

The Case for Skewed Joints

R. H. COOLEY, Statewide Paving Engineer, Portland Cement Association, Los Angeles District

The use of skewed joints in concrete pavements in California dates back to 1932, when an experimental installation was built on U. S. 40 southwest of Sacramento.

No further installations were made until 1951. Influenced at least in part by the satisfactory performance of the 1932 installations, skewed joints have since been used on portions of at least eight projects. In these, various joint spacings and angles of skew were used and their performance observed.

The results of these studies indicated that: (a) when measured by the number and magnitude of faulted joints there was a decided advantage in favor of the skewed joints; (b) the joints spaced at 15 ft and 20 ft showed a marked superiority over joints spaced at larger intervals; and (c) after study of heavy truck specifications for axle and wheel spacing, a skew of 2 ft in a 12-ft slab with the obtuse angle at the outside edge of the forward slab was adopted.

A description of various projects and a summary of performance of various joint spacings is included.

●THE IDEA of placing transverse joints at other than right angles to the pavement centerline is not new. A review of the literature (1) shows that patents were issued for skewed joint systems in 1906 and later in 1918. Drawings for the 1906 patent show a skew of 5 ft for a 12-ft lane width. The drawings do not show whether the obtuse angle formed by the skewed joint and the outside pavement edge is ahead of or behind the joint in the direction of travel.

The 1918 patent was issued for a joint with a 45-deg skew. However, this skew does not extend across the full pavement width. Instead, the joint is at right angles to pavement centerline for a distance of about 18 in. in from each pavement edge.

Skewed transverse joints conforming to these patents, or to other skew designs, were installed in experimental concrete pavements and were occasionally used in normal construction work during the 20-yr period from 1910 to 1930. Very little is known about the performance of the skewed joints constructed during this period.

SKEWED JOINTS IN CALIFORNIA

The modern day development of skewed joints started in 1932. In that year the California Division of Highways installed skewed joints on a section of a two-lane highway located about 6 mi southwest of Sacramento on US 40. The joints were hand formed, with a skew 4 ft in the 10-ft wide traffic lanes. This section is now located on the westbound lanes of a four-lane divided highway carrying heavy traffic between Sacramento and San Francisco. The 1957 traffic count for this route was more than 21,000 vehicles per day of which about 17 percent were trucks. Figures 1 and 2 show the present condition of these skewed joints after 26 yr of service. The joints are not

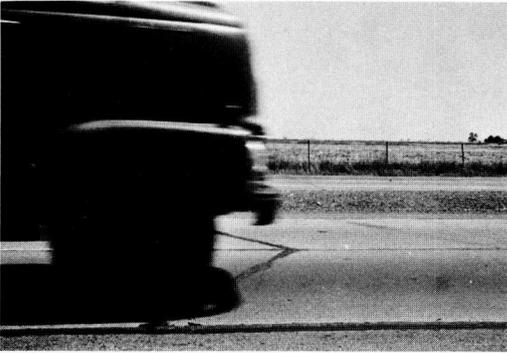


Figure 1.

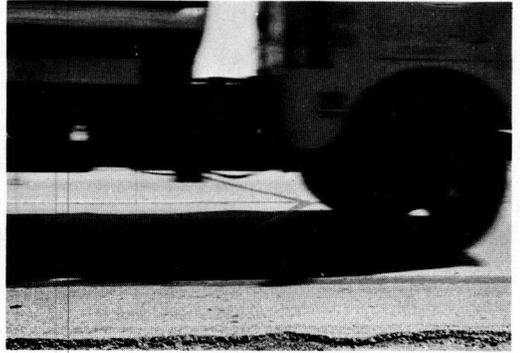


Figure 2.

faulted and a 1958 inspection showed no structural distress in the form of corner breaks. The absence of corner breaks is particularly significant, because the direction of skew forms an acute angle at the outside corner ahead of the joints in the direction of travel. These acute angle corners are critical locations for corner breaks because the outside wheel path of heavy trucks is close to outside edges of the 10-ft wide lanes. The absence of corner breaks indicates that the skewed joints have the effect of providing a high degree of load transfer. As a result stresses in the acute angle corners are kept within safe limits.

Further construction of skewed joints in California was deferred until service performance of the 1932 project could be established. World War II caused additional delays, and it was not until 1951 that construction of projects with skewed joints was resumed.

