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CAP GROUTING TO STABILIZE FOUNDATION ON CAVERNOUS LIMESTONE

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In 1925 construction of the American Bemberg Rayon Plant was started in Elizabethton, Tennessee, on a site near the Watauga River on a level plateau at average elevation of 40 feet above normal river level.

The first units of the plant, including manufacturing building, power house and miscellaneous buildings was erected in 1925-26 and immediately put into operation. The balance of the plant was erected in 1927-28 and put into operation in 1930.

The chemical building is of reinforced concrete construction, two to six stories high with a basement housing heavy process machinery, equipment and tanks. The spinning, washing, drying and textile units constitute a single one story building of structural steel framing brick walls and saw-tooth roof. Foundations for all buildings are concrete spread footings designed for $2\frac{1}{2}$ to 3 tons per sq. ft.

The main manufacturing building covers a ground area of approximately 305,000 sq. ft., and 24 supplementary structures occupy ground areas of from 1,000 sq. ft. to 35,000 sq. ft. each.

The Plant contains a network of fluid carriers, including sewers, process water carriers, fire protection and water supply lines, practically all laid in the ground under or outside the buildings.

Concrete trenches in the floors of certain departments carry large quantities of waste process fluids to sewer lines that flow into settling basins. The process water systems handle from $4\frac{1}{2}$ to 6 million gallons per day.

Soil formation at the site is comprised of an alluvial sandy clay-loam surface boulder bed, overlying a soluble limestone bed-rock. Normally the soil mantle is so firm it cannot easily be excavated by hand.

In 1932 a soil cave-in occurred at a bend in a storm water sewer northeast of the main building. This cave-in was attributed to leakage in the storm water sewer and hence caused no apprehension at that time as to general ground stability. Subsequently, cave-ins occurred with increasing frequency until March 27, 1940, all being associated with discovered leakages or breaks in fluid carrier lines.

On March 27, 1940, a major cave-in, causing a serious collapse of machinery, occurred in the spinning room floor, leaving an open pit averaging 35 feet wide by 40 feet long and 22 feet deep. (See photo).

During the night of March 29, 1940 a second cave-in under the spinning room floor occurred, leaving an open pit some 35 feet by 25 feet in plan area and 40 feet deep.

The services of Engineers and a Geologist were immediately obtained and after the two cavities were filled with river rock and concrete, a thorough exploratory program was undertaken, including sub-soil borings and examination and testing of all underground fluid carriers and floor drains.

The report following these examinations stated that the cave-ins had been caused by cumulative leakage of fluids from poorly installed and badly damaged fluid carriers, wet floors and floor drains, and recommended the immediate repair of all fluid carriers to prevent future serious cave-ins, and the pressure-grouting of the overburden in the cave-in areas.

