Square bars and a special clip-on plastic sheath solve the problem

# A Solution to Cracking and Stresses Caused by Dowels and Tie Bars

by Ernest K. Schrader

Dowels and tie-bars are important to the design of floor slabs and pavements. They provide improved support at the edge of slabs by transferring wheel loads from one slab to the next, and prevent "faulting," or offsetting of adjacent slab surfaces (Fig. 1). Tie-bars also prevent slabs from drifting apart and leaving larger and larger joint openings.

Tie-bars are deformed bars, or are made with some type of end anchorage so that they will not pull out of the concrete. They were originally used in early airfield taxiways to tie the outside two rows of small 15 x 15 ft (4.6 x 4.6 m) pavement slabs to the interior slabs. Without tieing, the exterior slabs would drift away from the interior slabs do to expansion and contraction on the cross slope or crown used to provide drainage. This accounts for the early practice of using tie-bars rather than smooth dowel bars in longitudinal joints.

Dowels must be free to slide in and out of the concrete to allow the joint to open and close as the slabs expand and contract. They were originally used primarily in transverse joints, where the adjoining slabs did not need to be tied by hand to be free to move to accommodate drying shrinkage and temperature changes. Longitudinal drift was usually prevented by the level longitudinal grade and the large number of slabs on each side of a joint. Many designers seem to follow past history and old habits by routinely using dowel bars for transverse joints and tie-bars for longitudinal joints and tie-bars for longitudinal joints in all situations. However, unless there is some special reason for specifying tie-bars in a particular joint, using smooth dowels in both the transverse and longitudinal joints is usually a better technical choice. This practice is becoming more prevalent in today's designs.

## Dowel and tie-bar problems

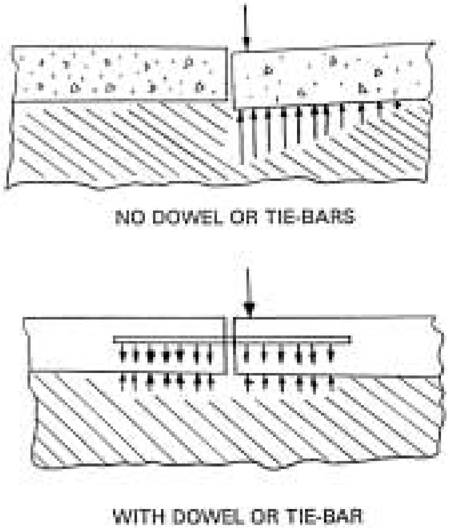
Dowels and tie-bars appear to be quite simple. However, like so many things, their application and complete analysis in the real world is not so simple. For example, if dowels are not exactly aligned perpendicular to the joint, they will restrain contraction of the slabs and can cause or significantly contribute to cracking. Other problems include corrosion that can inhibit free movement of dowels in and out of the slabs and can also cause spalling.

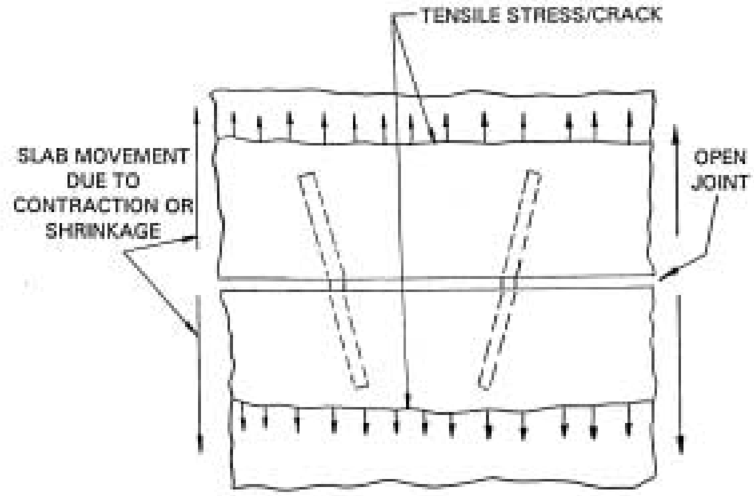
Doweled joints must be free to open and close as the concrete contracts and expands. To allow movement, dowels must be smooth and slippery so they can slide in and out of the concrete without resistance. Smoothness alone doesn't ensure unrestrained joint movement – a bond breaker is also needed at the dowel surface. Dowel performance can be helped with the correct use of grease, a mortar-tight sleeve, or a noncorrosive sleeve that helps reduce bond and improve slippage.

