CENTER OF EXCELLENCE FOR AIRPORT TECHNOLOGY

TECHNICAL NOTE

TECH NOTE NO: 41
TITLE: HWD Testing Results for Runway 9L-27R

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1. Introduction

Heavy Weight Deflectometer (HWD) testing was performed to validate the in situ properties of the pavement layers on Runway 9L-27R. The testing was performed on November 12, 2008 by the OMP testing consultant Applied Pavement Technology Inc. (APTech). APTech also analyzed the data and provided the in situ pavement layer properties based on the HWD deflection data.

2. Objectives

The objective of this study is to determine and summarize the in situ properties of the pavement layers using nondestructive testing (NDT). The properties to be determined include the elastic modulus (E) of the PCC surface, Asphalt Concrete Base and Asphalt Treated Permeable Base, the modulus of subgrade reaction (k-value) and the load transfer efficiency (LTE) at joints.

3. Experimental Program

HWD Testing Plans

The HWD testing plan was divided into two layouts (“General” and “Intensive” testing). The “General” testing layout consisted of center slab tests in two lanes on each side of the centerline (four lanes total) with test intervals of approximately 200 feet. The four testing lanes were centered at 9 feet south, 9 feet north, 47 feet south and 47 feet north of the pavement centerline. Additional testing was conducted at transverse joints to determine the LTE across the joints. The joint testing was conducted at approximately 25 percent of the center slab locations (every fourth center slab test). Figure 1 shows the “General” testing layout.

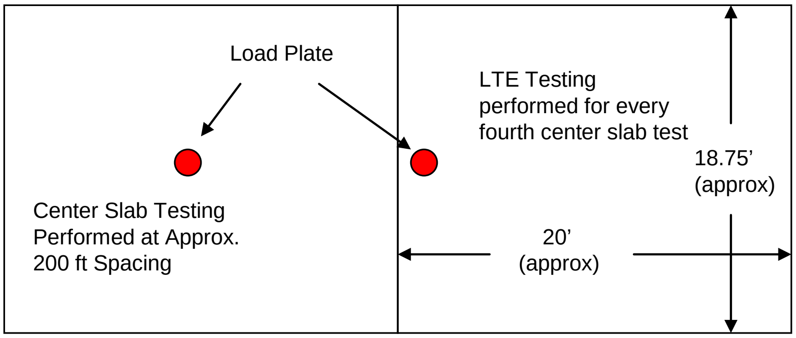
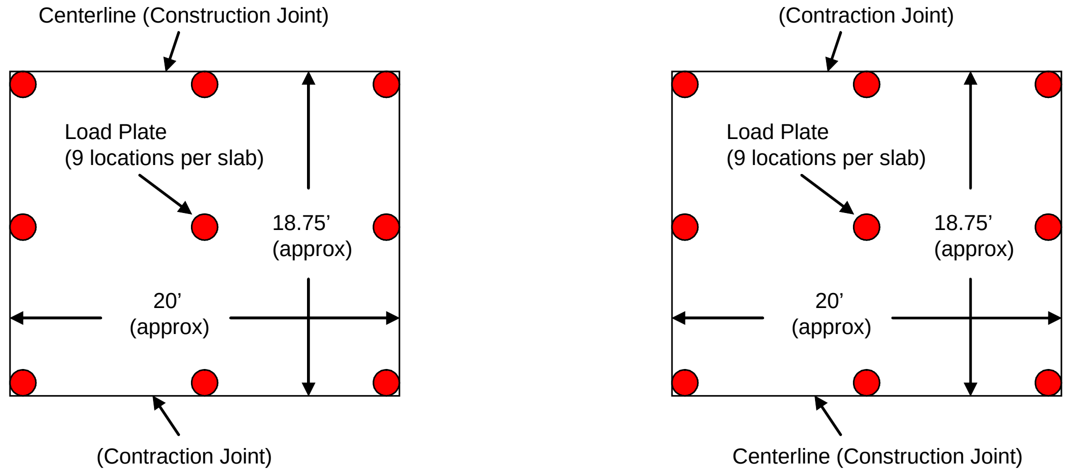


FIGURE 1. “General” Testing Layout

The “Intensive” testing layout consisted of a series of eight consecutive slabs at each end of the runway (sixteen total slabs). Each slab was tested at nine locations (center, mid-slab transverse and longitudinal joints, and each corner). The center slab and mid-slab transverse LTE testing locations were not completed on the western eight slabs because O’hare operations requested the HWD to leave the runway.

Figure 2 shows the “Intensive” testing layout. Testing on the west end included eight consecutive slabs just south of the centerline, while the testing on the east end included eight consecutive slabs just north of the centerline. A construction joint was located at the centerline while contraction joints were located at 18.75 feet north and south of the centerline.



(a) Testing South of Centerline Near West Runway End

(b) Testing North of Centerline Near East Runway End

FIGURE 2. “Intensive” Testing Layout

A three-drop load sequence was recorded at all test locations with target loads of 35, 45 and 55 kips. A seating drop was also performed but not recorded. The radius of the loading plate was 8.9 inches. Deflection sensors were placed at 12-inch intervals from the loading plate to 72 inches in front of the load plate. Additional sensors were placed at 12 inches behind and 12 inches to the side of the loading plate to facilitate LTE testing at the joint locations.

4. Experimental Results and Analysis

The following information is based on the HWD testing performed on November 12, 2008. All of the results and analysis are based on pavement deflections measured at that time. The results for all target loads (35, 45 and 55 kips) are shown in the following analysis. The average pavement surface temperature was 46.1°F and the average air temperature was 44.2°F during the HWD testing.

Maximum Deflection Data (Center Slab Testing)

The maximum deflections measured directly below the loading plate were normalized to a load of 50-kips. Results for both the “General” and “Intensive” testing layouts are shown in Figure 3. The “intensive” testing near the west runway end only consisted of one test location because O’hare operations requested the HWD to leave the runway. The data at this location is consistent with the “General” testing performed nearby.

