Highway and Transportation Engineering Dept.

Airport & Railway Engineering

Third Stage

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Airport Engineering

Syllabus

1) Introduction (General ,Transportation systems, Typical air trip, The air age, World civil air transport, Geographic distribution of world air transport, General aviation, Air ports).

2) Airport Classification (Community size and airport types, Airport classification according to types of services, Functional classification of airports, airport classification for the purpose of stipulating geometric standards).

3) Aircraft Characterizes (Related to airport design characterizes of principle transport aircrafts , Gear configuration, Static weight on main gears and nose gear, Trends size, speed and productivity of transport aircraft, Turning Radii).

4) Airport Planning (Size and type of airport, Selection of site for the airport, Analytical methods for air travel demand for casting).

5) Geometric design (Element of an airport, runway and taxi way width, Runway profile and runway length, Runway orientation).

6) Airport capacity (Ultimate and Practical runway capacity, Runway arrangement factors effecting runway capacity, Practical annual capacity and practical hourly capacity).

7) Airport Drainage System.

8) Airfield Pavements (Highway and airfield Pavements compared , Design of rigid airport pavements , Methods of rigid airport pavement , Junction of flexible and rigid pavements , Application , Design of Flexible airport pavement).

9) Airport Marking and lighting (The need for marking and lighting , Runway marking , Runway designation marking , Runway center marking , Threshold marking, Fixed distance marking , Touchdown zone marking , Runway side strips marking).

References:

1) Yoder , E. J. & Wi czek , M. W. " Principles of Pavement Design " 2nd edition-1975.

2) AASHTO, "AASHTO Guide for Design of Pavement Structures", 1993.

3) Huang, Y.H., "Pavement Analysis and Design", Pren ce Hall, New Jersey, 1993.

4) Horonjeff, R. and Mc-Kelvey , X." Planning and Design of Airports" , 4th edi on ,McGrew Hill, 1994.

5) Ashford, N., and P. H. Wright. 1992. *Airport Engineering*, 3rd ed. New York: John Wiley & Sons.

6) Richard H., "Standard Handbook for Civil Engineers" ,sec on 18, McGrew Hill, 2004

7) *Alexander T. Wells, & Seth B. Young* "Airport planning and Management" 5ed , McGrew Hill, 2004

8) International Civil Aviation Organization (ICAO). International Standards and Recommended Practices, Aerodromes, Annex 14 to the Convention on International Civil Aviation, Volume 1 Aerodrome Design and Operations, 3rd edition, International Civil Aviation Organization, 2004.

Introduction

According to ICAO (International Civil Aviation Organization) define.

Aerodrome (Airport):-

Is a defined area on land or water including any buildings, installations, and equipments intended to be used either wholly or in part for arrival, departure and surface movement of aircrafts.

مساحة معرفة من الأرض أو الماء تتضمن المباني و الأجهزة و المعدات المستخدمة في أو كجزء من عمليات الهبوط أو الإقلاع والحركات الأخرى على سطح المطار.

Aerodrome Reference Point:- نقطة الدلالة (المرجع) للمطار

The designated geographical location of an aerodrome . ألموقع الجغرافي التصميمي للمطار

The aerodrome reference point shall be located near the initial or planned geometric center of the aerodrome and shall normally remain where first establish the position of the aerodrome reference points shall be measured and given to the nearest second latitude and longitude.

نقطة الدلالة (المرجع) للمطار يجب أن تحدد بالقرب من المركز الجغرافي للمطار وهذه النقطة يجب أن تثبت بصورة دقيقة ونهائية وتقاس أوتعطى لأقرب ثانية من خطوط الطول والعرض.

Airport Engineering:-

Involves design and construction of a wide variety of facilities for the landing, takeoff, movement on the ground, and parking of aircraft, maintenance and repair of aircraft, fuel storage, and handling of passengers, baggage, and freight.

<u>Transportation Systems:</u>

التصنيف حسب السطح أو الوسط الناقل:

1) Classification of transportation systems based on surface of transport:

a) Land transportation system (Highway, Railway,…, other)

الأنظمة التي تستخدم الأرض كوسط ناقل

b) Water transportation system (River ways, Cannel ways …others)

الأنظمة التي تستخدم الماء كوسط ناقل

c) Air transportation system (Airways)

الأنظمة التي تستخدم الهواء كوسط ناقل

التصنيف حسب درجة حرية الحركة للمركبات أو واسطة النقل.

2) Classification of transportation system based on Degree of Freedom:

a) Systems with one degree of freedom (Vehicles are free to move only along line– Railways, pipeline)

المركبات المتحركة على امتداد خط (درجة حرية واحدة ليس لليسار أو اليمين) مثل خطوط السكك الحديدية و أنابيب نقل الوقود.

b) Systems with two degree of freedom (Vehicles can move along the line as well as laterally highway)

المركبات تستطيع الحركة متجاورة على خط واحد كما في الطرق.

c) Systems with three degree of freedom (Vehicles are free to move in any plane; vehicles are neither laterally nor vertically restrained (Airplanes, vehicles under water).

المركبات لها حرية الحركة بكل الاتجاهات وتنتقل جانبيا و عموديا (الطائرات و الغواصات).

مميزات كل صنف واستخدامه:-

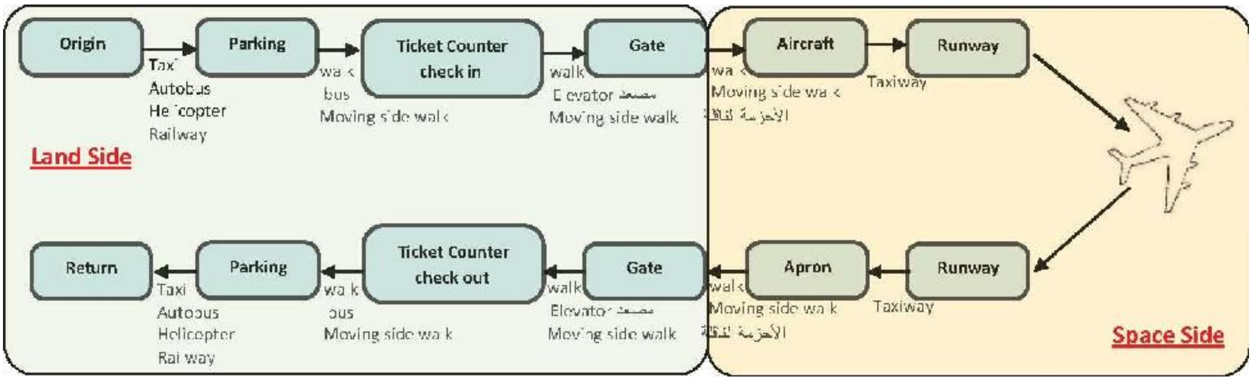
- **Railway;** have their greatest utilization in the transport of large volumes of heavy and commodities over long distance.

  الوسيلة الأكثر أستخداماً لنقل البضائع الثقيلة والكبيرة الحجم لمسافات طويلة
- **Roads ;** door to door service.
- **Airport;** attains maximum utility where saving of time in transport is of at most important rather than the money.

  لها القدرة العالية لأختصار الوقت بغض النظر عن المال
- **Water ways;** provide facilities for transport of heavy and bulk commodities a have time may not be of much importance, this is most economic mode of transport.

تستخدم لنقل البضائع الثقيلة جدا والذي لا يكون الوقت فيها مهماً وهي أكثر اقتصادية (نقل البضائع الكبيرة الحجم والثقيلة لمسافات طويلة جداً وباسعار مناسبة).

A Typical Air Trip:



نلاحظ إن الجزء الأكبر من الرحلة تكون هي الحركة على الأرض .

Revenues:

(العوائد أو الارباح)

الارباح الناتجة من استخدام المطار تقسم الى :-

1) Operating Revenues:

الأرباح او العوائد عندما يعمل المطار

a) Landing Area.

الأرباح الناتجة من السماح بعمليات الأقلاع والهبوط

b) Terminal Area concession.

الأرباح او العوائد الناتجة من تأجير المساحات الغير مخصصة للأقلاع او الهبوط

c) Airline leased Areas.

الأرباح الناتجة من حجز الخطوط

d) Other leased Areas.

الأرباح الناتجة من تأجير او حجز الساحات للبضائع

e) Others Revenues.

2) Non-Operating Revenues (الأرباح او العوائد عندما يكون المطار متوقف عن العمل

1- تاجير الساحات والاراضي الغيرمخصصة للطيران (الفندق ، الكازينو).

2- الأسواق.

Expenditures:

(المصاريف)

1) Operating Expenditures

المصاريف عندما يكون المطار يعمل

a) Maintenances Costs

1) Airport Maintenances

المصاريف الناتجة من كلفة الصيانة للمطار وملحقاته (الطرق، المباني، التأسيسات الصحية والكهربائية).

2) Aircraft Maintenances

المصاريف الناتجة من كلفة صيانة الطائرات

b) Operating Costs

2) (كلفة العمليات الداخلية) نقل الركاب والبضائع والوقود

Non-Operating Expenditures

1- تسديد القروض المترتبة على انشاء المطار.

2- تسديد رسوم عمليات الاقلاع والهبوط لطائرات الشركة في مطارات دول أخرى

Airport Classification

Community Size and Airport Types
حجم السكان وأنواع المطارات

1. **Airport Classification According to Community Size;**

Community Size	Airport Types
Small:- up to 25000 population المدينة الصغيرة التي لا يتجاوز عدد سكانها ٢٥٠٠٠ نسمة.	**Local:-** airports to serve on local service routs providing service in the short haul category normally not exceeding 500 miles. المطارات المحلية -: المطارات التي تخدم خطوط النقل المحلية التي لا تتجاوز ٥٠٠ ميل
Medium:- 25000 – 250000 population المدينة المتوسطة التي يتراوح عدد سكانها بين ٢٥٠٠٠- ٢٥٠٠٠٠ نسمة.	**Trunk:-** airports to serve on airline trunk routs and engage in international to long haul normally not exceeding 1000 miles. المطارات الرئيسية -: المطارات التي تخدم الخطوط الرئيسية وتشمل الخطوط الوطنية (ولمسافة لا تتجاوز ١٠٠٠ ميل).
Large:- over 250000 population المدينة الكبيرة التي يزيد عدد سكانها عن ٢٥٠٠٠٠ نسمة.	**Continental :-** airports serving long non-stop flights, these airports serve non-stop flights up to 2000 mile. المطارات القارية -: المطارات التي تخدم الرحلات الطويلة وبدون توقف ولمسافة لا تتجاوز ٢٠٠٠ ميل.
Global Centers:- المراكزالعالمية (London, Paris, …).	**International (Inter Continental):-** airports to serve the longest range, non-stop flights in the transcontinental, trans oceanic & international category's. المطارات الدولية :- المطارات التي تخدم المعدلات العالية من الطيران وبدون توقف(زيادة طول المدرج نتجه لزيادة سرعة الطائرات)

2. Airport Classification According to Type of Services; **التصنيف حسب نوع الخدمة**

a) Airport with scheduled service المطارات ذات الرحلات المجدولة الخدمات وتشمل

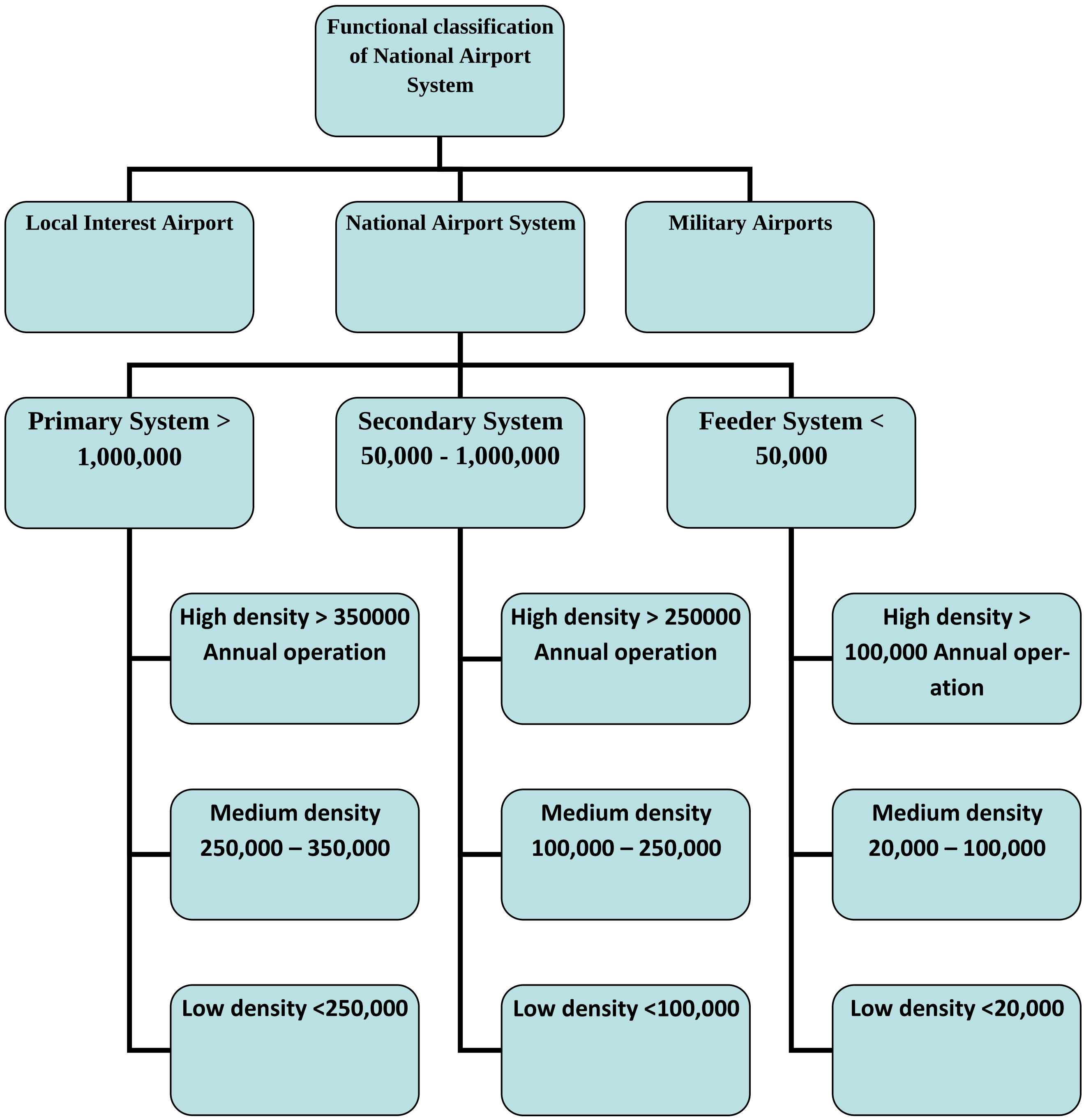
Passenger, Exports, Low cargo, Air mail, Aerial, Taxi-service.

b) Airport with non-scheduled service. المطارات ذات الرحلات الغير مجدولة الخدمات وتشمل
Private & business flying, Air training school, Twist & sport, travel, Aerial photogrammetric, Industrial flight, Helicopter.

c) Airport with mixed service (scheduled and non-scheduled)
المطارات ذات الرحلات المختلطة الخدمات

3. Airport Classification According to Function of Role; التصنيف حسب الوظيفة

a) Local interest airport.
b) National system airport.
c) Military airports.
The national system airport can be divided according to public serve level classified by en-plane according to (Annual Operation).



Functional Classification of Airport according to Annual Operation of Aircrafts

4. Airport Classification for the Purpose of geometric Design standards;

التنصيف حسب متطلبات التصميم القياسية للمطارات.

For the purpose of design standards for the various sizes of airports and function which they service, letter and numerical codes or word used to descriptors have been adopted to classify. The ICAO now used two elements (reference code to classify the geometric design standard for airport). The code elements consist of **(Numerical and Alphabetical).**

1) Numerical, the code number (1, 2, 3, 4) classify the length of the runway available.

2) Alphabetical , the code letter (A, B, C, D, E) classify the wing span and outer main gear wheel span for aircraft for which airport has been design.

تصنف المطارات حسب التصميم الهندسي حيث تستخدم أرقام تشير إلى طول المدرج المتوفر و حروف تشير إلى نوعية الطائرات التي يسمح لها بالهبوط.

Gear span: - is the distance between outside edges of the main wheel gear.

Code Element No.1		Code Element No.2		
Code No.	Reference field length for Runway	Code Letter	Wing Span	Outer Main Gear Span
1	Less than 800 m	A	Up to but not including 15 m	Up to but not including 4.5 m.
2	800 m – up to but not including 1200 m	B	15 m - up to but not including 24 m.	4.5 m - up to but not including 6 m.
3	1200 m – up to but not including 1800 m	C	24 m - up to but not including 36 m.	6 m - up to but not including 9 m.
4	1800 m and over	D	36 m - up to but not including 52 m.	9 m - up to but not including 14 m.
		E	52 m - up to but not including 60 m.	14 m and over

Note: - Baghdad International airport can be classify as (4-E) because the runway length= 4 km and runway width= 60 m

Aircraft Characteristic

Aircraft Characteristics Related to Airport Design:

1- **Characteristics of Principal Transport Aircraft.**

2- **Gear Configuration.**

3- **Static weight on main gears and nose gear.**

4- **Turning Radii.**

1- **Characteristics of Principal Transport Aircraft**

Principle of aircraft characteristic (Size, Weight, Capacity, Necessary runway length)

Size: - (The wing span, face large length, wheel tread, wheel base, Max. length, …..)
Aircraft size has an effect on:
1) Size of parking aprons which in turn influence the configuration of terminal building.
2) Size also dictates width of runways and taxiways as well as distance between these traffic way.
3) Hangers.
Weight: - Weight of aircraft is important for determining the thickness of runway, taxiway and apron pavements.

وزن الطائرة مهم في حساب سمك التبليط للمدرج والطرق وساحة وقوف الطائرات

Capacity: - the passenger capacity has an important bearing on facilitates within and adjacent to the terminal building, aircraft used in airline operations have passenger capacity ranging from 20 to nearly 500.
Runway Length: - influence a large part of the land area required at an airport.

Aircraft	Wingspan	Length	Wheel base	Wheel track	Max. Structural takeoff weight, lb	Max. loading weight ,lb	Operating empty weight , lb	Zero fuel weight, lb	Number and type of engines	Max. payload passenger	Runway length , ft	Manufacture
DC-9-32	93 ' 04 "	119' 04"	53' 02"	16' 05"	108000	99000	56855	87000	2TF	115-127	7500	McDonnel - Douglas
DC-9-50	93' 04"	132' 00"	60' 11"	16' 05"	120000	110000	63328	98000	2TF	130	7100	
B-737-200	93' 00"	100' 00"	37' 04"	17' 02"	100500	98000	59958	85000	2TF	86-125	5600	Boeing
B-727-200	108' 00"	153' 02"	63' 03"	18' 09"	169000	150000	97400	138000	3TF	134-163	8600	Boeing
B-747B	195' 09"	229' 02"	84' 00"	36' 01"	234300	175000	115000	156000	4TF	131-149	6100	Boeing
Concorde	83' 10"	202' 03"	59' 08"	25' 04"	389000	240000	175000	200000	4TJ	108-128	11300	British Aircraft

Runway length at standard conditions (at sea level) [No wind, standard day and level runway)

<u>Note;</u> it is impotent to note that it is not valid to assume that the larger weight of aircraft required larger runway length.

ليس صحيحا بان طول المدرج يزداد بزيادة وزن الطائرة

Types of Aircrafts according to Type of Propulsion and Thrust- Generating Medium:

تصنيف الطائرات على أساس قوة الدفع للأمام(توليد القوة الدافعة)

1-Piston Engine Aircraft= applies to all propeller driver aircraft powered by gasoline reciprocating engine.

الطائرات ذات المحركات التي تدار بالبنزين المحسن

2- Turbo Propeller Aircraft = refers to propeller driven aircraft powered by a turbo in engine.

3- Turbojet Aircraft = refers to those aircrafts which are not dependent on propellers for thrust but which obtain the thrust directly from the turbine engine.

4- Turbofan Aircraft = Turbojet engine with a fan added in the front or rear of it most fans are installed in front of the main engine.

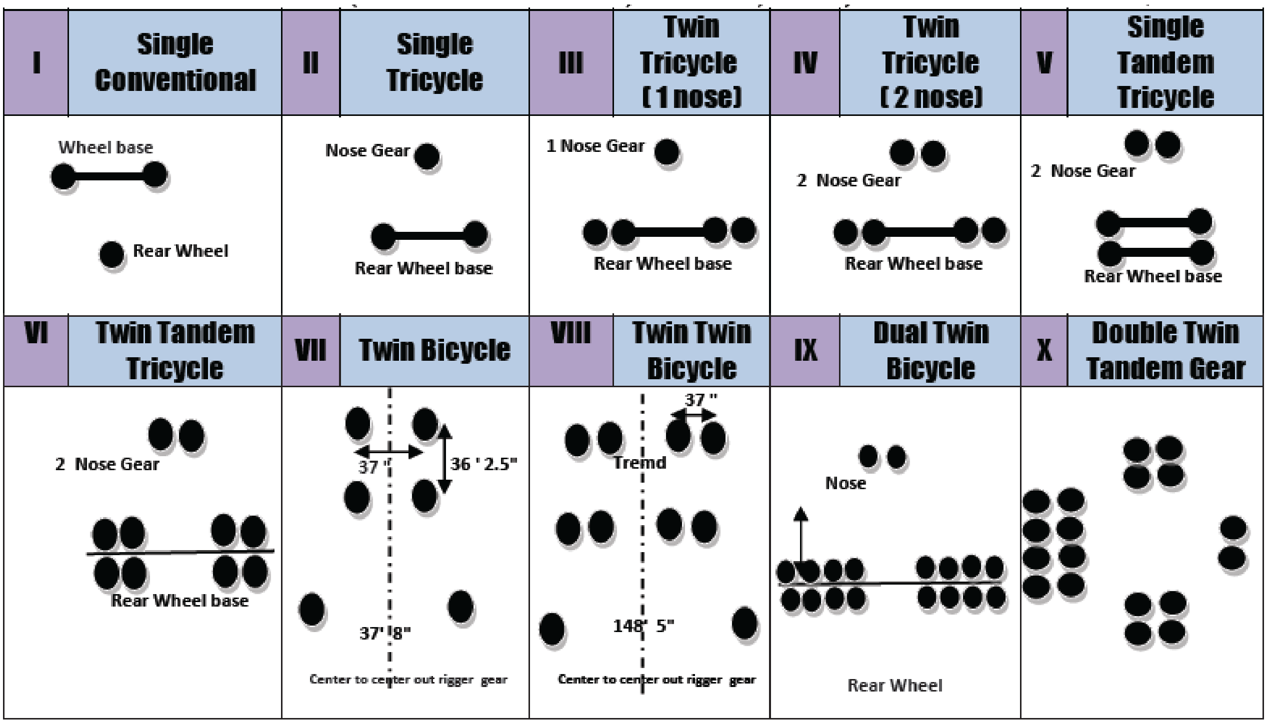
Note: - nearly all airline transport aircrafts are non-powered by turbofan as they are more economical than turbojet.

