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No. M-1

A NEW METHOD OF IMPERMEABILIZING AND IMPROVING THE PHYSICAL PROPERTIES
OF PERVIOUS SUBSOILS BY INJECTING BITUMINOUS EMULSIONS

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Summary. By the injection of specially prepared emulsions of asphaltic bitumen fine waterbearing sandy soils can be made permanently impermeable.

The injection may be achieved in a rather simple way through tubes by low or moderate pressures. The critical gradient of the sand is increased considerably by the treatment, but the angle of internal friction is not affected.

Two examples of practical applications are given.

Apart from the impermeabilization a consolidation of loose soils can be obtained by the use of bituminous emulsion when the soils are above water level.

Under water level mixtures of bituminous emulsion and cement are preferred for this purpose. Such mixes are also eminently suitable for the sealing of cracks in waterbearing rocky soils, even when the velocity of the water is rather high.

A new method for impermeabilizing has lately been developed. By this process a very fine bitumen emulsion is pumped under moderate pressure into the permeable soil, the emulsion being so prepared that it conglomerates and breaks when a sufficient quantity has been injected.

Description of the Process. By an emulsion of asphaltic bitumen is meant asphaltic bitumen divided in extremely fine particles in an aqueous fluid. Since the globular particles of bitumen are 1 to 2 microns: $\left(\frac{1}{25000} - \frac{1}{12500}\right)$ of an inch) in size, 1 cub. mm of emulsion contains many millions of such

particles. In the dilution in which such an asphalt emulsion is used for this impermeabilization process, it is practically as thin as water.

As the specific gravity of the asphaltic bitumen differs little from that of water, the asphalt emulsion can be made to flow, without sedimentation, through permeable soil containing fine pores, in the same way as water percolates and according to the same laws of hydraulics as the flow of water. Under the same conditions, the emulsion moves, only a little slower than water, through the soil. For this reason the asphalt emulsion can be pumped through injection tubes into the soil under treatment under comparatively low pressure. The groundwater in the pores of the soil is then replaced by the emulsion without mixing of the emulsion with the groundwater.

In this state the asphaltic bitumen does not as yet have any particular effect upon the soil. For that it is necessary that the globules of bitumen should agglomerate to complexes which clog the pores of the sand. This is achieved by adding substances to the asphalt emulsion solution specially selected to ensure that the bitumen globules shall conglomerate at the expiration of a previously determined period (which may vary from a few minutes to several days). The phenomenon is designated as "flocculation" for the formation of conglomerates, while the transformation of these conglomerates to small solid lumps of asphalt is called "coagulation". The substances added to the emulsion to produce the desired effect are called "Coagulants".

The chief purpose of the procedure, as was explained above, is to render the soil watertight. Its characteristic properties may be summarized as follows:

a. As a result of the fact that the coagulated particles of asphaltic bitumen wholly or for the most part clog the pores of the soil, the permeability decreases to a very small percentage of what it was before the treatment. The movement of the water in highly water-bearing strata can thereby be greatly and permanently diminished and in many instances even completely prevented. This depends on the quantity of bitumen injected per volume unit of the ground.

b. As one has control not only of the concentration of the asphalt emulsion to be injected, but also the time of flocculation and the quantity to be introduced into the soil, the process is very flexible and easily adapted to the particular exigencies of the job.

c. The asphaltic bitumen which has been deposited in the pores makes free movement between the grains of soil themselves practically impossible. Thus a treated mass of sand will be less liable to erosion and to being loosened by groundwater movement. Nor, after a bituminous emulsion treatment, will the fine particles of soil be washed out of the coarser part by flowing groundwater, as the critical gradient of treated sand has a value of above $i = 15$, whereas the untreated sand has a critical gradient of about $i = 1$.

d. As the asphalt is plastic, the emulsion treatment, unlike other tightening processes, does not make the soil stony. Experiments have shown that the elastic properties and the angle of internal friction are not effected by the treatment.

Practical applications. 1. Sealing the bottom of a leaking building pit. (J. van Hulst. Dichting van den Bodem van een kwellenden Bouwput door injectie met asphaltemulsie volgens het Shellperm procede. De Ingenieur (50), 1935, bladz. B 66, enz.). The $4\frac{1}{2}$ metres deep building pit at Gouda, (the Netherlands) sketched in Fig. 1 & 2, was suddenly filled up through the welling up of the groundwater, as the thin clay layer was disturbed by the driving of piles.

