(8) Each mud-jack mix was effective in reducing cracking. Only one new crack occurred in seven slabs treated with mix "A"; none occurred on four mix "D" slabs; and 10 new cracks occurred on sixteen mix "C" slabs.

(9) During the two years following treatment, mud-jacking has been successful in reducing the average settlement of slabs at pumping joints. In this period 48 per cent of the treated slabs had not settled as compared to 26 per cent not settling for untreated slabs. Sixty-eight per cent of the treated joints had settled less than one-eighth inch as compared to 53 per cent of the untreated slabs.

(10) The limited data contained in this report regarding mud-jacking procedures prevent recommendation for operational procedures; however, by way of observation the following are pertinent:

(a) The work should be under the direction of an experienced operator or one competent to judge when a slab has been properly treated, since mistakes will perhaps prove detrimental rather than beneficial.

(b) Each slab should be handled as an individual case rather than by following a standard procedure of operation.

(c) Traffic should be kept off of treated slabs for at least 24 hr. following treatment.

(d) In areas where surface drainage is exceptionally poor, the slab should be given some form of supplemental drainage that should receive periodic maintenance.

PUMPING OF CONCRETE PAVEMENTS IN NEW JERSEY, CORRECTIVE MEASURES AND FUTURE DESIGNS

By William Van Breemen

Pumping and faulting at joints in heavy-duty concrete pavements were first observed in New Jersey in 1930. Load transfer at these joints consisted of six ¾-in. round dowels, 20 in. long. An increase to 12 dowels of the same size in later work retarded the rate of deterioration but soon proved ineffective. The use of crushed stone drains along the pavement edge in conjunction with these 12-dowel joints appears to have been at best temporarily effective in postponing faulting. They may be effective to some extent in minimizing pumping.

Until recently, no effort was made to classify pumping and non-pumping types of soil on the basis of detailed physical and chemical analysis. Subgrade soils, with respect to their tendency to pump, have been judged primarily in terms of permeability and susceptibility to erosion. Generally, where pumping has occurred in New Jersey the subgrade soil and the adjacent shoulders were more or less impervious, and the subgrade soil has been eroded.

In 1932 a test road was constructed on silty-clay soil. One joint with no load transfer device, two with six ¾-in. round dowels, two with twelve ¾-in. round dowels, and several with various combinations and sizes of heavy rectangular dowels were installed in the 10-ft. width of pavement. Repeated applications of heavy loads under extremely wet conditions indicated that the use of large rectangular dowels prevented faulting entirely and materially retarded pumping. Following the test, a joint comprising twelve 2-in. depth channel-dowels, 20-in. long, was designed and adopted in standard construction.

A survey in September, 1944 of 60,000 channel-dowel joints in heavy-duty highways disclosed only three joint failures due to pumping. No faulting was found at these joints; failure occurred by simultaneous sagging of both slab ends. Stone drains along the pavement edge were found partially clogged with subgrade soil pumped out laterally at these joints.

A survey of pavements laid on granular

subbase materials substantiated the opinion that their use would minimize pumping, reduce damage due to frost action, and increase load bearing capacity. All pavements built since 1939 were supported on a layer of bank-run sand, gravel, or cinders at least 8 inches thick. To date, where granular materials have been used in conjunction with channel-dowel joints there have been no indications of pumping, nor any signs of distress due to heavy truck traffic.

The possibility of using pre-compressed wood for expansion joint filler at some time in the future is being considered. In the meantime ordinary wood is being specified. A study of wood indicated that for most varieties a pressure greater than 500 but less than 1000 lb. per sq. in. applied transversely to the grain results in considerable compression. At approximately 50 per cent compression the pressure required to produce further compression increases very rapidly. Most dry woods if compressed to 50 per cent of original thickness recover to not more than 65 per cent when the pressure is removed and remain at that thickness indefinitely if kept dry. Subsequent soaking in water causes the wood to swell to practically its original thickness although repeated compression, drying, and soaking results in a slow progressive loss in swelling range which, however, appears eventually to become stabilized so that even after many cycles of compression over a long time the wood retains considerable swelling range. Continued studies since 1942 indicate that wood as a joint filler has the following merits:

1. Unlike conventional bituminous fillers, wood will not extrude, regardless of the extent of compression. (This applies only to wood with the grain direction installed vertically and restrained from lateral extrusion by dowels passing through it, or by other means.)

