

CHAPTER THREE

CHAPTER THREE

DESIGN METHODOLOGY

3.1 Introduction

The design of an airfield pavement requires realistic methods of assessing the loading characteristics of aircraft and the structural response of the pavement. It has long been recognized that the severity of load-induced stresses in a pavement and the sub-grade depends on the gross weights of the aircraft using the pavement and the configuration spacing and tire pressures of their undercarriage wheels. The response of the pavement in resisting these stresses depends on its thickness, composition, the properties of materials used in its construction and the strength of the sub-grade on which the pavement is built.

An airfield pavement must be able to support loads imposed by aircraft without excessive distortion or failure. It should be smooth, firm, stable, and free from dust or other particles that might be blown or pushed up by propeller wash or jet blast. It must be usable in all seasons and in all weather conditions. The ability for a pavement to perform these functions for given aircraft traffic depends on the foundation or sub-grade, the quality of construction materials and workmanship, the design or proportioning of the materials in the pavement mix, and the thickness of the layers of the pavement system.

3.2 Geometric Design:

In view of the vital function of runways in providing for safe and efficient aircraft landings and take-offs, it is imperative that their design take into account the operational and physical characteristics of the aero planes expected to use the runway, as well as engineering and economic considerations. The aerodrome elements associated with runways which are directly related to the landing and take-off of aero planes are: runway strips, runway shoulders, stop ways, clearways and runway end safety areas. This manual concerns the provision of runways and these associated elements and summarizes specifications and guidance material relating to their geometric design.

3.2.1 Definition of terms:

- **Aerodrome:** a defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft.

- **Aerodrome elevation:** The elevation of the highest point of the landing area.
- **Clearway:** A defined rectangular area on the ground or water under the control of the appropriate authority selected or prepared as a suitable area over which an aero plane may make a portion of its initial climb to a specified height.
- **Displaced threshold:** A threshold not located at the extremity of a runway.
- **Landing area:** That part of a movement area intended for the landing or take-off of aircraft
- **Maneuvering area:** That part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, excluding aprons.
- **Movement area:** That part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, consisting of the maneuvering area and the apron.
- **Runway:** Defined rectangular areas on a land aerodrome prepared for the landing and take-off of aircraft.
- **Shoulder:** An area adjacent to the edge of a pavement so prepared as to provide a transition between the pavement and the adjacent surface.

3.2.2 Runway Configurations

The term “runway configuration” refers to the number and relative orientations of one or more runways on an airfield. Many runway configurations exist. Most configurations are combinations of several basic configurations. The basic configurations are:

- (1) single runways
- (2) Parallel runways,
- (3) intersecting runways
- (4) open-V runways

1. Single Runway

This is the simplest of the runway configurations and is shown in Fig. 3-1. It has been estimated that the hourly capacity of a single runway in VFR conditions is somewhere between 50 and 100 operations per hour, while in IFR conditions this capacity is reduced to 50 to 70 operations per hour , depending on the composition of the aircraft mix and navigational aids available

