SOME DESIGN CONSIDERATIONS FOR JOINTED, REINFORCED CONCRETE PAVEMENTS (JRCP)

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It is not known precisely when the first reinforced concrete pavements were built. The Wire Reinforcement Institute has a series of photographs showing the construction of experimental concrete pavements in California from 1912 to 1919. Two of these photos show the installation of rolled welded wire fabric in the construction of a road at the Oakland, California waterfront in 1913. The series also includes photos showing the use of triangular "mesh" and flat sheets. Incidentally, one photo shows a pavement with "diagonal" joints which was installed in 1912 in Yolo County, California. Most of the pavements were 4, 5 and 6 inches thick. Reinforced pavements were thus an early entrant into concrete pavement technology and have been playing an important role ever since.

The study of reinforced pavements continued during the twenties and by the end of the thirties usage was well established. The greatest period of growth was during the construction of the Interstate System. Institute figures show that the equivalent of over 69,000 miles of 24-ft. wide pavement were constructed in the 25-year period from 1950 through 1975. This is a very substantial amount of the total concrete pavement placed during this period. The Institute further observes that a substantial amount of the concrete pavement being placed today is jointed, reinforced pavement. The latter statement is based on tonnage shipments of paving fabric supplied by our membership.

FEATURES OF JOINTED, REINFORCED PAVEMENT

The three basic types of concrete pavement are: (1) plain, jointed pavement (JCP), (2) continuously reinforced concrete pavement (CRCP), and (3) jointed, reinforced concrete pavement (JRCP). Each pavement type has advantages and each is most effectively used under certain climatic and traffic conditions. Plain pavement is unreinforced and requires a very close joint spacing which is a disadvantage. It is obviously lowest in initial cost unless it is thickened to compensate for the absence of reinforcement. On the other end of the spectrum is continuously reinforced concrete pavement (CRCP) which has no joints except for a few at intersections and bridges and those necessary for construction. CRCP is heavily reinforced, using 0.5 to 0.7 percent steel. A large percentage of CRCP is constructed using rebars although welded wire fabric is used in some areas.

Jointed reinforced concrete pavement (JRCP) is widely referred to as "mesh-dowel" pavement, pavement with distributed steel, mesh pavement and as conventionally reinforced pavement. Jointed reinforced concrete pavements are what one might call a "middle-of-the-road" pavement -- and that is not intended to be a pun.

The basic features of JRCP are:

1. Transverse joints to subdivide the slab into practical, yet manageable panel lengths with a minimum number of joints.

2. Reinforcement to help control cracking and subsequent distress to the slab. The pavement is reinforced in both the longitudinal and transverse directions.

3. Load transfer devices (dowels) across the transverse joints and longitudinal ties across the longitudinal joints.

Thus JRCP incorporates longer panels than plain pavement because the panels are reinforced. Longer panels require fewer joints and this is an asset from the standpoint of rideability, construction and maintenance. Since the transverse joints are doweled, load transfer across these joints is provided. CRCP has the advantage of no joints but requires heavy reinforcement. Most conventionally reinforced pavements require 0.05 to 0.15 percent steel whereas CRCP requires 0.5 to 0.7 percent. Thus the steel requirements are considerably lower for JRCP.

The fewer number of joints and lesser amount of steel are the reasons for the remark that JRCP is a "middle-of-the-road" pavement type when compared to plain and CRC pavements. JRCP is thus a compromise between heavily jointed, undoweled plain pavement and heavily reinforced, jointless CRCP.

JRCP COMPONENTS AND THEIR FUNCTION

The basic components of a jointed reinforced pavement are the (1) soil and/or subbase, (2) concrete slab, (3) reinforcement, (4) load transfer devices, and (5) joints and joint sealants. Each component performs a necessary function in the design of reinforced pavements.

Soil and Subbases

This paper will not dwell upon this key subject except to mention that support must be uniform, non-pumping and well-drained. If support is deficient, the pavement will show distress.

Concrete Slab

The slab is the pavement. It's assumed that all elements such as quality control, sufficient cement content and strength, air-entrainment if needed, finishing and curing will be adequate.