Conventional round dowels must be parallel with each other and with the sides and surface of the slab. If dowels are misaligned, they have to bend as the joint opens (Fig. 2). This can put an enormous tensile stress in the concrete. The result is cracking, reduced load carrying capacity, or a lower usable strength level for the slab. Prefabricated alignment cages can help position the bars and hold them in place during construction. Unfortunately these cages still allow some misalignment, although it is usually not obvious.

Even with these precautions problems still occur. If the top of bottom of the bar is heavily greased, one slab must deflect by an amount equal to the grease thickness before load is transferred to the adjacent slab. High stresses can build up long before the load is transferred. A similar problem may occur if there is any space between the bar and the top or bottom of a sleeve. Also, if mortar enters the sleeve, or if the bare and sleeve corrode, dowel movement will be restrained.

The most significant problem with dowels and tie-bars is their restraint to sideways movement perpendicular to the bars and parallel to the joint, even when the bars are perfectly installed (Fig. 3 and 4).



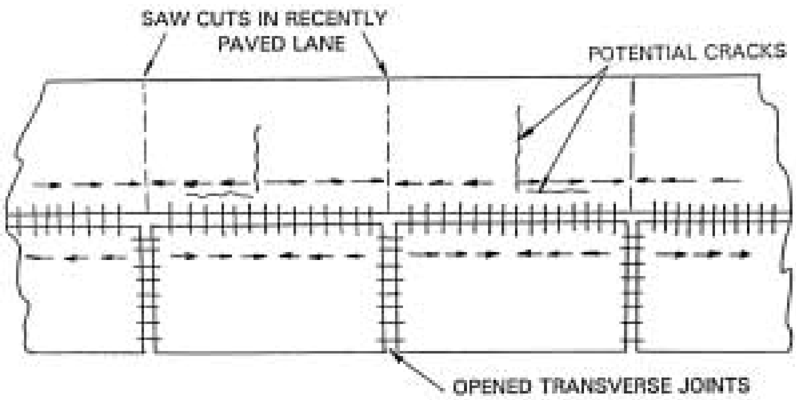



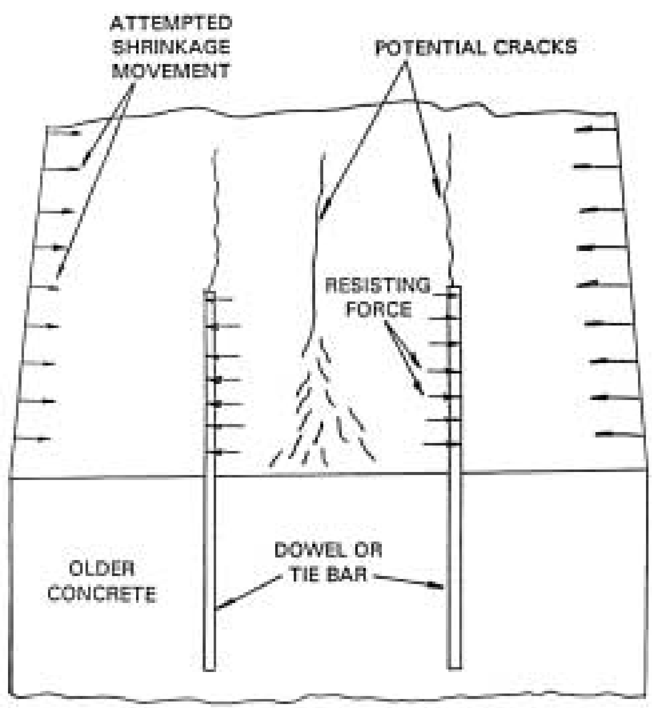

Fig. 1 – (upper left) Dowels and tie-bars transfer loads from one slab to the next and prevent differential movement of slab surfaces.