مقدار الوقود المصروف وتأثيره على وزن الطائرة

Aircraft	Fuel Consumption	
B-727-200	7000 lb/hr	تحتاج إلى ٧٠٠٠ باون بالساعة
B-747-A	21000 lb/hr	تحتاج إلى ٢١٠٠٠ باون بالساعة

2- Loading Gear Configurations

حمل الطائرة ينقل إلى التبليط من خلال سلسلة من الإطارات(تشكيلة هذه الإطارات تكون بالأشكال التالية):



Data for several Aircraft types according to Yoder ;

Type of plane	Max. gross weight (kips)	Type of gear	Main gear n dimension	Max. load on each main assembly	Tire pressure psi
Boeing 747-320L	336	Twin tandem	56 w*34.5 L	157	180
Boeing 747	713	Double Twin tandem	58 w*44 L	166.5	204

3-Static Weight Main Gears and Nose Gear:-

مركز ثقل الطائرة متغير اعتمادا على عدد الركاب وتغير موقعهم في الطائرة

The distribution of the load between the main gears and the nose gear depends on the type of aircraft and the location of the center of gravity of the aircraft for design of pavement it's normally assumed that

1- 5% of the weight supported on the nose gear and 95 % on the main gears for the tri-cycle configuration.
2- 50% of the weight supported on the nose gear as well as for the main gear for the bicycle configurations.

Example:-

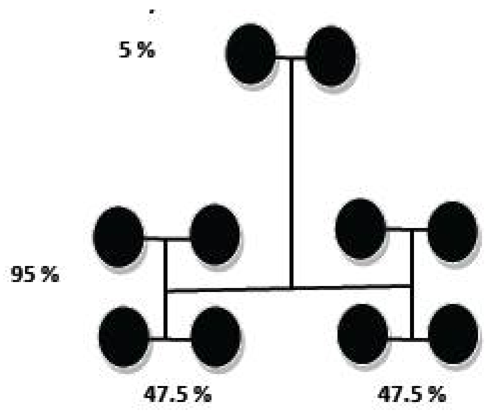
Take-off weight of an aircraft =300 kips (Twin Tandem Tricycle)

Solution:

· Each main gear support = 0.475 *300=142.5 kips

· Load on each tire of the main assembly =142.5/4=35.625 kips

· Kips= 1000 lb



4-Turning Radii:-

1-For determining aircraft positions on the apron adjacent the terminal building and establishing the paths of aircraft at other locations on the airport , it is important to understand the geometry of movement of an aircraft.

لتحديد موقع الطائرة في الساحة المجاورة للمباني وتثبيت مسارات الطائرات الاخرى بالمطار من الضروري فهم هندسة الحركة للطائرة.

2- Turing Radii; are a function of the nose-gear steering angle (the larger angle , the great are the radii) from the center of rotation the distances to the various parts of the aircraft such as the wing- lips . the nose gear or the tail result than number of radii.

نصف قطر الدوران بعتمد على زاوية الاستدارة لأنف الطائرة (كلما تزداد الزاوية يزدد نصف القطر) فالمسافة بين مركز الدوران واجزاء الطائرة تكون متغيرة (حافة الجناح او أنف الطائرة او نهاية ذيل الطائرة) فنحصل على عدة انصاف اقطار.

3- The largest radius is the most critical from the standpoint of clearance to building or adjacent aircraft. The min. turning radius corresponds to the max. nose-gear steering angle specified by the aircraft manufacture.

نأخذ اكبر نصف قطر وهو سوف يكون الاحرج (المساحة الصافية للمباني والطائرات المتجاورة) اقل نصف قطر للاستدارة يكون بالزاوية الذي تحدد من قبل الجهة المصنعة للطائرة Max. Steering. استدارة

4- The max. angle varying from $(60 – 80^{o})$

5- Determine center of rotation by drawing a line through the axis of the nose gear at whatever steering angle is desired .The intersection of this line with a line drown through the axis of 2 main gear (when more the 2 main gear (B-747), the axis is drown midway between the gears.

Note:-

Min. turning radii are not used in practice very often because the maneuver produces excessive tire wear and in some instances results in scuffing of the pavement surface. (Accordingly lesser angles on the order of 50^{o} are more proper).

بصورة عامة نستخدم زاوية لا تقل عن ٥٠ درجة ، ان استخدام نصف قطر استدارة اقل منه يسبب

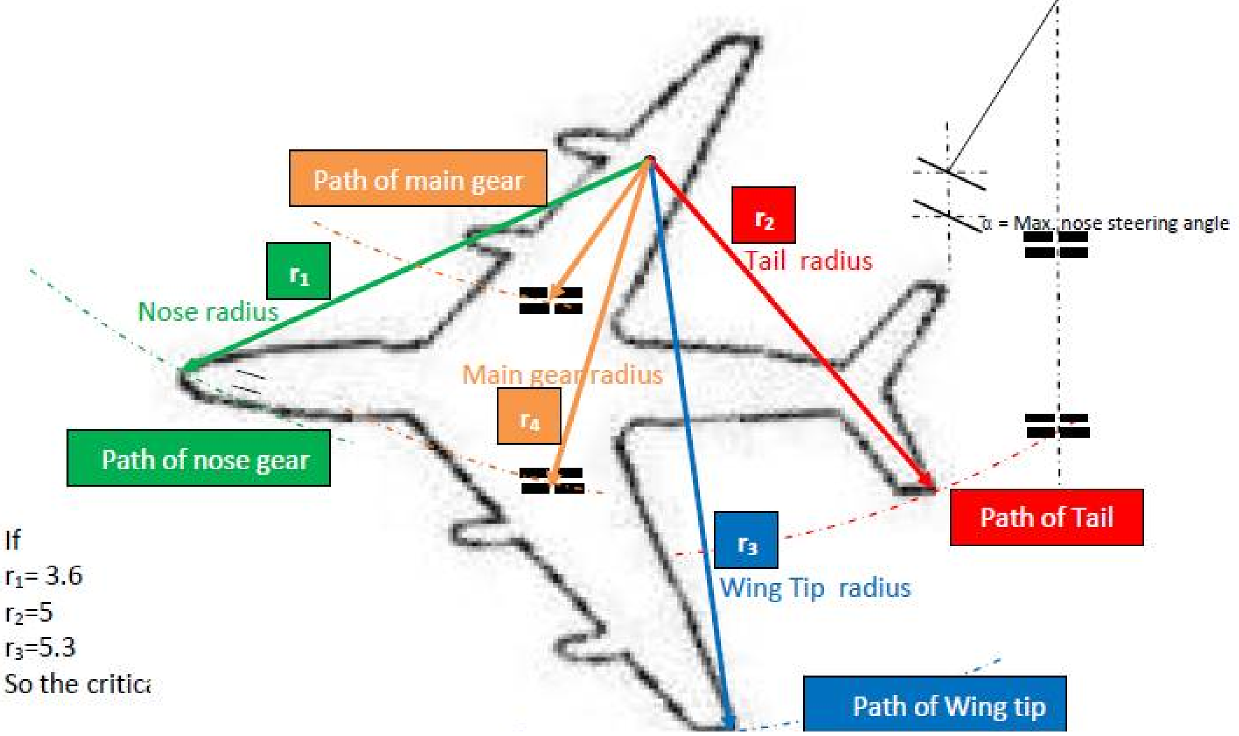
١- تلف الاطارات.

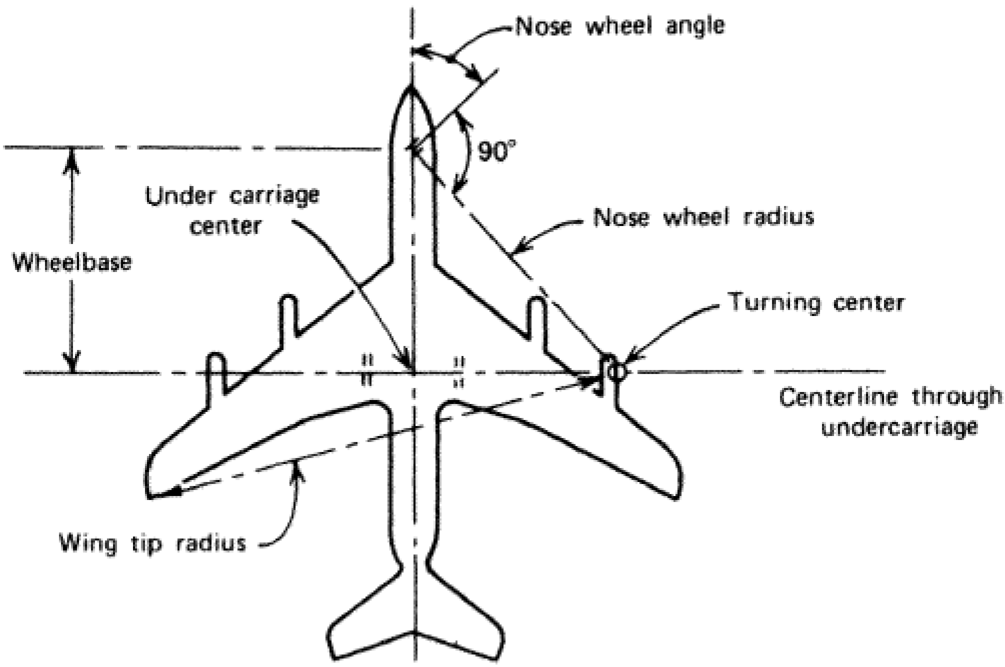
٢- تلف سطح التبليط.

تحديد موقع مركز الدوران-:

1- ميل اطارات أنف الطائرة بزاوية المقود (steering) المطلوبة بحيث لاتتجاوز زواية الاستدارة العظمى الموضوعة من قبل المصمم والتي تعطي اقل نصف قطر او استخدام زاوية اقل من ٥٠ درجة
2- نرسم خط عمودي على محور أنف الطائرة nose المائل بالزاوية المطلوبة ويتقاطع مع محورmain gear في نقطة تمثل المركز.
3- نوصل بين هذة النقطة وابعد النقاط الموجودة بالطائرة (حافة الجناح ، حافة الذيل ، حافة انف الطائرة).

4- نأخذ اكبر نصف قطر منها.





Horizontal Distribution Concepts for Passengers (Parking Apron):

1-Linear Distribution

2-Pier Distribution

3-Stellite Distribution

4-Transporter Distribution

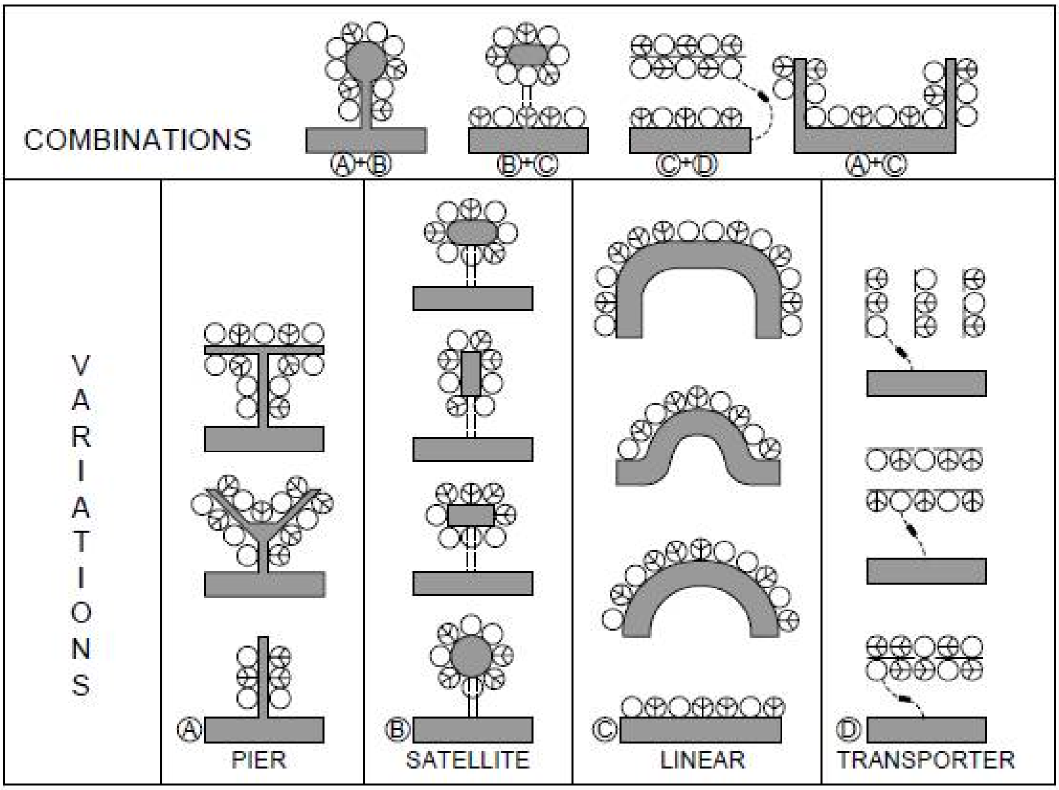


FIGURE 59.16 Terminal configurations. (From FAA, *Planning and Design Guidelines for Airport Terminal Facilities,* Advisory Circular AC150/5360-13, 1988b.)

Airport Planning ***Size and Type of Airport***

Airport planning: may be defined as the employment of an organized strategy for the future management of airport operations, facilities designs, airfield configurations, financial allocations and revenues, environmental impacts, and organizational structures.

هناك أنواع مختلفة من دراسات تخطيط المطار وقد يعرّف تخطيط المطار كتوظيف لإستراتيجية منظّمة لتنظيم وإدارة عمليات المطار المستقبلية، تصاميم الخدمات، ترتيبات جانب الطيران في المطار، التخصيصات والعائدات المالية، التأثيرات البيئية، المنشئات والهياكل التنظيمية.

There are various types of airport planning studies, including:

هنالك انواع مختلفة من دراسات تخطيط المطار وتتضمن:

•**Facilities Planning**.

التخطيط الخدمي: الذي يركّز على الحاجات المستقبلية لبناء جانب الطيران في المطار مثل المدارج ، taxiways، ساحات وقوف وأنتظار الطائرات، الأضاءة ، أنظمة الإتصال الملاحية، المحطات الطرفية، ووسائل الدعم مثل محطات الوقود، محطات الكهرباء، وكذلك أستعمال الأرض الغير مخصصة للطيران كمتنزهات، مكاتب، فنادق، مطاعم، أو مواقع سيارات الأجرة.

• **Financial Planning.**

التخطيط المالي: والذي مهتمّة توقّع العائدات والنفقات المستقبلية، وضع ميزانية المصادر، والتخطيط للمعونة المالية من خلال برامج المنح، او إصدار السندات، أو الإستثمار الخاصّ.

• **Economic Planning**.

التخطيط الإقتصادي: الذي يهتم بمستقبل النشاط الإقتصادي للمطار، مثل التجارة و نشاط الصناعات الذي يكون ضمن او خارج ملكية المطار ويتأثر بشكل مباشر أو غير مباشر نتيجة عمليات المطار.

• **Environmental Planning.**

التخطيط البيئي: الذي يركّز على إبقاء أو تحسين الشروط البيئية الحالية من التغييرات نتيجة نشاط مطار مستقبلاً. يتضمّن التخطيط البيئي تخطيط إستعمال أرض، تخفيف الضوضاء، إستصلاح الأهوار، وحفظ الحياة البريّة.

•**Organizational Planning.**

التخطيط التنظيمي: الذي يستلزم إدارة متطلبات العمل المستقبلية والهياكل التنظيمية لإدارة المطار، كموظّفون، وكادر العمالة المرتبطة، وغيرها.

• **Strategic Planning.**

التخطيط الإستراتيجي: الذي يحول كلّ نشاطات التخطيط الأخرى إلى جهد متكامل لزيادة الإمكانية المستقبلية للمطار لأستيعاب الحجم السكاني المتزايد.

The Airport Master Plan:

Airport master plan is a concept of the ultimate development of an airport. The term development includes the entire airport area, both for aviation and no aviation uses, and use of land adjacent to the airport.

The overall objective of the airport master plan is to provide guidelines for future development which will satisfy aviation demand and be compatible with the environment, community development, and other modes of transportation. The typical airport master plan has a planning horizon of 20 years.

The Federal Aviation Administration notes that for a master plan to be considered valid it must be updated every 20 years or when changes in the airport or surrounding environment occur, or when moderate and major construction may require federal funding.

التخطيط الأساسي للمطار يتضمن كل العناصر التخطيطية اللازمة لإنشاء المطار او المكونات العامة للمطار والذي يحتاجها المصمم لانشاء المطار (تحديد مواقع الابنية ، تحديد مواقع المدارج داخل المطار، تحديد مواقع مساحات الوقوف ، تحديد مسارات وسائط النقل الاخرى) وكذلك تحديد التطورات المستقبلية للمطار ويتم أعداد هذا التخطيط قبل أعداد المخططات الهندسية والإنشائية للمطار وكذلك تحوي كل البدائل الممكنة لتحديد موقع المطار.

Elements of the Master Plan:

An airport master plan typically consists of the following elements:

Phase I

Airport Requirements

يتم في هذة المرحلة تهيئة المتطلبات اللازمة لانشاء المطار

Inventory

في هذة المرحلة يتم اعداد جرد اولي لماموجود في المنطقة التي سوف ينشئ عليها المطار (جرد المواد الاولية ، جرد السكان ، جرد البضائع...)

Forecasting

في هذة المرحلة يتم الاستفادة من الجرد السابق للتنبؤ او توقع اعداد المسافرين او البضائع

Demand – Capacity Analysis

يتم في هذة المرحلة تهيئة المتطلبات اللازمة لانشاء المطار

Facility Requirements Analysis

تحليل المتطلبات الواجب توفيرها خلال فترة الانشاء (الخدمات و مدئ توفر المواد الاولية اللازمة للانشاء)

Environmental Impact

التاثيرات البيئة الناتجة من المطار (تلوث الماء والهواء) على المنطقة التي سوف ينشأ المطار فيها

Phase II

Site Selection

After airport needs have been established the FAA recommends that there are at least ten factors which should be considered when analyzing potential airport sites:

1- Convenience to users: If it is to be successful, an airport must be conveniently located to those who use it.

2- Availability of land &land cost: Vast acreages are required for major airports and it is not uncommon for new airports in large cities to require more than 10000 acres.

3- Design and layout of the airport: In considering alternate potential airport sites, the basic layout and design should essentially be constant.

4- Airspace and obstruction: to meet essential needs for in-flight safety two requirements must be met.

   a- Adjacent airports must be located so that traffic using one in no way interferes with traffic using the other.

   b- Physical objects such as towers, poles, buildings, mountain ranges,……

5- Engineering factors: an airport site should have fairly level topography and be free of mountains, hills, further the terrain should have sufficient that adequate drainage can be provided.

6- Social factor: one of the most difficult social problems associated with airport location is that of noise. Airports are not good neighbor and some control in the development of land surrounding an airport should be exercised.

7- Availability of utilities: airports must depend upon existing utilities. The site should be accessible to water, electrical service, telephones, gas lines, etc. and these utilities should be of the proper type and size.

8- Atmospheric conditions: such as fag, smoke, snow, or glare that may rule out the use of some potential airport site.

9- Hazards due to birds: airport should not be situated near birds on natural preserves and feeding grounds.

10- Coordination with other airports: heavily populated metropolitan areas indicate that more than one major airport will be required to meet future air travel needs.

Phase III

Airport Layout Plans

في هذة المرحلة يبدأ أعداد مخططات تفصيلية في المواقع المختارة لانشاء المطار

Airport Layout Plans	أعداد مخططات تفصيلية في المواقع المختارة لانشاء المطار
Land Use Area Plan	أعداد مخططات تفصيلية لاستخدامات الاراضي داخل المطار (تخصيص الارض داخل المطار ، ارض المدرج ، ارض المساحات ارض المباني)
Terminals Area Plan	أعداد مخططات تفصيلية معمارية و مدنية لابنية المطار
Airport Access Plans	أعداد مخططات تفصيلية لمدخل او مخرج المطار (طريقة ربط المطار مع شبكة النقل داخل المدينة

Phase IV

Financial Plan

في هذة المرحلة يتم تحديد الخطة التمويليه لانشاء المطار في المواقع المختارة

Development and Cut	أعداد خطة تفصيلية في بحجم ومراحل التتطورات وكلفتها
Economic Feasibility	دراسة الجدوى الاقتصادية للبدائل
Financing	من هو المسؤول عن تمويل انشاء المطار

The airport system: it is divided into two major components (air side and land side) as shown in the figure below.