Reinforcement

The function of reinforcement in pavement is to control cracking not to prevent it. The amount of steel used in JRCP is minimal, usually less than 0.1 percent. If a slab were truly reinforced the amount of reinforcement would be considerably higher and the location of the steel varied to meet stress conditions. Reinforcement does add some structural capacity to pavement slabs. No one really knows how much and no value has been assigned for additional structural capacity. It is somewhat analagous to the old assumption that concrete had no tensile strength and thus none was assumed.

A slab is subjected to internal, external and climatic conditions which cause cracking. Once a crack has formed, the unreinforced slab depends upon aggregate interlock to transfer load across the crack. When the width of a crack exceeds 0.035 to 0.04 in., the crack is too wide for aggregate interlock to be effective and distress can usually be anticipated at the crack, particularly if the ADTT is high and/or the subbase marginal.

The reinforcement is therefore designed to keep the cracked sections tightly together so that the cracked slab acts as a unit and so that aggregate interlock can perform effectively.

Reinforcement also provides some doweling action across a section helping to maintain vertical alignment of the cracked sections.

The reinforcement is placed in the top part of the slab, generally $2\frac{1}{2}$ to 3 inches below the top surface. Experience has shown that cracks starting at the top will remain tighter when the reinforcement is in the upper third of the slab.

Load Transfer

Load transfer is necessary across joints particularly if the pavement is subjected to heavy traffic or moderately heavy truck traffic. Aggregate interlock can rarely be relied upon to provide load transfer under these conditions. As mentioned previously, aggregate interlock is ineffective when the width of a crack or joint such as a sawed transverse joint, exceeds 0.035 to 0.04 in. The two factors primarily causing contraction of a slab are shrinkage and thermal drops. Shrinkage is sometimes overlooked and it should not be. It has been observed that concrete has its greatest volume at the time it is placed. As it cures and ages, it contracts unless there are unusual situations such as reactive aggregates or chemical attack. Many factors, such as water-cement ratio, type of aggregate, climatic conditions, curing and thickness of slab affect shrinkage. Numerous values have been assigned for shrinkage. The WRI manual on JRCP paving design uses a value of 0.00005 in./in. in mature concrete or about 50×10^{-6}. Others use shrinkage coefficients generally higher than this and they are often in the range of 200 to 300×10^{-6}. Temperature drops also cause a slab to contract. The factor used by WRI in its manual is 0.000004 in./in./F^{O}. The AASHTO Road Test Laboratories determined values of 4.6×10^{-6} to 5.1×10^{-6} per degree F. The lower WRI figure allows for subgrade restraint. The contraction of a slab using WRI values can be determined with the following equation:

(1) $w = 12L\,(eT + d)$

w = Joint or crack opening, in.
L = Slab length, ft.
e = Temperature contraction coefficient (0.000004 in./in./F^{O})
T = Temperature drop, F^{O}
d = Shrinkage coefficient (0.00005 in./in.)

Using this formula with conservative coefficients and a conservative temperature drop of 60^{O} F, it is found that a slab section 11.5 ft. long will open to a width of 0.04 in. or the maximum width for effective aggregate interlock action. The above formula can be used to calculate joint openings in a plain uncracked slab or a reinforced slab. It can also be used to calculate the width of a crack in a plain slab.

It is thus necessary to use dowels to transfer load across transverse joints when the anticipated opening exceeds 0.04 in. Dowels are necessary when the pavement has a high level of truck traffic, where there is heavy rainfall or a poor draining soil or where the subgrade is marginal. Treated bases add support but have not been found to be a substitute for dowels.

Joints and Joint Sealants

Jointed pavements have both longitudinal and transverse joints. They are an integral part of jointed pavement systems and they perform a necessary function. Longitudinal joints are primarily installed to provide curling relief.

Transverse joints are placed either at right angles across the pavement or skewed at an angle approximately 2 ft. longitudinally to 12 ft. transversely. Transverse joints may be (1) contraction joints, (2) expansion joints, (3) a combination of contraction and expansion joints, or (4) construction joints.