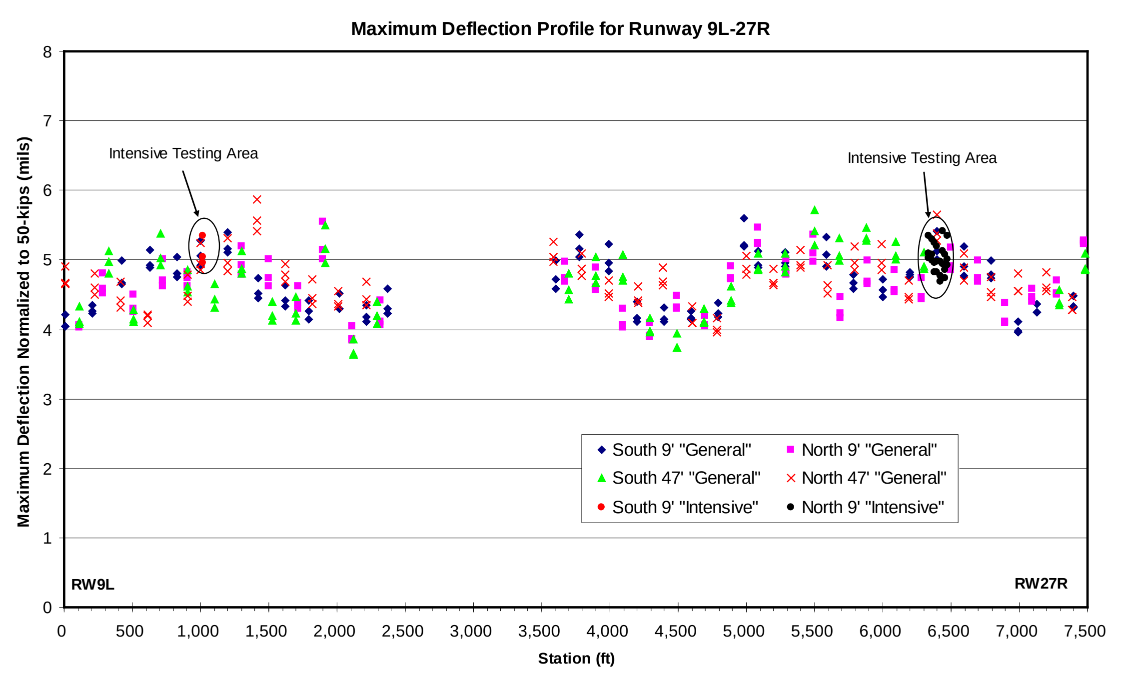


FIGURE 3. Maximum Deflection Profile for Runway 9L-27R

Figure 4 shows that there is only minor variability in the maximum deflections for the "Intensive" testing performed on the east runway end. The "Intensive" testing results are consistent with the "General" testing performed nearby.

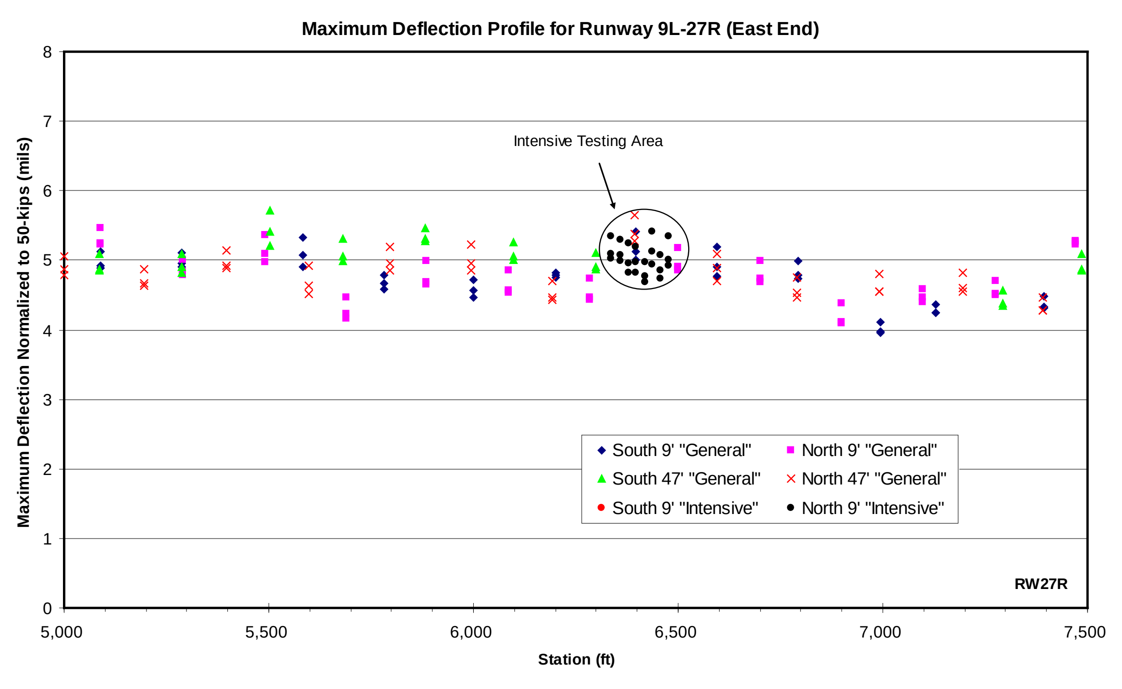


FIGURE 4. Maximum Deflections Near the East Runway End

Table 1 provides a summary of the Maximum Deflection Data (normalized to 50-kips). The maximum deflection at 50 kips is approximately 5 mils which is extremely small. There is only minor variability within each testing lane, i.e., the coefficient of variation is less than 10 percent for all four lanes. The averages for the "Intensive" testing layouts are slightly higher than the "General" testing layouts, however these only represent localized areas on the runway.

TABLE 1. Summary of Results for Center Slab Testing

Lane / Testing Layout	Maximum Deflection Normalized to 50 kips (mils)			Dynamic k-value (psi/in)			PCC Modulus (Mpsi)		
	Average	Std Dev	COV	Average	Std Dev	COV	Average	Std Dev	COV
South 9' / General	4.65	0.40	0.09	672	162	0.24	4.71	0.84	0.18
South 47' / General	4.65	0.48	0.10	629	174	0.28	5.10	0.82	0.16
South 9' / Intensive*	5.12	0.21	0.04	538	30	0.06	4.73	0.19	0.04
North 9' / General	4.60	0.40	0.09	659	142	0.22	4.88	0.71	0.15
North 47' / General	4.71	0.36	0.08	605	121	0.20	5.08	0.75	0.15
North 9' / Intensive	5.03	0.20	0.04	543	48	0.09	4.91	0.55	0.11

*Based on 3 FWD drops at 1 test location (3 total tests)

Backcalculated Epcc and k-values (Center Slab Testing)

The design pavement layer thicknesses are as follows:

16 inches of PCC
6 inches of dense-graded HMA
6 inches of open graded asphalt concrete base
12 inches of lime stabilized soil
12 inches of lime modified soil (as needed, when poor conditions existed)

The in situ layer properties were backcalculated from the HWD deflection testing data assuming infinite slab assumptions. APTech provided the backcalculation results based on two scenarios. The first scenario assumed that the PCC was bonded to the underlying HMA layer. The second scenario assumed that the PCC was not bonded to the underlying HMA layer. Both scenarios assumed that the HMA modulus is 10 percent of the PCC modulus. The concrete modulus values assuming a bonded interface were lower than the unbonded values. The results presented here assume that the PCC is bonded to the underlying HMA. The k-values actually represent the “effective” k-value just below the HMA layers (at the surface of the lime stabilized soil layer).

