The Case for

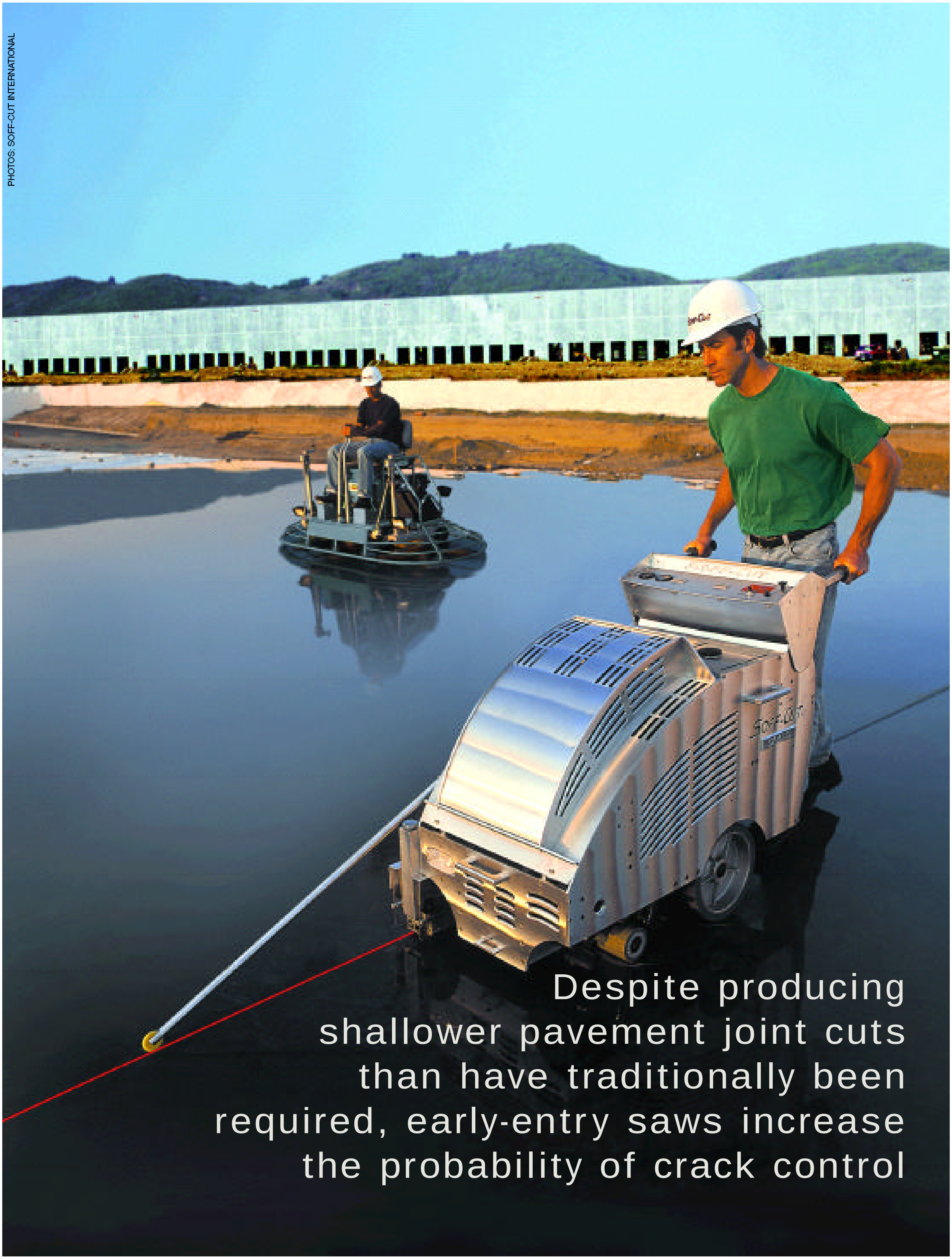
Early-Entry Saws

By Dan G. Zollinger

There's an ongoing debate about the minimum sawcut joint depth needed to minimize random cracking in pavements. For many years, specifiers have required a minimum depth one-third or one-fourth the slab thickness, with the deeper cuts being used for longitudinal joints in highway pavements. Many documents from the American Concrete Institute, Portland Cement Association, and American Concrete Pavement Association still recommend using these joint-cut depths.