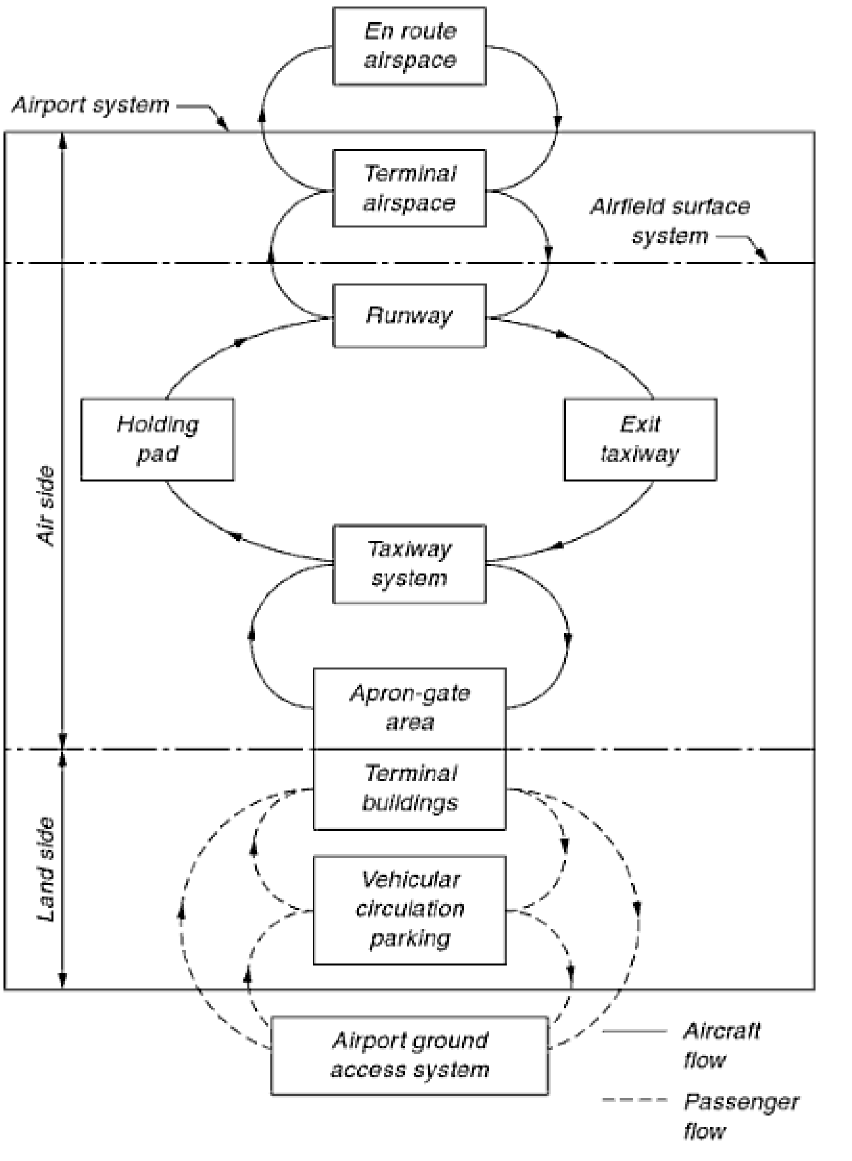
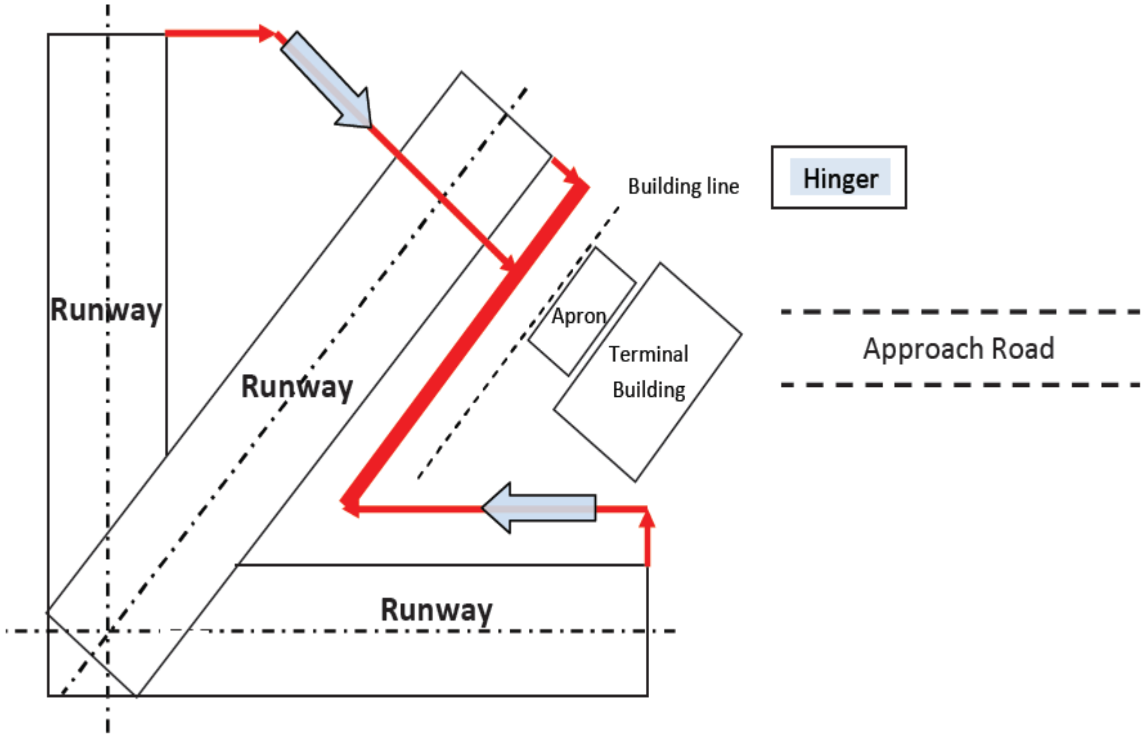


FIGURE 4-1 Components of the airport system for a large airport.

Geometric Design

Airport Components:



A typical airport, there are terminal buildings and hangars; pavements for aircraft runways, taxiways, and aprons; roads, bridges, and tunnels for automobiles and walks for pedestrians; automobile parking areas; drainage structures; and underground storage tanks. Aircraft include airplanes, helicopters, and the anticipated tilt rotor aircraft.

Airport engineers have the responsibility of determining the size and arrangement of these facilities for safe, efficient, low-cost functioning of an airport.

Elements of an Airport;

Runway:- Area for landing and takeoff operations.

المساحة اللازمة لعمليات الاقلاع والهبوط (عملية الاقلاع والهبوط تكون عكس اتجاة الرياح وبما ان الرياح متغيرة الاتجاه بصورة مستمرة لذلك نستخدم عدد اكبر من المدارج وبكافة الاتجاهات لاستخدامها حسب اتجاه الرياح).

Taxiway:- Connection between apron and runway.

حلقة الوصل بين المدرج وساحة الوقوف.

Apron:- Planes parking are next to the building s line in which loading takes place.

مساحات وقوف الطائرات قرب خط المباني لتستخدم لتحميل البضائع.

Hanger: Building for storage of airplanes al so maintenance ; hangers for repair and servicing of longer planes will usually be built for a specific air line according to its specification and most major repairs will be done at a planes home base.

مباني لحفظ الطائرات و الصيانة او التصليح و تجهيز الخدمات للرحلات الطويلة.

Terminal Building Consists of an administration facility and passenger services building. (Ticket offices, Rest rooms, waiting rooming).

1-Runway length:

As the first step, a basic length should be selected of a runway adequate to meet the operation requirement of the airplanes for which the runway is intended.

الخطوة الاولى هي اختيار الطول الاساسي للمدرج اعتمادا على نوعية الطائرة المستخدمة حيث نستخدم الطول اللازم لانجاز عمليات هذه الطائرة الذي تحدد من قبل الشركة المصنعة وكما مبين في الجدول ادناه :

Table 18.2 Federal Aviation Administration Standards for Airport Design[a]

Item		Airports Serving Aircraft Approach Categories[b] A and B: Airplane Design Group[c]					Airports Serving Aircraft Approach Categories[b] C and D: Airplane Design Group[c]					
Length, ft.		I[d]	I	II	III	IV	I	II	III	IV	V	VI
Runway[e]		2,800	3,200	4,370	5,360	6,370	5,490	6,370	7,290	9,580	10,700	12,000
Runway safety area	< 3/4[f]	600	600	600	800	1,000	1,000	1,000	1,000	1,000	1,000	1,000
(beyond runway end)	≥ 3/4[g]	240	240	300	600	1,000						
Runway object-free area	< 3/4[f]	600	600	600	800	1,000	1,000	1,000	1,000	1,000	1,000	1,000
(beyond runway end)	≥ 3/4[g]	240	240	300	600	1,000						
Width, ft.												
Runway	< 3/4[f]	75	100	100	100	150	100	100	100	150	150	200
	≥ 3/4[g]	60	60	75	100	150						
Runway safety area	< 3/4[f]	300	300	300	400	500	500	500	500	500	500	500
	≥ 3/4[g]	120	120	150	300	500						
Runway object-free area	< 3/4[f]	800	800	800	800	800	800	800	800	800	800	800
	≥ 3/4[g]	250	400	500	800	800						
Taxiway		25	25	35	50	75	25	35	50	75	75	100
Taxiway safety area		49	49	79	118	171	49	79	118	171	214	262
Taxiway object-free area		89	89	131	186	259	89	131	186	259	320	386
Taxilane object-free area		79	79	115	162	225	79	115	162	225	276	334
Minimum distance between, ft.:												
Center lines of parallel[a] runways[h]		See Advisory Circular 150/5300-13, Chapter 2										
Center lines of runway and center line of taxiway	< 3/4[f]	200	250	300	350	400	400	400	400	400	450	600
	≥ 3/4[g]	150	225	240	300	400	300	300	400	400	450	600
Center line of runway and aircraft parking area	< 3/4[f]	400	400	400	400	500	500	500	500	500	500	500
	≥ 3/4[g]	125	200	250	400	500	400	400	500	500	500	500
Center line of taxiway and aircraft parking apron		45	45	66	93	130	45	66	93	130	160	193
Center line of parallel taxiways		69	69	105	152	215	69	105	152	215	267	324
Center line of runway to building line or obstruction[i]	< 3/4[f]	875	875	875	875	875	875	875	875	875	875	875
	≥ 3/4[g]	600	600	600	600	600	713	713	713	713	713	713
Center line of taxiway to obstruction		45	45	66	93	130	45	66	93	130	160	193
Maximum runway grades[j], %:												
Longitudinal		2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5
Transverse[k]		2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5

Basic Runway:- L_{BRW}

Is a runway length selected for aerodrome planning purposes which are required for landing or takeoff under standards atmospheric conditions for; (according to ICAO)

1) Sea level elevation.

2) Standard sea level temperature 59 F (15C^{o}).

3) Zero percent of effective gradient.

طول المدرج المختار لاغراض التخطيط للمطار واللازم لعمليات الاقلاع والهبوط وحسب الظروف القياسية اعلاه .ولكن في الحقيقة فان هذه الظروف تكون غير متوفرة لذلك نحتاج الى تصحيح هذا الطول الاساسي L_{BRW} وحسب الظروف القياسية المحددة من قبل منظمة الطيران المدني .

Factors that influence required runway length:

1- Performance characteristics of aircraft using airport.
2- Landing & takeoff grass weight of the aircraft.
3- Elevation of the airport.
4- Air temp.
5- Runway gradient.
6- Humidity.
7- Wind.
8- Natural & condition of runway surface.

$$\text{reference field length} = \frac{\text{planned or existing field length}}{F_e \times F_t \times F_g}$$

$$F_e = 0.07 \times E + 1$$

where E = airport elevation (thousands of feet)

$$F_t = 0.01[T(^\circ C) - (15 - 1.981E)] + 1$$

$$F_g = (0.10G + 1)$$

Correction to Basic Runway length due to;

1) Correction due to Elevation:

Standard lengths must increase by 7% per each 1000 ft of elevation above sea level.

طول المدرج الاساسي محسوب على اساس مستوى سطح البحر فكل ١٠٠٠ قدم فوق مستوى سطح البحر نزيد بمقدار ٧%.

$$L_{RW} = L_{BRW} + L_{BRW} * 0.07 * E$$

وكذلك الحال في حالة الانخفاض عن سطح البحر (لكل ١٠٠٠قدم تحت مستوى سطح البحر نطرح ٧%)

2) Correction due to Temperature:

Standard lengths must increase by 0.5 % for each 1 F^o which the mean temperature at the site for the no hot month of the year.
Average of over expressed of years exceeds the standard temp. for that elevation.

Standard temperature site is obtained by reducing the standard sea level temp. of 59 F^o at the rate of 3.566 F^o per 1000 ft elevation.

1. درجة الحرارة القياسية على سطح البحر هي ٥٩ فهرنهايت (١٥مئوي).
2. درجة الحرارة القياسية في الموقع الذي سوف ينشئ عليه المطار يساوي درجة الحرارة القياسية على سطح البحر مطروحاً منه 3.566 فهرنهايت لكل ١٠٠٠ قدم.

T_s=59-3.566 *E (elevation greater than 1000 (above or down M.S.L))

3. نجد الفرق بين درجة الحرارة القياسية للموقع ومعدل درجة احر شهر بالسنة T_m.

$\Delta T = T_m - T_s$

نأخذ احر شهر بالسنة ونجد المعدل.

4. لكل فرق مقداره (١ فهرنهايت) نعطي زيادة مقدارها 0.5 %

$L_{RW} = L_{RW} + L_{RW} * \Delta T * 0.005$

$C^o = 5/9 * (F^o - 32)$

3) Correction due to Effective Gradient:-

The effective runway gradient is found by dividing the max. different in elevation by the total length of the runway, should be noted that the developed as the result of experience with many different types on takeoff and landing .

1. نجد مقدار نسبة الميل للمدرج المصحح % G = (منسوب اعلى منطقة – منسوب اوطئ منطقة \ الطول الكلي للمدرج) .

2. لكل ١ % نسبة ميل نعطيها زيادة بالطول مقدارها ٢٠%.

$L_{RW} = L_{RW} + L_{RW} * G\% * 0.2$

ان مقدار الميل بالمدرج يؤثر على عملية التعجيل والتباطؤ للطائرة في الاقلاع او الهبوط وتحدث هذه الظاهرة بسبب الاعمال الترابية. أحتمالية حدوث هبوط بالمدرج عند الحدل خصوصا عند ما يكون fill لذا يفضل تجنب الاعمال الترابية.

Example:-

Pre limiting investigation indicates that aircraft to service a particular town will require a truck line airport with runways 4100 ft long under standard conditions. The airport site is located 2700 ft above M.S.L, the av. Temp. during the hottest month is 67 F^o and the effective gradient is 0.18 % . Find the required length of runways.

Solution:-

L_{BRW}=4100ft

1) Correction due to Elevation:

$L_{RW}= L_{BRW} + L_{BRW}*0.07*E = L_{BRW}*1.07$

=4100 +4100* (2700/1000)*0.07= 4875 ft.

2) Correction due to Temperature:

T_s=59- 3.566*(2700/1000)= 49.4 F^o

$\Delta T=T_m-T_s$ = 67 - 49.4 = 17.6 F^o

$L_{RW}= L_{RW} + L_{RW}*\Delta T*0.005$

L_{RW}= 4875 + 4875*17.6*0.005=5304 ft.

3) Correction due to Effective Gradient:

$L_{RW} = L_{RW} + L_{RW}* G\% * 0.2$

L_{RW}= 5304 +5304* 0.18 * 0.2= 5495 ft . =5500 ft.

The selected length would normally be multiple of 100 ft

4) % of correction = (planned length-basic length) / basic length *100%

= 5500-4100/4100*100%

= 34% < 35% O.K

Field runway required based on the

1) Aircraft characterize.

2) Safety regulation.

لغرض توفير متطلبات الامان للمدارج نحتاج الى المناطق التالية-:

Stop way;

An area beyond the runway not less in width than the width of the runway and designed by the airport authorities for use in decelerating the aircraft during on aborted takeoff to be considered as such the stop way must be capable of supporting the aircraft without in during structural.

مساحة مجاورة للمدرج وتقع على امتداده و لاتقل بالعرض عن عرض المدرج وتقع على امتداد مركز المدرج ومن نفس التبليط تستخدم من قبل سلطات المطار لتوجية الطائرة اثناء الاقلاع او الهبوط الاضطراري ويجب ان يكون الطيار قادرا على ايقاف الطائرة بدون ان يسبب اي تلف انشائي لها وفي نهايتها تحتوي على شبكات لايقاف الطائرة.

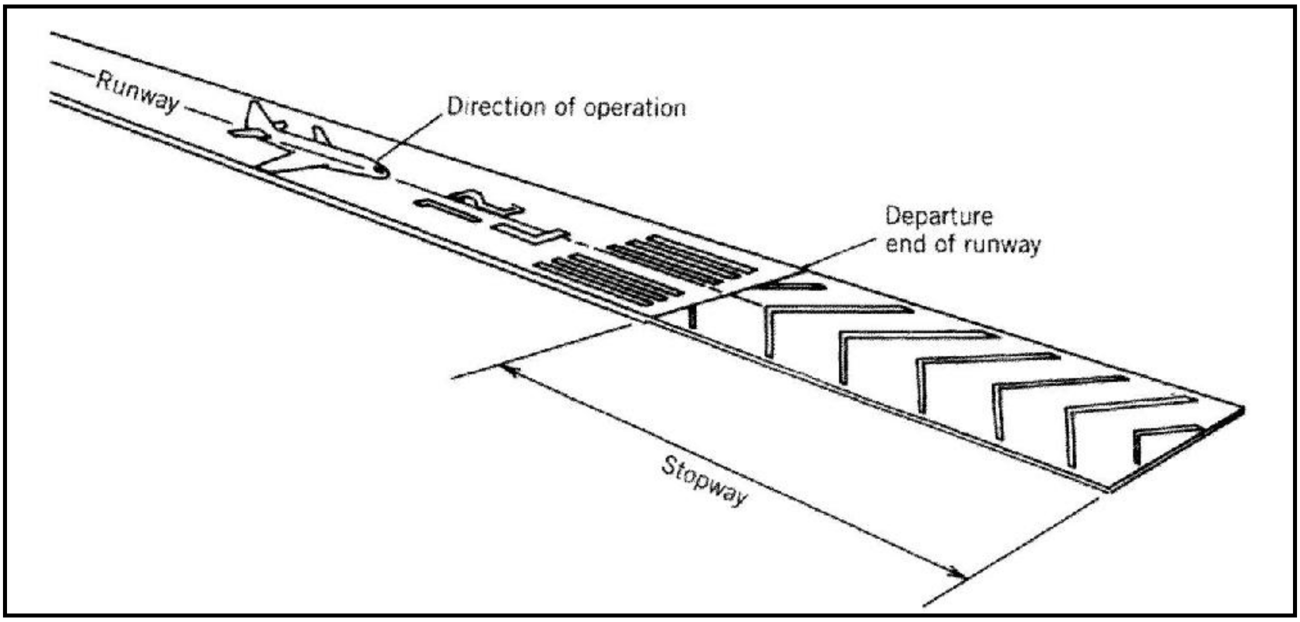


Figure (1) Runway stop way

Clear way;

An area beyond the runway not less than 500 centrally located about the extended center line of the runway and under control of the airport authorities.

مساحة معينة من الارض مجاورة للمدرج وتقع على امتداده ولا يقل عرضها عن ٥٠٠ قدم وتكون تحت سيطرة سلطات المطار تستخدم في حالة الهبوط الاضطراري عندما تكونStop way غير كافية لا يقاف الطائرة.