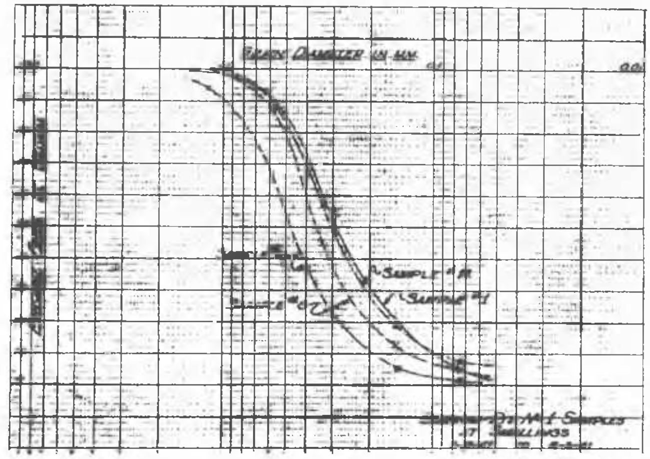


FIG. 1

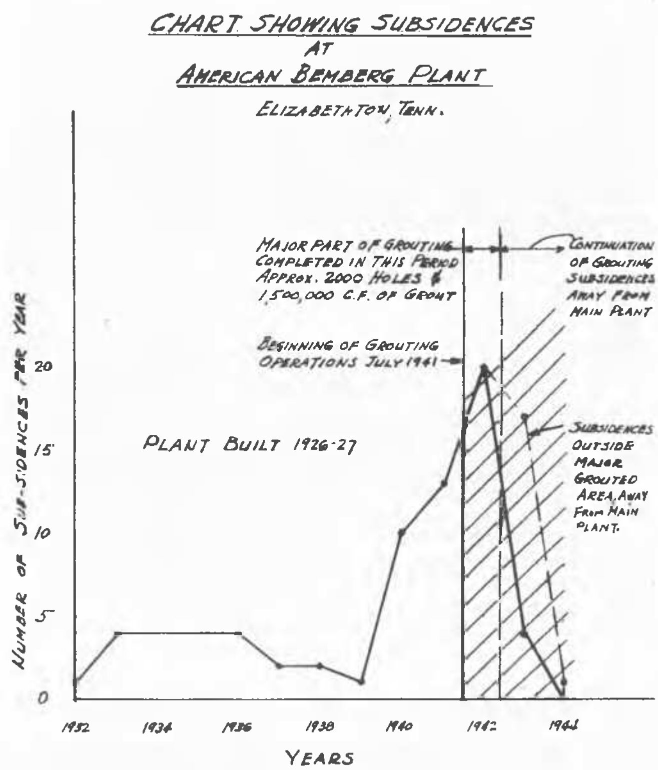
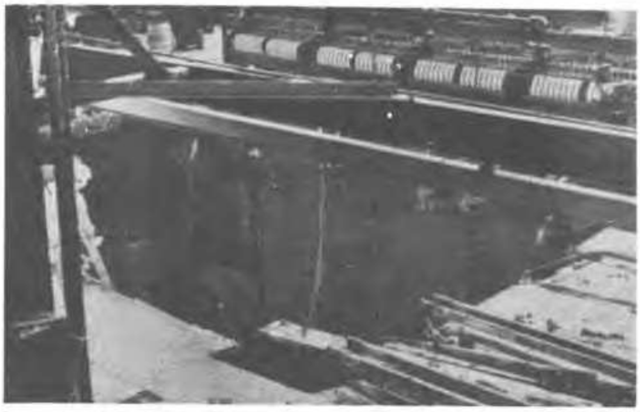


FIG. 2

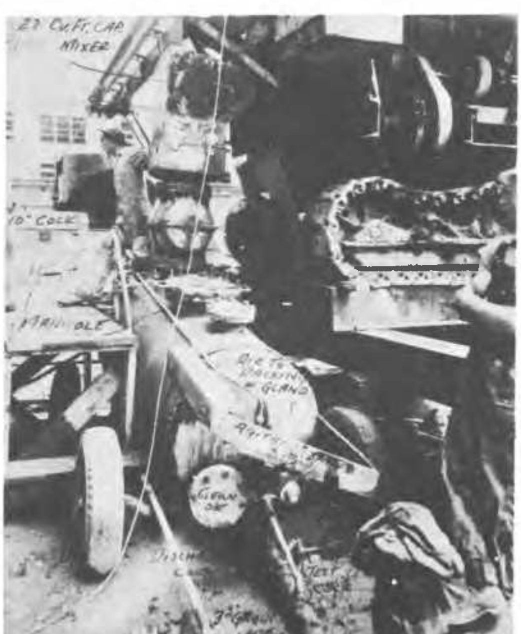
These recommendations were approved and adopted.

Alternatives that were also considered in the report, were, the feasibility and cost of underpinning to rock those sections of the plant where the handling of large quantities of fluids in trenches and in underground lines offered the most serious hazard of fluid leakage into the soil; the practicability and cost of eliminating all underground fluid carriers by pumping to new overhead lines; and a bed-