For the analysis, APTech based the PCC thicknesses on core thicknesses of 16.31, 15.68 and 16.18 inches. The asphalt thickness was assumed to be the design thickness of 12 inches (total). Figure 5 shows the backcalculated PCC modulus and dynamic k-values. The static k-value typically used for design is approximately half of the dynamic k-value.

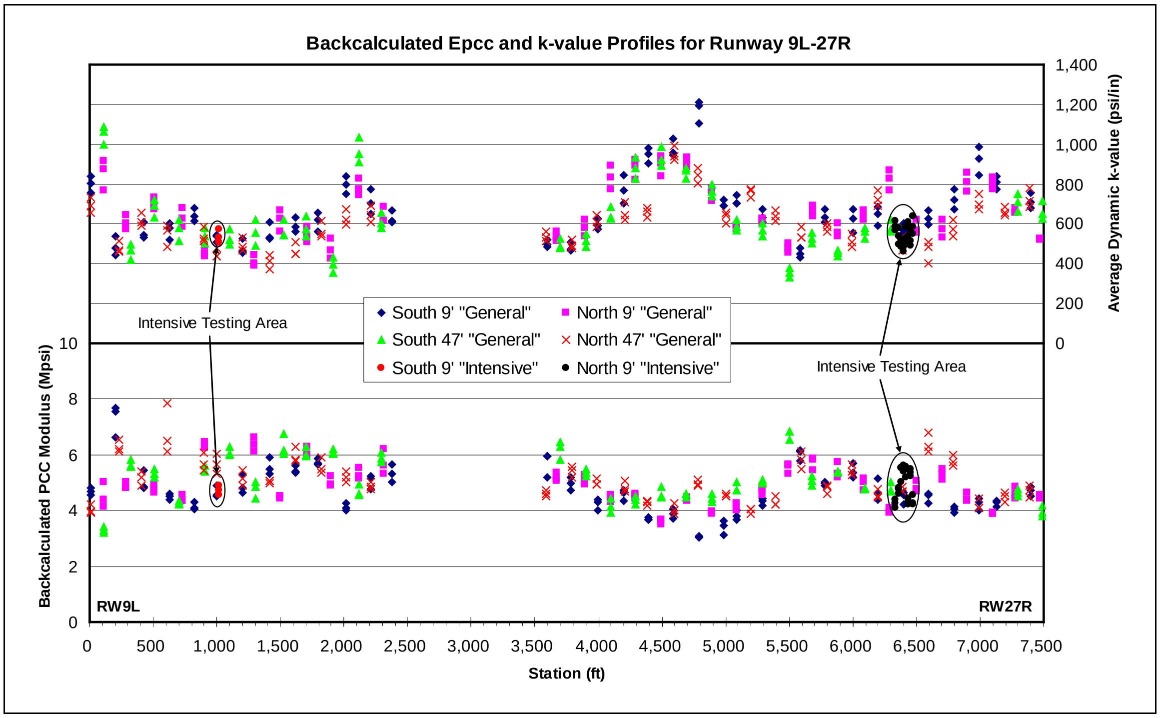


FIGURE 5. Backcalculated PCC Modulus and Dynamic k-values for Runway 9L-27R

Figure 6 shows the variation in the PCC modulus and k-values for the “Intensive” testing performed on the east runway end. The “Intensive” testing results are consistent with the “General” testing performed nearby.

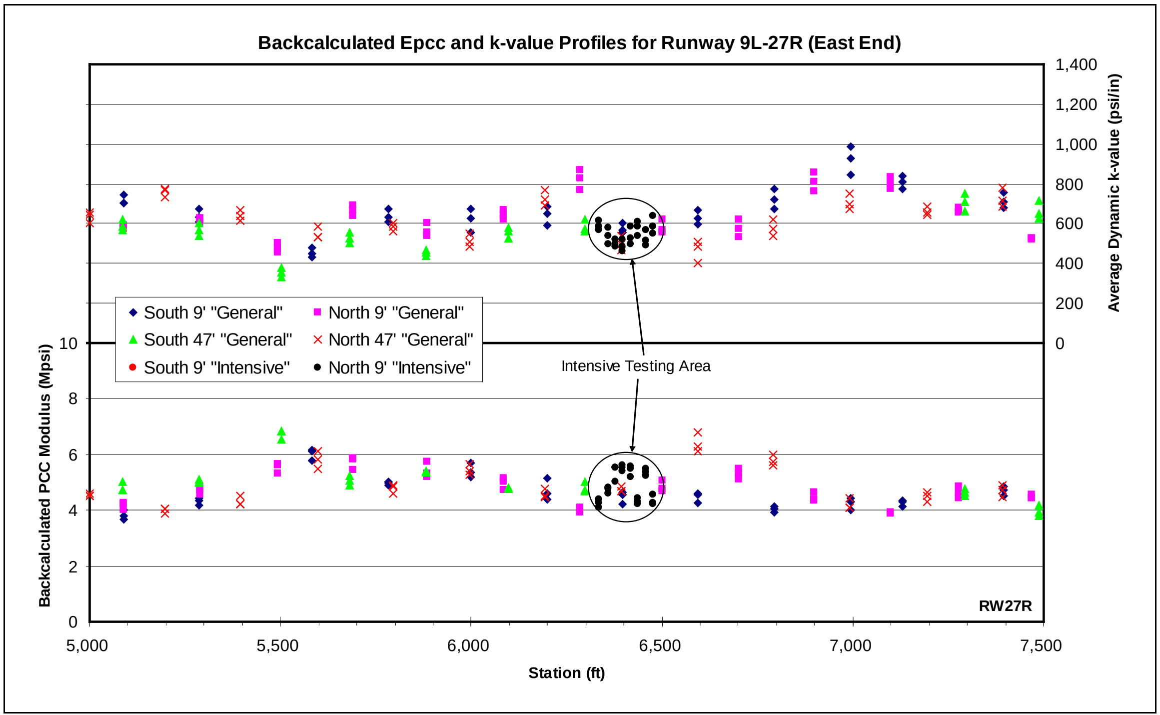


FIGURE 6. PCC Modulus and k-values Near the East Runway End

Table 1 provides a summary of the PCC modulus and k-values. The average dynamic k-values for the “Intensive” testing layouts are slightly lower than the “General” testing layouts, however these only represent localized areas on the runway. The average dynamic k-values are all above 500 psi/in which is excellent when compared to the design static k-value of 150 psi/in (design dynamic k-value of approximately 300 psi/in). The average elastic modulus of the PCC is almost 5,000,000 psi which is well above the typical value of 4,000,000 psi for PCC.

Load Transfer Efficiency (Joint Testing)

The Load Transfer Efficiency (LTE) is the ratio of the unloaded slab edge deflection divided by the loaded slab edge deflection expressed as a percentage. The LTE discussed here is actually the deflection load transfer efficiency. A deflection load transfer efficiency of 83% will approximately transfer 25% of the free edge stress across the joint. Typical PCC joint designs expect that 25% of the free edge stress will be transferred to the adjacent slabs through load transfer. Testing in hot weather can provide higher LTE values than in cool weather due to the thermal expansion of the PCC slabs which results in smaller joints widths. The mean pavement surface temperature was below (46.1°F) average during the LTE testing.

