# DESIGN OF AIRPORT PAVEMENTS AS AFFECTED BY LOAD TRANSFER AND SUPPORT CONDITIONS

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Current FAA Design Criteria for major airports are based on the assumption of edge loading conditions, with an assumed load transfer of 25 percent, and a stabilized subbase equal in thickness to the thickness of the PCC slab. This paper examines the validity and cost effectiveness of these requirements. Theoretical analyses and results from field tests confirm that it is more economical to develop structural capacity of the PCC pavement by increasing the thickness of the PCC slab and reducing the thickness of the stabilized subbase. It is shown that three inches of added thickness in the PCC slab will reduce the deflection of the pavement, the stresses transmitted to the subgrade, and the stresses in the PCC slab more than 12 to 18 inches of stabilized subbase and at a lower initial cost. It is also demonstrated that effective load transfer is needed to prevent excessive corner deflections of PCC slab under the wide bodied aircraft gear loadings. Large diameter dowels and heavy tie bars are used at the load transfer mechanisms. Significant savings were demonstrated using these approaches to pavement design over the thicknesses obtained using the design recommendations in the FAA Advisory Circular.

FAA Advisory Circular AC 150/5320-6C, dated December 7, 1979 (1), changed the design criterion for PCC airport pavements from the maximum stress under loads at an interior point to that of the maximum stress with loads placed near an edge. This approach to design is more realistic as it can be shown that maximum stress in PCC pavements occur under edge loading conditions, and further that it is physically impossible to place an aircraft load on most pavement slabs in a manner to produce anything approaching a true interior loading condition. It has also been shown that nearly all distress in jointed concrete pavements is joint related (2).

The design approach presented in the previous Advisory Circulars was based on the assumption that the load transfer efficiency across the joints in the pavements would effectively reduce edge load stresses by 25 percent over the life of the pavement. This value was based on earlier work by the Corps of Engineers (3) which showed this to be a realistic value. Furthermore, since the design thickness in the earlier Advisory Circular was based on the stresses calculated due to a load at an interior point, the degree of load transfer across the joints had no real effect on the thickness design.

With the change in the criterion from an interior load stress to an edge load stress, this situation has significantly altered. If the thickness design is based on the maximum stress in a slab due to a load near an edge location, then it is critical to know the degree of load transfer one can achieve with the various types of joints, and to what extent this load transfer can be relied upon throughout the design life of the pavement. In addition, more must be known on the extent to which the load transfer efficiency across a joint actually affects the critical stresses and deflections in the pavement.

PCC pavement design charts in the Advisory Circular based on the "Westergaard Solutions" of the equations of an elastic slab on a Winkler Foundation (4, 5). Solutions, are available for the interior edge and corner loading positions, but are generally available only for single loads. When multiple loads are encountered the so called Pickett and Ray Influence Charts are usually used (6, 7). These influence charts, or corresponding computer programs, (8) permit stresses to be calculated for multiple wheel loading, but, like the Westergaard solutions, are not valid for edge loading conditions with full or partial transfer of load from a loaded slab to an adjacent unloaded slab. Since the FAA Design Charts were developed using basically the Westergaard solutions and the Pickett and Ray Influence Charts, it follows that the load transfer effectiveness cannot be taken into account except in an arbitrary manner such as by a predetermined reduction in the maximum stress in the loaded slab. This approach does not permit any tradeoff between slab thickness and good joint design, nor does it encourage engineers to try to find more effective ways to strengthen the slabs near the edges in an effort to design more effective pavement systems.

With the increasing gross weights of commercial aircraft there is a trend towards the use of heavier subbases for airport pavements. In the current FAA Advisory Circular it is indicated that the subbases for all PCC pavements designed for aircraft with a gross weight greater than 100,000 pounds (444 kN) must be constructed with stabilized materials. The current Advisory Circular also indicates that the

thickness of the subbases must be equal to that of the PCC slab. With slab thicknesses of 16 and 18 inches typical for airport pavements, the required pavement sections are very costly to construct. The question then arises as to whether there is a more effective and less costly way to achieve the same structural capacity for these pavements. The Mathematical models used to develop the current design curves do not permit the evaluation of tradeoffs between subbase and slab thicknesses or between subbase thickness and joint design.

In 1978 a finite element program was developed for the analysis of PCC pavement systems rather than for the analysis of PCC slabs (9, 10). This program called ILLISLAB is capable of analyzing single or multiple slabs of any size, with single or multiple loads at any location, and with varying degrees of load transfer efficiency across the joints. Doweled joints of aggregate interlock, either acting alone or in combination, can also be analyzed as the load transfer mechanism. The ILLISLAB program is also capable of analyzing PCC pavements comprised of either one or two layers, either bonded together or unbonded, and supported on a Winkler type foundation. This finite element model has been used to analyze a number of pavements including several pavement designs for Chicago's O'Hare International Airport, in an effort to develop more cost effective pavement systems.

