R&T UPDATE
Concrete Pavement Research & Technology

An Evaluation of Jointed Plain and Jointed Reinforced Concrete Pavements

In the design of jointed concrete pavements, engineers have a decision to make regarding whether or not to use distributed steel reinforcement. They may select a plain, non-reinforced pavement with short joint spacings, or a reinforced pavement with longer joint spacings. While both designs can provide good service, most engineers are aware that plain pavements offer advantages both in pavement performance and costs.

The purpose of this publication is to provide information that will be helpful in making this decision. An understanding of the purpose and function of these pavement types will lead to the selection of cost-effective and well-performing pavements.

The information given here applies equally to all uses of jointed concrete pavements: streets, parking lots, highways, airports, and industrial facilities.

Difference Between Jointed Plain and Reinforced Concrete Pavement Designs

If the pavement is jointed to form relatively short panels that will control cracking, distributed steel is not necessary. This design is called plain or non-reinforced concrete. For light traffic situations, load transfer is provided by aggregate interlock – the roughness of the cracked faces beneath the joint. For medium to heavy traffic, smooth dowel bars are installed in the transverse joints to help load transfer.

On the other hand, if joints are placed to form longer panels, intermediate cracking between the joints can be expected. Distributed steel is required to hold the crack faces tightly together and this design is called reinforced concrete. (The distributed steel is also referred to by other terms such as wire mesh, welded wire fabric, temperature steel, bar mats, and steel reinforcement.) With longer joint spacings, larger joint openings will result from temperature changes, making load transfer by aggregate interlock less effective. Therefore, dowels must be installed to ensure load transfer. Some engineers call this a jointed reinforced or mesh-dowel design.

Natural Crack Development

An understanding of how concrete pavements crack is paramount in the pavement designer's selection of joint spacing and whether distributed steel is needed or not.

Cracking occurs naturally in concrete and is caused by initial drying shrinkage, by changes in temperature and moisture, and by stresses due to traffic loadings. If the concrete could move freely in response to these forces, no cracking would occur. However, friction and shear forces of the underlying subbase or subgrade resist the movement of the concrete pavement. The resulting tensile stresses can be excessive and crack the concrete.

A major cause of early cracking is temperature change. Considerable heat is generated in the concrete by the chemical reaction of cement hydration, and the temperature usually peaks during the first day after the concrete is placed. Then, during the first night of pavement life, temperature declines due to reduced hydration activity and the cooler air temperature. As the temperature drops, the concrete contracts. It is the restraint to the contraction that induces stress, which can ultimately crack the concrete.

Another factor contributing to early cracking is initial drying shrinkage. Concrete mixes contain more water than that required for cement hydration. This extra water is needed to provide adequate workability for placing and finishing operations during construction. With time, much of the excess water evaporates, which results in shrinkage of the concrete. Again, restraint of the shrinkage contributes to stress buildup in the concrete.

To visualize the action of early cracking, it is helpful to consider the natural crack pattern of a pavement constructed without joints, as shown in Figure 1.

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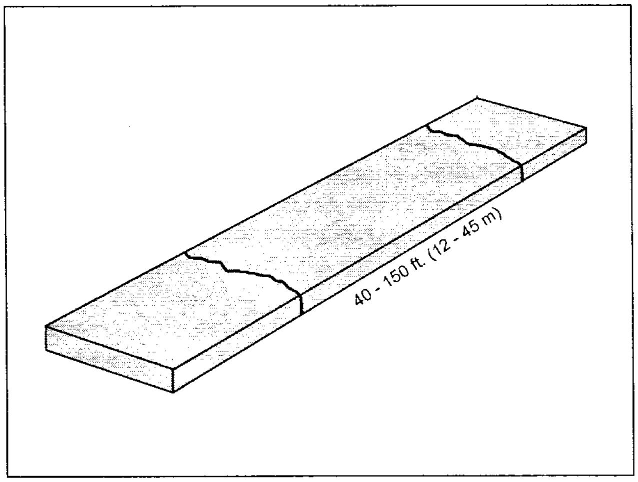