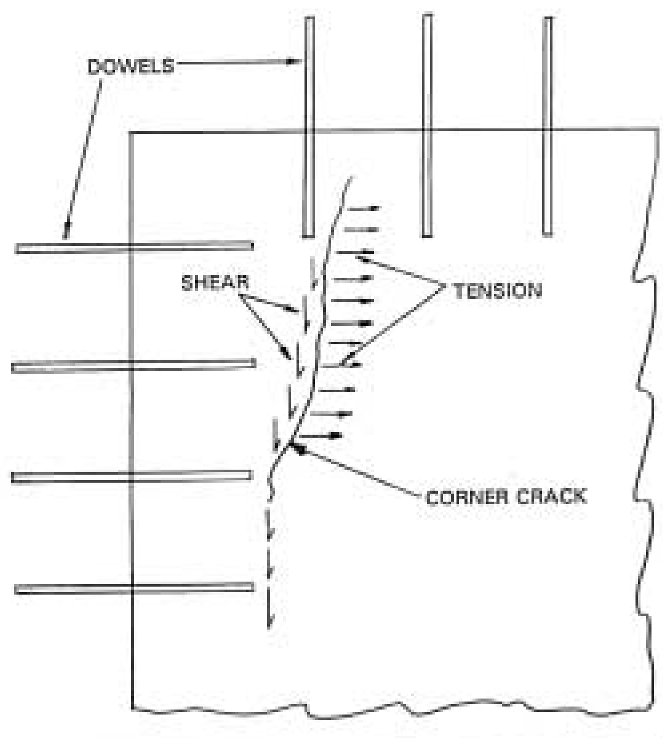
Fig. 2 – (above) Misaligned dowels have to bend as the joint opens.

Fig. 3 – (left) Cumulative effect of dowel restraint.

Fig. 4 – (lower left) Individual effects of dowels and tie-bars.

Fig. 5 – (below) Cracking caused by bars at corner of slab.

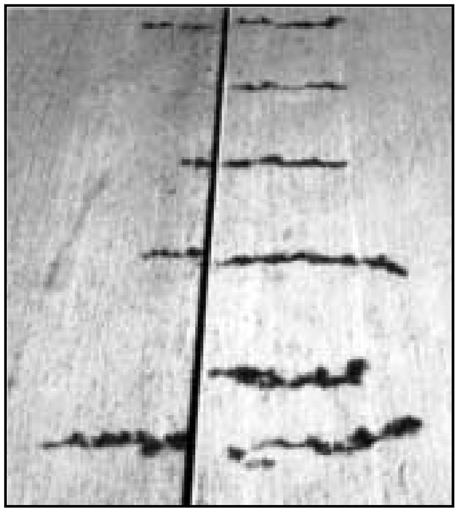


This very basic problem causes internal stresses that unfortunately are not part of routine design procedures, even though they can significantly contribute to or cause cracking and failure. Until recently this problem was ignored by designers and contractors simply because they either did not understand and evaluate it, or when they did there was no practical and economical solution to the problem. Now there is a simple solution. But, first let's examine the problem itself.

A common and efficient way to place large floor slabs or pavements is in long alternating strips or lanes, with infill or adjacent lanes placed later. Workers typically place one or more separated lanes each day, and saw cut transverse contraction joints that night or the next day. Cracks usually appear below the saw cuts within one or two days as planned, and the joints open.

But what happens several days later when the infill or adjacent concrete is placed? Transverse joints are sawn in the new concrete, and the concrete tries to contract as it did in the earlier slabs. But the dowels or tie-bars that go across the LONGITUDINAL joints into the older slabs form a series of immovable steel pins that prevent the new slab from contracting (Fig. 3). The only way for any movement to occur is for the bars to actually shear off at the joint line, or for the older slabs to squeeze together. Since the compressive resistance of the older concrete and the shear strength of the bars is much greater than the tensile capacity of the new placement, the newer concrete develops internal tensile stress that can be very substantial and lead to serious performance problems or cracking. These forces should be considered in design, but, as mentioned earlier, this has not normally been done in the past.



