U.S. Department
of Transportation

**Federal Aviation
Administration**

Advisory Circular

Subject: AIRPORT PAVEMENT DESIGN FOR THE BOEING 777 AIRPLANE
Date: 10/22/95
Initiated by: AAS-200
AC No: 150/5320-16
Change:

1. PURPOSE. The purpose of this advisory circular is to provide thickness design standards for pavements intended to serve the Boeing 777 airplane.

2. APPLICATION.

a. New Pavements. The guidelines and standards contained herein are recommended by the Federal Aviation Administration (FAA) and are applicable to the thickness design of airport pavements intended to serve the Boeing 777 airplane. Other facets of pavement design are equally important and should be performed in accordance with AC 150/5320-6, Airport Pavement Design and Evaluation. Thickness design for pavements not subject to Boeing 777 traffic should be determined using AC 150/5320-6. This program was specifically developed as a pavement design program. Traffic is assumed to be composed of a mixture of different aircraft. The program is not intended for use as a tool to compare one aircraft with another, i.e., ACN type calculations. Attempts to use the program in this fashion will likely lead to erroneous results. If only one aircraft is input, a warning will appear indicating that the program is designed for a mix of traffic.

b. Existing Pavements. The ACN/PCN method, as described in AC 150/5335-5, is recommended to determine the adequacy of existing pavements to serve the B-777. Generally speaking, existing pavements which currently serve wide body aircraft should be adequate for Boeing 777 traffic.

3. BACKGROUND. The Boeing 777 airplane is supported by a landing gear arrangement made up of two main gears and a single nose gear. The main landing gears are unique in that they have 6 wheels arranged in a tri-tandem (3 pairs of wheels in a row) configuration. The nose gear is composed of a single dual wheel arrangement. When the main gear assembly is analyzed using the conventional FAA design methodology, the pavement thickness requirements are considered to be unduly conservative. This is particularly noticeable for flexible pavements. A new airport pavement design methodology was adopted for the Boeing 777 to reduce some of the conservatism experienced with the present method and to phase in a more mechanistic approach. The new method is computer based and is code named LEDFAA v1.2 (Layered Elastic Design Federal Aviation Administration, version 1.2). The methods of design for flexible and rigid pavements and overlays of rigid pavements were originally developed by the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS and are reported in DOT/FAA/RD-

74/199, DOT/FAA/RD-77/81 and DOT/FAA/PM-87/19, respectively. See Appendix 1. The new design method uses a general purpose layered elastic analysis procedure code named JULEA developed by Dr. Jacob Uzan, Technion at Haifa, Israel.

4. RELATED READING MATERIAL. Appendix 1 provides a listing of documents containing supplemental material relative to the subject. Information on ordering these documents is also provided.

5. METRIC UNITS. The computer program in its present form does not provide metric dimensions. Future revisions will include metric dimensions.

6. AVAILABILITY. The computer program for airport pavement design for the Boeing 777 airplane is available on the Office of Airport Safety and Standards Electronic Bulletin Board (BBS). There is no charge to access the bulletin board or download information. The bulletin board requirements and parameters are listed below:

Equipment Requirements:

Computer with modem
Communications software

Bulletin Board Parameters:

Telephone number 202-267-5205 (2 lines)
or 800-224-6287 (FAA Corporate BBS Gateway)

Data Bits	8
Parity	(N)one
Stop Bits	1
Baud Rate	300/1200/2400/9600/14400
System Operator	Rick Marinelli, AAS-100 202-267-7669
Co-System Operator	Jeffery Rapol, AAS-200 202-267-7474

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BACKGROUND

1. INTRODUCTION. The Boeing 777 produces an unprecedented airport pavement loading configuration which seems to exceed the capability of the current methods of design. Existing methods incorporate some empiricism and have limited capacity for accommodating new gear and wheel arrangements. A new method of design based on layered elastic analysis has been developed to calculate design thicknesses for pavements for the Boeing 777. The new design method is computationally intense and is thus in the form of a computer program.