Transverse joints are installed to control and minimize cracking due to warping, frictional stresses, load stresses, shrinkage, and thermal and moisture changes. Joints must be properly designed and sealed with serviceable yet economical joint seals. Sealants deter water and de-icing agents from entering the joint and subsequently damaging the concrete, dowels and subbase. Equally important, sealants prevent the entry of incompressibles such as stone particles from entering the joint at low-temperature periods and accumulating sufficiently to restrict expansion during hot weather. If expansion is restricted by the accumulation of incompressible materials, pavement distress will usually occur -- often in the form of a pavement blow-up. Joint sealants should be durable, economical, generally impregnable and have sufficient extensibility to keep the joint effectively sealed at all times.

DESIGN OF SLAB THICKNESS

The two most widely used methods of determining slab thickness are the Portland Cement Association (PCA) method and the AASHTO method. There are several other recognized methods of thickness design. Some states use an arbitrary minimum thickness based on one of the above methods and couple this with their experience with soil, climatic and traffic conditions in their area.

Normally, the same procedures are used to determine the thickness of both plain and conventionally reinforced pavements. Some highway departments add one inch or more to slab thickness when using plain concrete. There is also a provision by the U. S. Army Corps of Engineers to reduce thickness if the slab is reinforced with a minimum amount of steel. At the present time the Institute suggests use of the PCA method for JRCP which considers most of the critical design factors encountered in pavement design.

DESIGN OF REINFORCEMENT

Three types of mild reinforcement can be used for JRCP. These are welded wire fabric, bar and rod mats and rebars fabricated into reinforcement mats. Welded wire fabric is used almost universally in conventionally reinforced pavements.

Welded Wire Fabric

Welded wire fabric is a prefabricated reinforcement consisting of a series of cold-drawn wires welded together in square or rectangular grids. The wires at intersections are resistance welded where pressure and heat fuse them together into a homogeneous section. There are two types of fabric -- smooth and deformed. Smooth fabric relies upon the welded intersection to develop bond with the concrete. Deformed fabric has deformations along the wires. Bond is developed by the deformations and at welded intersections of the wires. Table 1 gives the properties of welded wire fabric.

Table 1
Properties of Welded Wire Fabric

Type of Fabric	Specification Number ASTM	Specification Number AASHTO	Yield Strength psi	Tensile Strength psi
Smooth	A 185	M 55	65,000	75,000
Deformed	A 497	M 221	70,000	80,000

Paving fabric is used in the form of flat sheets or mats. The designation of a style of fabric gives the longitudinal and transverse wire spacings in inches, the type of wire and the cross-sectional area of both wires. In 1971 ASTM changed from the use of gauge numbers to a letter-number combination which denotes the type of wire and its size in hundredths of a square inch. The letter "W" designates a smooth wire and "D"

designates a deformed wire. For instance, W5 indicates a smooth wire with a cross-sectional area of 0.05 sq. in. W7.5 would indicate a smooth wire with a cross-sectional area of 0.075 sq. in. D9 would indicate a deformed wire with a cross-sectional area of 0.09 sq. in. It appears that the industry will follow the system of area designation when we change to the metric system. We urge the various highway departments to change their style designations from the somewhat archaic gauge numbers to the new cross-sectional area method.

A typical paving fabric style might appear as follows: 6 x 12 - W6.5 x W4. The first two numbers designate the spacings of the longitudinal and transverse wires respectively. In this instance the longitudinal wires are 6 in. apart and the transverse wires are 12 in. apart. Hence the combination "6 x 12". The second part of the style designation is a letter-number combination and gives type of wire and cross-sectional area. In the example, W6.5 indicates that the longitudinal wire is smooth and has a cross-sectional area of 0.065 sq. in. The transverse wire is a smooth wire with an area of 0.04 sq. in.

Either smooth or deformed fabric can be used in JRCP. There are limits on the relationship of the size of the transverse wire to the longitudinal wire which must be followed. In smooth fabric the smaller wire, which is generally but not always the transverse wire, must have an area of at least 40 percent of the size of the larger wire. In deformed fabric the smaller wire must have an area 35 percent or more of the larger wire. The wire size relationship is specified to assure that the wires are properly sized for effective welding of the fabric.

