POROUS ASPHALT

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1.Introduction

Porous asphalt pavement is one alternative solution to the problem of stormwater drainage from parking and other low traffic density areas. In operation, this type of pavement allows incipient rainfall and local runoff to soak through the pavement surface course of open graded asphalt concrete mix and accumulate in a porous base consisting of large open graded gravel from which the water would percolate into the natural ground below, if this is possible, or would drain laterally to a sump or channel (Fig.1).

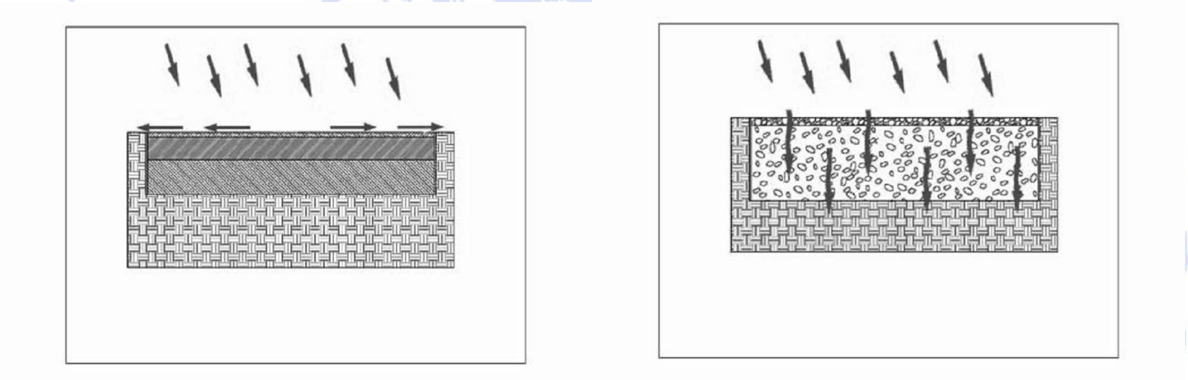

Fig.1. Rain on traditional asphalt (left) and porous asphalt (right).

Porous asphalt (PA) also namely open-graded asphalt has been use as a wearing surface since the 1950s. Its first major use in Australia was about 1973 and in Japan was about 1987. Porous asphalt is a developing in road surfacing technology; Porous asphalt is an innovative road surfacing technology, which allows water to enter into the asphalt mixes beyond its continuous air voids. Porous asphalt designed so that after laying and compacting, they form a surface with a void’s more than 20 percent. They are used in wearing courses and always laid on impervious base course, was promising and effective in enhancing traffic safety. The use of porous asphalt also to reduce noise and glare (Sasana and Ismanto, 2003).

PA used in place of traditional impervious paving materials decreases the total amount of runoff leaving a site, promotes infiltration of runoff into the ground, reduces the amount of pollutants carried to a storm drain or waterway, and aids with reducing peak runoff velocity and volume. Developing land for residential, commercial and industrial use carries the detrimental effect of vastly increasing the amount of impervious surface area as land is paved to create roads and parking lots. During a storm, runoff flows over impervious pavement, picking up pollutants such as dirt, grease and oil, and transports these contaminants to streams and storm sewer systems. In response to this issue, designers developed porous paving systems that allow runoff to pass through the pavement into a stone base, then into the soil below to recharge the groundwater supply. With proper installation and maintenance, porous paving allows for infiltration of up to 80% of annual runoff volume. Additionally, studies indicate that porous paving systems can remove between 65 and 85 percent of undissolved nutrients from runoff and up to 95% of sediment from runoff.

PA is used worldwide for its favorable splash and spray properties and its reduction of aquaplaning under rainy conditions as well as its noise reduction properties. Switzerland started using PA in 1979 with mixed results. According to a survey taken in 2004, nine of the 26 cantons use PA. In particular, canton Vaud in western Switzerland is known as one of the leaders in promoting and using PA. Currently, 1/3 of the Vaud motorways are covered with porous asphalt and the use of PA is planned to be extended to most of the motorway surfaces in the canton Vaud up to an altitude of 600m. In addition, there are several bridge trial sections with PA. Despite its benefits, porous asphalt can suffer from problems, which can affect both its performance and its service life. The open structure exposes a large surface area to the effects of air and water, leading to rapid aging of the binder. In addition the clogging of the pores can reduce the functionality prematurely (Poulikakos D. L. et al., 2006).

