Concrete Runway Construction Lessons Learned

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The Navy recently administered the construction of a critical Air Force facility—the parallel runway at Clark Air Base in the Philippines. The Pacific Division of the Naval Facilities Engineering Command administered the design and construction of this new runway. The project required construction of a concrete runway 3,200 m (10,500 ft) long by 61 m (200 ft) wide with connecting taxiways and holding aprons, aids to navigation, lighting, storm water drainage, and other facilities. The pavement section included portland cement concrete varying in thickness from 254 mm (10 in.) to 356 mm (14 in.), a 152 mm (6 in.) central plant–mixed cement stabilized base, and a fill subgrade of predominately sandy soils. Features of the design and construction are identified and how these features relate to pavement quality is discussed.

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The initial construction contract was awarded to the joint venture of the George A. Fuller Co. and Capitol Industrial Construction Groups. A second contract for completion of the project, after default of the joint venture, was awarded to Sundt Corp. of Phoenix, Arizona. Sundt's paving subcontractor was the Coffman Corporation.

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The runway pavement was constructed using a slip form paver 12.2 m (40 ft) wide. Joint spacing was 6.1 m by 6.1 m (20 ft by 20 ft). The longitudinal construction and contraction joints in the thicker central portion of the runway were provided with dowels for load transfer. Longitudinal construction joints in the outer sections were formed with keyways using a metal insert installed by the paving machine. The outermost longitudinal joint was a saw cut joint with deformed tie bars installed to tie the two slabs together. Transverse contraction joints were saw cut with no dowels and therefore relied on aggregate interlock for load transfer. The last three transverse joints at each end of the runway had dowels provided for load transfer.

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The runway became operational in November 1990. When Mt. Pinatuba erupted nearby in June 1991 covering the entire Air Base with a layer of volcanic ash, the U.S. government closed and vacated the facility. Currently the Philippine government is looking into reopening the facility as an international airport.

LONGITUDINAL CONSTRUCTION JOINTS

Modern concrete paving practices generally result in high-quality finished work. Construction joints, whether constructed with side forms or slip forms, are inherently the weaker portion of the pavement. Variables affecting the concrete mix, including humidity, temperature, water and air content, cement content, and aggregate gradation, result in frequent change in concrete slump. Voids along the sides or excessive edge slump or mortar buildup may occur. Joint edges may be overworked or patched and may contain deficiencies, which can lead to early chipping and spalling, water ponding, and other distress.

On runways, longitudinal joints may have a negative impact on the ride quality and the life expectancy of a pavement. When the centerline joint is uneven, the ride quality of all aircraft is affected negatively. If the unevenness is severe, this rough ride may impose high loads on aircraft landing gear, resulting in a reduced aircraft life and magnified impact loads on the pavement. The next longitudinal construction joint on each side of the centerline may be located near the main gear of larger aircraft. When these joints are uneven, they may have negative impacts on both aircraft and pavement structural integrity.

Traditional pavement design shows the runway cross section with a pointed crown at the center (Figure 1). Most construction drawing also indicate that this crown should be at a longitudinal construction joint. Thus, this joint is subject to all the problems noted. To avoid problems with the quality of this centerline joint, the paving subcontractor for the Clark runway project used a large slip form paver to place a slab 12.2 m (40 ft) wide, centered on the centerline of the runway. The paver had a hinge system, which permitted the center to be constructed as a crown. The contractor also installed a double screed system on the paver, which resulted in a very smooth finished slab. This screed effectively rounded off the centerline "point." The longitudinal centerline joint was then saw cut (Figure 2).

Most aircraft using this runway had main landing gear close to the centerline. The gear rode on the smooth interior portion of the 12.2-m (40 ft) concrete pour. The result of having both the nose wheel and main gears riding on an interior portion of the slab was an extremely smooth aircraft ride. The finished runway received many favorable comments from pilots.