Load transfer testing was performed at longitudinal and transverse joints. The “General” testing layout only consisted of testing the transverse joints at the mid-slab location (see Figure 1). The “Intensive” testing layout consisted of testing both the longitudinal and transverse joints at each mid-slab location and each corner (a total of 8 locations per slab) for LTE (see Figure 2).

Transverse joint LTE results for both the “General” and “Intensive” testing layouts are shown in Figure 7. These results are for the mid-slab location on the transverse joints. The data at the “Intensive” testing locations is consistent with the “General” testing performed nearby.

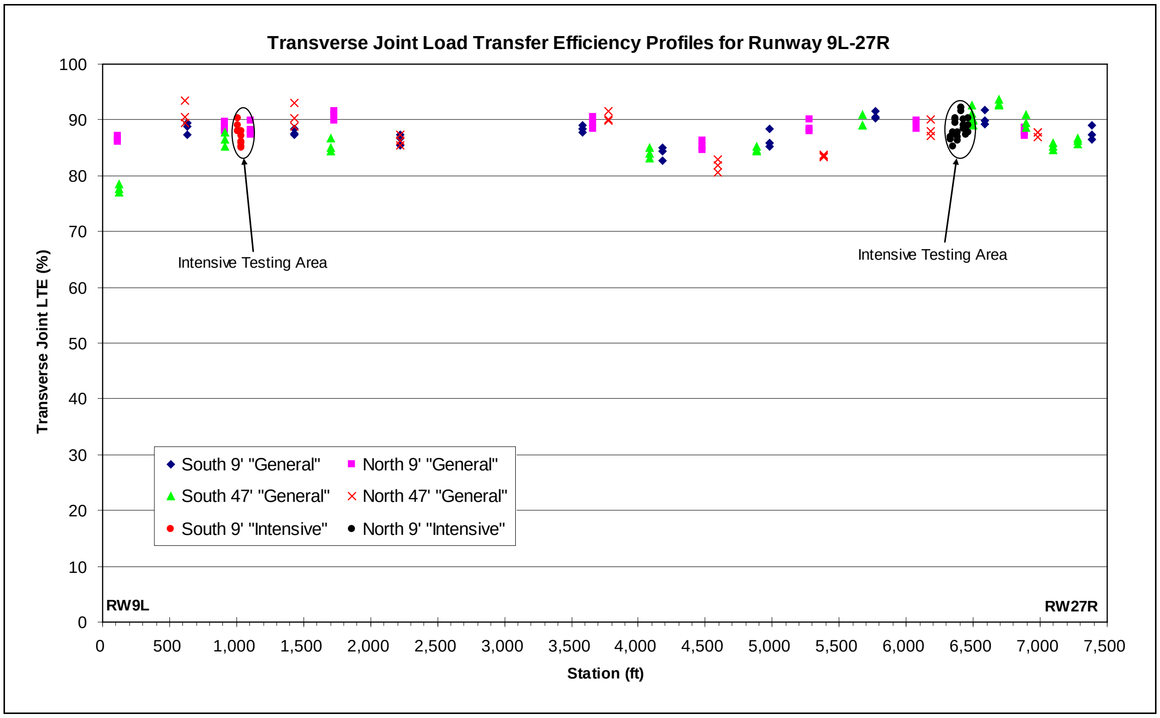


FIGURE 7. Dowelled Transverse Joint LTE (Mid-Slab) for Runway 9L-27R

Figure 8 shows that there is only minor variability in the mid-slab transverse joint LTE for the “Intensive” testing performed on the east runway end. Table 2 provides a summary of the mid-slab transverse joint LTE results for both the “General” and “Intensive” testing layouts. The transverse joint LTE results are similar at the mid-slab locations of the tested lanes. The LTE at the dowelled mid-slab transverse joints are almost 90 percent which is excellent. Table 2 also shows that the dowelled transverse joint edge deflections normalized to 50 kips are less than 6 mils The edge stresses will be very low at these locations considering the low deflections and excellent load transfer.

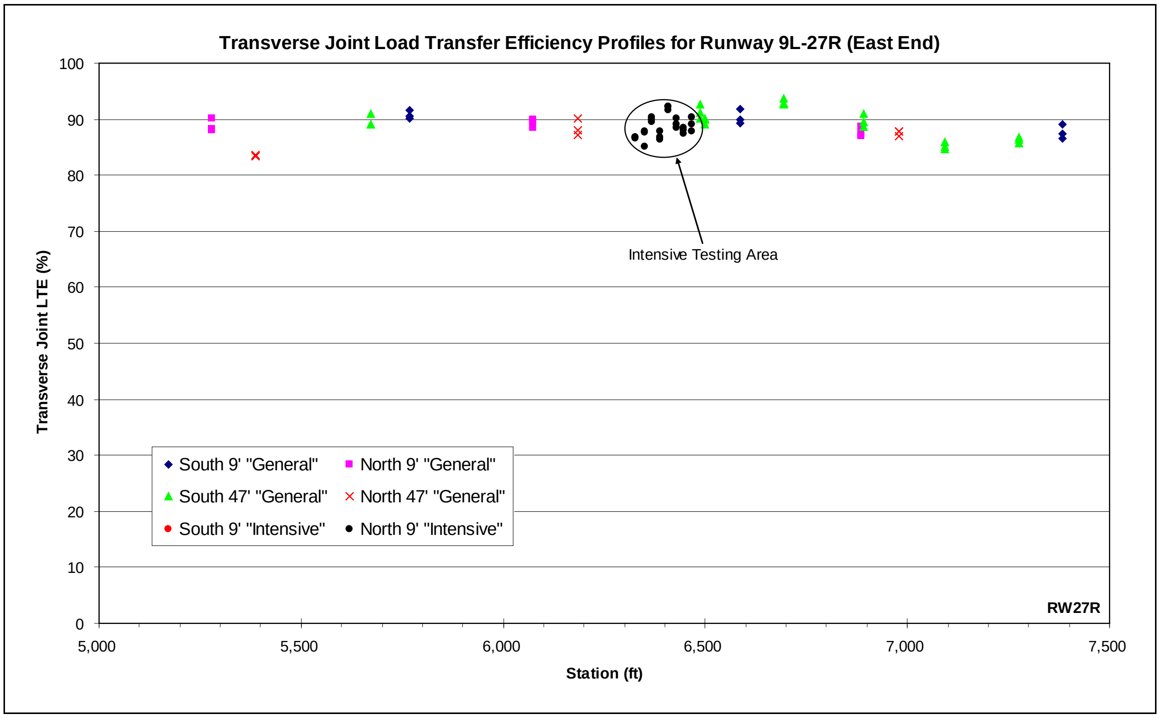


FIGURE 8. Dowelled Transverse Joint LTE (Mid-Slab) near the East Runway End

TABLE 2. Transverse Dowelled Joint LTE and Deflections (Mid-Slab Locations)