An important item in the 1951 construction program was an experimental jointing project designed to compare (a) the relative performance of skewed and right angle joints and (b) the relative performance of joint spacings ranging from 15 to 60 ft. This 7,000-ft project is located on US 99 between Los Angeles and Bakersfield in the Tejon Pass of the Tehachapi Mountains. The 8-in. plain pavement is 24 ft wide, constructed lane-at-a-time with a keyed longitudinal joint tied with $\frac{5}{8}$ -in. bolts at 30-in. centers. The pavement was placed on a cement-treated subbase 4 in. thick and 24 ft wide.

No expansion joints were used. Both right angle joints and joints with a skew of 3 ft in 12 ft were constructed in various sections of the pavement at spacings of 15, 20, 30, 40 and 60 ft. The contraction joints were formed by 2-in. asphalt impregnated fiber strips. Some difficulty was encountered in holding the strips vertical and flush with the pavement surface. As a result there has been considerable spalling of the joints. Figure 3 shows a skewed joint in the section with a joint spacing of 15 ft. Unsatisfactory joint alignment and spalling are evident.

The experimental sections are on the two southbound lanes of a four-lane divided highway which carries more than 12,000 vehicles per day, including 3,200 trucks. Most of the southbound trucks are fully loaded with cargoes bound for Los Angeles. As a result the experimental joint sections have been subjected to a severe test.

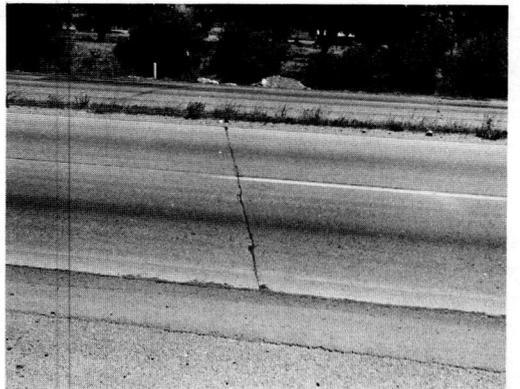


Figure 3.

Truck speeds over the section vary with the grades which are not particularly steep in this section of the Tejon Pass. Most southbound trucks stop at a loadometer station shortly before entering the section. The speed of several 5-axle truck-trailer combinations, when checked, showed an average speed of 21 mph over part of the test section. At one check point where grades were slightly steeper the average speed was 16 mph and at another location the trucks averaged 40 mph. Truck traffic over this route is almost as heavy at night as during daylight hours.

The flexural strengths of the concrete on this project were on the low side. As a result there is considerable joint faulting and distress in the form of corner breaks. For experimental purposes the low strengths and resultant defects have served to accelerate the effects of traffic on the various joint designs, permitting earlier comparison of test results.

A comprehensive survey of this experimental pavement was made in 1955. The results of this survey are given in Tables 1 and 2. Table 1 gives the relative performance of skewed and right angle joints. The data shows marked superiority of skewed joints over the right angle joints. Skewed joints had 90 percent fewer corner breaks than right angle joints, and skewed joints had 75 percent fewer faults than right angle joints.

Table 2 gives the relative performance of the various joint spacings. These data show that both corner breaks and faulted joints increased as the joint spacing was increased from 15 to 60 ft with marked superiority for the 15-ft joint spacing. Data from both tables show that skewed joints at a spacing of 15 ft gave the best performance of any combination tested.

This project was inspected again during the fall of 1957. At that time the pavement had begun to show considerable distress, particularly in sections where the longer joint spacings had been used. However, the 15- and 20-ft sections with skewed joints were still in remarkably good condition when compared to right angle joints at the same spacings.

Since 1950 skewed joints have also been installed in portions of seven additional projects. Except for one project constructed in 1957, the skew was either 2.5 or 3.0 ft in 12 ft. On the 1957 project the skew was reduced to 2 ft in 12 ft.

This 2-ft skew in 12 ft was adopted after considerable study of specifications for truck axles and wheel spacings. Figure 4 shows the tire imprints of a tandem-axle, dual-wheel truck equipped with eleven 22.5 tires in relation to a skewed joint. The dual wheels are spaced at $12\frac{3}{4}$ in. center to center and the distance center to center of the inside wheels on each axle is $59\frac{1}{2}$ in. The tandem-axle spacing is 52 in. The skew of 2 ft in 12 ft is the minimum amount which will result in movement of the dual wheels across the joint one-at-a-time.

TABLE 1

Type	Joints		Faulted Joints (%)
	Panels (no.)	Corner Breaks (%)	
Skewed	133	2	11
Right angle	158	22	76

TABLE 2

Spacing (ft)	Joints		Corner Breaks (%)	Faulted Joints (%)
	Panels (no.)	Corner Breaks (%)		
15	135	2	9	
20	62	12	72	
30	43	25	78	
40	31	30	80	
60	20	40	95	

It will also be noted that the joint is skewed in a direction that results in an obtuse angle at the outside edge of the forward slab. This affords additional protection against corner breaks at this critical location. It is true, of course, that there is an acute angle at the inside corner ahead of the joint. However, this inside corner is less susceptible to corner breaks because it is tied to the adjacent slab on the other side of the longitudinal joint.