2. COMPUTER PROGRAM. The computer program operates under Microsoft Windows. The core program , JULEA, is a Microsoft Windows FORTRAN application. The remainder of the program is written in Visual Basic.

3. HARDWARE AND SOFTWARE REQUIREMENTS. In order to achieve reasonable solution times, an IBM compatible computer with a 486 or Pentium ® central processing unit (CPU) and a math co-processor is recommended. Windows 3.1 is the required software. These requirements are intended to be compatible with the in-house capabilities of most consulting firms. The program will operate with a 386 CPU and a math co-processor, however, solution times may be objectionably long.

4. AIRCRAFT CONSIDERATIONS. A wide variety of aircraft with pertinent pavement design characteristics are stored in the program library. The designer has some latitude in selecting aircraft parameters.

a. Mixed Traffic. The computer program was developed and calibrated specifically to analyze a mixture of different aircraft. If a single aircraft is used for design, a warning will appear in the Aircraft Window indicating the program was intended for use with a mixture of different aircraft types. Nearly any traffic mix can be developed from the aircraft in the program library. A maximum of 20 aircraft can be analyzed. Solution times are a function of the number of aircraft in the mix. The design procedure described herein deals with mixed traffic differently than previous methods. There is no need to determine a design aircraft. The program calculates the damaging effects of each aircraft in the traffic mix. The damaging effects of all aircraft are summed in accordance with Miner's Law. When the cumulative damage factor (CDF) sums to a value of 1.0, the design conditions have been satisfied.

b. Boeing 777. In addition to the requirement for mixed traffic, Boeing 777 aircraft must be in the mixture. If a 777 airplane is not in the traffic mix, a warning will appear on the screen and on the printout.

5. PAVEMENT CONSIDERATIONS.

a. Design Life. The FAA design standard for pavements is based on a 20 year design life. The computer program is capable of considering other design life time frames. Use of a design life other than 20 years constitutes a deviation from standards and will require FAA approval.

b. Design Reliability. The reliability of this method of design should be approximately the same as the reliability of the CBR method of pavement design.

c. Materials. Pavement materials are characterized by thickness, elastic moduli, and Poisson's ratio. Layer thicknesses can be varied at will except where minimum thicknesses are required. Elastic moduli are either fixed or variable depending on the material. The permissible range of variability for elastic moduli is fixed to ensure reasonable values. Poisson's ratio for all material is fixed. Materials are identified with their corresponding FAA specification designations, for example, crushed stone base course is identified as Item P-209. The list of materials contains an undefined layer with variable properties. If an undefined layer is used, a warning will appear in the Structure Window stating that a non standard material has been selected and its use in the structure will require FAA approval.

FLEXIBLE PAVEMENT DESIGN

6. SCOPE. This section presents FAA standards for the design of flexible pavements intended to serve a mix of traffic which includes the Boeing 777 airplane.

7. INTRODUCTION. The design process considers two modes of failure for flexible pavement, vertical strain in the subgrade and horizontal strain in the asphalt layer. Limiting vertical strain in the subgrade is intended to preclude failure by subgrade rutting. Limiting horizontal strain at the bottom surface of the asphalt surfacing layer guards against failure by cracking of the asphalt surface layer.

8. HOT MIX ASPHALT SURFACING. Hot mix asphalt surfacing should meet the requirements of FAA Item P-401. A minimum thickness of 5 inches (127 mm) of hot mix surfacing is required for traffic mixes which include the Boeing 777. The landing gear of the 777 is articulated (rear dual wheels are steerable) thus scrubbing during turns is expected to be no worse than existing dual tandem gears. Item P-401 surfacing should provide adequate surface stability. A fixed modulus value for hot mix surfacing is set in the program at 200,000 psi (1380 MPa). This modulus value was chosen to produce results which closely matched thickness requirements for pavements designed with the CBR methodology.

