Expedient Stress Analysis of Jointed Concrete Pavement Loaded by Aircraft with Multiwheel Gear

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The load-carrying capacity of an airport pavement is limited by the flexural stresses that aircraft induce in a jointed plain concrete pavement (JPCP). Aircraft gear characteristics have a significant effect on the magnitude of the slab edge stress. For those aircraft that have multiwheel gear, a pavement engineer cannot directly use Westergaard's analysis for loads placed at the interior, edge, or corner of a slab. In addition, Westergaard's analysis does not account for load transfer across a joint in a JPCP. Regression models were developed during research at the University of Illinois that allow the engineer to use an equivalent single-wheel radius to determine the free edge stress in a JPCP. These models have been developed for several gear configurations so that a free edge stress equation based on Westergaard's analysis and joint load transfer efficiency models can be used to quickly determine the stress in a JPCP. Thus, instead of a computer program such as the H51 or a finite-element program such as ILLI-SLAB, regression models may be used to more efficiently and expediently determine edge stresses with no sacrifice in accuracy of the results. The expediency of the stress analysis procedure presented in this paper makes it an appropriate tool for use in the field or for inclusion in knowledge-based expert systems (KBES). In lieu of a fielded KBES, a simple electronic spreadsheet has been developed as an interim approach for this stress analysis procedure.

In the past, agencies have made approximate assumptions in the calculation of flexural stresses in a jointed plain concrete pavement (JPCP) that result from aircraft loads (*1–3*). Agencies often assume that load transfer across a joint reduces slab edge stress by 25 percent regardless of the joint type. This assumption should no longer be used, since it does not describe a very important performance measure of a JPCP, namely, joint behavior. Foxworthy, Ioannides, and Korovesis have developed models that describe the load transfer behavior of concrete joints (*4–6*). Their work shows that temperature, joint type, and load radius significantly affect the deflection and stress load transfer efficiencies. This in turn affects the magnitude of the stress in a JPCP and the allowable aircraft loads that should be permitted on a pavement.

The variability of aircraft characteristics such as gross weight, gear configuration, tire pressure, and tire contact area makes it necessary for engineers to evaluate each aircraft in the design or evaluation of an airfield pavement. Many aircraft have multiwheel gear, so a stress analysis of a JPCP cannot directly use Westergaard's analysis (*7*) for any of the three load locations. This limitation can be overcome by using the equivalent single-wheel radius (ESWR) concept (*8–11*) to determine the free edge stress and the stress load transfer efficiency. Once the ESWR is known, the actual edge stress at the transverse joint of a JPCP can be computed for any type of aircraft. Next, the ratio of the edge stress to the portland cement concrete (PCC) modulus of rupture can be used to predict the allowable number of aircraft passes on a JPCP (*4*).

CURRENT METHODS OF ANALYSIS

At present, most design agencies use one of three methods to analyze the stress in a JPCP (*11*): Westergaard's analysis, an elastic layer analysis, or a finite-element program. In the past, most organizations have used the method that is most appropriate for the user's needs. Since the first two methods are generally more expedient, they are frequently used in the field. Finite-element programs are more powerful research tools, but the level of understanding and computer hardware required to use these programs restricts their use primarily to the research field.

Those agencies that use Westergaard's analysis normally use a computerized version of the Pickett and Ray influence charts (*12*). One program in widespread use today is H51 (*13*), which is used to determine the free edge stress of a JPCP. This program is widely used since it allows the user to enter more than one load for those aircraft that have main gear with multiple wheels. Its use is restricted to those situations that adhere to the semiinfinite plane assumptions in Westergaard's analysis (*14*). The free edge stress must be reduced to account for load transfer if the edge or corner loading location is considered in the design analysis. For this situation, most agencies assume that the average stress reduction is 25 percent, regardless of temperature, joint type, or aircraft gear configuration.

In order to simplify the analysis of a JPCP, the U.S. Army Corps of Engineers Waterways Experiment Station developed regression equations for common aircraft in the U.S. inventory. They used H51 to obtain regression constants for Equation 1 (*15*). Equation 1 is included in airfield design and analysis programs:

$$\sigma_e = \frac{P}{h^2}[a_0 + a_1 (\ln l) + a_2 (\ln l)^2] \qquad (1)$$

where

σ_e = free edge stress (psi),
P = actual gear load (lb),
h = slab thickness (in.), and

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a_i = regression constant calculated for a specific gear to match the computerized solutions of Pickett and Ray influence chart solutions.

$$l = \left[\frac{Eh^3}{12(1 - \mu^2)k}\right]^{1/4} \qquad (2)$$

where

l = radius of relative stiffness (in.),
E = modulus of elasticity of the concrete (psi),
h = thickness of the concrete (in.),
μ = Poisson's ratio of the PCC slab, and
k = modulus of subgrade reaction (psi/in.).