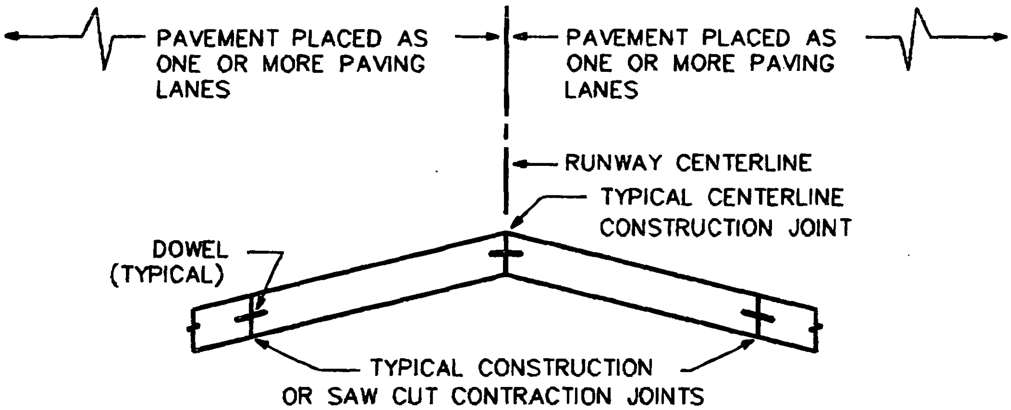

FIGURE 1 Typical runway centerline.

The first longitudinal construction joint was 6.1 m (20 ft) from the centerline of the runway. This joint is therefore close to the location of the heavy main gear on some large aircraft (B–747, KC–10, C–5). It was observed that this joint was fairly smooth, with some minor irregularities. However, when this joint conforms to FAA, military, or International Civil Aviation Organization criteria, it still may have vertical and horizontal deviations, which can induce roughness into the aircraft ride. Also, because the heavy gear of large aircraft are at or near the slab edge, any edge weakness may result in premature distress.

On this project, some of the longitudinal joints constructed under the initial joint venture contract failed to meet alignment and edge slump criteria. This occurred on paving lanes that were 6.1 m (20 ft) wide. Full-depth sawing and removal of the outer .3 m (1 ft) of the centerline paving lane were proposed. This proposal was made to preserve as much of the concrete as possible, while eliminating that section of concrete that contained the most serious deficiencies. Because many other problems existed during the initial paving on this project and the initial contractor was to be terminated, the proposal to remove the outer foot was rejected. Eventually all concrete placed by the original contractor was removed and replaced.

Although saw cutting and removal of a portion of the slab were rejected in this specific case, the concerns for longitudinal joint quality are still valid. It is believed that full depth removal of the outer 0.3 m. (1 ft) of a paving lane is a viable option in meeting the edge slump and smoothness requirements of most paving specifications. The benefits of removal include the following:

- The construction joint would be smooth both longitudinally and vertically because it is an interior portion of the slab.
- The edge of the adjacent pavement slab should also be stronger and smoother at the joint because it will not pick up any unevenness from the first slab.
- The joint quality should be better because the concrete of the first slab should not have any internal weakness due to honeycomb, slumping, or excessive mortar buildup.

It is also believed that paving a lane 12.2 m (40 ft) wide, when combined with saw cutting and removal of the outer .3 m (1 ft) of the lane (Figure 3), can provide a smooth and high-quality runway section. If required for load transfer, dowels can be drilled and grouted into hardened concrete instead of set into plastic concrete.

A question arises about how the missing 0.6 m (2 ft) of the runway is to be made up. Depending on paver width, this might not be a problem, but if no other solution exists, a shoulder .3 m (1 ft) wider might be constructed. It should be noted that runways constructed to international standards of 45 m (147.6 ft) and 60 m

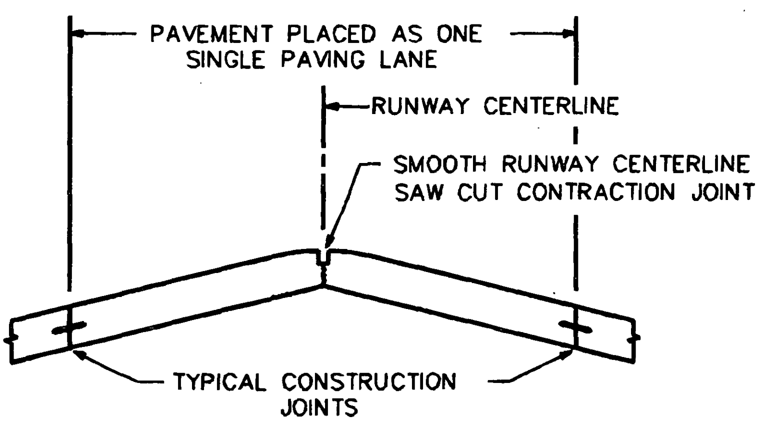

FIGURE 2 Smooth centerline joint constructed as internal saw cut contraction joint.

