NCAT Report No. 89-1

WATER DAMAGE TO ASPHALT OVERLAYS: CASE HISTORIES

by

Prithvi S. Kandhal
Carl W. Lubold, Jr.
Freddy L. Roberts

Presented at the Annual Meeting of the Association of Asphalt Paving Technologists in Nashville, Tennessee, February 20-22, 1989.

-

WATER DAMAGE TO ASPHALT OVERLAYS: CASE HISTORIES

by

Prithvi S. Kandhal
Carl W. Lubold, Jr.
Freddy L. Roberts

National Center for Asphalt Technology

NCAT Report No. 89-1

WATER DAMAGE TO ASPHALT OVERLAYS:CASE HISTORIES

Prithvi S. Kandhal, [1] Carl W. Lubold[2] and Freddy L. Roberts[3]

ABSTRACT

Numerous papers have been published on the phenomenon of stripping especially on the possible causes of stripping, methods for predicting stripping potential of asphalt paving mixtures, and use of additives to minimize or prevent stripping. However, very few papers have evaluated this phenomenon considering the subsurface drainage in the total highway pavement system.

Three case histories of water damage to asphalt overlays over portland cement concrete (PCC) pavements during the last ten years in Pennsylvania have been presented. Field observations have been documented in detail. Pavement layer samples were obtained using a jack hammer (rather than a core drill), thus avoiding the use of water, so that in-situ observations of water damage, actual moisture content determination in each layer, and study of subsurface water and/or water vapor migration in the pavement system could be accomplished. Cores from one project were also analyzed for tensile strength to assess the moisture induced damage.

These case histories indicate that in many cases the stripping of asphalt pavements may not be a general phenomenon occurring on the entire project but rather a localized phenomenon in areas of the project which are oversaturated with water and/or water vapor due to inadequate subsurface drainage conditions. Recommendations have been made to improve the existing subsurface drainage

---

[1]Assistant Director, National Center for Asphalt Technology, Auburn, AL
[2]Executive Director, Pennsylvania Asphalt Pavement Association, Harrisburg, PA

[3]Director, National Center for Asphalt Technology, Auburn, AL

system of the PCC pavements prior to placing the asphalt overlays so that persistent problems of stripping and/or potholing do not occur. Recommendations include the use of Asphalt Treated Permeable Material (ATPM), increased depth of longitudinal underdrains in cut sections, and lateral intercepting drains on grades.

WATER DAMAGE TO ASPHALT OVERLAYS:CASE HISTORIES

INTRODUCTION

In recent years the problems of water damage to asphalt pavements has drawn attention toward the phenomenon called "stripping". This term is applied to asphalt paving mixtures that exhibit separation of asphalt films from aggregate surfaces due primarily to the action of water. Numerous papers have been published on the possible causes of stripping, methods for predicting stripping potential of paving mixtures, and use of additives to minimize or prevent stripping. However, very few papers are available in the literature to identify and evaluate this phenomenon considering the subsurface drainage in the total highway pavement system.

This paper presents three case histories of water damage to asphalt overlays over portland cement concrete (PCC) pavements during the last ten years in Pennsylvania. The most recent case of water damage was observed in the summer of 1986 on Interstate 80. Since similar damage had been observed (and documented) on Pennsylvania Turnpike (both East-West and North-East Sections) in the summer of 1978 it was considered prudent to include those unreported ten year old case histories in this paper as well. Data on existing moisture contents in the wearing, binder and levelling courses which is generally not found in the literature, has also been presented. It should be noted that stripping has not been identified as a major problem in Pennsylvania. It has occurred in very few cases such as, these three case histories where excessive water and/or moisture vapor was apparently present in the pavement system. Unfortunately, the subgrade or subbase underneath the PCC pavements constructed in the past are generally highly impermeable to water. These pavements when overlaid with asphalt overlays present a persistent problem due to entrapped water and/or moisture vapor.

PROBLEM AND OBSERVATIONS

East-West Pennsylvania Turnpike (1977)

The East-West Pennsylvania Turnpike (Mile Post 218 to 226) was overlaid in 1977. The existing pavement consisted of RCC pavement which had received several overlays consisting of 2" limestone binder course (1962), 1" slag wearing course (1962), and 1" gravel wearing course (1973). The 1977 overlay consisted of 1" limestone levelling course, 2" limestone binder course and 1" wearing course, totalling 4 inches. The work also included the installation of new pipe drain and paving of the median as shown in Figure l(a); and paving and surface treating the shoulders as shown in Figure 2(a). Therefore, the total width of asphalt paving (including four lanes, median and shoulders) ranged from 72 to 78 feet.

During the summer of 1978 small potholes started to develop mainly in the inside wheel track of the slow traffic lanes. Both slow lane (SL) and passing lane (PL) had wet spots scattered throughout the project. Usually at these wet spots water oozed out during hot afternoons. Some of the wet spots contained fines suspended in the water which were tracked on the pavement by the traffic. At some wet spots, free water could be squeezed out easily when pressed by shoes. Most of the wet spots containing suspended material developed into potholes.

Figures 3 and 4 show typical potholes in the inside wheel track of the slow lane. The fatty areas (resulting from asphalt stripping and migrating to the surface) seen in the pictures usually preceded the formation of potholes. Small blisters or asphalt bubbles were also observed similar to one shown in Figure 5 (framed by the jaw of an adjustable wrench). A big blister (about 9 inches in diameter) was seen in the eastbound slow lane. When it was burst a thick slurry was observed at the bottom of the wearing course (Figure 6). Chemical analysis of this slurry confirmed that the suspended fines came from the coarse aggregate in the wearing course and apparently resulted from the grinding of stripped aggregate under traffic.

Figures 7 through 10 show the general pattern of the potholes which have been patched over the years. These pictures were taken in June 1988. Figure 10 shows three adjacent patches placed at different times. It should be noted that most of the pothole patching was done during the first two years (1978 and 1979).

It was decided in August 1978 to determine the source of water oozing out from the pavement surface and also observe the condition of all underlying pavement layers. Use of a jack hammer was preferred to cut holes (usually 24" x 18") in the pavement, thus avoiding the use of water. This way the actual moisture (water) content in each layer could be determined. Each pavement layer sample was examined visually for moisture and stripping, and then put in a sealed can for moisture determination in the Pennsylvania Department of Transportation (PennDOT) Asphalt Laboratory.

Figure 11 shows the outline around a pothole before jack hammering, Figure 12 shows the rectangular trench after the new wearing course was removed, and Figure 13 shows the trench after the entire new overlay (wearing, binder and levelling) was removed. Figure 14 clearly shows the wetness in pavement layers especially the new binder course. Figure 15 shows the removed slabs of binder and wearing courses which exhibited severe stripping.

Tables 1 and 2 describe the visual assessment of the moisture and stripping, and include the actual moisture contents of the pavement layers determined in the laboratory.

It was surprising to find significant amount of free moisture in the pavement layers and the damage due to stripping. The new wearing course (1977) was usually damp and had started to strip from the bottom upwards. The new binder course was usually wet to very wet and had stripped badly in less than a year. In some excavated holes, water started to ooze out from the side of this binder course. The new levelling course was dense and appeared moist only with no significant stripping. The old gravel wearing course (1973) was moist to wet, stripped and friable. The old slag wearing course (1962) was moist without any stripping. The old stone binder course was wet and partly stripped. Cement concrete was damp and sometimes deteriorated. In all excavations, three damp layers (new binder course, old gravel wearing course, and old binder course) were very distinct when viewed from the sides.

The moisture contents reported in the tables include the free moisture in the mix and the moisture absorbed by the stripped aggregate. Due to this, the moisture content in the mix containing highly absorptive slag aggregate is high. So, it is not possible to make any comparisons between layers containing different aggregates. However, the moisture contents in general appear very high compared to median moisture contents of 0.34% for surface courses and 0.35% for binder courses indicated in a limited nationwide study of satisfactory pavements (1). The average void content in the new wearing course was 3.0 percent and it contained 1.8 percent moisture by weight of the mix.' This means the voids in this course were over-saturated (253 %) with water. Similarly, the average void content in the new binder course was 3.8 percent and it contained 1.8 percent moisture by weight which amounts to 197% over-saturation. Apparently, some water had been absorbed by the stripped aggregate and also additional voids were created by the loss of asphalt due to stripping caused by pore water pressure under heavy traffic.

Grease ring tests performed in the passing lane indicated that the road surface was practically impermeable to surface water. A 1/8''-1/4" layer of water within a 9-inch diameter grease ring did not soak through the surface for 45 minutes. Actually, the wheel tracks in the slow lanes were on the verge of flushing.

Visual observations (Tables 1 and 2) indicate that the pavement layers were getting water and water vapor from the subbase in the median (Figure la) and from the cracks and joints in the deteriorated concrete. This mechanism will be discussed in detail later.

Asphalt stripping from the aggregates in the pavement layers was attributed to the presence of water and water vapor in the mix. This mechanism will also be discussed later. However, it should be mentioned here that the severe stripping which occurred in the inside (left) wheel track of the slow lane is believed to be due to:

1. Close proximity to the longitudinal center line joint of the PCC pavement where ingress of water from the subgrade is usually high,
2. increased distance from the pavement base drain at the edge compared to the outside (right) wheel track, and
3. more and heavier traffic in the slow (driving) lane compared to the passing lane.