Equations 1 and 2 are used by the U.S. Army Corps of Engineers and the U.S. Air Force because they are fast and efficient methods of determining free edge stresses.

The regression constants that were developed for each aircraft using Equation 1 are based on aircraft main gear that were positioned at either the transverse or longitudinal joint of a JPCP. Foxworthy found that the transverse joint is normally the critical location in the design of a PCC pavement (*4*) because of the magnitude of the stress in the concrete slab and the pass-to-coverage ratio of each aircraft's gear with respect to the transverse and longitudinal joints of the pavement.

Another method of analyzing the stress in a JPCP is to use an elastic layer analysis. The U.S. Army Corps of Engineers is developing computer programs for elastic layer analysis of airfield pavements. Elastic layer analysis is more representative of the layer material properties than is Westergaard's analysis (*15*). An elastic layer program also has the advantage of allowing the engineer to consider several layers in a pavement structure. However, a major disadvantage of an elastic layer analysis is that it cannot model joint behavior in concrete pavements. Therefore, this method must also use an assumed joint load transfer efficiency to attempt to model tensile stresses that occur in the JPCP slab. This is important since JPC pavements in the field do not have 100 percent load transfer efficiencies.

The last method of analysis uses a finite-element program such as ILLI-SLAB to consider specific JPCP issues like slab curing and nonuniform subgrade support conditions. Unlike the previous two methods, this program considers joint load transfer and computes the stress at any point in the JPCP slab with a high degree of accuracy (*16*). However, use of a finite-element program requires a good theoretical understanding of JPCP performance, and it generally is not an appropriate tool for use in the field. In addition, a program such as ILLI-SLAB requires several inputs and more powerful computer hardware than is typically available in the field.

PROPOSED METHOD OF ANALYSIS

The work that was conducted by the Waterways Experiment Station using H51 provided a fast and efficient method for determining the free edge stress in a JPCP, but a prototype expert system developed at the University of Illinois needed a tool that could also be used to determine joint load transfer efficiencies (*10*). This objective was met by using the equivalent single-axle radius (ESAR) concept (*8–10*) to develop ESWR regression models for several aircraft (*11*). It appears that the equivalent radius concept was first introduced for dual truck tires by Bradbury in 1934, but no further research was conducted in this area until Ioannides began his studies in 1989 (*8–10*).

The definition of ESWR is identical to the definition of an equivalent single-wheel load (ESWL) given by Yoder and Witczak (*18*), except that the words "load on" replace "radius of." The corresponding modification of Yoder and Witczak's ESWL definition for ESWR reads as follows:

> An equivalent single-wheel radius (ESWR) is defined as the radius of a single tire that will cause an equal magnitude of a preselected parameter (stress, strain, deflection, or distress) at a given location within a specific pavement system to that resulting from a multiple-wheel load at the same location within the pavement structure. (*18*)

Once the ESWR regression models had been developed, a pavement engineer could easily compute the ESWR for an aircraft's main gear for each JPCP trial section. After the ESWR is computed for a trial section, the engineer can compute the free edge stress at the transverse joint and the stress load transfer efficiency. Finally, the designer can use these values to compute the edge stress at the transverse joint of the pavement.

Aircraft ESWR Model Development

Ioannides et al. used the finite-element program ILLI-SLAB to review and identify the correct form of Westergaard's free edge stress equation (*7,19*), which is shown as Equation 3. Like all the original Westergaard equations, Equation 3 is limited in applicability to a single load with a radius *a* (i.e., it is not applicable for larger aircraft with multiwheel gear). However, Equation 3 can be used for an aircraft with multiwheel gear if the ESWR is substituted for *a* and the entire gear load is used to compute the free edge stress.

The procedure used to develop an ESWR model for an aircraft is shown in Figure 1 (*11*). Equation 4 shows the general form of this regression model. For very large aircraft, as many as six tires on a gear had to be converted to an ESWR before the engineer could use Equation 3 to calculate the free edge stress in a JPCP slab.

$$\sigma = \frac{3(1 + \mu)P}{\pi(3 + \mu)h^2}\left[\ln\frac{Eh^3}{100ka^4} + 1.84 - \frac{4\mu}{3} + \frac{1 - \mu}{2} + 1.18\,(1 + 2\mu)\,(a/l)\right] \qquad (3)$$

where

σ = free edge stress (psi),
E = modulus of elasticity of the concrete (psi),
h = thickness of the concrete (in.),
μ = Poisson's ratio of the pavement,
k = modulus of subgrade reaction (psi/in.),
a = actual load radius for single-wheel gear or ESWR for multiwheel gear (in.),
l = radius of relative stiffness (in.), and

STEP 1:	Use the H51 computer program to determine the flexural stress for the transverse edge loading condition. Determine edge stresses for pavement structures with ℓ (EQN 2) values ranging from 12 to 130.
STEP 2:	Solve for "a" in EQN 3 using the total gear load and the H51-determined edge stress. This results in a unique ESWR for each trial JPCP section, or ℓ value, which can then be used to compute the free edge stress.
STEP 3:	Use multiple regression to determine equation models for ESWR as a function of ℓ.
STEP 4:	Validate the regression equations using an independent set of ℓ values. Compare stresses using the H51 program and Equations 1 through 4.