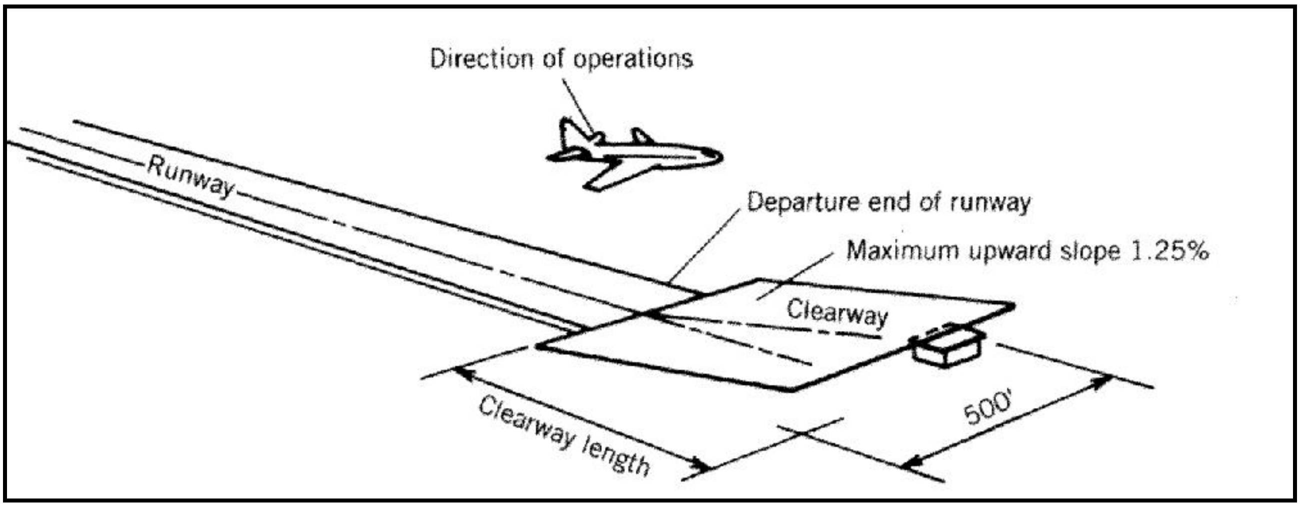
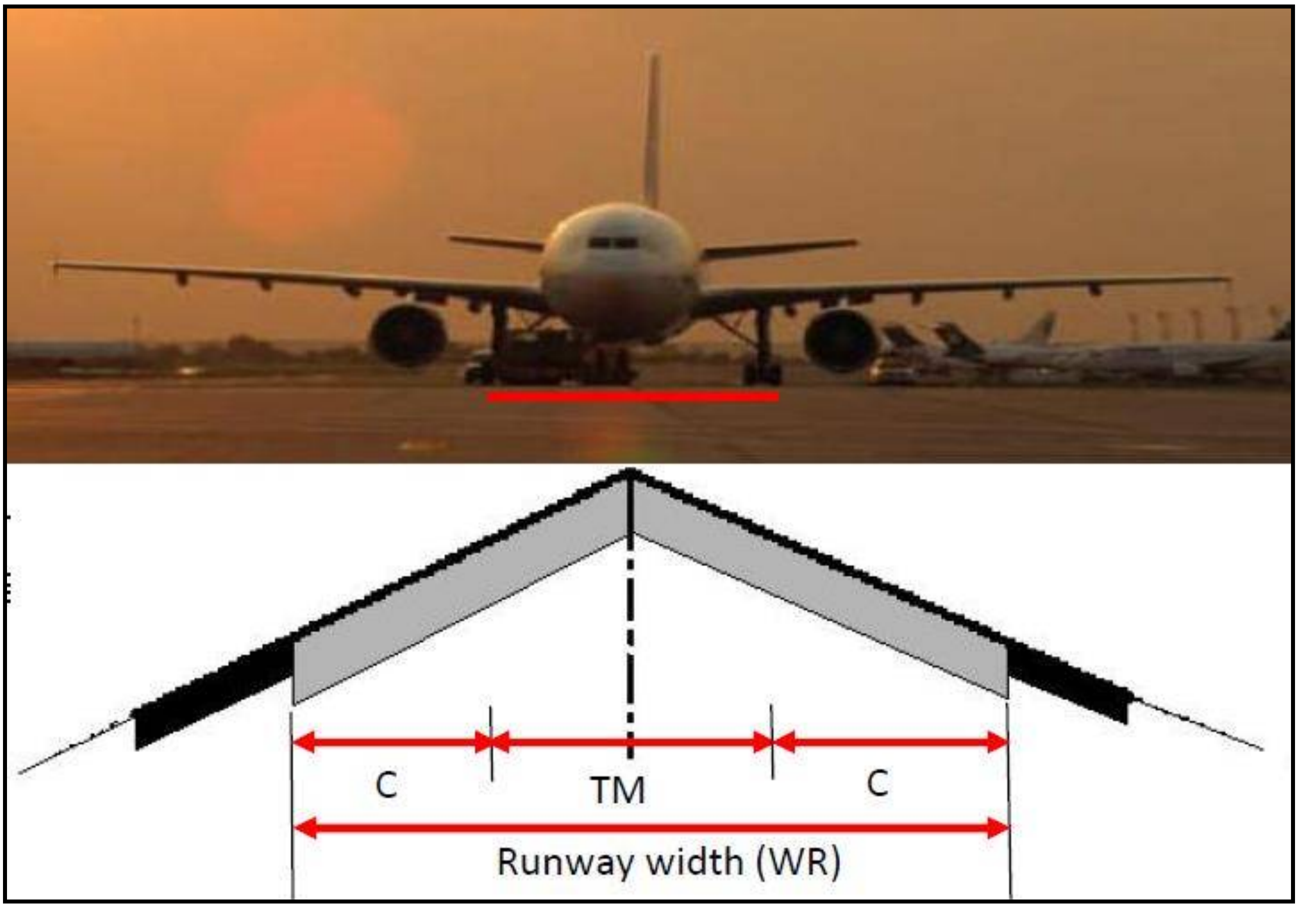


Figure (2) Runway clearway

<u>Note:</u>

***The field length includes the runway length plus the stopway and/or clearway lengths, if provided.**

2-Runway Width:



WR=TM+2C

Where;

TM= Outer main gear wheel span.

C= Clearance between the outer main gear wheel and the runway edge.

2-1-Runway Width Requirements:

The width of a runway is one of the elements that is affected by several geometrical characteristics of aeroplanes:

- The distance between the outside edges of the main gear wheels.
- The distance between wing mounted engines and the longitudinal axis of an aeroplane.
- The wing span.

However, the required runway width is also affected by the operational elements:

- The approach speed of the aeroplane
- The prevailing meteorological conditions.

Lack of sufficient width will cause constraints on the operations. The minimum runway width is therefore specified in Annex 14 by interrelating both of the code elements, see Table (2)

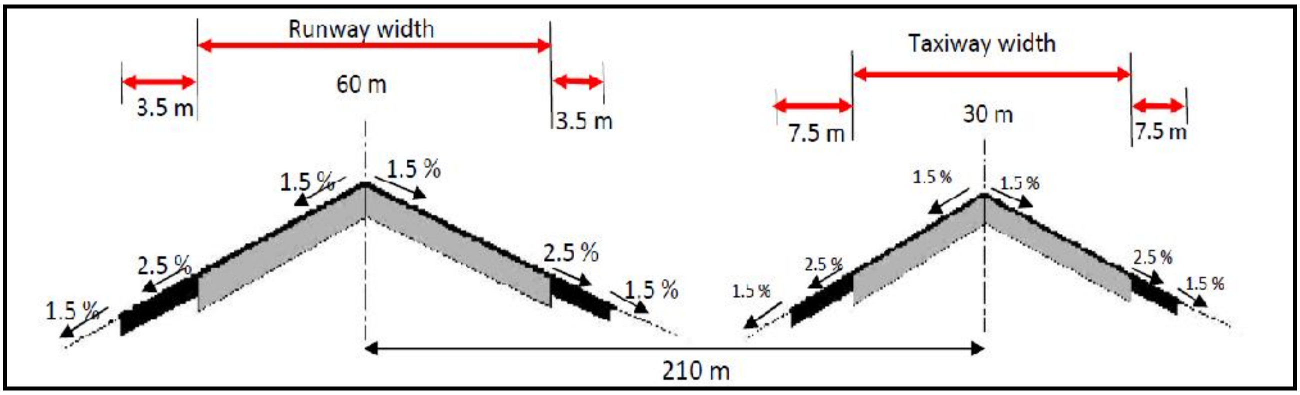
Under normal conditions, the width of a runway should ensure that an aeroplane does run off from the side of the runway during the take-off or landing, even after a critical engine failure causing the aircraft to yaw towards the failed engine.

Table (2) Minimum runway width

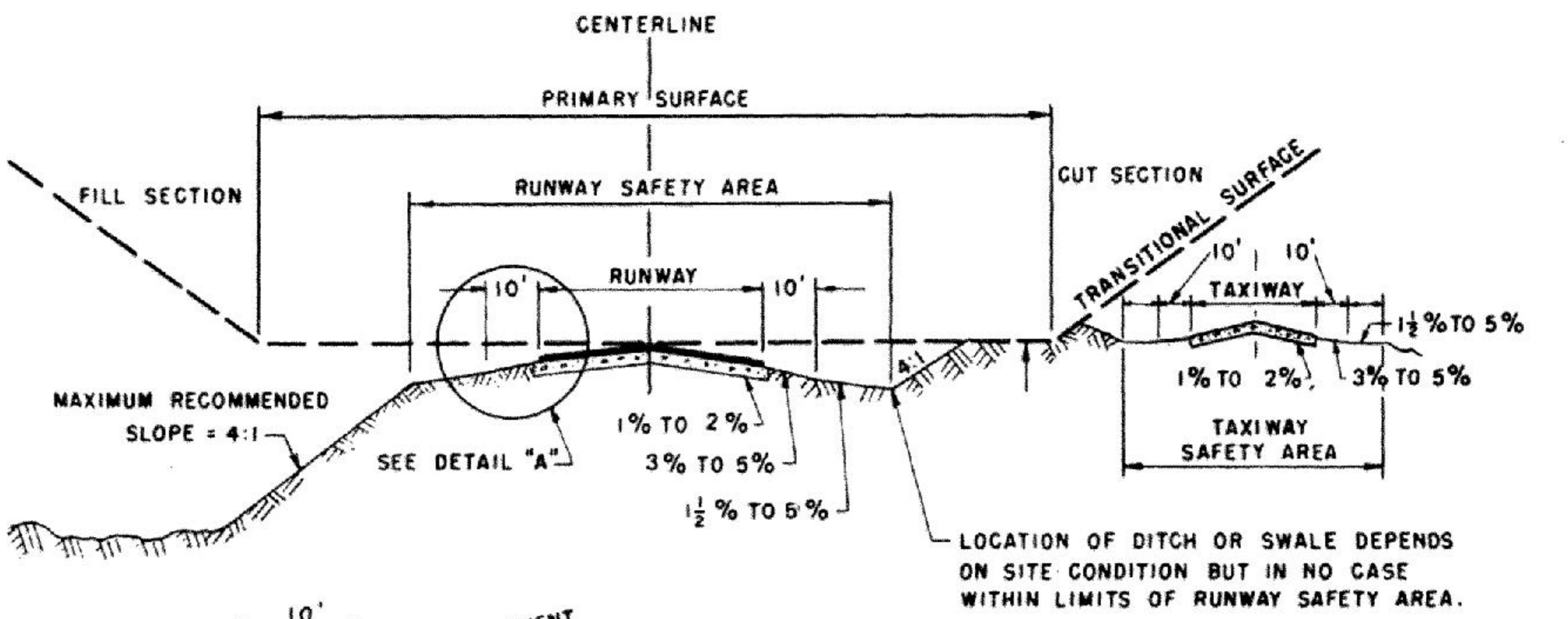
Code number	Code letter					
	A	B	C	D	E	F
1/x	18 m	18 m	23 m	-	-	-
2/x	23 m	23 m	30 m	-	-	-
3	30 m	30 m	30 m	45 m	-	-
4	-	-	45 m	45 m	45 m	60 m

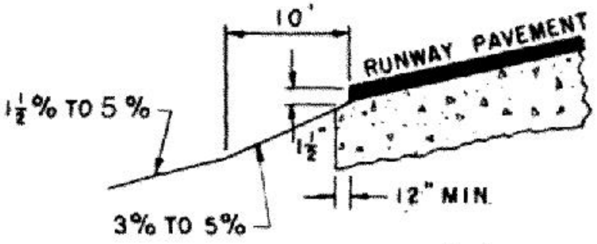
x/ The width of a precision approach runway should be not less than 30 m where the code number is 1 or 2.

Example : Baghdad International Airport (WR=60 m)



The Runway typical cross-section is shown in the figure below:





DETAIL "A"

NOTES:

1. TRANSVERSE SLOPES SHOULD BE ADEQUATE TO PREVENT THE ACCUMULATION OF WATER ON THE SURFACE BUT SHOULD FALL WITHIN THE RANGES SHOWN ABOVE.
2. THE RECOMMENDED 1½" PAVEMENT EDGE DROP IS INTENDED TO BE USED BETWEEN PAVED AND UNPAVED SURFACES.
3. FOR THE FIRST 10' OF UNPAVED SURFACE IMMEDIATELY ADJACENT TO THE PAVED SURFACE IT IS DESIRABLE TO MAINTAIN 5% SLOPE MINIMUM REQUIRED 3% SLOPE.

2-3 Runway Shoulders:

The runway is a paved load-bearing area that varies in width from about 60 ft at the smallest general aviation airports to 150 ft or more at the largest air carrier airports. Studies have shown that the distribution of wheel load applications occurring during landings and takeoffs approximates a normal

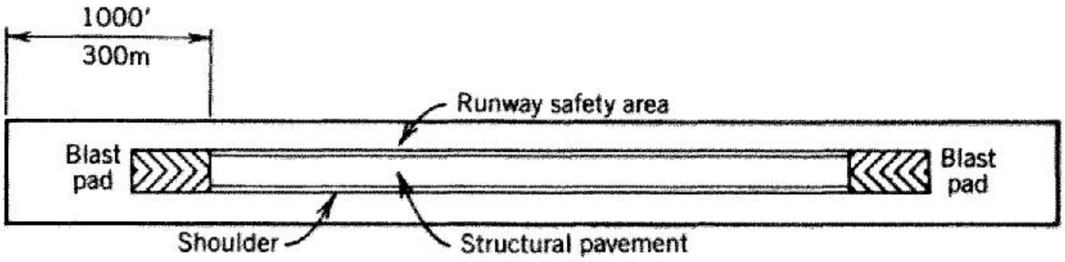


Figure (3) Plane view of runway elements

distribution centered about the runway centerline. Virtually all the load applications are concentrated in a central width of about 100 ft. The additional 50 ft of width on major runways protects jet aircraft engines from ingestion of loose material and also provides an added measure of safety for errant aircraft.

The FAA recommends shoulder widths ranging form 10 ft to 40 ft for transport airports (4). The ICAO recommends that the overall width of the runway plus its shoulders be not less than 60 m or approximately 200 ft (1).

Airports serving military aircraft may require runways and runway safety areas wider than those provided at civilian airports. For example, the Air Force (5) requires a runway width of 150 ft for runways serving fighter and trainer aircraft but a width of 300 ft for those serving heavy bombers. A graded area bordering the runway 200 ft in width is uniformly specified for conventional aircraft. The Navy (6) specifies a 200 ft runway and a 500 ft runway safety area width.

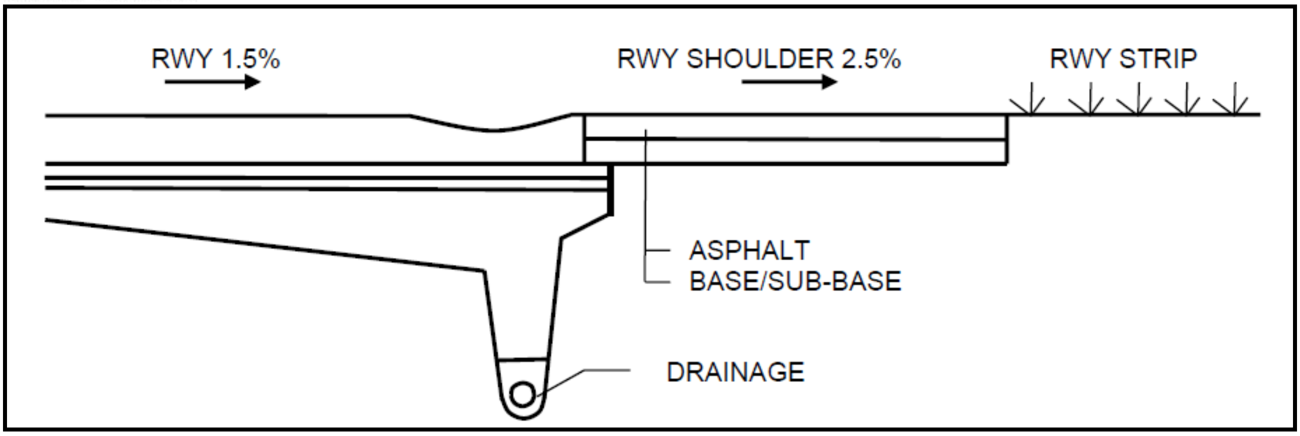


Figure (4) Runway with runway shoulder

Vertical Profile Around center Line of Runway

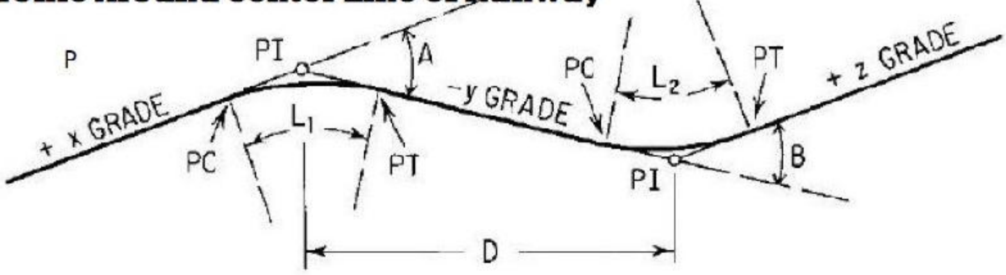


Fig. 18.5 Vertical profile around runway center line shows changes in longitudinal grades. (*Federal Aviation Administration.*)

Table 18.6 Vertical Curve Data and Maximum Grade Changes for Runways

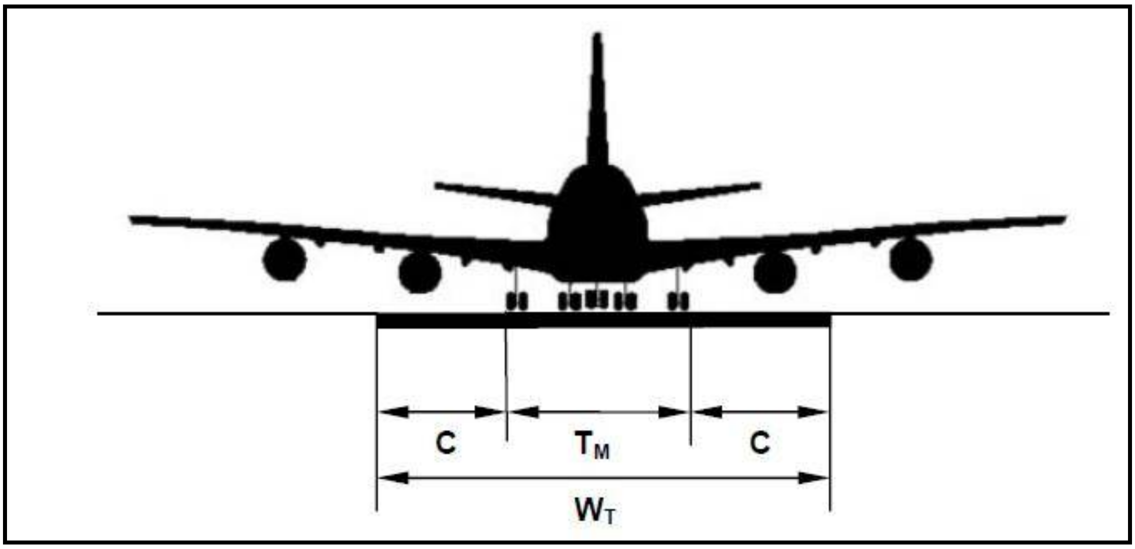
	Runways serving categories A and B airplanes	Runways serving categories C and D airplanes
Maximum gradient at ends of runaway, such as x grade or z grade (Fig. 18.5)	0 to 2.0%	0 to 0.8%, first and last quarter of runway length
Maximum gradient in middle portion of runway, such as y grade (Fig. 18.5)	0 to 2.0%	0 to 1.5%
Maximum grade change, such as A or B (Fig. 18.5)	2.0%	1.5%
Minimum length of vertical curve L_1 or L_2 (Fig. 18.5) for each 1.0% grade change	300 ft*	1000 ft
Minimum distance between points of intersection for vertical curves, D (Fig. 18.5)	$250(A + B)$ ft†	$1000(A + B)$ ft†

*Vertical curves not required at utility airports for grade changes less than 0.4%.

†A% and B% are successive changes in grade.

3-Taxiways:

3-1 Taxiway Width;



The taxiway width, WT is based on a formula:

WT = TM + 2C

where:

WT - taxiway width on the straight parts of the taxiway

TM - outer main gear span

C - clearance between the outer main gear wheel and the taxiway edge

The clearance value depends on the taxiway code letter.

In cross-section, a taxiway is similar in appearance to a runway. The dimensions are, of course, much smaller. The taxiway structural pavement is typically 20 to 60 ft wide at general aviation airports and 50 to 125 ft wide at air carrier airports. Both the Air Force and the Navy specify a standard taxiway width of 75 ft.

Table (3) ICAO Recommended Practices-width of Taxiways

Code Letter	Taxiway Width
A	7.5 m[a]
B	10.5 m
C	15 m if the taxiway is intended to be used by airplanes with a wheel base less than 18 m
	18 m if the taxiway is intended to be used by airplanes with a wheel base equal to or greater than 18 m
D	18 m if the taxiway is intended to be used by airplanes with an outer main gear wheel span of less than 9 m
	23 m if the taxiway is intended to be used by airplanes with an outer main gear wheel span equal to or greater than 9 m.
E	23 m

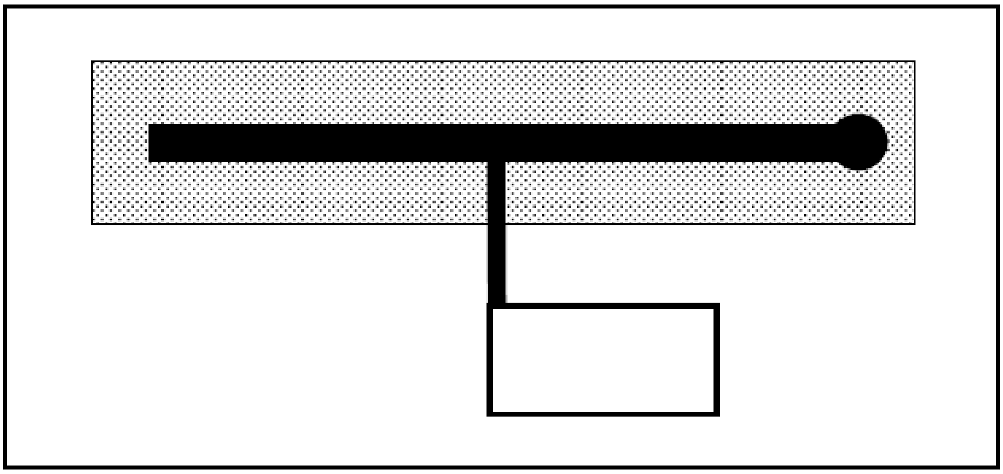
[a] 1 m = 3.2808 ft.