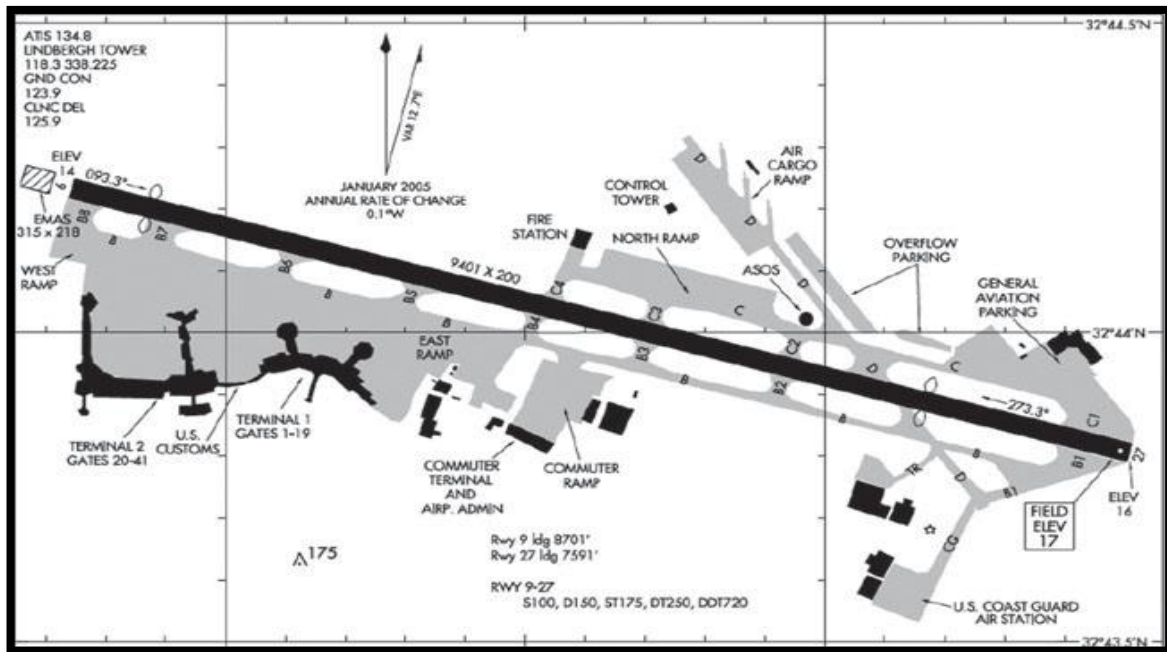


Figure (3-1): Single runway configuration

2. Parallel Runways

The capacities of parallel runway systems depend on the number of runways and on the spacing between the runways. Two, three, and four parallel runways are common. The spacing between parallel runways varies widely. For the purpose of this discussion, the spacing is classified as close, intermediate, and far, depending on the centerline separation between two parallel runways. Close parallel runways are spaced from a minimum of 700 ft (for air carrier airports) to less than 2500 ft. In IFR conditions an operation of one runway is dependent on the operation of other runway. Intermediate parallel runways are spaced between 2500 ft to less than 4300 ft . In IFR conditions an arrival on one runway is independent of a departure on the other runway. Far parallel runways are spaced at least 4300 ft. In IFR conditions the two runways can be operated independently for both arrivals and departures. Therefore, figure 3-2

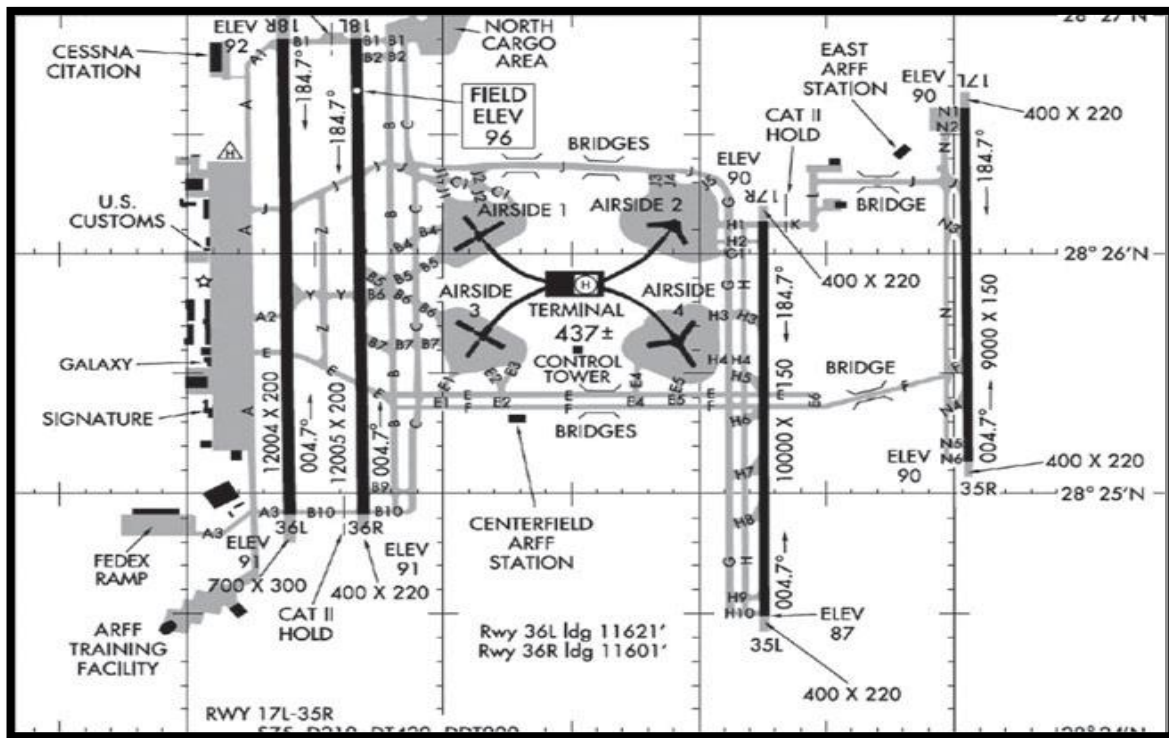


Figure (3-2): parallel runway configuration

3. Intersecting Runways

Many airports have two or more runways in different directions crossing each other. These are referred to as intersecting runways. Intersecting runways are necessary when relatively strong winds occur from more than one direction, resulting in excessive crosswinds when only one runway is provided. When the winds are strong, only one runway of a pair of intersecting runways can be used, reducing the capacity of the airfield substantially. If the winds are relatively light, both runways can be used simultaneously. The capacity of two intersecting runways depends on the location of the intersection (i.e., midway or near the ends), the manner in which the runways are operated for takeoffs and landings, referred to as the runway use strategy, and the aircraft mix. The farther the intersection is from the takeoff end of the runway and the landing threshold, the lower is the capacity. The highest capacity is achieved when the intersection is close to the takeoff and landing threshold. Figure 3-3 provides an example of intersecting runways with the intersection closer to the runway thresholds.