9. BASE COURSE. A minimum 8 inch (203 mm) thick stabilized base course is required for pavements serving these aircraft. LEDFAA includes two stabilized flexible base options which are designated: P-401 and Variable. The word flexible is used to indicate that these bases have a higher Poisson's Ratio (0.35) and act as flexible layers as opposed to rigid layers and are not likely to crack. P-401 is the standard FAA Item P-401 bituminous base which has a fixed modulus of 400,000 psi (2760 MPa). The variable stabilized flexible base can be used to characterize a bound base which does not conform to the properties of P-401. It has a variable modulus ranging from 150,000 to 400,000 psi (1035 to 2760 MPa). This modulus range was selected to closely duplicate results from using an equivalency factor range of 1.2 to 1.6 in the CBR method of design. Stabilized (rigid) bases, P-304 and P-306 may also be used as base course although they are subject to cracking and can induce reflection cracking in the hot mix asphalt surfacing. Item P-301 Soil Cement Base is not acceptable for use as a base course for these pavements.

10. SUBBASE COURSE. Subbases may be aggregate or bound materials. The minimum thickness of subbase is 3 inches (76 mm). Acceptable aggregate materials are P-209, Crushed Aggregate Base Course, P-208 Aggregate Base Course, or P-154, Subbase Course. Acceptable bound materials are P-401, P-304, P-306. Use of Item P-301 is limited to locations not subject to freeze thaw cycles. More than one layer of subbase material may be used, i.e., P-209 over a layer of P-154. Layering must be done so as not to produce a sandwich (granular layer between two bound layers) section.

11. SUBGRADE. The subgrade is assumed to be infinite in thickness and is characterized by either a modulus or CBR value. The computer program converts CBR to modulus by multiplying by 1500. Subgrade compaction and embankment construction should be in accordance with AC 150/5320-6, Airport Pavement Design and Evaluation, and AC 150/5370-10, Standards for Specifying Construction at Airports.

12. SEASONAL FROST AND PERMAFROST. Seasonal frost and permafrost effects should be considered by applying the techniques in AC 150/5320-6.

RIGID PAVEMENT DESIGN

13. SCOPE. This section presents FAA standards for the design of rigid pavements intended to serve a mix of traffic which includes the Boeing 777 airplane.

14. INTRODUCTION. The design process considers one mode of failure for rigid pavement, cracking of the concrete slab. Limiting horizontal stress at the bottom surface of the concrete surfacing layer guards against failure by cracking of the surface layer. The computer program iterates on the concrete layer thickness until the CDF reaches a value of 1.0. Once a CDF of 1.0 is achieved, the section satisfies the design conditions. A design life of 20 years is recommended for airport pavements.

15. CONCRETE PAVEMENT SURFACING. Concrete pavement surfacing should meet the requirements of FAA Item P-501. The minimum concrete surfacing thickness is 6 inches (152 mm).

16. STABILIZED SUBBASE COURSE. Bound materials are required for subbase for rigid pavements serving these aircraft. Acceptable bound materials are: P-304, P-306, P-401, variable stabilized rigid and variable stabilized flexible . The minimum thickness of subbase is 4 inches (102 mm). More than one layer of subbase may be used, i.e., P-306 over a layer of P-209. Layering must be done so as not to produce a sandwich (granular layer between two bound layers) section.

17. SUBGRADE. The subgrade is assumed to be infinite in thickness and is characterized by either a modulus or k value. The computer converts k to modulus by using the logarithmic relationship: $\log E = 1.415 + 1.284 \log k$. Subgrade compaction requirements and embankment construction should be in accordance with AC 150/5320-6 and AC 150/5370-10.

18. SEASONAL FROST AND PERMAFROST. As with flexible pavements, seasonal frost and permafrost effects should be considered by applying the techniques in AC 150/5320-6.

19. JOINTING DETAILS. Jointing details for rigid pavements are presented in AC 150/5320-6 Airport Pavement Design and Evaluation. The limitations on jointing of rigid pavements for wide body aircraft also apply to pavements designed to serve the B-777.

