Sawed Contraction Joints for Concrete Airfield Pavements

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THE sawing of contraction joints in concrete pavements during the recent construction at the Lockbourne Air Force Base was one of the first applications of this method on a large scale in airfield pavement construction. This construction was carried on during warm and cold weather, and both portland cement and a blend of portland cement and natural cement were used in the concrete mixes. Pavement thicknesses ranged from 6 to 12 in. and all transverse contraction joints were sawed to a depth of one fourth the thickness of the pavement.

Experience at this project indicates that excellent contraction joints can be obtained by using properly trained workmen and exercising normal care in choosing the time for sawing the joints. Weather conditions and character of the cement used are important factors in influencing the time interval between placing the concrete and cutting the joints. No difficulty is encountered in filling the joints, except when jet-fuel-resistant fillers are used. These fillers have a narrow temperature range through which they may be applied, and the joints have to be filled in several stages to compensate for shrinkage of the material as it cools.

It is too early to evaluate the actual performance of the sawed joints in use, and this paper is limited mainly to the experience gained and observations made in sawing and filling sawed joints. From these observations the advantages of the sawed joints are that they provide a better surface for traffic, avoid damage due to manipulation of the concrete at the joint during hardening, permit a better sequence of operation during construction, permit earlier application of curing compounds, reduce the quantity of joint fillers required, and present a better appearance in the finished surface.

● THE problem of providing satisfactory joints in concrete pavements has been with us since the first use of concrete in pavements. The objectionable features of the hand-formed contraction joints, such as the checking, spalling, and deterioration of the concrete at the joints and the unevenness of the pavement surface in these areas are well known. Recently a new procedure has been introduced for the construction of joints in pavements. This is the sawing of contraction joints in the pavements after the concrete has hardened.

During the spring of 1951, the Huntington District of the Corps of Engineers initiated a large pavement-construction program for the improvement and expansion of the facilities at the Lockbourne Air Force Base. Soon after the pavement construction was started, it became apparent that the joints formed in the plastic concrete were not entirely satisfactory. As a result, it was decided to experiment with the use of a concrete saw for cutting joints in the hardened concrete. This operation proved to be satisfactory and was continued for the remainder of the pavement construction.

This construction included about 730,000 sq. yd. of concrete pavement having thicknesses of 6, 11, and 12 in. Altogether, about 250,000 ft. of transverse contraction joints were sawed. In addition grooves were sawed for about 200,000 ft. of longitudinal construction joints. This paper discusses the experiences with the sawing of joints in the concrete pavements at the Lockbourne Air Force Base, which was one of the first uses of this method on a large scale for airfield pavement construction.

DESCRIPTION OF PROJECT

The construction of airfield pavements at the Lockbourne AFB included several new concrete aprons and taxiways, and the extension, widening and resurfacing of the existing NE–SW runway. All of the aprons and the taxiways had a concrete thickness of 12 in., but the NE–SW runway had several different pavement sections, as illustrated in Figures 1 and 2.

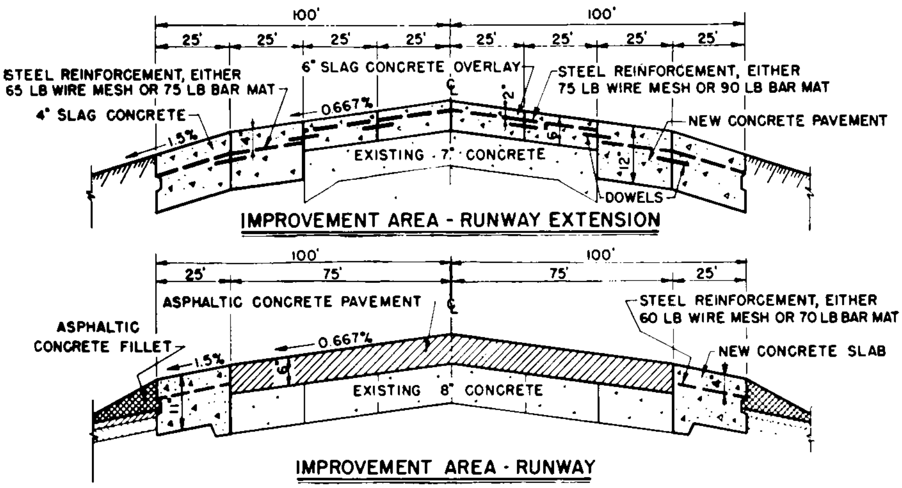

Figure 1. Pavement sections through resurfacing and widening of existing NE-SW runway.

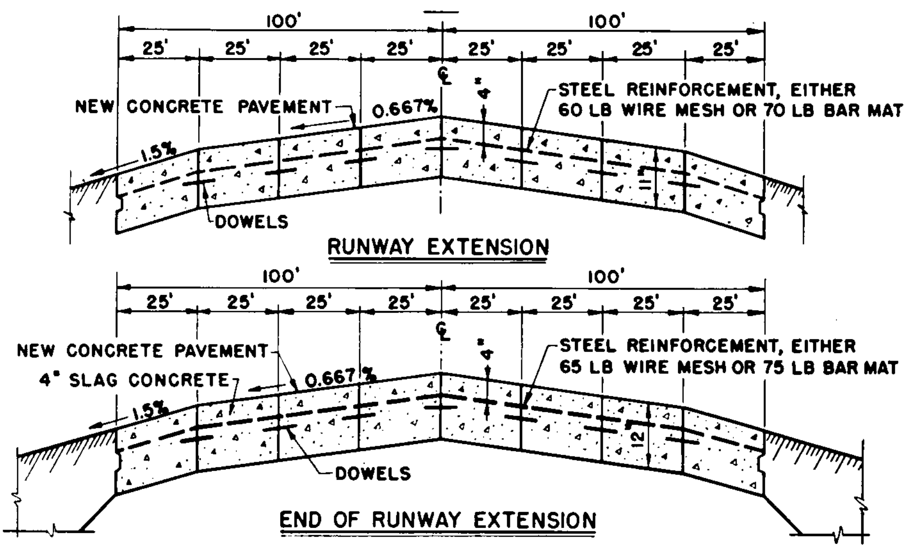

Figure 2. Pavement sections through extension of north-east end of runway.

Figure 1 shows the pavement sections through the resurfacing and widening of the existing runway and the existing taxiway at the end of this runway which was included as part of the new runway. The first 1,000 ft. at the southwest end of the existing runway and taxiway was overlaid with a 6-in. slag-concrete overlay. The widening lanes were 12 in. thick and consisted of a 4-in. slag-concrete surface course placed monolithically over 8 in. of regular concrete. The remainder of the existing runway was overlaid with 6 in. of bituminous concrete and the concrete widening lanes in this area were 11 in. thick.