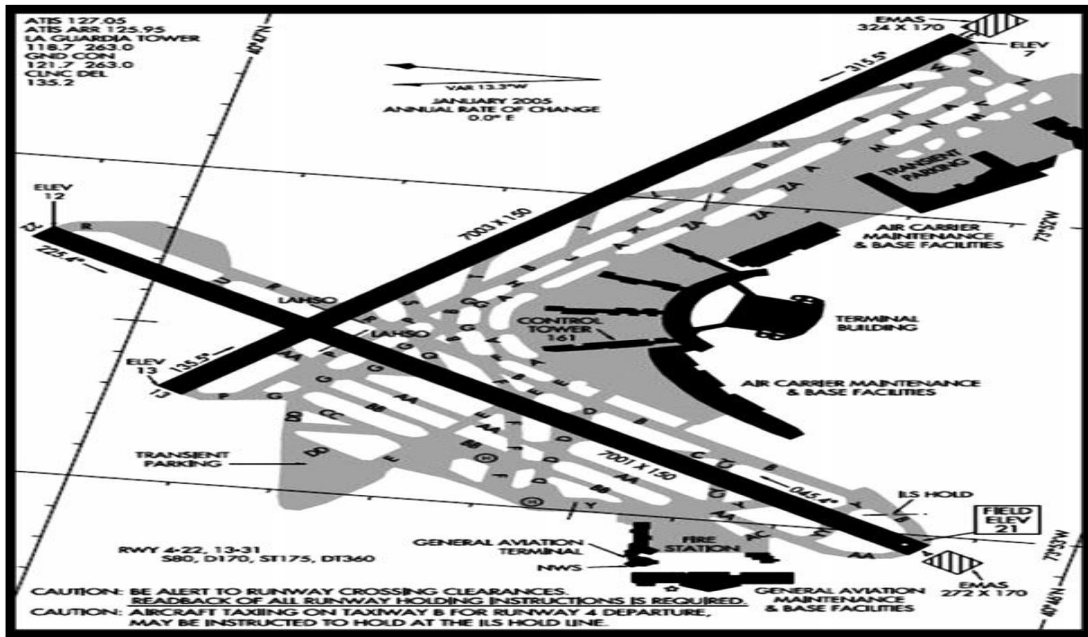


Figure (3-3): intersecting runways configuration

4. Open-V Runways

Runways in different directions which do not intersect are referred to as open-V runways. This configuration is shown in Fig. 3-4. Like intersecting runways, open-V runways revert to a single runway when winds are strong from one direction. When the winds are light, both runways may be used simultaneously the strategy which yields the highest capacity is when operations are away from the V and this is referred to as a diverging pattern. In VFR the hourly capacity for this strategy ranges from 60 to 180 operations per hour, and in IFR the corresponding capacity is from 50 to 80 operations per hour. When operations are toward the V it is referred to as a converging pattern and the capacity is reduced to 50 to 100 operations per hour in VFR and to between 50 and 60 operations per hour in IFR