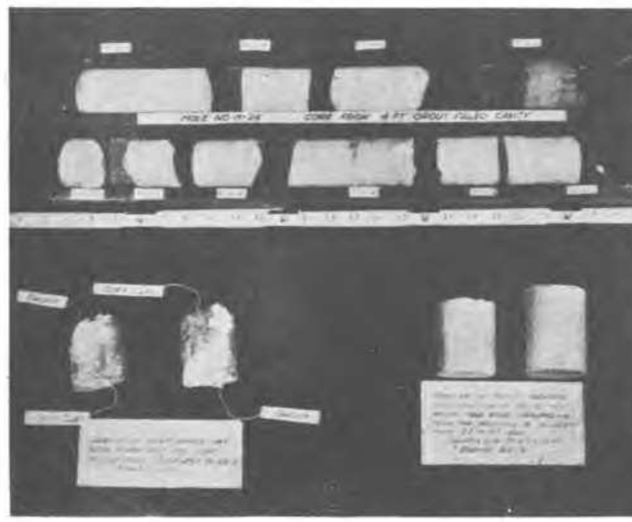
PHOT. 1

PHOT. 2



PHOT. 3

PHOT. 4



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PHOT. 6

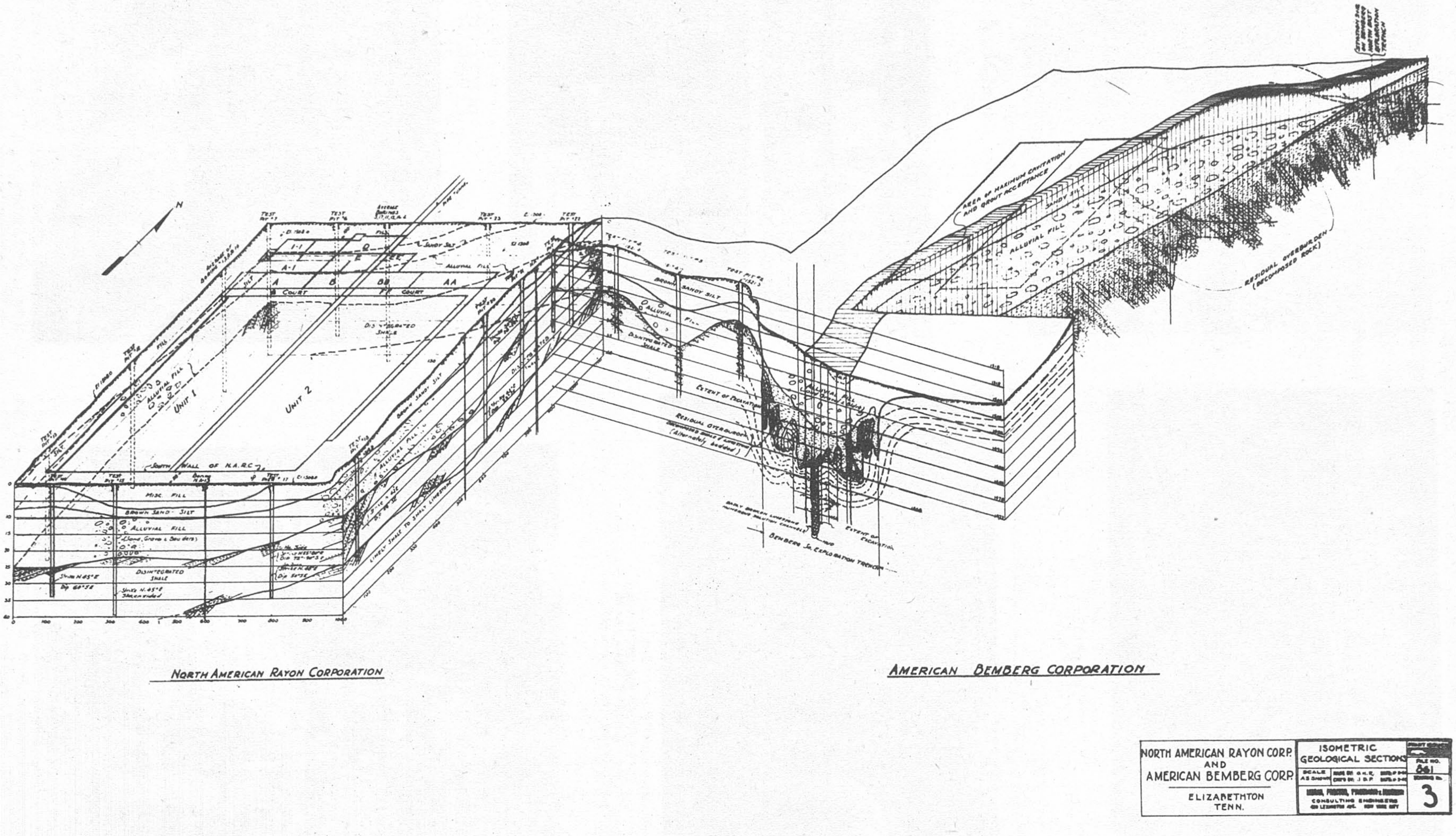
N
UNIT 1
UNIT 2
SOUTH WALL OF N.A.R.C.
COURT
MISC. FILL
BROWN SAND - SILT
ALLUVIAL FILL
DISINTEGRATED SHALE
ALLUVIAL FILL
SANDY SILT
RESIDUAL OVERBURDEN
EXTENT OF EXCAVATION
RESIDUAL OVERBURDEN (RECOMPOSED ROCK)
AREA OF MAXIMUM CAVITATION AND GROUT ACCEPTANCE
BEMBERG So. EXPLORATION TRENCH
NORTH AMERICAN RAYON CORPORATION
AMERICAN BEMBERG CORPORATION
NORTH AMERICAN RAYON CORP.
AND
AMERICAN BEMBERG CORP.
ELIZABETHTON
TENN.
ISOMETRIC
GEOLOGICAL SECTIONS
CONSULTING ENGINEERS
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FIG. 3