Since different types of aggregates are involved in these layers constructed during different periods, it is hard to believe that all aggregates have stripping tendencies. Moreover, the Perry Rock sandstone aggregate (used in the new wearing course) was evaluated using the immersion-stability test and compared favorably with other aggregates used successfully in the past as shown by the following results:

Aggregate	Stability after 40 min. immersion @ 140F	Stability after 3 days' immersion @ 140 F	% Retained Stability
Perry Rock (Sandstone)	2841	2156	75.9
Adonizio Aggregate (Limestone)	3491	2750	78.7
Summit Station (Siltstone)	2625	2008	76.5

North-East Pennsylvania Turnpike (1977-78)

The North-East extension of Pennsylvania Turnpike (Mile Post A-57 to A-67) consisted of 10" PCC pavement which was overlaid for the first time in 1977 and 1978. The new asphalt overlay consisted of 1" levelling course, 2" binder course and 1" wearing course. This section of turnpike had 4 feet wide raised concrete median divider unlike the East-West Turnpike which had a paved depressed median about 10 feet wide. The work also included providing a 6" U-Drain in the cut sections. The shoulders were paved with a 4" binder course to which a bituminous surface treatment was applied for waterproofing. The typical cut section is shown in Figure 16.

AU pavement lanes (slow and passing lanes) started to exhibit white spots on the surface during the summer of 1978. These white spots were occurring in clusters interspersed with scattered white spots (Figure 17). Apparently these white spots had developed from the oozing water containing some salt. Wet spots with clear water were also common and usually appeared in the afternoon on a hot day. Although no potholes had developed in this section there was a concern that a distress pattern similar to that experienced on the East-West Turnpike would develop. Therefore, similar investigations were also conducted on this section in August/September of 1978.

Tables 3 and 4 give the visual assessment of moisture and stripping, and laboratory determined moisture contents of the pavement layers. From the appearance of the surface marked with clusters of white spots and no potholes, it did not seem likely that the pavement layers were saturated with water. However, when holes were made by jack hammering, all layers (consisting of 1" wearing course, 2" binder course and 1" levelling courses) were found to be wet. The wearing course had started to strip from the bottom upwards, and severe stripping of the binder course was observed. The concrete was wet and deteriorated at places. The pavement layers were found to be wetter near the concrete median (Figure 18) compared to the area near the center line (Figure 19) in cut areas. Evidently, the new U-drain installed at the toe of the cut slope (Figure 16a) was not deep enough to substantially lower the water table in the vicinity of the median.

This section has a 4 ft. wide concrete median and it appears that the stripping has been caused by the presence of subsurface water coming through the joints, cracks and disintegrated portions of the underlying PCC pavement. Although the pavement surface was almost impermeable to surface water, its surface texture was not as dense as that observed on the East-West Turnpike. This probably facilitated the uniform escape of trapped moisture all over the pavement surface and, thus, the presence of scattered white spots.

The binder course and subbase in the shoulder areas were found to be drier in the fill area than in the cut area. Also, the new binder course in the shoulder was stripped in the cut area, and no stripping was observed in the fill area. Typical cross section (Figure 16a) shows that the shoulder subbase is sandwiched between two impermeable layers with no outlet in cut areas. This would keep the subbase saturated at all times and would provide water for stripping of the new binder course.

East-West Turnike Pavements (1971, 1975 and 1976)

After observing stripping in the East-West and North-East pavements overlaid in 1977 and 1978, the question was asked: Why did the pavements overlaid prior to 1977 not exhibit such surface distresses? Did excessive precipitation occur in 1978, which the subsurface drainage could not handle?

Monthly precipitation records from years 1971 to 1978 for the South Central Mountain (East-West Turnpike) and East Central Mountain Divisions (North-East Extension) were obtained from the U.S. Weather Bureau and tabulated in Tables 5 and 6 respectively. The data indicates that the precipitation in 1977 had not been very unusual. Except for the year 1974 (in case of South Central Division only) all years had precipitation more than the normal. The total rainfall for this region during May, June and July of 1978 was about 4 inches more than the normal for this period.

It was decided to examine 3 sections of the older East-West Turnpike pavements which were overlaid in a similar manner during the years 1971, 1975 and 1976. The condition of pavement layers are given in Tables 7, 8 and 9. Although the pavement layers in general did not show any visible moisture, the stripping, particularly in the top wearing and binder courses, was found to be severe. Most of the moisture is probably contained in the absorptive stripped aggregates and thus not visible to the eye. Also, it appeared that the pavement had stripped to such an extent that the moisture in the pavement layers could evaporate easily throughout the surface. It was hard to believe that the badly stripped gravel wearing course was still holding, although some potholes had begun to develop near Mile Post 156.2 (Table 7).

The underlying PCC pavement in these sections was damp to wet and disintegrated at places. The old binder course over PCC pavement was found damp and stripped. The observations indicated that the water in the overlaid layers was coming from the joints, cracks and deteriorated portions of the old PCC pavements. This was very evident at M.P. 156.2 on the West bound slow lane (Table 7) where the maintenance crew had exposed the PCC pavement in large areas for patch repairs. The concrete was wet, badly disintegrated, and water was coming out.

The water and/or water vapor was probably getting into the overlaid layers from the median subbase also as observed in 1977 East-West Turnpike section.

It was also noted that the new binder course in the shoulder stripped in the cut area, whereas, no stripping was observed in the fill area (Table 9), this same observation was noted on the North-East Extension (Table 4). The shoulder subbase in the cut area is sandwiched between two almost impermeable layers with no outlet.

It was concluded from the observations of these older overlay projects on East-West Turnpike that the same problem existed in an advanced stage, although not apparent on the surface. These observations lead one to conclude that completely paving the roadway from one shoulder edge to another without improving the existing subsurface drainage system has been detrimental to the pavement structural system in general. These detrimental effects will be discussed later.

Interstate 80- Monroe County (1985)

Westbound lanes of Interstate 80 in Monroe County (Station 495 to 743) were rehabilitated and resurfaced in October/November 1985. The resurfacing in this 4.7 mile long section consisted of a levelling course, 2“ sandstone binder course and 1-1/2” sandstone wearing course after some distressed concrete slabs of the original 10” reinforced cement concrete (PCC) pavement were removed and replaced. Pavement base drain was also installed at the edge of the pavement toward the 10 foot shoulder.

The development of potholes was observed in the summer of 1986. The project was inspected in August 1986 to investigate the cause of premature distress. It was observed that a series of potholes (about 24) had developed mostly in the left (inside) wheel track of the slow lane as was observed on East-West Turnpike in 1978. A majority of potholes existed between station 530 to 605 (about 1.4 mile). Although it had not rained for two days prior to the day of inspection, free water was observed in some potholes. It was also determined from observations of the District personnel who frequently drive on this road that first water stains would appear on the road surface, then localized flushing of the surface occurred, and finally a pothole developed. These observations indicated that the potholing was probabaly occurring as a result of stripping of asphalt from the aggregate. It is hypothesized that the bituminous mix is saturated with water, the pore pressure from stresses induced by traffic can cause the asphalt-aggregate bond to fail. The stripped asphalt migrates to the surface causing flushing, followed by potholing due to the loss of binder in the underlying mix.

It was decided to test the roadway to investigate and establish the possible cause(s) of premature distress. Twenty (20) 6“ diameter cores were obtained. Ten cores were taken from potholed areas and 10 from areas which did not have any potholes at that time-hereinafter called good areas. Twelve (12) loose mix samples of wearing and binder course were also obtained by using a jack hammer rather than a core drill so that the actual moisture content existing in the pavement layers could be determined. These were obtained at three locations each in potholed and good areas. All cores were taken in the inside (left) wheel track of the slow lane. Cores in the potholed areas were taken about a foot away from an existing pothole.

Average core and mix test data is given in Table 10. Good and potholed areas have comparable void contents (2.7%) in the wearing course. The average void contents in the binder course are considered to be high (7.9% in good areas and 6.5% in potholed areas) especially after one year service. At high void content levels (from 6 or 7% up), the voids are interconnected and get saturated with water readily.

The cores were tested for tensile strength at 77°F @ 2"/min. The tensile strength of the pavement usually decreases from moisture induced damage (stripping). The tensile strength of both wearing and binder courses in potholed and good areas given in Table 10 are quite comparable. This was confirmed by the visual observation of the mix which showed no significant stripping in the potholed area. It should be noted that the cores were taken about one foot away from the potholes. Apparently, excessive stripping had occurred in small localized spots resulting in potholes, whereas the adjacent areas had not been affected significantly.

The potholed areas had about 1/2% higher moisture than did the good areas. The binder mix in the potholed area has an average void content of 6.5% and its moisture content is 1.23% by wt. of mix which means that about 44% of the voids were filled with moisture on the day the pavement was sampled. Similarly, the voids in the wearing course were over-saturated (118%) with water, apparently some water had been absorbed by the aggregate.

The preceding discussion of test data indicates that the potholes were primarily caused by localized water action. It was also observed that most potholed areas were located on steep grades and were in the transition between cut and fill areas. Usually the water table in the cut areas is closer to the pavement structure. This subsurface water in the cut area tends to flow longitudinally down the steep grade towards the fill area rather than transversely towards the pavement edge drains. Unless transverse drains are installed to intercept this water flow, it emerges at the surface in the cut/fill transition as observed on this project. The existing special subgrade under the original 10” PCC pavement does not have the draining capability for the areas subject to excessive subsurface water. Pumping of concrete slabs was observed even in high fill sections of Interstate 80 which had not received the asphalt overlay. Due to reasons mentioned in the discussion of East-West Turnpike this inadequate drainage allowed a supply of water to induce localized severe stripping mostly in the inside wheel track of the slow lane.

DISCUSSION

Stripping Phenomenon

The presence of moisture and/or water in the pavement structural system of these overlaid projects has been established by the extensive visual observations and the laboratory determinations reported earlier. So, the stripping phenomenon will be discussed within that context.

Jimenez (2) has stated that “all stripping failures have been associated with the presence of water. The stresses that cause failure of the asphalt film are assumed to be water pressure and erosion caused by traffic or thermal cycles or both on wet pavements”. Lottman et al. (3) have reported that “it is possible to have a disintegrated pavement layer that is caused by moisture damage without pavement performance criteria being affected significantly. However, the pavement will have to be repaired by using overlays.” This applies to the North-East Turnpike and three older East-West Turnpike sections overlaid in 1971, 1975 and

1976.