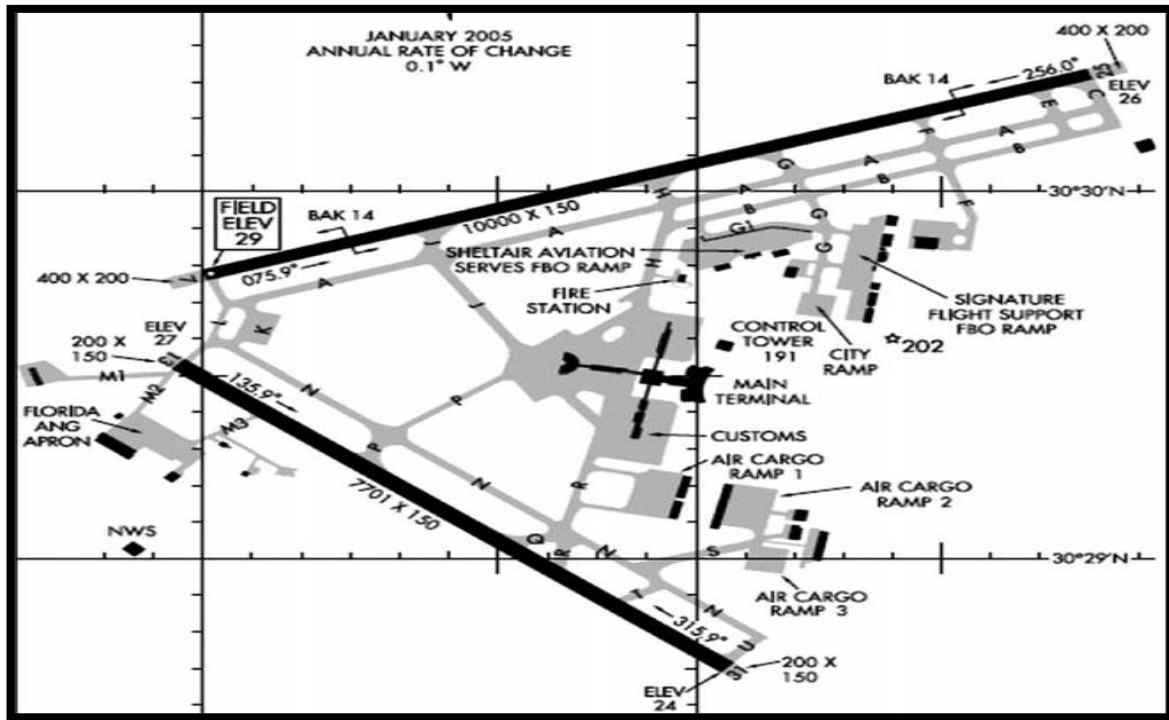


Figure (3-4): open-V runways configuration

3.2.3 Runway Length

Selecting a design runway length is one of the most important decisions an airport designer makes. To a large degree, the runway length determines the size and cost of the airport, and controls the type of aircraft it will serve. Furthermore, it may limit the payload of the critical aircraft and the length of journey it can fly. The runway must be long enough to allow safe landings and takeoffs by current equipment and by future aircraft expected to use the airport. It must accommodate differences in pilot skill and a variety of aircraft types and operational requirements. The following factors most strongly influence required runway lengths:

1. Performance characteristics of aircraft using the airport
2. Landing and takeoff gross weights of the aircraft.
3. Elevation of the airport.
4. Average maximum air temperature at the airport.
5. Runway gradient.

A. Factors Affecting on the Length of Runways

Factors which have a bearing on the runway length to be provided are:

- Performance characteristics and operating masses of the aero planes to be served.
- Weather, particularly surface wind and temperature.
- Runway characteristics such as slope and surface condition.
- Aerodrome location factors. And aerodrome elevation.

B. ICAO procedure runway length corrections for elevation,

Temperature and slope:

- Runway length corrected for elevation:

$$\left(\text{Length} * 0.07 * \frac{\text{Elevation}}{300} \right) + \text{Length}$$

- Runway length corrected for elevation and temperature:

$$\left(\left\{ \begin{array}{l} \text{Length corrected for elevation} \\ * (\text{temp}^{\circ}\text{C} - \text{temp at standard atmosphere}^{\circ}\text{C}) * 0.01 \end{array} \right\} \right. \\ \left. + \text{Length corrected for elevation} \right)$$

- Runway length corrected for elevation, temperature and slope:

$$\left(\text{length corrected for elevation and temp} * \text{slope} * 0.10 \right) \\ + \text{length corrected for elevation and temp}$$

3.2.4 Runway Width

The factors affecting the width of runways are:

- Deviation of an aero plane from the centre line at touchdown;
- Cross-wind condition
- Runway surface contamination (e.g. rain, snow, slush or ice);
- Rubber deposits
- Crab landing approaches used in cross-wind conditions;
- Approach speeds used;
- Visibility
- Human Factors.

The runway widths shown in Table 3-1 are the minimum widths considered necessary to ensure safety of operations

Table (3-1): Runway widths

Code Number	Code Letter					
	A	B	C	D	E	F
1 ^a	18 m	18 m	23 m	-	-	-
2 ^a	23 m	23 m	30 m	-	-	-
3	30 m	30 m	30 m	45 m	-	-
4	-	-	45 m	45 m	45 m	60 m

a. The width of a precision approach runway should be not less than 30 m where the code number is 1 or 2.

3.2.5 Orientation:

The orientation of a runway is defined by the direction, relative to magnetic north, of the operations performed by aircraft on the runway.

Typically, but not always, runways are oriented in such a manner that they may be used in either direction. It is less preferred to orient a runway in such a way that operating in one direction is precluded, normally due to nearby obstacles.

In addition to obstacle clearance considerations, which will be discussed later in this chapter, runways are typically oriented based on the area's wind conditions. As such, an analysis of wind is essential for planning runways. As a general rule, the primary runway at an airport should be oriented as closely as practicable in the direction of the prevailing winds. When landing and taking off, aircraft are able to maneuver on a runway as long as the wind component at right angles to the direction of travel, the crosswind component, is not excessive.

The FAA recommends that runways should be oriented so that aircraft may be landed at least 95 percent of the time with allowable crosswind components not exceeding specified limits based upon the airport reference code associated with the critical aircraft that has the shortest wingspan or slowest approach speed.

When the wind coverage is less than 95 percent a crosswind runway is recommended.

ICAO also specifies that runways should be oriented so that aircraft may be landed at least 95 percent of the time with crosswind components of 23 mph for runway lengths of 1500 m more, 15 mi/h for runway lengths between 1200 and 1500 m, and 11.5 mi/h for runway lengths less than 1200 m [1, 2].