I believe that deep cuts made many hours after concrete placement often are less effective in controlling random cracking than shallow cuts made earlier. To explain the reasons, I'll discuss the differences between these two approaches to sawcutting joints and present research on the factors affecting the ability of the sawcut to control random cracking.

Conventional sawing and the cutting window. There's a window of time, with near and far limits, during which cutting joints with conventional water-cooled saws must be done. But cutting isn't always done within this window. If workers saw too early, cut edges of the joint ravel excessively. Typically, the concrete must reach a compressive strength of about 500 psi to avoid raveling. And if workers don't understand that the far limit of the window varies with weather and material combinations, they may wait too long (slabs sometimes aren't sawcut until 24 hours after placement). Then



PHOTOS: SOFF-CUT INTERNATIONAL

Despite producing shallower pavement joint cuts than have traditionally been required, early-entry saws increase the probability of crack control

Although the pavement for Highway 210 in Pasadena, Calif., is 13 inches thick and the sawcut is only 1 inch deep, the drilled core shows that a crack still formed beneath the sawcut notch.

random cracks are likely to occur before or during the time that joints are sawed.

In addition, many factors affect a contractor's ability to control cracking in newly constructed concrete pavements during sawcutting operations. These include:

- Water and cement content of the concrete
- Coarse-aggregate type
- Base support and friction characteristics
- Slab thickness
- Curing method and quality
- Sawcutting method used for crack control

Given the large number of factors that influence the limits of the sawcutting window, it's not surprising that random cracks can occur even when workers start sawing at the window's *near limit*, defined in research for the Federal Highway Administration as the earliest time at which a water-cooled conventional saw can feasibly be used. The near limit has been found to vary with aggregate type and the level of raveling one is willing to accept (Ref. 1).

Early-entry saws. When early-entry, dry-cut saws were introduced in 1988, it became possible for contractors to saw joints much earlier than the FHWA-defined near limit for conventional saws. Using early-entry saws, workers could start cutting as soon as they could walk on the concrete, which at this point might have a compressive strength as low as 25 to 50 psi. During hot weather, for instance, joints might be cut as early as 3 hours after concrete placement. At lower temperatures, workers might have to wait 5 hours. But either wait was less than that for sawing with conventional saws. And there was less guessing about the timing.

Combinations of variables studied

Aggregate type	Placing temperature, °F	Relative humidity, %
Limestone	60 to 80	10 to 50
River gravel	60 to 80	10 to 50
Limestone	85 to 100	10 to 50
River gravel	85 to 100	10 to 50
Limestone	60 to 80	50 to 95
River gravel	60 to 80	50 to 95
Limestone	85 to 100	50 to 95
River gravel	85 to 100	50 to 95

Despite this reduced reliance on just-right timing, concerns about the shallower cut depth (usually about 1 inch) of early-entry saws persisted. In 1994, my co-researchers and I published results of a field investigation conducted in cooperation with the Texas Department of Transportation (Ref. 2). We monitored joint formation and crack control for 13-inch-thick plain concrete pavement test sections placed directly on subgrade soils. Variables included different concrete mixes, coarse-aggregate types, curing methods, and sawcutting techniques.

Workers cut joints in the test sections at 15-foot intervals using two methods—conventional water-cooled sawcutting to a 3-inch depth and early-entry dry sawcutting to a 1-inch depth. They typically started early-age sawing about 3 hours after concrete placement.

Of all the transverse cracks that developed, only two occurred be-

tween sawcut joints. Both of these random cracks occurred at re-entrant corners for inlet drainage structures. We concluded that it's reasonable to use early sawcuts about 1 inch deep to initiate cracking at joints. Similar results were noted by the California DOT (see photo on page **50**). But doubts about the ability of shallow joint cuts to minimize random cracking still persist, despite the fact that it's difficult to calculate a verifiable minimum acceptable joint depth for conventional sawing methods. Researchers who attempted this concluded there were too many confounding factors (Ref. 1).

