becomes an important factor, and I certainly would like to endorse Professor Agg's statement that the major element involved is left rather unsettled Personally, I have little sympathy or little reliance on statistical data concerning maintenance facts starting with the flexibles and moving up to the rigids, in that the quality of construction is changed

REPAIR OF PAVEMENT SETTLEMENTS

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A survey of this problem reveals that until this year three methods of repair of pavement settlements have been in general use These methods are as follows·

1 Filling the settlement with bituminous mixture

2 Raising the pavement with jacks and filling underneath with earth, or with sand forced in by compressed air

3 Breaking up the old slab, filling in the sub-grade and constructing a new slab

Each of these methods has its limitations and weaknesses The first method, which is probably the most used, produces a smooth riding surface but it has one serious defect, namely, that the voids under the pavement are not filled and further settlement is, therefore, not stopped or retarded

The second method is effective but it has the disadvantage that traffic must be detoured, also, it is expensive (Iowa's average cost is $1 75 per square yard of pavement raised) This method is not feasible where the lifts are less than 2 or 3 inches, due to the fact that material cannot be properly forced into such a narrow opening

The third method is entirely feasible if the slab is badly broken and if no further settlement is likely to occur, however, if this type of repair is adopted and further settlement does take place an embarrassing situation results

The engineering profession is familiar with the laws of hydraulic pressure and their various applications to engineering problems, however, it remained for John Poulter, a mechanic of the Iowa State Highway Commission, to apply this hydraulic principle to the raising of pavement slabs For a considerable period of time he experimented with simple homemade devices for producing hydraulic pressure and applying it to slabs When he had convinced himself that slabs could actually be raised by hydraulic pressure he developed a machine to produce the pressure and applied for a patent on the process

Figure 1 shows the first machine used for raising a slab by this method It consists of a tractor valve and valve guide The guide was grouted in a hole which had been drilled through the slab, and mud was poured into the guide and the valve stem inserted. Pressure was produced by the weight of a man standing on the valve.

From this small beginning has been developed the modern Poulter mud pump for raising pavement slabs. This pump is shown in Figure 2. It is a two-cylinder reciprocating pump powered by a 20 horse power gasoline motor. It is made up of the following principal parts:

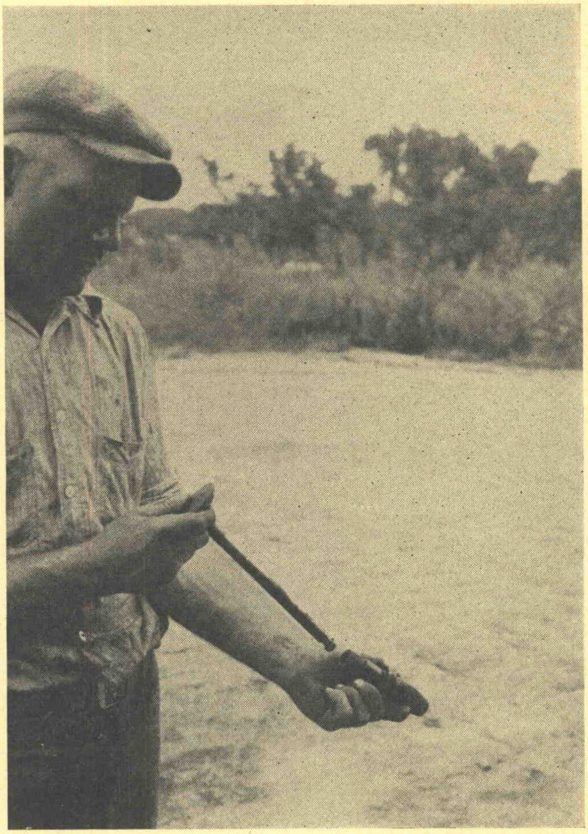

Figure 1. The First Hydraulic Machine for Raising Pavements

A hopper for receiving earth, water and cement.
A mixing chamber for mixing the materials.
A receiving chamber for holding the mud and delivering it to the cylinders.
The pump itself.
An outlet hose.
The power plant.

The actual raising of the slab is a simple process. First, a 4 inch expansion opening is cut across the pavement at one end of the settlement. This is done to prevent a binding action when the slab is raised. Next, $2\frac{1}{2}$ inch holes are drilled through the slab, some near the edge and some near the center joint. The holes are spaced from 4 to 10 feet apart, depending upon the location of the cracks in the slab. This work is done with the ordinary compressed air jack hammer and pavement breaker.

Figure 3 is a drawing showing the settled slab, the slab prepared for raising and the raised slab.

