cost was $5.55 per cu. yd. or $0.46 per sq. yd., making the total cost of the rigid patch, less excavation, $2.75 per sq. yd.

CONCLUSION

Soil-cement mixtures have not been used in patching pavements over the entire State, although their use would have proved more economical in several instances. The availability of excellent sand, sand-clay, and gravel in certain localities, together with fair subgrade conditions, makes their use more economical than soil-cement mixtures. In certain cases, however, it has been necessary to reinforce the worst subgrades in these localities with soil-cement mixtures before the patches would hold. Weight and volume of traffic has also been a governing factor. In areas where the traffic is light, the use of good granular materials has been quite successful and economical.

The use of soil-cement mixtures in patching is advocated only when their use is more economical than other materials or when a very dependable material is desired. In areas subjected to traffic which consists of some heavy vehicles and where subgrade conditions are bad, its use will be found to be quite satisfactory and economical.

SOME WARTIME SOIL-CEMENT CONSTRUCTION EXPERIENCES

By Miles D. Catton, *Manager, Soil-Cement Bureau, Portland Cement Association, Chicago, Illinois*

SYNOPSIS

The application of soil-cement to war projects on the North American Continent began in the summer of 1940 with the construction of 330,000 sq. yd. of taxiway and runway widening at Camp Borden, Canada. It was followed with an increasing number of military projects in the United States, the largest of which consisted of a landing mat 355 acres in area built by the Navy in the fall of 1942. Included in military activities were training schools and demonstration field projects for substantial numbers of U. S. Army Aviation and Airborne Aviation Engineer units, Seabee Battalions and Marine Aviation Engineer units.

At the request of the Office of Chief of Engineers, U. S. Army; Bureau of Yards and Docks, U. S. Navy and of individual officers of the Army and Navy responsible for the construction of individual projects and the training of troops, the Portland Cement Association cooperated on the work undertaken in the United States. This cooperation included laboratory testing work, construction supervision assistance, the preparation of special tests and training manuals for military use and assistance in conducting training schools. This close association with the laboratory and field work has given the Portland Cement Association first hand information on the accomplishments and developments in the use of soil-cement by the Army and Navy in the United States.

As would be expected, the Army and Navy successfully built projects under soil and weather conditions never attempted previously. They built paving projects of a magnitude that pleased even the pre-war dreamer. They developed construction procedures and equipment in a matter of days that would have required months or even years under previous peacetime conditions. Most important of all, it was demonstrated repeatedly that the simplicity of soil-cement construction operations permitted construction to proceed at speeds unheard of in previous paving experience. Daily construction of 20,000 to 30,000 sq. yd. of soil-cement became commonplace.

A brief review of the highlights of the Army and Navy experiences with soil-cement construction is of value to the paving engineer in planning and executing his work. In the following summary, details are given of construction procedures, equipment and accomplishments on some of the more important projects. Also, some of the unusual weather and subgrade conditions encountered on some jobs are described together with results obtained.

The use of soil-cement on army and navy road, street and airport construction in the United States was foreshadowed by military uses and interest in foreign countries. Prior to the start of our military program, it was learned that the Chinese had built about 100 miles of soil-cement road with low cement factors of 4 per cent and 6 per cent on the old Russian Caravan Route between Sian and Lanchow and on the first sections of the now famous Burma Road. The Japanese had completed an extensive soil-cement road research project, using the same basic control factors of optimum moisture, maximum density and cement content that were developed and used for scientific control in the United States. The Germans had been making extensive use of soil-cement and developing special construction equipment. The British Road Research Laboratory predicted that soil-cement may fulfill the particular requirements of the military engineer. The French had conducted research on a soil-cement test track and were preparing to build a large number of airdromes of soil-cement at the time they were invaded.

The use of soil-cement paving in building our war plants has supplied valuable information on construction under unusual weather conditions and rates of daily production which are believed to be without precedent or equal in the history of paving construction. The following discussion gives the highlights of some of the more notable projects that pay tribute to the unusual accomplishments of Army, CAA, CQM, Navy and WPA engineers, and makes the information available for the use of all engineers interested in paving work.

During the entire war construction program the Portland Cement Association contributed the services of their personnel in assisting government agencies on the design, testing and construction of projects involving the use of cement and concrete. In the case of soil-cement construction, the tests were conducted in the soil-cement laboratory in Chicago which relieved various government agencies of many hundred man days of laboratory work and thus expedited other testing work by these agencies, as well as reduced their personnel requirements. The Association also placed trained and experienced soil-cement construction engineers on projects as they got underway. These engineers were intimately familiar with the most practical, economical and rapid methods of building soil-cement since the Association served as a clearing house for all such information. Thus, construction was able to proceed with dispatch even though the contractor and engineers on a particular project may not have had previous field experience with soil-cement. The reports and records of the Association personnel made during their association with this work supplies the first-hand information given in this report.

The probable rôle that soil-cement would play in military construction was shown long before Pearl Harbor. In the summer of 1939, a representative of the Army Air Forces made a confidential visit to the soil-cement laboratory at which time complete information was given on soil-cement paving and its use for runway construction for pursuit and light bomber plane bases was thoroughly discussed. At about the same time, the same ground was covered with a representative of the Office of Chief of Engineers.

TRAINING OF MILITARY PERSONNEL

It was at this time that the now famous U. S. Army Aviation Engineer Battalions were in the embryo stage. Plans were made for their training in soil-cement construction and soon after the activation of the 21st Engineers as the first Aviation Engineer unit they learned how to build soil-cement by actual field experience by constructing soil-cement streets in their cantonment area at Fort Belvoir, Va.

The training of U. S. Army Aviation Engineer and Airborne Aviation Engineer Battalions, Seabees and Marine Aviation Engineer Battalions serves as an illustration of the basic simplicity of soil-cement construction since these units, containing men having all types of educational and experience backgrounds, were able to learn the technique in a very short time. Figure 1 illustrates these activities. All these organizations were fully equipped with field testing kits and the necessary construction equipment such as rotary speed mixers, heavy duty offset disc harrows, heavy duty field cultivators, pressure water distributors, pneumatic tire and smooth wheel rollers. Several thousand officers and men have been trained in this technique.[1]

[1] "Cement Stabilized Bases for Runways" by Lt. Col. Alexander Brest, CE, and First Lt. Dillard D. Woodson, CE, *Military Engineer*, January, 1944.

Plans for the first practical military field application of soil-cement were made in the fall of 1939. The rush of the preparedness program prevented selection of a site until the summer of 1940 when it was decided to build the demonstration runway in the Caribbean area. In August, 1940, the Office of Chief of Engineers had the district engineer, Puerto Rico, Virgin Islands ship representative soil samples to the soil-cement laboratory for test as a prelude to construction. At the same time the Soil-Cement Bureau and the district engineer conferred regarding construction details which culminated in the ordering of the required equipment to be shipped to the Caribbean. Arrangements were made then for a PCA soil-cement construction engineer to go to the Virgin Islands at the beginning of construction operations.

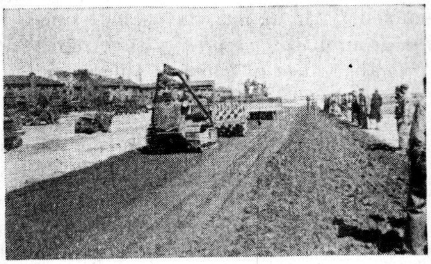


Figure 1. Each step of construction is demonstrated by use of construction equipment supplied to engineer units.