Excessive pore pressure buildup has also been reported (4) as the cause of stripping in some mixtures. The pressure buildup is caused by traffic and results in the water being in frequent motion. It is hypothesized that considerable pore pressure may be built up which results in stripping and subsequent failure of the road mixture.

Extensive research has been conducted on the mechanism of asphalt stripping at the University of Idaho (5,6). It has been reported that "air voids in asphalt concrete may become saturated with water even from vapor condensation due to water in the subgrade or subbase. A temperature rise after this saturation can cause expansion of the water trapped in the mixture voids resulting in significant void pressure when the voids are saturated. It was found that void water pressure may develop to 20 psi under differential thermal expansion of the compacted asphalt mixture and could exceed the adhesive strength at the binder-aggregate surface. If asphalt concrete is permeable, water could flow out of the void spaces under the pressure developed by the temperature rise and, in time, relieve the pressure developed. If not, then the tensile stress resulting from the pressure may break adhesion bonds and the water could flow around the aggregates causing stripping. The stripping damage due to void water pressure and external cyclic stress (by traffic) mechanisms is internal in the specimens, the exterior sides of the specimens do not show stripping damage unless opened up for visual examination". Observations on the Pennsylvania turnpike appear to support the action of the above mechanism. Oozing out of water was seen in the hot afternoons.

Hallberg (7) has reported that "the required internal water pressure causing an asphaltic mixture to have adhesive or interracial tension failure (stripping) is inversely proportional to the diameter of the pores. He stated that densely graded aggregates will help to eliminate these failures." Observations on the turnpike indicate that the binder course mixtures have generally stripped more than the wearing course mixtures, possibly due to larger diameter pores in the binder course.

Majidzadeh and Brovald (8) have also stated that the pore pressure from stresses induced by traffic cause the failure of the binder-aggregate bond. Initially, the traffic stresses may further compact the mixture and trap or greatly reduce the internal water drainage. Therefore, the internal water is in frequent motion (cyclic) and considerable pore pressure is built up under the traffic action.

Mack (9) has described the pumping action by which tires cause movement of water in a wet pavement. He stated that these forces are far greater than thermodynamic ones, and gave primary importance to the resulting loosening and perhaps emulsification of the binder.

It was suspected that the deicing salts might have interacted to accelerate stripping on the turnpike. However, Schulze and Geipel (10) have reported no deleterious effects of salt on the asphalt mixtures they tested.

McKesson(11) has made some interesting observations. He observed that "ground water and water entering the roadbed from the shoulders, ditches and other surface sources, is carried upward by capillarity under a pavement. Above the capillary fringe water moves as a vapor and, if unimpeded at the surface, it passes to the atmosphere. This method of reduction of moisture has been termed Drainage by Evaporation, and it is the considered opinion of this writer that Drainage by Evaporation is usually as important as drainage downward by gravitation. If the pavement or seal coat constitutes a vapor seal or a vapor barrier, the moisture during cool nights and in cool weather condenses beneath the surface. When the pavement absorbs solar heat, the water is again vaporized and, if not free to escape, substantial vapor pressure results because water as vapor has more than a thousand times the volume of water in liquid form. Vapor pressure forces the moisture up into the pavement and through the surface. Blistering in bituminous pavements is a well known example of the effect of entrapped moisture and moisture vapor."

Observations on the turnpike seem to confirm McKesson's experience. It appeared that water vapor and/or water was escaping from the pavement surface on North-East Extension rather easily and uniformly due to somewhat open texture, whereas, the wheel tracks in the slow lanes of East-West Turnpike (overlaid in 1977) were too impervious to allow moisture to escape. This resulted into severe stripping of the new wearing course due to entrapped water and/or water vapor, and development of potholes in the wheel track of the slow lanes. As mentioned earlier, one big blister was also observed in the slow lane of East Bound Turnpike. Wet spots were observed in all lanes due to escape of water vapor and/or water both on East-West Turnpike and North-East Extension overlaid in 1977 and 1978. It is hypothesized that the older East-West Turnpike pavement overlays (1971-1976) were either open or had opened up due to progressive stripping sufficiently to allow the moisture in the pavement layers to be continuously lost by evaporation and avoid moisture accumulation.

Subsurface Drainage

It should be mentioned at the outset that before being overlaid, the PCC pavement structural system was probably losing moisture by evaporation from the joints, cracks, disintegrated portions of PCC pavement, uncovered depressed median and possibly treated shoulder areas. After the new overlay design of completely paved 72-78 feet wide roadway (paving a typical pavement cross section including the depressed median from toe of slope to toe of slope in cut areas, and from shoulder edge to shoulder edge in fill areas), all moisture and water in the pavement system had to be removed by the subsurface drainage system. It appears that the existing subsurface drainage was not effective in draining the excessive amounts of water or preventing water vapor build-up in the pavement system.

This problem has been rightly stated by Cedergren and Lovering (12) as follows: "As the highway system requires the construction of multilane highways to greater widths, gentler slopes and milder curves in all kinds of terrain, the physical problems of developing stable roads have multiplied. This is equally true of subsurface drainage. Doubling the road width for example, makes drainage about four times as difficult as before. Consequently, practices that worked when roads were only two narrow lanes do not work for four and six lanes. Greater amounts of ground water and seepage enter wider roadbeds constructed in deeper cuts, and must be conducted greater distances for removal from places where it could cause damage or failure." The East-West Turnpike consisted of 2 two-lane highways separated by an unpaved median and flanked by two treated shoulders. After the complete full width bituminous concrete paving of 72-78 feet, it is equivalent to a six-lane highway without any increase in the subsurface drainage capability.

Barber and Sawyer(13) have studied the subject of highway subdrainage in great detail. They have reported that "even after drainage a dense-graded material (such as, the subbase under PCC pavements) will hold considerable water by capillarity if protected from evaporation. Water may also move through a soil as a vapor and considerable amount may be transferred by convection. If water evaporates continuously from the surface, the soil will dry out enough to establish a tension gradient sufficient to maintain the flow required for continuous operation (of evaporation). If evaporation stops (due to covering the surface) the moisture increases toward the value for static equilibrium. Rates of flow due to capillarity may be much greater than those due to gravity alone, especially for clay."

They also found that the permeability of portland cement concrete without cracks or honeycombed structure is of the order of magnitude of the permeability of clay samples A-6 and A-7. Low permeability was found in the field for bituminous mixtures due to traffic compaction particularly near the surface. This indicates that a PCC pavement can cause some drainage by evaporation from the subgrade or subbase, especially if the concrete is old and disintegrated.

Lovering and Cedergen (14) have reported that "with insufficient drainage, water may flood the base and rise through the pavement. Many drainage problems and deteriorated pavements can be attributed to water that enters the structural section from below. Ground water is most troublesome in areas where the road grade is near or beneath the surrounding ground water level, for example, in sections of freeway that are depressed below the surrounding ground and in mountainous areas where the road is deep in wet cuts." This problem was observed on the North-East Turnpike where the water table was in close proximity of the pavement structure near the concrete median in cut areas. Also, the potholes on Interstate 80 on steep grade in the cut/fill transition area can be attributed to this phenomenon.

Reporting on the underdrain practices of the Connecticut Highway Department, Keene (15) has stated that "Depth of pipe is extremely important and the objective is simple: to lower sufficiently the water table beneath the roadway. We have found many cases of old drains placed only 3-1/2 feet below edge of shoulder which were too shallow. Water seeped beneath the pipe to cause trouble under the roadway and capillary rise caused severe frost heave. Accordingly, our modern installations are always 4-1/2 feet deep, usually 5 or 5-1/2 feet deep, and increases toward the 'value for" static equilibrium. " Rates of flow" due to capillarity the edges of shoulders on North-East Extension Turnpike are only 3 feet deep from the surface (Figure 16). Their effectiveness to sufficiently lower the water table and drain a 72 feet wide paved roadway seems questionable. This can be explored by the methods of analysis of flow problems for highway subdrainage reported by McClelland and Gregg (16) where they have drawn flow nets for parallel subdrains under the pavement edge. If the distance between the two parallel subdrains exceeds a certain value, the water line can be in a very close proximity to the bottom of pavement structural section at the center.

RECOMMENDATIONS

The following conclusions were drawn and recommendations made based on the observations from the preceding case histories and the literature review:

East-West Turnpike (1977)

Water and/or water vapor was getting into the pavement structural system from underneath primarily through the longitudinal and transverse joints, cracks in the PCC pavement and the disintegrated concrete itself at some places. There was also evidence that moisture was being drawn from the subbase under the paved median into the asphalt overlay layers probably in the form of water vapor during the heat of the day (Figure la). Water vapor which accumulated in the pavement layers during the day condenses during the night until the asphalt pavement layers become saturated with water. With saturation the pore water pressure developed by differential thermal expansion and cyclic stresses from the traffic ruptures the asphalt-aggregate bond causing stripping.

If extensive stripping takes place in the bottom portion of the wearing course, the bare aggregates grind against each other by the action of heavy traffic loads producing a slurry (water with suspended fines) which is squeezed out onto the surface and when dried appears as a white spot. Chemical analysis of this slurry sampled from the East-West Turnpike confirmed that the suspended fines came from the course aggregate (Perry Rock) in the wearing course mix.