Lane / Testing Layout	Transverse Joint LTE (%)			Maximum Slab Edge Deflection Normalized to 50 kips (mils)		
	Average	Std Dev	COV	Average	Std Dev	COV
South 9' / General	87.8	2.18	0.02	5.71	0.56	0.10
South 47' / General	86.9	4.03	0.05	5.35	0.77	0.14
South 9' / Intensive*	87.2	1.80	0.02	5.93	0.16	0.03
North 9' / General	88.4	1.71	0.02	5.47	0.56	0.10
North 47' / General	87.5	3.48	0.04	5.77	0.79	0.14
North 9' / Intensive	89.0	1.69	0.02	5.91	0.22	0.04

* Based on 3 FWD drops at 3 test locations (9 total tests)

Longitudinal LTE testing was performed at the centerline (construction joint) and at contraction joints (18.75 feet north and south of the centerline) for the “Intensive” testing layout. The longitudinal LTE was tested at all corner and mid-slab locations. Figure 9 shows the longitudinal LTE results for the “Intensive” testing area near the west runway end. As expected, the longitudinal LTE for the centerline joint (dowelled construction joint) is lower than the LTE for the dowelled contraction joint at 18.75 feet south of the centerline. This is true for the LTE at corners as well as the mid-slab locations. Table 3 shows that the longitudinal LTE at the dowelled contraction joint is excellent (almost 90 percent) while the LTE at the longitudinal centerline (dowelled construction joint) is lower than the typical design value of 83 percent for the west runway end. Table 4 shows that the average maximum corner and edge deflections normalized to 50 kip are less than 10 mils. The low corner and edge deflections suggest the slightly lower LTE at the dowelled construction joint is not an issue.

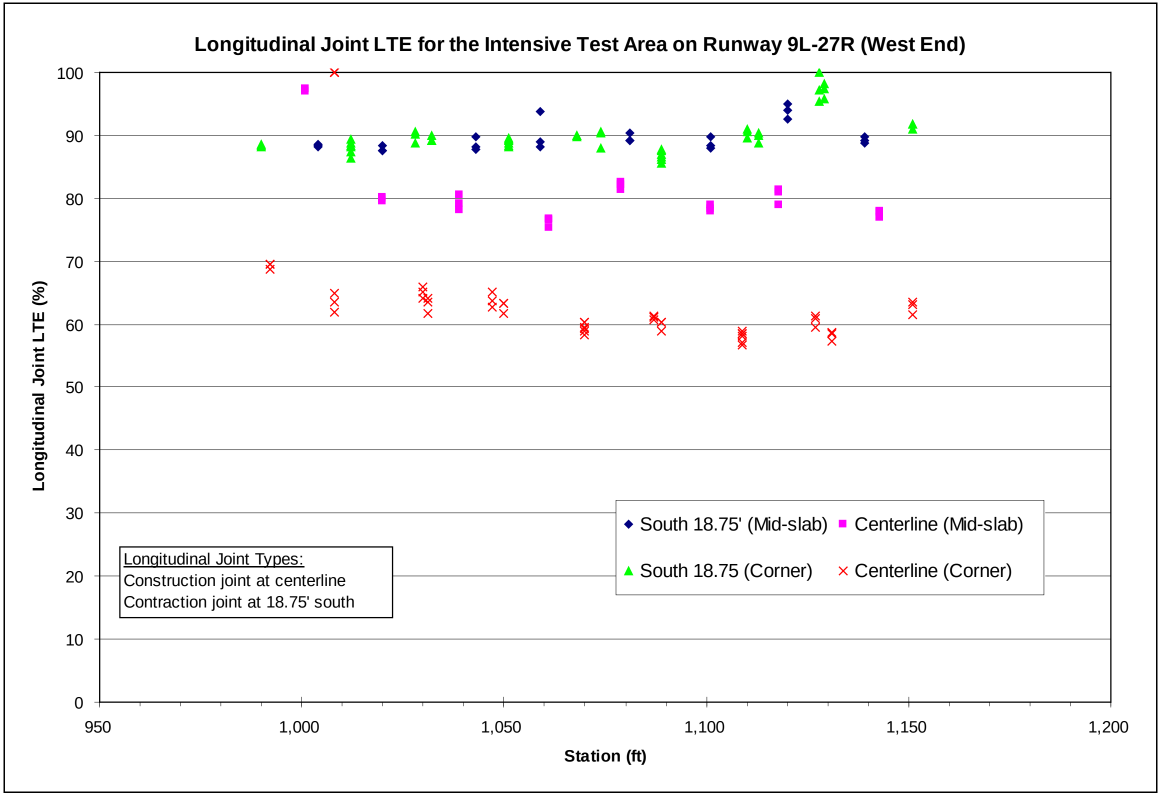


FIGURE 9. Dowelled Longitudinal Joint LTE for the West "Intensive" Test Area

Figure 10 shows the longitudinal LTE results for the "Intensive" testing area near the east runway end. Table 3 shows that the average longitudinal LTE at the centerline joint (corners) is only slightly lower than the other locations for the east runway end, however, there is more variability in the longitudinal LTE at the centerline corner locations. The average longitudinal LTE for the dowelled joints (construction and contraction) is almost 90 percent (excellent) on the east runway end, however, due to large variability there are some corner values well below 80 percent for the centerline construction joint. Table 4 shows that the average maximum corner deflections normalized to 50 kips are less than 8 mils which is very low. Considering that the corner deflections are small, the low LTE at the dowelled construction joint is not an issue.