It can now be told that the site selected for the first job was at St. Croix. Construction was in charge of an officer of the 21st Engineers trained in soil-cement construction as previously noted. The project was to be built with local labor entirely, however, rather than with military personnel. The Association representative arrived on the job early in February, 1941.

The following equipment had been placed on the project:

1—No. 12 motor patrol
3—Heavy duty field cultivators
1—Heavy duty disc harrow, 28-in. discs
2—Three-bottom gang plows
3—1,000-gal. water distributors
1—75-H.P. track type tractor
1—60-H.P. track type tractor
1—20-H.P. rubber tire tractor
1—Double drum sheeps foot roller
1—Single drum sheeps foot roller
1—Broom Drag
1—Spike Tooth Harrow
1—5-ton smooth wheel roller

Maintenance and repair of all of this equipment rested in the hands of a local small machine shop.

Construction lanes consisted of areas 25 ft. wide and 500 ft. long. The length of construction was increased as the crew obtained experience. The large amount of local common labor was used to obtain efficient cement spreading operations by splitting up the procedures into simple one step operations with each step handled by alternate crews. The soil processed was similar to some of the marls and limecracks of Florida or caliches of Texas. The usual tropical rains were common at this season of the year and in the 22 day period

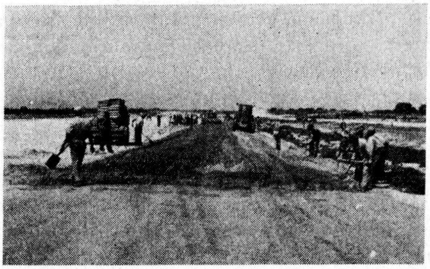


Figure 2. Construction operations on St. Croix, V. I., project

between February 18 and March 11, while the PCA representative was on the job, construction took place on 11 days. The 11 days not worked was due to lack of cement, Sundays and holidays. No one day was lost because of rain. Average daily construction for the period averaged 1,800 sq. yd. However, the efficiency of the crew was shown by the fact that on the last day, the PCA representative was present March 18, 2,639 sq. yd. were processed which is almost exactly twice the first day's work. Figures 2 and 3 illustrate construction operations.

The remainder of the first runway and a second runway were completed by the USED. The runways were used extensively by all types of aircraft until needs were reduced as 1944 progressed. The success of the installation is attested by a representative of the Office of Chief of Engineers who officially inspected the runways in the fall of 1944 and said of them, "They are in excellent operating condition today."

The foregoing construction record is of value in demonstrating that soil-cement construction is simple and easy to learn and can result in substantial daily construction even though the skilled, semi-skilled and common labor on the job may be entirely inexperienced in this construction and of the type common to the Virgin Islands.

The Corps of Engineers and the Army Air Forces continued their studies of soil-cement construction for strictly military use by making installations of various types under

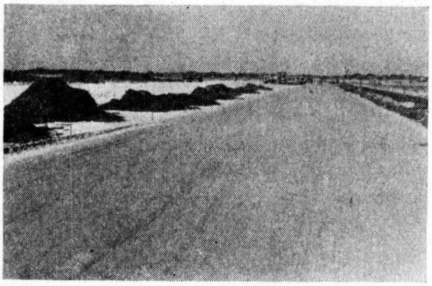


Figure 3. Completed section. Damp straw was used for surface protection to prevent surface evaporation losses.

various conditions. Included was a demonstration street project built in the cantonment area at Baer Field, Ft. Wayne, Indiana by the Development Section, CAA, for the study of the Corps of Engineers and the Army Air Forces. The project was visited by representatives of these organizations and included Major General S. C. Godfrey who was in command of all Aviation Engineer and Airborne Aviation Engineer Units until he was sent overseas as Engineer Officer in charge of airport construction in the China-Burma-India Theatre of Operations. Figure 4 illustrates mixing operations.

The story of the construction of soil-cement to meet various combat conditions overseas must be told by those connected with it after they return from the war. However, it is known that soil-cement has played an important part in overseas military construction on more than one occasion.[2]

FIRST U. S. SOIL-CEMENT RUNWAY INSTALLATIONS

The first soil-cement airport project on the North American Continent was built by the Canadian Department of National Defense in the summer of 1940 at Borden Field, Canada. It consisted of 300,000 sq. yd. of taxiways and runway widening. The first soil-cement airport project in the United States was awarded to contract to the D. W. Winkelman Co., Syracuse, N. Y. by the Construction Quartermaster Corps for a 150-ft. runway 2500 ft. long at Westover Field, NE Army Airbase, Chicopee Falls,

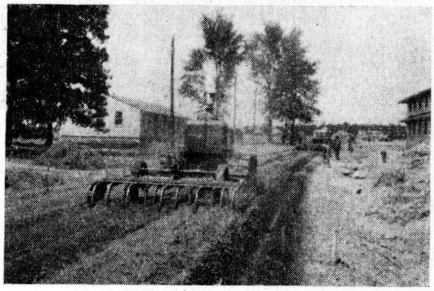


Figure 4. Mixing operations on demonstration soil-cement streets built by Development Section, CAA.

Massachusetts. The contract was awarded August 23, 1940, and actual processing was started September 13. The contract price was $0.553 per sq. yd. for a 6-in. compacted

[2] "Soil-Cement Aids Pilots at Australian Airports," *Soil-Cement News*, page 4, No. 7, July, 1942.

"Soil-Cement Used by Axis Powers in War Program," *Soil-Cement News*, page 4, No. 7, July, 1942.

"Soil-Cement at War (Henderson Field, Guadalcanal)," *Soil-Cement News*, page 1, No. 11, June, 1943.

"Reports wide Use of Soil-Cement in War Theaters," *Soil-Cement News*, page 1, No. 13, December, 1943.

"South Africa Next to U. S. in Soil-Cement Use," *Soil-Cement News*, page 3, No. 13, December, 1943.

"Aviation Engineer Reports on Soil-Cement Work in Europe," *Soil-Cement News*, page 1, No. 15, August, 1944.

"Use Soil-Cement for Base Stabilization in Great Britain," *Soil-Cement News*, page 3, No. 15, August, 1944.

"South Africa Planning More Soil-Cement," *Soil-Cement News*, page 1, No. 16, December, 1944.

"Germans Use Soil-Cement Base for Long-life Runways," *Soil-Cement News*, page 3, No. 17, February, 1945.

depth containing 10 per cent cement by volume or 0.45 bags per sq. yd. Material processed was a sand-gravel soil imported for the work at a cost of $0.076 per sq. yd. for a 7-in. depth.

The project was completed September 29. Construction took place on 14 days which gave an average daily production of 2,868

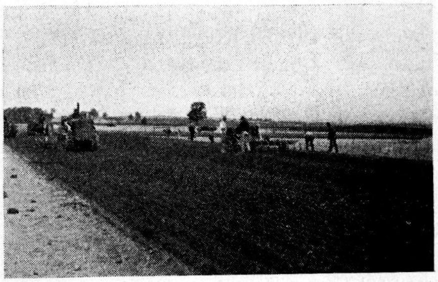


Figure 5. Mixing operations on Chicopee Falls, Mass. project

sq. yd. The best day's run was achieved September 27 with the completion of a section 50 ft. wide and 618 ft. long which constitutes 3,433 sq. yd.