rock grouting program, designed to effect soil stabilization through pressure grouting in those areas of the plant where serious fluid leakage was most probable.

Seven additional cave-ins occurred in 1940, during the period of pressure-grouting around previous cave-ins and in the locations of known large fluid losses, while the fluid carriers were being repaired and made tight. Although one of these cave-ins was 30' x 20' x 14' deep and others up to 12 ft. deep, all were traceable to discovered leakages, and therefore were accepted as necessary attributes to the corrective measures being taken. They were treated by filling the holes with river rock and concrete and pressure grouting of the overburden in the cave-in area. Similar corrective methods were applied to 3 small cave-ins in the plant area during the first 6 months of 1941.

On June 9, 1941, a major cave-in of approximately 29' in plan diameter and 25' deep, occurred without warning. (In the appendix to this paper is a chart of the incidence of cave-ins per year.). Immediately thereafter the writer was called to the site for investigation and report as to cause and remedy of the situation.

Such report contained the following conclusions and recommendations:-

That the plant was supported on an alluvial overburden that immediately overlay a soluble, broken, limestone bed-rock. That the site was over a previous course of the Watauga River over a sincline fault, the crest of the sincline fold having been removed by erosion and scour, and that the overburden consisted of a river deposited clay, silt, fine to coarse sand, gravel and boulders. The limestone bed-rock was honeycombed with solution channels and large cavities, and included a wide zone of badly broken and jointed rock materials.

When in a previous geological age, the river flowed over this area, the softer, less stable and surface fractured rock had been eroded and dissolved, leaving a pinnacled hard superficial rock crust, below which solution channels and cavities had been dissolved and eroded by the continued flow of the river through the deep sincline fault.

This condition of bed-rock cavitation had permitted the ravelling of overburden soils into the rock cavities and as such ravelling or collapse of the overburden progressed, the soil mantle arched over the cavities. Fluid leakages had saturated the soil forming such arched covers, causing soil to flow into the rock cavities and fault channels, such progressive failure in the overburden being accelerated by flood flows of the river, until failure of the arched roofs occurred, causing the sudden, large-scale, deep cave-ins or "sink holes", extending to the surface of the ground.

While the elimination of fluid carrier leakage would reduce the immediate hazard of cave-ins by checking the principal cause of rapid deterioration of roof arches of the soil cavitations, those cavities in the overburden that had approached a condition of incipient failure must continue to constitute a major hazard, unless they were adequately and permanently filled.

The large quantities of plant leakage, with its solvent content, caused an accelerated chemical attack on the already weakened limestone bed-rock, thus creating additional instability of the rock floor supporting the cavitated overburden.