Cracks between dowels caused by their restraint of shrinkage parallel to the joint. (Cracks have been epoxy-injected).

Another stress that is not normally considered in design is the horizontal shear force that develops parallel to the joint at about the end of the bars. This condition is theoretically necessary in order for the system to remain in equilibrium.

By the time the slab or pavement is put into service, it can already be cracked or stressed to the point where it begins to fail with little applied load or relatively few load repetitions. Where transverse and longitudinal joints intersect, the stressed combine to cause or contribute to corner cracking. (Fig. 5).

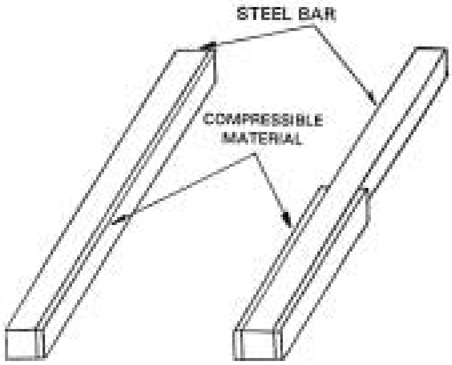
Crack due to misaligned dowel bars in a joint that opened. (Crack has been routed and sealed).

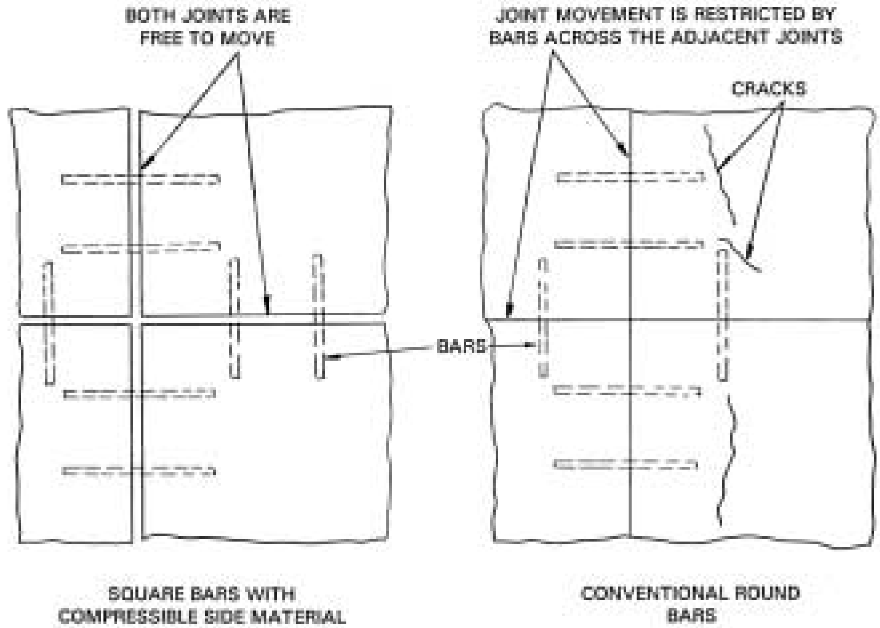
Typical dowel layout.

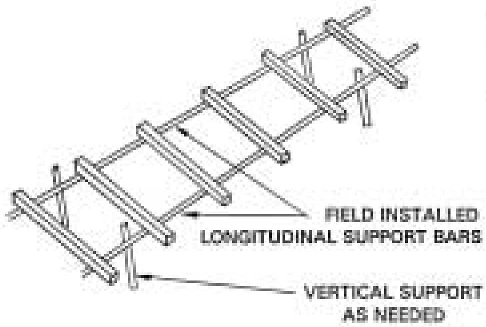
## A Simple solution

To provide adequate load transfer, the top and bottom of a dowel bar must have complete contact with the concrete. Load transfer capacity is not affected if the sides of the bar are not in contact with the concrete. In fact, side contact is undesirable in dowels because it increases friction between the concrete and the dowel, thereby making it more difficult for the bar to slide in and out of the slab.