The equipment used on this job consisted of the following items:

1—Rubber tired motor patrol
2—Heavy duty field cultivators
1—30-in. rotary speed mixer
1—14-in. walking plow
2—1,000-gal. pressure water distributors
1—40-H.P. track type tractor
1—30-H.P. track type tractor
1—15-H.P. rubber tired tractor
1—Double drum sheeps foot roller
1—Spike tooth harrow
1—York grader with rake attachment
1—10-ton smooth wheel roller
1—3-ton smooth wheel roller
1—1½-ton smooth wheel roller

It is of interest to compare these construction operations with those at St. Croix previously cited where average construction was 1,800 sq. yd. per day with a maximum of 2,639 sq. yd. It will be noted that the amount of equipment used was less than on the St. Croix work and that it produced more yardage. This is explained largely by the difference between the type of labor available on the two jobs. See Figure 5.

An additional 310,000 sq. yd. of soil-cement was built at this airport by the Corps of Engineers in succeeding years.

BRUNSWICK, MAINE PROJECT

The second airport project to get under way was built at Brunswick, Maine by the WPA and CAA. Note Figure 6. The projected work consisted of two 100-ft. runways, 3,000 ft. long. Construction got under way late in the fall.

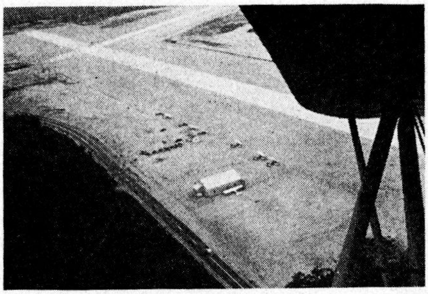


Figure 6. Completed work at Brunswick, Me., airport

The following equipment was used on the project:

1—Motor patrol
1—Heavy duty field cultivator
1—Rotary speed mixer
1—14-in. walking plow
2—1,000-gal. pressure water distributors
1—35-H.P. track type tractor
1—15-H.P. rubber tired tractor
1—Spike tooth harrow
1—Pneumatic tire roller
1—8-ton smooth wheel roller
1—½-ton smooth wheel roller

It will be noted that sheeps foot rollers were not used in compaction, which was due to the fine sand used that contained practically no minus No. 200 sieve size material and could not be compacted with sheeps foot rollers. Satisfactory densities were obtained with pneumatic tire rollers and smooth wheel rollers.

Construction was hardly started in 1940 until it was shut down by cold weather after the construction of 19,445 sq. yd. The remaining 47,937 sq. yd. were completed in the spring of 1941 in 22 processing days that averaged 2,179 sq. yd. per day. Maximum day's production was 5,097 sq. yd. The ability to obtain these daily yardages in this fine sand with the very minimum of equipment should be noted.

In subsequent years the WPA and the

Navy built an additional 161,000 sq. yd. of runways.

LARGE PROGRAMS BEGIN IN 1941

The construction of the U. S. military plant began in earnest in 1941. During the year soil-cement was used on 36 airport projects in 18 States and represented 5,344,347 sq. yd. of construction. It was during this period that the USED and Navy CEC engineers proved that soil-cement could be built at unheard of speeds and under weather conditions that were considered prohibitive until they proved them to be otherwise. Sizes of projects ranged from a small installation of 2,250 sq. yd. by the WPA and USED at the Jackson, Miss., Municipal Airport to a 680,277 sq. yd. job completed by the USED at the Victorville, California, Airport.

FIRST NOTABLE BAD WEATHER EXPERIENCES

A soil-cement construction project was started in December, 1940 at Camp Livingston, Louisiana that developed into a remarkable record for the Construction Quartermaster Corps. A large cantonment was under construction with all buildings, roads and other facilities being built at the same time. The roads and street program lagged behind the building program. As the fall and winter rains set in this began to present most serious conditions because the trucks hauling building materials for the barracks, etc. would mire down and thus seriously interfere with the building construction program. The streets and roads being built consisted of compacted sand-clay-gravel and as the rainy weather continued it became impossible to give the gravel adequate compaction with the result that it rutted out as rapidly as it was built.

It became evident late in November that some relief must be found for this road and street situation or building construction would be seriously handicapped. The U. S. Construction Quartermaster Corps made arrangements with S & W Construction Co. and Associates, Memphis, Tenn. for the demonstration construction of 3500 ft. of 22-ft. streets, 6-in. thick, of soil-cement. The first move in this program was to barricade the area to be built to keep all traffic from it which churned it up into mud and made impossible construction conditions. Finally on December 10, after several days of rain, a section 336 ft. long was built using a traveling mixing machine. In the succeeding days of typical winter rains a procedure was developed of blading sections to grade whenever they could be found dry enough to permit operation of a motor patrol, keeping traffic from these graded sections, preventing water from standing and soaking up the subgrade, blading surface mud from areas to be processed and selecting sections dry enough for construction. Dry enough in this case consisted of a general moisture condition of undisturbed soils of about optimum which in the sandy loams, loam, silt loams, clay loams and clay consisted of moistures varying from 11 to 16 per cent. Actual moisture in the undisturbed soils sometimes ran as high as two percentage points to four percentage points above optimum.

It was found that the completed work could be used soon without rutting. Construction conditions of rain and mud were so difficult and the success of the soil-cement was so outstanding that on December 12, two days after the start, the engineers on the job made arrangements at once for four machines to be used on the work. Construction operations were immediately organized for full utilization of this equipment and construction continued until toward the last of February which completed the immediate rush work and permitted the barrack's construction to proceed without interruption.

In the fall of 1941 additional soil-cement construction was placed under contract and when this work was completed more than 200,000 sq. yd. had been built. Only those engineers intimately familiar with winter rain conditions at Alexandria, Louisiana, where this camp is located, have a full appreciation of the construction handicaps overcome by the ability of the engineers and contractor on the project to adapt soil-cement to the prevailing conditions. Figure 7 illustrates construction.

NAVY LEARNS OF WINTER POSSIBILITIES

At about the same time that the Construction Quartermaster Corps was learning how to use soil-cement successfully under very unfavorable weather conditions, the Navy was presented with a similar problem in paving the streets of a completed war housing project at Portsmouth, Virginia identified as the St. Julien's Creek Naval Housing Project. At this location a sandy soil prevailed but presented rather unstable subgrade conditions because of a water table close to the surface. Further, freezing weather was imminent.

After a review of all construction factors, it became evident that it was a question of meeting these unfavorable conditions with soil-cement or deferring the street construction until spring and in this latter event it would be almost impossible to use the completed homes.

Construction was started December 19, 1940 by H. G. McCarthey, Norge, Va., subcontractor for Allen J. Saville, Inc., Portsmouth, Va. By paying careful attention to the basic principles of soil-cement construction requiring a specific density in the completed work together with intelligent control of moisture contents, construction procedures were evolved that resulted in satisfactory soil-cement. At times the moisture content of the mixture was as much as two percentage points above optimum and in one case as much as five percentage points above optimum. See Figure 8. It was necessary to use light equipment and keep heavy loaded trucks from the work before processing as they would mire down. The completed work was protected from freezing by hay, waterproof paper and at times by canvas and salamanders.