Results from the ILLISLAB analyses have lead to a modified approach to design of airport pavements for O'Hare Airport. The approach used for the O'Hare Airport pavements can be applied equally well to other airports but the specific conclusions may be different because of the design aircraft for the airport. Among the changes suggested are changes in joint design, and revised recommendations for subbase thicknesses. These recommendations and justification for them are presented in this paper.

## Design Concepts

As indicated, design of PCC airport pavements is based on the criterion of limiting the bending stress in the concrete slab under edge loading conditions (1). Because of the wide variety of load configurations and magnitudes of loading applied to major airport pavements, it is well to examine other modes and causes of distress to achieve more reliable designs. Some aircraft will, for example, produce high stress levels in the concrete slab with only moderate vertical stresses transmitted to the subgrade, whereas other aircraft may cause very high slab deflections with the concomitant high stresses transmitted to the subgrade, and yet cause relatively low stress levels in the concrete slab.

Table 1 shows the maximum bending stress in the slab, the maximum slab deflection, and the maximum stress transmitted to the subgrade for a given pavement for three popular aircraft, namely, the DC-10, B-727 and B-747. All values were calculated with the aircraft at the most critical location on the slab, and assuming a 25 percent load transfer efficiency across all joints. The maximum stress in the PCC slab was determined at a slab edge with a gear located near the edge. Maximum deflections and maximum stresses transmitted to the subgrade were calculated at the corner of the slab with the gear located near the corner. From these results it is seen that the highest stresses in the slab were due to the DC-10, B-727, and B-747 in that order, whereas the highest deflection and highest stress on the subgrade were due to the B-747, DC-10 and B-727 in that order. The slab deflections and resulting stresses on the subgrade shown in Table 1 are great enouth to cause permanent deformation of the subgrade and ultimately will produce distress in the pavements. These responses must therefore be considered along with the stresses in the slab to achieve a reliable design.

The above results are illustrative only, and, as indicated, are based on an assumed load transfer efficiency of 25 percent. Each change in subgrade and subbase conditions, and each change in load transfer efficiency may in fact change the relative significance of these responses. The critical fact to be made here is that good design requires the analysis of alternate pavement sections for all probable causes of distress and not to merely evaluate the pavements for a single failure criterion.

## Critical Aircraft and Loading

Figure 1 shows the lateral distribution of the tires for several popular aircraft relative to the longitudinal joint system of airport pavements when the centerline of the aircraft coincides with the centerline of the center 25 foot slab for a taxiway or runway. In all instances, either the outer inner edge of a tire is within 4 feet of a longitudinal joint, and for several aircraft, the tire location is within 2 feet of the joint. Considering the anticipated lateral wander of the aircraft (11), it is apparent that a significant number of wheel loads with all aircraft shown will be at or near a longitudinal joint in these pavements. This distribution supports the proposed edge loading as a basic design loading position.

Several analyses were made with the B-747 and DC-10-30 aircraft placed at different locations relative to the longitudinal and transverse joints. These analyses made with the aircraft both parallel to and at a skew the joints. Based on these analyses, the critical loading positions for the wide bodied aircraft are as shown in Figure 2. These load locations for maximum stress and maximum deflection were used for all subsequent analyses. These aircraft were used for the analyses of the pavements at Chicago's O'Hare International Airport because the preliminary analyses showed these aircraft cause the maximum stresses and deflections in the pavement, and because of the large percentage of these type aircraft at this facility. Other airports may find other aircraft critical for their facility, depending upon the percentage of each type aircraft using the facility.

Using the two aircraft indicated above (DC-10 and B-747), analyses were made to determine the best design for the pavements at the O'Hare International Airport. Among the factors considered were the trade off between pavement slab thickness versus subbase thickness, and requirements for load transfer at the joints.

## Effect of Subbase Thickness

With designated aircraft loads at the critical locations, various combinations of subbase thickness were analyzed in an effort to determine if it were more economical to increase slab subbase thickness to reduce the critical stresses and deflections in these pavement system. The subbase used in these analyses was an asphalt concrete with an assumed "E" value of 500,000 psi. It was also assumed that no bond existed between the AC subbase and the PCC slab. The modulus of subgrade reaction (k) for these analyses was held constant at 200 psi/in.