Therefore a program for grout filling of overburden cavities was recommended. This was to be accomplished through drilled, cased borings, and a grout procedure designed to cap grout over the outlets in the rock floor leading to the bed-rock cavities. Borings were to be continued until 3 ft. of continuous bed-rock had been intercepted to assure against grout filling over a thin rock shelf. The report advised a controlled introduction of grout until repeated grouting had closed off the rock floor openings by accretional cap grouting, after which controlled pressure grouting was to assure the complete filling of the intercepted overburden cavities.

This program contemplated the complete underpinning of the overburden, honeycombed with cavities, and the prevention of further ravelling of soil materials into rock cavities, so as to assure a substantial support of the soil on the bed-rock floor and protect against failure of loaded areas overlying bed-rock cavities near the top of the rock.

Evidence of an underground flow of water from the Watauga River through the faulted and folded zone and following the bed-rock strike in a generally S.W. direction, was obtained by placing a dye of a strongly fluorescent green color, in the cavities on the river side of the plant and the later identification of such dye in well water withdrawn S.W. of the plant.

By preventing the further ravel of overburden into rock cavities, through the introduction of a grout mixture capable of arching over channels and openings in the rock floor, and competent to resist the scour and erosion of flood river flow through the fault zone,the loads of the overburden and the plant would be transmitted to the bed-rock at a safely low intensity.

The report further endorsed and insisted upon the expeditious completion of the program then underway, to repair and where required replace, all fluid carriers in the plant to assure the elimination of leakage into the overburden. Also to slope yards away from buildings to prevent surface water from pooling near buildings.

These recommendations were all approved and the writer's firm was authorized to put the program into expedited operation. Accordingly, a large scale drilling operation was started at once, involving the employment of 12 drill rigs; the installation of grouting equipment, including the development and fabrication of large capacity pressure grouters, especially designed for this project; and the development of a bentonite grout mixture to best meet the demands of flowability, strength, resistance to scour and erosion, and economy.

Initially a grout pattern with holes at the corners of 20 ft. squares was followed throughout the plant area, the first grouting being done in those areas where the hazard of further cave-ins was considered greatest. The second pattern for grouting placed a grout hole at the center of each 20 ft. square.Thereafter drilling and grouting was concentrated in all zones where large overburden cavitation was indicated through large grout acceptance.

To check the presence and extent of a faulted zone acroos the site, two trenches to bed-rock, one southwest and one northeast of the plant, were excavated. From these trenches clear evidence was obtained that a fault zone traversed the plant from S.W. to N.E., and that the bed-rock under the alluvial overburden deposit in the original river bed, was honeycombed with cavities and solution channels.

Outside of the plant, in two rows, 5 and 20 ft. from the outer building walls, 4 inch

TABLE 1

RESULTS OF COMPRESSIVE STRENGTH TESTS ON GROUT MATERIALS FOR AMERICAN BEMBERG JOB - ELIZABETHTON, TENNESSEE

NO.	MIX (cement:sand: bentonite)	APPR. YIELD (cu.ft.grout per sack of cement)	WATER (gallons per sack cement)	3-DAY COMPRESSIVE STRENGTH Average of two 3" X 6" Cylinders (CONSISTENCY) liquid p.s.i.	plastic p.s.i.	stiffly plastic p.s.i.	28-DAY COMPRESS. STRENGTH Average of two 3" x 6" Cylinders (CONSISTENCY) liquid p.s.i.	plastic p.s.i.	stiffly plastic p.s.i.
1	1: 12: 0.35	11.2	31.0	54			104		
2	" " "	10.8	27.5		69			140	
3	" " "	10.2	22.5			98			195
4	1: 8: 0.35	7.8	22.0	88			214		
5	" " "	7.4	19.0		120			242	
6	" " "	7.0	16.0			174			314
7	1: 4: 0.35	4.3	11.5	225			414		
8	" " "	4.1	10.0		305			538	
9	" " "	3.8	7.8			472			835
				(July 18, 1941)			(Sept.2,1941)		

NOTE: 1) All mixes are given by volume, the following assumptions being made:
a) Sand has 9% surface moisture
b) Sand weighs 78.5 lbs/cu.ft.
c) Bentonite (Pontotoc) weighs 55 lbs/cu.ft.
d) The water given on the above table in gallons/sack of cement does not include the surface moisture.