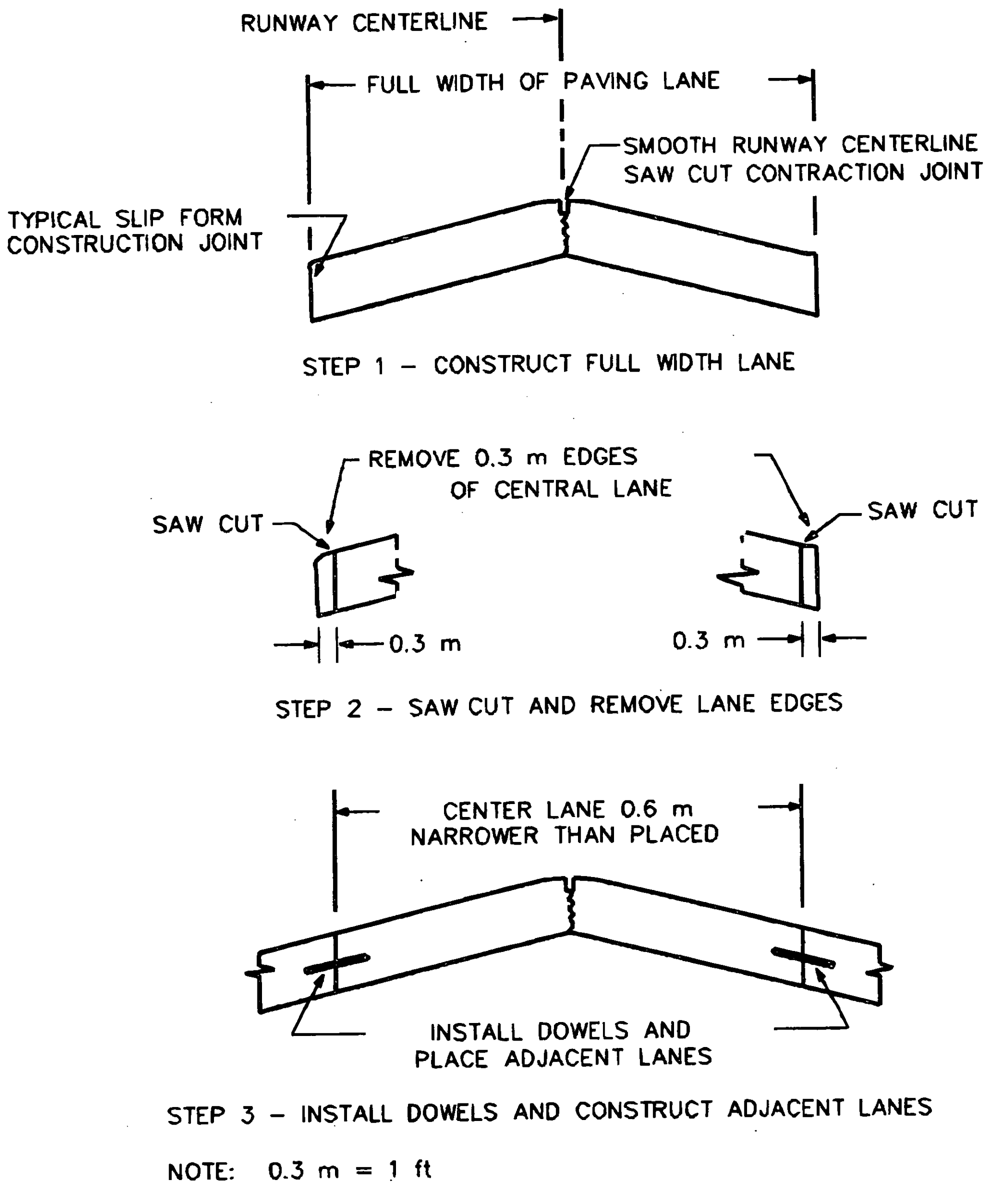

FIGURE 3 Removal of central lane edges.