3.2 Taxiway System Design:

It is often difficult to design an optimum system of taxiways. The taxiway system may have a decisive influence on the capacity of the runway system, and thereby also the overall capacity of the aerodrome.

1- **Runway and apron connected with short right angle taxiway:**

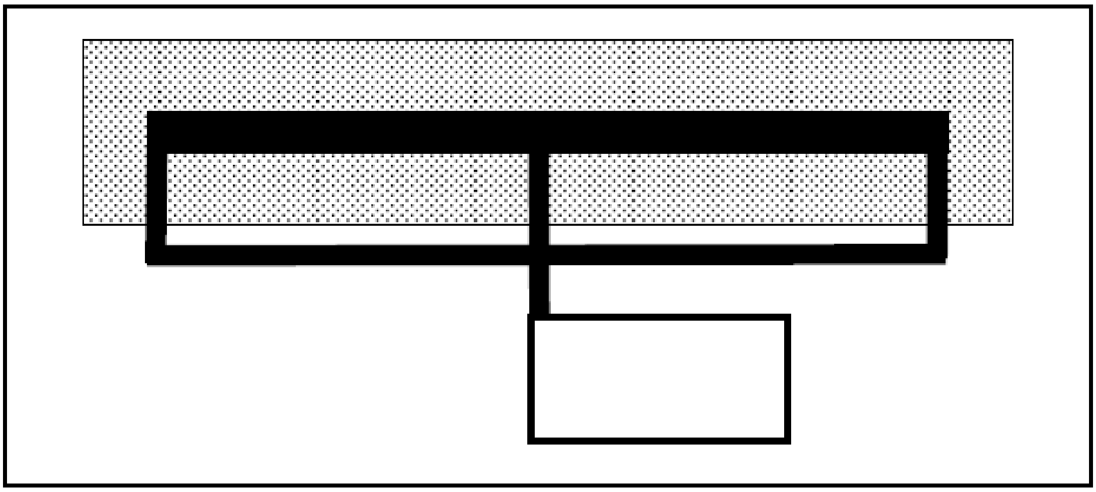
In those aerodromes where the number of aircraft movements during the peak hour traffic is relatively small, it is usually sufficient to provide only a short taxiway at right angles to the runway to connect it to the apron. To cope with larger airplanes, it is then usually necessary to provide additional pavement at the ends of the runway to allow the aircraft to turn round. The runway occupancy time is then considerable.



2- **System of a parallel taxiway with right angle connections:**

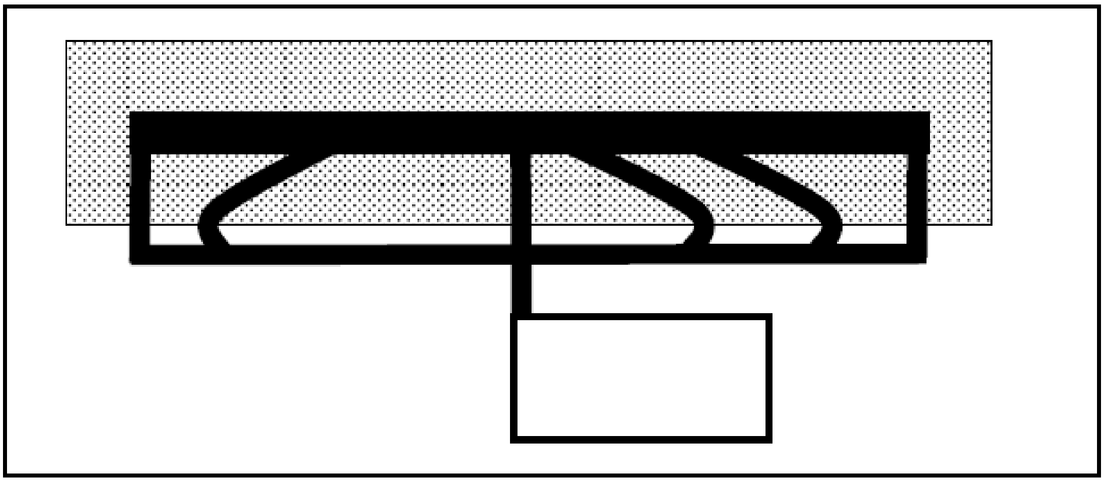
If the number of movements during the peak hour traffic exceeds about 12, consideration may have to be given to construction of a taxiway parallel to the runway, and right angle connecting taxiways at the ends of the runway. In addition, in the event of a longer runway, several right angle connecting taxiways may be constructed, usually at one third or quarter of the runway length.

The system of a parallel taxiway with right angle connections may be sufficient for up to 25 movements during the peak hour



3-System of a parallel taxiway with right angle connections and high-speed exit taxiway:

To improve the capacity further, it is necessary to construct one or more rapid exit (high-speed exit) taxiways, usually from the preferred direction of the main runway, whose parameters and location need to correspond to the type of operation on the given runway.



3-3 Taxiway Separation:

The minimum safe separation distance between the centre line of a taxiway and the centre line of a runway is defined as a standard in Annex 14.

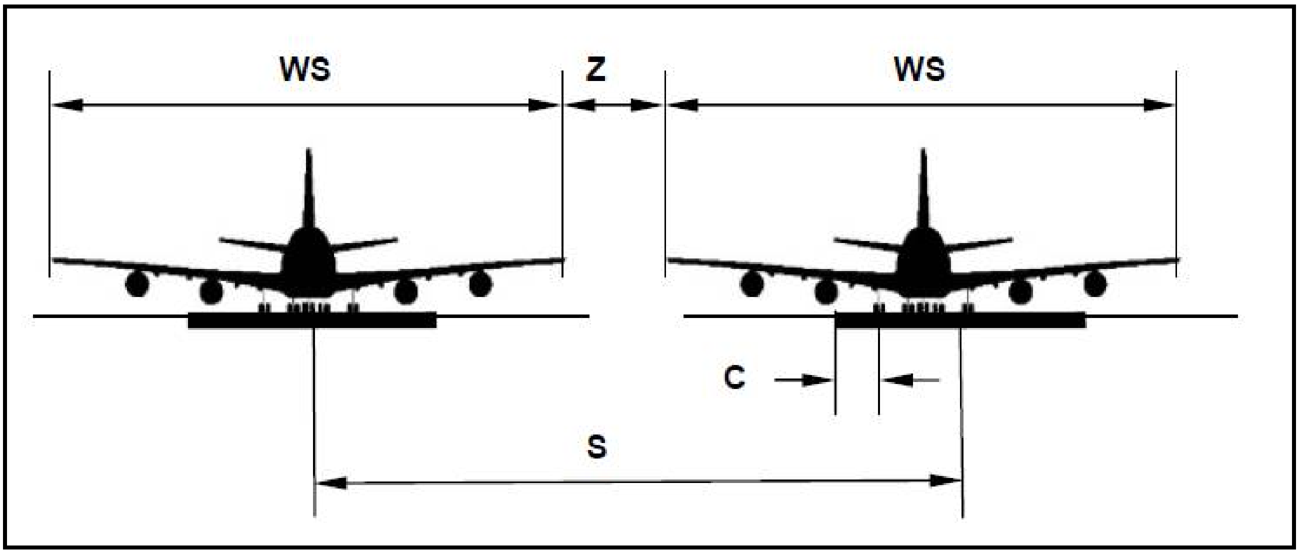


Figure (5) Parallel taxiways separation

The formula for the separation distance in this case is:

$$S = WS + C + Z$$

Where:
WS - Wing span
C - Clearance between the outer main gear wheel and the taxiway edge (maximum allowable lateral deviation).
Z - Wing tip clearance.

Table (4) Taxiway minimum separation distances

Code letter	Distance between TWY centre line and RWY centre line [m]				TWY centre line to TWY centre line [m]	TWY, other than aircraft stand taxilane, centre line to object [m]	Aircraft stand taxilane centre line to object [m]
	Instrument runways code number						
	1	2	3	4			
A	82.5	82.5	-	-	23.75	16.25	12
B	87	87	-	-	33.5	21.5	16.5
C	-	-	168	-	44	26	24.5
D	-	-	176	176	66.5	40.5	36
E	-	-	-	182.5	80	47.5	42.5
F	-	-	-	190	97.5	57.5	50.5

Note: Data for non-instrument RWYs are not shown.

Source: ICAO Annex 14, Aerodromes, Volume I, Aerodrome Design and Operation 4th edition

4- Aprons:

4-1 Apron Requirements

Aprons are designed for parking airplanes and turning them around between flights. They should permit the on and off loading of passengers, baggage and cargo, and the technical servicing of airplanes including refueling.

4-2 Apron Concepts:

The geometric and maneuvering characteristics of airplanes make it practically impossible in most cases to locate all the stands required for peak traffic directly adjacent to the central processing part of the terminal building. It is therefore necessary to generate other solutions.

Several basic concepts that have developed over time may be identified, depending on the total size of the airport. Each concept has its advantages and disadvantages, so the solution is often a compromise and a combination of the basic concepts discussed below. Apron design must be consistent with the adjacent terminal. Apron and terminal design is an iterative process where the optimum combination of apron and terminal concepts are analyzed at the same time.

4.2.1 Simple Concept:

This concept is used normally at very small airports with a few movements of commercial aircraft a day.

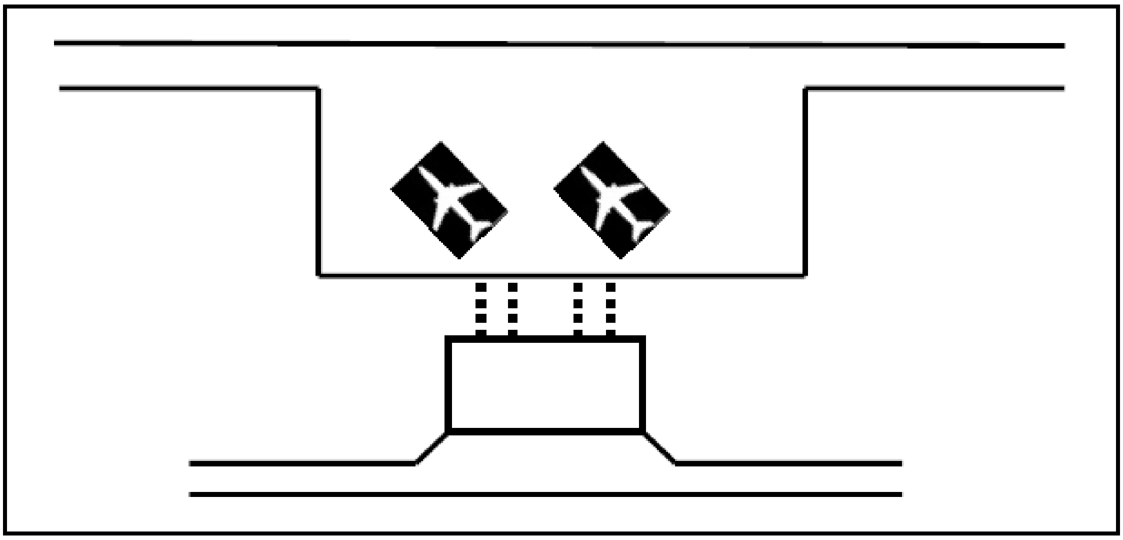


Figure (6) Simple concept

4.3.2 Linear Concept

At many airports the simple concept develops gradually to the linear concept. Individual stands are located along the terminal building.

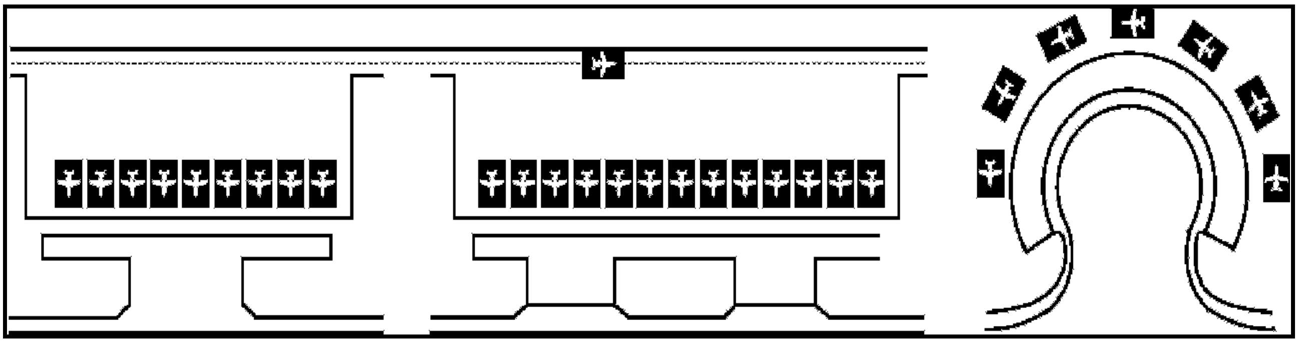


Figure (7) Linear concept

4.3.3 Open Concept:

In this concept, the stands are located on one or more rows in front of the building Figure (8).

One of the rows may be close-in, but most will be a long way from the terminal. The transport of passengers to the distant stands is provided by buses or mobile lounges, with only a short walk for passengers.

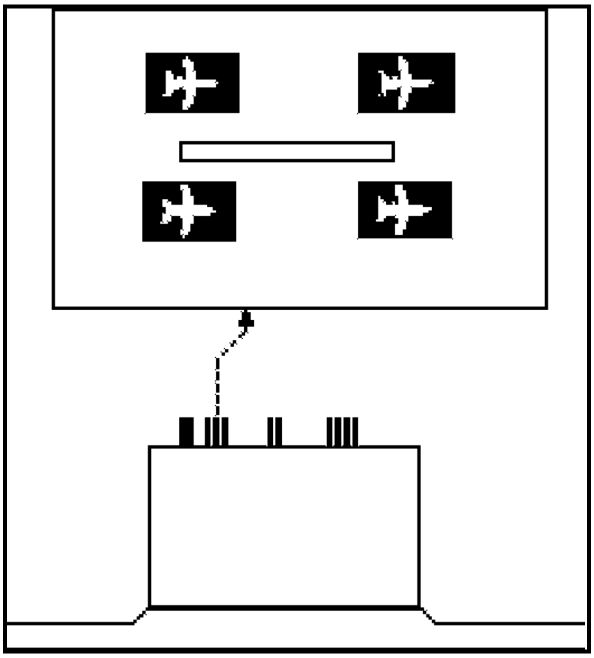


Figure (8) Open concept

4.3.4 Pier Concept:

In many large airports, the introduction or extension of piers was the most convenient way of providing a greater number of contact stands and to increase the capacity of the airport while providing weather protection for the passengers.

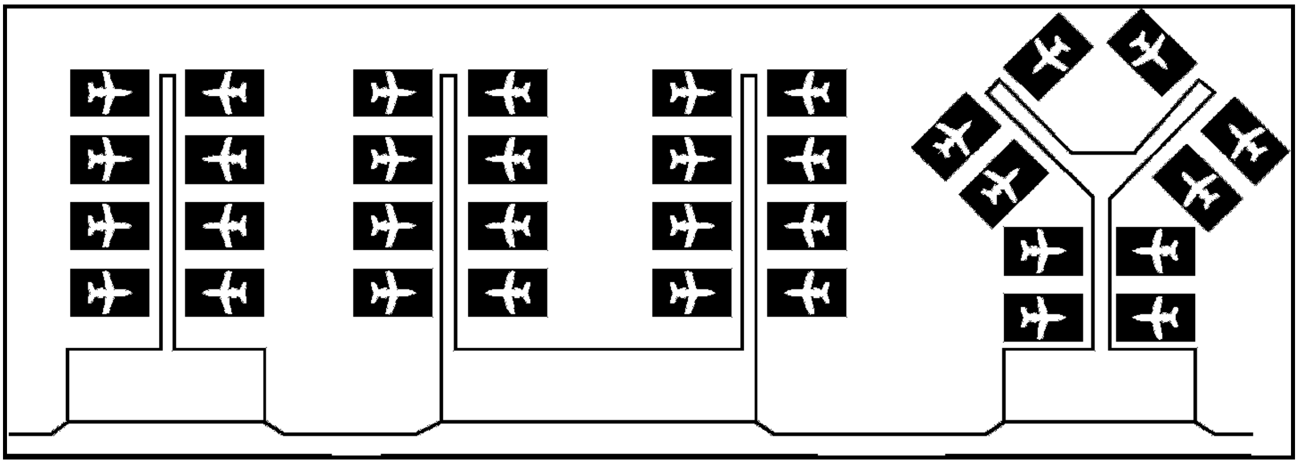


Figure (9) Pier concept

4.3.5 Satellite Concept:

In this concept, each of the remote passenger loading satellites is connected with the terminal building by underground tunnels or by overhead corridors, as in Figure (10).

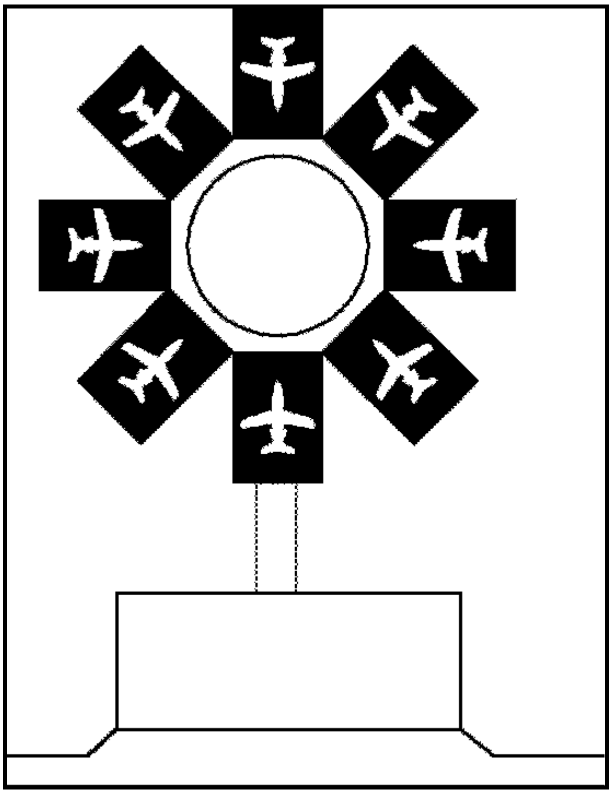


Figure (10) Satellite concept

4.3.6 Hybrid Concept:

At many airports combination of two or more above mentioned concepts is usual. During the summer peak season it is quite common to park some, especially charter aircraft, on the remote apron and transport passengers by busses or transporters to the aircraft stands.

Obstruction Clearance Requirements

Aircraft landing to or taking off from a runway need an area free of obstructions to safely operate. The Federal Aviation Administration (FAA) defines a series of ***imaginary surfaces*** that define the maximum allowable height of any structures that may be placed in the vicinity of an active runway.

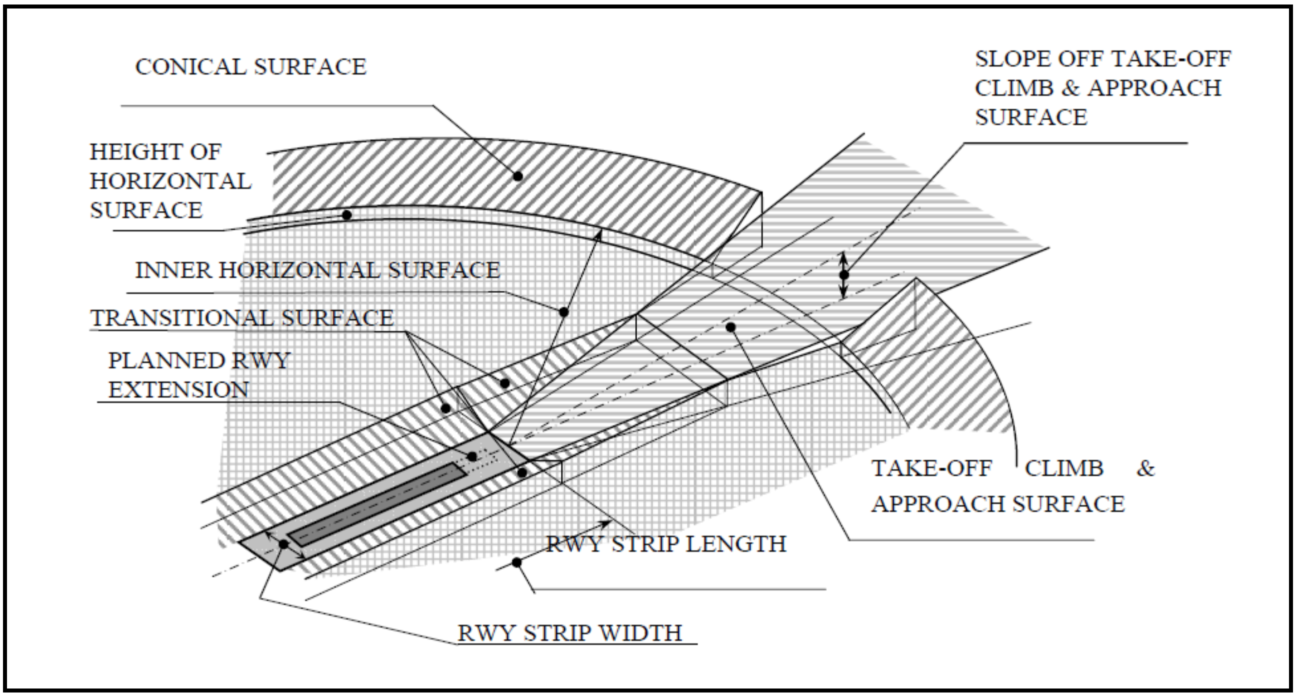
1-Primary surface: The primary surface is a surface that is longitudinally centered on the runway, extends 200 feet beyond the threshold in each direction in the case of paved runways.