Fig. 1. Initial cracking in unjointed pavement

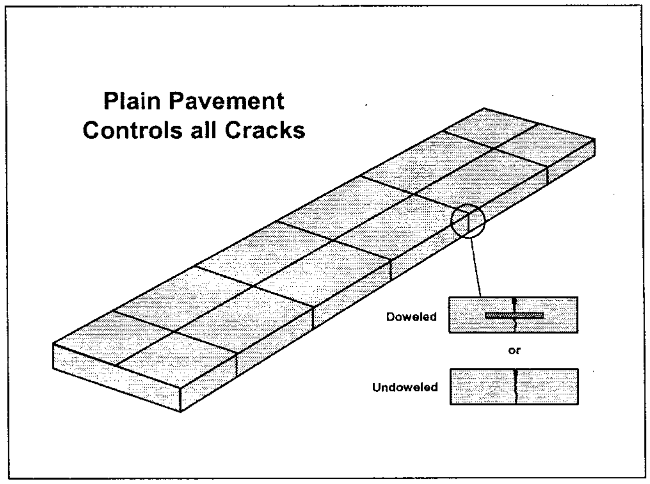

Fig. 3. Properly jointed plain pavement

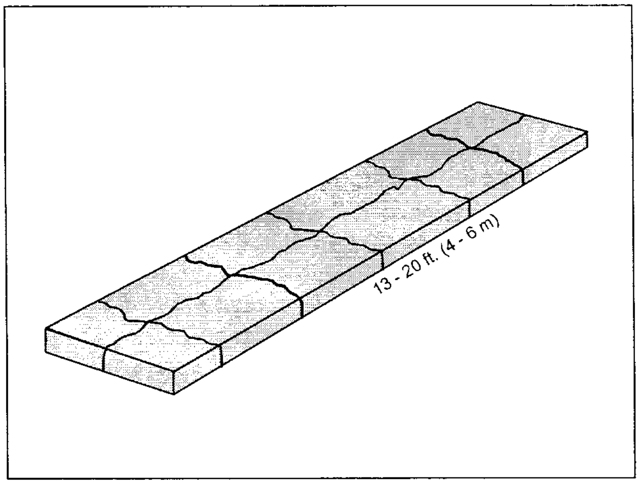

Fig. 2. Crack pattern in unjointed pavement due to environmental and load stresses

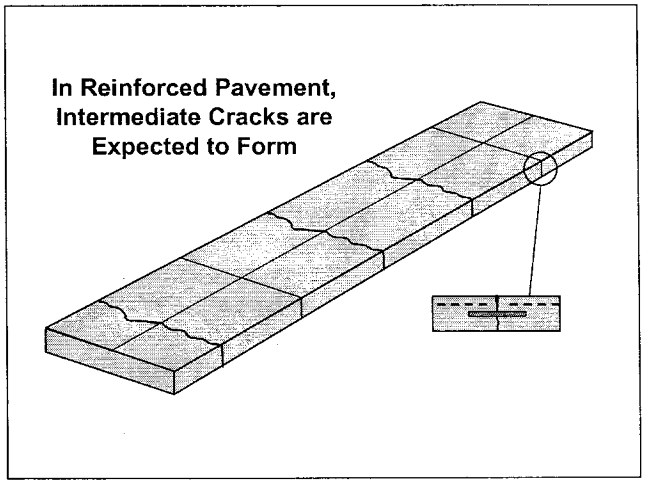

Fig. 4. Jointed reinforced pavement with distributed steel and dowels

Spacing of the initial cracks may vary from about 40 to 150 ft. (12 to 46 m) depending on concrete properties, point-to-point variations in subgrade or subbase friction, and climatic conditions during and after concrete placement.

After a time, additional cracking at closer spacings will occur due to environmental and load stresses. Seasonal temperature variations cause the pavement to contract and expand. Temperature and moisture gradients through the depth of the slab also have effects. The resulting crack pattern is shown in Figure 2.

Proper jointing of non-reinforced pavement provides a series of joints spaced to control the formation of these cracks as shown in Figure 3. The joint provides a plane of weakness that forces a straight-line crack to occur at that location, in plain (non-reinforced) concrete pavements, joint spacing is selected to be short enough that intermediate cracks do not form.

For pavements reinforced with distributed steel, a longer joint spacing is selected and after a period of time, intermediate cracks will form as shown in Figure 4. Distributed steel will not prevent the formation of cracks; its function is simply to keep the cracks tightly closed.

Joint Spacing for Plain Pavements

For plain pavements, a joint spacing is selected to

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be somewhat shorter than the natural crack spacing, which in turn depends primarily on slab thickness. Other factors that affect the spacing are local climate, shrinkage characteristics of the specific concrete used, and the presence or absence of traffic loads. Generally, an old rule-of-thumb has proven to be quite satisfactory for pavement placed on granular subbase layers – that the joint spacing (in feet) should not exceed twice the slab thickness in inches (in metric units, 24 times the slab thickness). Experience has shown that this can be stretched a bit for thin slabs, e.g., 10 ft. (3 m) joint spacing for a 4-in. (100 mm) slab, while for slabs thicker than 12 inches (300 mm), the spacing given by this rule should be reduced somewhat. More detailed information on recommended joint spacings for specific pavement applications (including pavement on stabilized bases) is given in the publications cited on the last page.

In the selection of joint spacing, local experience is often the best guide. Favorable conditions of climate and the other factors mentioned above may permit the use of longer spacings.

For plain pavements, the joint pattern should divide the pavement into panels that are approximately square. Long, narrow panels tend to develop an intermediate crack; this is not likely to happen if the length-to-width ratio does not exceed about 1.25 to 1.5.