It is difficult to prevent the ingress of water and/or water vapor from underneath the pavement. However, the asphalt overlay layers should at least be made freely draining on both sides to prevent the buildup of pore water and/or water vapor pressure in these layers. These layers sloped towards the shoulder, but there was no outlet due to the presence of 15" wide bituminous binder abutting against these layers (Figure 2a). One proposed solution was to provide a layer of Asphalt Treated Permeable Material (ATPM) on both sides of the two-lane pavement (Figures lb and 2b). ATPM is a highly permeable mix (more than 10,000 feet/day) made from AASHTO No. 57 or 67 aggregate (no fine aggregate) and about 2 percent AC-20 asphalt cement. Design details are given in PennDOT BMTR Research Report dated February 1974 (17). ATPM towards the median (Figure lb) should be connected to the existing No. 8 aggregate at the summit and bottom of vertical curves and every 100 ft. (arbitrarily chosen) so that accumulated water and/or water vapor can be drained or released from the system. The use of ATPM in subsurface drainage systems has been discussed by other researchers (12,14,18,19,20,21)

Although the new subbase layer in the shoulder in cut areas is sandwiched between two impermeable layers, at least the excessive water vapor should be able to escape through the ATPM at its upper end.

North-East Turnpike (1977-1978)

Water and/or water vapor was entering this pavement structural system also from underneath through the longitudinal and tranverse joints, cracks and disintegrated portions of the PCC pavement. Since the two longitudinal underdrains are only 3 feet deep and are spaced 70 feet apart at the shoulder edges in tangent cut sections; their effectiveness in lowering the water table (especially in the middle of the roadway) and draining the subgrade is questionable (Figure 16). This lack of effectiveness was confirmed by observations in cut areas where the pavement layers were wetter near the concrete median than in the area near the center line. Most of this North-East Extension section is mountainous and is predominantly built in cut sections.

The subsurface drainage should be improved by increasing the depth of the two longitudinal underdrains at the shoulder edge in cut areas. The proposed improvement, as shown in Figure 16b, will also drain the new shoulder subbase, which is sandwiched between two impermeable layers and is causing asphalt stripping in the overlying new binder course.

Interstate 80 (1985)

Localized potholes were occurring in areas with ineffective subsurface drainage. Although pavement edge drains have been installed the subsurface water from the cut areas tends to flow longitudinally along the steep grade rather than transversely towards the edge drain. This water causes oversaturation of the pavement system in the transition area between the cut and fill sections. Unless transverse intercepting drains are installed the subsurface water is likely to cause persistent problems in the asphalt overlays in these areas.

General

These case histories indicate that in many cases the stripping of asphalt pavements may not be a general phenomenon occurring on the entire project but rather a localized phenomenon in areas of the project which are oversaturated with water and/or water vapor due to inadequate subsurface drainage conditions. There is a general tendency among some highway engineers to specify and use anti-stripping agents in the hot mix asphalt indiscriminately rather than assess and rectify the cause of the problem which can be inadequately designed subsurface drainage systems as determined in these case histories. The long range effectiveness of anti-stripping agents in asphalt mixtures oversaturated with water and subjected to high pore pressures induced by traffic is highly questionable. Unfortunately, most of the published papers (such as, Reference 22) on stripping concentrate on the stripping mechanisms or tests to identify stripping mixtures and ignore the subsurface drainage problems that provide water for stripping.

It is imperative that the pavement design engineer closely examine drainage related problems of the existing pavement structure especially a PCC pavement when proposing asphalt overlays. Figure 20 shows a PCC pavement with a poorly draining subbase or subgrade. This water is coming out of the transverse joint and being tracked onto the pavement surface by traffic although it had not rained for three days. These localized drainage problems need to be rectified (in some cases transverse drains might be necessary) before the PCC pavement is overlaid for the first time. If the drainage problems are not solved then, a persistent problem of potholing near the transverse joint may haunt the maintenance forces for years, as shown in Figure 21. Periodic maintenance of the existing subsurface drainage system is essential, especially clearing the outlets of pavement edge drains (Figure 22) which can get clogged with debris over the time.

The use of Asphalt Treated Permeable Material (ATPM) as discussed and recommended for East-West Turnpike earlier appears to be an excellent alternative in designing an effective subsurface drainage system for the existing as well as new pavements. If a PCC pavement has a poorly draining subbase or subgrade and is pumping, consideration should be given to incorporating a 4-inch thick ATPM layer directly over the concrete after cracking and seating. This ATPM layer should then be connected to the longitudinal underdrain system to effectively drain the water originating beneath the concrete slabs.

REFERENCES

1. Foster, C. R. "Moisture in Hot-Mix Bituminous Pavements," National Bituminous Concrete Association (Presently NAPA), Publication QIP 37, July 1961.

2. Jirnenez, R. A. "Testing for Debonding of Asphalt from Aggregates," Transportation Research Record No. 515, 1974.

3. Lottman et al. "A Laboratory Test System for Prediction of Asphalt Concrete Moisture Damage," Transportation Research Record No. 515, 1974.

4. Majidzadeh, K. and F. N. Brovold. "Effect of Water on Bitumen-Aggregate Mixtures," Highwav Research Board Special Report No. 98, 1968.

5. Lottman, R. P. "The Moisture Mechanism That Causes Asphalt Stripping in Asphalt Pavement Mixtures," University of Idaho, Moscow, Idaho, Final Report Research Proiect R-47, Feb. 1971.

6. Lottman, R. P. "Debonding Within Water-Saturated Asphalt Concrete Due to Cyclic Effects," American Chemical Society, Vol. 16, No. 1, 1977.

7. Hallberg, S. "The Adhesion of Bituminous Binders and Aggregates in the Presence of Water," Statens Vaginstitut, Stockholm, Meddeland, 78, 1950.

8. Majidzadeh, K. and F. N. Brovold. "Effect of Water on Bitumen-Aggregate Mixtures," Report CE-1, Department of Civil Engineering, University of Florida, Gainesville, Sept. 1966.

9. Mack, C. Physical Chemistry of Bituminous Materials. Vol. 1, Chap. 2, Interscience Publishers, New York, 1964.

10. Schulze, K. and H. Geipel. "Effect of Street Salting on the Adhesion of Bituminous Binders and Gravel Under the Influence of Water and Frost," Bitumen, Teere. Asphalte, Peche, Vol. 19, No. 12, 1968.

11. McKesson, C. L. "Slippery Pavements - Causes and Treatments," Proc. Assoc. of Asphalt Paving Technologists, Vol. 18, 1949.

12. Cedergren, H. R. and W. R. Lovering. "The Economics and Practicality of

Layered Drains for Road Beds," Highwav Research Record No. 215, 1968.

13. Barber, E. S. and C. L. Sawyer. "Highway Subdrainage," Proc. Highwav Research Board Vol 31, 1952.

14. Lovering W. R. and H. R. Cedergren. "Structural Section Drainage," Proc. International Conference on the Structural Desire of Asphalt Pavements, Ann Arbor, Michigan, 1962.

15. Keene, Philip. "Underdrain Practice of the Connecticut Highway Department," Proc. Highwav Research Board, Vol. 24, 1944.

16. McClelland, B. and L. E. Gregg, "Methods of Analysis of Flow Problems for Highway Subdrainage," Proc. Highwav Research Board, Vol. 24, 1944.

17. Kandhal, P. S. and M. E. Wenger. "Experimental Asphalt Stabilized Base Under Portland Cement Concrete," Pennsylvania Department of Transportation, BMTR Research Report, Feb. 1974.

18. Federal Highway Administration. Implementation Package for a Drainage Blanket in Hitzhway Pavement Systems. May 1972.

19. Cedergren, H. R., J. A. Arman and K. H. O'Brien. "Development of Guidelines for the Design of Subsurface Drainage Systems," Federal Highwav Administration Report No. RD-73-14, Feb. 1973.

20. Kozlov, G. S. "Implementation of Internal Road Drainage Design and Application," Transportation Research Record No. 993, 1984.

21. Ridgeway, H. H. "Pavement Subsurface Drainage Systems," NCHRP Synthesis of Highwav Practice No. 96, November 1982.

22. "Evaluation and Prevention of Water Damage to Asphalt Pavement Materials," ASTM Special Technical Publication No. 899, December 1985.

LIST OF TABLES

TABLE 1. CONDITION OF EAST-WEST TURNPIKE PAVEMENT OVERLAID IN 1977 (MILE POST 220)

MILE POST 220 (WEST BOUND SLOW LANE

Pavement Layer	Summit of a vertical curve		Gentle slope (near bridge)	
	Inside Wheel Track	Pavement Edae[1]	Inside Wheel Track	Pavement Edae[1]
1" New Wearing Course (1977)	Pot hole, damp, stripped at bottom (1 .8%)	Damp, stripped at bottom	Damp, stripped at bottom	Damp, stripped at bottom
2' New Binder Course (1977)	Very wet, stripped badly, no cohesion (1.1%)	Wet, stripped	Wet, stripped badly	Very wet, stripped badly (no overflow)
1' New Levelling (1977)	Moist, no stripping, dense (0.4%)	Moist, no stripping	None (due to bridge)	None
1" Old Gravel Wearing Course (1977)	Moist to wet, stripped, friable (1 .0%)	Moist, stripped, fiable	None	None
1" Old Slag Wearing Course (1962)	Moist, no stripping (3.7%)	Moist, no stripping	None	None
2" Old Stone Binder Course (1962)	Wet, partly stripped (0.8%)	Wet, partly stripped	None	None
Concrete	Damp, hairline cracks	Damp	Damp	Damp and deteriorated

[1] Drainage of pavement layers blocked at the pavement edge by the binder course in the shoulder (Figure 2a). No. 8 stone was wet below the bottom line of PCC pavement, whereas, dry to damp above this line.

Notes: (a) No flow was observed on August 16 & 17, 1978 in 6" new pipe U' drain in the median near M.P. 220.
(b) Moisture contents in pavement layers are given in parentheses after the description of condition.