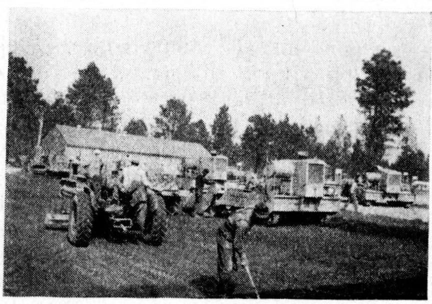


Figure 7. The intensity of construction operations on the Camp Livingston, La., work is shown in part by this illustration.

Figure 8. Construction handicaps successfully overcome on the Navy St. Julien's Creek, Va., housing project. Wet subgrade.

The freezing weather prevented construction at various times. On two occasions with rising temperatures a 2-in. frozen crust of sand was broken up and successfully thawed and processed with the usual addition of water and subsequent manipulation procedures.

EXPERIENCES WITH EXTRA CEMENT TOPS

Under the pressure of war construction, consideration was given to every possible procedure that would permit short cuts on initial construction even though additional work would be needed at a later date. A few field trials had demonstrated that it was possible to incorporate additional cement in the top 1-in. to $1\frac{1}{2}$-in. of soil-cement during final finishing operations to increase resistance to abrasion and give a surface capable of giving satisfactory service for a time before it would become necessary to place a bituminous surface. The amount of work involved in placing an extra cement top would be less that required for the bituminous surface and such construction would thus save considerable manpower and at the same time permit earlier use of the facility.

Three different projects involving the use of extra cement tops were built in the forepart of 1941. The experiences with these projects showed that the degree of construction and engineering control required for their successful installation was more than could be expected under the pressure with which all military work was being built. A brief review of the results obtained on these war jobs follows.

The first extra cement top project got under way at the airbase at Tallahassee, Florida on February 26, 1941. By April 2, the project, which totaled 143,970 sq. yd. of runway and parking apron, was completed by Ivy H.

Smith & S. S. Jacobs, Jacksonville, Fla., contractors for the USED. A very light bituminous surface consisting of essentially only a tar prime and about 10 lb. of sand per sq. yd. was placed on the parking apron and one-half the runway shortly after completion. See Figure 9. All the remaining unsurfaced extra cement top, as well as the primed areas, gave excellent service without dusting, but the expected slight chipping at cracks continued to develop with the result that in the spring of 1944 the work received a 1-in. sand-asphalt surface. The entire performance of the extra cement top on this project was fully up to expectations.

The second extra cement top project to get under way was a plane parking area totaling 82,000 sq. yd. at the Charlotte, North Carolina, Army Airbase. See Figure 10. The project was started March 12 and completed April 19, 1941 by Blythe Bros., Inc., Charlotte, N. C., contractors for the USED.

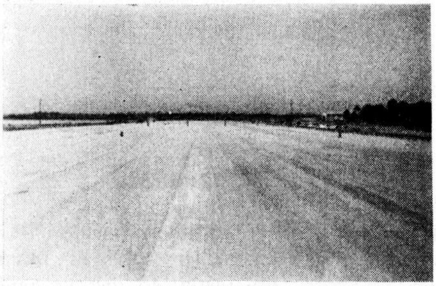


Figure 9. Completed surface containing extra cement for temporary service. Tallahassee, Fla. airport runway.

Later it was found necessary to widen the existing runways. Soil-cement was selected for this with an extra cement top and a total of 159,702 sq. yd. were built. Soil-cement paving was started June 5 and completed July 31.

The extra cement top gave good service until freezing weather occurred. A progressive "scaling" of the extra cement top began and progressed over the parking area and some of the runway widening. It was found that this "scaling" was generally only about $\frac{3}{8}$ in. to $\frac{1}{2}$ in. thick and that this scaled material had a very high cement content. It proved that the extra cement had not been dispersed to the 1 in. to $1\frac{1}{2}$ in. depth contemplated during construction.

The scaled material ground up readily under traffic and caused objectionable dust clouds. This material was not broomed from the surface but was wetted down and rolled repeatedly but only dusted again when dry. Inspection of the work late in March, 1942 showed that the underlying soil-cement was hard and durable and that where the extra cement had been incorporated for $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. that it did not flake from the underlying surface. In the summer of 1942 the loose soil-cement was broomed from the surface and a bituminous mat placed over the soil-cement.

Good engineering control was obtained on this project but inability to get full depth of dispersion of cement in the top as planned showed that such procedures were not advisable under the pressure of war construction.

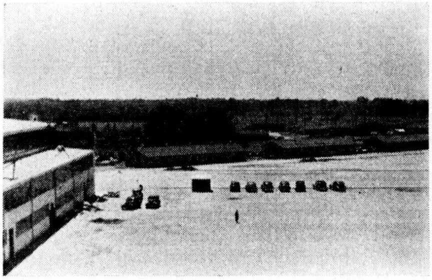


Figure 10. Completed surface containing extra cement for temporary service. Concentration of cement in top $\frac{1}{2}$ in. produced early "scaling" and unsatisfactory service. Charlotte, N. C. airbase.

The third extra cement top project was built at Morris Field, West Palm Beach, Florida and consisted of 306,170 sq. yd. of runway and plane parking apron built by Cleary Bros., West Palm Beach, Fla., contractors for the USED. The work started March 31, 1941 and was completed May 9, 1941.

The extra cement surface performed satisfactorily. A very thin mat consisting of about 0.2 gal. per sq. yd. of bituminous material plus 10 lb. of sand was placed in March, 1942. This likewise gave good service for considerable time and it may still be the only surface in place on this work.

Summarizing all of these construction experiences and service records on extra cement tops it was concluded that they do not meet the problems of wartime construction and their use was discontinued. However, they did show that there may be a few cases in normal civilian construction when they will serve a very good purpose for a time before the usual bituminous surface need be placed.

SOME NOTABLE CONSTRUCTION RECORDS

The project at Tallahassee, Florida previously mentioned was built in what was considered record time. However, it was only the beginning of a series of speed records which were made only to be shattered.

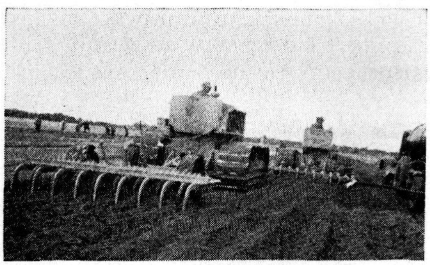


Figure 11. Construction operations on Tallahassee, Fla. runways

The following equipment was used on the project:

2—No. 12 motor patrols
1—Heavy duty disc harrow, 28-in. discs
2—Heavy duty field cultivators
1—Rotary speed mixer
1—4-bottom gang plow, 14-in.
4—800-gal. water supply tanks
1—Trailer distributor
1—60-H.P. track type tractor
2—40-H.P. track type tractors
1—30-H.P. track type tractor
2—20-H.P. rubber tired tractors
2—Double drum sheeps foot rollers
2—Spike tooth harrows
1—Nail drag
1—Broom drag
1—8-ton tandem smooth roller
3—Pneumatic tire rollers

The plane parking area of 47,270 sq. yd. was started February 1 and completed February 24, 1941, using 17 processing days although rain fell on five of them. Average daily production was 2,780 sq. yd.