The stratum of sand at the level of the foot of the sheet piling was made watertight by the bitumen emulsion process over the entire area of the pit. The screen analysis of the sand is given in Table I.

Fig. 1.

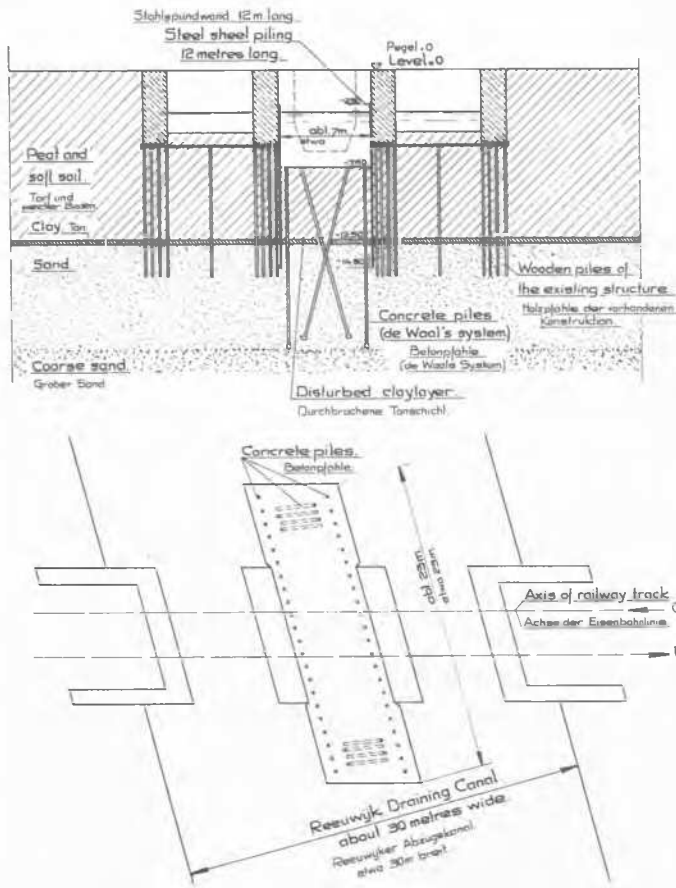


Fig. 2.