A summary of the results from the analyses of the subbase thickness are presented in Figure 3. The results are presented as ratios between the stresses

and deflection determined for the specific pavement sections, and the comparable values for a standard pavement. The standard for these analysis was 18 inches of PCC on 18 inches of AC subbase. This 18/18 pavement was selected as the standard as this is the pavement section approved by FAA and was determined by applying the design procedures and criteria in current FAA Advisory Circular (1). For these analyses, all pavement systems were assumed to have the same load transfer efficiencies at all joints. When the ratio in Figure 3 is greater than 1, it indicates the stress and deflection in the pavement being considered are greater than the comparable values in the standard 18/18 pavement section; whereas when the ratio is less than 1, it indicates a lower level for the stress and deflection in the pavement being considered.

The results shown in Figure 3 are for PCC pavement slabs with thicknesses of 18, 21, and 24 inches, and with AC subbases thicknesses ranging from zero up to the thickness of the PCC slab as specified in the FAA Advisory Circular (1). Of all the sections analyzed, only those sections with 18 inches of PCC and a subbase thickness less than 18 inches had stress and deflection ratios greater than 1. All pavement sections with 21 and 24 inch PCC slabs, regardless of the subbase thickness, had ratios of less than 1, indicating that increasing the PCC slab thickness by 3 inches from 18 to 21 inches had a greater effect on critical stresses and deflections in the pavement than 18 inches of AC subbase. Considering the relative costs of Portland Cement Concrete versus that of AC, it is obvious that the most economical way to reduce the stresses and deflections under these loadings is to minimize the subbase thickness and to put some of the savings into increasing the thickness of the PCC slab.

In making these analyses it is recognized that subbases for PCC slabs have functions other than merely reducing stresses and deflection of the pavements. Specifically, subbases under PCC slabs may be necessary to prevent pumping of the subgrade soils and as a construction platform. Also, for some climatic zones, the subbase layer is critical for preventing frost penetration into the subgrade. For this latter function it is not necessary to have a stabilized subbase, but to merely have a non-frost-susceptible material. Based on these considerations, it was determined that for this design a layer of AC subbase six inches thick would be adequate to prevent pumping, and would provide an adequate construction platform. Any additional subbase thickness needed to prevent frost penetration should be made up by the inclusion of a non-frost-susceptible granular subbase under the AC layer, and any increase in the pavement structural capacity could be achieved most economically by increasing the slab thickness.

## Load Transfer Efficiency

For this analysis, load transfer efficiency is defined as the ratio of the deflection of the unloaded slab divided by the deflection of the loaded slab. For convenience this ratio is usually expressed as a percentage.

Previous analyses have shown that the load transfer efficiency across a joint affects both the maximum stresses in the slab, especially under edge and corner loading conditions (9). There is not, however, a one to one correlation between the effect of the joint efficiency on the maximum stress and the maximum deflection in a pavement. Figure 4 shows the relative effect of load transfer efficiency of a joint on both the deflection and stress at the joint when the load is applied near the joint. Since the stress transmitted to the subgrade is the deflection times k, the subgrade stress will be affected in the same manner as the deflection.

The critical point to note in Figure 4 is that just a small reduction from a full joint efficiency results in a significant change in the stress ratio. Conversely, only a moderate level of load transfer efficiency is needed to meet the FAA assumption of a 25 percent decrease in the maximum slab stress. These data would tend to support the FAA assumption of a 25 percent stress reduction as a rational basis for design. A more detailed analysis, however, suggests that many benefits could be gained by designing joints with higher load transfer efficiencies.

Table 2 shows the maximum stresses and deflections in a plain jointed pavement slab 21 inches thick with 6 inches of AC subbase for loading conditions and joint efficiencies indicated. The maximum stress of 425 psi, occurs under an edge loading with a low (10 percent) load transfer efficiency under the DC-10-30 aircraft loaded to its maximum ramp weight of 558k. With the edge loading, only the efficiency of the joint along loaded edge will affect the results. For this loading it is seen that increasing the efficiency of the joint from 10 percent to 90 percent would reduce the maximum stress in the slab from 425 psi to approximately 270 psi. Assuming a factor of safety of two is required for a high capacity airport, this change in load transfer from 10 to 90 percent would change the minimum flexual strength requirement from 850 psi to 540 psi respectively.

Maximum deflection and maximum stress transmitted to the subgrade occurs when the aircraft gear is located near a corner of the slab. For these cases, the efficiency of both the transverse and longitudinal joints must be considered. Typical results showing these effects are shown in Table 2. For the DC-10-30 aircraft at maximum ramp weight, the maximum pavement deflection varies from approximately .20 inches when both joints have a relatively low load transfer efficiency, to approximately .06 inches when the load transfer efficiencies for the two intersecting joints are high. When the load transfer efficiency of one joint is high and the other low, intermediate values are obtained. Of greater concern than the maximum deflection is the maximum stress transmitted to the subgrade. With a k of 100 psi, the deflection of .20 inches (with both joints bad) and the maximum stress transmitted to the subgrade is 20 psi. The corresponding stress on the subgrade with both joints having a high load transfer efficiency is approximately 6 psi. When one joint efficiency is good and the other bad intermediate values are obtained.