A different approach. My coworkers and I have studied the effects of several factors on sawcutting results by using a modeling approach. We inserted several varying factors into a mathematical model to predict the probabilities that a pavement slab will crack either at a sawcut notch or at a random location (see "Analysis Methodology"**).** Subtracting the probability of a random crack from the probability of a crack at the sawcut yields an indicator of the control that different sawing methods can exercise over random cracking. If the value is high, it's possible to control cracking with good reliability. A low value indicates cracking can be controlled but with a lower degree of reliability. And a negative value means there's no way to control cracking by sawcutting. We used these probability-of-cracking differences to assess the effects of several factors, in combination, on crack control when workers sawcut pavements by three different methods:

- Early-entry sawing
- Conventional sawing at the near limit
- Conventional sawing 24 hours after placement

Factors studied. Of all the factors that affect a contractor's ability to control cracking, weather conditions during construction may be the most important. When contractors place a pavement slab, weather conditions at the time of placement govern, to a large extent, temperature and moisture variations within the concrete. Coarse-aggregate type also is important. Both weather and aggregate type significantly affect sawcut timing and depth requirements. Along with sawcut depth, slab thickness affects the ability of a sawcut notch to propagate a crack to the bottom of the slab.

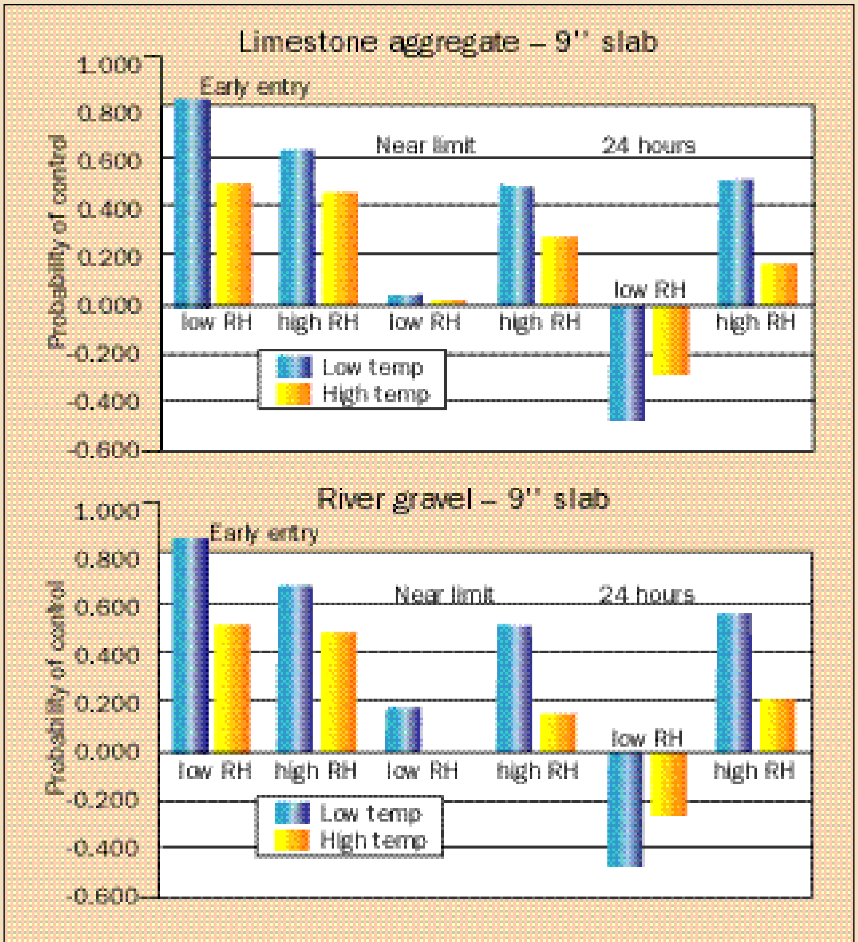
In our analysis, we systematically considered the key factors at two different levels. The table on page **50** shows climatic and aggregate-type combinations used in the model. We also assumed different slab pavement thicknesses—3, 6, 9, and 17 inches. Other factors such as subbase friction, concrete cement content, and joint spacing also were included in the model.