Once the maximum permissible crosswind component is selected, the most desirable direction of runways for wind coverage can be determined by examination of the average wind characteristics at the airport under the following conditions:

1. The entire wind coverage regardless of visibility or cloud ceiling
2. Wind conditions when the ceiling is at least 1000 ft and the visibility is at least 3 mi
3. Wind conditions when ceiling is between 200 and 1000 ft

The first condition represents the entire range of visibility, from excellent to very poor, and is termed the all weather condition. The next condition represents the range of good visibility conditions not requiring the use of instruments for landing, termed visual meteorological condition (VMC). The last condition represents various degrees of poor visibility requiring the use of instruments for landing, termed instrument meteorological conditions (IMC).

The 95 percent criterion suggested by the FAA and ICAO is applicable to all conditions of weather; nevertheless it is still useful to examine the data in parts whenever this is possible.

In the United States, weather records can be obtained from the

Environmental Data and Information Service of the National Climatic

Center at the National Oceanic and Atmospheric Administration located in Asheville, N.C., or from various locations found on the Internet.

Weather data are collected from weather stations throughout the

United States on an hourly basis and recorded for analysis. The data collected include ceiling, visibility, wind speed, wind direction, storms, barometric pressure, the amount and type of liquid and frozen precipitation, temperature, and relative humidity. A report illustrating the tabulation and representation of some of the data of use in airport studies was prepared for the FAA [15]. The weather records contain the percentage of time certain combinations of ceiling and visibility occur (e.g., ceiling, 500 to 900 ft; visibility, 3 to 6 mi), and the percentage of time winds of specified velocity ranges occur from different directions (e.g., from NNE, 4 to 7 mi/h). The directions are referenced to true north.

The Wind Rose

The appropriate orientation of the runway or runways at an airport can be determined through graphical vector analysis using a wind rose. A standard wind rose consists of a series of concentric circles cut by radial lines using polar coordinate graph paper. The radial lines are drawn to the scale of the wind magnitude such that the area between each pair of successive lines is centered on the wind direction.

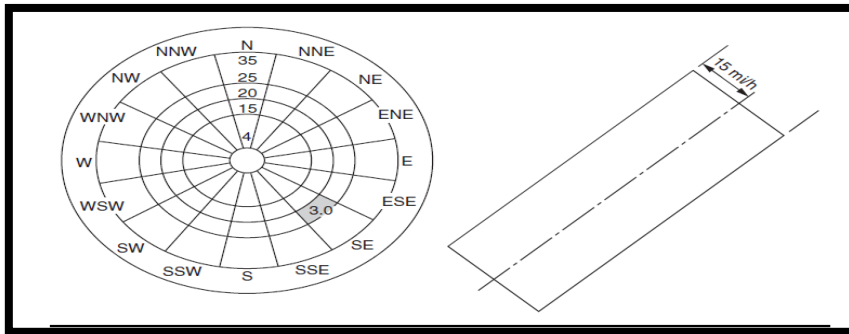


Figure (3-5): Wind Rose coordinate system and template

3.3 Structural Design:

Pavements are designed and constructed to provide durable all-weather traveling surfaces for safe and speedy movement of aircraft with an acceptable level of comfort to users. These functional requirements of pavements are achieved through careful considerations in the following aspects during the design and construction phases:

- Selection of pavement type.
- Selection of materials to be used for various pavement layers and treatment of sub-grade soils.
- Structural thickness design for pavement layers.
- Subsurface drainage design for the pavement system.
- Surface drainage and geometric design.
- Rid ability of pavement surface.

The two major considerations in the structural design of highway and airport pavements are material design and thickness design. Material design deals with the selection of suitable materials for various pavement layers and mix design of bituminous materials (for flexible pavement) or Portland cement concrete (for rigid pavements).

Where Thickness design Refers to the procedure of determining the required thickness for each Pavement layer to provide a structurally sound pavement structure with satisfactory performance for the design traffic over the selected design life.

3.3.1 Flexible Pavement Design Methods for Airports

There are many methods for airport flexible pavement.

1. The Asphalt Institute Design Method

The asphalt Institute published its airfield pavement design manual (MS-11) in 1973 along with an allied “computer program solution” manual. It is applicable to the design of only full-depth asphalt airfield pavement intended for air carrier (generally greater than 60-kip gross weight) aircraft.

In contrast to most other present airfield pavement’s design methods, the design utilizes the concepts of a mixed traffic analysis rather than the selection of a critical or design aircraft. This procedure is conceptually identical to traffic analysis frequently used in highway design. The standard aircraft used is a 358-kip gross weight DC-8-63F and the relative destructive effects of 22 major aircraft types are given, in figure in the manual.

A full depth pavement as a pavement having asphalt mixtures employed for all courses above the sub-grade or improved.

For airport, flexible pavement design the Asphalt Institute method is adopted:

The design method, similar to the design of full-depth asphalt concrete highway pavement, is based upon multi-layered elastic theory. The procedure employs the concept of limiting strain to prevent permanent deformation in the sub-grade (EC) and repetitive load cracking in the asphaltic concrete (ET).

The method involves the following elements:

- Multilayered stress-strain solutions.
- Materials characterization of the asphalt concrete and subgrade.
- Temperature distribution in the pavement.
- Effects of mixed aircraft traffic.
- Failure criteria (fatigue and deformation).