FIGURE 1 **Procedure used to develop aircraft ESWR models.**

P = tire load (lb) for single-wheel gear or gear load (lb) if the gear ESWR is used for multiwheel gear.

The procedure shown in Figure 1 was used to obtain Equation 4 coefficients presented in Table 1 for common military and commercial aircraft in the U.S. inventory. Figure 2 compares the ESWR of those aircraft with twin (two wheels) main gear.

$$\text{ESWR} = c_1 + c_2 l + c_3 l^2 + c_4 l^3 + c_5 l^4 \quad (4)$$

where l is the radius of relative stiffness (in.) and c_i are constants developed for a specific aircraft.

If all aircraft in Figure 2 had equal main gear weights and it was assumed that aircraft tire contact areas remained constant, these figures would show which aircraft gear configurations cause the most damage to a JPCP. In other words, Figure 2 shows which aircraft gear configurations cause the highest flexural stresses, thereby causing the most PCC fatigue damage for each gear coverage of the JPCP. As the ESWR for a given l-value decreases, the JPCP fatigue damage caused by that gear configuration increases.

Free Edge Stress Determination Using ESWR

Once the aircraft ESWR models had been developed for their respective multiwheel gear, determining the free edge stress for any aircraft at the transverse joint became a simple two step process. After the ESWR for an aircraft is computed using Equation 4, Equation 3 can be used to determine the free edge stress. Since the ESWR is used in this procedure, the total gear load is used in Equation 3. Because the ESWR indicates how well aircraft manufacturers have designed main gear to minimize pavement fatigue damage, it is advantageous to compare the free edge stress of a JPCP when all gear have the same load.

Figure 3 shows what the free edge stress in a 12-in. JPCP would be if each aircraft had a 100-kip load placed on the main gear. Figure 3 shows which aircraft gear configurations would

TABLE 1 **ESWR Regression Model Coefficients**

	EQUATION 4 COEFFICIENTS						
AIRCRAFT	**c_1**	**c_2**	**c_3**	**c_4**	**c_5**	**R^2**	**STD ERR**
A-300 ::	8.1753E+00	1.2817E+00	-2.4122E-02	2.0038E-04	-5.9445E-07	0.9985	0.1976
B-52 ..	7.2390E+00	8.3507E-01	-1.7009E-02	1.4602E-04	-4.3636E-07	0.9927	0.2924
B-707 ::	5.9076E+00	1.4834E+00	-2.8093E-02	2.3290E-04	-6.8985E-07	0.9967	0.3199
B-727 ..	9.4562E+00	7.2066E-01	-1.4560E-02	1.2220E-04	-3.5460E-07	0.9891	0.2957
B-737 ..	9.2827E+00	6.1666E-01	-1.3310E-02	1.2028E-04	-3.7428E-07	0.9934	0.2011
B-747 ::	2.0012E+00	1.8159E+00	-3.3448E-02	2.7245E-04	-7.9985E-07	0.9983	0.2998
C-9 ..	11.0601E+00	3.8631E-01	-8.6895E-03	8.1913E-05	-2.6306E-07	0.9858	0.2050
C-135 ::	5.1489E+00	1.5557E+00	-2.8865E-02	2.3541E-04	-6.8847E-07	0.9974	0.3089
C-141 ::	7.5708E+00	1.3139E+00	-2.5723E-02	2.1923E-04	-6.6525E-07	0.9937	0.3682
DC-10 ::	-0.8767E+00	2.0834E+00	-3.5900E-02	2.7808E-04	-7.8675E-07	0.9994	0.2277

NOTES:
1. :: - Twin-tandem main gear.
2. .. - Twin main gear.