Based on repeated load tests in the laboratory, the maximum allowable stress on this subgrade soil without significant permanent deformation is between 12 and 18 psi. To limit the stress transmitted to the subgrade to 12 psi requires that either both joints have at least moderate load transfer efficiency (60 to 70 percent efficiency), or that at least one joint have a high load transfer efficiency and the other a relatively low (or moderate load transfer) efficiency. For a reasonable factor of safety, however, both joints should be designed to have a high initial load transfer efficiency. This will allow for some loss of efficiency of both joints with time and repeated load applications without significant loss in pavement performance.

Results presented in Table 2 also shows comparable stresses and deflections in the pavement with the B-747 loaded to its maximum ramp weight. For both the maximum stress and maximum deflection, the DC-10-30 aircraft is critical; significantly so for

the bending stresses in the slab and somewhat so for the deflections. However, if a 1 million pound version of the stretched B-747 were to use this facility, the maximum stresses and deflections would increase approximately 28 percent over those shown in the Table. Thus, the maximum bending stress for the 1 million pound B-747 with poor load transfer at the joint would be about 460 psi and with good load transfer, about 280 psi. Maximum deflections would increase from about .18 inches to about .23 inches with poor load transfer conditions and to about .07 or .08 inches with good load transfer. While these numbers are somewhat high, especially with poor load transfer, if the load transfer can be maintained at a reasonable level, then the proposed 21 inch PCC slab with a 6 inch AC subbase should provide reasonable performance for 20 years even if a limited number of stretched B-747's are allowed to use the facility.

The analyses discussed were based on a 21 inch PCC slab on a 6 inch AC subbase. For these analyses the pavement system was assumed to be two elastic layers which were not bonded together. The two layers were assumed to act as a composite pavement system, with both layers having matched joints and cracks. The load transfer effectiveness of both layers were assumed to be the same at each joint or crack location. All deflection values are the mid-slab deflection values, and subgrade stresses values are the stresses at the top of the subgrade not on the surface of the subbase. In other words, the subbase is a part of the pavement system, not part of the support.

Analyses were also made to determine if increasing the slab thickness or increasing the subbase thickness would be equally effective as increasing the load transfer efficiency in reducing deflection and subgrade stress. As can be seen from Figure 3, neither approach would be particularly effective, but that increasing the slab thickness would generally be more effective than increasing subbase thickness. The only way the effect of the subbase layer could be improved significantly would be to 1) bond the subbase to the PCC slab, or 2) to prevent the joint or crack in the PCC slab from reflecting through the subbase. While one can find some instances of both events occurring under current field conditions, the reliability of achieving these conditions under normal construction procedures prohibits the assumption of this occurrence in the design analysis.

The analyses presented above demonstrate that the most effective way to decrease bending stresses in the pavement is to increase the thickness of the PCC slab, and the most effective way to decrease slab deflections and stresses transmitted to the subgrade is to improve the load transfer effectiveness across the joints. Whether both actions must be taken for a specific airport pavement design depends on the anticipated traffic on the pavement. If only the lighter aircraft such as the B-727 and DC-9 aircraft are expected to use the facilities, then the full load transfer system may not be required. If, however, the heavy wide bodied aircraft with large gear footprints and high magnitude loads are anticipated then both thick PCC slabs and good load transfer are required to provide the desired performance from these pavements.

## Load Transfer Systems

The most common types of load transfer systems (LTS) in use on airport pavements are 1) keyways; 2) dowels; and 3) aggregate interlock. All of these systems can provide a very high level of load transfer efficiency when operating properly. Each has shortcomings, however, which must be carefully evaluated for reliability over the design life of the pavement.

Keyways are generally not permitted in airport pavement slabs less than 12 inches in thickness. This is because of serious failure of the keyways in a number of airport pavements and the concomitant loose concrete which results from such failures. In a recent study for FAA, it was shown that keyways in many thicker pavements have also failed under the heavy loads (12). Consequently it has been recommended that keyways be eliminated from all airport pavements.

Aggregate interlock provides excellent load transfer when new but tends to deteriorate with repeated load applications. Figure 5 shows how the load transfer effectiveness of aggregate interlock changes with repeated load applications and width of crack. These data show that the long-term effectiveness of the aggregate interlock is greatly decreased by a large crack opening. Hence for aggregate interlocks to be effective with a high number of load applications the joint or crack should be held tightly closed. Tie bars are an effective means of holding a joint tightly closed. Furthermore, if large tie bars are used, they will also transfer significant load in much the same manner as dowel bars.