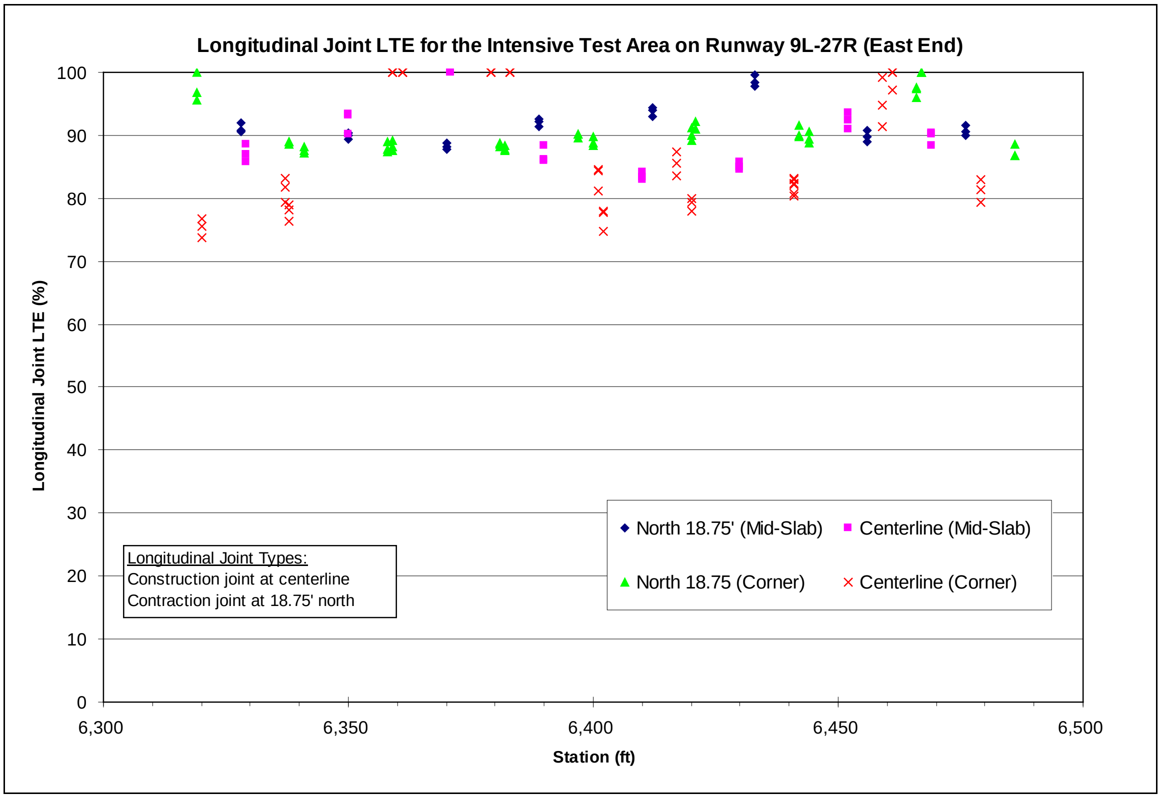


Figure 10. Dowelled Longitudinal Joint LTE for the East "Intensive" Test Area

Intensive dowelled transverse joint testing was performed near the corners (the longitudinal joints at the centerline and at 18.75 feet north or south of the centerline) and mid-slab locations (9 feet north or south of the centerline). Figure 11 shows that the transverse joint LTE was the lowest at the centerline corner locations for the "Intensive" testing area near the west runway end. The average transverse joint LTE at the centerline corner location was 68.6 percent which is much lower than the typical design value of 83 percent while the average transverse joint LTE at the remaining locations were almost 90 percent (excellent) for the west runway end. Table 4 shows that the average maximum corner deflections normalized to 50 kips were less than 10 mils (for the west runway end) which means the low LTE at the dowelled transverse joint corners is not a significant issue.

The transverse joint LTE results for the "Intensive" testing layout near the east runway end are shown in Figure 12. There is little difference in the dowelled transverse joint LTE at the mid-slab and corner locations for the east runway end. The average transverse joint LTE near the east runway end are almost 90 percent (excellent). A summary of the transverse joints LTE results are provided in Table 3.