TABLE 3. CONDITION OF NORTH-EAST TURNPIKE PAVEMENT OVERLAID IN 1977-78

M.P. 64.3 (Sta. 722+95) South Bound Passing Lane[1]

Pavement Layer	Right Wheel Track	Next to Concrete Median	Center Line of South Bound Lanes
1" New Wearing Course (1978)	Wet, some stripping at bottom (1.4%)'	Wet underneath	Moist and stripped at bottom
2" New Binder Course (1977)	Wet throughout, severe stripping at bottom (1.0%)	Wet throughout, some dripping wet (1.7%)	Moist and stripped
1" New Levelling (1977)	Wet throughout, crumbly looks like sand mix (1.3%)	Very wet (4.7%)	Wet
Concrete	Wet surface	Wet	Wet, very deteriorated, intersection of transverse and longitudinal joints.
General	Area with cluster of white spots. Wet spots start to appear in the hot afternoon.	There was a 1/2" wide joint between slab and concrete median.	This site had extruded mastic asphalt crack sealer lying on surface.

[1] This location was in a cut area, gentle grade and road surface had white spots.

[a] Moisture contents in pavement layers on September 6, 1978 are given in parentheses.

TABLE 5. MONTHLY PRECIPITATION (INCHES) - SOUTH CENTRAL MOUNTAIN DIVISION

MONTH	NORMAL 1971-73	NORMAL 1974-78	1971	1972	1973	1974	1975	1976	1977	1978
Jan.	2.98	2.72	3.38	2.59	2.42	3.89	4.06	3.21	1.48	6.52
Feb.	2.41	2.47	4.77	4.74	2.75	1.24	3.40	2.10	1.75	0.72
Mar.	3.85	3.73	2.48	2.49	2.31	3.95	4.43	2.93	5.62	2.36
Apr.	3.68	3.66	0.97	5.81	5.83	2.52	3.25	1.69	4.22	2.40
May	4.22	3.95	4.62	4.83	4.74	4.12	3.84	2.84	1.77	6.50
June	4.11	3.78	3.43	11.0	4.11	5.62	5.81	4.68	2.61	4.63
July	4.20	4.06	5.29	2.56	3.15	2.61	2.01	4.06	8.02	5.19[a]
Aug.	3.80	3.54	4.26	2.84	3.61	2.25	5.70	3.37	2.84	1.80a
Sept.	2.88	2.77	6.06	3.02	4.20	3.96	6.80	4.19	4.10	
Oct.	2.92	2.72	3.05	2.73	4.10	1.39	3.94	9.11	4.34	
Nov.	2.84	3.16	3.43	5.79	2.55	1.92	1.95	2.31	3.40	
Dec.	2.92	2.88	2.79	5.05	4.38	4.91	3.02	2.55	3.02	
Total	4083	3944	4453	5345	44.15	3838	4821	4158	43.17	

[a]Obtained from PTC Station at Everett (Bedford County).

TABLE 7. CONDITION OF EAST-WEST TURNPIKE PAVEMENT OVERLAID IN 1971

Pavement Laver	West Bound Slow Lane (M.P. 156.05) Around pot hole between wheel track, cut/fill section near overhead bridge	"East Bound Slow Lane (M.P. 156.11) Outside wheel track, high rocky cut on grade	West Bound Slow Lane[1] (M.P 156.2) Inside wheel track, high rocky cut on grade
1" New Wearing Course (1971)	No visible moisture in the gravel mix, badly stripped, (1 .3%)"	Slag wearing course, no visible moisture and no stripping (2.3%)	Gravel wearing course, no visible moisture, badly stripped, friable (1.2 %)
2' New Binder Course (1971)	Binder directly on concrete, badly stripped, presence of wet slurry (0.9%)	No visible moisture, some stripping (0.6%)	No visible moisture, badly stripped, friable (0.9%)
1" New Levelling (1971)	None	No visible moisture, some stripping (0.8%)	No visible moisture, some" stripping (1.1 %)
1" Old Wearing Course (1959 or 1960)	None	No visible moisture in the slag course, no stripping (2.5%)	Slag mix, appeared damp, no stripping (4.9%)
2" Old Binder Course	None	Appeared damp, some stripping (0.9%)	Appeared damp, badly stripped (1.0%)
Concrete	Badly disintegrated and wet	Damp (concrete OK)	Badly disintegrated and damp

[1] Some pot holes are developing in this area of WB lanes. Maintenance crew was engaged in patch repairs, concrete was wet and badly disintegrated and water was coming out.

[a] Moisture contents in the pavement layers sampled on September 12, 1978 are given in parenthesis after the condition description.

TABLE 9. CONDITION OF EAST-WEST TURNPIKE PAVEMENT OVERIAID IN 1976

Pavement Layer	East Bound Slow Lane (M.P. 190.1) Inside wheel track, rocky cut area	East Bound Slow Lane (M.P. 190.2) Inside wheel track, fill area
1" New Wearing Course (1976)	Gravel mix, no visible moisture, badly stripped (2.1 %)'	Gravel mix, no visible moisture, badly stripped (0.9%)
2" New Binder Course (1976)	Damp, 50% stripped, no bond with underlying layer (0.9%)	Damp, wet at bottom, badly stripped with globules of asphalt, no bond with underlying layer (0.9%)
1" New Levelling (1976)	No visible moisture, some stripping, no bond with underlying layer (1.0%)	No visible moisture, some stripping
1" Old Gravel Wearing Course (1971)	No visible moisture, badly stripped (1 .7%)	No visible moisture, badly stripped
1' Old Slag Wearing Course (1960)	No visible moisture, no stripping, appears damp from side (9. 1%)	Damp, no stripping
2" Old Binder Course (1960)	Some moisture, some stripping (4.1%)	Damp, stripped, contains some slurry from cement concrete (2.5%)
Concrete	Very damp and disintegrated	Damp and disintegrated
Middle of Shoulder	Binder course did not have visible moisture but stripped badly. Subbase appeared saturated.	Binder course did not have visible moisture and no stripping. Subbase appeared saturated.

[a]Moisture contents in the pavement layers sampled on September 12, 1978 are given in parenthesis after the condition description.