Using a square bar instead of a round bar provides total vertical load transfer while allowing a compressible material to be attached to the side of the bar. The compressible material needs to be attached to one side of the bar along its full length, or two opposite sides of the bar for half the bar length (Fig. 6). From a constructibility viewpoint, attaching the compressible material to both sides of half the bar is preferable. This allows the bar to be installed into the first slab (on one side of the joint) without anything attached to it. The



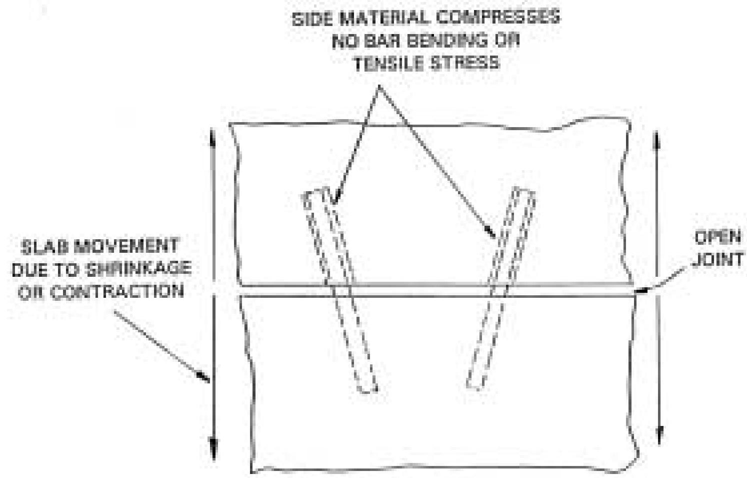




Fig. 6 – (top left) Alternative placements for compressible material attached to bar.
Fig. 7 – (top right) Bars with compressible material allow total vertical load transfer without restraining movement parallel to the joint.
Fig. 8 – (right) Compressible side material solves the problem of bar misalignment.
Fig. 9 – (above) Bar placement parallel to the slab surface is easily achieved using parallel supports such as two steel bars.

compressible side material is later attached to the portion of the bar sticking out of the slab. This method also allows the use of automatic dowel inserting equipment with slipform paving machines.

Because the side material is compressible, it simply squeezes together when adjacent slabs need to expand and contract independent of each other. There is no restraint to movement at right angles to the dowel (parallel to the joint), but there is total load transfer in the vertical direction (Fig. 7). As well as solving the problem with adjacent pavements or slab sections in new construction, square bars with compressible side material are ideal for highway joint repairs, replacement slabs, and when adding new shoulders or traffic lanes to existing old concrete that has already undergone all of its shrinkage.

Square bars with compressible side material are especially useful with post-tensioned slabs, since they allow adjacent slabs to be constructed and stressed independently, and allow incremental stressing at different times. The slab movement (contraction) during post tensioning, which can be 1/4 to 3/4 in. (6 to 19 mm) in large industrial floors, no longer has to control the construction schedule, stressing sequence, slab layout, or slab sizes.

Still another application is with shrinkage-compensating concrete, which requires elastic movement (expansion and contraction) of each slab without restraint or interference from the adjacent slabs.

## Misalignment problems solved

The compressible side material also solves the problem of misalignment (Fig. 8). A misaligned bar with compressible material on the sides does not bend as the joint opens or closes. Instead, the material on the side simply compresses. The amount of permissible horizontal misalignment with this system is extraordinary. For example, if the material can compress 1/8 in. (3 mm) and the joint opening is 1/4 in. (6 mm), the dowels can be misaligned by as much as 27 degrees!

The dowels still must be parallel to the slab surface, but that is easily established by placing them on parallel construction supports such as two steel bars (Fig. 9).

## More advantages

Although they have the same shear strength as round bars of equal weight, square bars provide more resistance to

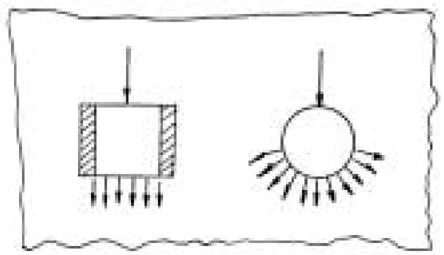


Fig. 10 — Load transfer stresses for square and round bars.