The minimum size wire recommended for paving fabric is W4 or D4 which has a cross-sectional area of 0.04 sq. in. and a diameter of 0.225 in.

Determining Steel Requirements

The traditional subgrade drag theory formula is almost universally used to determine the amount of steel reinforcement used. The formula is:

$$(2) \quad A_s = \frac{FL6.25h}{f_s}$$

A_s = Cross-sectional area of steel in sq. in. per lin. ft.
F = Coefficient of friction
L = Panel length (or width if appropriate), ft.
h = Slab thickness, in.
f_s = Working stress of steel, psi.

When a slab contracts frictional resistance between the pavement and the base develops tensile forces in the concrete. When the tension in the concrete exceeds the tensile capacity of the slab, a crack will develop. Friction between the slab and base is important and varies with the base material. Thus the Coefficient of Friction, F, was developed to account for the factor. Frictional coefficients will vary with many factors such as the type of base material, thickness and length of slab and the uniformity of the bottom surface of the slab. For typical aggregate bases many engineers use a coefficient of friction of 1.5. Some conservative designers use a value of 2.0. An interesting problem occurs when evaluating "F" for treated bases. In some instances, the slab is fully or partially bonded to cement treated bases which increases frictional resistance. In this case designers should probably use both the thickness of the slab and treated base when determining thickness "h". The entire area of friction coefficients needs more study since it effects all types of concrete pavement. Polyethylene, for instance, reduces "F". Partial bond to a treated base will conversely increase "F". The selection of the correct value is important since steel requirements are directly proportional to the coefficient of friction.

Panel length "L" is expressed in feet. The steel requirements are directly proportional to the panel length. Panel lengths typically vary from 40 to 100 feet in the U. S.

The working stress of the steel is calculated by using a certain percentage of the yield strength of the steel. FHWA uses a working stress of 0.75 f_y which gives a factor of safety of 1.33. The Federal Aviation Authority uses 0.67 f_y which provides a factor of safety of 1.5. Some engineers use lower working stresses with factors of safety up to 2. The working stress values for smooth and deformed fabric for 0.67 f_y and 0.75 f_y are:

Smooth fabric:

$f_s = 0.67\ f_y = 0.67 \times 65{,}000 = 43{,}000$ psi

$f_s = 0.75\ f_y = 0.75 \times 65{,}000 = 48{,}750$ psi

Deformed fabric:

$f_s = 0.67\ f_y = 0.67 \times 70{,}000 = 47{,}000$ psi

$f_s = 0.75\ f_y = 0.75 \times 70{,}000 = 52{,}500$ psi

General Comments on Fabric Design

Specifying engineers can sometimes effect considerable economies by the proper design of fabric sheets. Side and end laps affect the width of sheets. End laps or splices should be about 30 times the diameter of the longitudinal wire and the splice should include overlapping of at least two transverse wires in each sheet. Side laps should overlap at least 20 diameters but not less than 6 inches. The reinforcement should extend to 2 to 6 inches of the edge of the pavement. Three inch edge coverage is a widely used specification.

Fabric production machines vary in their capabilities. There are a number of machines that can produce fabric up to 156 in. in width and up to 50 ft. in length. Shipping and handling affects sheet width and length. Railroad shipments are generally restricted to 138 in. or less in width and 40 ft. or less in length. Truck shipments are generally restricted to widths of 96 to 102 in. and lengths of 40 ft. Selection of sheet length can affect shipping costs also. For instance, two stacks of sheets 18 ft. or less can be loaded on a 40-ft. long trailer or rail car whereas only one stack of sheets with lengths of 18 ft. and over can be loaded. The design of sheets should not be determined by shipping requirements but sheet length is a point to be considered.

A typical fabric style for reinforcement for JRCP is a 6 x 12 in. arrangement. Fabric production equipment can normally produce fabric with a 2, 3, 4, 6, 8 or 12 in. longitudinal wire spacing and 4, 6, 8, 12 or 16 in. transverse spacings. A few machines can produce a 24-in. long transverse wire spacing. The ability to vary wire size spacing and wire size permits an engineer to specify reinforcement extremely close to design requirements. The minimum sized wire recommended for paving is W4 or D4. The minimum longitudinal wire spacing for paving is 4 in. but not over 12 in.