2.**Summary of the advantages and disadvantages of porous asphalt**

Advantages and disadvantages of porous asphalt have been well established in the literature; below a summary is listed:

2.1 Advantages

Reduction in splash and spray, reduced aquaplaning

Compared to dense mixes, surface water can drain through porous asphalt due to the large amount of continuous pores in the structure. The material provides good visibility under rainy conditions, thus preventing the reduction in traffic flow volumes, which normally accompany rain.

In addition, the absorption of surface water is effective in reducing aquaplaning which occurs when vehicles move at high speeds on a thin water layer. It has been shown that porous asphalt contributes to the reduction of the number of accidents in rainy days (Maupin, 1976). This effect can be seen in Fig.2.

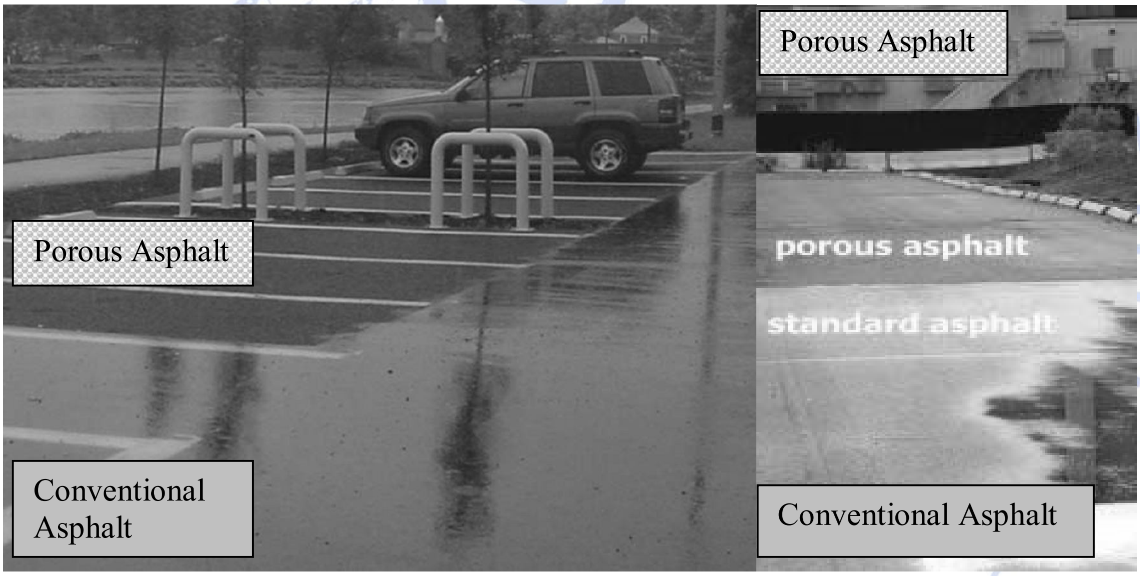

Fig.2. Anti- aquaplaning effect of porous ashalt pavement.

Reduction in light reflection and headlight glare

Because porous asphalt acts as a drainage layer, enabling rainwater to percolate through the mix, thus light reflection and headlight glare, some of the dangerous factors for drivers especially in night time, decrease dramatically and lane markings are enhanced clearly on wet surfaces.

Noise Reduction

Road surfaces are laid with coarse macro-texture, which are in contact with the tire tread. This texture is known to contribute to the noise absorption between the surface and the tire. Many trial sections show lower noise levels on porous asphalt, which may be 6 dB(A) lower than concrete layers (Tesoriere et al., 1989) or 2 to 6 dB(A) lower than the HRA (Nicholls, 1996). According to the Swiss standards, under dry conditions in a 70 dB(A) area by using porous asphalt a noise reduction of 5 dB(A) can be achieved (SN 640 433b, 2001).

Swiss experience also indicates an advantage on the high speed traffic lanes in excess of about 80 km/h. Although the noise level of porous asphalt on the lower speed lanes is almost the same as other conventional dense mixes, porous asphalt is still effective in reducing the noise in the frequency range of 1.25 to 2 kHz at 60 km/h (Köster, 1991). The experience in the Netherlands indicates that on the lower traffic speed lanes less than 70 km, the noise level of porous asphalt is even higher than dense mixes due to its rough macro-texture on the surface. To improve this aspect, 2 layer porous asphalt (Twinlay) was developed (Bochove, 1996). It consists of a bottom layer of the porous asphalt with a coarse single grained aggregate (11/16 mm) and a thin top layer of fine graded porous asphalt (4/8 mm).This double-layer structure can contribute to reduce the traffic noise at any vehicular speed. According to their report, additional advantages of the Twinlay are better clog resistance against dirt and better cleaning properties.