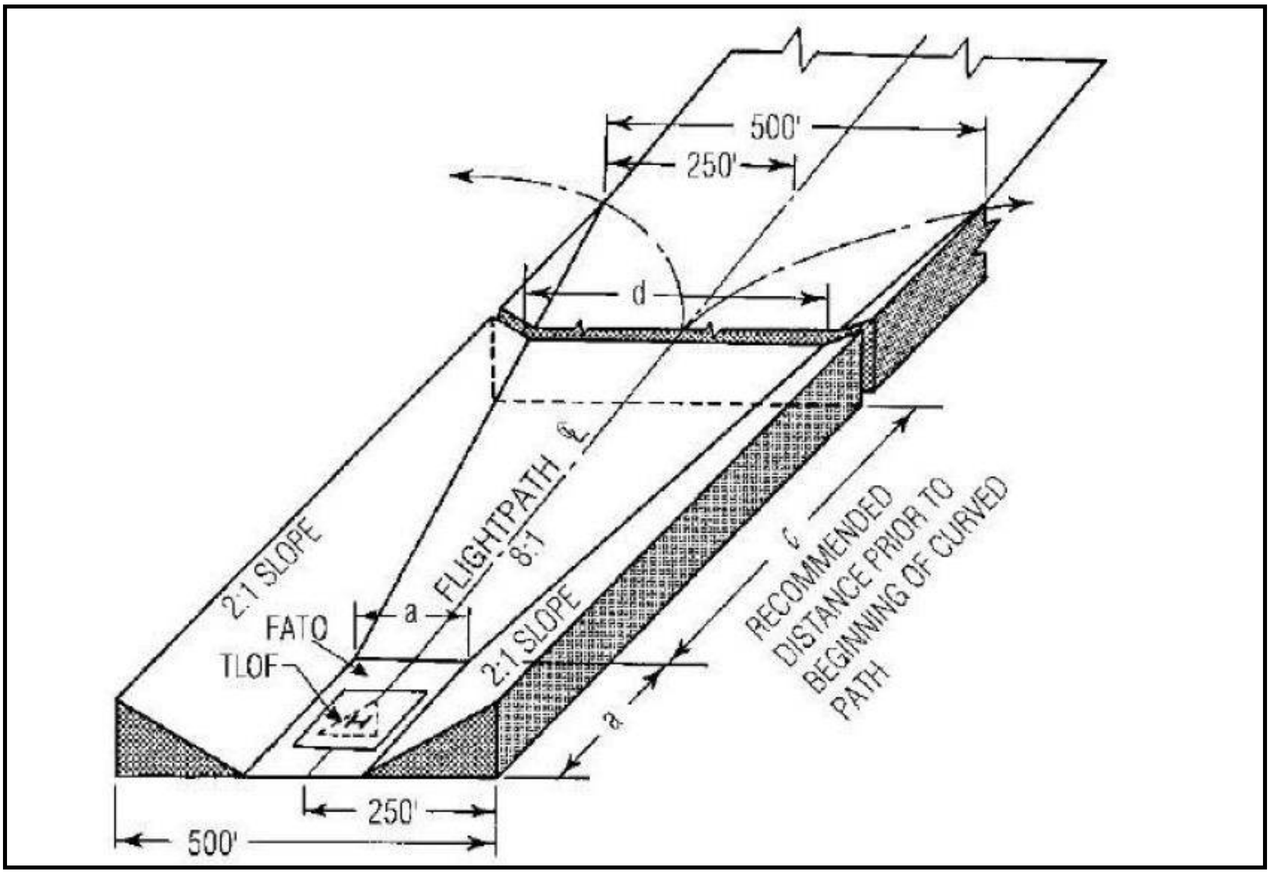
2-Approach surface: The approach surface is an inclined plane or combination of planes of varying width running from the ends of the primary surface (40:1).

3-Horizontal surface: The horizontal surface is a horizontal plane 150 feet above the established airport elevation. The plane dimensions of the horizontal surface are set by arcs of specified dimensions from the end of the primary surfaces, which are connected by tangents.

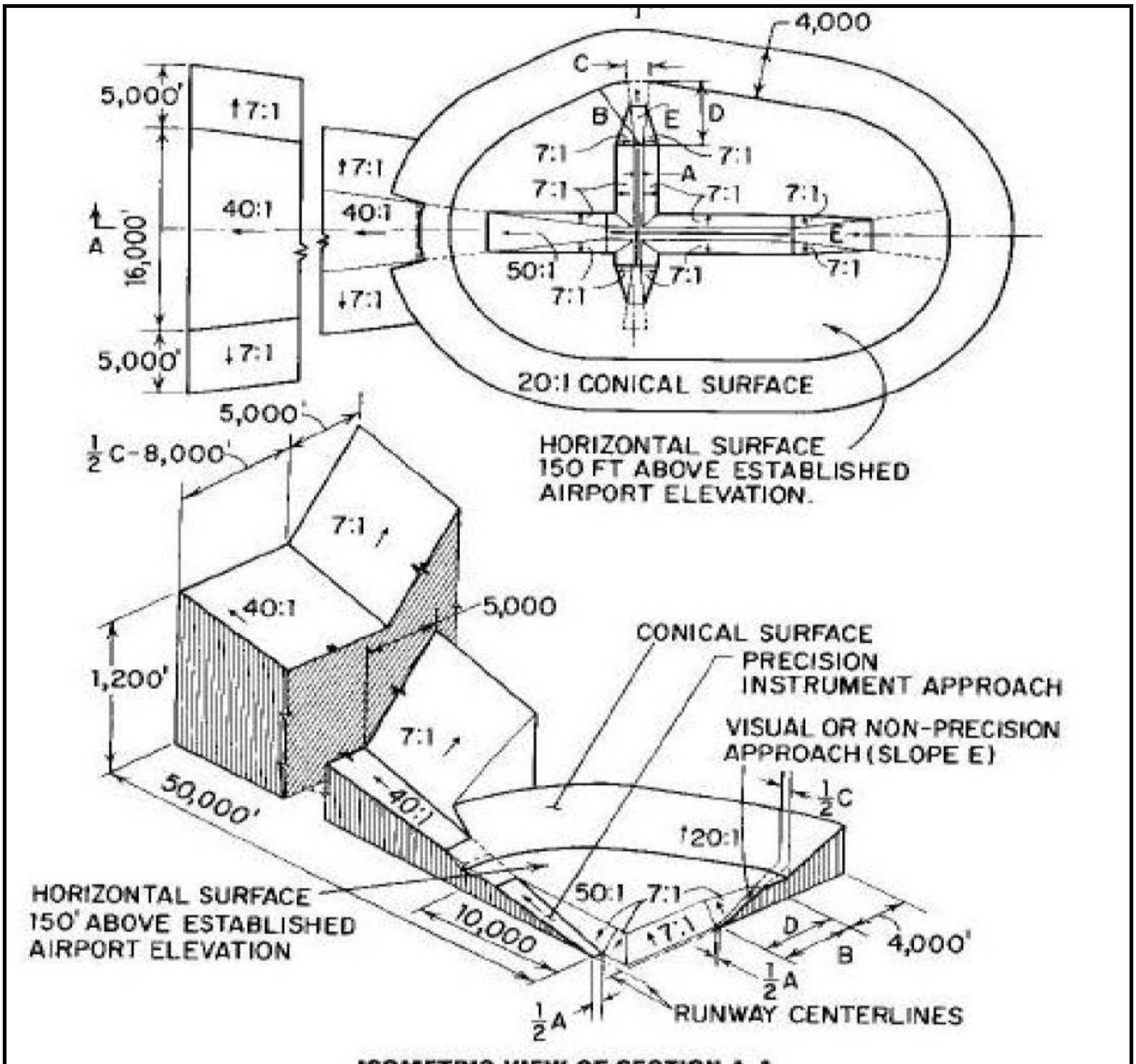
4-Transitional surface: Transitional surface is an inclined plane with slope of (7:1) extending upward and outward from the primary and approach surfaces terminating at the horizontal surface where these planes meet.

5-Conical surface: The conical surface is an inclined plane at a slope of (20:1) extending upward and outward from the periphery of the horizontal surface for a horizontal distance of 4,000 feet.





PERSPECTIVE VIEW OF APPROACH-DEPARTURE PATH



ISOMETRIC VIEW OF SECTION A-A

Airport Capacity and Configuration

Airport capacity analyses are made for two purposes:

1- To measure the ability of various components of the airport system of heading passengers and aircraft flow.

2- To estimate the delay experiment in the system at different level of demand.

Capacity analysis is required for:

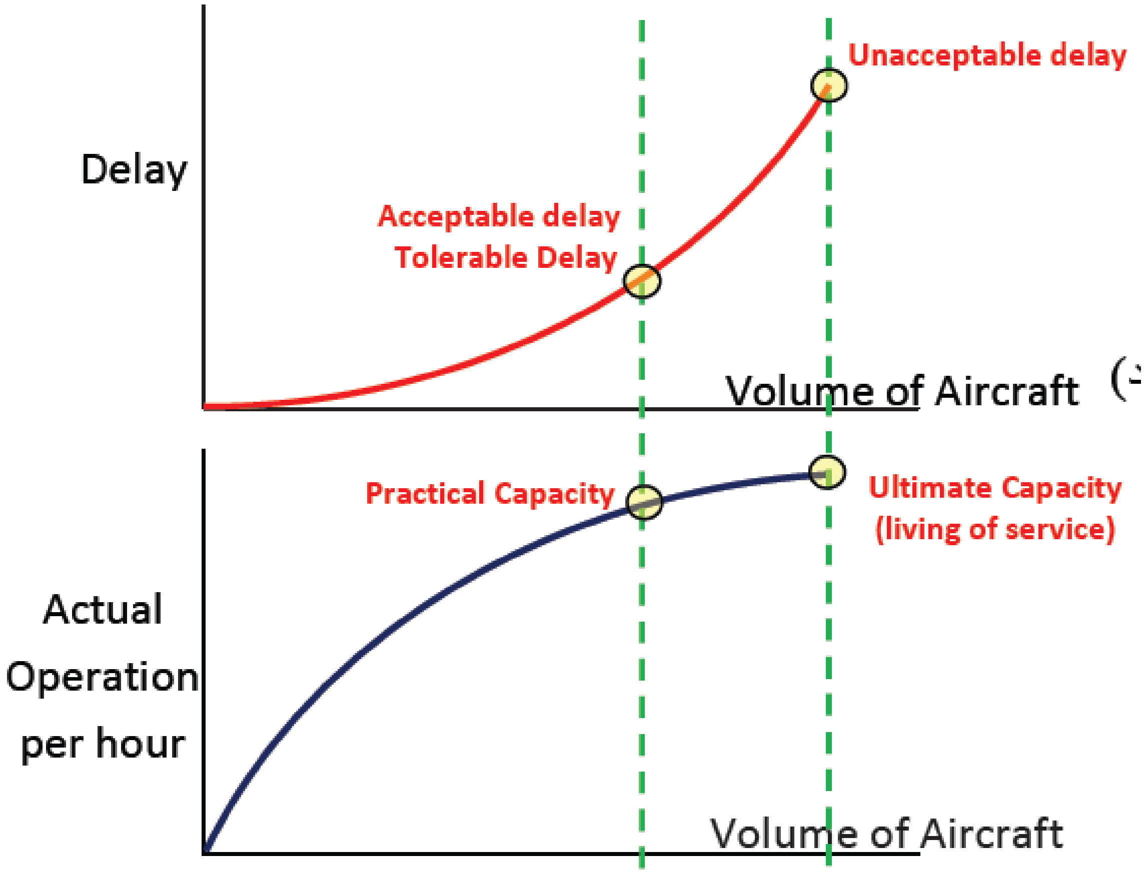
1- For determining the No. of required runways.

2- To identify potentially suitable configuration.

3- To compare alternative design.

4- To estimate the delay experienced in the system at different levels of demand.

** Delay can results from problems in the airside or landside.



Runway Capacity: is the ability of runway system to accommodate aircraft operations (landing or takeoff) per unit time (op/hr) or (op/yr).

Ultimate or Saturation Capacity of Runway: The max. number of aircraft that can be handled during a given period under conditions at continuous demand.

Factors Effecting on Runway Capacity

1- **Characteristics of demand (Traffic Mix):**

Categories of aircraft for determination of airport capacity are generally as follows:

a) Type A ; 4-engine jet and larger .

b) Type B ; 2 to 3 engine jet and 4 engine piston and Turbo prop.

c) Type C ; Executive jet and transport type twin engine piston.

d) Type D; Light twin engine piston and single –engine piston.

يمكن تقيم الاستيعاب حسب نوع الطائرة التي تهبط الى اربعة درجات ١,٢,٣,٤

Capacity number	A%	B%	C%	D%
1	0	0	10	90
2	0	30	30	40
3	20	40	20	20
4	60	20	20	0

2- **Aircraft Control:**

a) VFR (Operation by Visual Flight Rule).

Or **VAW** (Visual Airport Weather).

وهي عملية هبوط أو أقلاع الطائرة اعتمادا "على الرؤية الشخصية للطيار (العمليات تدار من قبل رؤية الطيار)

b) IFR (Operation by Instrument Flight Rule).

Or **IAW** (Instrument Airport Weather).

وهي عملية استخدام الأجهزة والمعدات (الرادار والكمبيوتر) في عملية الإقلاع والهبوط وخاصة عند ظروف الرؤية الغير جيدة أو الظروف الجوية السيئة وخاصة في المناطق الكثيفة او الشديدة الضباب أو الغيوم (مدى الرؤية فيها يكون فيها قليل خلال السنة).

VFR ; Operation are made in good weather conditions.

IFR ; Operation are made in the period of bad weather conditions or poor visually under these conditions positive traffic control is maintained by Radar and others electronic devices.

لان العمليات التي تنجز بواسطة الأجهزة تكون بطيئة وبالتالي يقل الاستيعاب وكذلك تأثير مدرج على المدارج المجاورة كبير لذلك يجب ان تكون المسافة بنيهما بمقدار معين بحيث لا يحدث تتداخل بين أجهزة السيطرة.

3- Environmental Condition in the airport vicinity

التأثيرات البيئية كالجليد الذي يؤدي الى أغلاق المدارج خوفا من خطورة الأنزلاق لذلك تأثيره على السعة السنوية (Annual Capacity) وبالتالي تؤثر على (AADT) المعدل السنوي للمرور اليومي.

According to (FAA) classify the capacity into:

1- **PHOCAP** (Practical Hourly Capacity).

2- **PANCAP** (Practical Annual Capacity).

There are three categories of airports according to its airspace:

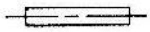
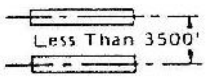
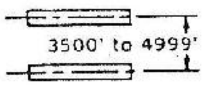
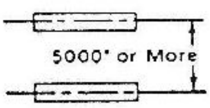
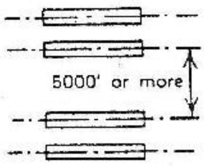
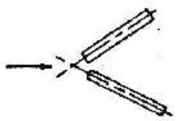
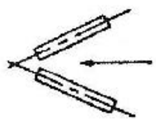
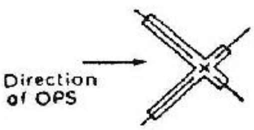
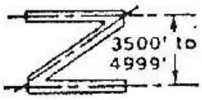
a- Unrestricted airspace.

b- Normal.

c- Restricted airspace.

4- Runway Configuration:

الاستيعاب يزداد بزيادة عدد المدارج وعدد المدارج يعتمد على مقدار التغطية الذي يستطيع توفيرها والذي تعتمد على اتجاهات الرياح بما ان الرياح تكون متغيرة خلال السنة فيجب ان يكون هنالك عدد من المدارج كافية لتغطيتها. **وكما مبين في الجدول التالي:**

Runway Configuration					PHOCAP	
Layout		Description	Mix	PANCAP	IFR	VFR
A		Single runway (arrivals = departures)	1	215,000	53	99
			2	195,000	52	76
			3	180,000	44	54
			4	170,000	42	45
B		Close parallels (IFR dependent)	1	385,000	64	198
			2	330,000	63	152
			3	295,000	55	108
			4	280,000	54	90
C		Independent IFR approach-departure parallels	1	425,000	79	198
			2	390,000	79	152
			3	355,000	79	108
			4	330,000	74	90
D		Independent IFR arrivals and departures	1	430,000	106	198
			2	390,000	104	152
			3	360,000	88	108
			4	340,000	84	90
H		Independent parallels plus two close parallels	1	770,000	128	396
			2	660,000	126	304
			3	590,000	110	216
			4	560,000	108	180
K_1		Open V, dependent, operations away from intersection	1	420,000	71	198
			2	335,000	70	136
			3	300,000	63	94
			4	295,000	60	84
K_2		Open V, dependent, operations toward intersection	1	235,000	57	108
			2	220,000	56	86
			3	215,000	50	66
			4	200,000	50	53
L_1		Two intersecting at near threshold	1	375,000	71	175
			2	310,000	70	125
			3	275,000	63	83
			4	255,000	60	69
L_2		Two intersecting in middle	1	220,000	61	99
			2	195,000	60	76
			3	195,000	53	58
			4	190,000	47	52
O_1		"Z" configuration and parallel with both intersecting	1	465,000	87	217
			2	430,000	87	167
			3	390,000	87	118
			4	365,000	81	99

Practical capacity is based on the following assumed conditions:

1- Availability of full airport instrumentation IAW operations.
2- Existence of sufficient taxiway for airport system.
3- Availability of unrestricted airspace.
4- An annual weather condition of 90%VAW &10% IAW

Example:

Determine the PHOCAP of a single runway used for arrival and departure.

The following conditions are given:

1- Aircraft mix : A=35%, B=45%, C+D+E= 20%
2- Radar control.
3- Ratio of arrivals to departure =0.75
4- **Runway rating =56 sec.
5- Airspace is normal.

** **Runway rating R.R.:** is the average runway occupancy time for a given landing aircraft on a given runway (4 min.).

Solution:

Mix (A+B) = 80%.

To determine the VAW departure capacity for stated conditions we enter Figure (6.3) and find the hourly departure capacity.

From Figure (6.3) HDCv =26.

From Figure (6.4) we take the hourly arrival capacity HACv =36.

The arrival / departure ratio is 0.75 which means that there are four departures for every three arrivals.

The arrival demand is therefore   26*0.75=19.5 < HACv

Since the arrival demand is less than the hourly arrival capacity.

PHOCAP=26+19.5 =45.5   say 45op/hr for VAW.

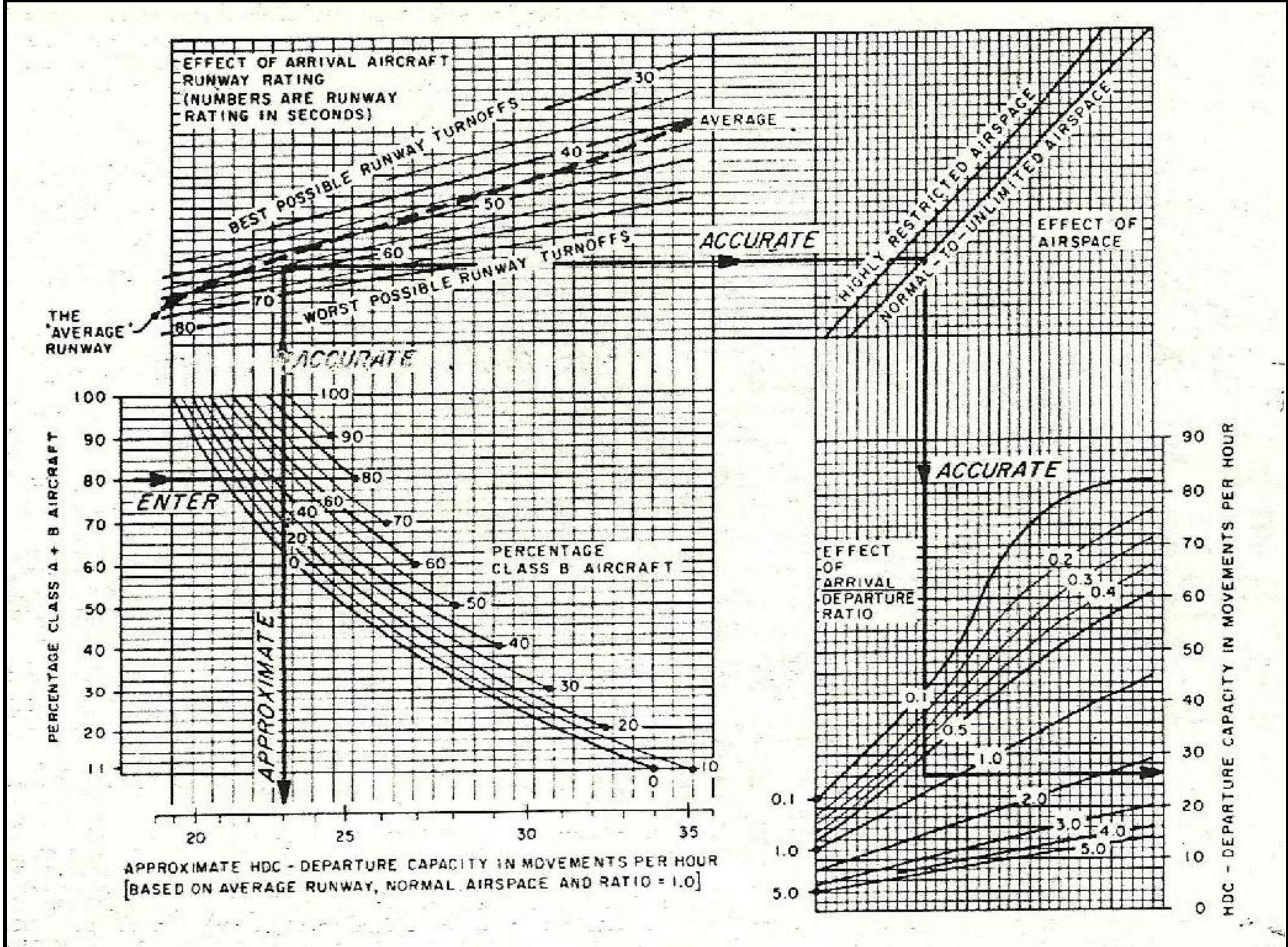


Figure 6.3 Hourly departure capacity nomograph for air carrier airports, single-runway, mixed operations, VAW conditions. (*Source*: Reference 8.)