Construction was started on the runway February 26 and completed April 2. The construction constituted 96,667 sq. yd. for a runway 300 ft. wide and 2,900 ft. long. It was completed in 25 processing days and the 11 other days of elapsed time are accounted for by a cloud burst stopping work for 4 days, Sundays accounted for 4 more days, construction organization difficulties accounted for 1 day and normal rain stopped work only 2 days. Average daily construction was 3,867 sq. yd. which is equivalent to $\frac{1}{3}$ mile of 20-ft. roadway each working day. See Figure 11.

This project also supplied specific information showing that soil-cement could be built under weather conditions considered unfavorable for any other type of paving. Temperatures were below 45 degrees on all but 13 days of February and March. During these two months rain fell on 25 days yet processing was only interrupted 6 days because of rain.

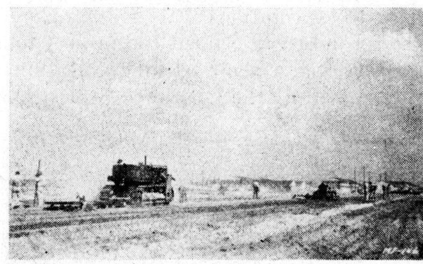


Figure 12. Mixing operations on West Palm Beach, Fla., project

WEST PALM BEACH, FLORIDA PROJECT

A small truck parking area and a large plane parking area totaling 105,000 sq. yd. was started at West Palm Beach, Florida, March 31, 1941. It soon became evident that the engineers and contractor on this project were going to achieve some unusual daily construction records. See Figure 12.

A total of 1,556 sq. yd. was completed on the first working day and production was progressively improved toward the completion of the plane parking area. A record was set of an average of more than 6,000 sq. yd. for each of five consecutive days. A final record was made on the truck parking area when almost two acres of 6-in. soil-cement was completed on each of two succeeding days. On these 12-hour days an area 510 ft. by 300 ft., was completed.

Later in the year the same contractor was awarded contract to build 201,170 sq. yd. of runway widening.

The following equipment was assembled for this work:

2—Motor patrols
1—Road grader, 10-ft. blade
3—Heavy duty field cultivators
2—Heavy duty disc harrows
1—Heavy duty disc plow
2—3-bottom gang plows
1—12-in. walking plow
1—1,100-gal. pressure water distributor
1—900-gal. pressure water distributor
1—850-gal. pressure water distributor
2—Double drum sheeps foot rollers
1—70-H.P. track type tractor
4—40-H.P. track type tractors
4—20-H.P. track type tractors
3—Spike tooth harrows
1—Nail drag
1—Broom drag
1—5-ton tandem smooth wheel roller
1—Pneumatic tire roller

The previous experience of the contractor was evident on the work at once after organization and preliminaries were out of the way. Processing for the first seven days of organized work totaled 23,147 sq. yd. and averaged 3,307 sq. yd. per day compared with 2,444 sq. yd. per day on the first seven days of the first contract. This daily production was gradually and systematically increased to another record of 8,563 sq. yd. toward the completion of the work.

The high day's work of 8,563 sq. yd. on the runway widening is equivalent to almost $\frac{3}{4}$ of a mile of 20-ft. roadway and the 9,166 sq. yd. record on the truck parking area is equivalent to almost 0.8 of a mile of 20-ft. roadway.

AVONDALE FIELD, MACON, GEORGIA

At about the time the West Palm Beach project was being completed a contract was awarded by the USED to W. F. Scott & Co., Thomasville, Georgia to build 120,000 sq. yd. of apron at U. S. Army Flying School No. 1, Avondale Field, Macon, Georgia. At the same time the McDougall Construction Co. was awarded a contract to widen one runway with soil-cement involving about 75,000 sq. yd. and the W. L. Cobb Co., Decatur, Georgia was awarded the contract to widen a second runway involving about 70,000 sq. yd. The J. B. McCrary Engineering Corporation, Atlanta, were engineers for the project. See Figure 13.

The contractors started construction about the middle of May, 1941 and rushed their work to completion in an elapsed time of 50 days.

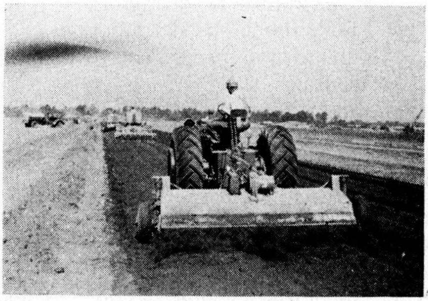


Figure 13. Mixing equipment and operations on Avondale Field, Macon, Ga., project.

W. F. Scott & Co. used the following equipment:

1—No. 12 motor patrol
1—Heavy duty disc harrow, 24-in. discs
2—Heavy duty field cultivators
1—Rotary speed mixer
1—Two-horse plow
1—3-bottom gang plow
2—1,000-gal. water distributors
2—550-gal. water supply tanks
1—Trailer distributor
1—70-H.P. track type tractor
1—60-H.P. track type tractor
1—50-H.P. track type tractor
2—30-H.P. rubber tired tractors
2—Double drum sheeps foot rollers
1—Spike tooth harrow
1—Nail drag
1—Broom drag
1—5-ton tandem smooth roller
2—Pneumatic tire rollers

The contractor began work May 17 and completed his 64,000 sq. yd. on June 4 in 17 processing days. He averaged 5,714 sq. yd. per working day with this equipment. The daily output averaged 6,667 sq. yd. on 15 working days.

The W. L. Cobb Company used the following equipment:

2—Motor patrols
1—Heavy duty disc harrow, 24-in. discs
2—Heavy duty field cultivators
1—Rotary speed mixer
1—3-bottom gang plow
3—1,000-gal. pressure water distributors
1—40-H.P. track type tractor
1—35-H.P. track type tractor
1—55-H.P. rubber tired tractor
1—30-H.P. rubber tired tractor
2—Double drum sheeps foot rollers
1—Nail drag
1—Broom drag
1—5-ton tandem smooth roller
2—Pneumatic tire rollers

The W. L. Cobb Co. started their work on May 15 and completed it on June 7 in 21 processing days. They averaged 3,755 sq. yd. daily.

The McDougall Construction Company averaged 3,665 sq. yd. per working day. They completed their first soil-cement on May 11 and had completed their 66,000 sq. yd. contract on June 2 in 18 processing days.

The lowest day's production by the three companies working simultaneously was 10,610 sq. yd. and maximum daily production was 16,221 sq. yd. The three companies were working on the same day on 13 days and obtained an average production of 14,100 sq. yd. each day. This is equivalent to 1.2 miles of 20-ft. roadway.

TURNER FIELD, ALBANY, GEORGIA

The Hardaway Contracting Company, Columbus, Georgia was awarded a contract by the USED for 384,565 sq. yd. of runways and taxiways at the U. S. Flying School No. 6, Turner Field, Albany, Georgia in May, 1941. Pressure for completion of this job was as great, if not greater, as for any project in the country. Actual construction got under way June 2 with the completion of 3,472 sq. yd. The contractor added to his equipment and crew as fast as possible and was soon making unheard of daily runs. His final equipment setup was as follows:

3—No. 12 motor patrols
3—Heavy duty disc harrows, 20–24-in. discs
3—Heavy duty field cultivators
1—Disc plow, 8–22-in. discs
1—Disc plow, 5–20-in. discs
1—Rotary speed mixer
1—4-bottom gang plow
1—3-bottom gang plow
7—1,000-gal. pressure water distributors
3—50-H.P. track type tractors
2—40-H.P. track type tractors
1—30-H.P. rubber tired tractor
1—20-H.P. rubber tired tractor
5—Double drum sheeps foot rollers
1—Spike tooth harrow
1—Nail drag
1—Broom drag
3—Pneumatic tire rollers

This equipment is equivalent to about two normal construction units.