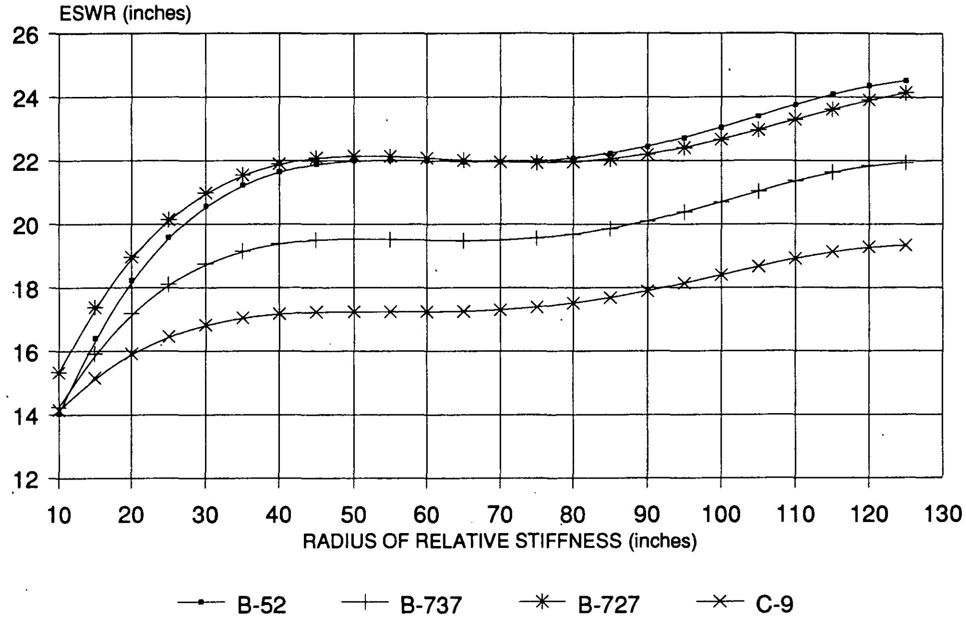
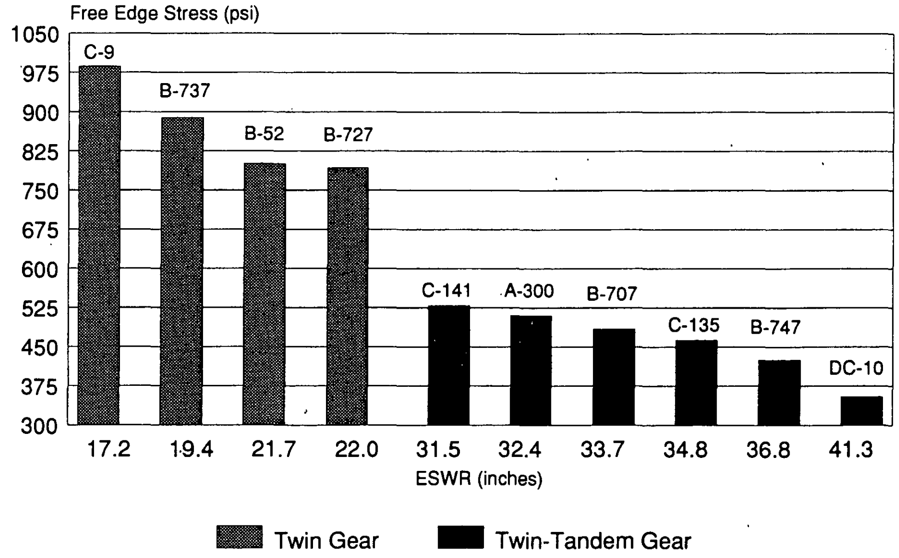


FIGURE 2 ESWR of several twin gear configurations.



Note: 100 Kip Gear Load k = 200 psi/in
h = 12 in. E = 4000 ksi u = 0.15

FIGURE 3 Relationship between gear configuration and JPCP edge stress.

cause the most fatigue damage in the JPCP if tire contact areas remained the same. Aircraft with the smallest ESWR induce the highest free edge stress for a 100-kip gear load.

The statistical analysis of Figure 3 shown in Table 2 emphasizes how the free edge stress in a JPCP can be reduced by increasing the number of wheels on the main gear to distribute the gear load over a larger area, but it also shows that other gear characteristics affect the magnitude of the free edge stress and the ESWR. The characteristics that contribute to the ESWR and edge stress variation within the twin and twin-tandem gear groups include the tire contact area and tire spacing. Although additional wheels, larger tire contact areas, and increased tire spacings may increase the production cost of an aircraft, airline companies may recoup this cost since future landing fees may be based on the JPCP damage caused by each aircraft (*20*).

TABLE 2 Edge Stress Variance due to Gear Configuration

	TWIN GEAR			TWIN TANDEM GEAR		
	Mean	S.D.	C.V. (%)	Mean	S.D.	C.V. (%)
ESWR (in)	20.09	2.24	11.1	35.07	3.57	10.2
Free Edge Stress (psi)	867	91	10.5	461	64	13.9
Tire Contact Area (in^2)	212.3	37.4	17.6	237.2	39.7	16.7
Transverse Tire Spacing (in)	29.4	5.7	19.4	37.9	9.6	25.3
Longitudinal Tire Spacing (in)	NA	NA	NA	58.5	6.2	10.6

NOTES:
1. Analysis is for only those aircraft shown in Figure 3.
2. Main gear load is 100 kips for all aircraft.
3. $h = 12$ in, $E = 4000$ ksi, $u = 0.15$, $k = 200$ psi/in.