Dowel bars are probably the most reliable and effective load transfer system currently in general use. Dowels are generally used in transverse joints but there are cases when dowels have been used as the LTS in the longitudinal joints between paving lanes (13).

Dowels have been shown to provide excellent load transfer effectiveness, especially when new. Furthermore dowels will provide excellent long term performance provided the dowel does not corrode or the dowel sockets in the concrete does not elongate. Elongation of the dowel socket appears to be a function of the bearing stress between the dowel and the concrete (9).

Figure 6 shows the performance record for several sets of dowels from different test pavements and the corresponding bearing stresses between the concrete and the dowels calculated with a 3-dimensional finite element program (9). These data suggest there is a relationship between the performance of the dowelled joints and the level of bearing stress between the dowel and the concrete. Thus, to insure long term performance of the joints, the appropriate dowel sizes must be selected to maintain an acceptable level of bearing stress on the concrete.

The maximum bearing stress ($\sigma_{br}$) between the dowel can be estimated by the equation (9).

$$\sigma_{br} = \frac{(800 + .068\ E_c)}{D^{4/3}} \times (1 + .355W)\ \overline{LT}$$

where

$\sigma_{br}$ = Maximum bearing stress in psi

D = Dowel diameter in inches

$E_c$ = Young's Modulus for concrete, ksi

W = Joint opening in inches

$\overline{LT}$ = Maximum load transferred by a dowel in kips (1000 lb units)

Values for the $\overline{LT}$ can be obtained from the ILLI-SLAB computer program (Ref. 1), for the specific loading conditions, or can be estimated from nomographs (9).

From the above equation it can be seen that the maximum bearing stress is a function of the modulus of the concrete, diameter of the bar, width of the

joint, and magnitude of load transferred. Furthermore, it can be shown that the load transferred is primarily a function of the spacing of the dowels and the magnitude and configuration of the applied load. Slab thickness and subgrade support have almost no effect on the bearing stress between the bars and the concrete.

Tie bars in the longitudinal joints are used to keep the joints tightly closed. Thus, even with a straight butt joint, there can be some load transfer due to friction if the joints are held tightly closed. Consequently, tie bars can be somewhat smaller in diameter than dowel bars for equal performance. Also, longitudinal joints are generally not subjected to the violent stress reversals found in the transverse joints.

The proposed design for the O'Hare Airport pavements utilizes 2 inch dowel bars at the transverse joints and 1 3/8 inch (#11) deformed bars as ties for the three central longitudinal joints. This combination will produce maximum bearing stresses shown in Table 3 for the loading conditions specified, for an assumed 1/4 inch joint opening for the doweled joints. For the #11 tie bars, the calculated stresses will be about 9 percent greater than the values given in Table 3 assuming no load transfer due to friction between the tied faces. Considering that only one loading condition, namely the fully loaded DC-10-30, causes a maximum stress approaching 4000 psi, it is believed that the proposed joint design of #11 tie bars at 12 inch centers for the three central longitudinal joints and the 2 inch diameter dowels at 12 inch center for the transverse joints will provide long term performance desired for these pavements.

## Verification of Concepts

Non-destructive testing of pavements at O'Hare International with the U.S. Army Engineer's WES 16-kip vibrator has provided data on several alternate pavement sections which fit the patterns discussed above. Table 4 shows the cross-sections of the pavements tested and the results obtained. Results are given in terms of the mid-slab deflection in mils (inches x $10^3$) and the ratio of the deflection between the indicated pavement cross section and that of the 18/18 standard discussed above.

The ratios in the last column of Table 4 are generally consistent with the theoretical results discussed earlier in this paper. There is a minor inconsistency in the ratio for the 18/12 and 18/18 pavement as the 18/12 pavement shows slightly less deformation than the 18/18. Considering that these tests were from test locations at opposite ends of the airport, such an anomology is not surprising. If anything, these data suggest that the effective increase in pavement stiffness due to increased slab thickness is even greater than indicated by theory. This may be due in part to the type loading used in these tests.

The total gear loads used in the analysis for the DC-10 and 747 type aircraft was of the order of 200,000 pounds. With loads of this magnitude the pavement response will obviously be effected to a much greater extent by the subgrade support than when tested with the 28,000 pound vibratory load. Also, with the vibratory loads, the inertial effects of the thicker pavements may reduce the deflection more than indicated by theory.

Considering the overall effect of slab thickness versus subbase thickness, and the normal variability one gets in testing pavements in service, it is apparent that the trends indicated by the theoretical analyses are substantiated by these test results.

Load transfer effectiveness of the dowels systems were also evaluated with the NDT equipment. Table 5 shows the deflection results for center of slab, edge and corner loading conditions for three pavement sections loaded with the WES Vibrator. The 15 inch slab has carried many years of traffic prior to testing and shows the almost complete lack of load transfer across the joints.