Figure 2 shows the sections through the extension at the northeast end of the NE–SW runway. The concrete thickness for 1,000 ft. at the northeast end was 12 in., and consisted of 4 in. of slag concrete placed monolithically over 8 in. of the regular concrete. The remainder of the runway extension had a concrete thickness of 11 in.

Except for the concrete overlay portion of the runway, all of the concrete pavements were constructed in 25-ft.-wide lanes with dummy groove contraction joints spaced 25 ft. apart. The concrete overlay portion of the runway was constructed in 25-ft. lanes but was divided into smaller slab units by constructing dummy groove joints to conform with the joint spacing in the original pavement. No expansion joints were included in the pavement lanes.

Wire mesh, weighing from 60 to 75 lb. per 100 sq. ft., was placed 4-in. below the surface of the concrete runway. The mesh did not extend through the contraction joints, except that, in the outside lanes, it was laid continuous through the joint. The wire mesh was omitted in certain designated areas of the apron paving.

The concrete for the bulk of the construction was made with natural sand and 3-in.-maximum-size crushed gravel. Petrographic examinations indicate that the sand and gravel contained limestone in the amounts of 44 and 85 percent respectively. However, a 1-in. slag aggregate was used in the slag concrete mix for the 6-in. overlay at the southwest end of the runway, and for the 4-in. surface course of this concrete which was placed monolithically with the regular concrete at both ends of this runway. Type 1A portland cement was used in about 60 percent of the concrete, and the remainder contained a blend of 80 percent of the Type 1A portland cement and 20 percent natural cement. A cement factor of 6 bags per cu. yd. of concrete was used throughout most of the construction. All of the mixes were air entrained, with an air content of about 4 percent in the freshly mixed concrete.

The pavement construction was started in May 1951 and continued through November 1951. Additional concrete pavements were constructed during the period from May to October 1952. Weather conditions varied widely during these construction periods and air temperatures during concrete placement ranged from a maximum of about 95 F. during the summer months to a low of about 21 F. during November 1951. All of the concrete was cured with membrane curing compounds, but additional coverings of sisal kraft paper and straw were used for cold weather protection. The influence of the different conditions encountered during this construction on the joint sawing operation will be discussed later.

JOINT CONSTRUCTION

When construction of the pavements was started, the contraction joints were formed in the plastic concrete, using a joint machine which cut the fresh concrete and then forced a metal strip into it to form the groove. With the 12-in. pavement which required a 3-in. groove, considerable difficulty was encountered in the forming of the joints. If the joint was formed while the concrete was fairly plastic, it had a tendency to flow together after the bar was removed and during the edging operation. Also, the concrete had a tendency to be depressed in the region of the joint, due to movement of the plastic concrete. If the joint-forming operation was delayed, there was considerable disturbance of the concrete when the bar was forced into the concrete, and the concrete had a tendency to be humped at the joint. On this job the difficulties in hand forming the joints were aggravated by the use of a 3-in. aggregate in the mix.

Because of the difficulties encountered in forming the dummy groove joints in the plastic concrete, it was decided to experiment with sawing of the joints.

JOINT DETAILS

Details of the contraction joints, and the longitudinal and transverse construction joints for the pavements are shown in Figure 3.

All weakened plane contraction joints were constructed to a depth of one fourth of the thickness of the pavements. For the three pavements thicknesses of 6, 11, and 12 in., depths of the groove were 1½, 2¾, and 3 in., respectively, for both formed and sawed joints. The original plan for the formed contraction joints required a beveled groove ¼ in. wide at the bottom and ⅜ in. wide at the top, with the top edge rounded with an edging tool of ¼-in. radius. The sawed joints were carried to the same depth, with a uniform width of cut of about 1/8 in. to 3/16 in.

The original plan for the longitudinal and transverse construction joints required that a groove 1/4 in. wide and 1 in. deep with rounded top edges be constructed at the top of the joint to permit sealing of the joint. When the contractor changed to the sawing operation, he found it more convenient to saw the groove with a 13 hp. air-cooled, two-cylinder gasoline engine connected to the saw mandrel with a 4-V-belt drive. A floating three-point suspension automatically protected the blade from binding. Other notable features were positive screw feed for cutting depth control, water-spray system for cooling the blade, front and rear pointers to guide the machine in a straight line, blade guards and solid nonsway wheels.

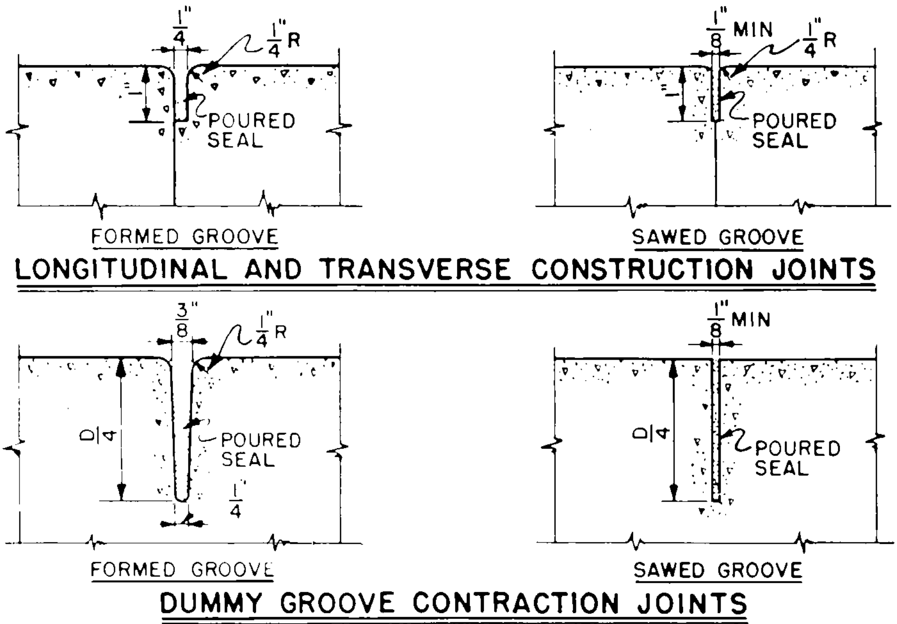

Figure 3. Typical joint details.

at the top of the construction joints, instead of forming it during construction of the lanes.

All joints were sawed to the full required depth in one cut, and the time required for sawing a joint 3 in. deep and 25 ft. long was about 6 min. It has been the contractors experience on this project to saw about 4,000 in.-ft. per blade.

EQUIPMENT

The concrete saw consisted of a compact power unit which drove a spindle upon which was mounted a thin, circular, segmented diamond-abrasive wheel. The entire assembly was mounted on four rubber-tired wheels, balanced so that it could be moved from one location to another quite easily. The type of concrete saw used on this project was powered

Total weight of the machine was approximately 500 lb. It was equipped with a water-supply tank, but for a larger-scale sawing it was necessary to supply the water from a tank wagon through a flexible hose. Figures 4 and 5 show views of the sawing equipment used on this project.