2. Unlike previously used fillers, the wood, if sufficiently thick, will probably retain ample swelling range and resiliency to prevent the detrimental accumulation and distribution of infiltrated material in joint spaces which in many instances has caused rupturing of the concrete.

New Jersey's heavy-duty concrete pavements to be constructed during the immediate post-war period are being planned essentially as follows:

Pavement Thickness: 9-in. or 10-in. uniform.

Slab Length: Approximately 60 ft.

Dummy or Contraction Joints: None specified.

Joint Filler: Cypress, $1\frac{1}{8}$-in. thick, fabricated, grain direction vertical, sealing strip at bottom.

Longitudinal Reinforcement: Single or double line of $\frac{3}{8}$-in. dia., bars $7\frac{1}{2}$-in. c. to c.,—or equivalent in welded steel mats.

Longitudinal Joints: Tongue and groove, or tie bars.

Subbase: Sand, sand-gravel, stone-sand, or cinders—minimum thickness 8-in., under all pavements on impervious, erodible, or frost-susceptible soils.

Load Transfer in Expansion Joints: Dowels of rectangular solid bars, or of structural shape, having a bending resistance within the elastic limit of not less than 7500 inch pounds—12-in. c. to c.

Dowels probably will consist of corrosion-resistant material for the following reasons:

Early in 1945 it was definitely determined that the sliding resistance of dowels may materially increase with age due to a progressive accumulation of rust on their sliding surfaces and that if the rusted area is sufficiently large the restraint to pavement contraction will be of a magnitude great enough to cause wide cracks which ultimately fault, and failure of the reinforcing steel. This possibility has been suspected for some years inasmuch as in 1942 it was noted that the seasonal opening and closing of certain experimental joints with large dowels installed in 1932 had become progressively less than during early life. At present the seasonal changes in width are so minute as to say that these joints are practically "fixed." This lead to the opinion that certain obscure changes were taking place tending to cause increasing restraint.

In February, 1945 a section of six-year-old pavement including a channel-dowel joint which had evidently been offering considerable resistance to opening was removed for detailed inspection. The sliding resistance of the dowels was determined with a special puller and it was found that the resistance per dowel had increased from what was very likely less than 1000 lb., to an average of 18,000 lb., during the six year period. Appreciable rusting of the dowel surfaces was noted.

The rust had formed notwithstanding the fact that the dowels had been given two coats of paint—white lead and red lead—and a coat of oil prior to installation, and in spite of being surrounded by very dense concrete.

Apparently the restraint is due to the confinement of the rust which, in forming, exerts a very considerable expansive effort.

In view of the foregoing, a corrosion-resistant dowel material such as one of the cheaper grades of stainless steel is being considered for future work. Because of the higher cost of corrosion-resistant dowels, studies are now in progress to determine the most economical cross-section and length that will meet requirements.

The corrosion of dowels, considering the very serious defects that may result therefrom, is considered to be a phase of joint design the importance of which cannot be over-emphasized. The detrimental effects of rust are evidently not limited to the larger dowel sizes, such as 2-in. channels, because cracks have been progressively widening and faulting during the past three years in a pavement laid 1932 in which joints with twelve ¾-in. round dowels were installed, coated with cut-back tar. No really satisfactory explanation as to the cause was at hand when first noted. Evidently the magnitude of the restraint is a direct function of the extent of the area of dowel surface that is rusted. Although heavy truck traffic probably hastens the widening of cracks and failure of the reinforcing steel, the widening of cracks has also occurred where traffic is extremely light.

A great deal more has still to be learned about the influence and effectiveness of all the elements involved before the ideal balance of materials and parts becomes attainable. The essential features of the post-war design are given, however, because pavements of similar design have been carrying heavy truck traffic in New Jersey for several years with negligible evidence of deterioration that can be attributed in any way to traffic. For the most part, the pavements with channel-dowel joints are in excellent condition and the structural adequacy of the channel-dowel joint from the standpoint of preventing faulting and minimizing pumping appears to be an established fact. But there is evidence that rusted dowels are inducing excessive tension in some of our older pavements and it is recognized that this condition may ultimately become extensive.