The 18/12 pavement is in a holding ramp area and thus has had little traffic prior to testing. Here the load transfer is still very effective. The 21/6 pavement is less than 2 years old but, as a connector between the inner and outer circular taxiway, carries considerable traffic. Load transfer for this pavement is very good.

At this time it can be concluded from these results that the 1 1/4 inch dowels are not adequate for heavy traffic areas for major airports but may be adequate for light aircraft and/or low traffic volumes. It is too early to determine the long term performance of the 2 inch dowels, but the preliminary results indicate these dowels are very effective as load transfer devices. These results are consistent with the findings presented earlier based on the analysis of these pavements.

## Summary and Conclusions

Increasing weights of modern aircraft using civilian airports have resulted in a need to reexamine the design criteria used for PCC pavements. Development of more precise analysis procedures such as the finite element model (ILLISLAB) provides the necessary tools to examine the effects of subbase thickness and load transfer efficiencies across joints on the behavior of PCC pavements under aircraft loading.

Based on analysis of many combinations of subbase and slab thicknesses with various combinations of load transfer systems using the ILLISLAB model the following guidelines should produce the most efficient PCC pavement system for airports with a high percentage of wide body aircraft:

1. A stabilized subbase layer should be used to prevent pumping, and provide a construction platform. Thickness of the subbase layer should be the minimum needed to accomplish the above objectives. Increased structural capacity of the PCC pavement can be obtained much more economically through increasing the thickness of the PCC slab then through increased subbase thickness.
2. Effective load transfer systems are necessary at all joints to prevent overstressing the subgrade. Effective load transfer can reduce the maximum stress transmitted to the subgrade by nearly two thirds over that obtained with an unprotected corner. Increasing slab subbase thicknesses will decrease the maximum stress transmitted to the subgrade by nearly two thirds over that obtained with an unprotected corner. Increasing slab subbase thicknesses will decrease the maximum subgrade stresses somewhat but not enough to make this approach to design cost effective.
3. Dowels and large tie bars with aggregate interlock are the most effective load transfer systems in use today. To be effective, however, dowels must be of large enough diameter to keep the bearing stresses between the dowel bar and the concrete at acceptable levels. For aggregate interlock to be effective the crack or joint must be held tightly closed.

Based on the above conclusions the most effective design for the O'Hare Airport pavements was a 21 inch PCC slab on 6 inches of stabilized subbase, with 2 inch dowels at 12 inch centers for transverse joints

and 1 3/8 inch tie bars at 12 inch centers in the center 3 longitudinal joints. This design was much stronger and significantly less costly to construct than the alternate 18/18 design initially approved for these pavements.

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Table 1. Comparison of Pavement Responses to Aircraft Loading.

| Aircraft | Maximum Responses | | |
|---|---|---|---|
| | Stress in PCC Slab psi | Deflection (inches) | Vertical Stress on Subgrade psi |
| B 727 | 340 | .09 | 9 |
| DC-10 | 405 | .16 | 16 |
| B-747 | 315 | .18 | 18 |

Table 2. Summary of Maximum Stresses and Deflections for 21" PCC Slab on 6" AC Subbase.

| Aircraft | Loading Descriptive (kips) | Max Stress (Edge Load) | | Max Deflection (Corner Load) | | |
|---|---|---|---|---|---|---|
| | | Joint Efficiency | | Joint Efficiency (T/L)* | | |
| | | <10% | >90% | 10/10 | 10/90 | 90/90 |
| 747 | Max Ramp (778) | 360 | 220 | .18 | .10 | .06 |
| | Max Landing (600) | 280 | 175 | .14 | .08 | .05 |
| DC-10-30 | Max Ramp (558) | 425 | 270 | .19 | .11 | .06 |
| | Max Landing (403) | 285 | 185 | .14 | .08 | .05 |

Note: ($E_c$ = 5,000,000 psi, $k_{sub}$ = 100, $E_{AC}$ = 500,000 psi)

*T/L = Transverse/Longitudinal Joint

Table 3. Maximum Bearing Stresses on 2 inch Diameter Dowels at 12 inch on Centers.

| Aircraft/Gross Weight (kips) | Location | |
|---|---|---|
| | Edge | Protected Corner |
| DC-10-30/558$^K$ | 3219 | 4097 |
| DC-10-30/403$^K$ | 1678 | 2962 |
| 747/778$^K$ | 2991 | 3840 |
| 747/600$^K$ | 2320 | 2962 |