The saw blade was a segmented wheel 12 in. in diameter and approximately 1/8 in. thick. The blade had a specially treated steel center with a bonded rim of sintered metals and diamonds which combine to provide smooth, fast, economical sawing.

PROCEDURE

The sawing of transverse contraction joints at Lockbourne Air Force Base was started as an experiment, and little information was available regarding procedure or proper time and sequence for sawing the joints. It was reasonable to believe that a definite time existed when this sawing should be done, but just how soon the concrete could be sawed and how much latitude in time could be allowed was not known. The problem was to delay sawing until the concrete had hardened to a state where no damage would be done to the surface, yet complete the sawing before voluntary cracking of the slab would occur. It was decided to saw at 500-ft. intervals as soon as

Figure 4. Concrete saw in operation. Hose line is connected to water wagon.

the setting characteristics of the concrete would permit, then to saw at 100-ft. centers, and finally picking up the intermediate joints on 25-ft. centers, all in the order in which the concrete was placed. With this sawing sequence a few cracks occurred, and it was apparent that it would be necessary to modify the procedure. It was then assumed that setting of the concrete to a stage which would permit satisfactory sawing would progress at the same rate as the placing and finishing, and the procedure was changed to require sawing of the contraction joints at the specified 25-ft. intervals progressively as the concrete attained the proper hardness. This procedure was followed throughout the remainder of the pavement construction with satisfactory results.

As soon as the concrete hardened to the sawing stage, a chalk line was struck across the pavement at the desired intervals. The pavement was wet down with water to protect the curing membrane from abrasion. The saw machine was set with the pointers on the chalk line at one side of the paved lane. For intermediate lanes between existing concrete, the sawing was completed in a single operation from one side of the lane to the other. However, where the lane was paved between forms, the cut was made to the opposite side, stopping just short of the steel form. The machine was

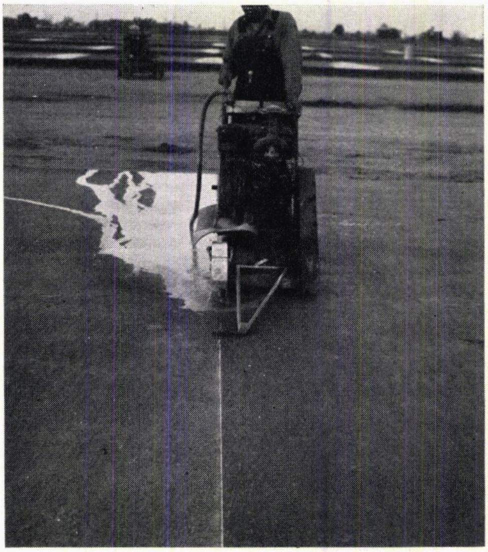

Figure 5. Front view of concrete saw in operation. Chalk line is used as a guide in obtaining a straight cut.

then reversed and the short section that had been under the machine in its starting position was sawed. The uncut triangular sections adjacent to the forms were cut through when sawing the intermediate lanes. Mechanical guides were given a trial test for straight line sawing, but the idea was discarded as being too cumbersome.

With respect to the longitudinal construction joints, the sawing time was not important, as the joint already extended completely through the pavement section. The sawing was done only to provide a groove for holding the joint-sealing material. For these joints the top edges of the concrete were rounded as required during the finishing operations, and the sawing of the groove was completed at the convenience of the contractor.

CONDITION AFFECTING SCHEDULE

It has been the experience at this project that no definite time factor can be applied between the placing of concrete and sawing contraction joints but that the time of sawing must be determined experimentally to meet varying conditions. It appears that major factors that control the time element are: weather and temperatures, quantity of cement per cu. yd., and type of concrete.

Insofar as weather is concerned, time of day, season, temperature, temperature change, humidity, wind velocity, sunlight, all have an influence on the time interval between placement of the concrete and sawing of the joints, as well as on the period during which the joint sawing has to be completed. Most of the concrete was placed during the summer months, when the weather was generally hot, dry, and windy. The air temperatures ranged from about 65 F. to 75 F. at night and up to about 95 F. during the daytime. Concrete placed in the morning generally could be sawed within 6 to 8 hr. on hot, windy days. However, concrete placed after sundown on the night shift during this same period could be sawed about 12 hr. later on the following day. A small amount of concrete was placed in November with air temperatures varying from 21 F. to 38 F. It was necessary to cover this concrete immediately after placement, and sawing of the joints was accomplished approximately three days later. This concrete has been observed for a period of 12 mo. during which the air temperature has ranged from minus 14 F. to 95 F., but no uncontrolled cracking has been found.

During the peak of the 1951 construction season, when a cement shortage occurred, the contractor substituted a blend of 20 percent natural and 80 percent portland cement for the portland cement used in the concrete. The use of natural cement retarded the setting time somewhat, and together with the advance of cooler weather, the period of time between placing concrete and sawing the joints greatly increased. As an example, concrete that was placed at 2 P.M. on September 28, 1951, when the maximum temperature was 58 F., could not be sawed until 24 hr. later. The temperature during the night dropped to 37 F. and elevated to 60 F. the next day.

Other factors, such as cement content, water content, and consistency, influence the hardening and strength gain of the concrete, which, in turn, affects the time interval before joints can be sawed. However, these factors generally do not vary appreciably after the conditions are established for the construction, and their effects generally do not have to be considered in the day-to-day sawing operation.

The experiences with these conditions indicated that no definite time interval between placing of the concrete and sawing of the contraction joints can be set which would be satisfactory for all conditions which might be encountered on any project. However, it was found that the time for cutting the joints is not critical, and that the proper time can be determined in the field through experience with the sawing operation in much the same manner as a cement finisher is able to determine when concrete is ready to be finished. Sawing too early produces a groove with ragged edges, due to disturbance of the aggregate. The saw blade also tends to accumulate a coating of fine particles which causes binding of the blade, reduces the speed of the saw, and slows down the cutting operation. On the other hand, there is no harm in delaying the sawing so long as random cracking of the concrete does not occur. One rule that is of prime importance in the successful sawing of joints is to be ready to saw when the concrete is ready, not when it is convenient for the operator. An extra saw should be available as a standby unit for use in case of a breakdown of the sawing equipment.

JOINT FILLING

The forming of controlled cracks or joints in the pavements necessitates the filling of the groove to prevent the movement of moisture through the joint. It has been shown, in Figure 3, that the contraction-joint groove which had a top width of ⅜ in. and a bottom width of ¼ in. when formed in the plastic concrete was reduced to approximately ⅛ in. uniform width when the joints were sawed. Although this was favorable in that it reduced the quantity of filler required, some difficulty was encountered in filling the sawed joints with some of the fillers used.

