NAVY EXPERIENCE IN ELIMINATING KEYS FROM CONSTRUCTION JOINTS OF CONCRETE AIRFIELD PAVEMENTS

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Introduction:

Some form of key has long been used in the longitudinal joints of paving lanes to prevent faulting and to reduce stresses at the slab edges. The common alternatives to forming keys are to provide either dowels along the joint or to thicken the edges of the slabs.

Because of the increased incidence of failure along keyed joints in its airfield pavements in recent years, the Navy is now constructing the longitudinal pavement joints without keys or dowels, simply using a straight butt joint with unthickened edges, and always underlain by a high quality stabilized base course. This design (see Figure 1) is similar to that used for a number of years by California for highways. It is simply constructed and avoids many of the complexities associated with placement or insertion of dowels, or the forming of keys, particularly in slipform pavement construction.

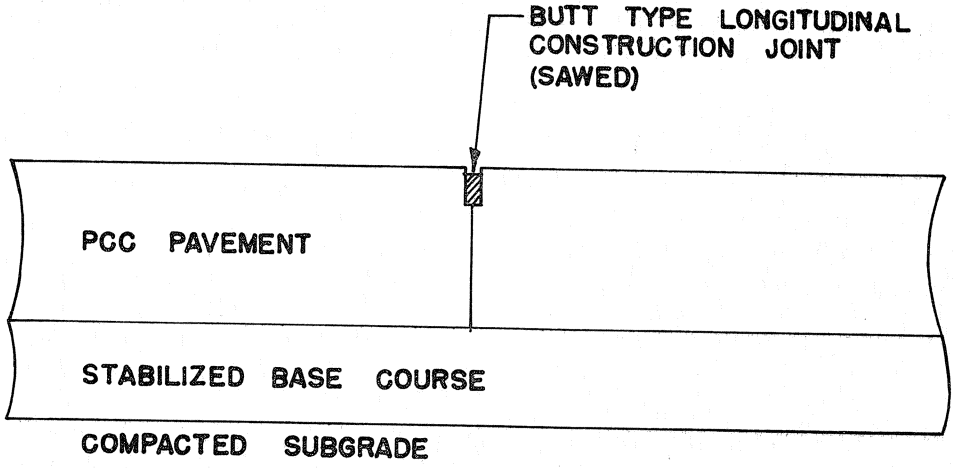


FIGURE 1.
TYPICAL CONSTRUCTION JOINT.

Experience with Keyed Joints:

Although many square yards of Navy airfield pavements have been constructed with keyed joints, the occurrence of failures has increased in recent years. These failures are believed to be associated with the increased use of multi-wheel gear aircraft, particularly the C-141 and C-5A aircraft which operate on many Navy airfields. Other failures can be attributed to poor consolidation of the concrete along the joints, to the use of excessively large aggregate, or to incipient failure by construction equipment operating on the edges of the pavement.

Rice (1) reported extensive key failures in test pavements under heavy multi-wheel gear loadings at the Waterways Experiment Station. Failures occurred in pavements from 8 to 14 inches thick which were constructed over a low strength subgrade. Keyway failures in Navy pavements have occurred in pavements on strong sandy subgrades and one serious failure was observed where a stabilized base was used. Another failure occurred in an overlay pavement where the separation course was composed of unbound crushed stone fines.

The most serious type of keyway failure is that in which the upper keyway portion shears through to the surface of the pavement. Figure 2 is a typical illustration of the surface deterioration associated with this type of failure. If not repaired promptly, sections of the keyway will continue to spall, presenting a serious hazard for the operation of aircraft.

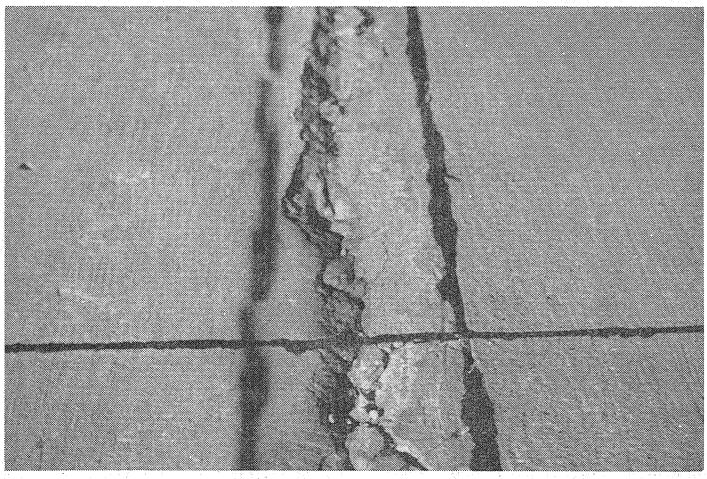


Figure 2 - Typical Keyway Failure

Similar failures presumably can occur in the lower portion of the keyway, however, the results are not so evident nor hazardous. Failure of the key itself is less likely, at least in the Navy pavements observed, because most of these were constructed with a base key dimension equal to 0.3 of the pavement thickness.