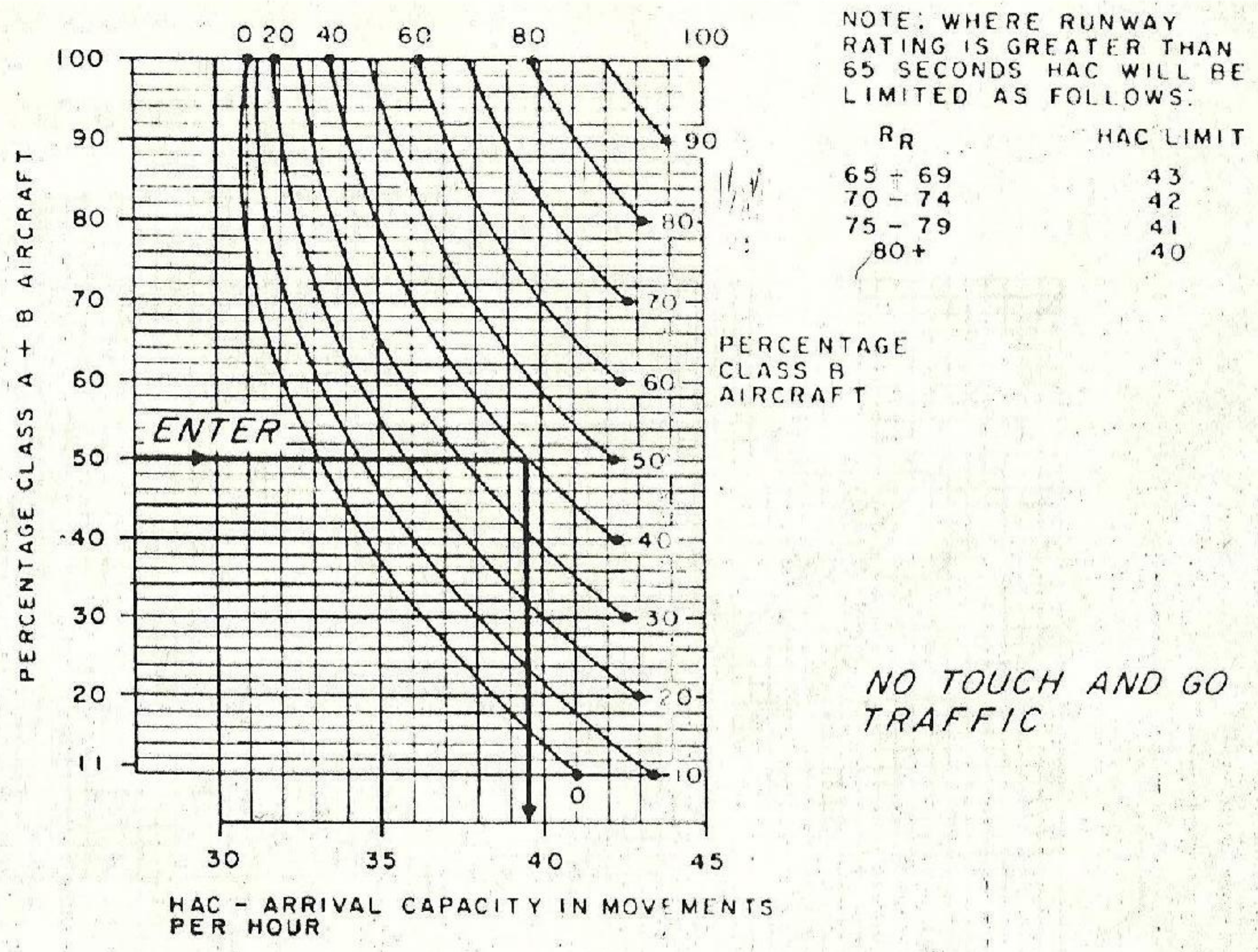


Figure 6.4 Hourly arrival capacity nomograph for air carrier airports, VAW conditions (Source: Reference 8.)

Using Figure (6.5) the hourly departure capacity under IAW conditions HDCi=23.

From Figure (6.6) the hourly arrival capacity under IAW conditions is HACi=35.

Again taking the arrival / departure ratio into consideration.

The arrival demand is therefore 23*0.75=17.3 < HACi

PHOCAP=23+23*0.75=40.3 say 40 op/hr for IAW.

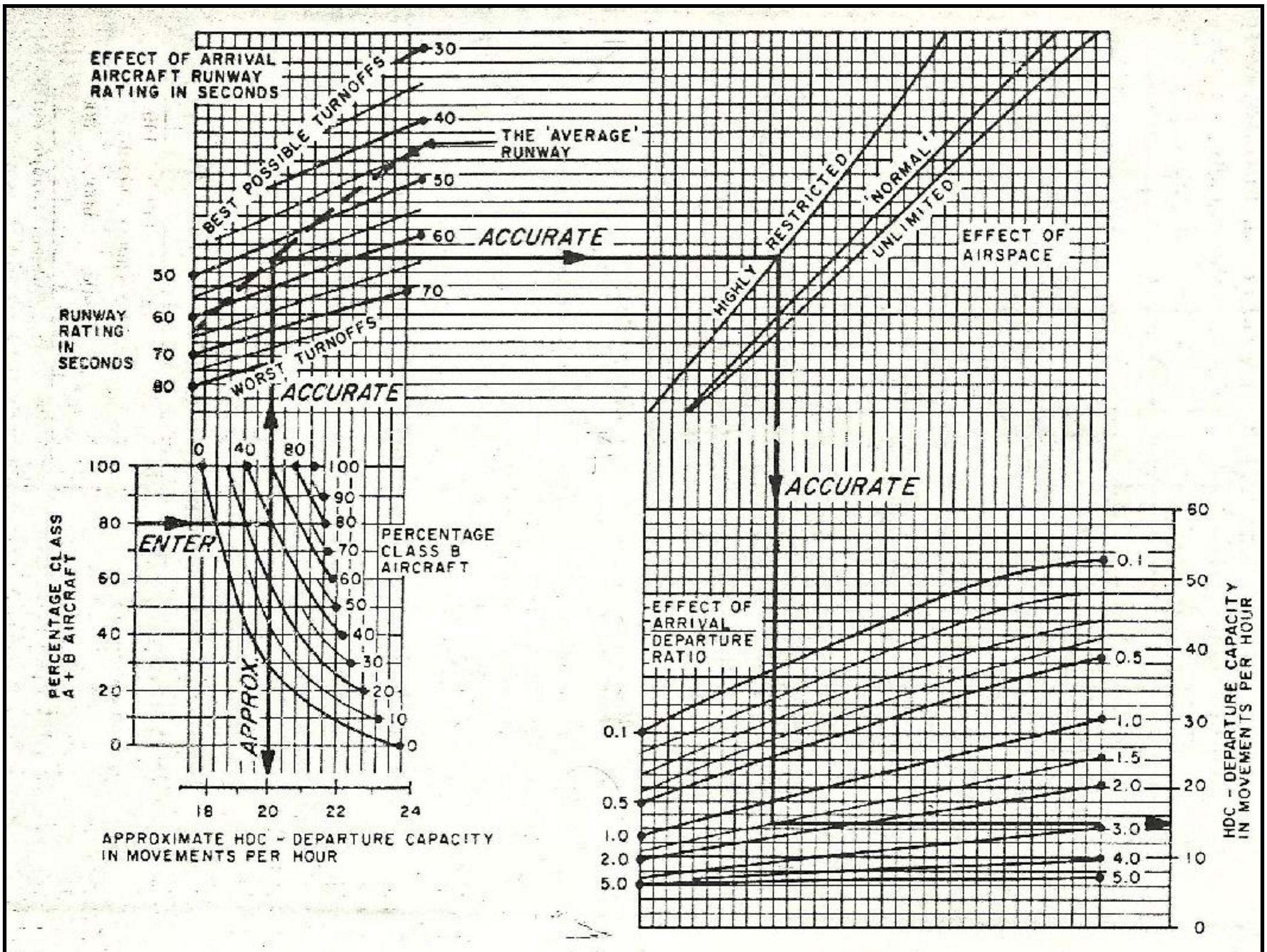
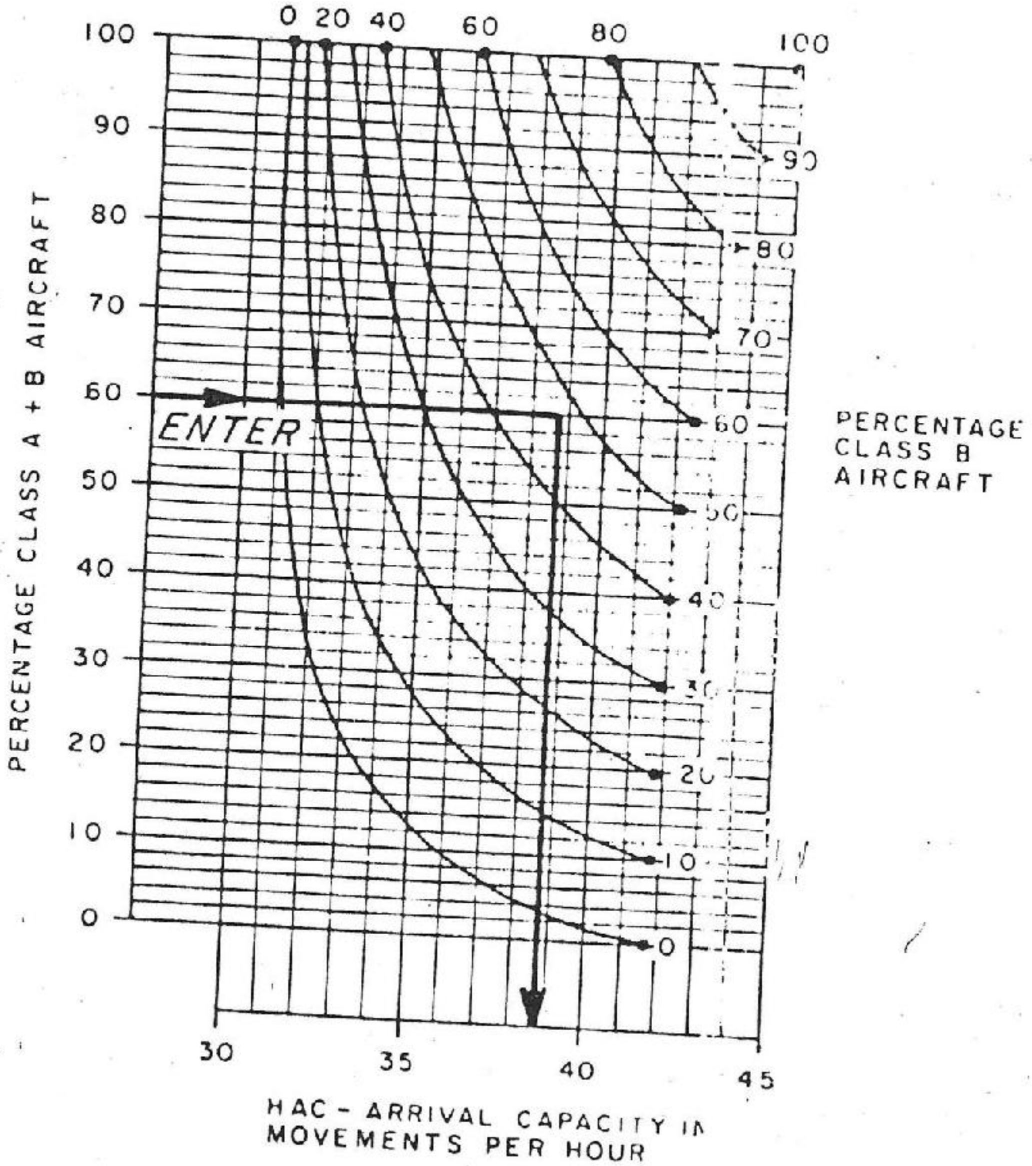


Figure 6.5 Hourly departure capacity nomograph for air carrier airports, single-runway, mixed operations, IAW conditions (Source: Reference 8)



NOTE: WHERE RUNWAY RATING IS GREATER THAN 65 SECONDS, HAC WILL BE LIMITED AS FOLLOWS:

R_R	HAC LIMIT
65 - 69	43
70 - 74	42
75 - 79	41
80+	40

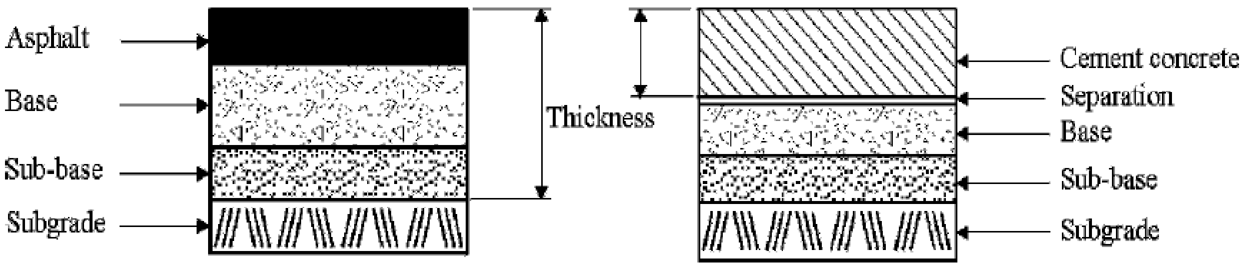
Figure 6.6 Hourly arrival capacity nomograph for air carrier airports, IAW conditions. (*Source*: Reference 8.)

Airport Pavement Design

Airfield pavements must be:

1. **Able to support loads imposed by aircraft without excessive distortion or failure.**
2. **Smooth, firm, and stable.**
3. **Free from dust or other particles that might be blown or pushed up by propeller wash or jet blast.**
4. **Usable in all seasons and in all weather conditions.**

A pavement is a structure consisting of one or more layers of processed or unprocessed materials placed on a prepared subgrade. There are two general classes of pavements: flexible and rigid.



Flexible pavements typically consist of bituminous "surface course," a "base course," and a subbase course." These courses or layers are carefully placed and compacted on a prepared subgrade in an embankment or excavation.

Rigid pavements consist of slab of portland cement concrete that rests on a prepared subgrade or subbase. Distributed steel or tiebars and dowels are used in portland concrete pavements to control and minimize the harmful effects of cracking and to provide for load transfer between adjacent slabs. Relatively thin subbases (4–6 in.) may be placed under rigid pavements to prevent pumping. Subbases may also be used to improve a low-strength subgrade.

Variables that influence pavement performance area:

Load Variables
- Aircraft gross load
- Wheel load
- Number and spacing of wheels
- Tire contact pressures
- Number of applications
- Duration of load application
- Distribution of lateral placement of loads
- Type of load (static or dynamic)

Environmental variables
- Amount and distribution of precipitation (especially rainfall)
- Ambient temperatures
- Aircraft blast and heat
- Fuel spillage

Structural design variables
- Number, thickness, and type of pavement layers
- Strength of materials

Construction variables

Maintenance variables

1- **Rigid airport pavement design:**

The FAA method:

This method of design depends on determining the gross aircraft weight of the design aircraft, the flexural strength of the concrete, the modulus of subgrade reaction, and the annual equivalent departure.

Concrete Flexural strength. The 28-day flexural strength of concrete is determined by ASTM Test method C78. A 90-day flexural strength may be used. It can be taken to be 10% higher than the 28-day strength, except when high early strength cement or pozzolanic admixtures are used.

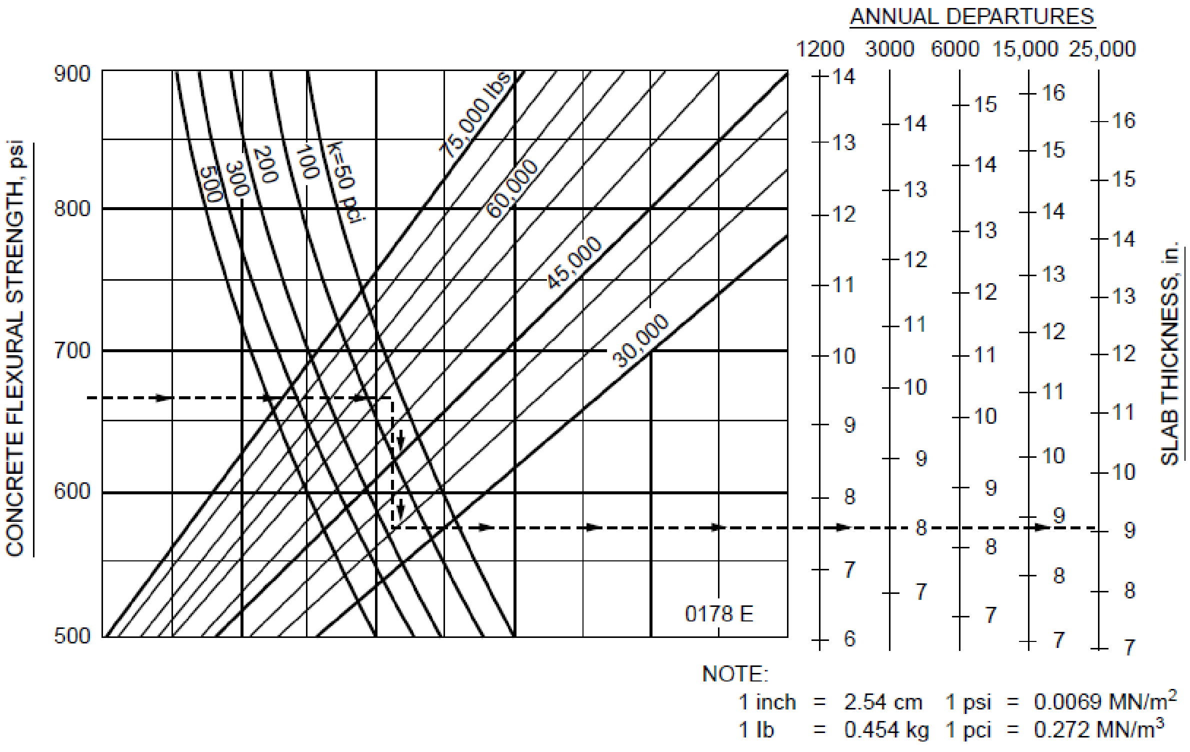


Figure (1) Rigid pavement thickness for single- wheel gear.

Note:

High Traffic Volumes. For airports with design traffic exceeding 25,000 annual departures, the FAA suggests using thicker pavements as follows: 104, 108, 110, and 112% of design thickness for 25,000 annual departures for annual departure levels of 50,000, 100,000, 150,000, and 200,000, respectively. This suggestion is based on a logarithmic relationship between percent thickness and departures.

The design procedure is performed using the figures (1, 2, 3) from the left ordinate of the figure, representing the flexural strength, a line extended horizontally to its intersection with the appropriate modulus of subgrade reaction (k) line , vertically to the aircraft weight line, then horizontally to the annual departure and slab thickness.

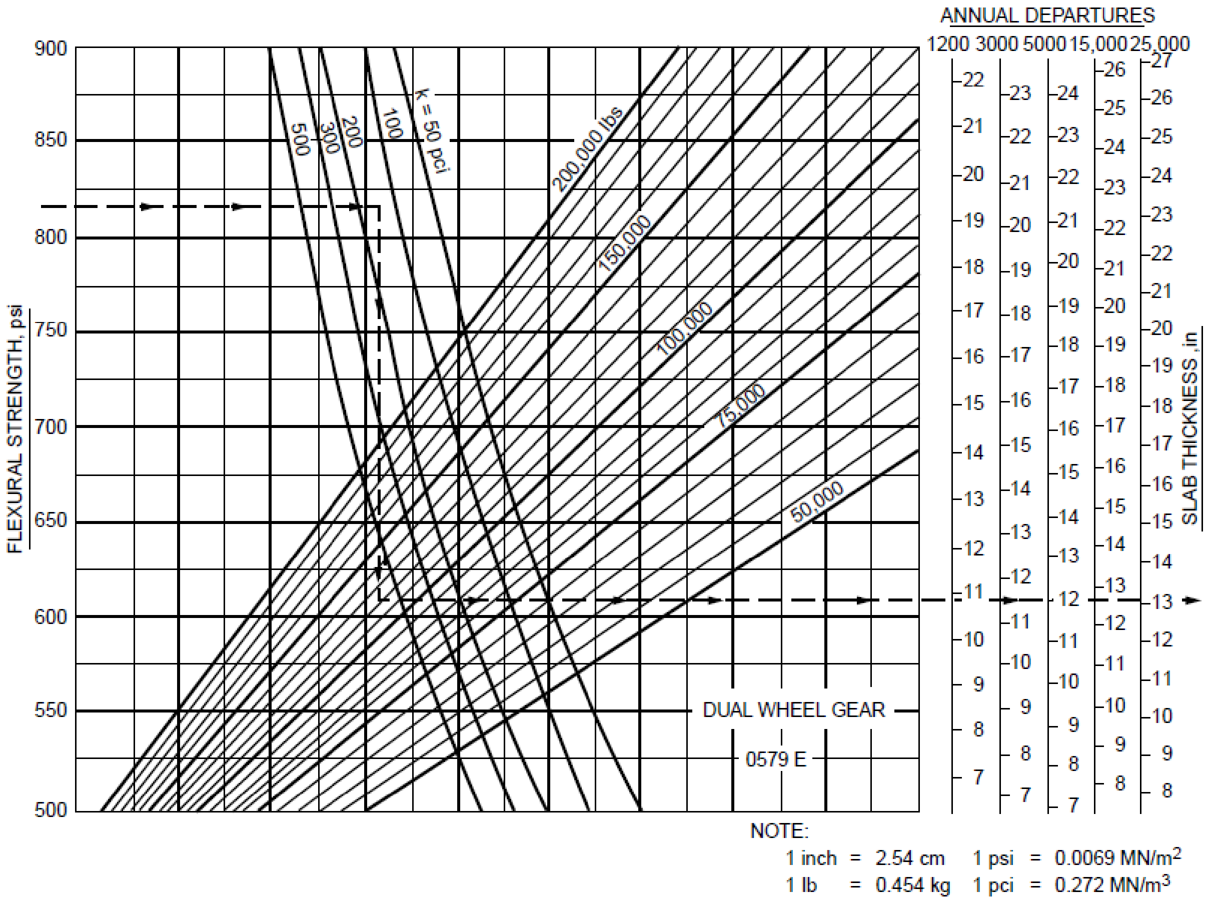


Figure (2) Rigid pavement thickness for dual – wheel gear.