Therefore, this unique structure is expected to be introduced in their urban areas on a regular basis to meet the high environmental demand. Japanese experience reveals that porous asphalt is effective in noise reduction, but that this advantage is gradually lost over the years due to a decrease in mix porosity, especially in snowy areas where tire chains are used (JHRI).

As an example from the USA in Oregon, two types of noise measurements were taken. The first was roadside noise and the second was interior vehicle noise. The results indicated that porous asphalt pavements reduce the noise in the higher-frequency zones. This conclusion is supported mostly from the roadside measurements and not from those taken in the interior of the vehicle, possibly since the higher frequencies are dampened by the vehicle shell. As high-frequency noises have a shorter wavelength, they are more apt to be reflected off the vehicle's thin shell (Moore et al., 2001).

Improvement in Skid Resistance, Reduction in vehicle rolling resistance

Increasing skid resistance under wet conditions is one of the main reasons for using porous asphalt. Assuming that a rougher wearing course would increase frictional properties. In Oregon friction properties of porous asphalt were compared with dense graded asphalt. The data accumulated indicated that porous asphalt mixes had slightly improved friction properties in dry conditions and a much improved friction properties during rainy conditions when free water was present on the pavement (Moore et al., 2001).

Skid resistance is a function of macro and micro textures. At high speeds, the contribution of the macro texture is more dominant. In the A38 Burton trial section, 1987, Porous asphalt showed a skid resistance at least as good as that of the HRA (Daines, 1992). In Japan, it is reported that the skid resistance of porous asphalt was initially the same as conventional non-porous asphalt, but this value increased gradually during the service life, whereas the dense mixes did not show any significant change. In addition, fresh porous asphalt layers may have a reduced skid resistance due to the bitumen film on the aggregates exposed to the surface. It is noteworthy to mention that some Swiss experts recommend not using porous asphalt with aggregate size in excess of 16 mm on wearing courses. According to their experience, the use of larger top size aggregates may provide less skid resistance on wet road surfaces.

Rut-resistance

In Japan, despite its high porosity, a number of trial sections show lower permanent deformation on porous asphalt than other dense mixes. Tighter aggregate skeleton in porous asphalt may contribute to withstand the load under traffic (EHRFJ, 1993). On the 1987 Burton trial in the UK, the deformation rate of this porous asphalt section in the near side lanes was less than 2 mm/year and 0.5 mm/year on average after 8 years trafficking. This result was evaluated as an acceptable rate in Britain. Although deformation of pavement depends on several conditions, such as climate, traffic intensity and loads, porous asphalt may provide acceptable rut resistance compared to other dense mixes (Daines, 1992).

2.2 Disadvantages

Aging and Stripping

Although porous asphalt has many obvious advantages, there are also some disadvantages. One of the most critical factors in the performance of bituminous mixes is the tendency of the binder film on the surface of the aggregate to be continuously exposed to oxygen, sunlight, water etc. This results in binder hardening and a reduction in pavement service life (Hoban et al., 1985). When bitumen hardens, aggregates can be stripped easily from the asphalt mixes. It is well known that, due to its high porosity, porous asphalt ages much faster than conventional dense mixes. In full-scale road trials in the UK, the results conclude that the life of porous asphalt is ultimately limited by binder hardening with likely failure when its penetration drops below 15 pen (Daines, 1992).

Another potential disadvantage of porous asphalt is the water sensitivity of the mix. Rainwater can penetrate through the porous matrix. Sometimes the water remains in the structure keeping the asphalt in wet condition for a long time. This moisture can cause some extra damage in porous asphalt by stripping the binder film from the aggregate surfaces.

Reduction in Porosity

During service life, the pores tend to be clogged by dirt, dust or other clogging agents. On high speed lanes, tires produce a self-cleaning effect (Heystraeten and Moraux, 1990). Thus clogging is more serious on low speed lanes or minor roads. With the loss of pores, the advantages of noise reduction and drainage function will gradually disappear. This is another serious problem for road maintenance. To overcome this disadvantage many types of cleaning methods, including vacuum vehicles with hydraulic jet water, have been developed to maintain the advantage of porous asphalt long term. However, no conclusion on the optimum type of cleaning method can be recommended. Porosity loss is also caused by secondary traffic compaction, especially on heavy routes.