NOTE: 2) The mixes (1), (4) and (7) approximately correspond to the most liquid workable consistency. The mixes (3), (6) and (9) correspond to the stiffest possible and may even be too stiff for practicable use.

PHOT. 7

PHOT. 8

diameter churn drill holes, both vertical and inclined under the wall footings, were installed. Inside the building only 2½" diameter drill holes were installed, including angle holes under all immovable equipment or inaccesible locations.

A field laboratory was set up and a considerable number of potential borrow pits were sampled to provide soil materials that would produce a grout to best meet the demands of economy, ready flowability through hose lines and pipes with minimum abrasive destruction to grout pumps and grout machine parts, controllability as to slump so as to seal off openings in the rock floor with minimum loss of grout into the deeper rock cavitations, resistance to erosion and leaching, adequate compressive strength, and sufficient swell on setting to assure a tight contact to the roof and side wall of overburden cavities.

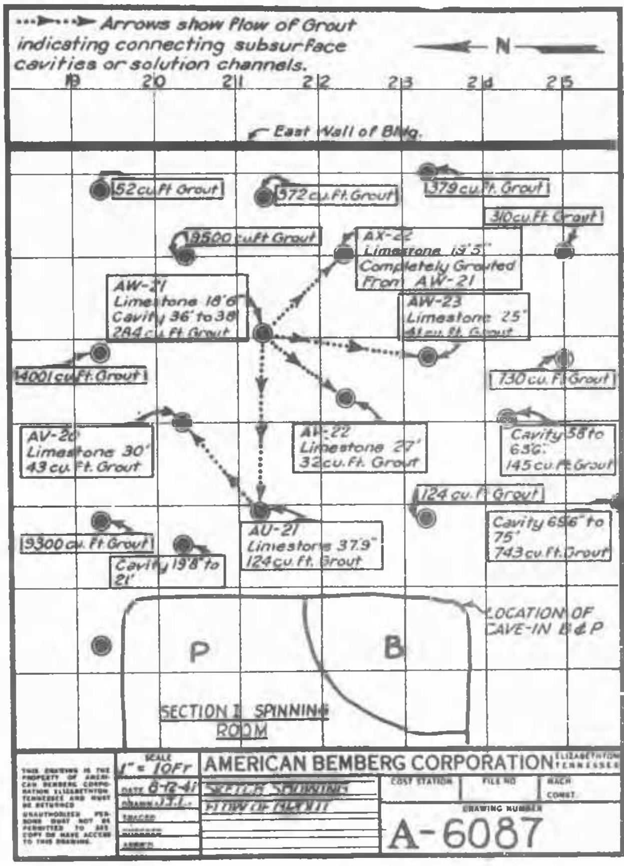

FIG. 4

While the grout proportions were varied slightly as the supply from each borrow pit was exhausted and new borrow pits employed, the average mix consisted of 1 part cement to 8 parts of a fine silty sand with a small clay content:--to which was added 1/3 part of bentonite.

By the end of the year 1941, sufficient grouting had been accomplished to afford assurance as to the safety of the plant and surrounding service roads and thereafter drilling and grouting operations were extended to the outlying buildings and service areas. While sections of the plant had been temporarily put out of operation and roped off during the initial drilling operations and while one incipient cave-in, where the soil had fallen away from the concrete floor slab over an 18 ft. diameter and to a 6 ft. depth, required that drill rigs for this grouting area be supported by hangers from the roof girders, no further actual cave-ins in the plant area developed and no serious interference with plant operation became necessary. The completed grouting operation required the installation of over a million and a half cubic feet of grout.