The sawed joints were thoroughly cleaned prior to pouring the sealing compound to remove loose material which might interfere with its bond to the concrete. A worn saw blade of the type used in making the initial cut was passed through the sawed joint to loosen any foreign material. This was done with the regular sawing equipment, but without the use of water, which was required for the original cut. A power-driven wire brush was then used to remove all traces of curing material and accumulated material adjacent to the joint. Finally, a high-pressure air jet was used to remove all loose material in the groove and at the surface near the joint.

Joint-sealing materials conforming with Federal Specification SS-F-336a were required

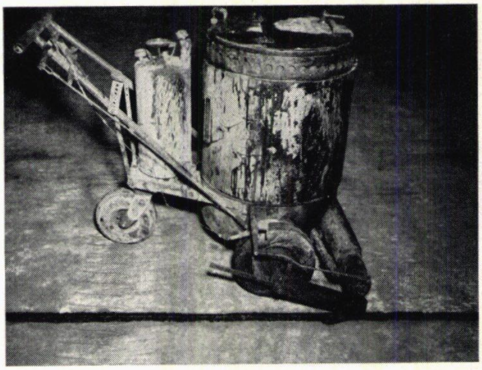

Figure 6. Mechanical applicator used in filling joints with hot-poured sealing compounds.

for this project, and furthermore, for certain areas the filler was required to be jet-fuel resistant. No great difficulty was encountered in filling the sawed contraction joints when the regular, hot-poured sealer was used, but considerable difficulty was encountered in filling these joints with hot-poured, jet-fuel-resistant materials. The difference is that the materials are poured at a higher temperature and have a more limited temperature range through which they are usable. When filling the sawed joint, which in most instances presented a narrow, square-edged opening 3 in. deep, the thin stream of JFR material cooled so rapidly that difficulty was encountered in completely filling the joints. Also, the JFR materials showed high shrinkage on cooling, and it was necessary to make three or four passes with the sealer applicator in order to fill the joint. The hand-formed joints, which had a wider groove with rounded edges, could be filled more readily.

In the sealing operation, the joint-sealing materials were first heated in a power-agitated melting kettle and then transferred to an oil-jacketed applicator, which maintained the material at the proper temperature during filling of the joints. A view of the mechanical applicator used in filling the joints is shown in Figure 6. This is a double-boiler, push-type unit which maintains the proper temperature of the joint material by means of an oil-heated bath surrounding the 20-gallon inner tank.

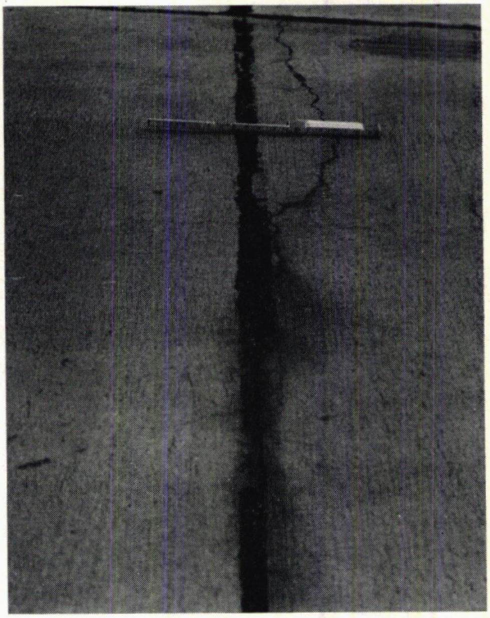

Figure 7. Transverse crack at a sawed joint. A few cracks occurred during experimental sawing of transverse contraction joints.

DISCUSSION OF SAWED JOINTS

So definite was the improvement in efficiency of sawing joints during the experimental program that this method was continued for the remainder of the 1951 and 1952 paving program, and it is contemplated that it will be used on all future paving work at this project. A few random cracks have been observed, most of which occurred at the start of the sawing operation. Most of the cracks are in the area of the planned joint. In several instances the cracks were observed when the operator prepared to saw the joints, and no sawing was done. It is believed that all cracks in the region of the sawed joints occurred before the joint was sawed, but the crack was too small to be observed. Figures 7 and 8 show typical cracks of this type. In most instances the cracking started opposite a joint in the adjacent lane. Omission of wire mesh in certain areas did not affect sawing time and no uncontrolled cracking has been noted in those areas.

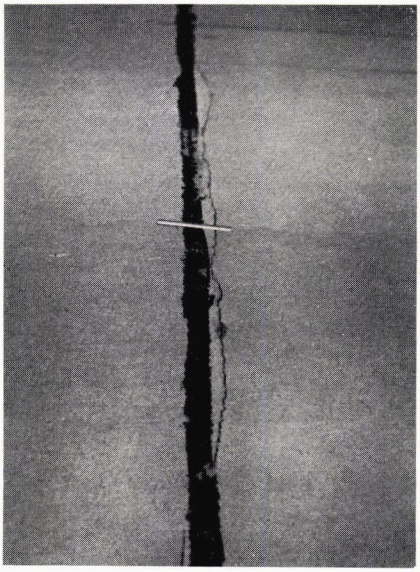

Figure 8. Another example of a transverse crack which occurred before joint was sawed.

The hand forming of joints tends to damage the concrete in that area, due to over manipulation and disturbance of the concrete after it is partially set. An example of severe scaling was found in the original concrete pavements at the Lockbourne Air Force Base, which were built about 10 yr. ago under pressure of war-time construction. While this scaling variously has been attributed to bad aggregate, overfinishing, vibrating screeds, and wet mixes, it generally originated at the hand-formed joints and progressed toward the center of the slabs, with the greatest depth of scaling at the joints. A typical view of this scaling is shown in Figure 9. This is a strong indication that concrete deterioration is likely to originate at the joints and be most severe in this area. The sawing of the joints avoids the manipulation and distribution of the concrete during its initial hardening period, which often contributes to the deterioration of the concrete at the joints.

The difficulties in obtaining a smooth surface when the joint is formed in the concrete have been discussed previously. On the other hand,

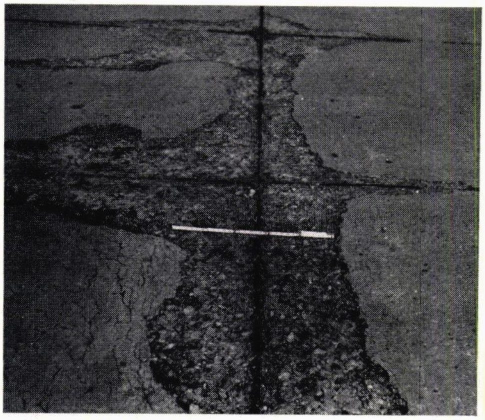

Figure 9. Severe scaling at formed joints in original runway.