OVERLAY DESIGN

20. INTRODUCTION. Layered system design permits a direct design approach for overlays. The other FAA method relies on an empirically based thickness deficiency approach. The layered system design calculates the thickness of overlay required to provide a 20 year life, which satisfies the layered elastic failure criteria for limiting stress or strain. The 20 year life thickness is defined as the design thickness. The design method for overlays of rigid pavement was developed by Dr. R. S. Rollings under an FAA funded research effort, as listed in Appendix 1. Overlay pavements are grouped into 4 different types as follows:

Hot Mix Asphalt Overlay of Existing Flexible Pavement	Concrete Overlay of Existing Flexible Pavement	Hot Mix Asphalt Overlay of Existing Rigid Pavement	Concrete Overlay of Existing Rigid Pavement

21. OVERLAYS OF EXISTING FLEXIBLE PAVEMENTS. The design of an overlay for an existing flexible pavement is essentially the same as designing a new pavement. The existing flexible pavement is characterized by assigning the appropriate thicknesses and moduli of the existing layers. Characterization of the existing pavement layers requires engineering judgment.

a. Hot Mix Overlay Of An Existing Flexible Pavement. A trial thickness of overlay is then selected and the program iterates until a CDF of 1.0 is reached. The overlay thickness required to achieve a CDF of 1.0 is the design thickness.

b. Concrete Overlay Of An Existing Flexible Pavement. The design of a concrete overlay of an existing flexible pavement is essentially the same as designing a new rigid pavement. The existing flexible pavement is characterized by assigning the appropriate thicknesses and moduli of the existing layers. A trial thickness of overlay is then selected and the program iterates until a CDF of 1.0 is reached. The overlay thickness required to achieve a CDF of 1.0 is the design thickness. The design process is relatively simple, however, the characterization of the existing pavement layers requires engineering judgment. The interface between the concrete overlay and the existing flexible surface is assumed to be frictionless.

22. OVERLAYS OF EXISTING RIGID PAVEMENTS. The design of overlays for an existing rigid pavement is complex because deterioration of the underlying pavement as well as deterioration of the overlay must be considered. The condition of the existing rigid pavement prior to overlay is important and is expressed in terms of the structural condition index (SCI). The SCI is derived from the pavement condition index (PCI). The PCI is a numerical rating indicating the operational condition of an airport pavement based on visual survey. The scale ranges from a high of 100 to a low of 0, with 100 representing a pavement in excellent condition. The PCI is measured using ASTM standard test method D 5340, Standard Test Method for Airport Pavement Condition Index Survey. For rigid pavements 15 different types of distress are considered in measuring the PCI. These distress types all reduce the PCI of a pavement depending on their severity and relative effect on performance. Not all distress types are indicative of structural distress. Rollings has identified 6 distress types that are indicative of the structural condition of the pavement. The 6 distress types are listed in Table 1.

TABLE 1. RIGID PAVEMENT DISTRESS TYPES USED TO CALCULATE THE STRUCTURAL CONDITION INDEX, SCI

Corner Break
Longitudinal/Transverse/Diagonal Cracking
Shattered Slab
Shrinkage Cracks[a] (cracking partial width of slab)
Spalling - Joint
Spalling - Corner

[a] Used only to describe a load induced crack that extends only part way across a slab. The SCI does not include conventional shrinkage cracks due to curing problems.

To illustrate, an SCI of 80 is consistent with the current FAA definition of initial failure of a rigid pavement, i.e., 50% of the slabs in the traffic area exhibiting initial structural cracking. The SCI allows a more precise and reproducible rating of a pavement's condition than previous FAA condition factor ratings, C_b and C_r.

a. Hot Mix Asphalt Overlays Of Existing Rigid Pavements. The design process for hot mix overlays of rigid pavements considers two conditions for the existing rigid pavement to be overlaid. The SCI of the existing pavement may be equal to, or less than, 100.

(1). Structural Condition Index Less Than 100. The most likely situation is one in which the existing pavement is exhibiting some structural distress, i.e., the SCI is less than 100. If the SCI is less than 100, the overlay and base pavement deteriorate at a given rate until failure is reached. An overlay thickness is assumed and the program iterates on the thickness of overlay until a 20 year life is predicted. A 20 year predicted life satisfies the design.