LIST OF FIGURES

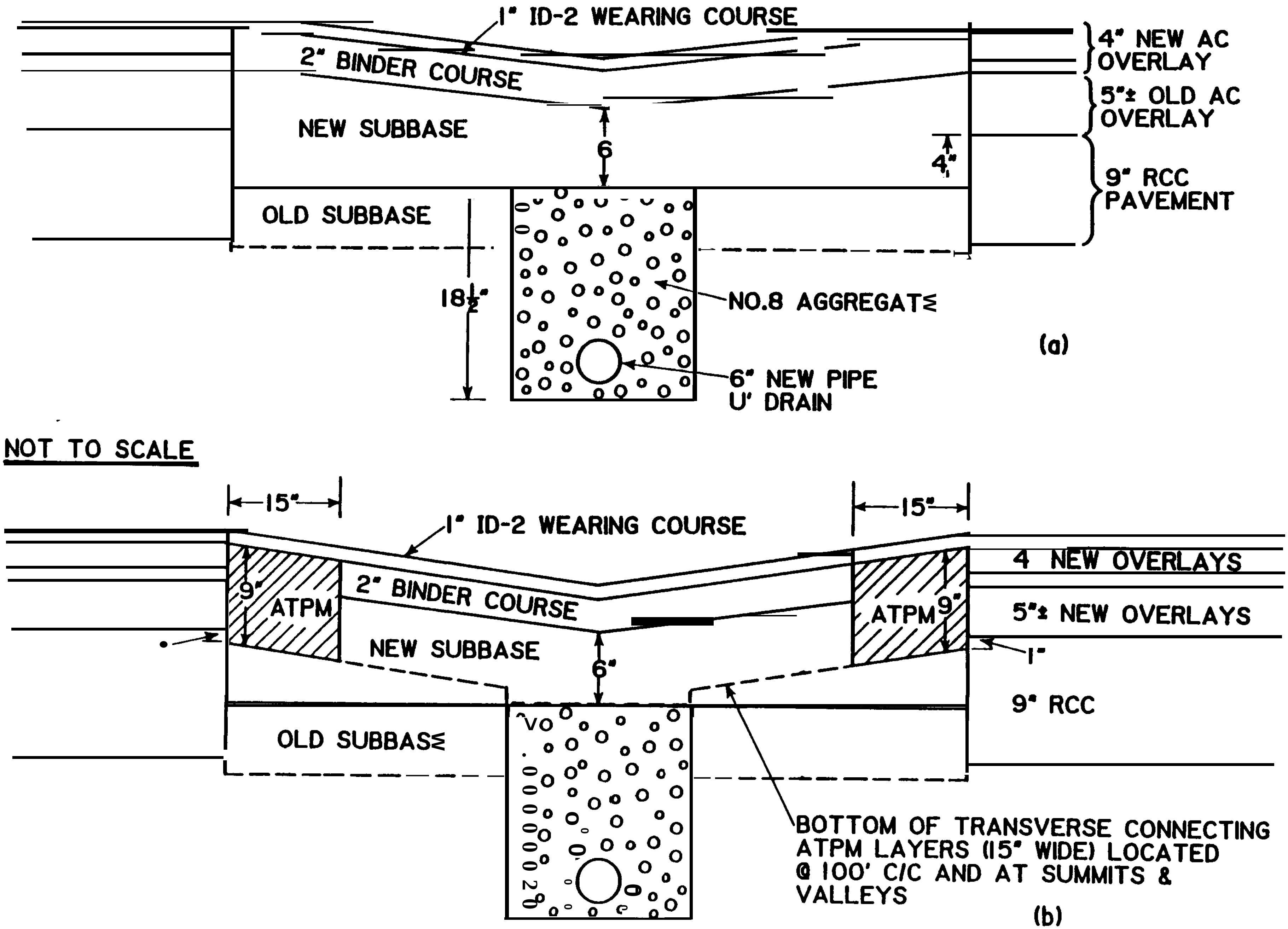

FIG. . EAST-WEST TURNPIKE TYPICAL MEDIAN SECTION
(a) EXISTING (b) PROPOSED

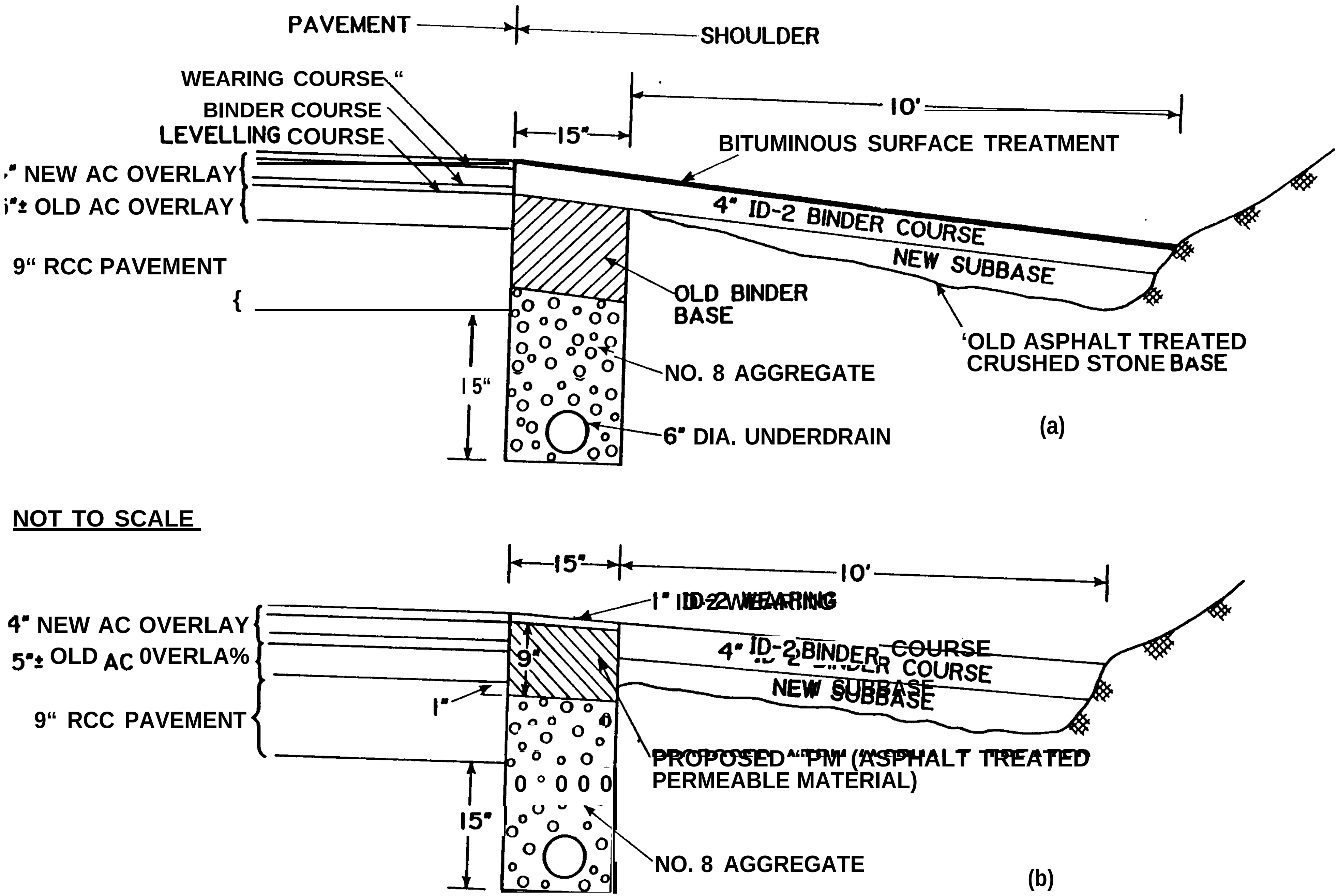

FIG. 2. EAST-WEST TURNPIKE TYPICAL CUT SECTION
(a) EXISTING (b) PROPOSED

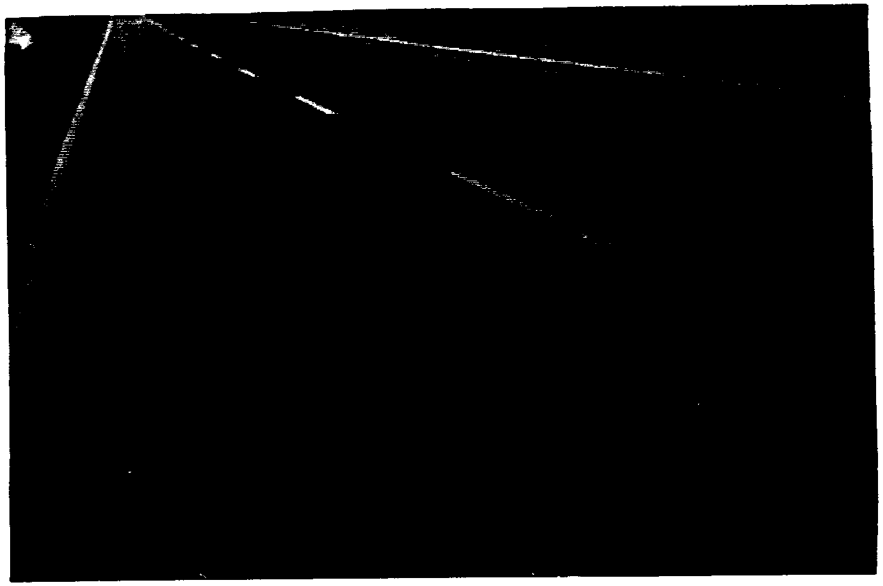

Fig. 3. East-West Turnpike (General view showing a typical pothole)

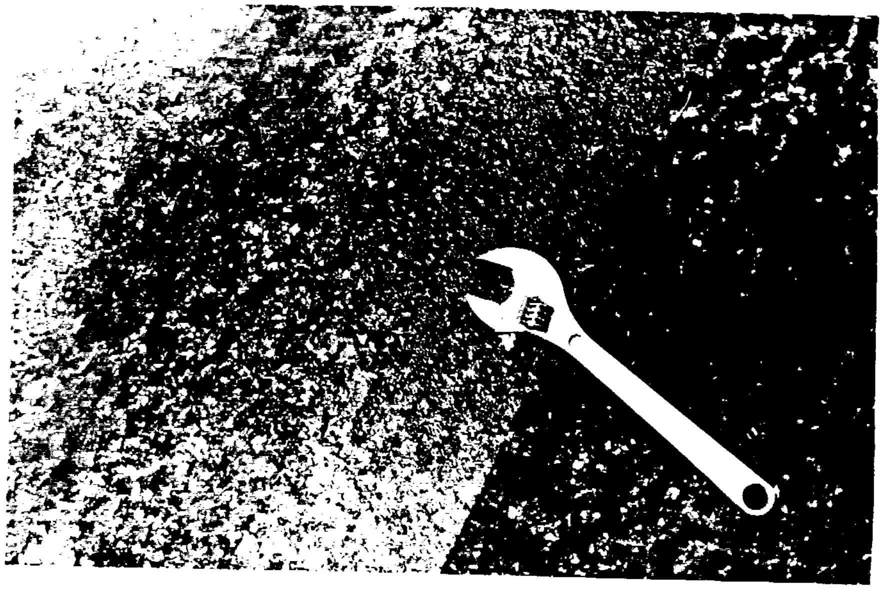

Fig. 5. East-West Turnpike (Asphalt Bubbles - One Framed by Wrench)

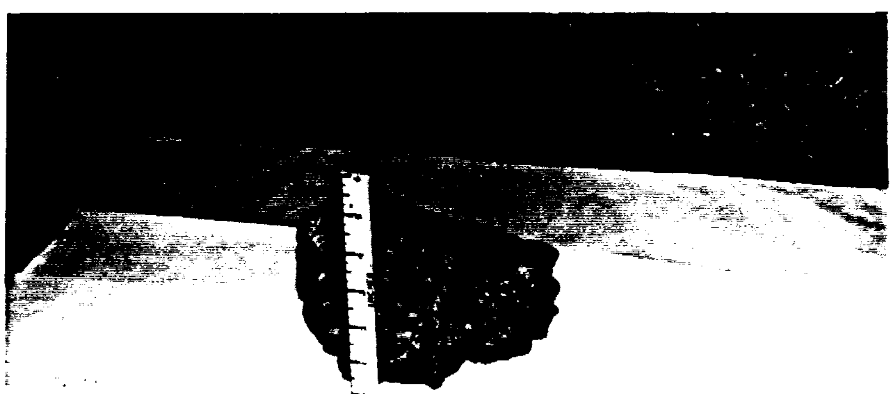

Fig. 6. East-West Turnpike (Bottom of Wearing Course Coated with Slurry)

Fig. 7. East-West Turnpike (General View Showing a Series of Patched Potholes on Inside Wheel Track of Slow Lane)

Fig. 8. East-West Turnpike (Closeup of Patched Potholes)

Fig. 9. East-West Turnpike (Closeup of Long Patched Pothole)