As Step 4 in Figure 1 indicates, H51 computer runs were used to validate the aircraft ESWR equation coefficients shown in Table 1. Since the free edge stresses obtained from H51 are usually within 3 percent of the free edge stresses obtained from using a finite-element program, the H51 results were the basis for comparison. Figure 4 shows that the use of the ESWR concept as originally proposed by Bradbury (*8*) leads to accurate determination of free edge stresses. The results shown in Figure 4 are typical for other aircraft models developed during this research and demonstrate that use of an ESWR usually produces better results than those obtained using Equation 1.

Load Transfer Efficiency

Now that the ESWR for several aircraft can be used to accurately determine the free edge stress at the transverse joint of a JPCP, the aircraft gear ESWR can next be used to determine stress load transfer efficiency. This allows field engineers to accurately estimate JPCP flexural stresses for "semiinfinite" slab conditions without the use of a finite-element program.

Figure 5 shows models that have been developed by Ioannides and Korovesis to express the relationship between deflection load transfer efficiency (DLTE) and stress load transfer efficiency (SLTE). DLTE and SLTE are defined in Equations 5 and 6, respectively. Equation 7 coefficients for each of the curves shown in Figure 5 are presented in Table 3. The coefficient of determination (r^2) for each curve is 1.0 and the standard error of SLTE estimation in Figure 5 ranges from 0.0064 to 0.062.

$$\mathrm{DLTE} = \frac{\delta_u}{\delta_l} * 100\% \qquad (5)$$

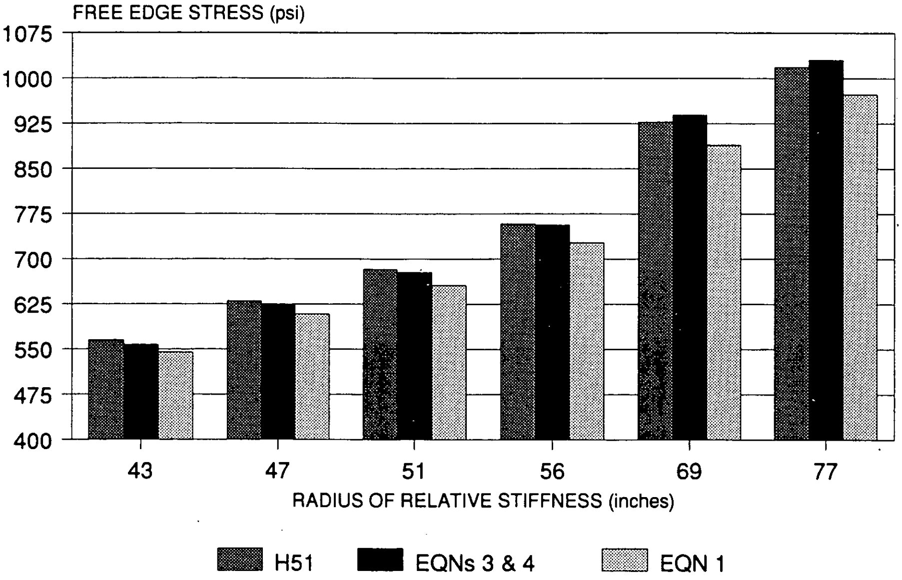


FIGURE 4 B-747 induced free edge stress in a 15-in. JPCP.

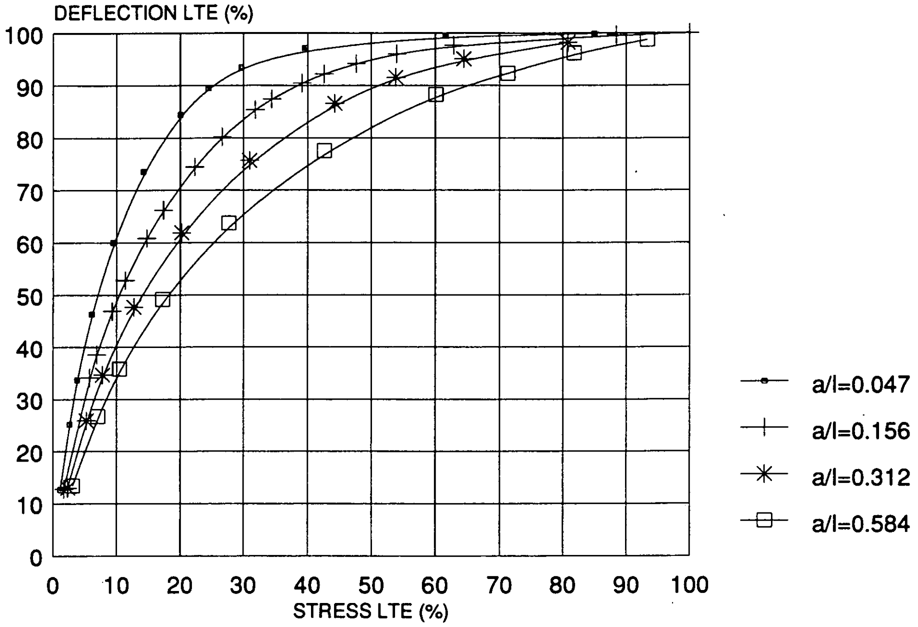


FIGURE 5 SLTE versus DLTE for a symmetric edge load (*9*).