Table 4. NDT Test Results

| Pavement Cross Section | | | Deflection under 28 KIP Peak-to-Peak NDT Force at 15 Hz | | |
|---|---|---|---|---|---|
| PCC (inches) | Subbase Type | Subbase inches | Mils[1] | Ratios Theoretical[2] | Ratios Actual |
| 15 | Gravel | 12 | 2.7 | 1.13 | 1.59 |
| 18 | AC | 12 | 1.6 | 1.01 | 0.94 |
| 18 | AC | 18 | 1.7 | 1.00 | 1.00 |
| 21 | AC | 6 | 1.3 | .89 | .72 |

1. Mils = inches x $10^3$

2. Comparable to values in Figure 3 but interior loads.

Table 5. Load Transfer Effectiveness Measured with NDT.

| Pavement Cross Section | | | | | Deflection Under 28-Kip Peak to Peak NDT Force (Mils) | | |
|---|---|---|---|---|---|---|---|
| PCC | Subbase | | Dowels | | | | |
| inches | Type | inches | Dia. | Ctr.to Ctr. spacing inches | CTR. | JOINT | CORNER |
| 15 | Gravel | 12 | 1¼ | 12 | 2.7 | 5.7 | 23.5 |
| 18 | AC | 12 | 1¼ | 12 | 1.7 | 3.6 | 3.6 |
| 21 | AC | 6 | 2 | 12 | 1.3 | 2.0 | 2.3 |

Figure 1. Lateral location of aircraft tires when aircraft centered on taxiway.

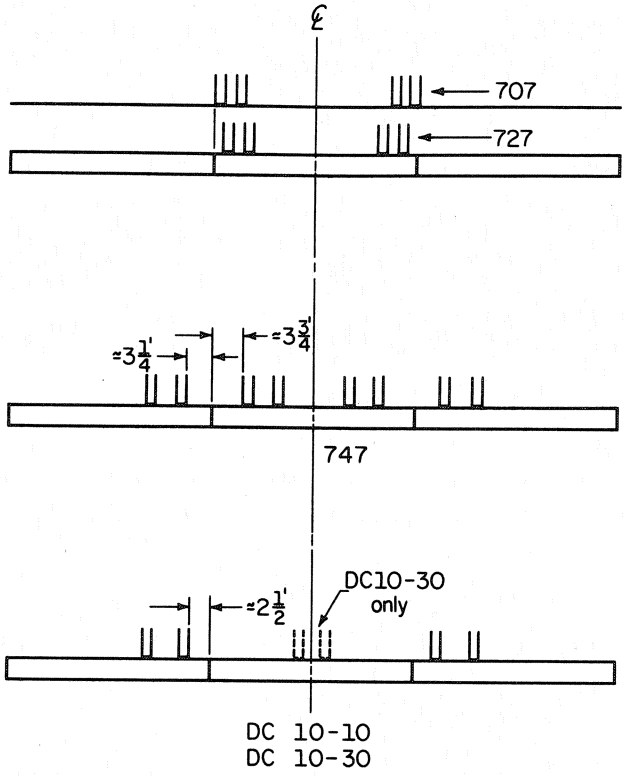



Figure 2. Main gear locations for maximum Pavement responses.

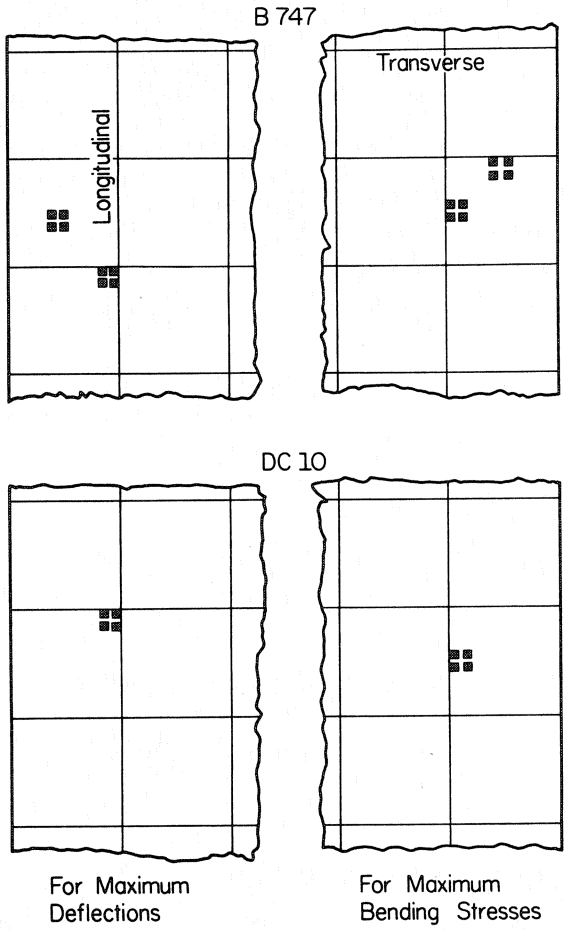


Figure 3. Relative stresses and deflections for alternate pavement systems.