(196.9 ft) are more than .6 and .9 m (2 and 3 ft) narrower than those designed in the United States. Perhaps no real problem exists.

STANDARDS FOR ACCEPTANCE OF LONGITUDINAL CONSTRUCTION JOINTS

Problems of longitudinal joints have been previously discussed. Current design standards treat all pavements and all joints alike. It is suggested that a high standard, which would allow only minor horizontal and vertical deviations, be applied to the central joints. These high standards should be strictly enforced. Cutting off the edges is a radical suggestion, treating the most critical joints near the center of the runway. Although more costly, it is a clear and enforceable means to ensure a quality joint.

The high cost of this type of joint construction could be partially offset by allowing larger tolerances for the longitudinal construction joints in the outer paving lanes. These outer joints do not have a major impact on the ride and durability of the runway. If transverse drainage is adequate at the joints, a greater degree of unevenness should be acceptable at no loss of serviceability. Sawing, grinding, or building up low spots should not be required, except in extreme cases.

TRANSVERSE CONSTRUCTION JOINTS

Standard runway specifications allow the contractor to decide how to construct transverse construction joints. These joints are built at the end of a paving lane for emergency reasons or end-of-day stoppage. Most designs provide some type of load transfer at these joints

and may include other details. Generally the smoothness requirement, as measured by a straightedge, is applied to this joint as to all other portions of the pavement. At Clark Air Base these construction joints resulted in a "bump" in ride quality. The deviation is usually rectified by grinding down the high portion. However, when an unacceptable spot is low, there is a tendency to attempt a repair either by building up the surface with a partial depth patch or grinding down a large enough area to meet the straightedge test. Despite the effort, these remedies often result in an uneven ride at the joint.

One method to alleviate roughness at transverse construction joints is to pave several feet past the intended joint location. Thus a full pavement section will exist at this location and no fixed forms or other devices need to be used to support the end of the slab. After the concrete is sufficiently cured, it is sawn off at the joint location and the concrete beyond the construction joint removed. If required for load transfer, dowels can be drilled and set with a rapid setting epoxy grout. Paving then continues from this straightedge, with the paver beginning on the existing slab and moving out onto the new, freshly placed concrete.

This construction technique is more costly, and contractors cannot be expected to do this unless it is required. Such a requirement could be incorporated into the specifications for the central lanes of the runway.

RELATIONSHIP BETWEEN LANE WIDTHS AND OTHER FACTORS

Most design criteria specify exact lane width, transverse joint spacing, and required joint details (*1–3*). The choice of lane width and transverse joint spacing is often based on agency experience, amount of reinforcement, load transfer requirement, and some accepted ratio of slab length to width. The size of available pavers should also be a consideration.

Designers should not limit the lane width considerations to locally available machines. Large paving machines are available today, and they can be configured in a range of widths. A large part of mobilizing a paving plant is the setup and breakdown costs. Modern transportation facilities permit moving machines long distances quickly. The extra cost to move larger equipment, even a few thousand miles, is low relative to the other mobilization costs. Because of increased productivity and reductions in length of construction joints, the total cost of the project may be lower if these large paving machines are used.

Another factor considered by designers is the size of the concrete plant specified in contract documents. Plant size is based on the need to deliver an adequate amount of concrete to the paving machine so that it may pave without interruption. The wider the paving lanes specified and the thicker the pavement, the larger the required concrete plant. Designers should be aware that the manufacturer's rated capacity may be for an ideal condition, and actual plant output may be significantly lower. It is suggested that specifications require a manufacturer's rated plant capacity equal to two times the actual volume required to be delivered to the site.

Many typical paving specifications in use today list a range of equipment requirements. Many of these requirements are specific to older paving equipment and may preclude the use of some newer equipment. One factor rarely mentioned is the weight of the slip form paver. When thick concrete runway pavements are constructed, adequate paver weight is critical to achieving required smoothness and quality of the finished pavement.

It is believed that this is an area that requires more input from equipment manufacturers and contractors. Depending on the size of a particular project, specifications should allow the contractor a range of lane widths and transverse joint spacings. Maximum and minimum paving lane widths with a specified transverse joint spacing for each width should be provided. Minimum concrete plant output (volume delivered to the site) for each width should also be specified. Placement of lanes wider than the normal 7.6 m (25 ft) will reduce the number of construction joints and lead to better performing pavements.