TABLE 3 SLTE Regression Model Coefficients

a/ℓ	c_1	c_2	c_3	c_4	c_5
0.047	-0.12231E-00	0.63129E-02	0.93482E-03	-0.18447E-04	0.10421E-06
0.156	0.64787E-01	0.47221E-02	0.89586E-03	-0.16478E-04	0.89222E-07
0.312	-0.74232E-01	0.37497E-01	-0.28618E-03	-0.15080E-06	0.12778E-07
0.584	-0.20500E-03	0.42797E-01	-0.51432E-03	0.35116E-05	-0.6599E-08

where δ_u is the deflection of the adjacent unloaded slab and δ_l is the deflection of the loaded slab.

$$\text{SLTE} = \frac{\sigma_u}{\sigma_l} * 100\% \qquad (6)$$

where σ_u is the edge stress of the adjacent unloaded slab and σ_l is the edge stress of the loaded slab.

$$\text{LOG}_{10}\,(\text{SLTE}) = c_1 + c_2\,(\text{DLTE}) + c_3\,(\text{DLTE})^2 + c_4\,(\text{DLTE})^3 + c_5\,(\text{DLTE})^4 \qquad (7)$$

where c_i are the constants developed for one *a*/*l* curve in Figure 5.

Figure 5 also shows that the DLTE versus SLTE relationship depends on the load size ratio, *a*/*l* (*10*). Since the slab length over *l*(*L*/*l*) and slab width over *l*(*W*/*l*) ratio assumptions (i.e., semiinfinite slab response) of Figure 5 represent typical ratios in the field, the curves in this figure can be used to estimate SLTE. DLTE values in the field are usually determined using a falling weight deflectometer (FWD) during a nondestructive pavement evaluation, but if no evaluation results are available, a mean DLTE must be estimated for the pavement design life. Darter et al. reported the range of typical DLTE values shown below for the various types of joints in JPCP (*1*). These DLTE values can be used for design of a new or reconstructed JPCP, or local FWD data can be used to estimate the LTE behavior of each joint type.

Joint Type	*Base Type*	*DLTE (%)*
Weakened plane	Granular	40 to 60
Weakened plane	Stabilized	50 to 70
Keyway	Granular	50 to 70
Keyway	Stabilized	60 to 70
Doweled	Any type	70 to 90

An objective of the airfield pavement research conducted at the University of Illinois was to acquire as much existing pavement technology as possible for rehabilitation designs of a JPCP. The *a*/*l* ratios shown in Figure 5 were developed for single loads, but not for multiple wheel loads. In addition, single-load radii ranged from 1.70 to 21.03 in. (*6*), but the ESWRs for aircraft with twin-tandem gear are greater than 30 for typical field *l*-values (i.e., typical pavement cross sections). Therefore, if Figure 5 were to be used in this prototype expert system, it would be important to validate the use of these *a*/*l* curves for multiwheel gear. The finite-element program ILLI-SLAB was used to validate the curves using the parameters and values shown in Table 4. Ideally, the ILLI-

TABLE 4 Aircraft SLTEs

	DLTE	40%		70%		90%	
	ℓ (in)	69.7	53.8	69.7	53.8	69.7	53.8
F-15 (1 Wheel)	SLTE$_{ioan}$	6	7	16	19	31	38
	SLTE$_{whls}$	7	7	16	18	32	35
	SLTE$_{eswr}$	NA	NA	NA	NA	NA	NA
B-727 (2 Wheels)	SLTE$_{ioan}$	10	11	27	29	51	57
	SLTE$_{whls}$	13	14	30	32	55	59
	SLTE$_{eswr}$	12	13	28	32	56	61
B-1 (4 Wheels)	SLTE$_{ioan}$	11	13	30	37	59	69
	SLTE$_{whls}$	14	15	33	35	60	62
	SLTE$_{eswr}$	14	16	34	37	64	69

NOTES:

1. SLTE$_{ioan}$ is the stress load transfer efficiency interpolated from Figure 5 by using ESWR/ℓ.

2. SLTE$_{whls}$ is the stress load transfer efficiency obtained from using the finite element program ILLI-SLAB with actual wheel locations. For the B-727 the two wheels were placed at the transverse joint while the two front wheels of the B-1 main gear were placed at the transverse joint.

3. SLTE$_{eswr}$ is the stress load transfer efficiency obtained from using the finite element program ILLI-SLAB and the ESWR of the B-727 and B-1 main gears.

4. "ℓ" values are based on thicknesses of 24 and 17 inches, Poisson's ratio of 0.15, PCC modulus of elasticity of 4 million psi, and a modulus of subgrade reaction of 200 psi/in.