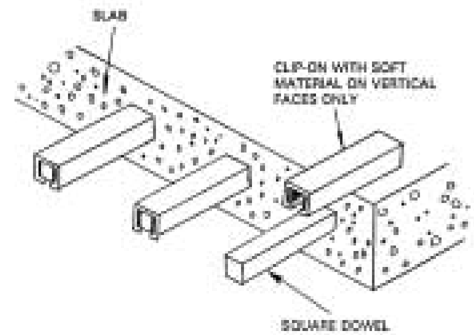



Fig. 11 — Plastic clip with foam attached to inside vertical faces is easily snapped or slipped onto bar.

bending, so they provide more resistance to edge and corner curling for the same amount of steel.

When square bars are substituted for round bars, the bars can be spaced further apart for the same steel weight and fewer dowels need to be installed. This is because a square bar has more cross-sectional area than a round bar of the same nominal size, Alternatively, load transfer strength based on bar capacity will be greater if a direct substitution of square bars is made for round bars of the same nominal size without decreasing the number of bars.

Another advantage of square bars is related to the direction of forces radiating off the bar. The effect of load transfer in round bars induces tensile splitting stresses within the slab or pavement (Fig. 10). This splitting stress is eliminated with square bars. Both bar shapes induce similar downward shear stresses in the concrete.

## Square tie-bars

In order to create a tie-bar rather than a dowel, the square shape must have resistance to pullout. This could be accomplished with deformed bars, but deformed square bars for use in concrete have not been a standard product since about the mid or late 1930's. Actually, until then, square bars were standard in reinforced concrete construction, in projects ranging from water tanks, bridges, and buildings to mammoth undertakings such as Hoover Dam and Powerhouse.

The options for providing pullout resistance in standard smooth square bars include specially fabricated or machined shapes, swedging the bar ends, and using hooked or bent ends. A more simple and economical approach is to simply drill a hole in each end of the bar and drop a bolt or pin through it.

## Attaching compressible side material

Until a clip-on attachment recently became available, the use of square dowels and tie-bars with a compressible side material was possible, and it was done, but it was not very simple. Successful use of the system depended on the skill of laborers in the field carefully attaching and trimming the right material to each bar.

Someone had to locate an easily-compressible closed-cell foam that does not absorb water. The foam had to be carefully trimmed to the correct size for each bar, the sides of the bars had to be cleaned so that the foam would not fall off during concrete placement, and the correct amount of the right adhesive had to be applied. Weather could be a factor, A better method was needed because of quality control concerns and the time involved to do the work.

A practical and economical way to overcome these difficulties is now available – a specially manufactured plastic (ABS) clip that can be snapped or slipped onto the bars (Fig. 11). The clip already has the right foam attached to its sides. The clips are manufactured under factory-controlled conditions with materials engineered for the function of the bars in concrete. The clip lays flat and snug to the top of the bar and is made with a material that does not deflect or compress significantly under loads that are transferred to the bars. On the other hand, the side material is easily compressed under relatively small loads. The side foam also prevents the intrusion of mortar or paste into the clip during concrete placement, and is resistant to water absorption. Both the clip and its compressible side material are noncorrosive and stable in the alkali environment of the concrete.

## Corrosion protection and related advantages

When the clip-on device is used to provide the compressible side material, it inherently provides significant additional advantages.

Because the clip is designed to slide easily along the surface of a steel bar and also be non-bonding to concrete, it eliminates or greatly minimizes the need for greasing dowels. Rust and dirt are unacceptable with conventional dowel bars, but tolerable when the clip is used because it isolates the bar from the concrete. For the same reason, the clip permits dowels to function correctly even if they corrode in service, and especially important advantage where deicing salts are used. Even if corrosion occurs, the clip will still permit the bar to slide in and out of the concrete on one side of the joint.

Another advantage is that the compressible side material provides a place for the products of corrosion to occupy if corrosion develops. This not only helps to assure that the dowel will still slide in the concrete, but it also

## Comments on keyways

Keyways have been used in some designs as an alternative to, or in addition to dowels and tie-bars. Unfortunately, keyways have problems and drawbacks related to both design and construction.