In some instances, particularly airport pavement, the sheets have been turned 90 degrees and the transverse wires used as the primary reinforcement.

The question of rust on fabric sometimes arises. A coating of rust is desirable since it increases bond of the concrete to the steel. The rust must not, however, be heavy enough to decrease the original diameter of the reinforcement nor should it have loose scale which would lessen bond.

DESIGN OF PANELS AND JOINTS

Panel length, reinforcement and joints are inter-related and dependent upon each other. Joints in pavement are not particularly an asset. E. A. Finney, in his book Better

Concrete Pavement Serviceability, remarks, "Sealing of joints has been a problem to the engineer, a nuisance item to the contractor, a costly maintenance operation and a headache to the highway user." It is desirable to use as few joints as possible. Table 2 gives the number of joints for various panel lengths.

Table 2
Number Transverse Joints per Mile

Transverse Joint Spacing feet	Transverse Joints per Mile	Lin. ft. Transverse Joints per mile (2 lanes - 24' wide)
12	440	10,560
15	352	8,448
20	264	6,336
30	176	4,224
40	132	3,168
50	106	2,544
70	75	1,800
100	53	1,272

Panel Length

Panel lengths normally vary from 40 to 100 ft. in the U. S. One state highway department uses a reinforced concrete panel length of 27 ft. with skewed joints. Square end fabric sheets are used and the dowel baskets are skewed. Another state highway uses a 45-ft. joint spacing but saws two warping joints across the panel at 15 ft. centers. The reinforcement is designed for a panel length of 45 ft. Another state highway department uses a 50 ft. panel length for calcareous and 25 ft. for siliceous aggregates. FHWA suggests a maximum panel length of 40 ft. for JRCP and 15 ft. for plain pavement. The Institute feels that a panel length of 40 to 60 ft. should be considered with the longer panels being used in the warmer areas where thermal effects are less pronounced. Panel length affects the structural performance of the slab, rideability of the pavement, maintenance and finally but certainly not least, economics. Generally, and assuming that all parts of the pavement system function properly, longer slabs require fewer joints and thus give better rideability. Incidentally, rideability will certainly become a much more critical factor as cars become lighter and more affected by pavement roughness. I suspect that rider comments on pavement roughness will increase as the size and weight of cars decreases.

As panel length increases, cracking increases. One can generally expect cracks to form at 15 to 30 ft. intervals. A designer should expect some cracking in JRCP. However, one must remember that the primary purpose of reinforcement is to control cracking, not to prevent it. When a slab is reinforced, the amount of steel required will be directly proportional to the length of the panels. For instance, a 100-ft. long panel will require twice as much steel as a 50-ft. long panel. It might be pointed out that the total cost of heavier reinforcement in place should not increase proportionally because chairing and placing costs are not appreciably higher for the placement of a heavier fabric over a lighter fabric. As panel length increases, fewer dowel assemblies are needed for load transfer. This factor affects the economics of pavement considerably.

Panel length directly affects joint design. Formula 1 gives the width across the joint in either plain or reinforced pavement as it is affected by shrinkage and temperature drops. The designer must therefore consider the type of joint to be used when designing panel length. If the panels are too short, jointing costs will probably be high particularly if dowels are required. If the panels are too long, it may be difficult to find sealants that will perform satisfactorily. Thus performance, maintenance and costs are three

elements that the designer should consider when determining panel lengths.

Longitudinal Joints

Longitudinal joints are usually lane joints. They provide curling relief and are tied with deformed rebars to prevent horizontal movement. They are normally one of three types: (1) weakened plane, (2) keyed, and (3) butt joints. When full width pavement is used, the joints are usually sawed and sealed. The seal is usually a hot poured sealant since extensibility is not important because of the ties. If the tie bars are bent, it is essential that Grade 40 rebars be used since they are more ductile than Grade 60 and can be straightened easier.