Failures are believed to occur as a result of high concentrations of stress between key and keyway when the load approaches the slab edge. Photoelastic and finite element analyses reported by the Civil Engineering Laboratory (2), show bearing and shear stress concentrations of 2 to 3 times the nominal stress in this area.

Keyway failures of the type described are very difficult to repair, and it is virtually impossible to restore the pavement to its initial condition and strength. Normally, temporary repairs are made by patching with asphalt which, of course, does nothing to restore the structural capacity. Epoxy patching has been attempted with varying degrees of success. A number of elaborate methods for strengthening keyways before failure have been proposed by Grau (3), but most of these are quite expensive.

Butt Joint Design:

The aforementioned factors have led us to the conclusion that the key is a very vulnerable mechanism to build into a pavement and that the seriousness of these failures and the difficulties of making satisfactory repairs outweigh any benefits which the keyed joint may have. The alternate practice of using dowels, although technically better, has some construction disadvantages, particularly in slipform construction.

With the increased use of stabilized bases under concrete pavement, a simple butt joint has more chance of success than it did in early days. As a replacement for the key, a high quality stabilized base course prevents faulting much as an underlying sleeper slab does. The extent to which it reduces the edge load stresses or effects "load transfer" is not easily analyzed. Ball and Childs (4) report from tests that cement treated bases substantially improve joint performance, and that the greatest benefit occurs in untied aggregate interlock joints. Direct comparisons were not made with smooth face butt joints.

The Westergaard analysis, of course, does not permit an appraisal of the edge support contribution of the stabilized base course under the adjacent slab because it - assumes no shear stress transfer in the soil or base material at the edge of the slab. Nevertheless, one knows intuitively that a continuous strong layer beneath the joint must reduce the theoretical edge stress, and that if it were infinitely strong the edge stress would approach the interior slab stress.

Taken all together these considerations suggest that stabilized base courses benefit joint performance substantially, even though a rigorous theoretical explanation of the mechanism is not possible at the present time. In the design of pavements using the butt longitudinal joints, we have assumed that the edge support contribution of the underlying stabilized base course layer is at least equivalent to the load transfer contribution of a keyed joint.

Construction Experience:

The first installation of this type design was a helicopter parking apron at the Marine Corps Air Facility, Santa Ana, CA. This pavement was designed for a single wheel load of 15,000 lbs and consisted of a slipformed 7 inch PCC surfacing and a 6 inch plant-mixed cement treated base. This installation was specifically designed to take advantage of the highway design and construction practices in Southern California at that time.

At a later date, and in direct response to the increasing number of key failures, NAVFAC has constructed over 800,000 square yards of concrete pavement in this manner. Table 1 presents a summary of the projects constructed to date. Pavement thicknesses vary from 6 inches on training fields to 12 inches on fleet operating stations. With one exception the base courses have been composed of high quality, plant-mixed, cement treated aggregate.

The butt joint design is attractive to contractors, particularly for slipform. The cost of the cement treated base is believed to be offset by elimination of keyway liners, or the cost of dowels. Limited available