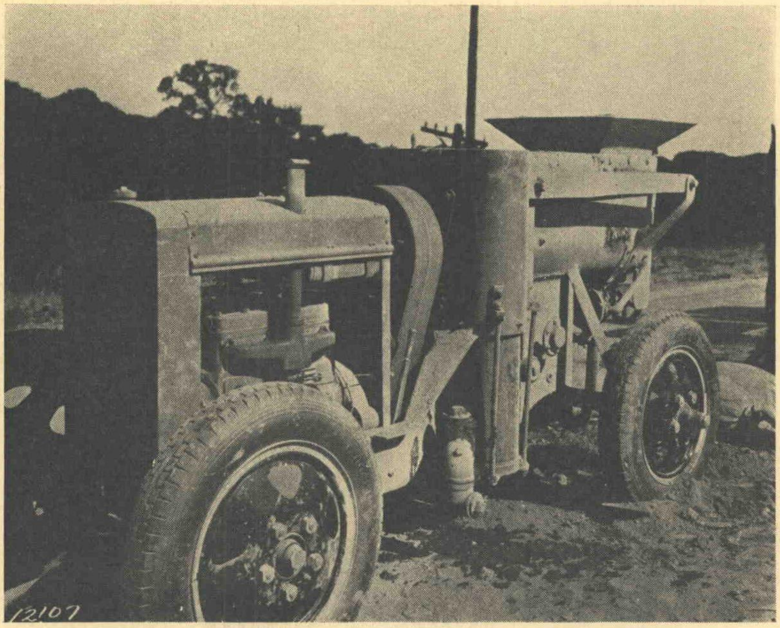

Figure 2. Modern Type Poulter Mud Pump for Raising Pavements

After the slab has been prepared the mud pump is put into operation. Earth is brought to the pump in trucks; black top soil and loess have proven most satisfactory. Sand wears the cylinders too fast, gravelly soil clogs the valves and heavy clays do not readily form the creamy grout necessary.

Portland cement is added to the earth in the ratio of 1 to 20. The primary reason for adding cement is to cause the grout to set up quickly after it is pumped. This "setting up" is not a typical cement set but is an action which produces the same effect as a slight drying out of the mixture. It was early found that under certain conditions the mud pumped in one hole would escape from other holes or from under the edge of the slab and no pressure could be built up It was found that by waiting for an hour or two the mud would stiffen sufficiently so that pumping could be resumed The addition of 1 part cement to 20 parts earth has reduced this waiting time from one or two hours to from fifteen to twenty minutes Laboratory experiments were carried on, using various proportions of lime, cement and Plaster of Paris, and the 1 to 20 ratio, using Portland cement, was established as most satisfactory These experiments also showed that the addition of cement

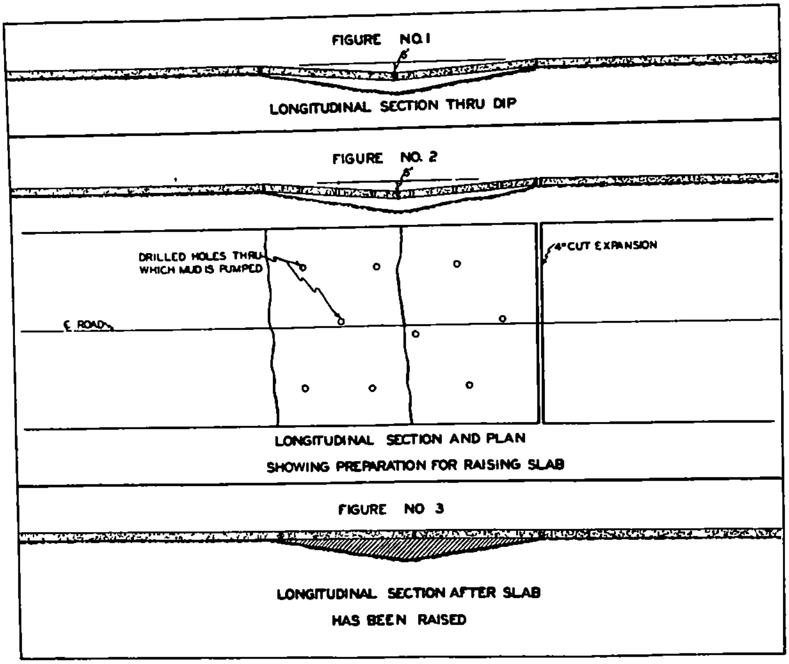

Figure 3 Sections of Pavement Settlement Showing the Original Condition, the Slab Prepared for Raising, and the Condition After the Slab has been Raised

greatly reduced the shrinkage The shrinkage of plain earth and water mixture was found to be 10 per cent, while the shrinkage of the 1 to 20 mixture was found to be only $3\frac{1}{2}$ per cent

The hose leading from the pump is a high pressure $2\frac{1}{2}$ inch fire hose This is reduced at the outlet to a 2 inch steam hose, which has some elasticity This outlet hose is placed in the hole in the pavement and when the pump is started the pressure of the mud passing from the $2\frac{1}{2}$ inch hose to the 2 inch outlet expands the latter and holds it tightly in the hole

The earth and cement are shovelled from the truck directly into the receiving hopper and water is added The materials pass from the receiving hopper to the mixing chamber, which resembles the old style continuous concrete mixer. When the material enters the pump it is a soft grout, the moisture content of which is about 45 per cent.