(2). Structural Condition Index Equal to 100. An existing pavement with an SCI of 100 may require an overlay to strengthen the pavement in order to accept heavier aircraft. If the SCI of the base pavement is equal to 100, an additional input is required (CDFU -

cumulative damage factor used) which estimates the amount of pavement life used up prior to overlay. The program assumes the base pavement will deteriorate at one rate while the SCI is equal to 100 and at a different rate after the SCI drops below 100. As before, a trial overlay thickness is input and the program iterates on that thickness until a 20 year life is predicted. The design thickness is that which provides a 20 year predicted life.

b. Concrete Overlays Of Existing Concrete Pavements. The design of a concrete overlay of an existing rigid pavement is the most complex type of overlay to be designed. Deterioration of the concrete overlay and existing rigid pavement must be considered as well as the degree of bond between the overlay and existing pavement. Two degrees of bond are considered and addressed separately.

(1). Fully Unbonded Concrete Overlay. An unbonded concrete overlay of an existing rigid pavement is one in which purposeful steps are taken to eliminate bonding between the overlay and existing pavement. Commonly the bond is broken by applying a thin, nominal 1½ inch thick, hot mix layer to the existing rigid pavement. For this case the interface friction coefficient between the overlay and existing pavement is set to reflect an unbonded condition. The interface coefficient is fixed and cannot be changed by the user. As with hot mix asphalt overlays, an SCI is required to describe the condition of the existing pavement. A trial overlay thickness is input and the program iterates until a 20 year service life is predicted. The thickness which yields a 20 year service life is the design thickness.

(2). Partially Bonded Concrete Overlay. A partially bonded overlay is one in which no particular effort is made to either eliminate or achieve bond between the concrete overlay and the existing rigid pavement. They are normally appropriate for existing rigid pavements which are in good condition, i.e., when the SCI is 77 or greater. For this case the interface coefficient is set to reflect a small degree of friction between the overlay and base pavement. This coefficient is fixed and cannot be changed by the user. An SCI for the existing pavement is required. A trial overlay thickness is input and the program iterates until a 20 year service life is predicted. The thickness which yields a 20 year service life is the design thickness.

APPENDIX 2. USERS MANUAL

This appendix contains the users manual for LEDFAA. It provides detailed information on proper execution of the computer program LEDFAA v1.2. Note that this design method is considered to be an FAA standard only if a mixture of traffic is considered and the Boeing 777 airplane is a part of that mixture.

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APPENDIX 1. RELATED READING MATERIAL

1. The latest issuance of the following free publications may be obtained from the Department of Transportation Utilization and Storage Section, M-443.2, Washington, D.C. 20591. Advisory Circular 00-2, updated triannually, contains the listing of all current issuances of these circulars and changes thereto.

a. AC 00-2, Federal Register, Advisory Circular Checklist and Status of Federal Aviation Regulations.

2. The following advisory circulars which can be found in AC 00-2 may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Use the Superintendent of Documents stock number when ordering, along with the AC number and title. Send a check or money order in the amount listed for each document. No c.o.d. orders are accepted.

a. AC 150/5335-5, Standardized Method of Reporting Airport Pavement Strength PCN, dated June 15, 1983 and Change 1, dated March 6, 1987.

b. AC 150/5370-10A, Standards for Specifying Construction of Airports, dated February 17, 1989

c. AC 150/5320-6C, Airport Pavement Design and Evaluation, dated December 7, 1978.

3. Copies of the following reports may be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

a. DOT/FAA/RD-74/199, Development of a Structural Design Procedure for Flexible Airport Pavements, November 1974.

b. DOT/FAA/RD-77/81, Development of a Structural Design Procedure for Rigid Airport Pavements, April 1979.

c. DOT/FAA/PM-87/19, Design of Overlays for Rigid Airport Pavements, April 1988.

4. Copies of ASTM standards may be obtained from the American Society of Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.