Shorter Service Life

Due to the above listed disadvantages, the service life of porous asphalt surfaces is shorter than that of dense mix layers. In addition, it depends on several factors such as binder content and type, aggregate gradation, traffic volume and climate. Although previous experiences show an optimistic life expectancy of around 15 years, some maintenance should be necessary within about 5 to 8 years according to the results in many countries. Such maintenance costs for porous asphalt (from cleaning the clogged pores to replacement of those layers, which lost their drainage function) are considered higher than for the conventional asphalt. However, this does not mean that cost-effectiveness of porous asphalt surface is lower than that of other surface mixes. When this issue is discussed, the significant contribution of this pervious layer for social benefits, such as traffic safety and environmental issues, can not be ignored.

Winter Maintenance

Snow and ice removal from porous surfaces requires at least twice the quantity of de-icing salt treatment compared to that of other dense mixes. However, the damage to porous asphalt due to salt is still unclear. Vehicular tire chains, spiked tires and snow ploughing sometimes cause severe damage on the open textured mixes requiring additional repair when the aggregates are stripped from the surface. Swiss standards recommend explicitly that porous asphalt not be used in areas where chains and spiked tires are used (SN 640 433b, 2001). CEN suggests an abrasion test by studded tires to evaluate the chain damage (EN13108-7, 2006). Japan also applies either a similar test for porous asphalt, which was originally developed for dense mixes in snowy areas, or a decrease in the temperature down to - 20 °C in the Cantabro test (Japan Highway Public Corporation, 2006). It should be noted that, because of the lower thermal conductivity of the porous asphalt, in winter this surface may colder than dense asphalt (Köster, 1991). Therefore, on the porous asphalt surface, snow tends to settle earlier and remain longer, also ice forms earlier when the roads are wet (Nicholls, 1996).

3. Design Criteria

Firstly, here is a summary of design guidelines for subsurface infiltration;

1. Avoid piping water long distances. Look for infiltration opportunities within the immediate project area.
2. Consider past uses of the site and appropriateness of infiltration design and porous pavement.
3. Consider the source of runoff. Incorporate sediment reduction techniques as appropriate.
4. Perform site tests to determine depth to seasonal high water table, depth to bedrock, and soil conditions, including infiltration capabilities. Design accordingly. Maintain three feet above high water table and two feet above bedrock.
5. Avoid excessive earthwork (cut and fill). Design with the contours of the site. Maintain a sufficient soil buffer above bedrock.
6. Do not infiltrate on compacted fill.
7. Avoid compacting soils during construction.
8. Maintain erosion and sediment control measures until site is stabilized. Sedimentation during construction can cause the failure of infiltration systems.
9. Spread the infiltration over the largest area feasible. Avoid concentrating too much runoff in one area. A good rule of thumb is 5:1 impervious area to infiltration area (i.e., 5 acres of impervious area to 1 acre of infiltration area). A smaller ratio is appropriate in carbonate bedrock areas.
10. The bottom of the infiltration area should be level to allow even distribution.
11. The slope on which the porous pavement is placed should notexceed 5 percent. Use conventional pavement in steep areas that receive vehicular traffic.
12. Provide thorough construction oversight.

Typical porous asphalt pavement can be shown in Fig.3.

