to additional air drying; substantiating the maximum practical air drying period. The volume change varied from a contraction of 0.36 percent to an expansion of 0.88 percent, showing little volume change due to immersion.

In the major phase of the investigation, 4 inch diameter by 8 inch high cylinders were molded with varying amounts of 0.00 to 0.05% Arquad 2HT, air-dry cured until moisture loss was within the range previously noted, soaked with water for 48 hours, and triaxially shear tested. The results obtained were analyzed for determination of the effects of Arquad 2HT on the cohesion and angle of internal friction of the crushed rock material.

Molding of the triaxial shear test specimens required special techniques. In order to retain the cylindrical dimensions, each specimen was molded inside a triaxial membrane by a vibratory method. With the exception of the rubber membranes and dimensions of the specimen and apparatus, the method of compaction was similar to that proposed by ASTM in relative density determination of cohesionless soils. This uses a mold mounted on a vibratory table operating at a frequency of 3600 vibrations per minute and amplitude varying between 0.002 and 0.025 inch. The use of this method produced specimens molded at 92 percent of the maximum dry density obtained in the standard Proctor density tests. Higher densities were obtainable by using larger periods of vibration (5-10 minutes) but created definite visual segregation of coarse and fine materials in each specimen.

Following air-dry curing in the membranes, to the conditions previously noted, each specimen was placed in a water tank with water level maintained at 1/2 inch above the top of the specimen. A porous stone at the base of the specimen allowed water to infiltrate while a metal band inside the top of the membrane prevented its collapse and allowed the upper face of the specimen to be exposed to air; a saturation condition similar to that expected in the field. After saturation the specimen was allowed to drain for 10 minutes before placement in the triaxial shear apparatus.

Specimens for each lateral pressure (5, 10, 20, 30, 40, 50, 60 and 75 psi) and Arquad 2HT treatment condition were subjected to the unconsolidated-undrained (quick) triaxial shear test. The following table very briefly shows the average effect of Arquad 2HT treatment on the saturated shear strength of the crushed stone materials

Arquad 2HT Content, % oven-dry soil weight	Angle of Internal Friction (Φ) degrees	Cohesion (c), psi.
0.00	16.5	11.7
0.01	23.1	4.5
0.03	22.7	7.5
0.05	24.3	5.9

The Mohr shear diagrams of the Arquad 2HT treated material showed circles and envelopes of failure that were fairly consistent and yielded about the same results for the different percentages of treatment. The friction angles were all within 1 degree of the average value of 23.4 degrees while the cohesion was within 1.5psi. of the average value of about 6 psi.

By comparison, the test results of the untreated material were very erratic; ie, a linear envelope of failure could not be drawn.

As a result, average values of the angle of friction and cohesion of the untreated specimens were obtained by applying the method of least squares used by the U.S. Bureau of Reclamation.

During soaking it was noted that all treated specimens had free water on their tops within one hour. Similar saturation was noted for some of the untreated specimens but for the remainder water did not rise to the specimen top. Three untreated specimens were then tested at a lateral pressure of 60 psi and showed maximum axial stresses of 120, 140 and 156 psi. In the first two specimens water had appeared on the specimen top; the latter specimen showed no water on top during soaking. In other cases where untreated specimens were tested at duplicate lateral pressures, the specimens not showing free water at the top also gave higher maximum axial stresses.

In general, the above situation indicates the extreme variation in water adsorption and in pore water pressures of the untreated specimens, whereas the absorption and thus the pore pressures of the treated specimens were more uniform. It appears that Arquad 2HT stabilizes the structural units of the crushed stone material, limiting the amount of absorbed moisture to the large pores. This effect then appears to limit the pore pressure within the structural units of the stone and results in a better shearing resistance than the untreated material under the same moisture conditions. The rapid movement of water during the soaking phase also indicates the general increase in permeability and reduction of segregation by the use of the Arquad 2HT treatment.

The quantity of moisture absorbed during soaking showed minimal variation between treated and untreated specimens and was measured primarily by variation in weight of the samples after curing as compared to weight following soaking and draining. The average weight of moisture absorbed by the untreated specimens and their standard deviation was 206 ± 49 grams. The treated specimens absorbed 261 ± 27 grams for 0.01%, 266 ± 7 grams for 0.03% and 264 ± 13 grams for 0.05% Arquad 2HT treatment.

In summary, the study indicated that Arquad 2HT is an effective additive for improving the shear strength of the crushed stone material under adverse moisture conditions. The treatment seems to have imparted its maximum benefit with the Taylor County material at about 0.02% by oven-dry soil weight. The treatment also appears to impart a greater permeability to the stone indicating that the Arquad 2HT is not effective in keeping water out of the material as a whole but is effective in waterproofing and increasing the stability of the structural portions of the material. For maximum benefit of shearing strength the treated material should lose 4 1/2 to 5% or greater of its moisture content following compaction.

A more comprehensive technical report of this study for presentation at the January 1965 Highway Research Board meeting is being planned by Prof. Demirel and Mr. Farrar. A Soil Engineering Research Brief will soon be available also on this study.