Design steps

Step (1): Determine the allowable thickness (T_A), for each strain criterion fatigue and deformation from the design sub-grade modulus of elasticity E_s , and mean annual air temperature (MAAT) for the design location.

$$E_s = 1500 * CBR \quad \text{_____} \quad (3-1)$$

Step (2): Determine values of asphalt concrete tensile strain and subgrade vertical strain (f_{ix}) then Determine fatigue value and deformation regression constants (f_{ih}) for each aircraft on traffic mix.

Step (3): Determine the equivalent DC-8-63F strain repetitions by following:

$$N_{ex} = \sum_{j=1}^j p_j \cdot f_{jx} F_{jh} \quad \text{_____} \quad (3-2)$$

Equation (3-2) obtain equivalent DC-8-63F strain repetitions for the fatigue criteria

N_{ex} = Equivalent dc-8 repetitions

P_j = no. of passes

f_{ix} = asphalt concrete tensile strain

F_{ih} = fatigue values

$$N_{ex} = \sum_{j=1}^j 10^c (p_j \cdot f_{ix})^{A1+1} \quad \text{_____} \quad (3-3)$$

In addition, Equation (3-3) obtains equivalent DC-8-63F strain repetitions for the deformation criteria.

N_{ex} = Equivalent DC-8 repetitions.

P_j = no. of passes.

f_{ix} = sub-grade vertical strain.

$A1$ = regression constants.

c = regression constants

Step (4): determine the design thickness based upon the analysis of two separate thickness selection for each criteria .and the design thickness based upon the maximum of these tow values.

2. FAA Rigid and Flexible Iterative Elastic Layered Design

FAARFIELD is a computer program for airport pavement's thickness design. It implements both layered elastic based and three-dimensional finite element-based design procedures developed by the Federal Aviation Administration (FAA) for new and overlay design of flexible and rigid pavements. The thickness design procedures, implemented in the program are the FAA airport pavement's thickness design standards referenced in Advisory Circular (AC) 150/5320-6E.

The core of the program is a structural response module consisting of two programs, LEAF and NIKE3D (version 3.3.2.FAA.1.0).

Design information is entered by means of two graphical screens, one for the structure and one for the traffic. Default values and ranges for the various input parameters have been set so that the designs produced by FAARFIELD are compatible with designs produced by the previous FAA design procedures in AC 150/5320-6D (Chapters 3 and 4) for airplanes up to and including the B747 (i.e., S, D, 2D and 2D/2D2 gears). Designs for new generation airplanes having 3D landing gears, such as the Boeing B777 and Airbus A380 series, were not covered by the previous design procedures. AC 150/5320-6E, in conjunction with FAARFIELD, provides the necessary information for thickness design when 3D and complex airplane gears are included in the airplane mix.

FAARFIELD represents a significant departure from previous FAA standards. Apart from the procedures being implemented, as a computer program instead of as nomographs, the main change in pavement design from the user's perspective is that the "design airplane" concept has been replaced by design for fatigue failure expressed in terms of a "cumulative damage factor" (CDF) using Miner's rule. In addition, the major material property of the pavement layers is now uniformly expressed as an elastic modulus instead of the previous CBR (California Bearing Ratio) for flexible pavements, or k value for rigid pavements. Formulas for transforming CBR and k values to modulus values are provided where appropriate in the documentation. Automatic conversion is provided in the program.

Design steps

Step (1): open program, then create a job by press on "new job"(1) and named the job, from job files list on left side select "samples" then on the right side select section name and pavement type ,press "copy section" (2) .duplicate

section name and pavement type are been selected to the new job by press “dup. section”(3). These steps are showing in figure (3-8).

Step (2): open the job and select section name to be designed (1), select design life (2), set design aircrafts by press “airplane” (3) and add aircraft in traffic mix, select sub-grade CBR (5), design the structure by press “design structure”. (6) When design completes the program will view the design thickness of each layer in pavement .and finally save designed structure by press “save structure” (7). Program enable user to modify designed structure by press “modify structure” (4).