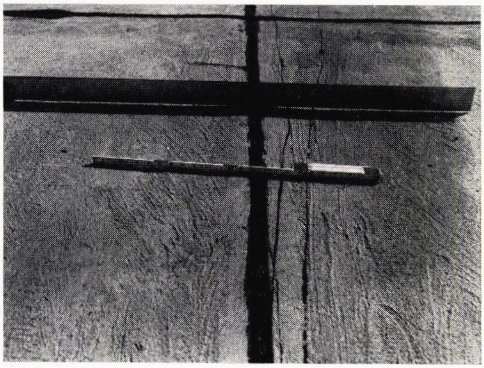

Figure 10. Hand-formed joint higher than surrounding area.

the surface at the sawed joint is as true as the general concrete surface. View of typical bad joints obtained in forming joints in the plastic concrete are shown in Figures 10 and 11. Figure 12 shows the smooth surface obtained by sawing the joints. It is obvious that the sawed joint will provide a better-riding surface. Also, the appearance of the sawed joints, which are of uniform width and depth, is greatly improved over that obtained by forming the joint. This comparison is shown in Figures 13 and 14. Figure 13 is a general view showing

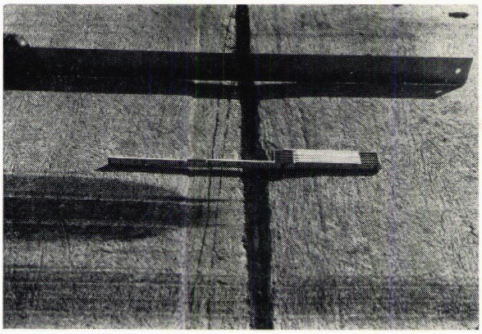

Figure 11. Depression at hand-formed joint.

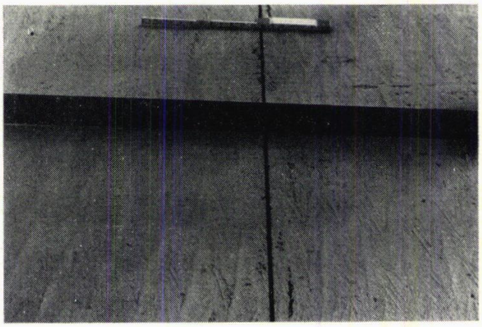

Figure 12. Smooth surface at sawed joint.

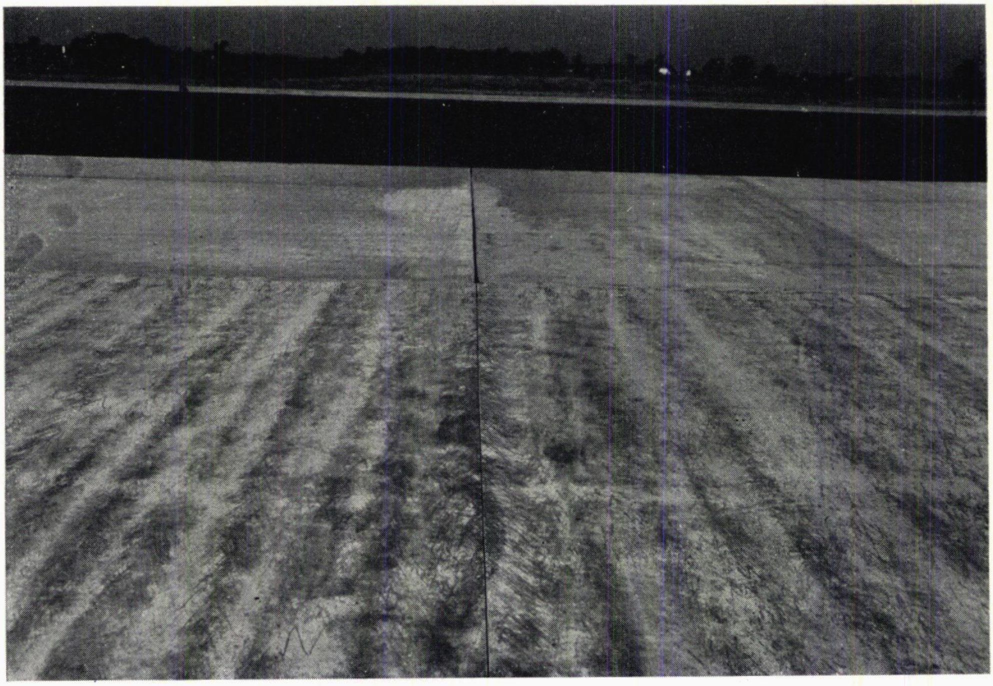

Figure 13. Appearance of formed and sawed joints.

both sawed and formed joints and Figure 14 is a closeup of the two types of joints. Figure 15 shows cracking through the pavement at a sawed joint.

It is still too early to evaluate the actual performance of the sawed joints in use; however, there are some areas where vehicular traffic has been exceedingly heavy. Under this traffic the sawed joints show no chipping nor spalling. Little usage has been made of the pavement in the area of the hand-formed joints. Neither has there been sufficient time for the elements to create noticeable damage. However, close observation of the hand-formed joints in some cases indicates considerable hair cracking at the surface adjacent to these joints. This is generally the first step in any deterioration due to weathering.

COST DATA

There are no figures available at present which might reflect an accurate cost relationship between sawed and hand-formed joints. The factors affecting cost vary from one project to another—and even on the same project. It is safe to assume that the cost of sawing will be somewhat higher than forming the joint by hand. Preliminary figures compiled indicate that sawing alone will cost about 7 cents per in.-ft. The savings in the quantity of joint sealer in sawed joints as compared with the amount required for filling of hand-formed joints will reduce the total cost per foot of joint sawed and sealed.

Figure 14. Close-up view of Figure 13 in area where change is made from formed to sawed transverse joint.

In spite of the apparent adverse cost comparison for the sawed joints, the contractor preferred to continue the sawing of the joints on additional paving work awarded after this construction was in progress.

SUMMARY AND CONCLUSIONS

The experiences at the Lockbourne Project have demonstrated that excellent sawed joints can be obtained by using properly trained workmen and exercising normal care in selecting the proper time for sawing the joints. The sawing time is influenced by many factors related to the materials and mix characteristics of the concrete, as well as by external temperature and weather conditions. However, the time limit is not critical and the proper sawing time can be selected without difficulty.

Based on the field observations, the sawed joints are considered to have many advantages over the conventional formed joints, since they: 1) are more uniform and have a better appearance; 2) provide a smoother surface for traffic; 3) avoid damage due to manipulation of the concrete during hardening; 4) permit a better sequence of operation during construction; 5) permit earlier application of curing compound and earlier protection of the concrete during cold weather; 6) reduce the quantity of joint filler required.

Against these benefits there is an apparent slight increase in cost for the sawed joints.

Figure 15. Dummy groove joint showing typical cracking through concrete slab at sawed joint. Joint-sealing material completely fills cut.