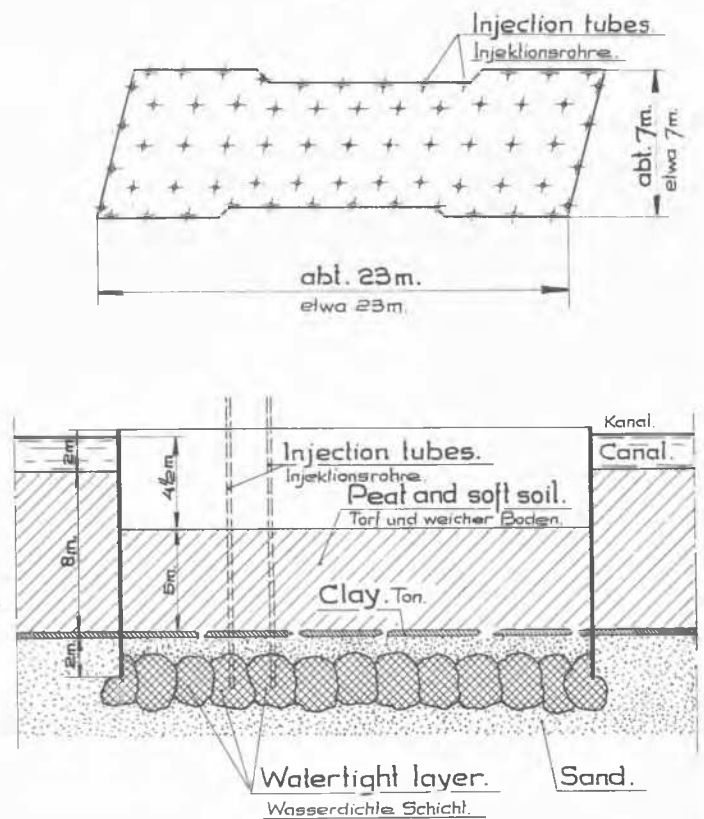


TABLE I

Passes ASTM. screen	Retained on ASTM. screen	Dim. of mesh	% by wt.
	No. 10	> 2000 μ	1.5
No. 10	" 20	2000 - 840 μ	3.8
" 20	" 30	840 - 590 "	3.8
" 30	" 40	590 - 420 "	7.5
" 40	" 50	420 - 297 "	13.1
" 50	" 80	297 - 177 "	43.1
" 80	" 100	177 - 149 "	9.1
" 100	" 200	149 - 74 "	17.1
" 200		< 74 "	1.0

When injection was completed, the pit was easily pumped empty and kept empty, as only a little water got into it from seepage through the sheet piling.

For this job about 60 injection tubes were needed.

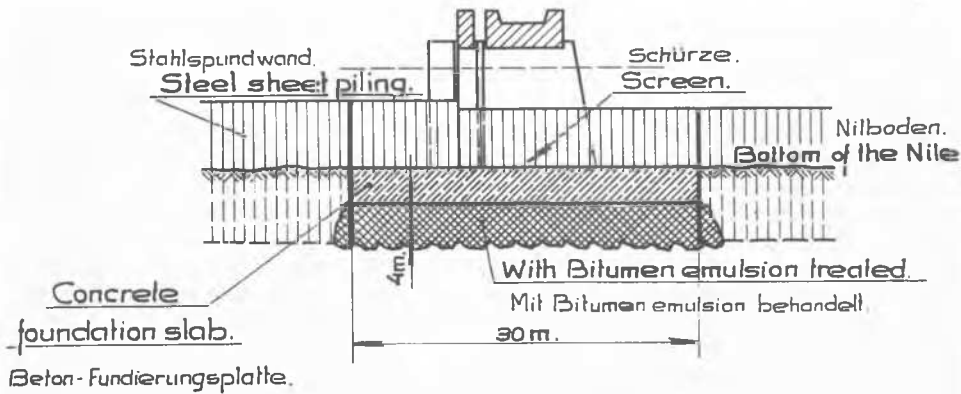
2. Application at the Assiut barrage on the Nile (Upper-Egypt). In view of irrigation operations now being carried out in the Sudan, it was decided to strengthen the barrage in the Nile at Assiut and to enlarge its foundation.

A coffer dam was to be made by driving sheet piling into the river bed on both sides of the barrage.

Where the sheet piling that reached 4 m below the foundation slab converged on the dam, it naturally could not be driven in, owing to the presence of the concrete slab which forms the foundation of the barrage, and the piling was therefore driven in up to the edge of this slab, and continued over the top of it till the upstream and downstream piling met at the barrage itself.

Owing to the permeable natures of the subsoil, water would have seeped into the building pit under the foundation, and it was therefore necessary to render the subsoil impermeable at this point to the same depth as the sheet piling.

Fig. 3.



The subsoil consisted of sand of which the composition is given in Table II.

T A B L E II

Passes ASTM. Screen	Retained on ASTM. Screen	Dim. of mesh	% by wt.
No. 10	No. 10	> 2000 μ	1.6
" 20	" 20	2000 - 840 μ	6.8
" 30	" 30	840 - 590 "	19.6
" 40	" 40	590 - 420 "	20.8
" 50	" 50	420 - 297 "	20.9
" 80	" 80	297 - 177 "	17.0
" 100	" 100	177 - 149 "	8.0
" 200	" 200	149 - 74 "	12.2
		< 74 "	3.1



Fig. 4

Drilling injection pipes for the bitumen emulsion treatment through concrete foundation at Nile barrage, Assiut, Upper-Egypt.



Fig. 5

The injection of bitumen emulsion under the concrete foundation of the Nile barrage at Assiut, Upper-Egypt.

Holes were drilled through the concrete foundation and bitumen emulsion was injected at a low pressure to form an impermeable screen 30 metres long, 5 metres wide and 4 metres deep underneath the foundation. See Fig. 3, while Fig. 4 shows the apparatus used.

All impermeabilization work for the four barriers was carried out in 1935.