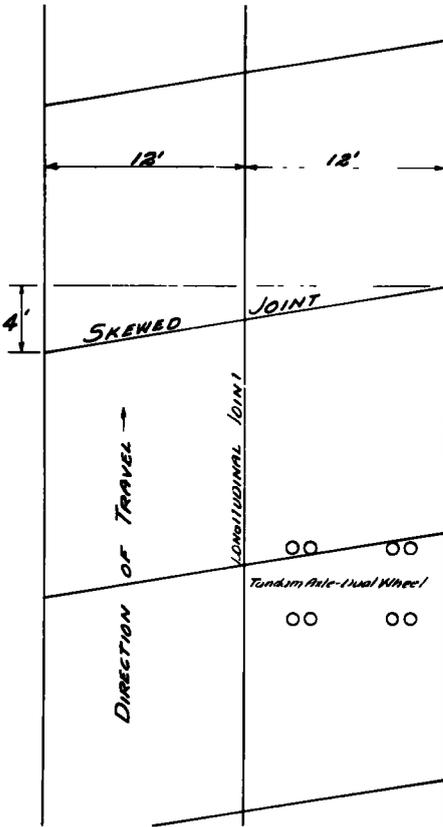


Figure 4. Full width (24 ft) construction.

are sawed in lane-at-a-time construction of four-lane highways. It is necessary to construct the outside lane first and saw the skewed joints. When the adjacent inner lane is placed the joints can be sawed at right angles to pavement centerline. With this arrangement the skewed joints are in the outside lane which carries almost all of the heavy truck traffic. It should be noted that this procedure is not necessary where joints are formed in the plastic concrete, or where the pavement is placed full width. In these cases the skewed joints can be continued across the full pavement width in a chevron pattern where joints are formed in the plastic concrete, or in a straight line continuation of the skew where joints are sawed.

Skewed joints were placed on a section of the Hollywood Freeway constructed in 1951. This pavement has the same design as the experimental project—an 8-in. plain pavement on a 4-in. cement-treated subbase. This section of the Freeway

Until recently all California pavements have been paved lane-at-a-time. After the end of World War II it became general practice to saw transverse joints. The combination of lane-at-a-time paving and joint sawing resulted in certain complications where skewed joints were used. No particular problems were encountered in sawing the first lane placed. However, it was found that subsequent lanes had to be sawed at just the right time to prevent transverse cracks from forming ahead of the saw cut. If sawing was just a little too late transverse cracks had already formed, and these cracks were at about right angles to pavement centerline rather than skewed. Even when the second slab placed had not cracked, but enough tensile stress had developed to cause tension cracking ahead of the saw, this crack did not follow the direction of skew but formed a right angle to the outside edge or longitudinal joint.

Figure 5 shows a procedure for avoiding these difficulties where transverse joints

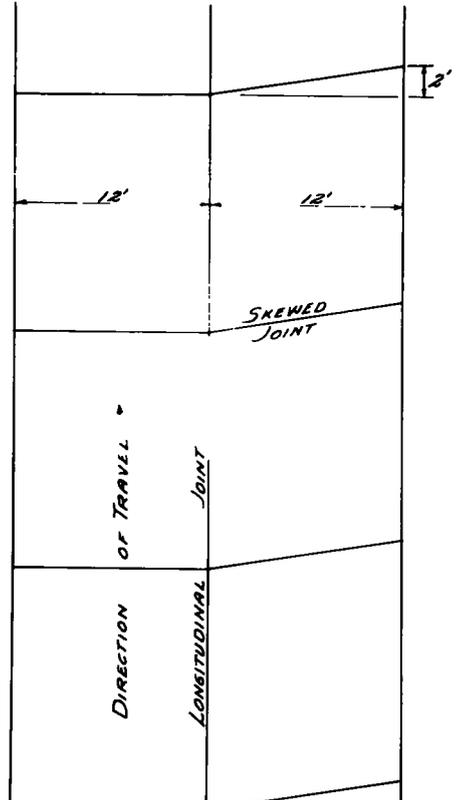


Figure 5. Lane at a time construction.

carries 190,000 vehicles per day with 6.6 percent, or 12,500 trucks per day. Present condition of the skewed joints is shown in Figure 6. They are free of faults and there are no corner breaks.