A key must be straight and smooth. This is difficult to accomplish on a routine basis in the field. Extra care is needed to assure consolidation of concrete around the key. Stay-in-place galvanized heavy gauge sheet metal bulkheads are a good approach to getting the best possible effectiveness out of keyways if cost is not a problem and the metal edge a the top of the slab does not become a problem in service. When wood is used, extra labor is needed and stripping can be difficult after the wood swells.

The first design disadvantage with keyways is that the key is only as strong as about 1/3 of the slab thickness. About 2/3 of the slab strength is not available for load transfer. The second disadvantage is that after the joint opens, the slab edge must deflect considerably before the key makes contact with the other slab and begins to transfer load. If the joint opens by any significant amount, the slab edge on one side of the joint may deflect to the point of failure before a load is transferred to the other slab (Fig. 12).

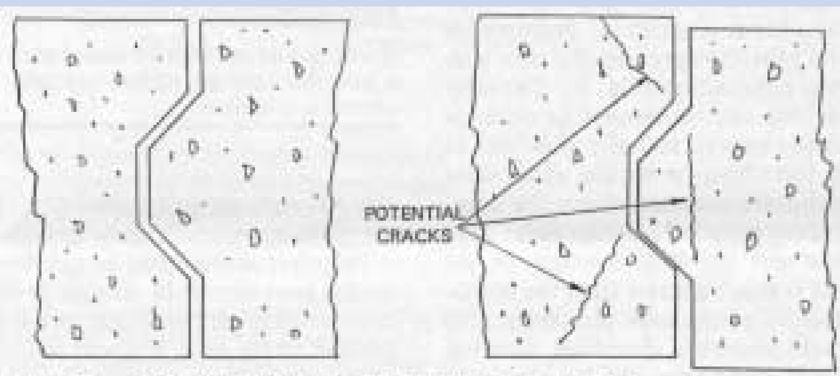



Fig. 12 — Slab must deflect before keyway transfers load.

reduces or eliminates the forces that cause spalling from corrosion.

The clip, at least at this time, probably should not be considered as a total means of preventing corrosion, but it does encase the top, the sides, and part of the bottom of the bar. Moisture and chloride ions must travel down past the bar, turn, and then rise up inside the dowel clip if they are going to attack the bar. This protection can be provided for the full length of the bar if the designer elects to use a full length clip. However, if a dowel slips easily on only one side of a joint there really is no need for it to also slip on the other side.

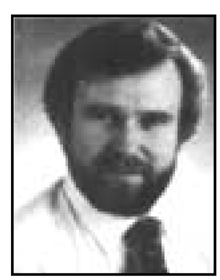
### Installation procedure

Square dowels can be easily placed during construction by setting them on two supports that are parallel with the slab surface and essentially parallel with the joint (Fig. 9). This provides simple vertical alignment. As mentioned earlier, horizontal alignment is not critical when the compressible side material is used with square bars – a visual check of alignment is adequate. Because the bars are square they will not roll on the support prior to being tied. Tieing is not even necessary if enough care is used during concrete placement, but is recommended due to the rigors of actual placing operations.

The support bars provide an important added benefit by reinforcing the edge of the slab and distributing wheel loads to several adjacent dowels or tie-bars so that they act as a group rather than as individual bars.

### Conclusions

Dowels and tie-bars are an important part of slab and pavement design. They provide load transfer at edges and corners, thereby allowing a thinner, more economical, and efficient design. Unfortunately, design and construction realities can result in cracking, reduced load carrying capacity, or reduced service life when conventional round bars are used. These problems can be easily and economically overcome by using square bars with a clip-on plastic sheath having compressible material on its sides.



ACI member Ernest K. Schrader is a civil engineer and concrete specialist from Walla Walla, Washington. He is a member of ACI Committees 207, Mass Concrete; 210, Erosion in Hydraulic Structures; 224, Cracking; 506, Shotcreting; and 544, Fiber Reinforced Concrete.