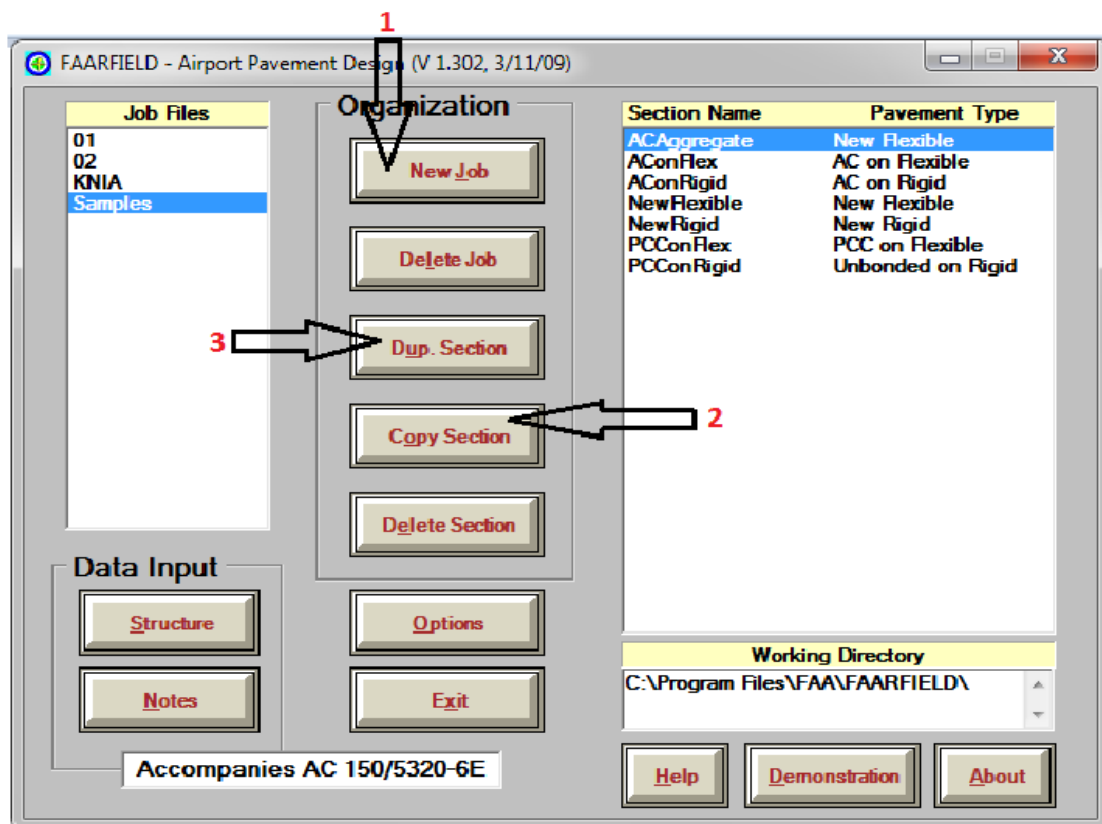


Figure (3-6) steps to create job in FAARFIELD program

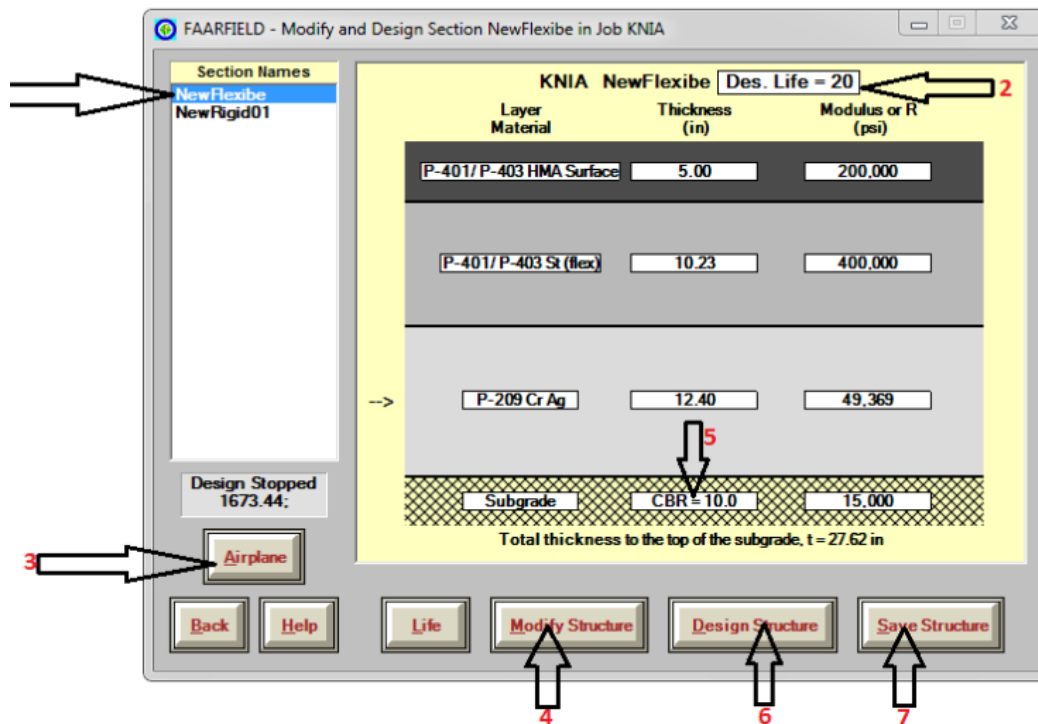


Figure (3-7) steps to design pavement thickness in FAARFIELD program

3.3.2 Rigid Pavement Design Methods for Airports

There are many methods for airport rigid pavement.

1. Portland Cement Association (PCA) method

The Portland Cement Association's (PCA) thickness-design procedure for concrete highways and streets was published in 1984, superseding that published in 1966. The procedure can be applied to JPCP, JRCP, and CRCP. A finite element computer program called JSLAB (Tayabji and Colley, 1986) was employed to compute the critical stresses and deflections, which were then used in conjunction with some design criteria to develop the design tables and charts. The design criteria are based on general pavement design, performance, and research experience, including relationships to performance of pavements in the AASHO Road Test and to studies of pavement faulting.