For unreinforced concrete pavement, the U.S. Air Force and the U.S. Navy specify maximum slab size of 6.1 by 6.1 m (20 by 20 ft) (*1,2*). The FAA permits up to 7.6 m (25 ft) square slabs (*3*). A generally accepted standard for the ratio of slab length to width is 1.25 maximum. Under a performance specification, selected paving lane width must accommodate these values.

STRAIGHTEDGE TESTING IS UNSATISFACTORY

Traditional surface testing of airfield pavements has been with a straightedge 3.0, 3.7, or 4.9 m (10, 12, or 16 ft) long. Straightedge testing criteria and procedures are not related to aircraft performance and have not been standardized for airports. At Clark Air Base, the specification permitted a 6.4-mm (¼-in.) deviation in the transverse direction and a 3.2-mm (⅛-in.) deviation longitudinally in 3.0 m (10 ft). Most specifications further limit the deviation of the finished pavement elevation from the design elevation to 13 mm (½ in.) or a similar number. These tests are not always adequate to obtain a smooth riding pavement. It is possible, for example, to start at an elevation 13 mm (½ in.) above design grade, dip to 13 mm (½ in.) too low, then rise to the 13-mm (½-in.) high elevation in less than 60 m (200 ft), and completely conform to the straightedge and elevation criteria. Thus a runway having a continuous sine curve can be built and still conform to criteria.

At Clark Air Base, the final runway surface consistently met the specified longitudinal tolerance of 3.2 mm (⅛ in.) in 3.0 m (10 ft). Although not directly quantifiable, the measurements on this project were an accurate assessment of superior ride quality. The only noted failures to meet longitudinal straightedge requirements were across transverse construction joints. Similarly, the only bumps in ride quality were found to coincide with these joints.

At Clark Air Base a condition was also observed in which the smooth riding pavement did not consistently conform to the straightedge test in the transverse direction. On some paving lanes, to prevent edge slump, the paving machine operator used a float attachment that tended to over-build near the edge. This overbuild resulted in a slightly concave upward surface from .3 to 1.0 m (1 to 3 ft) inward from the edge. The 6.4 mm (¼ in.) in 3 m (10 ft) transverse requirement was not always met in these locations. Such a minor deviation in the transverse direction does not affect ride quality and is of no consequence. Overbuilding is preferred to excessive edge slump and shallow patchwork that otherwise might have occurred.

The Air Force and Navy have been experimenting with the use of profilographs for quality control of the longitudinal profile on runways. Future specifications will incorporate these devices. Preliminary, unpublished data, which have been collected by the Army, indicate that a limit of 178 mm (7 in.) per 1.6 km (1 mi) of roughness, using a California-type profilograph, can be achieved for runway construction. This is consistent with many highway

specification requirements (*4*). The FAA continues to support research to determine the response of aircraft to variable profiles. This is a complex problem, given the wide range of aircraft and possible profiles. A means of better specifying acceptance criteria is certainly warranted at this time.

TIED EDGE JOINTS

The joints at the outside of wide pavements are tied to keep outside slabs together when pavement expands and contracts. Constructing tied edge joints presents problems when installing the tie bars and ensuring the pavement does not crack at nearby locations.

The outside lane on the Clark runway project was thinnest at the center of the runway. The two lanes were placed in one 12.2-m (40-ft) wide pass, and the tied joint was created by saw cutting the slab directly above preset tie bars. Cores indicated that most of the joint cracked on the saw cut during the initial shrinkage period. However, in a few locations, a parallel crack developed about 1.5 m (5 ft) inward on the second lane. The cause of this cracking was never conclusively determined. It is believed that either excessive stress built up at this point due to restraint by the tie bars or a cement-stabilized base construction joint caused reflective cracking. This joint in the stabilized base was close to where the cracks occurred.

The value of tied joints is questionable. Ties are normally intended to restrain opening of keyways and prevent loss of load transfer. In the outside paving lanes of runways, only occasional traffic loading is experienced, so load transfer is not a major concern. Although some older pavements may have suffered from outer slab movement, this problem appears less common today. Even if the outside slab moves outward 25 or 50 mm (1 or 2 in.), a point would be reached at which further movement would cease. A widened joint poses no practical problem other than joint seal maintenance. At intersections, where aircraft traverse this portion of the pavement, thicker slabs and load transfer would be provided, and adjacent pavements would serve to inhibit outward movement. It is suggested that the requirement for tied joints in the outside lanes be removed from design criteria.