The project was completed July 17. Detailed records are available for the 38 days elapsed time between June 2 and July 9 when 282,367 sq. yd. were completed in 31 processing days at an average rate of 9,108 sq. yd. per day. The maximum day's production of 17,938 sq. yd. was obtained on June 19. This is an average day's production equivalent to 0.78 miles of 20-ft. roadway and a maximum day's production equivalent to 1.53 miles of 20-ft. roadway. It is of interest to make a comparison of the 17,938 sq. yd. maximum day with the 16,221 sq. yd. maximum day by three contractors on the Macon, Ga., job, previously cited.

The field was placed under constant and very heavy service immediately and the bituminous mat was not placed until about 9 months later. There was some dusting of the surface but not enough to constitute an operational hazard. A section about a foot wide ravelled out progressively along one longitudinal construction joint on one day's section but did not produce an operational hazard. The performance of the unsurfaced soil-cement through a few emergency winter months was in conformance with expectations as was the need of the previously planned bituminous mat placed in 1942.

The foregoing detailed construction information includes the 1941 projects of major interest for which PCA records are available. There are other projects on which equally high daily construction records were achieved.

SOME 1942 RECORDS

The major construction developments on soil-cement in 1942 were still higher daily production records, construction of two exceptionally large jobs, one totaling 750,661 sq. yd. and the other totaling 1,685,665 sq. yd., and the development of a "train processing" procedure on a large landing mat built for the U. S. Navy.

BIGGS FIELD, EL PASO, TEXAS

In the spring of 1942 the USED made arrangements with Arizona Constructors to build runways, taxiways and aprons of 6-in. soil-cement which when completed totaled more than 750,661 sq. yd. Construction was started on May 24 and the construction equipment consisted of the following:

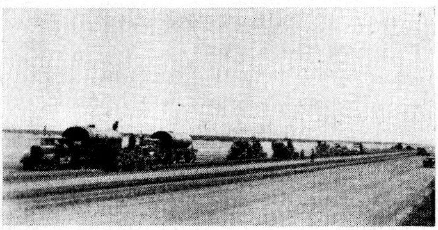


Figure 14. Construction train is led by battery of traveling mixers. El Paso, Texas, Airbase.

3—Traveling mixing machines
1—Cement spreader
2—600-bag bulk cement supply trucks
2—500-gal. water distributors
3—1,000-gal. water distributors
2—1,000-gal. pressure water distributors
1—Motor patrol, furrow plow attached
3—Motor patrols
1—Rotary speed mixer
1—Heavy duty field cultivator
8—Track type tractors, H. P. details not available
4—Double drum sheeps foot rollers
1—Broom drag
1—8-ton tandem smooth roller
4—Pneumatic tire rollers

The entire yardage was completed with this equipment in an over-all period of 49 days with processing taking place on 42 days which gave an average of 17,850 sq. yd. per day. From June 20 to July 3 on 13 days construction, a total of 312,757 sq. yd. were completed which is an average of 24,000 sq. yd. per day. Figures 14 and 15 illustrate construction.

The highest production was achieved on July 3 with the completion of 35,011 sq. yd. On this day's work the cement spread was started at 1:15 AM but the mixing equipment did not start until 5:30 AM and stopped work at 6:30 PM with $1\frac{3}{4}$ hour shut down for minor repairs. The final rolling and finishing was completed on all the work at 8:00 PM.

One of the most interesting features on this project was the use of a cement spreading machine and bulk cement which was loaded from box cars into cargo trucks with an elevating loader.

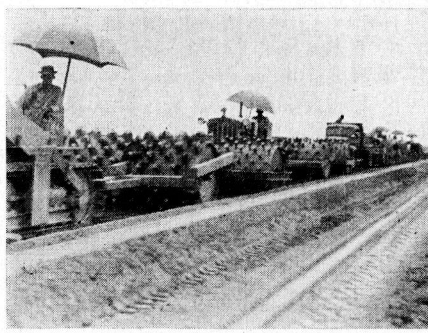


Figure 15. Last of construction train consisted of battery of sheeps foot rollers. El Paso, Texas, Airbase.

Although this job was designed for 15,000-lb. wheel loads it was no more than completed when it was called upon to carry B-17 bombers and equivalent loadings. In recent months there have been numerous landings of B-29 bombers. This excellent load carrying capacity record shows the high shear values of soil-cement and the great influence of subgrade support on load carrying capacity. The subgrade at this location is very granular, has excellent drainage and is said to be almost ideal. Further, rain fall is negligible.

355 ACRE LANDING MAT

As the USED job was nearing completion at El Paso, Texas, the Navy began the construction of a huge landing mat 4-in. thick at Pasco, Washington for use of light trainer planes. The subgrade consisted of sandy soil of very high load carrying capacity and the annual rainfall at this location averages about 7-in. The work was sublet by the prime contractor, The Austin Company, to the Callowell Construction Company. Construction was started July 19, 1942 and completed in 55 working days which accounted for 1,685,665 sq. yd. of 4-in. soil-cement.

Construction equipment and setup was quite similar to the El Paso job and involved the use of traveling mixers and cement loaders and spreaders.

The following equipment was used:

3—Traveling mixing machines
2—Cement spreaders
3—600-bag bulk cement supply trucks
3—2,000-gal. water distributors
1—700-gal. water distributor
6—Motor patrols
1—Heavy duty field cultivator
2—60-H.P. track type tractors
2—20-H.P. rubber tired tractors
1—Spike tooth harrow
3—Pneumatic tire rollers

Average production with this equipment was 30,648 sq. yd. per day. In the first 31 processing days from July 7 to August 13 a total of 1,165,851 sq. yd. were completed which gave an average 8-hour day production of 36,350 sq. yd. or an average hourly production of 4,518.7 sq. yd. The greatest day's production slightly exceeded 66,000 sq. yd. which was obtained in a working day of 10 hours and 45 minutes. This is equivalent to 6,140 sq. yd. per hour. The day's operations would be equivalent to 5.6 miles of 20-ft. roadway. *However, it should be borne in mind that only a 4-in. thickness was built and that therefore the volume of material handled is only ⅔ of that involved in all the records previously cited.*

TRAIN PROCESSING

As the size of soil-cement projects increased contractors systematized operations more and more to simplify construction procedures, increase efficiency and increase production. More and more frequently, construction was organized on jobs to permit various pieces of equipment to follow each other in definite sequence and to perform definite prescribed operations. From this procedure, a terminology was evolved of "train processing" to designate such systematized routine procedures.

An excellent example of "train processing" was evolved on a very large landing mat built by the Navy at Ottumwa, Iowa. It was started in the fall of 1942 under very adverse weather conditions and winter weather closed the job down after 403,837 sq. yd. had been built. This part of the landing mat was used during the winter months and the remainder 439,986 sq. yd., was completed in the spring of 1943 to give a total of 843,823 sq. yd. or 174 acres in this one land mat.