Transverse Joints

Transverse joints are placed at 90 degrees to the edge of the pavement or skewed. The various types of transverse joints are: (1) contraction, (2) expansion and (3) construction joints. Some state highway departments use only contraction joints, some use a combination of contraction and expansion, and one department uses only expansion joints. Contraction joints are generally sawed to a depth of $\frac{1}{4}$ h. The width of the joint is usually 1/8 to $\frac{1}{4}$ inch. Contraction joints are also called control joints since one of their functions is to control the location of cracks. In some areas, contraction joints for streets are formed with inserts and sealed. Sawed contraction joints are used almost universally in plain pavement and extensively in reinforced pavement at the dowel assemblies. Expansion joints are placed at structures and intersections to absorb end movement of a pavement if temperatures become excessive. One state highway department uses expansion joints only. Thus every doweled joint is an expansion joint. Expansion joints are full-depth joints. The key element in an expansion joint is a treated compressible board 3/4 to 1 in. thick placed vertically in the joint. If the joint is doweled, the board is placed at dowel mid-length. The plastic or metal cap on the end of a dowel must be at least as long as the thickness of the board. The top inch of the board is removable and is removed after the pavement is placed and the area sealed. Some states use a combination of contraction and expansion joints using an expansion joint every 200 to 500 feet. Expansion joints also act as contraction joints so in reality they are multi-purpose joints. Expansion joints appear to do a sound job in keeping incompressibles out of joints. The specifications for expansion joint materials are AASHTO M33 and M213.

Joint Sealants

Joints are no better than their sealants. A sealant should stop the movement of water through the joint and keep foreign incompressible materials from entering and accumulating in the joint. A good sealant will adhere to the walls of the joint and have sufficient extensibility to elongate when the panels contract. The two types of sealants used are preformed strips of an elastomeric material and poured type sealants using one or two components. Common practice today is to saw or preform an opening to 1/8 to $\frac{1}{4}$ in. wide and h/4 deep. If sawed, the joint is cut 4 to 18 hours after placing the concrete. Later, perhaps up to 3 days, a reservoir 3/4 to 1 inch wide is cut directly over the original saw cut. An FHWA notice suggests recommendations for proportioning the size of reservoirs. The entire joint is cleared mechanically of all larger pieces and then the joint is flushed with water or cleaned with compressed air. A piece of rope or tape is placed at the bottom of the reservoir and the joint is filled with a poured type sealant. The width of the reservoir, R, can be found with the following formula:

(3) $$R = \frac{12L\,(eT+d)}{q}$$

R = Width of reservoir in inches
q = Cold temperature extensibility
L, e, T & d = See definition, Formula 1

As one can see from the formula, a long panel filled with a material with a low extensibility requires a totally inappropriate reservoir width. In this instance either the panel should be shortened or a sealant with greater extensibility used.

The joint sealants of lowest cost are hot-poured sealants. The AASHTO specification covering them is M173. They are usually asphalt-rubber compounds and are most effectively used in mild environments where joint movements are small.

Cold poured elastomerics are usually two component systems meeting ASTM Specification D 1850. They are costlier than hot-poured materials and have greater extensibility.

Preformed sealants are installed mechanically. They are precompressed and placed with special equipment into the recess. A solvent-lubrication is used to facilitate installation. Many preformed or premolded sealants are compartmented. They are compressed at least 20 percent and not over 50 percent. The AASHTO specification covering preformed sealants is M220.

DESIGN OF LOAD TRANSFER DEVICES

A joint is a weakened section in a pavement. As wheel loads move across a joint, it will fault if load transfer through aggregate transfer or load transfer devices are not provided. Load transfer devices help maintain vertical alignment. Their purpose is to provide shear transfer. They are particularly needed in pavements with heavy loads, areas subjected to soil volume change or frost action and pavements with loss of support due to pumping.

Dowel assemblies are almost invariably used when load transfer devices are required. Properly installed dowels work fine. Improperly placed or corroded dowels can be a disaster. Most dowels are held in dowel baskets. There is some equipment which implants loose dowels. Dowels are placed at mid-depth and capped on one end to permit horizontal movement. They are used with both contraction and expansion joints. The joints may be sawed, formed or they may be full-depth.