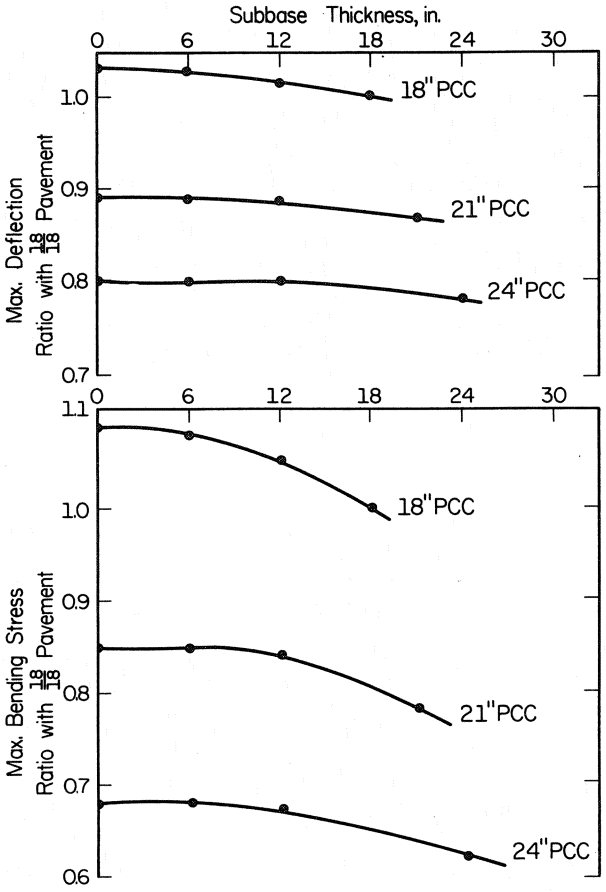



Figure 4. Relationship between load transfer efficiency determined by deflection criterion and changes in stress ratios.

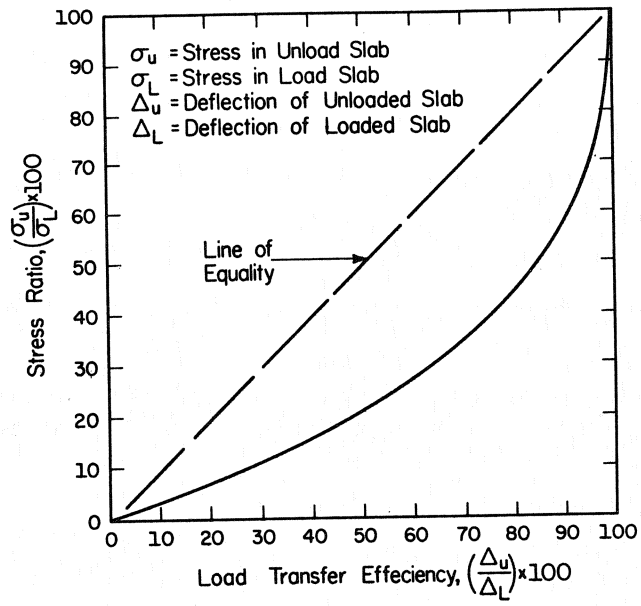
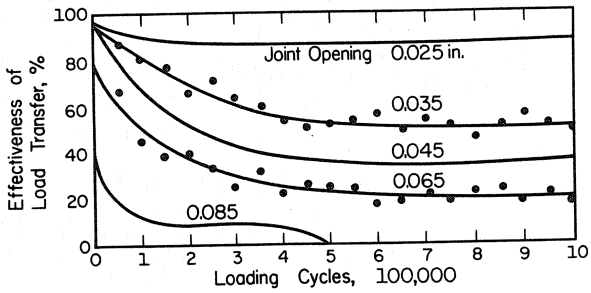
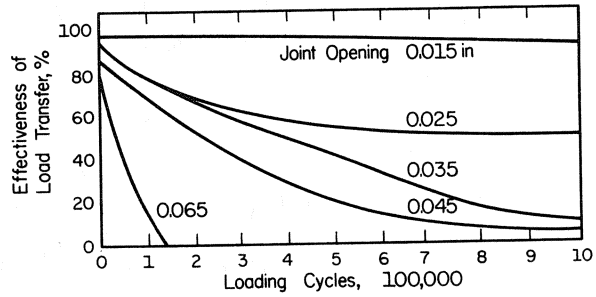



Figure 5. Influence of joint opening and slab thickness on performance of aggregate interlock.




9 IN. CONCRETE SLAB, 6 IN. GRAVEL SUBBASE.




7 IN. CONCRETE SLAB, 6 IN. GRAVEL SUBBASE.

Figure 6. Effect of bearing stresses and load application on dowel loosness.