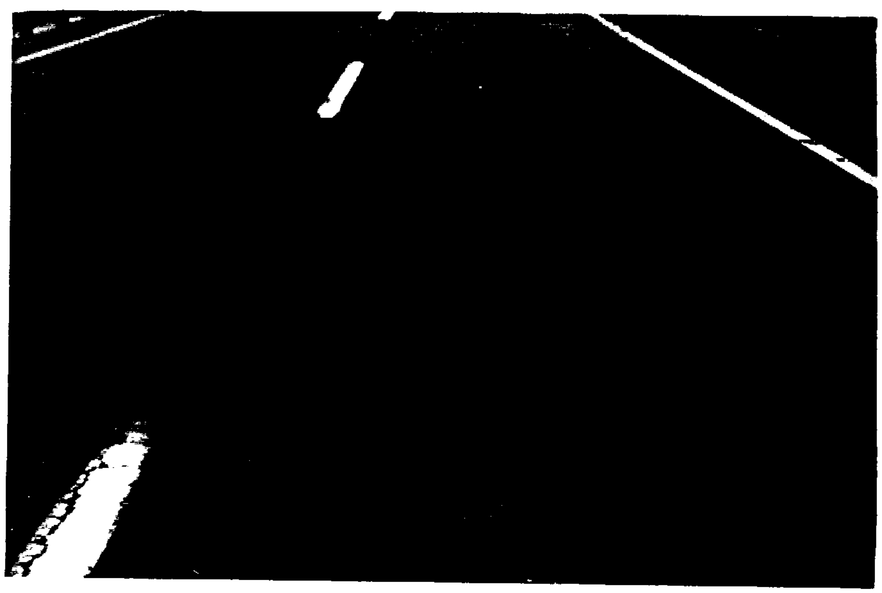

Fig. 10. East-West Turnpike (Potholes **Patched** at Different **Times)**

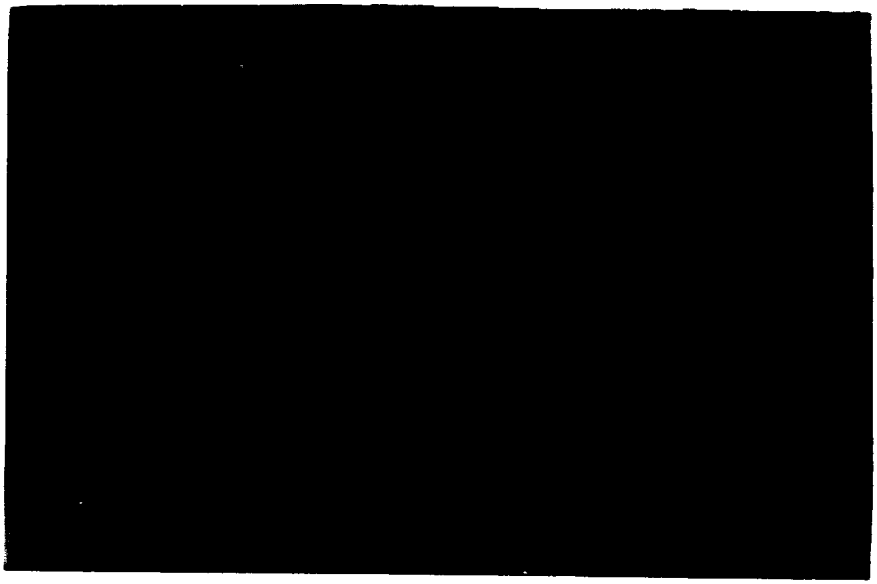

Fig. 11. East-West Turnpike (Pothole with Rectangular Outline for Jack **Hammering)**

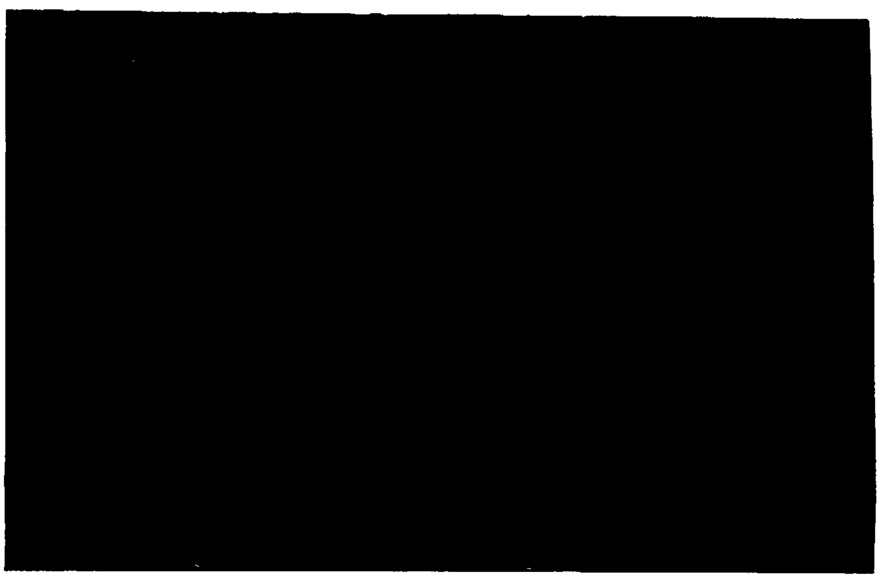

Fig. 12. East-West Turnpike (Pothole after Removal of Wearing Course)

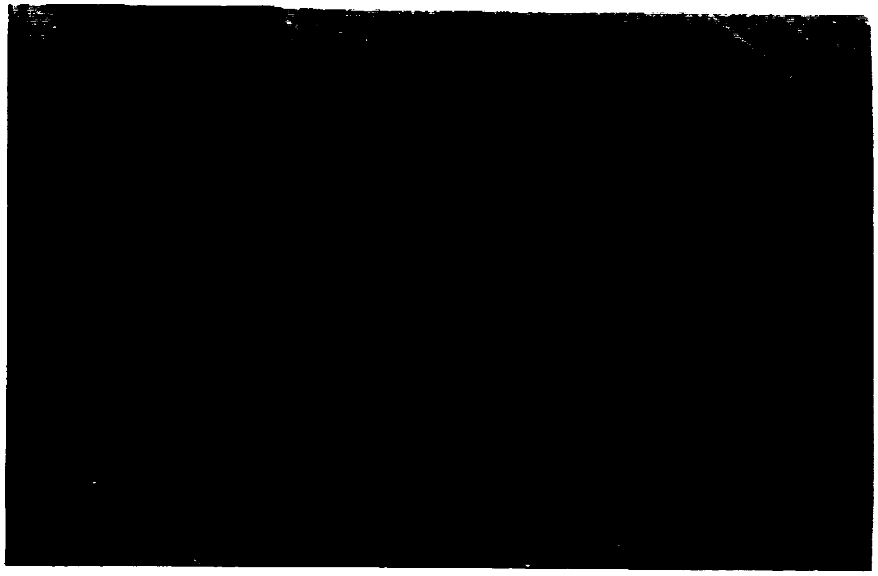

Fig. 13. East-West Turnpike (Wearing Binder and Levelling Courses Removed)

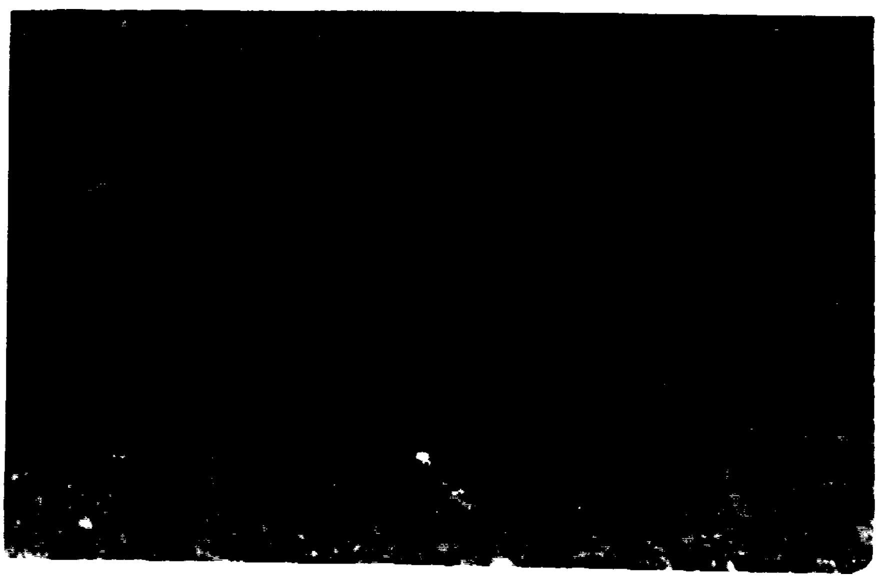

Fig. East-West Turnpike Old Overlays Removed

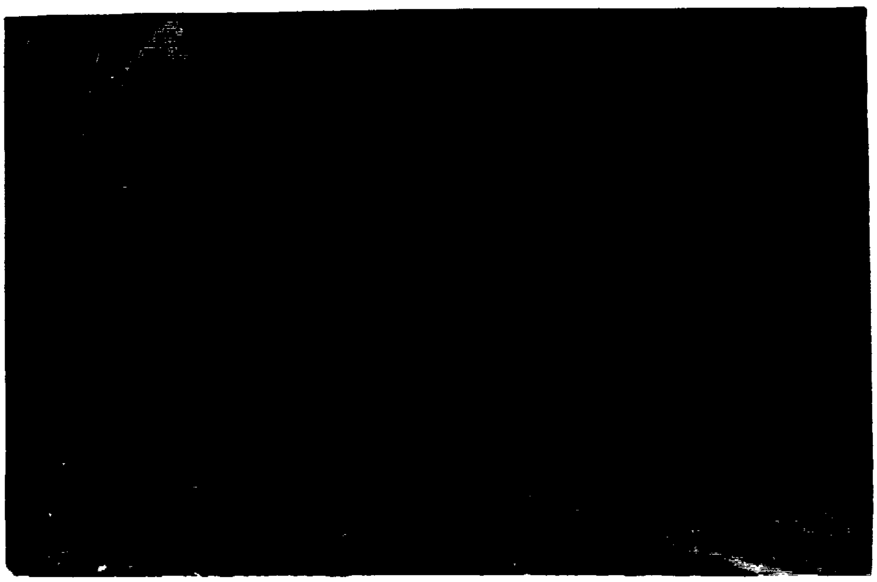

Fig. 15. East-West Turnpike (Removed Slabs Placed Upside-Down to Show stripping)