SLAB runs would show that the *all* curves in Figure 5 could be used for multiwheel gear by converting the exact configuration to an ESWR and then using the ESWR/l ratios shown in Figure 5.

This hypothesis was validated by performing two ILLI-SLAB runs for each combination of l and DLTE values for an aircraft. The objective of the first run was to determine the SLTE by using a mesh that included the exact tire location and contact area for all wheels of a main gear. Next, Equation 4 was used to compute the ESWR for a main gear and then use that radius in the finite-element mesh to determine the SLTE. Finally, the ESWR/l ratio could be used in Figure 5 to interpolate between the curves as necessary to arrive at a third SLTE.

The results of these finite-element runs are shown in Table 4 and support the hypothesis that the *all* curves in Figure 5 apply for multiwheel gear. Figure 6 shows that if the DLTE is plotted against the SLTE for an ESWR/l ratio, there is good agreement between both finite-element runs. In addition, the results of the finite-element runs correlate well with the original curves developed by Ioannides and shown in Figure 5.

ESWR Stress Analysis Example

The stress analysis procedure presented in this paper is summarized through an example problem. The example presented in Figure 7 assumes that a pavement engineer is designing a new JPCP pavement and that the critical aircraft is B-727. The current trial PCC thickness is 17 in. and includes the same thickness design inputs shown in Table 4. Figure 7 gives the steps required to use the ESWR concept to determine the edge stress at the transverse joint of the JPCP. For this example, the assumed DLTE is 70 percent.

The ESWR method of determining the actual edge stress in the JPCP is based on the assumption that the sum of the stresses of the loaded and unloaded slabs is approximately equal to the free edge stress of a loaded slab. This is a reasonable assumption regardless of the type of load transfer (aggregate interlock or dowels) because Ioannides and Korovesis have shown that the primary mechanism of load transfer is through shear forces (*21*). If dowels are used for load transfer, a small percentage of the load is transferred through the moment at the joint. If it is assumed that the load transferred through the moment at a doweled joint is negligible and a SLTE of 28 percent is used, this example shows that the edge stresses of 313 and 88 psi in the loaded and unloaded slabs equal the total free edge stress of 401 psi.

Figure 8 shows that the stress analysis procedure presented in this paper compares very well with the results that were obtained using the finite-element program ILLI-SLAB. Figure 8 also shows that the edge stresses in the loaded and unloaded slabs approach 50 percent of the free edge stress as the DLTE approaches 100 percent. Finally, the vertical line