Design problems can be worked out by hand with tables and charts presented herein or by a microcomputer program available from PCA.

Several major factors are involved in the structural design of Concrete airport pavement:

- Properties of the concrete.
- Supporting strength of the sub-grade or sub-base-sub-grade combination

- Type of aircraft and loads anticipated on the pavement and approximate frequency of operation.
- Type of pavement being designed, such as runway, taxiway, apron, hangar floors.

Determination of slab thickness is made through the following steps:

Step (1): The k value is determined by plate-loading tests or by correlation to sub-grade soil's test data.

Step (2): A careful estimate of future, as well as present, operating and load conditions is made and an appropriate conservative safety factor is selected. Working-stress for a specific aircraft is determined by dividing the modulus of rupture of the concrete by the safety factor chosen.

Step (3): From the design chart for the specific aircraft, determine the pavement thickness for the working stress determined in Step 2. Proceed horizontally from stress to gear load, vertically to k value, then horizontally to thickness.

Step (4): Repeat the process for other aircraft of critical loads, again selecting new, appropriate safety factors for the Level of operations expected for these aircraft, and select a design thickness for the most critical condition.

2. FAA Rigid and Flexible Iterative Elastic Layered Design

To design rigid pavement by FAARFIELD program follow the same procedures and design steps of flexible pavement design by same program, except section name and type have to be changed to “new rigid”. This change is shown in figure(3-10).

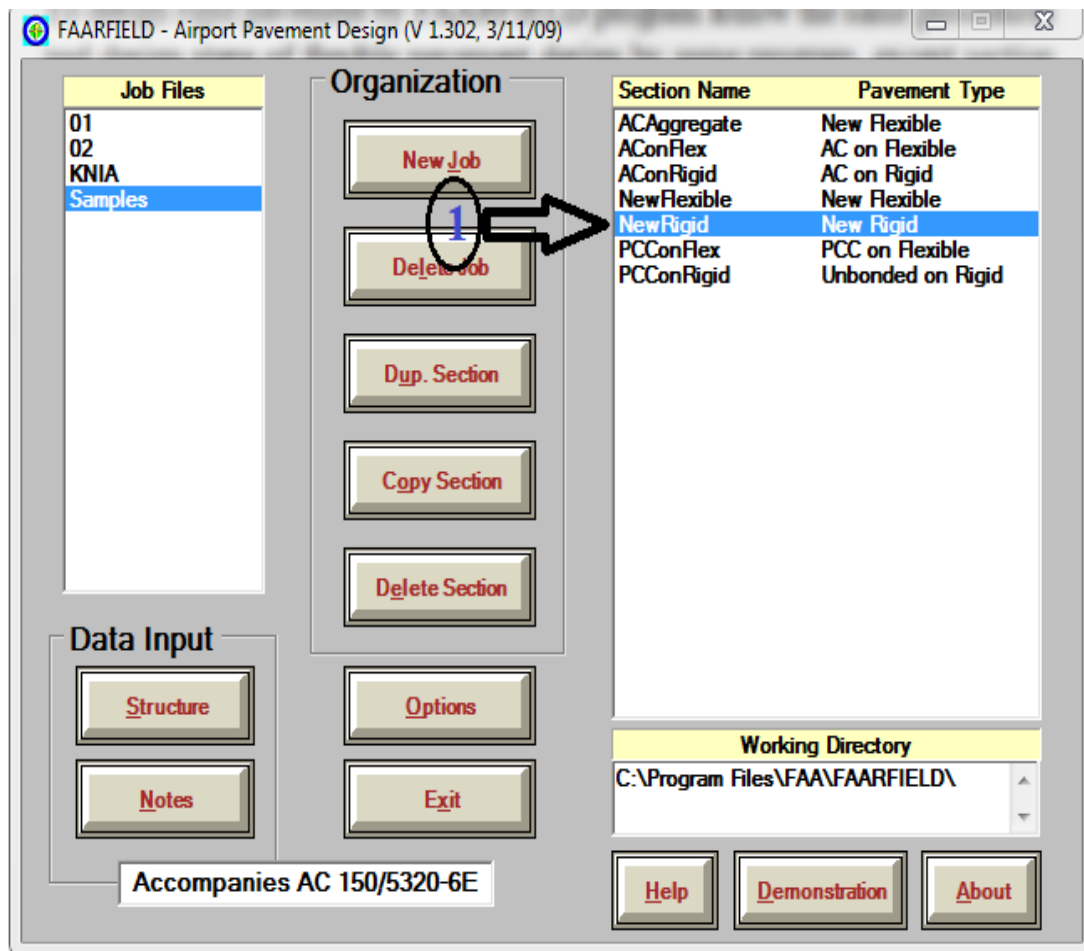


Figure (3-8) steps to create job in FAARFIELD program