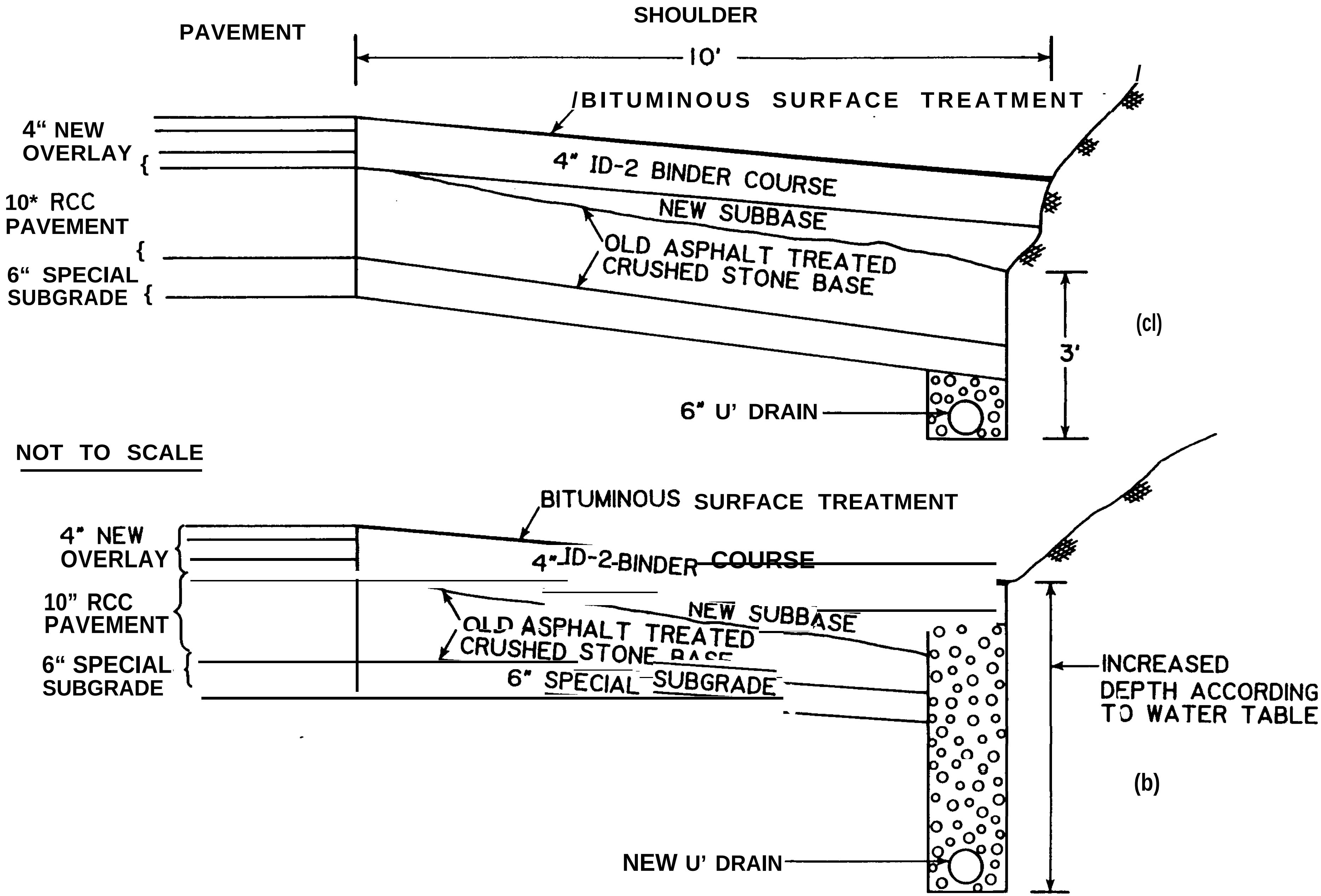

FIG. 16. NORTH-EAST TURNPIKE TYPICAL CUT SECTION
(a) EXISTING (b) PROPOSED

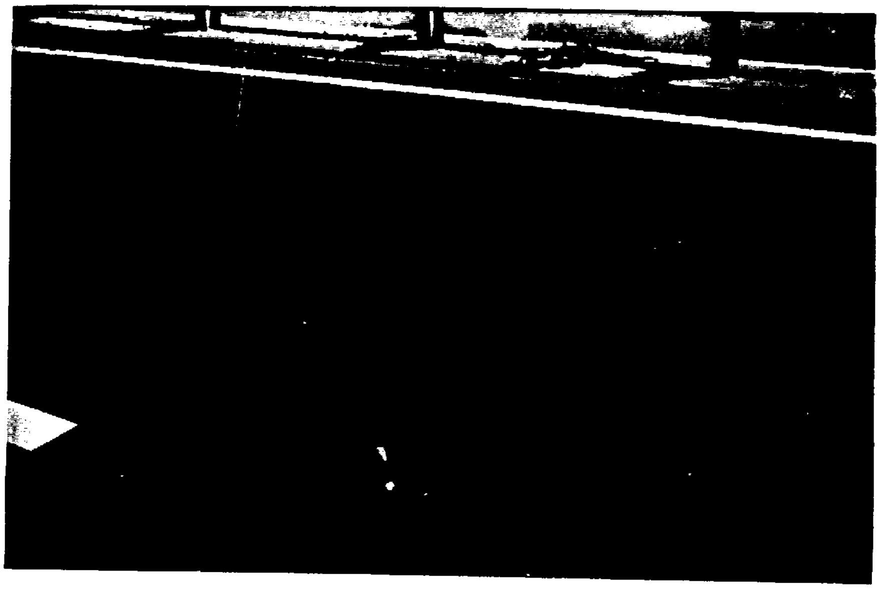

Fig. 17. North-East Turnpike (White Spots Near Concrete Median)

Fig. 18. North-East Turnpike (Pavement Layers Adjacent to Median Removed)

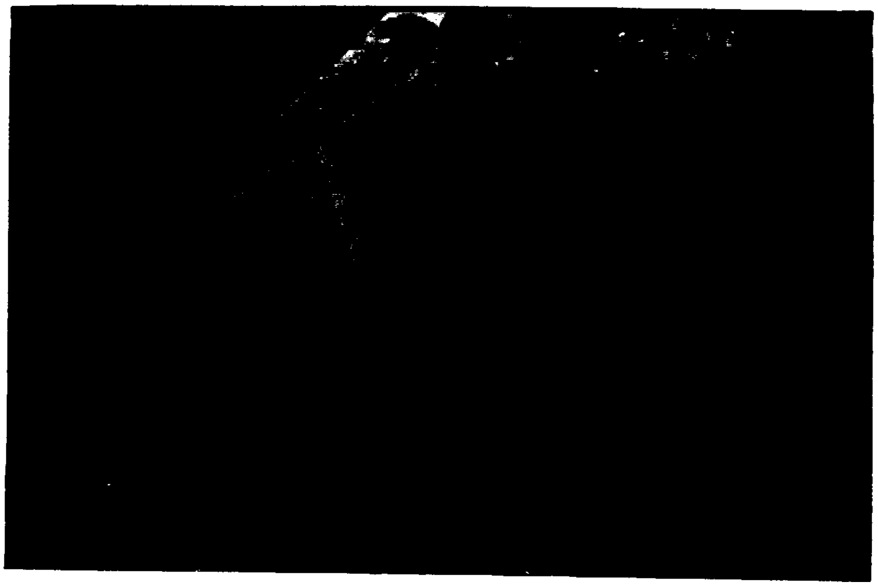

Fig. 19. North-East Turnpike (Pavement Layers Adjacent to Center Line Removed)

Fig. 20. PCC Pavement (Water Pumping from Transverse Joint)

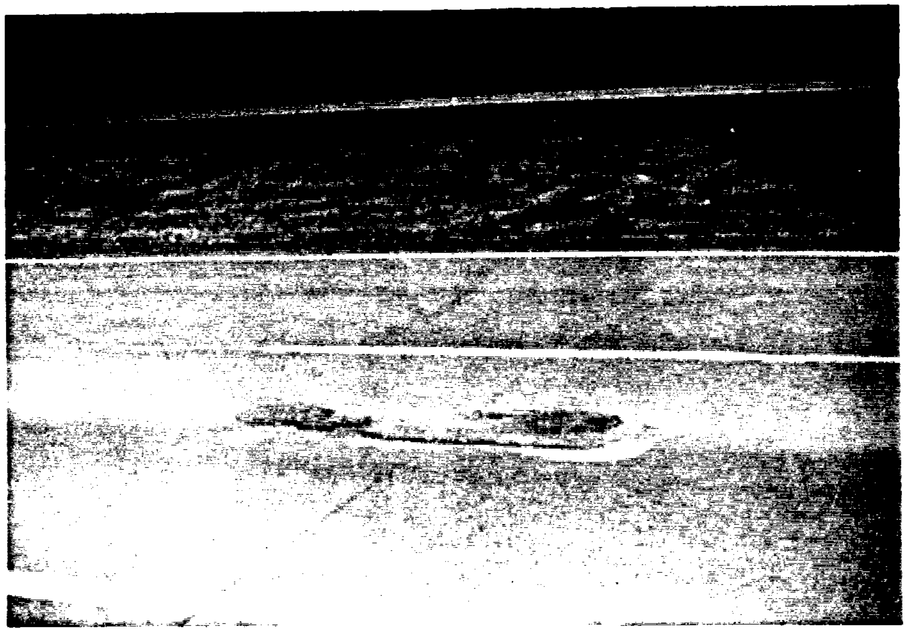

Fig. 21. Patched Pothole in Asphalt Overlay on Either Side of Transverse Joint of Underlying PCC Pavement

Fig. 22. Outlet of the Pavement Edge Drain