No difficulties were experienced, in spite of the hot weather, in pumping the emulsion considerable distances through pipes from bulk storage on the river bank to the injection tubes at the barrage. Fig. 5.

The results of the impermeabilization work with asphaltic bitumen emulsion at Assiut appear to be very satisfactory, practically complete impermeability having been achieved.

From the foregoing it can be seen that the scope of this bitumen emulsion process has primarily been the treatment of permeable but otherwise comparatively fine soils, which are difficult of access.

In some cases, and especially when the soil is above water level, the process may be used to improve the cohesiveness of the soil, while at the same time the permeability to water and air is reduced.

In soils below the ground-water level a consolidation may be attained by using a mixture of bitumen emulsion and cement slurry. The process of injecting bitumen emulsion and cement simultaneously but separately had already been known for some time. Recent developments have now made it possible to prepare the emulsions in such a way that they can be mixed with cement slurry before pumping and injecting.

By this procedure a solidification of the soil can be obtained which results in rendering it resistant to a pressure of approximately 150 lb. per sq in.

This treatment can only be effected in rather porous soils containing only very few grains finer than $1/30$ of an inch.

The solidification and impermeabilization of such soils has up to recently always been effected by means of cement slurry injections.

Mixtures of bituminous emulsion with cement slurry, however, have the great advantage over the use of cement slurry alone that they produce a uniformly treated, completely impermeable soil. The injected material solidifies to a mass which is homogeneous throughout and is not attacked by aggressive water, while it does not shrink when setting.

Such mixes are therefore also suitable for sealing cracks in rocky, water-bearing soils. When the velocity of the water in the cracks in the rocks is rather important, the bituminous emulsion-cement mixes can be brought to set instantaneously by injecting at the same time small quantities of a rather concentrated solution of certain chemicals. With this process too, the setting time can be regulated by the kind and the amount of chemicals used.

By changing the ratio of the different compounds and by the addition of certain chemicals, the nature of the resulting material may vary from a somewhat plastic to a firm and strong mass.

The strength of this mass may be increased to such an extent that it can withstand shearing stresses up to 50 lb per sq in.

The invention of using bitumen emulsions for the impermeabilization and the solidification of sub-soils was made in the Amsterdam Laboratory of the N. V. De Bataafsche Petroleum Maatschappij of the Royal Dutch Shell Group.

For convenience, it is usually called the Shell Impermeabilization Process, or, more briefly, the Shellperm Process.

Patents have been granted or applied for in most of the countries of the world. By way of references the following printed patent specifications may be cited: Great Britain No. 409,760 and 410,479, Germany No. 612,494, France No. 743,782, 797,139 and 798,966, the Netherlands No. 33,038.

No. M-2

EARTH EMBANKMENTS FOR THE PICKWICK LANDING DAM

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Since its inception in 1933, the Tennessee Valley Authority has authorized the construction of five major dams, varying in cost from \$26,000,000 to \$36,000,000 each. Of these five dams, the Norris and Wheeler dams are practically completed. The Pickwick Landing Dam, to which this paper relates, has been under construction for about a year and will require two and one-half years more to complete. Work on the last two, the Gunterville and Chicamauga dams, was started early this year.

Of these five, the Pickwick Landing Dam requires the largest amount of earthwork, totaling about 3,300,000 cubic yards. The site of the dam is located on the Tennessee River, 53 miles below Muscle Shoals, in the southwestern part of the State of Tennessee. At this point the river channel is approximately 1200 feet wide. The flood plain on the south side of the river is approximately 4500 feet wide and on the north side 1500 feet wide. A practically level ledge floor extends through under the valley. This floor is about 12 feet below the bed of the river and from 40 to 50 feet below the surface of the flood plains on either side.

A concrete spillway section with 24 gates, 40 feet wide by 40 feet high, is to be built across the main channel of the river. At the north end of the spillway an area is being excavated for a future power house, forebay, and tailrace, and the material from this excavation is being used for the construction of an earth dam and fill connecting the end of the concrete section of the dam to the bluff on this side of the valley.

On the opposite side of the river, at the south end of the spillway, an area is being excavated into the bank for a lock having a chamber 110 feet wide by 600 feet long. This excavated material, amounting to approximately 1,500,000 cubic yards, is being used for the construction of an earth embank-