Forms were set to permit processing lanes in 25-ft. widths but all mixing operations were completed by the train processing methods on each 12½-ft. width before progressing to the next 12½-ft. width. The following equipment was used on the project:

2—Motor patrols
2—Heavy duty field cultivators
3—Rotary speed mixers
3—3-bottom gang plows, 16-in.
4—1,000-gal. pressure water distributors
7—35-H.P. track type tractors
2—50-H.P. track type tractors
1—25-H.P. rubber tired tractor
1—Triple drum sheeps foot roller
2—Double drum sheeps foot rollers
1—Air transport tire pneumatic roller
1—Spike tooth harrow
1—Tractor weeder, (used instead of nail drag and broom drag)

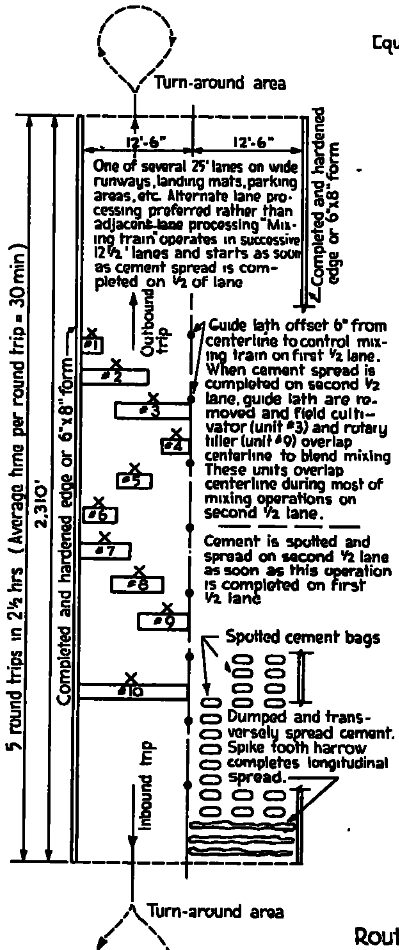
The work was organized to process, on the average, three lanes 25 ft. wide and 2,280 ft. long which equalled about 19,000 sq. yd. per day. On an occasional day, a fourth lane was processed to give a maximum daily production of 25,668 sq. yd. The details of this method of processing are given in Figure 16. The 403,837 sq. yd. was completed in 35 working days which gave an average daily production of 12,297 sq. yd.

The contractors were Sollitt-Lancaster-White, Chicago and the engineer was the Russell B. Moore Company, Indianapolis.

As the Ottumwa project was being built, the Navy was also building another very large landing mat at Peru, Indiana. Train processing was used on this job likewise (Fig. 17). A total of 594,253 sq. yd. equivalent to 50.6 miles of 20-ft. roadway was completed in 62 working days or an elapsed time of 93 days. Maximum day's run was 17,010 sq. yd. J. L. Simmons Co., Inc. and United Construction Co. were contractors.

All the foregoing production records given in connection with detail equipment list show the extensive yardage of 6-in. soil-cement that can be completed each day by experienced builders. These examples are

SOIL-CEMENT "TRAIN" PROCESSING



Mixing Train

Equipment Unit

#1 Single bottom 16" plow with depth gage to ride and clean form or completed edge. Wing extension* on mold board throws soil-cement 2' to 3' from form line. Works independent of "train". Each edge at form line is turned back at least 6 times during dry and damp mix. See Fig. 49, page 81, "SOIL-CEMENT ROADS-CONSTRUCTION HANDBOOK", third edition, for illustration of this type equipment. Motive power-23 HP rubber tired tractor.

#2 8' heavy duty spring tooth cultivator. Motive power-35 HP track type tractor.

#3 9' heavy duty spring tooth cultivator. Motive power-35 HP track type tractor.

#4 3-bottom, 14" mold board plow — 3'-6" turnover. Motive power-23 HP rubber tired tractor.

#5 3-bottom, 16" mold board plow — 4' turnover. Motive power-35 HP track type tractor.

#6 3-bottom, 16" mold board plow — 4' turnover. Motive power — 35 HP track type tractor

#7 6' heavy duty, self-powered rotary tiller. Motive power — 35 HP track type tractor.

#8 6' heavy duty, self-powered rotary tiller. Motive power — 35 HP track type tractor

#9 6' heavy duty, self-powered rotary tiller. Motive power - 35 HP track type tractor.

#10 1,000 gal pressure water distributor, 12½ ft. spray bar. (Four on project)

* Unless wing extension is placed on plow, it is necessary to follow plow with motor patrol to move soil-cement mixture back from forms.

Routine of Mixing Train

Section pre-wet before cement spread to point where three to five water applications will fulfill water requirements during mixing.

First round trip — Plows and water pressure distributor omitted.

Second round trip — Entire train. Add about ⅓ water needs.

Third round trip — Entire train. Add about ⅓ water needs.

Fourth round trip — Entire train. Add remaining water needs on outbound trip. This enables thorough incorporation of moisture on inbound trip. IF TOTAL WATER NEEDS CANNOT BE ADDED IN THREE TRIPS, CONTINUE ENTIRE TRAIN UNTIL ALL WATER IS ADDED, OR ADD ADDITIONAL WATER BETWEEN TRAIN TRIPS.

Fifth (last) round trip — Water distributor omitted.

Mixing train moves to next half lane. Sheeps foot roller compaction train and finishing operations follow.

Fig. 16. Soil-Cement "Train" Processing

typical of many that were taking place daily during the construction seasons of 1941 and 1942 particularly. The great difference in daily production on the first jobs listed, which seem quite satisfactory, and that achieved in the later years is most notable.

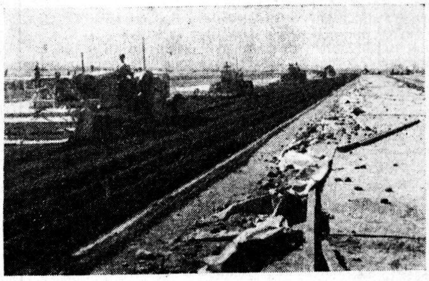


Figure 17. Mixing train on Navy project at Peru, Ind.

Figure 18. General view of mud and grade conditions. Presque Isle, Me., project.

Figure 19. Preparing lane for processing. Completed work on right. Presque Isle, Me., project.

SOME ADDITIONAL BAD WEATHER EXPERIENCES

The full impact of war construction needs were beginning to be felt as the fall of 1941 progressed. Construction was started on some airports in the northeastern part of the United States that we now know were links in a chain on the "Northeast Passage" to England. The reason great pressure was brought to bear to complete these projects under any and all circumstances is shown by by the traffic now carried over this chain of airports by the Army Transport Command. The A.T.C. is now flying 60,000,000 plane

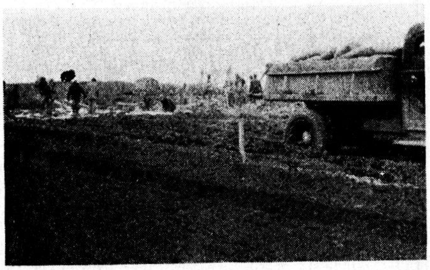


Figure 20. Dumping and spreading cement in mud. Note aeration, and pulverization and mixing in near lane produced by rotary speed mixers. Presque Isle, Me., project.

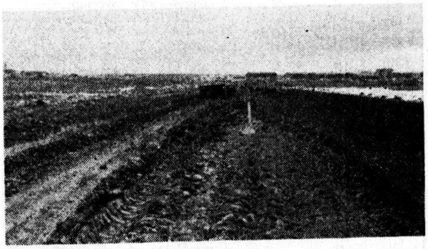


Figure 21. Rotary speed mixers processing right hand lane. Note mud on left. Presque Isle, Me., project.