Disaster occurs when dowels "freeze" or "seize". This situation occurs when dowels are misaligned, either vertically or horizontally, or when they corrode and develop bond with the concrete. If a number of adjacent doweled joints freeze, a situation not unlike under-reinforced continuously reinforced pavement develops. The cross-sectional area of steel at the dowels is about the same as that used for CRCP while the cross-sectional area of steel through the JRCP is probably a little less than 0.1 percent. Naturally the distributed steel is grossly over-stressed and sometimes fractures. The fracture often occurs at a mid-panel crack. To make matters worse, the pavement has no load transfer capability since the crack is usually too wide then for aggregate transfer. Locked or frozen doweled joints can also cause pavement blowups and result in spalling at these joints.

To prevent dowel seizure there are practical remedies, which are: (1) use dowel baskets of sufficient rigidity to permit proper alignment, (2) insist that inspectors check both vertical and horizontal alignment before and during placement of concrete.

All dowels must be parallel to each other and to the longitudinal direction of the pavement. It helps to carefully place some concrete around dowel assemblies to stabilize them before the pavement equipment places and finishes the slab. Proper placement is essential. A little time here can save hundreds of thousands of dollars for repairs later. FHWA suggests a placement tolerance of $\pm \frac{1}{4}$ in. per 18-in. dowel Dowel baskets should be pinned securely to the subgrade.

3. Use coated dowels or dowels clad with non-corrosive metal. There are several plastic and epoxy coated dowels which have performed exceedingly well in tests. Some states use stainless steel clad dowels to control corrosion. Corrosion protection is important in areas subjected to heavy salting. Ironically, dowels are necessary where truck traffic is heavy which is often on Interstate routes where salting may also be heavy. Some coated and clad dowels require applications of a lubricant to further reduce chance of bond with the coating.

Dowels are usually 18 inches long and spaced on 12 in. centers. They are quite often either 1 or $1\frac{1}{4}$ in. in diameter. A rule of thumb is to use 1/8 in. in diameter for each inch of pavement thickness. The steel for solid dowels should meet Grade 40, ASTM A 615. Tubular dowels with capped ends are produced to ASTM A 501 or ASTM A 53. Dowels should be sawed not sheared to provide smooth, burr-free ends. One end of each dowel is greased to prevent bond. Dowels should have caps to accommodate movement.

SOME COST CONSIDERATIONS

The principal cost items for concrete pavement are inter-related. The highway engineer should be cognizant of them because they do affect pavement cost. Some considerations are:

1. Pavement thickness. FHWA reported that pavement costs (both rural and urban) averaged $8.62 per sq. yd. in 1975 for a pavement 8.7 in. thick and without reinforcement or joints. Thus proper pavement thickness selection is important.

2. Doweling costs increase as panel length shortens. For instance, dowels at $4.00 per lin. ft. in place would cost $1.80 per sq. yd. on a 20-ft. spacing and 90¢ per sq. yd. on a 40-ft. spacing. Longer panels thus reduce doweling costs.

3. As panel length increases, the cost of reinforcement increases. Using the subgrade drag theory formula, a 100-ft. long panel will require $2\frac{1}{2}$ times as much reinforcement as a 40 ft. panel.

4. As panel length decreases, the number of joints increases. For instance, a mile of 24-ft. wide pavement with a 15-ft. joint spacing will require 352 transverse joints with a total lin. footage of 8,448 lin. ft. Sealing costs will vary with the length, reservoir size and type of sealant selected. The number of joints and their treatment has a considerable effect upon pavement costs. The designing engineer must evaluate all of the above factors. Initial cost is important but annual cost is even more significant. The pavement must provide good rideability when it is built and years later, require low maintenance and of course have a long service life.

SOME DESIGNS THAT MIGHT BE CONSIDERED

There has really been little innovation in the design of JRCP or concrete pavement for that matter for years. We think that it's time that some innovations and new ideas be tried. As engineers we have increased our knowledge of pavement performance, new materials are available, sophisticated equipment has been developed and we have the tremendous efficiency and know-how of the contractors. Here are some thoughts on possible innovations that might be "food for thought."