Figure 4 shows the machine at work. Note that traffic is allowed to go through.

No figures are available as to the exact amount of pressure built up by the pump. The weight of the slab, of course, is only about $\frac{3}{4}$ of a pound per square inch but fairly high pressures are necessary in order to break the slab loose. Once it starts, little pressure is needed to raise it. Some difficulty has been experienced in starting the slabs but none have been encountered that could not be raised. Some of the older

Figure 4. Mud Pump in Operation

outlet hose have blown out. It is estimated that in some cases a pressure of 50 pounds per square inch has been built up.

Iowa has had five mud pumps operating the past season. Some of the slabs which were raised early in the year settled slightly again and the mud pump was brought back and the slabs again raised to grade. The holes in the slab will not be filled permanently until further settlement is improbable.

The fact that a considerable quantity of water is introduced into the sub-grade is not considered to be a serious matter. While the mud as pumped has a moisture content of about 45 per cent and the mud which has been under the pavement for two weeks in the fall of the year still contains about 43 per cent moisture it is not believed that serious harm will result. The earth as delivered to the pump has a moisture content about the same as the average sub-grade on fills, or approximately 25 per cent.

Figure 5. A Pavement Settlement at the Approach to an Overhead Railway Crossing

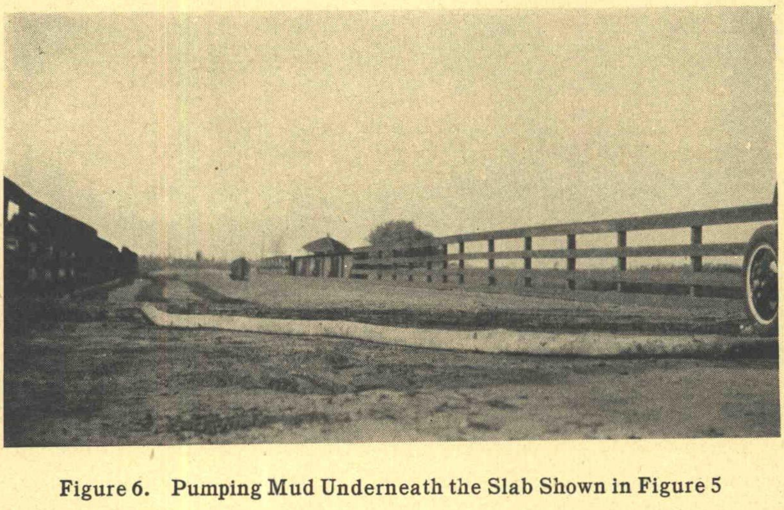

Figure 6. Pumping Mud Underneath the Slab Shown in Figure 5

The figures on the Iowa work are interesting. During the season 200 settlements, comprising 9,292 linear feet, have been raised from 3 inches to a maximum of 13 inches. For this work 1,911 cubic yards of earth and 2,299 sacks of cement have been used. 899 cubic yards of black top would have been required to raise the settlements by that method.

The materials have cost $1,580.16, the labor $8,329.08 and the rentals of equipment $8,987.29, making a total cost of $18,896.53. As 18,584 square yards have been raised the cost has been $1.02 per square yard. Also, as 1,911 cubic yards of earth have been pumped the cost has been $9.88 per cubic yard of material pumped. Of the 1,911 cubic yards of material used, 899 cubic yards were required to raise the slab to grade. The remaining 1,012 cubic yards (53 per cent of the total) went to fill the voids under the pavement.

Figure 7. The Slab Shown in Figure 5 Back in Place

Figures 5, 6 and 7 show three stages in the raising of a slab at a railroad overhead crossing. Note the evenness with which the raised slab meets the bridge floor.

While this method is slightly more expensive than the black top method (Iowa costs are about 75¢ per square yard for raising with black top), it is so much more permanent that it is believed the extra cost is justified.

It is anticipated that this method can be extended to prevent settlements. Pavements on fills which are expected to settle can be sounded occasionally and if the soundings show voids under the pavement these voids can be pumped full of mud before the pavement settles. Such procedure would result in greater safety to the traveling public and in greater economy to the state.