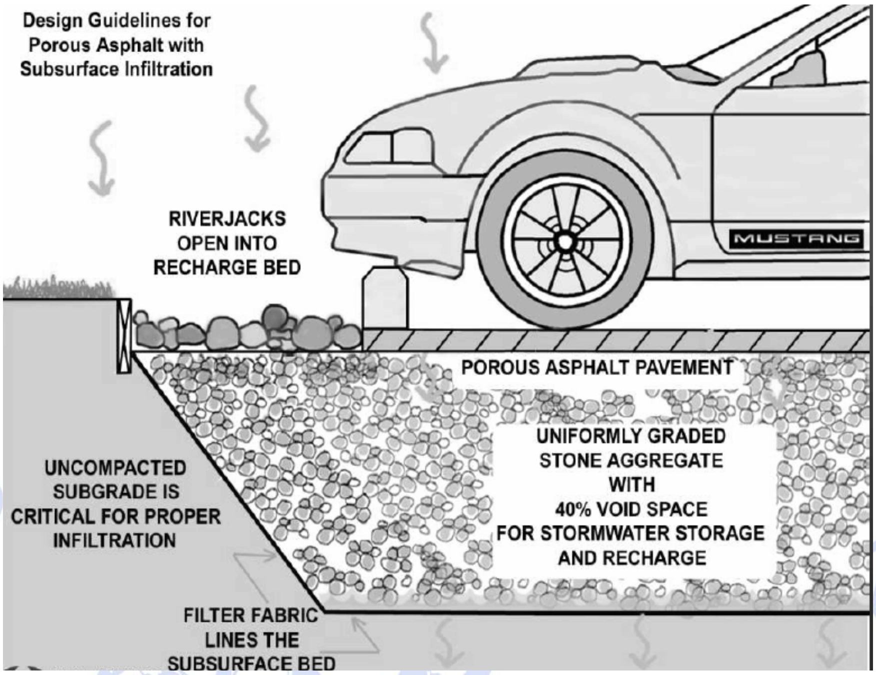

Fig.3. Typical porous ashalt pavement.

Porous asphalt consists of standard bituminous asphalt in which the fines have been screened and reduced, creating void space to make it highly permeable to water. The void space of porous asphalt is approximately 16%, as opposed to two to three percent for conventional asphalt. Porous asphalt pavement consists of a porous asphalt surface layer, a top filter base course of 1/2 inch open graded aggregate, an aggregate subbase layer to provide temporary water storage and structural support, a geotextile filter fabric, and the existing subgrade soil. Porous asphalt surface course is also called Open Graded Friction Course (OGFC) (Iowa Stormwater Management Manual , 2009).

Porous asphalt has the positive characteristics of an ability to blend into the normal urban landscape relatively unnoticed. It will typically allow a reduction in the cost of other stormwater detention infrastructure by increasing the time of concentration and reducing the peak discharge rates for the larger storms. This can offset the somewhat greater placement cost over traditional impervious pavements. A drawback is the cost and complexity of porous asphalt systems compared to conventional pavements. Porous asphalt systems require a modified construction protocol for equipment and placement than is typical for regular asphalt pavements. The level of construction workmanship is not necessarily more difficult, just different. As with other pavement systems, pervious pavements can experience an increased failure rate if they are not designed, constructed, and maintained properly (Iowa Stormwater Management Manual , 2009).

For the purpose of sizing downstream conveyance and structural control system, porous asphalt surface areas can be assumed to 20% impervious. An approximate curve number for pervious pavement area would be in the range of 30 to 35 (i.e. meadow/pasture/grassland on hydrologic soils group A soils). In addition, credit can be taken for the runoff volume infiltrated from other impervious areas conveyed onto the pervious pavement system. The cross-section typically consists of four layers, as shown in Fig. 4. A description of each of the layers is presented below :