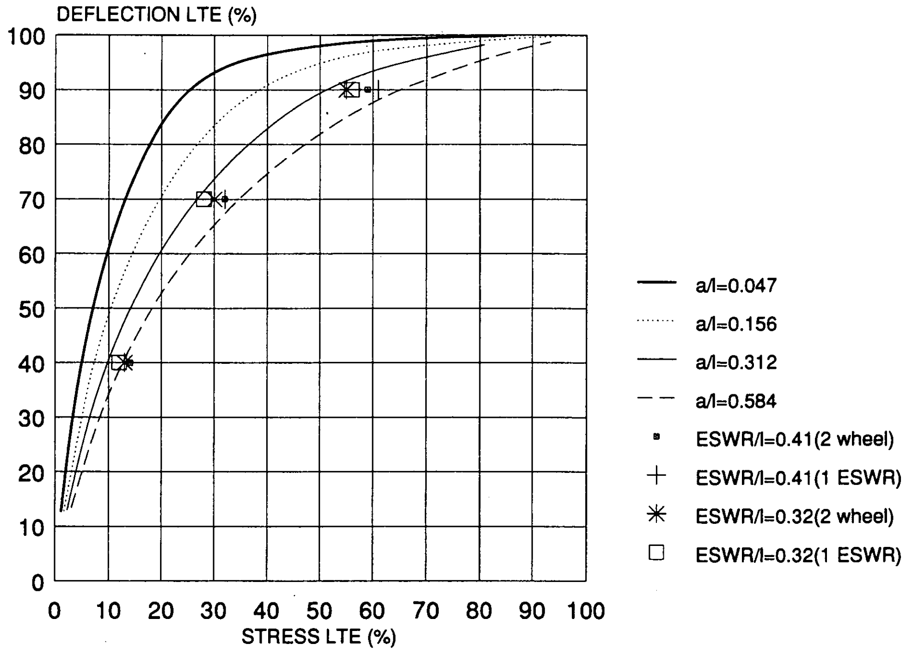


FIGURE 6 **B-727 load transfer efficiencies.**

STEP	INPUT	OUTPUT	REFERENCE
1. Calculate ℓ	h = 17 in E_{PCC} = 4,000,000 psi u = 0.15 k = 200 psi/in	ℓ = 53.7 in	EQN 2
2. Calculate ESWR	ℓ = 53.7 in	ESWR = 22.1 in	EQN 4 TABLE 1 FIGURE 2
3. Calculate Free Edge Stress	h = 17 in E_{PCC} = 4,000,000 psi u = 0.15 k = 200 psi/in ESWR = 22.1 in ℓ = 53.7 in P = 81 kips	σ_{free} = 401.2 psi	EQN 3
4. Calculate ESWR/ℓ	ESWR = 22.1 in ℓ = 53.7 in	ESWR/ℓ = 0.412	
5. Determine SLTE	DLTE = 70% ESWR/ℓ = 0.412	SLTE = 28%	FIGURE 5 EQN 7 TABLE 4 FIGURE 6
6. Calculate Actual Edge Stress	σ_{free} = 401.2 psi SLTE = 28%	σ_l = 313.1 psi σ_u = 88.0 psi	EQN 6

FIGURE 7 **Example problem using a B-727 ESWR to compute an edge stress.**

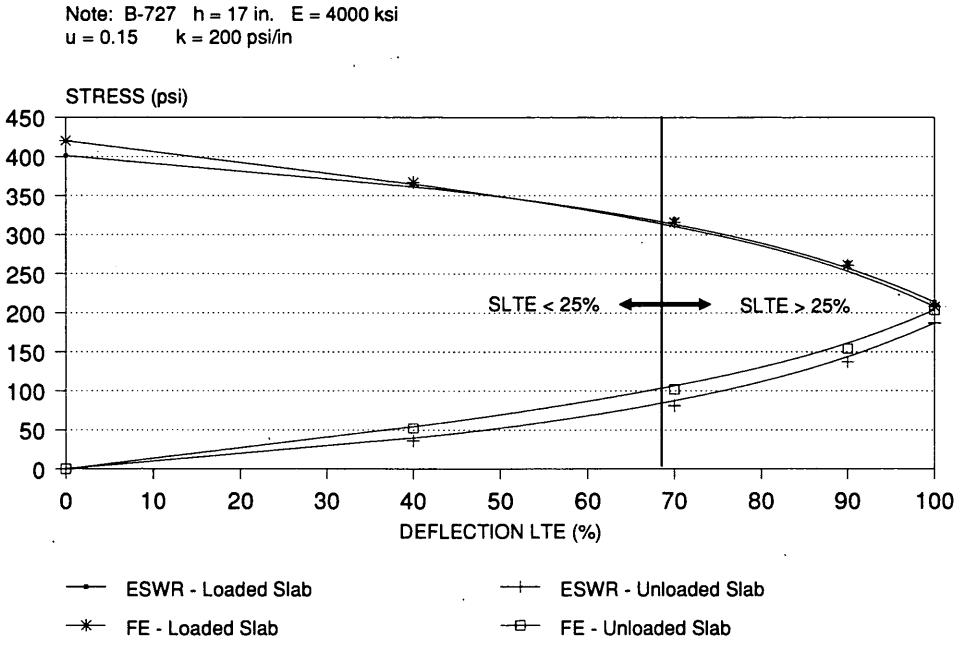


FIGURE 8 Edge stresses obtained using an ESWR and a finite-element program.

in Figure 8 represents an SLTE of 25 percent. If all joints in the JPCP are not doweled, the expected DLTEs will lead to edge stresses that are higher than those obtained using current FAA and U.S. Air Force design procedures, since each agency assumes a constant SLTE of 25 percent. As one moves to the left of the 25 percent SLTE line in Figure 8, the increase in edge stress in the loaded slab will decrease the fatigue life of the PCC and lead to early failure of the JPCP.

CONCLUSIONS

This paper presents a method for determining the flexural stress in a new or existing JPCP for aircraft with multiwheel main gear. ESWR regression models were developed for loading at the transverse joint of a JPCP for several aircraft. Once the ESWR is known for a trial JPCP section, Westergaard's analysis is used to determine the free edge stress. This research demonstrated that the ESWR can also be used to determine the SLTE, given the DLTE. Finally, the actual edge stress in a JPCP at the transverse joint can be determined using the free edge stress and the SLTE.

This analysis procedure is a fast and efficient means of accurately modeling JPCP behavior. Stress analysis results obtained from this procedure are almost as accurate as the results that would be obtained from a finite-element analysis and do not require the more powerful hardware that is used to run finite-element computer programs. Since this procedure also considers joint behavior, which is crucial to JPCP performance, it is a good tool for use in the field or for research checks of finite-element analyses.

This procedure has been incorporated into a prototype expert system that was developed at the University of Illinois. Future work on the edge stress analysis procedure presented in this paper should include ESWR regression models developed for main gear placed at the longitudinal joint of a JPCP. The results of this work could be added to the prototype expert system, which could then be programmed to evaluate both the transverse and longitudinal loading conditions and identify situations in which the longitudinal joint may be the critical location in a design analysis.

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