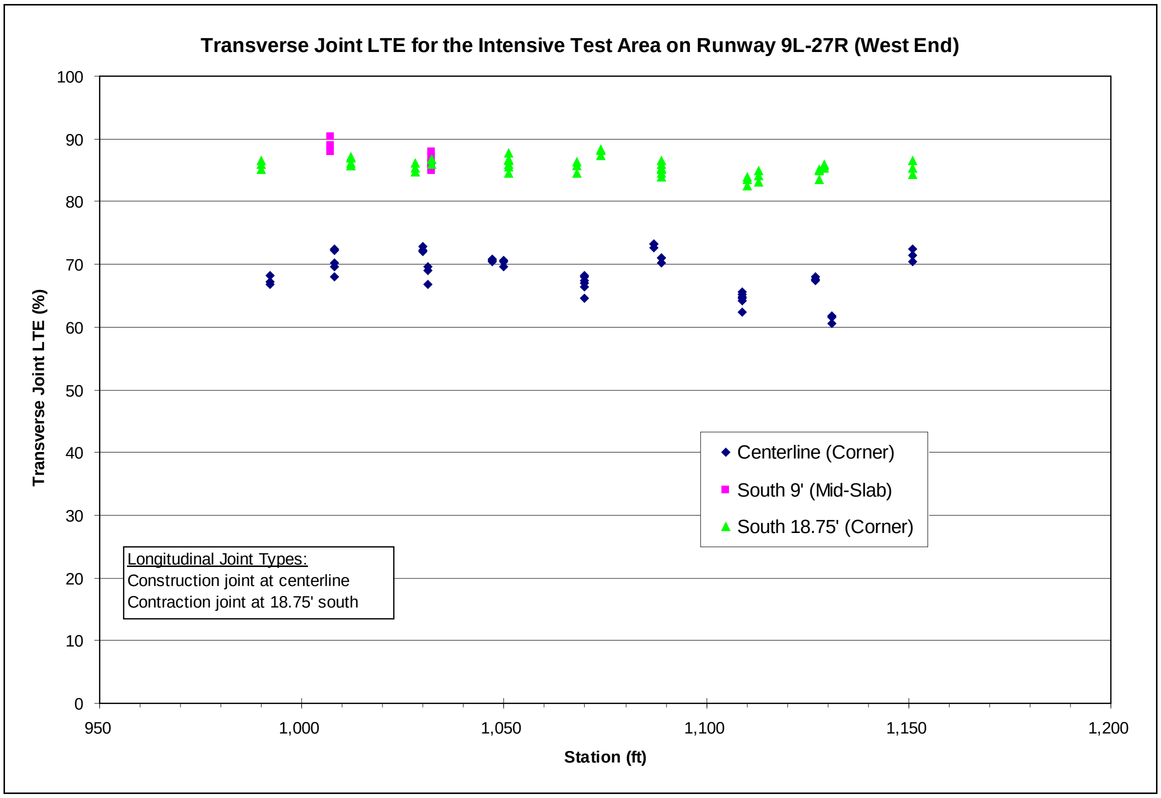


Figure 11. Dowelled Transverse Joint LTE for the West "Intensive" Test Area

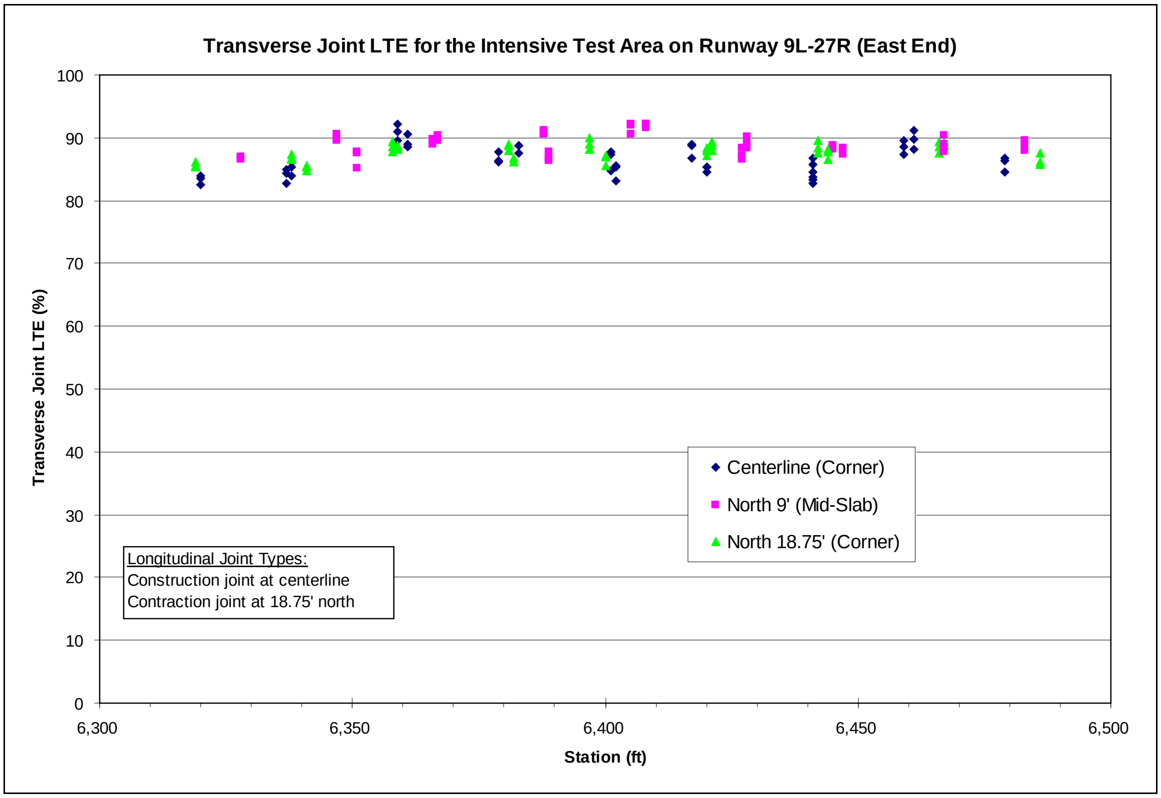


Figure 12. Dowelled Transverse Joint LTE for the East "Intensive" Test Area

Table 3. LTE Results for the "Intensive" Testing Areas (Dowelled Joints)

"Intensive" Testing Area (Runway End)	Offset from Centerline (approx.)	Corner or Mid-Slab Testing	Type of Joint Tested	Longitudinal Joint LTE (%)			Transverse Joint LTE (%)		
				Average	Std Dev	COV	Average	Std Dev	COV
West	18.75' South	Mid-Slab	Longitudinal Contraction	89.6	2.12	0.02	-	-	-
West	18.75' South	Corner	Longitudinal Contraction	90.1	3.15	0.03	-	-	-
West	At Centerline	Mid-Slab	Longitudinal Construction	81.4	6.40	0.08	-	-	-
West	At Centerline	Corner	Longitudinal Construction	64.1	9.86	0.15	-	-	-
West	18.75' South	Corner	Transverse	-	-	-	85.6	1.26	0.01
West*	9' South	Mid-Slab	Transverse	-	-	-	87.2	1.80	0.02
West	At Centerline	Corner	Transverse	-	-	-	68.6	3.31	0.05
East	18.75' North	Mid-Slab	Longitudinal Contraction	91.8	3.12	0.03	-	-	-
East	18.75' North	Corner	Longitudinal Contraction	90.7	3.87	0.04	-	-	-
East	At Centerline	Mid-Slab	Longitudinal Construction	89.6	5.13	0.06	-	-	-
East	At Centerline	Corner	Longitudinal Construction	87.4	9.55	0.11	-	-	-
East	18.75' North	Corner	Transverse	-	-	-	87.6	1.36	0.02
East	9' North	Mid-Slab	Transverse	-	-	-	89.0	1.69	0.02
East	At Centerline	Corner	Transverse	-	-	-	86.6	2.47	0.03

* Based on 3 FWD drops at 3 test locations (9 total tests)

Table 4. Corner and Edge Deflection Results for the "Intensive" Testing Areas (Dowelled Joints)

"Intensive" Testing Area (Runway End)	Offset from Centerline (approx.)	Corner or Mid-Slab Testing	Type of Joint Tested	Maximum Corner Deflection Normalized to 50 kips (mils)			Maximum Edge Deflection Normalized to 50 kips (mils)		
				Average	Std Dev	COV	Average	Std Dev	COV
West	18.75' South	Mid-Slab	Longitudinal Contraction	-	-	-	5.87	0.27	0.05
West	18.75' South	Corner	Longitudinal Contraction	6.60	0.28	0.04	-	-	-
West	At Centerline	Mid-Slab	Longitudinal Construction	-	-	-	6.67	0.27	0.04
West	At Centerline	Corner	Longitudinal Construction	9.28	0.50	0.05	-	-	-
West	18.75' South	Corner	Transverse	6.60	0.28	0.04	-	-	-
West*	9' South	Mid-Slab	Transverse	-	-	-	5.93	0.16	0.03
West	At Centerline	Corner	Transverse	9.28	0.50	0.05	-	-	-
East	18.75' North	Mid-Slab	Longitudinal Contraction	-	-	-	6.04	0.24	0.04
East	18.75' North	Corner	Longitudinal Contraction	6.91	0.32	0.05	-	-	-
East	At Centerline	Mid-Slab	Longitudinal Construction	-	-	-	6.08	0.35	0.06
East	At Centerline	Corner	Longitudinal Construction	7.29	0.39	0.05	-	-	-
East	18.75' North	Corner	Transverse	6.91	0.32	0.05	-	-	-
East	9' North	Mid-Slab	Transverse	-	-	-	5.91	0.22	0.04
East	At Centerline	Corner	Transverse	7.29	0.39	0.05	-	-	-

* Based on 3 FWD drops at 3 test locations (9 total tests)

Analysis of Voids Under Slab Corners (Corner Testing)

The deflection data collected at the slab corners (for the “Intensive” testing layout only) was used to detect the presence of voids under the PCC slab corners. The analysis performed by APTech used the three loads and resulting deflections to determine if voids were present under the slab corners at the time of the FWD testing. The deflections were plotted at a function of the applied loads for each test location. A linear regression was used to determine the deflection y-intercept, i.e., where the load is zero. A y-intercept value above 2 or 3 mils is typically used to indicate the presence of voids under the slab corners. The intercept values for the “Intensive” testing layouts are shown in Figure 13. None of the tested corner locations have an intercept above 2 mils, therefore it is assumed that no voids were present at these locations during the testing.