LOAD TRANSFER AND STABILIZED BASES

Dowels and keyways for load transfer are costly items and may not always be necessary. Dowel and keyway installation can be difficult and, when improperly installed, cause joint spalling and cracking. Repairs to joints containing dowels and keyways is expensive and difficult, and sometimes the attempt to replace the load transfer mechanism results in more damage to the pavement. Joints near the center of the runway can expect direct application of loads. If the pavement design thickness is calculated on the basis of expected load transfer and this transfer does not occur, the life of the pavement may be greatly reduced.

Few airports today can afford to close a runway for long periods for repair. Current thinking by many leaders in airfield pavement technology is to design pavements for a life longer than 20 years. Considering the enormous cost and flight delays as a result of runway repair, a longer design life makes economic sense. Pavement failure often begins at the edges of slabs, which are inherently the weakest feature. Conservative design of the edges would have a favorable impact on pavement life and therefore long-term economic costs. One proposal for improving the quality of the central joints is discussed earlier in this paper. Another means to increase pavement life would be to increase base course quality and concrete thickness in the central portion of the runway and other areas experiencing a high volume of channelized traffic.

Many current design standards call for providing a stabilized base where pavements are designed for large aircraft. This base is usually good quality, intended to prevent loss of fines, improve subgrade support, and provide a stable platform for operating paving equipment. Most designs require the base to be of a uniform thickness, which is usually the thinnest section permitted by design criteria.

A stronger stabilized or lean concrete base would reduce edge stresses and prevent faulting. Consideration should be given to providing a stronger and thicker base for the central portion of the runway. The outer areas might remain at their reduced dimension. However, providing a stronger base for the full runway width might be a means of ensuring adequate support for thinner pavements at the edge when, on rare occasions, they are traversed by heavy aircraft.

The Navy has designed many airfield pavements with smooth butt-type longitudinal construction joints on high-strength stabilized bases. The high-strength base provides a high subgrade reaction (k-value) and allows the pavement to be designed to accommodate full edge load condition. This design approach requires a moderately thicker slab, but eliminates dowels and keyways. For the relatively light Navy aircraft loads and traffic volume, faulting has not been a problem, and overall performance has been very good.

REFLECTION OF CEMENT-TREATED BASE JOINTS INTO PAVEMENT

As mentioned, reflective cracking from a cement-treated base may occur in the thinner sections of a runway. If even thicker and stronger stabilized bases are to be constructed, this problem may become more severe.

Providing a liberal bond breaker and requirements for a smooth base course surface would help prevent such cracking. However, practical problems arise in maintaining a good quality bond breaker surface during construction, which involves heavy equipment moving about on the surface. At this time, it is recommended that a good bond breaker, such as double applications of curing compound, be used on high-strength cementitious base courses.

CONCLUSIONS

This paper has reviewed recent experience with the construction of a portland cement concrete runway at Clark Air Base in the Philippines. It was found that the use of a wide paver, capable of placing 12.2-m (40-ft) wide lanes, greatly improved the ride quality and the quality of the longitudinal joints. The completed runway was extremely smooth. Transverse construction joints were found to be the only source of bumps in the finished pavement.

Under certain conditions, saw cutting and removal of the outer .3 m (1 ft) of the central interior paving lane when constructing runways are advocated. Removal (and replacement) of the outer .3 m (1 ft) will improve the smoothness and quality of the concrete along the longitudinal construction joints in the heavy traffic areas of the runway.

More flexibility in paving lane and joint design features is also recommended to permit more contractor innovation and use of new and modern paving equipment. Specifications for major runway paving projects should have input from contractor and equipment manufacturers.

Straightedge testing for surface smoothness may be useful as a means of quality control, but it does not relate to aircraft or pavement performance. Better methods of measuring smoothness and profile on airfield pavements are necessary.

It is recommended that tie bars not be placed in keyed longitudinal construction joints and that lean concrete and cement stabilized bases be treated with a heavy bond breaker.

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