Also, some difficulty was encountered in sealing the sawed joints with hot-poured fillers which are resistant to jet fuel. The normal rubber-asphalt types of joint filler offered no problem in sealing of sawed joints.

Although it is too early to evaluate the performance of the sawed joints in use, their present condition indicates that their performance has been satisfactory.

ACKNOWLEDGMENT

The pavement construction at the Lockbourne Air Force Base was performed under the supervision of the Huntington District Office, Corps of Engineers, U. S. Army. The contractor for this work was the W. L. Johnson Company of Columbus, Ohio, to whom much credit is due for the success of the joint sawing operation.

The author wishes to express his appreci-

ation to the personnel of the Ohio River Division Laboratories, Corps of Engineers, particularly to I. Narrow of these laboratories for his assistance in the preparation of this paper.

DISCUSSION

William Van Breemen, *Supervising Engineer, Engineering Research and Soils, New Jersey State Highway Department*—The author is to be complimented for a most-valuable contribution dealing with the sawing of contraction joints, especially as concerns the practical application of sawing. This writer agrees with him wholeheartedly in regard to the superior riding qualities and appearance of sawed joints, as compared with average hand-formed joints. Moreover, as the author points out, sawing avoids the excessive manipulation and over-finishing of the concrete within the joint area that often occurs in connection with the conventional method of construction and which, in certain locations, has apparently been an important factor contributing to serious disintegration and scaling adjacent to joints.

As amply demonstrated at Lockbourne and numerous other projects, with the equipment now available the actual sawing operation involves no practical difficulties. The sawing is accomplished at a surprisingly rapid rate and, with due care, the footage of sawed joint per blade is considerable. Moreover, with the prevailing wages paid to concrete finishers, and the overtime usually incurred in connection with finishing operations, the cost of sawed joints may actually be very little if any more than that of conventional hand-formed joints, especially on a large project.

The writer feels, however, that the proper time interval between placement of the concrete and sawing of the pavement warrants some discussion. As found by experience, if the sawing is done before the concrete has attained sufficient hardness the saw will loosen and chip out the aggregate particles, which results in a very ragged cut. Excessive delay, on the other hand, results in transverse cracking, which may become apparent either before or after sawing, depending upon conditions.

In this regard, it is felt that the author's statements to the effect that the time for cutting the joints is not critical may be misleading. Moreover, these statements do not appear to be consistent with the one which reads: "One rule that is of prime importance in the successful sawing of joints is to be ready to saw when the concrete is ready, not when it is convenient for the operator." In view of the procedure employed at Lockbourne, it is presumed that the author has reference to a time limit measured in hours, at the very most, rather than days. To the writer, the clarification of this point seems very important, since it may not be generally appreciated that any prolonged delay is almost certain to result in extensive transverse cracking.

The author lists a number of factors which determine the proper time interval, among these being character and quantity of cement, type of concrete, season, temperature, temperature change, humidity, wind velocity, sunlight, and time of day. It is agreed that all of these factors are very important. The author did not, however, include curing – perhaps for the reason that he felt it desirable to mention only those factors which determined the time interval at Lockbourne, where only one type of curing was employed. But in considering the subject of sawing from an overall standpoint, the type of curing is most certainly an extremely important factor. If the pavement is cured by either the transparent-membrane or bituminous-membrane methods, it is highly important that the sawing be done as soon as possible, especially in connection with a pavement constructed on a hot, sunny day. On the other hand, if the curing method is of a type that prevents excessive temperature loss, the probabilities are that sawing may be considerably delayed.

The author stated that all of the concrete pavement at Lockbourne was cured with membrane curing compound, but did not mention the type. Although the photographs suggest that the transparent type was employed, specific information in this regard seems desirable.

New Jersey's experience with the sawing of joints on three paving projects during 1952 indicates that considerable care needs to be exercised if transverse cracking is to be prevented. It has also been our experience that a change in procedure, accompanied by a change in weather conditions, can produce altogether different results, as will be apparent from the following:

During the spring of 1952, for experimental purposes, it was decided to saw the joints in two day's work on one of our projects. The plans called for a pavement of unreinforced concrete, 24 ft. wide, of 10-in. uniform thickness, with hand-formed, undowelled, groove-type contraction joints at 15-ft. intervals and no expansion joints. The plans also called for the pavement to consist of two 12-ft lanes, the longitudinal joint between lanes being of the tongue-and-groove type, without tie bars.

As is standard practice in New Jersey, each lane was constructed independently. In constructing the second lane, the concrete was deposited directly against the first lane, after first applying a coat of tar paint to the edge of the first lane, i.e., along the longitudinal joint. On both days the sawing was done in lanes immediately adjacent to previously constructed lanes. All of the concrete on this project was air-entrained, and all of the pavement was cured by the transparent-membrane-spray method.

The first section in which the joints were sawed was constructed on May 8. The maximum air temperature on this day was 66 F. Prior to 3:30 P.M. the weather was cloudy, after which it was sunny. The length of this section, which represented the entire day's work, was 1,815 ft. Since it was appreciated that transverse cracking might occur if the pavement were constructed without joints of any kind, so-called control joints were installed at 60-ft. intervals (opposite every fourth joint in the previously constructed lane). These joints were simply hand-formed contraction joints similar to those installed elsewhere on the project, the depth of the groove being 3 in. As a further precaution, it was decided to saw as soon as possible.

Sawing was first attempted at 3:30 P.M., this being in connection with the pavement laid about 8 A.M. at the beginning of the day's work. However, due to the cool, cloudy weather and resulting slow rate of hardening, there was considerable ripping out of the aggregate. But by 6:30 P.M. it was found possible to make a clean, unragged cut. The sawing operations were therefore started, progressing from joint to joint, from the beginning of the day's work, and continued until 9:30 P.M., at which time concrete was encountered that was still too soft for sawing. In all, 27 joints were sawed during this 3-hr. period, the remaining 63 joints being sawed the following day. At all joints the depth of saw cut averaged about 2 in.

To date, there is only one transverse crack in this section. This crack, which occurred during the first night, is in the portion sawed the following day, and 8 ft. from a control joint. Its cause is not known.

The second section was constructed on May 22. The maximum air temperature on this day was 78 F., and the weather was clear and sunny. Due to a shortage of blades, it was decided to limit sawing to an 840-ft. section located approximately in the central portion of the day's work, which had an overall length of 1,830 ft. As in the case of the first section, control joints were installed at 60-ft. intervals. However, in view of the occurrence of only one crack in the first section, it was decided to find out what would happen if sawing were postponed until 7:30 A.M. the following day. But by the following morning cracking had occurred at numerous places, especially near the beginning of the section. As of the present, March 1953, this section contains 35 transverse cracks which extend clear across the lane, and five cracks which extend partly across the lane. In almost every case these cracks are in line with the contraction joints in the adjacent previously constructed lane, i.e., within a few inches one way or the other. The influence of the adjacent lane on the location, and possibly even on the occurrence, of these cracks is quite apparent, despite the absence of tie bars. Only 18 of the proposed 42 sawed joints in this section were actually sawed, for two reasons: first, because there appeared to be no reason to saw where cracking had already occurred, although this was inadvertently done at 7 joints and, second, the supply of saw blades became depleted.