Curling of the PCC slabs can occur due to several reasons. Curling due to cyclical temperature and moisture gradients is only temporary while permanent curling can be due to irreversible drying shrinkage and temperature gradients within the slab at the time of concrete setting. Permanent curling results in the slab curling upward with the corners potentially lifting off of the underlying base. Considering that voids were not detected under the slab corners and that the corner deflections are very low, it is believed that the PCC slab is in full contact with the underlying HMA. Therefore, it does not appear that upward “permanent” curling is a concern for this pavement.

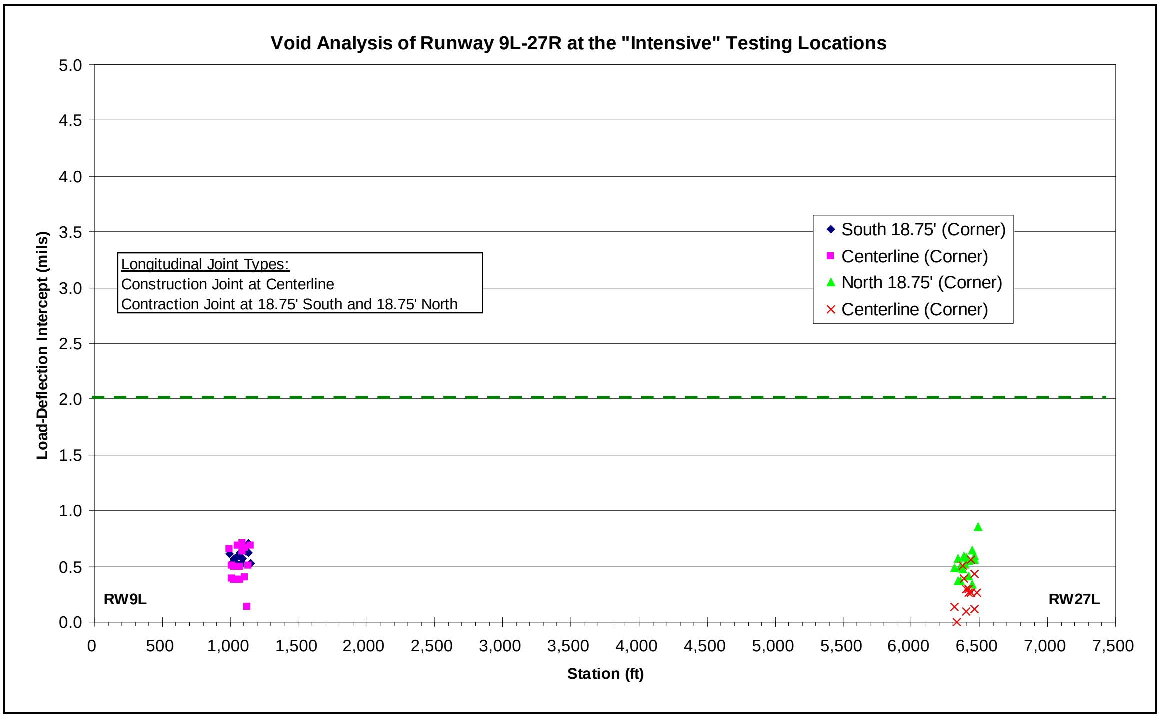


Figure 13. Void Analysis at the “Intensive” Testing Locations

5. Summary

HWD testing was performed on the newly constructed Runway 9L-27R to determine the in situ properties of the pavement layers. The properties include the elastic modulus (E) of the PCC surface, Asphalt Concrete Base and Asphalt Treated Permeable Base, the modulus of subgrade reaction (k-value) and the load transfer efficiency (LTE) at joints.

The HWD testing plan was divided into "General" and "Intensive" testing layouts. The "General" layout provided a simplified testing scheme that covered the entire runway length while the "Intensive" layout provided a detailed investigation of localized areas near both runway ends. The "General" testing layout included center slab testing and load transfer efficiency (LTE) testing at the transverse (mid-slab) joint locations. The "Intensive" testing layout included center slab testing, LTE testing at both longitudinal and transverse (mid-slab) joints and corner testing (9 tests per slab). The results of the "Intensive" testing were consistent with the "General" testing results.

The average normalized maximum deflections at the slab center are approximately 5 mils (at 50 kips) which are extremely low for this load level. It was assumed that the PCC was bonded to the underlying HMA for this analysis and that the HMA modulus is 10 percent of the PCC modulus. The average dynamic k-values are all above 500 psi/in which is excellent when compared to the original design static k-value of 150 psi/in (dynamic k-value of approximately 300 psi/in). Therefore the soil modification and stabilization procedures used during construction were more than adequate to fulfill the subgrade design assumption (static k-value of 150 psi/in). The average elastic modulus of the PCC is also 5,000,000 psi which is above the typical value of 4,000,000 psi signifying a strong concrete material.

HWD testing at the dowelled joints shows that the average LTE is almost 90 percent (well above the typical design value of 83 percent) at most of the tested longitudinal and transverse joint locations. Exceptions were found near the west runway end where the mid-slab and corner longitudinal joint LTE were low at the centerline construction joint and near the east runway end where the corner longitudinal joint LTE were low near the centerline construction joint. The transverse joint LTE (at corner locations near the centerline construction joint) were also low near the west runway end. The lowest LTE were observed at corner locations (near the centerline construction joint) where the deflections are also the highest. Even though low LTE values was observed at some locations along the dowelled construction joint, the deflection magnitudes are small and therefore this lower LTE should not be a concern.

All of the locations where low LTE was measured are associated with the centerline dowelled construction joint. Construction joints are expected to have lower LTE than contraction joints because the construction joint interface is relatively smooth as compared to the aggregate interlock that is achieved in a dowelled contraction joint. It is unclear why the LTE for the dowelled centerline construction joint is lower on the west runway end. There may be some variability in the dowel installation procedures that are causing this difference. It is possible that the dowels did not properly bond to the existing slabs due to air pockets in the grout or that too much grease was applied to the exposed dowels causing an initial looseness between the dowel and the hardened PCC on the west runway end.

The analysis does not indicate that any voids were present at the tested slab corners during the HWD testing. Considering that voids were not detected under the slab corners and that the corner deflections are very low, it is believed that the PCC slabs are in full contact with the underlying HMA. Therefore, upward “permanent” curling is not a concern for this concrete pavement section.

Results of the HWD testing indicate that the in situ pavement properties meet or exceed the values assumed for design. Although some LTE at the dowelled longitudinal construction joint are low, the corresponding slab edge and corner deflections will still allow the pavement to perform well. Upward “permanent” curling is also not an issue for this concrete pavement.

6. Acknowledgements

We would like to thank Mr. Jim Bruinsma of APTech for his efforts in the project coordination, HWD data collection, and data analysis.