TABLE 1. CONCRETE PAVEMENT CONSTRUCTED WITH NO KEYED JOINTS

LOCATION	PAVED AREA	YEAR BUILT	AREA (S.Y.)	PCC PAVEMENT	BASE COURSE
MCAS Santa Ana, CA	helicopter apron	1968	158,000	7" slipform	6" CTB
NAS No. Island, San Diego, CA	taxiways, aprons	1972	49,000	9" sideform	6" CTB
NAS Pensacola, FL	runway, taxiway	1972	66,500	10" slipform	6" CTB
OLF Choctaw, FL	apron, runway, taxiway	1973	64,800	6" slipform	6" CTB
MCAS Santa Ana, CA	runway, aprons	1973	13,308	7" sideform	6" CTB
NAS No. Island, San Diego, CA	taxiway, towway	1974	9,924	6" slipform	6" CTB
OLF Bravo, MS	runway, taxiway	1974	44,900	6" slipform	6" CTB
NAS Norfolk, VA	parking apron	1975	35,300	6" sideform	6" CTB
NAS Moffett Field, CA	parking apron	1975	36,000	10" slipform	6" CTB
Keesler AFB, MS	runway, taxiway	1975	85,400	12" slipform	6" CTB
NAS Miramar, San Diego, CA	taxiway, towway	1975	5,200	12" slipform	6" CTB
NAS Pensacola, FL	floor slab	1976	12,600	8" sideform	6" CTB
NAS Jacksonville, FL	apron	1976	6,800	10" sideform	6" Econocrete
NAS Miramar, San Diego, CA	apron, towway	1976	56,840	8" slipform	6" CTB
NAS Willow Grove, PA	parking apron	1976	34,500	9" -	6" CTB
MCAS Beaufort, SC	apron	1976	5,200	8" sideform	6" CTB
NAS Cecil Field, FL	apron, washrack	1976	25,100	8" sideform	6" CTB
NAS Cecil Field, FL	apron, floor slab	1976	16,400	8" sideform	6" CTB
NAS Pensacola, FL	apron	1976	37,600	10" sideform	6" CTB
NAS Pensacola, FL	apron, floor slab	1976	28,700	7½" sideform	6" CTB
NAS Dallas, TX	apron	1976	55,600	10" slipform	6" CTB
NAS No. Island, San Diego, CA	apron, towway	1976	19,760	9" slipform	6" CTB
NAS Miramar, San Diego, CA	apron	1976	79,277	8" slipform	6" CTB
NAS No. Island, San Diego, CA	parking apron	1976	34,574	10" slipform	6" CTB

cost data have shown an average cost of $2.90 per square yard for a 6 inch stabilized base course over the past four years.

Performance:

The parking apron at Santa Ana has been under traffic for eight years and, with the exception of hardened joint seal, performance has been excellent. The joints are free of spalls and faulting and there are no indications of the tension cracking one would expect from overstress at the edge. Although no detailed traffic records are available, the apron is heavily used by CH-53 helicopters.

Soon after completion of the apron, plate bearing tests were performed at the joints and in the slab interior of both the new pavement and an older section of the apron which was built with keyed construction joints and a granular base. The measured deflections under this loading which simulates the design aircraft are presented in Table 2. It can be seen from this table that measured deflections for all load placements were substantially less for the new pavement. Of particular interest is that the deflection at the butt construction joint over CTB is less than half that for the keyed joint in the older pavement on the granular base.

As seen by Table 1, later installations of this design have all been constructed since 1972 and long term performance data is not possible. There are no known defects, however, which can be attributed to the use of smooth faced construction joints.

Tentative plans exist for a more detailed study of the performance including accelerated traffic testing and a theoretical study of edge stresses. It is hoped that these studies along with close observation on in-service pavements will lead to refinements of the design assumptions.

Conclusions:

Because Navy experience in airfield construction indicates that the keyed joint is a very vulnerable mechanism to incorporate into concrete pavements, the Navy has been using a butt-joint design since 1972. A vital element of this design is a high quality and uniformly strong stabilized base course, usually of the cement treated type.

This type of design eliminates the severe cracking and breakout problem which occurs when a keyed joint breaks upward to the pavement surface.

Performance of the no-key design to date has been excellent. An apron at Santa Ana shows no defects after 8 years of service, and more recent installations are also performing well.

From the construction standpoint, this design favors the economics of slipform paving, and incorporates all the advantages of a stabilized base.

Precise analysis of the pavement stresses involved are not possible because of limitations in the basic Westergaard assumptions. Nevertheless, it is clear that overstressing will evidence itself in a tension crack some distance back from the edge of the slab. We feel that, even if this occurs, it is a substantial improvement over the key failures which have been experienced, and which are extremely hazardous for aircraft operations and virtually impossible to repair adequately.

Acknowledgements:

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TABLE 2

COMPARATIVE DEFLECTION TESTS
(MCAS Santa Ana, CA)

7" PCC over 6" CTB Butt Construction Joints (No Keys or Dowels)	6" PCC over 12" Granular Base Keyed Construction Joints
LOAD ADJACENT TO CONSTRUCTION JOINT -	
.017"	.039"
CENTER SLAB -	
.010	.023"
WEAKENED PLANE JOINT -	
.011"	.039"
PAVEMENT EDGE -	(THICKENED TO 8 INCHES)
.024"	.038"

NOTES:

1. Tests made with 15,000 lbs on 12" diameter plate
2. 7" pavement constructed in 1968; 6" pavement constructed in 1958

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3. Grau, R.W. Strengthening of Keyed Longitudinal Construction Joints in Rigid Pavements, Report No. FAA-RD-72-106, August 1972.
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