Advantages of Plain Pavements Over Reinforced Pavements

The relatively small amount of distributed steel normally used in reinforced slabs does not increase the load-carrying capacity of the pavement nor does it permit a reduction in slab thickness. Since they are considered structurally equivalent, a comparison between plain and reinforced pavements should be based on performance and cost.

Performance. Pavement studies have shown that plain pavements perform at least as well as, and usually somewhat better than, reinforced pavements.

A national survey[1] of highway projects detected significant differences in the performance of plain and reinforced pavements. These pavements had been subjected to medium-to-heavy truck traffic for a period averaging 10 years. As to be expected, intermediate cracking was observed in reinforced pavements regardless of the joint spacing. Occasionally, these cracks had opened sufficiently to lose aggregate interlock load transfer indicating failure of the reinforcing steel. In these cases, major spalling and faulting had occurred at the cracks. Another characteristic observed was that, due to the increased joint movement associated with greater panel lengths, the extensibility of joint sealants was exceeded causing infiltration of debris into the joints and consequent joint spalling. These defects were absent in plain pavements.

At the AASHO Road Test,[2] both plain-doweled and reinforced-doweled pavements were subjected to truck loadings for 2 years. Studies of the resulting data[3,4] concluded that the plain slab design was definitely superior with specific regard to major cracking, and equal to or slightly better than reinforced pavements in other aspects of performance.

Additional national studies of the comparative performance of conventional pavement types[5,6] included both plain and reinforced concrete pavements as well as other types of pavement. Heavily trafficked highways in the age range of 10 to 25 years were selected for the survey, which reported the types of distress and amount of maintenance applied. Regarding the performance of plain and reinforced concrete pavements, the final report[6] concluded:

"Transverse joint spacing has a very significant effect on pavement performance. Decreasing transverse joint spacing has the following beneficial effects:

1. Decreases thermal curl stress
2. Decreases transverse cracking
3. Decreases upward curling of slab at joint
4. Decreases joint spalling
5. Decreases seasonal and daily joint opening,

which thus increases joint load transfer effectiveness and reduces sealant extension."

One of the principal objectives of this research was to determine which type of pavement offered the best long-term service with the least amount of maintenance and consequent disruption to traffic. Based on the performance survey of 5 pavement types, plain concrete was selected as the most promising.

Costs. Obviously a plain pavement will be more economical, but there are some trade-offs. The cost of sawing or forming joints will be greater for plain pavements since there are more joints. However, this is more than offset by the cost of the distributed steel and the requirement for dowel bars in jointed reinforced pavements. (As discussed previously,

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dowel bars may or may not be required for plain pavements depending on traffic volume.) In reinforced pavements, joints are sawed wider to form a sealant reservoir, necessitating the use of more sealant material per joint. Also, to accommodate larger joint movements, a higher quality, more costly sealant material is usually recommended.

A survey[1] of state highway agencies and contractors showed the following initial cost comparisons:

- Reinforced pavements cost 29 to 54% more than plain, **undoweled** pavement
- Reinforced pavements cost 8 to 19% more than plain, **doweled** pavements

The same survey also analyzed maintenance costs of highway agencies. On average, reinforced pavements had about 11% greater maintenance costs than plain pavements; however, there was considerable scatter in the data due to non-uniform maintenance practices among the agencies. Since routine maintenance is often neglected or not recorded, it is probable that this differential cost would be greater if adequate and timely maintenance operations had been performed and recorded.

Agency Use of Pavement Types

A survey conducted by ACPA in 1999 of state highway agencies (departments of transportation, or DOT's) showed that 10 states still have jointed reinforced designs in their standards and specifications, but it also noted that only 2 states still routinely build these types of pavements. Most DOT's have recognized the fact that jointed reinforced designs give a lesser grade of performance than jointed plain pavements and are more costly to build, maintain, and repair.

Summary

This publication is intended to demonstrate the viability of jointed plain concrete pavements containing no distributed steel. It is important to note that jointed plain concrete pavements perform much better than jointed reinforced pavements. In fact, pavement performance studies of heavily trafficked roadways have shown that plain pavements provide superior serviceability, show less distress, and require less maintenance than jointed reinforced pavements. More obvious is the fact that jointed plain pavements offer many advantages in cost and ease of construction due to the absence of distributed steel reinforcement.

In this discussion, the design of joints for plain and reinforced pavements, and the selection of appropriate joint spacings to control cracking, have been discussed only in a general way. For more details on these topics the reader is referred to the following ACPA publications:

- Design and Construction of Joints for Concrete Streets (IS061P)
- Design and Construction of Joints for Concrete Highways (TB010P)
- Design of Heavy Industrial Concrete Pavements (IS234P)
- Design of Concrete Airport Pavements (EB050P)

References

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6. Darter, M.I., Design of Zero-Maintenance Plain Jointed Concrete Pavement, Report No. FHWA-RD-77-111, Federal Highway Administration, 1977.

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