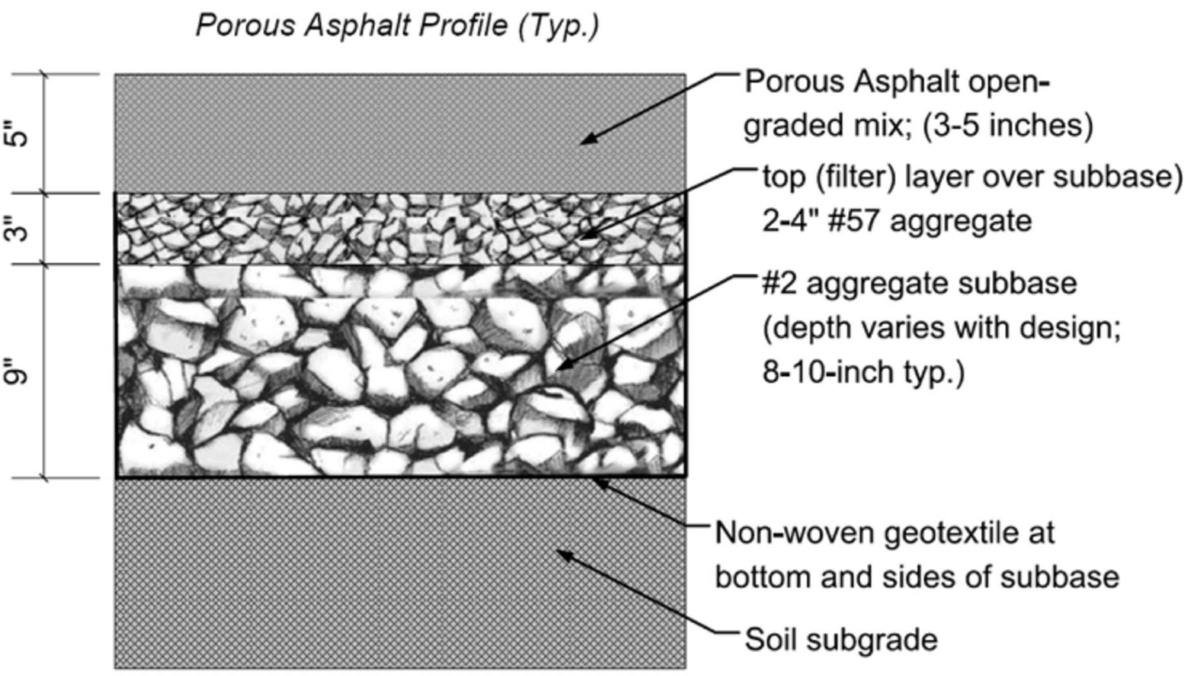

Fig.4. Typical cross-section for porous asphalt pavement (Iowa Stormwater Management Manual , 2009).

3.1 Description of Porous Asphalt Pavements

In general, porous pavement is composed of four layers (Diniz, 1980):

1. Minimally compacted subbase consisting of undisturbed existing soil or, in the case of unsuitable base soils, an imported and prepared base course. Auxiliary drainage structures (French drains, pipe drains, etc.) may also be required.

2. Reservoir base course consisting of 1 to 2 inches (2.54-5.08 cm) diameter crushed stone aggregate. The thickness of this layer is determined from runoff storage needs and frost depth consider- ations as described later in this report.

3. Two inches (5.08 cm) of ½-inch (1.27 cm) crushed stone aggregate to stabilize the reservoir base course surface.

4. Porous asphalt concrete surface course whose thickness is based on bearing strength and pavement design requirements. In most applications, 2½ inches (6.35 cm) has been found to be sufficient.

A typical porous asphalt pavement cross-section is presented in Fig. 5. The following descriptions are adapted from Thelen and Howe (1978, 1976).

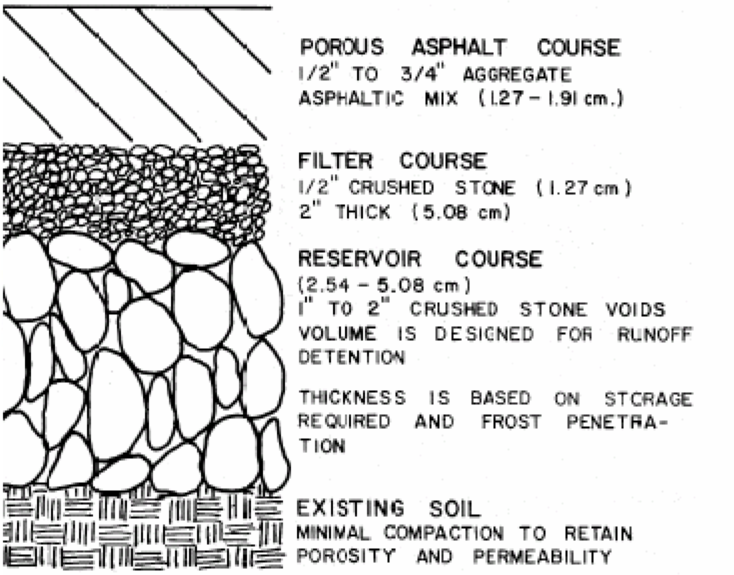

Fig.5. Porous asphalt paving typical section.

The Subbase

All soils under roads may become wet, but they must drain in order to maintain their bearing strength. Because soils under porous pavement will get wet, they must be permeable to water; they must not heave due to freezing or thawing, and they must not swell or substantially lose their strength when wet. Most soils can meet these requirements if proper drainage is available. In current practice it is very important that the subbase under conventional pavement remain dry and that pavements often may be wet due to cracks in the pavement, percolation through the shoulders, and capillarity from ground water. However, base strength is essentially retained because free water can drain away, leaving the soil particle structure intact. Soil strengths, as defined by the California Bearing Ratio, are measured on wet soils because soil wetness is anticipated.