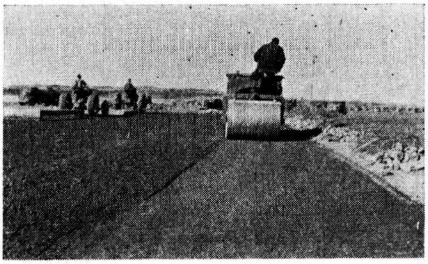


Figure 22. Finishing operations on Houlton, Me., project. Built at same time as Presque Isle and located 35 miles from it.

miles a month over this "Northeast Passage" to England and carrying 100,000 passengers and 100,000,000 lb. of high priority freight including 15,000 pints of whole blood.

Soil-cement was selected for parking aprons at two Army projects in Maine, one at Houlton and one 35 miles north at Presque Isle.

All factors were quite similar at the two airports except that grading progressed with soil-cement construction at Presque Isle, while it was completed ahead of time on the Houlton work. The Houlton job totaling 219,832 sq. yd. was completed just as winter weather made additional work impossible. A total of 213,360 sq. yd. was completed at Presque Isle which constituted the emergency aprons but did not include all the work contemplated.

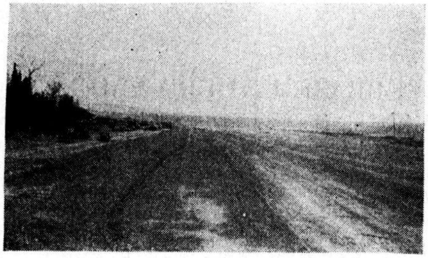


Figure 23. Completed apron, Houlton, Me., project

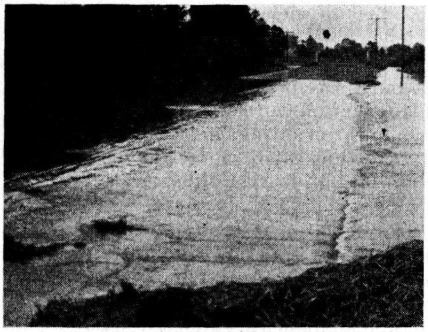


Figure 24. Daviess Co., Ky., project under water 6 days after construction

Unusually heavy, continued rains presented almost impossible subgrade conditions at Presque Isle. Grading operations were carried forward under these conditions that produced a subgrade of high moisture content and low density. Conditions were so bad that emergency roads leading to the construction required as much as 3 ft. of crushed stone to keep trucks moving into the job with cement. The neighboring country roads were impassable. At times cement was spread with free water present on the subgrade and at other times with snow present. Figures 18 to 21 inclusive illustrate some of these conditions. Under such conditions inferior soil-cement was built but it did have sufficient quality to take the emergency plane traffic for the remainder of fall, winter and spring months so the traffic was not interrupted. It was a question of building as good soil-cement as possible or having no parking areas or aprons around the hangars during the winter months.

The influence of subgrade conditions on the soil-cement is shown by comparing it with the work that was completed at Houlton, 35 miles away, under the same weather conditions but with a well drained and previously consolidated subgrade upon which to work. The results on the Houlton job were more in accordance with standard soil-cement construction and results. See Figures 22 and 23.

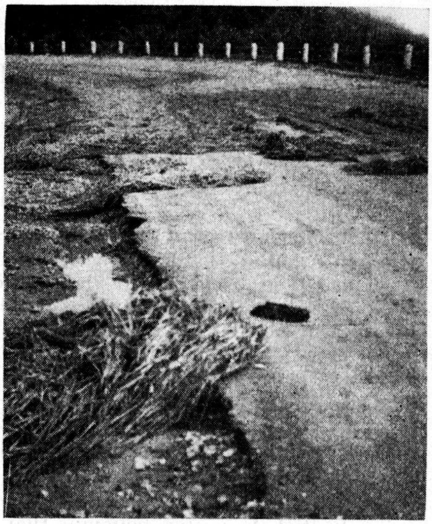


Figure 25. Daviess Co., Ky., project after flood receded. Note shoulder wash

An example of the resistance of newly completed soil-cement to flood conditions is illustrated by a project built in Daviess County, Kentucky by the Kentucky State Highway Department in 1941. The job was no more than completed when it was covered with several inches of flood waters four different times in eleven days as shown in Figures 24 and 25.

WINTER WORK IN THE SOUTH

One other winter job illustrates the judicious use of soil-cement in overcoming bad weather and subgrade conditions. At the Laurel, Miss. Airbase it was found necessary to use soil-cement or shut down construction on roads and storage areas. Through showers, low temperatures and excessive wet materials 60,000 sq. yd. of soil-cement were processed in 15 days elapsed time. However, all work was stopped on three days due to rain. The contractors were Taylor and Wheeless, Hattiesburg, Mississippi.

These highlights of construction accomplishments and the overcoming of apparently impossible construction conditions by engineers and contractors on Army and Navy work, illustrate in the paving field the same spirit shown by everyone in getting all parts of the war machinery into gear.

EMULSIFIED ASPHALT TREATED SUBBASE UNDER CEMENT CONCRETE PAVEMENT

By C. L. McKesson, *Director Engineering and Research, American Bitumuls Company*

SYNOPSIS

The phenomena of the warping of concrete pavements, particularly adjacent to joints and cracks, has long been recognized and has been the subject of many papers and discussions in the Proceedings of the Highway Research Board and other technical publications. The destructive effect of such warping is also well known.

Among the probable causes of distortion of slabs, there was enumerated in the 1938 report of the H. R. B. Committee on Warping of Concrete Pavement slabs, as external forces, nonuniform soil swell and frost action caused by water entering subgrade through cracks and joints and nonuniform shrinkage of soil caused by moisture loss. As internal forces, there was enumerated vertical moisture and temperature differentials and unequal deposition of crystalline matter in top and bottom of the slab.

In 1934 the writer, believing that high moisture content in the bottom of the slab due to contact with saturated subgrade and lower moisture content in the surface of the slab where exposed to evaporation was a substantial factor in producing warping, began tests to determine differences in warping of slabs on a granular subbase containing a low clay content and an identical subbase rendered water-resistant by the admixture of 3 per cent of emulsified asphalt. When water was made available to these subbases, the untreated base became quickly saturated and warping resulted. On the treated subbase the absorption of moisture was insufficient to cause measurable warping. The concrete beams were allowed to remain in place for 10 yr. and in 1944 it was found that the 5-ft. long slab on the untreated subgrade had a permanent warp upward at the ends of between 0.20 and 0.25 in. The slab on the treated subbase showed no measurable warp.

In 1938 the cities of Oakland and Los Angeles, California, constructed projects of substantial size on which the subgrade was made water-resistant by the incorporation of a small quantity of emulsified asphalt (usually 3 per cent) admixed to a depth of 4 in. All of these projects at the present time, after about six years of service, are remarkable in their freedom from cracks, lack of warping at joints and in no case is there evidence of vertical movement at joints. These projects are more fully described in this report.

It appears that the reasons for the successful performance on these projects may be: (a) Uniformity of moisture content in top and bottom of slab on a treated base due to the reduced rate at which moisture passes upward from the subgrade