Whether or not this extensive cracking was due entirely to the delay in sawing is a rather moot question, considering that the first and second sections were constructed under materially different climatic conditions. But it is at least apparent that one cannot afford to take liberties with this procedure. Incidentally, the remaining portions of this day's work, which, in accordance with the plans, were constructed with handformed contraction joints at 15-ft. intervals, have thus far remained uncracked.

Relative to the matter of sealing, there is the question of whether or not the conventional sawed joint will remain in a sealed condition even though the groove may have been completely filled in the beginning. This, of course, is a function of 1) how much the joint subsequently opens and 2) the capabilities of the sealing material. But when it is considered that, basically, all sealing materials are liquids, of constant volume, and susceptible only to a change in shape, it is apparent that the conventional width of groove imposes a very strict limitation on the permissible amount of opening. If, for example, a joint having a ⅛-in. groove were to undergo an opening of ⅛ in., the sealer would be obliged to undergo an extension of 100 percent. Moreover, during the open condition, 50 percent of the groove space would necessarily be devoid of sealer. This, in fact, actually would be the winter condition in New Jersey if the joints were spaced at 25-ft. intervals, that is, in connection with summer construction.

It consequently appears that if there is to be any expectation of effective sealing, sawed joints must either be installed at close intervals or the width of the groove must be increased. If it is assumed that a first-class sealing material may be extended 50 percent (this being in line with the standard laboratory extension test), but that 50 percent is the critical limit, it could perhaps be assumed that the minimum safe width of groove is about double that of the anticipated joint opening.

With respect to the creation of additional width, a method employed in the construction of concrete aprons at the Newark (N. J.) Airport last fall may be of interest. These aprons were constructed for and under the direction of the Port of New York Authority. In setting up the requirements for the contraction joints, which could be either handformed or sawed, the authority specified a groove width of not less than ¼ in., the purpose being twofold: First, to facilitate the initial filling of the grooves and second, in connection with maintenance, to facilitate resealing.

Shortly after the beginning of construction the contractor decided to try sawing, but was unable to obtain ¼-in.-thickness blades. He therefore was granted permission to saw the grooves full depth (2¼ in.) with a standard ⅛-in. blade, provided that, for a depth of ¾ in., they subsequently would be widened to ¼ in. This he accomplished very conveniently by attaching a worn-out 14-in. blade and a new 10-in. blade to the same shaft, side by side—the larger blade following the original cut and serving as a guide. During the final stages of construction, in a limited area, both cuts were made simultaneously by employing two new blades. Incidentally, it is understood that equipment has recently been developed, and may now be available, for widening the upper portion of sawed joints.

Based on observations in New Jersey, our present thoughts may be summarized as follows:

1. The major problem encountered in the sawing of joints is the prevention of transverse cracking.

2. Cracking is due primarily to an excessive loss in pavement temperature prior to sawing.

3. The sawing of joints may be successfully accomplished provided that certain precautionary measures are taken. These are: (1) sawing as soon as possible; (2) the employment of a curing method that will prevent excessive temperature loss (it is presumed that any of the accepted methods of curing are adequate from the standpoint of moisture retention); and (3) the installation of control joints.

It may not be necessary, however, to employ all of these measures simultaneously.

4. In connection with the sawing of joints the transparent-membrane-spray method is one of the most unsatisfactory methods of curing, since it has no material effect on preventing changes in pavement temperature. However, as apparently found at Lockbourne, this method may prove adequate if the sawing is done as soon as possible.

5. Unless the joints are sawed as soon as possible, the pavement should be cured by a method that prevents excessive temperature loss. A possible exception would be the installation of control joints at close intervals.

6. In general, the probability of cracking is very much greater during the summer than

in the spring or fall, especially in connection with membrane curing.

7. The use of white-pigmented curing compound may prove effective in the prevention of cracking, or at least in extending the critical limit between the time the concrete is placed and the joints are sawed. This was indicated in connection with a pavement constructed last September at Camden, New Jersey. In this instance, cracking ceased after a change from transparent to white-pigmented compound.

8. A procedure or curing method that has proved satisfactory in connection with spring or fall construction may not necessarily prove satisfactory during the summer months.

9. A groove-type contraction joint is probably not the most-effective type of control joint, since it can provide no relief until the concrete below the groove has been pulled apart. A type of joint that completely interrupts the continuity of the pavement would probably prove much more effective.

10. In order that a sawed joint may be maintained in a sealed condition, the width of the groove should properly be a function of the amount of joint opening—the greater the opening the greater the required width of groove.

In conclusion, the writer wishes to thank John M. Kyle, chief engineer, Port of New York Authority, for granting permission to comment on the sawing procedure employed at the Newark Airport.

Gordon K. Ray, *Engineer, Highways and Municipal Bureau, Portland Cement Association*—Vogel has given us a clear picture of his experiences with sawed joints at Lockbourne Air Force Base. We had the opportunity to observe this project from time to time, both during construction and after the pavement was put in service. The results obtained by Vogel and the contractor with their sawed joints were certainly excellent.

A large part of their success can be attributed to the fact that both parties were interested enough in this type of construction to take special pains to obtain satisfactory results. As Vogel pointed out, it is impossible to set up any hard and fast rules for the time of sawing the contraction joints. If special care is not taken in adjusting this time to suit the character of the mix, weather conditions, curing and other job conditions, raveling of the concrete or uncontrolled cracking will result.

Several highway departments have used sawed contraction joints during recent years. The Kansas Highway Commission, which saws contraction joints on all projects, uses a formed dummy groove at 80-ft. intervals. The use of this control joint, together with wet-earth curing, has permitted them to saw the contraction joints at 20-ft. intervals several days after construction, reportedly without fear of any intermediate cracks. The Colorado Department of Highways, which built its first project using sawed joints during 1952, set up a ½-mi. experimental section to determine the best time for sawing. On this project accurate records were kept of temperatures during and after construction, time intervals between placing and sawing, and elapsed time before the formation of cracks below the sawed groove. Information from this type of investigation permits the builder to saw at the most economical time and still control all cracking.

California and Wisconsin are other states where sawed joints are being used successfully. In California, experiments are now being carried out with saws employing multiple blades. One mobile, self-propelled saw uses eight blades in line for sawing a 12-ft. lane in approximately 20 sec.

Other airport-paving projects where sawed contraction joints have been successfully used are Newark Municipal, Idlewild, Grumman plant airfield on Long Island, and Buckley Naval Air Station at Denver.