Crack-control probabilities. For each of the four pavement thicknesses, we prepared bar charts such as those below. These charts illustrate the effects of aggregate type and weather conditions during placement on the probability of crack control for the three sawing methods studied.

With regard to random-crack control in jointed pavements, the charts clearly show the superiority of early-entry saws over conventional saws used either at the near limit or 24 hours later. These results apply to temperature and relative-humidity ranges given in the table.

Note that at a low relative humidity during concrete placement, regardless of the temperature, conventional sawing to a depth one-quarter the slab thickness is highly unlikely to control random cracking, even when it's done as soon as possible. I believe this is because the crack-inducing stresses caused by drying are very near the top surface, and deeper sawing depths place the notch too far below this highly stressed region. Thus the deeper

Probability of crack control



Effects of temperature and humidity during concrete placement, aggregate type, and sawcutting time on the probability of controlling random cracking.

sawcut is actually a detriment to crack control.

Note also that for early-entry or near-limit conventional sawing, it's easier to control cracking in concretes made with river-gravel aggregates than with limestone aggregates.

Certain theories for concrete strength suggest that for all pavement thicknesses, the thicker the pavement, the easier it is to control cracking, especially with early-entry saws.

In summary, paving contractors can't control many variables that affect the probability of random cracking. But by using an early-entry saw, they can reduce the influence of these variables and thus reduce the number of random cracks that do occur. ■

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References

1. *Guidelines for Timing Contraction Joint Sawing and Earliest Loading for Concrete Pavements*, FHWA-RD-91-079, Federal Highway Administration, Research and Development, Turner-Fairbank Highway Research Center, McLean, Va., 1991.
2. Dan G. Zollinger et al., "Sawcut Depth Considerations for Jointed Pavement Based on Fracture Mechanics Analysis," *Transportation Research Record 1449*, Transportation Research Board, Washington, D.C., 1994, pp. 91–100.

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Analysis methodology

Whether cracks occur randomly or are induced by sawcut notches, we assumed the stress in the concrete exceeds the strength of the concrete at the point of cracking. So we mathematically estimated strength gain and stress development as both changed with time. We used the maturity method to estimate strength-gain characteristics for a concrete containing 470 pounds of cement per cubic yard. Concrete maturity, and thus strength, is directly related to the temperature history of the concrete, which in turn is affected by heat of hydration and ambient temperature and relative humidity at the time of placement. We modeled temperature at different depths in the concrete over a 30-hour period.

We based calculated concrete stresses on mathematical models that simulate curling and warping behavior of concrete as it hardens. Key inputs were the temperatures mentioned previously and moisture and shrinkage differentials that develop as the concrete cures for up to 30 hours. Because many of the material properties used in the analysis are time dependent, the method adjusted them from hour to hour.

For several factors that affect strength and stress, but aren't listed in the table we assumed a statistically normal distribution about a mean typical value. Based on those distributions, placement temperatures and relative humidities, and aggregate types, the model predicted the probability that the stress at the tip of the sawcut notch at any time from 0 to 30 hours was greater or less than the strength at that time. If the stress was greater than the strength, cracking at the sawed joint would be expected. If the stress at the sawcut notch was less than the strength, random cracking at a location other than the joint might occur.

We believe the time at which random cracking occurs is determined primarily by shrinkage due to moisture loss. Thus our model for the probability of random cracking is based strictly on the amount of concrete shrinkage at the pavement surface due to moisture loss. Prediction of cracking at the sawcut notch was based on a combination of shrinkage and thermally induced strains.