1. Use of dual reinforcement -- two layers of reinforcement -- top and bottom. One highway department installed a test section of CRCP with two layers of welded wire fabric in 1948 on a heavily traveled road and it is performing well after almost 30 years of service. Pavement with dual layers of reinforcement is reported to be tough. Stress conditions vary in pavements and dual reinforcement might compensate for adverse stress.

Perhaps pavement thickness can be reduced. We suspect that this would be especially true for pavements with thicknesses greater than 10 to 12 inches.

2. Doweled joints with warping joints cut at intervals of 15 to 20 ft. Should lessen steel stress and might shorten joint openings or, conversely, permit overall panel to be longer. Perhaps the longitudinal wires should be coated at the warping joints for added corrosion protection.

3. Long, doweled joints with heavier steel reinforcement. In reality, a jointed semi-CRC pavement. Another possibility is an elastic jointed semi-CRC with doweled joints at long intervals. These systems would require development of a sophisticated joint at a calculated but at this time unknown length. The studies on prestressed pavement may provide information on joints that would be adaptable.

4. Use of shrinkage-compensating cement in JRCP with reasonably long joint spacings in the range of 80 to 150 ft.

5. Use of a concrete composite JRCP using Econocrete and a quality concrete wearing surface. Two-course placement is a natural for placement of distributed reinforcement.

6. Use of heavier wires or more wires at edge of pavement and next to longitudinal joints.

Some of these suggestions may sound far-fetched, but it appears to us that it's time to consider and evaluate some new ideas and concepts. They would have to be studied, analyzed from an engineering standpoint, researched, evaluated cost-wise and tried. Perhaps these suggestions may give you some better ideas. We hope so and we hope that you'll look into them further.

DESIGNING TODAY

The overall performance of JRCP has been excellent. I would like to point out that many thousands of miles of this pavement have been grossly overworked with far more and heavier traffic than was ever anticipated when the pavements were designed and built. Today's engineer has an advantage. He has at his disposal better statistical methods for forecasting traffic, improved subgrades and bases, more efficient construction equipment and knowledgeable contractors, improved joint sealants, coated dowels and a better overall understanding of pavement performance. The jointed reinforced concrete pavement designed and built today should be far superior to that built 15 to 25 years ago, and the pavement designed then has done a fine job overall.

REFERENCES

1. Bradbury, R. D. - Reinforced Concrete Pavements, Wire Reinforcement Institute, Washington, D.C., 1938.

2. Childs, L. D. - Jointed Concrete Pavements Reinforced with Welded Wire Fabric, Wire Reinforcement Institute, McLean, Virginia, 1975.

3. Finney, E. A. - Better Concrete Pavement Serviceability, American Concrete Institute, Monograph No. 7, Detroit, 1973.

4. Rigid Pavements for Roads, Streets, Walks and Open Storage Areas - U. S. Army Corps of Engineers EM 1110-345-292, June 1961.

5. Yoder, E. J. - Principles of Pavement Design, John Wiley & Sons, New York, 1959.

6. Interim Specifications and Methods Adopted by the AASHO Committee on Materials - American Association of State Highway and Transportation Officials, Washington, D.C., 1973.

7. Guide to Joint Sealants for Concrete Structures - ACI Committee 504 Report, American Concrete Institute, Detroit, 1970.

8. Recommended Procedures for PCC Pavement Joint Design - Load Transfer - FHWA Notice, Federal Highway Administration, Washington, D.C., 1973.

9. Joint Design for Concrete Highway and Street Pavements - Portland Cement Association, Skokie, Illinois, 1975.

10. Design, Construction and Maintenance of PCC Pavement Joints, NCHRP Synthesis #19, Highway Research Board, Washington, D.C., 1973.

11. Price Trends for Federal-Aid Highway Construction, Fourth Quarter, 1975 - Office of Engineering, Federal Highway Administration, Washington, D.C., 1976.