Costs of sawed joints have varied considerably over the country from a low of about 15 cents per ft. to over 50 cents per ft. Costs vary with depth of groove, aggregate type, time of sawing and, of course, the contractor's experience. Although the direct cost of sawing joints may be slightly higher than that for formed dummy grooves, increased production efficiency and reduced quantities of joint seal may offset the difference. Several contractors with sawing experience now prefer the sawed joints where the method of forming joints is optional.

One suggestion might be made in connection with Vogel's paper: Saw operators should be instructed to look carefully for cracks before sawing at a transverse joint location. If the pavement has already cracked, the sawed groove should be omitted at this location. A sawed groove immediately adjacent to a random crack is liable to develop spalling.

The sawing of transverse contraction joints probably would not work on pavement where slabs are mesh reinforced and panel lengths of 100 ft. or more are used. Michigan, which uses a 100-ft. contraction joint spacing, had one experience on a project built in 1951 where cracks developed before the sawing could be completed.

The use of a concrete saw for forming weakened-plane center (or hinged) joints in highway pavements and thin airfield pavements presents no problem in timing. Since this joint is intended to reduce combined traffic and warping stresses, it need not be formed until some time prior to opening the pavement to traffic. By sawing this joint several days after placement, reduced blade wear will lengthen their life and effect economy in joint sawing.

As pointed out by Vogel, the proper sealing of sawed joints is still not entirely successful. The narrow joint requires a much smaller nozzle on the sealing equipment. Hot-poured sealing materials must, therefore, be kept unusually hot to prevent plugging of the equipment, and this results in large volume changes which require repeated applications. Special equipment is needed to facilitate the joint-sealing operation. At the Newark Airport, two blades of different diameters were used to create a ¼-in.-wide groove for the top ¾ in. This increased the cost of sawing considerably but resulted in a wider surface groove which is more easily sealed.

Vogel's report of his experience at Lockbourne should help other engineers to build pavements using sawed contraction joints with confidence that cracking and raveling can be avoided if proper attention is paid to sawing time.

A. T. Bleck, *Construction Engineer, State Highway Commission of Wisconsin*—The construction of transverse joints in concrete pavement has always been a matter of considerable concern to the builders of pavements, as they are always a potential location of unsatisfactory surface smoothness.

The use of air-entrained concrete made this quite critical when the formed type of dummy groove joint was used. The use of a bituminized fiberboard insert about ⅛ in. thick produced extensive spalling at such joints.

In the 1952 construction season, at the instance of the Bureau of Public Roads, formed dummy groove joints were placed at 100-ft. intervals with four sawed joints 20 ft. apart between these. The joints were sawed to a depth of 2 in. A number of such joints on several of the projects were sawed to a depth of only 1 in. A number of these 1-in. joints were examined before the advent of cold weather, and it was found that, between the different jobs, from 40 percent to 90 percent of the 1-in. joints had cracked through to the bottom of the pavement.

In the 1952 work, the transverse joints were bid as a separate item. The formed dummy groove joints were bid at about 22 cents per linear foot of joint. In the earlier lettings of the year the sawed joints were bid at around 30 cents per ft., but on subsequent lettings this price was raised to about 50 cents per ft. of joint. The bid prices included the sealing of the joints with Wisconsin specification asphaltic-type joint filler.

These prices generated costs of about $2,500 per mi. for the joints in 24-ft. pavements.

The work in 1953 proposes sawed joints 1½ in. deep, spaced at 40-ft. intervals, without any formed dummy groove relief joints. The specifications provide that the joints shall be sawed not later than 24 hr. after the concrete has been placed. This is all premised on the results obtained in the 1952 work. As the pavements in Wisconsin are built upon drainable granular base and subbase courses, the 40-ft. spacing should inhibit random transverse cracks to within tolerable limits and will afford some economics in construction.

With reference to Figure 9 of Vogel's paper, we would be prone to question that the spalling shown is due to the method of constructing the joint. The view seems to indicate that the failure is occasioned by the so-called typical D-cracking, which we feel will, no doubt, also occur at cracks and other joints regardless of how constructed.

K. C. Vogel, *Closure*—Bleck substantiates the value of sawed joints in paving slabs but raises the point of costs. As nearly as it has been possible to determine at Lockbourne the cost of sawed joints is slightly higher than formed joints, however, the contractors admit that there are savings in the overall operation that are difficult to evaluate in dollars and cents. The proof of the pudding is that the contractors will saw the joints in preference to forming them when there is no difference in the contract price.

The costs quoted by Bleck as bids to the Wisconsin Highway Commission cannot be accepted as valid for the reason that contractors are prone to unbalance their bid in favor of items with which they have had little or no experience, particularly when the item will have little effect on the total bid.

Distribution of End Reactions of Concrete Floor Slabs Under Concentrated Loads

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This paper deals with the problem of the lateral distribution of the end reaction, or end shear, of a reinforced-concrete floor slab resting on two relatively rigid supports, when the slab is subjected to concentrated loads such as the wheels of a truck.

Bulletin 126 of the Iowa Engineering Experiment Station, published in 1936, reported experimental results on 20 individual slab specimens. Results indicated the thickness of the slab is the most-important factor which influences the effective width to be used in the computation of vertical end-shearing stresses in this type of structure. In order to extend the range of thicknesses of the experimental slabs, one additional slab has been constructed and tested.

The data obtained with this new, thicker slab supplement those previously reported in Bulletin 126, which are included in the paper. Conclusions are drawn on the basis of results obtained on all 21 of the experimental slabs. The principal conclusion is embodied in an empirical formula for effective width for a single concentrated load applied adjacent to a support and in the vicinity of the longitudinal centerline, which is $e = 6\sqrt{t}$ in which e is the effective width and t is the thickness of slab, both in feet. Modifications of this formula for loads placed near a free edge and for multiple loads are given the paper.

● BULLETIN 126 of the Iowa Engineering Experiment Station, published in 1936, gave the results of an extensive experimental study to determine the effective width for use in the calculation of end shear stresses in concrete floor slabs resting on two opposite supports and acted upon by concentrated loads. This earlier report included results on 20 individual slab specimens ranging in span from 3.5 to 10 ft.; in width from 5 to 7.5 ft.; and in thickness from 2.5 to 6.5 in. Certain empirical expressions for effective width were suggested in the bulletin, based upon the measured distributions of reactions on the slabs under several types of concentrated loads. The distribution of the reactions of the above slabs was measured by two different methods: one known as the lever method, in which the reaction on each of several longitudinal elements of a slab was measured by counterbalancing a lever, and the other called the friction method, in which the reactions under the several elements were determined by measuring the pull required to slide stainless steel ribbons between two surfaces arranged in such a manner that the reactions constituted the normal pressures on the ribbons.