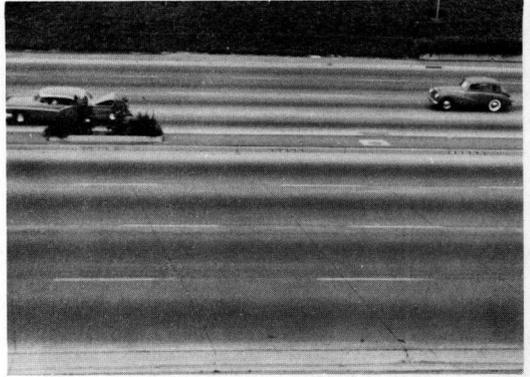


Figure 6.

In 1952 skewed joints were also installed on a section of the San Bernardino Freeway, east of Los Angeles. Again the design is the same, an 8-in. plain concrete pavement on a 4-in. cement-treated subbase. This route carries about 90,000 vehicles per day, including a large volume of heavy truck traffic. Figure 7 shows the present condition of the skewed joints. Even though the direction of skew makes an outside acute angle ahead of the joint in the direction of travel, there are no corner breaks or other evidence of structural distress, and there are no faulted joints.

SKEWED JOINTS IN WASHINGTON

In 1954 the Washington State Department of Highways installed sections with skewed joints on several four-lane projects located on US 99. This is the principal route between Portland, Oregon and Seattle, Washington. It is now Interstate Route 5, and carries a high volume of heavy truck traffic.

These projects have plain concrete pavements, 8 in. thick, placed on a granular subbase 6 in. or more thick. Expansion joints were placed only at bridge ends and other fixed structures. Transverse contraction joints were spaced at 15 ft with a skew of 2 ft 8 in. in 12 ft. The pavements were constructed lane-at-a-time with a tied longitudinal center joint. The skewed joints have been placed in two patterns: (a) a chevron pattern (Fig. 8) and (b) continuation of the skew in the same direction across 2 lanes (Fig. 9).

The exceptionally good riding qualities and the excellent performance of the experimental sections led to the adoption of skewed joints as standard for all projects with joints constructed while the concrete is plastic. Where sawed joints are cut in hardened concrete the joints are at right angles to pavement centerline.

CONCLUSIONS

1. Skewed transverse contraction joints spaced at 15 ft have been in service for 26 yr under heavy truck traffic. Performance of the skewed joints is excellent. They



Figure 7.

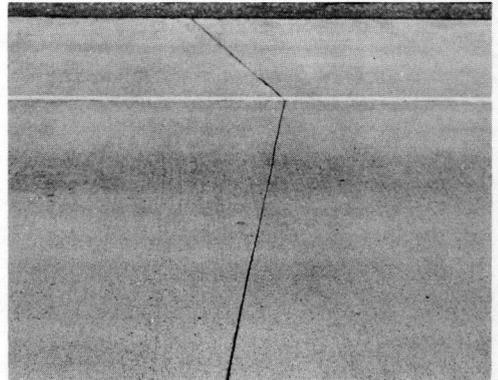


Figure 8.

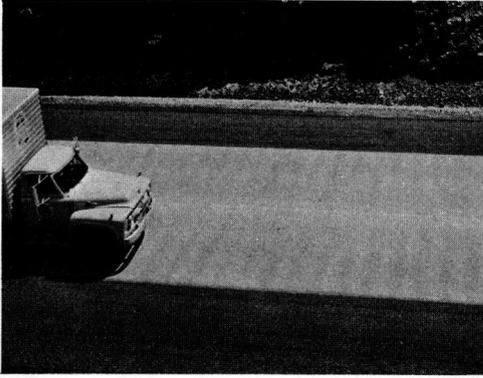


Figure 9.

Washington pavements indicates that moving wheel loads across transverse joints one at a time by means of skewed joints, results in improved riding qualities and better load transfer across the joints.

REFERENCE

1. "The Structural Design of Concrete Pavements." Part 4, Public Roads, Vol. 17, No. 7 (September 1937).

are free of faults and the pavement is free of structural distress.

2. An experimental jointing project was constructed in 1951 on a route carrying large volumes of heavily loaded trucks. Skewed and right angle joints were installed at spacings of 15, 20, 30, 40 and 60 ft. As given in Tables 1 and 2, the skewed joints have performed much better than right angle joints and short joint spacings have proven superior to longer joint spacings. The best performance was on skewed joints spaced at 15 ft.

3. A 1957 study of truck axle and wheel spacings resulted in adoption of a skew of 2 ft in 12 ft, with the obtuse angle at the outside edge of the forward slab.

4. The performance of California and