The contaminants on a road surface can range from random spills and pesticides to engine fuel residues.In a storm sewer or street system, they are typically collected in the initial runoff and discharged at one point in a receiving stream; in the porous pavement system they are delivered to the soil over the entire area of the pavement.

It is expected that contaminated water will tend to be purified as it passes through the soil, as a result of absorption of contaminants by soil particles, bacterial action, and dilution. On the other hand, water passing through soil may leach out minerals and pick up bacteria.

At the Franklin Institute Research Laboratories, preliminary tests indicated that aerobic bacteria con live in the soil under porous pavement; these could act like sewage treatment plants to digest organic contaminants. At The Woodlands, Texas site (Hollinger, 1979), aerobic digestion was discovered, with ammonia in the runoff being con- verteci to nitrites and nitrates. Further reduction was not possible due to faulty drainage of the subbase. However, the nitrogen in the runoff from the control pavement was mostly nitrates. Both total organic carbon and chemical oxygen demand were much lower in the porous pavement percolate than in the runoff, because of bacterial action in the base and subbase. The limestone base material also raised the conductivity of the percolate which then neutralized the carbonic acid in the rain and runoff.

Even though initial runoff had high lead concentrations, the percolate at The Woodlands site showed practically no lead, because of faulty drainage of the subbase, so that the percolate was diluted by storage, and because lead accumulations were not significant.

The Reservoir Base Course

In conventional pavement, the base consists of stones, sand, and dust particles packed into a dense mass and designed to transmit mechanical loads from the hardtop to the soil below.

In porous pavement, the base consists of large-sized and graded stones, lightly rolled into an open, interlocking structure which not only transmits mechanical loads, but also stores runoff water which the soil cannot immediately absorb. This water is held in the reservoir formed by voids in the rock matrix until it can percolate into the soil. For size gradations recommended in this report, the voids will be as high as forty percent of the total volume.Of course, if the soil has a higher permeability rate than the rate of rainfall, a reservoir is not needed. However, this is unlikely because maximum rainfall intensities of design storms are generally much higher than the infiltration rates of most soils.

The aim of having a reservoir is to store runoff water for several hours to allow it to percolate into the soil. On sloping pavements, base areas at the higher end of the site are not credited with storage capability even though water enters the base in these areas, because they drain laterally and do not contribute to the percolation system at the higher end of the site.

Because the base reservoir serves a purpose similar to retention basins, runoff from roofs or other impervious and pervious surfaces could be drained into it; but the base must be designed to have the required capacity.

The aggregate used in the base must be hard and durable. Generally it is angular and not round. Crushed stone is the most desirable material because the aggregate interlocks very well. Rounded gravel must be avoided for all areas where heavy traffic is anticipated. The crushed stone should come from one of the following rock groups:

a) Granite
b)Basalt
c)Gabbro
d)Porphyry
e)Blast Furnace Slag

Limestones which are susceptible to polishing by water should be used in only special situations where design loads are within the loading limits for this type of material.

The Reservoir Top Stabilizing Course

To assist in final grading of the reservoir base course to stabilize the surface, a two-inch (5.08 cm) layer of ½-inch (1.91 cm) crushed stone aggregate is recom- mended. Based on previous construction experience, this stabilizer course is necessary because construction vehicles hauling the asphalt hot mix across the reservoir course would create ruts which consequently require constant regrading to finished grade immediately prior to application of the hot mix.

Open Graded Asphalt Concrete Surface Course

Porous asphalt consists of a wearing course of open graded asphalt concrete laid over a base course of uniformly sized aggregate. It differs from conventional asphalt concrete chiefly in that it contains very little dust or sand; its void volume typically is around 16 percent, as compared with the two to three percent void volume of conventional asphalt concrete.

Asphalts used in asphalt concrete range from 50 to 100 penetration grade, depending upon the ambient temperatures and viscosity characteristics desired. In general, the grades used in a given locality for conventional asphalt concretes will suffice for porous asphalt as well. However, the porous product is more subject to scuff ing, such as occurs when the front wheels of stationary cars with power steering are turned. It is therefore suggested by Franklin Institute Research Laboratories that for porous asphalt, 50 to 60 penetration grade be used in the South (Texas, Florida, etc.), 65 to 80 in the mid-Atlantic states, and 85 to 100 penetration grade in the northern states.