The North American Rayon Corporation Plant under the same management and ownership as the Bemberg Plant, adjoins the Bemberg Plant to the west. While no subsidences had been experienced at North American, its operational conditions and volume of process fluids through its fluid lines were similar to Bemberg, and its management directed that a full investigation be made to determine the possibility of future cave-ins at this plant. Accordingly a series of test pits were excavated between the west end of the exploratory trench south of the Bemberg Plant and the easterly

PHOT. 9

PHOT. 10

side of the North American Plant, and similar test pits were put down to surround that plant. Also numerous sub-soil borings were made. From laboratory analyses of undisturbed test pit samples and from field examinations of test pits, together with a geological study and report, it was determined that whereas the underlying limestone was of a soluble character, the bed-rock at North American was relatively undisturbed by folding and a mantle of impervious shale and residual disintegrated shaley clays overlay the bed-rock to provide an insulation against piping and erosion of overburden soils into bed-rock cavitations.

Conclusions.

The Shenandoah Valley of the Appalachian Mountains, from Northern Virginia to Southern

Tennessee, is a region well known for its cavernous limestone bed-rock. Luray caverns is but one of a series of natural caverns of large extent. Large size caverns were intercepted and concrete filled under the site for Chicamauga Dam. This great valley is a growing industrial area. Foundation conditions in this and other known soluble limestone areas should be thoroughly investigated and the exact geological conditions determined before building operations are planned and areas overlying badly folded or crushed zones, where the protection of an impervious mantle over the bed-rock does not exist or has been destroyed or seriously disturbed, should be avoided or built upon only after special provisions will assure adequate protection and positive stability.

Where structures are founded on unstable overburden, susceptible to ravelling or erosion into underground cavitations, cap grouting may in many instances be the only economical corrective procedure. The bed-rock cavitations may be of such large volume that grout flowing into them would be entirely wasted, and the risk of cavitations in the limestone bed-rock approaching so close to the surface as to produce relatively thin rock shelves and overhanging ledges, makes an underpinning procedure involving concentrations of load on piles or caissons, unsafe against a shear failure of the supporting bed-rock.

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IX c 6

RESINOUS WATER REPELLENTS FOR SOILS

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SUMMARY

This paper presents the results of a field and laboratory investigation of resinous water repellents for soils to be used in road or airfield construction. The study indicated that certain resin-type repellents are effective in waterproofing soils which have some plasticity. Tentatively, based on the results of field tests, the quantity of Stabinol required for adequate waterproofing is determined by the plasticity index and soil type.

INTRODUCTION

As a part of the investigational program concerned with the design and construction of roads and runways conducted by the Corps of Engineers during World War II, the use of resinous water repellents as an admixture for waterproofing soils was investigated. It is the purpose of this paper to present the pertinent results of a combined field and laboratory study conducted by the Waterways Experiment Station in 1944 and 1945, in which the effects of various repellents on a range of soil types was investigated. Detailed descriptions of the tests are given in the interim report "Resinous Water Repellents for Soils", Waterways Experiment Station Technical Memorandum No. 217-1.

SCOPE OF INVESTIGATION

The laboratory study consisted of tests on fourteen soils treated with two water repellents (321 and Stabinol) to determine types of soils that could be effectively waterproofed according to available criteria. Additional laboratory studies were made on five of the soils to determine the efficacy of other water repellents made available after initiation of the investigation.

The field study included construction of 30 test sections, using five soils from the group studied in the laboratory and using untreated soil and various percentages of treatments. Several treated and untreated sections were covered with prefabricated bituminous surfacing and pierced steel plank. The sections were tested after dry and wet periods under wheel loads ranging from 2000 to 5000 lb.

LABORATORY TESTS

Materials

Only two water repellents were studied extensively at the start of the investigation. These were 321 and Stabinol, both products of the Hercules Powder Company. Another product of this company, Vinsol, was available, but review of data indicated that it would probably not be as effective over as wide a range of soils as the other two; therefore, only limited tests were scheduled with this material. Later on, other repellents became available for research purposes from the National Southern Products Company (NSP-121 and NSP-25-2)and the Hercules Powder Company (NVX).

The fourteen soils tested in the preliminary investigation included alkaline and acid soils ranging from friable sandy soils to heavy clay soils. It was also decided to include gravelly soils with different plasticity indexes. A complete list of the soils studied, together with all pertinent classification and compaction data for each, is shown in table 1.

Laboratory tests and criteria

Capillary rise and full-submersion tests for determining the proper repellent content