The percent of asphalt should be specified between 5.5 and 6, based on the total weight of the pavement. The lower limit is to assure adequately thick layers of asphalt around the stones and the upper limit is to prevent the mix from draining asphalt during transport, particularly if it is accidentally shipped cit a temperature of over 3000 Fahrenheit (149° C).

To avoid damage due to photo-oxidative degradation of the asphalt (since air and sunlight can penetrate further), the asphalt coatings on the aggregate surfaces should be thicker than usual. In this case, the asphalt can form skins or otherwise be mildly degraded without significant loss of cementitiousness.

The open graded asphalt concrete is similar in Marshall properties (strength and flow) to conventional asphalt concrete. Hence, the usual thickness of base course and paving should satisfy load requirements. The base course thickness may have to be increased to provide greater reservoir capacity where runoff volumes and/or soil percolation require it.

4. Construction Sequence

Construction sequence for porous asphalt pavements is given in Fig.6; below a summary is listed:

1. The subsurface infiltration bed located beneath the porous pavement must be excavated without heavy equipment compacting the bed bottom. Fine grading is done by hand.

2. Earthen berms (if used) between infiltration beds should be left in place during excavation. These berms do not require compaction if proven stable during construction.

3. Non-woven geotextile is laid immediately after fine grading is completed.

4. Clean (washed) uniform graded aggregate is placed in the bed as the storage medium.

5. The asphalt is laid down just like conventional asphalt.

6. The finished surface looks like conventional asphalt until it rains. Infiltration beds are completely under the parking lots, minimizing the disturbance envelope.

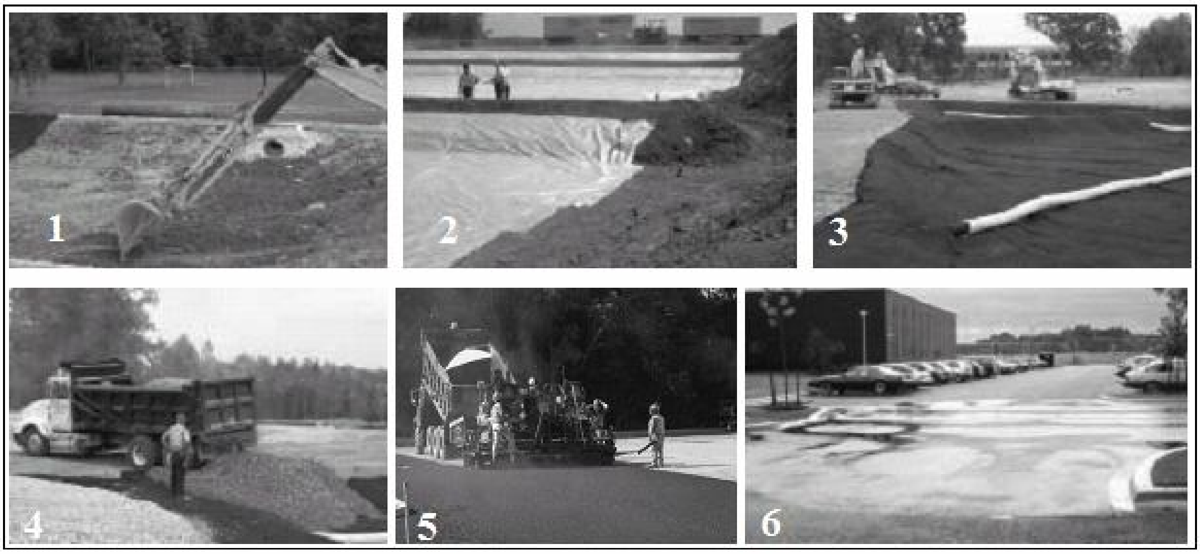

Fig.6. Construction sequence of porous asphalt pavements (Cahill et al., 2003).

5. Maintenance of porous asphalt

Maintenance of porous asphalt pavements is summarized as follows (Cahill, 2005):

1. Vacuum twice per year
2. Maintain adjacent planted areas
3. No construction staging on unprotected pavement surfacepavement surface
4. Clean inlets twice per year
5. Use salt, NOT sand
6. Plowing okay, raise blade slightly
7. Do not seal coat
8. Patch “small”areas with porous or standard
9. Patch “large”areas with porous only

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