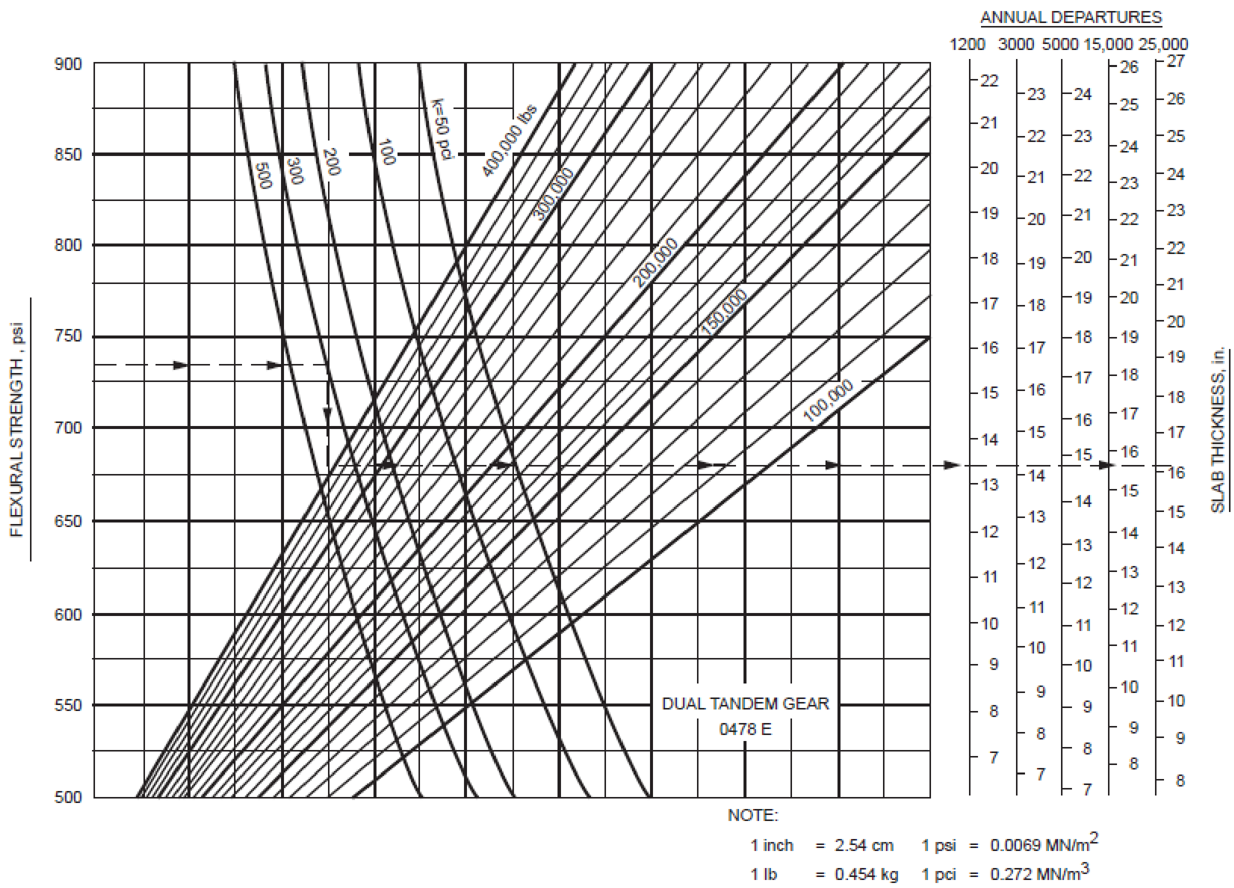


Figure (3) Rigid pavement thickness for dual – tandem gear.

Example (1):-

Determine the required thickness of concrete slab to be used for a given runway used by a design aircraft dual – wheel gear of 110000 Ib gross weight. The 90- day flexural strength of concrete is found to be 815 psi. The modulus of subgrade reaction (K) is 100 pci, and the annual equivalent departures were expected to be 3000.

Solution:-

From figure (2) rigid pavement thickness for dual – wheel gear. With 90- day flexural strength of concrete is found to be 815 psi on y-axis a line extended horizontally to its intersection with the appropriate modulus of subgrade reaction (k) line of 100 pci vertically to the aircraft gross weight line of 110 Ib, then horizontally to the annual departure 3000.

The slab thickness = 11.5 in

EQUIVALENT DESIGN DEPARTURES

To account for the effects of all traffic in terms of the design aircraft, convert all aircraft to the same landing gear type as the design aircraft. This is done by multiplying the number of departures by a factor selected from Table 12.8.

Annual Departures

Aircraft Type	Design Aircraft	Conversion Factor F
Single-wheel	Dual-wheel	0.8
Single-wheel	Dual-tandem	0.5
Dual-wheel	Dual-tandem	0.6
Double dual-tandem	Dual-tandem	1.0
Dual-tandem	Single-wheel	2.0
Dual-tandem	Dual-wheel	1.7
Dual-wheel	Single-wheel	1.3
Double dual-tandem	Dual-wheel	1.7

Note: Multiply the annual departures of given aircraft type by the conversion factor to obtain annual departures in design aircraft landing gear.

Convert the annual departures of all aircraft to equivalent annual departures of the design aircraft by the following formula:

$$\log R_{eq} = \log(R_i \times F_i) \times \left\{\frac{W_i}{W}\right\}^{0.5}$$

Where :

*R*eq = equivalent annual departures by the design aircraft

Ri = annual departures of aircraft type *i*

Fi = conversion factor obtained from

W = wheel load of the design aircraft

Wi = wheel load of aircraft *i*

Example (2):-

An airport pavement is to be designed for the traffic mix tabulated below. Convert the traffic to equivalent DC-8-61 departures.

Aircraft (Wheel Configuration)	Departures, R	Load per Wheel, W
CV-880 (Dual-tandem)	3,100	21,800
DC-9-32 (Dual)	11,00	25,200
DC-8-61 (Dual-tandem)	3,000	39,400

Convert the traffic to equivalent Dc-8-61 departures. The flexural strength of the concrete is 800 psi, and the modulus of subgrade reaction at the airport site is 200 pci. Determine the required thickness of concrete runway slab to carry a design aircraft of 150 000 Ib gross weight.

Solution:

For the CV-880 group,

$$\log R_1 = \log(1 \times 3{,}000) \quad \left(\frac{21{,}800}{39{,}400}\right)^{1/2} = 2.5966$$

$$R_1 = 395$$

For the DC-9-32 group,

$$\log R_1 = \log(0.6 \times 11{,}000) \quad \left(\frac{25{,}200}{39{,}400}\right)^{1/2} = 3.0547$$

$$R_1 = 1134$$

For the DC-8-61 group, $R_1 = 3000$, and

$$\text{total equivalent DC-8-61 departures} = 395 + 1134 + 3000 = 4529$$

Jointing of Concrete Pavements. Variations in temperature and moisture content produce volume changes and warping of pavement slabs and cause significant stresses to occur. To reduce the effects of these stresses and to control pavement cracking, joints are installed. By this means, the pavement is divided into a series of slabs of predetermined dimensions. Various types of joints are shown in Figure 12.15, typical uses of these joints are described in Table 12.10.

a- **Joint Categories. Pavement joints are categorized according to the function, which the joint is intended to perform. The categories are expansion, contraction, and construction joints. All joints regardless of type should be finished in a manner which permits the joint to be sealed. The various joints are describes as follows:**

1. *Expansion joints* provide space for the expansion of the pavement and are most commonly used between intersecting pavements and adjacent to structures. Two types of expansion joints are used: those that provide load transfer across the joint (Type A, Figure 12.15), and those that do not (Type B).
2. *Contraction joints* provide controlled cracking of the pavement that occurs because of contraction. The contraction may be caused by a decrease in moisture content, a drop in temperature, or by the shrinkage which accompanies the curing process. Contraction joints also reduce the stresses caused by slab warping. Details for contraction joints are shown as Types F, G, and H in Figure 12.15.
3. *Construction joints* are required when two abutting slabs are constructed at different times, such as the end of a work day, or between paving lanes. Details for construction joints are shown as Types C, D, and E in Figure 12.15 (8).

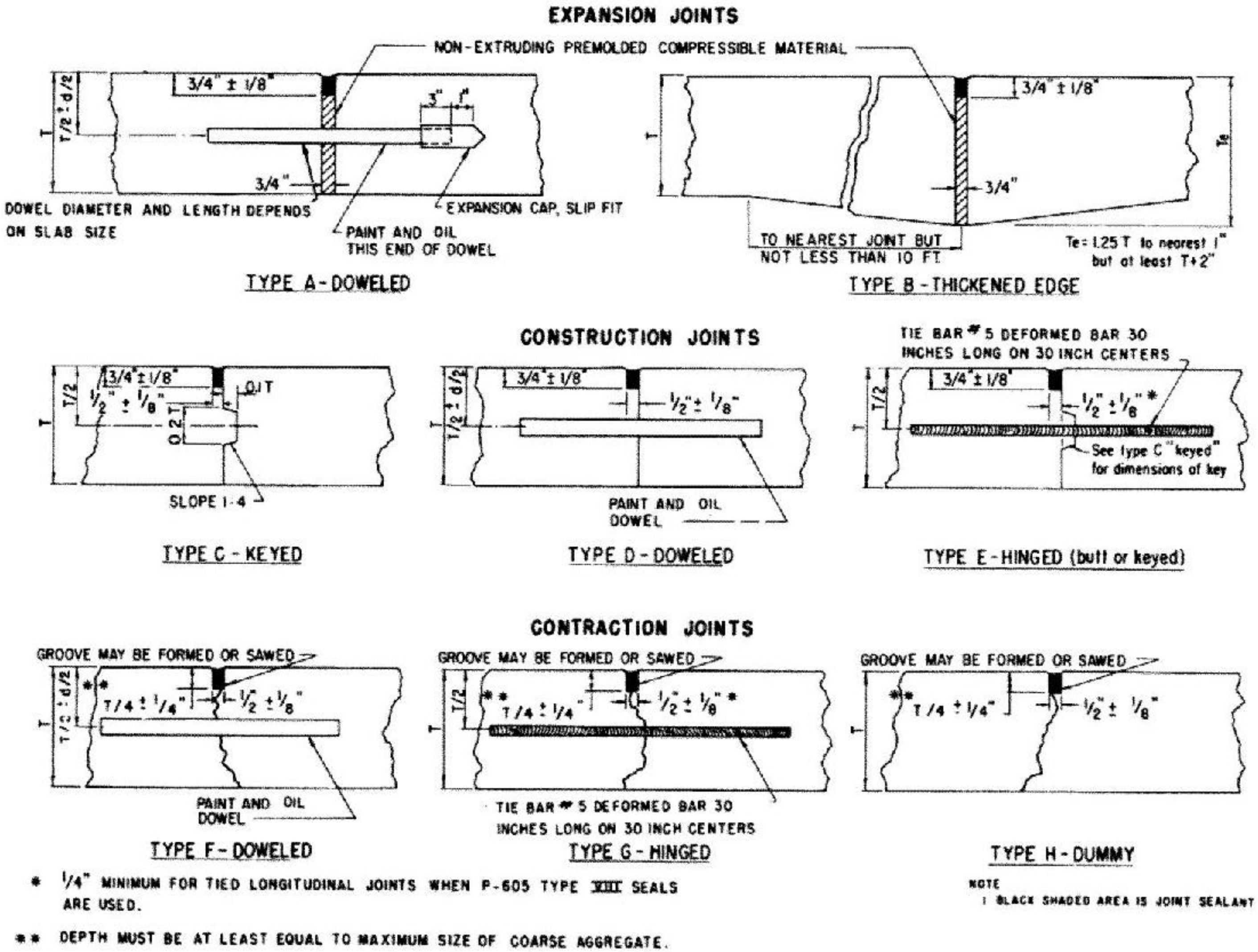
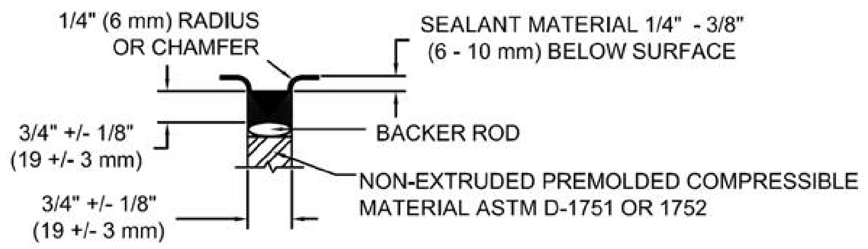
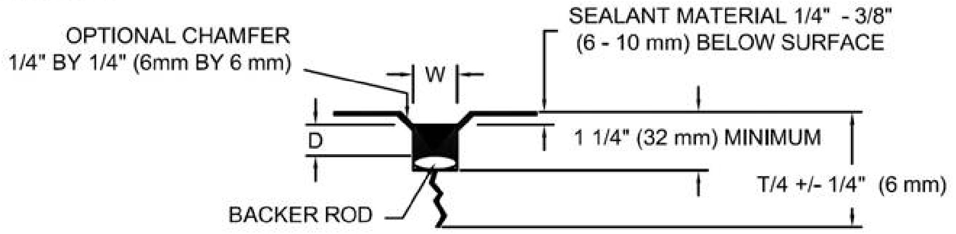


FIGURE 12.15 Details of joints in rigid pavement. (*Source*: Reference 8)

DETAIL 1
ISOLATION JOINT



DETAIL 2
CONTRACTION JOINT



DETAIL 3
CONSTRUCTION JOINT

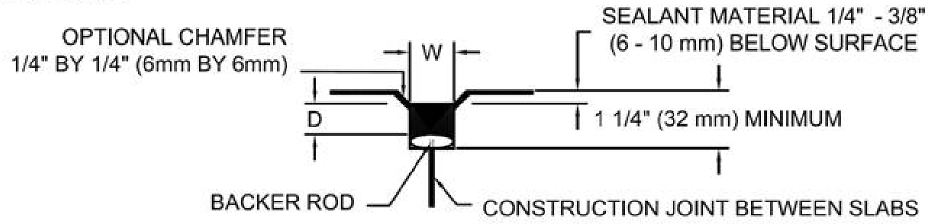


TABLE 12.10 Joint Types: Description and Use

Type	Description	Longitudinal	Transverse
A	Doweled expansion joint	—	Use near intersections to isolate them
B	Thickened edge expansion joint	Use at intersections where dowels are not suitable and where pavements abut structures	Provide thickened edge (or keyway) where pavement enlargements is likely
C or D	Keyed or doweled construction joint	Use for all construction joints except where type E is used; keyed joints are not recommended for slabs <9 in. thick	Use type D where paving operations are delayed or stopped
E	Hinged construction joint	Use for all contraction joints of the taxiway and for all other contraction joints placed 25 ft or less from the pavement edge, unless wide-body aircraft are expected	—
F	Doweled contraction joint	—	Use for contraction joints for a distance of at least three joints from a free edge, for the first two joints on each side of expansion joints, and for all contraction joints in reinforced pavements
G	Hinged contraction joint	Use for all contraction joints of the taxiway and for all other contraction joints placed 25 ft or less from the pavement edge, unless wide-body aircraft are expected	
H	Dummy contraction joint	Use for all other contraction joints in pavement	Use for all remaining contraction joints in nonreinforced pavements

Source: *Airport Pavement Design and Evaluation*, FAA Advisory Circular AC 150/5320-6C, including changes 1 and 2, September 14, 1988.

TABLE (2) PAVEMENT JOINT TYPES

TYPE	DESCRIPTION	LONGITUDINAL	TRANSVERSE
A	Thickened Edge Isolation Joint	Use at intersections where dowels are not suitable and where pavements abut structures. Consider at locations along a pavement edge where future expansion is possible.	Use at pavement feature intersections when the respective longitudinal axis intersects at an angle. Use at free edge of pavements where future expansion, using the same pavement thickness is expected.
B	Hinged Contraction Joint	For all contraction joints in taxiway slabs < 9 inches (230 mm) thick. For all other contraction joints in slabs < 9 inches (230 mm) thick, where the joint is placed 20 feet (6 m) or less from the pavement edge.	Not used.
C	Doweled Contraction Joint	May be considered for general use. Consider for use in contraction joints in slabs > 9 inches (230 mm) thick, where the joint is placed 20 feet (6m) or less from the pavement edge.	May be considered for general use. Use on the last three joints from a free edge, and for three joints on either side of isolation joints.
D	Dummy Contraction Joint	For all other contraction joints in pavement.	For all other contraction joints in pavement.
E	Doweled Construction Joint	All construction joints excluding isolation joints.	Use for construction joints at all locations separating successive paving operations ("headers").

2-**<u>Flexible airport pavement design:-</u>**

Flexible pavements consist of a hot mix asphalt wearing surface placed on a base course and, a subbase resting on subgrade conditions. The entire flexible pavement structure is ultimately supported by the subgrade. Definitions of the function of the various components are given in the following paragraphs.

1- **HOT MIX ASPHALT SURFACING.** The hot mix asphalt surface or wearing course must prevent the penetration of surface water to the base course; provide a smooth, well-bonded surface free from loose particles which might endanger aircraft or persons; resist the shearing stresses induced by aircraft loads. To successfully fulfill these requirements, the surface must be composed of mixtures of aggregates and bituminous binders which will produce a uniform surface of suitable texture possessing maximum stability and durability.

2- **BASE COURSE.** The base course is the principal structural component of the flexible pavement. It has the major function of distributing the imposed wheel loadings to the pavement foundation, the subbase and/or subgrade. The base course must be of such quality and thickness to prevent failure in the subgrade, withstand the stresses produced in the base itself, and resist volume changes caused by fluctuations in its moisture content.

3- **SUBBASE,** A subbase is included as an integral part of the flexible pavement structure in all pavements except those on subgrades with a CBR value of 20 or greater . The function of the subbase is similar to that of the base course.

4- **SUBGRADE.** The subgrade soils are subjected to lower stresses than the surface, base, and subbase courses. Subgrade stresses attenuate with depth, and the controlling subgrade stress is usually at the top of the subgrade, unless unusual conditions exist. Unusual conditions such as a layered subgrade or sharply varying water contents or densities can change the location of the controlling stress.

<u>Methods of the flexible pavement design:</u>

1- California Bearing Ratio Method (CBR Method)
2- The FAA Method of Flexible Pavement.
3- The Canadian Department of Transportation.
4- The Asphalt Institute Method.

FAA Method of Flexible Pavement.

This method of design depends on the:

1- **C**alifornia **B**earing **R**atio (**CBR**)
2- The gross weight of the design aircraft.
3- The equivalent annual departures.
4- Design aircraft gear configuration.

The design procedure is performed by using the following figures :
Fig.(3-2) for single wheel gear.
Fig.(3-3) for Dual wheel gear.
Fig.(3-3) for Dual Tandem wheel gear.
The design curves provide the required total thickness of flexible pavement (surface, base, and subbase) needed to support a given weight of aircraft over a particular sub-grade. Table (3-4) gives the minimum thickness of base course for various materials and design loading.

TABLE 3-4. MINIMUM BASE COURSE THICKNESS

Design Aircraft	Design Load Range		Minimum Base Course Thickness	
	lbs.	(kg)	in.	(mm)
Single Wheel	30,000 - 50,000 50,000 - 75,000	(13600 - 22 700) (22700 - 34 000)	4 6	(100) (150)
Dual Wheel	50,000 - 100,000 100,000 - 200,000	(22700 - 45 000) (45 000 - 90 700)	6 8	(150) (200)
Dual Tandem	100,000 - 250,000 250,000 - 400,000	(45 000 - 113 400) (113400 - 181 000)	6 8	(150) (200)
757 767	200,000 - 400,000	(90700 - 181000)	6	(150)
DC-10 L1011	400,000 - 600,000	(181 000 - 272000)	8	(200)
B-747	400,000 - 600,000 600,000 - 850,000	(181 000 - 272000) (272 000 - 385 700)	6 8	(150) (200)
c-130	75,000 - 125,000 125,000 - 175,000	(34 000 - 56 700) (56700 - 79 400)	4 6	(100) (150)

Note: The calculated base course thicknesses should be compared with the minimum base course thicknesses listed above. The greater thickness, calculated or minimum, should be specified in the design section.

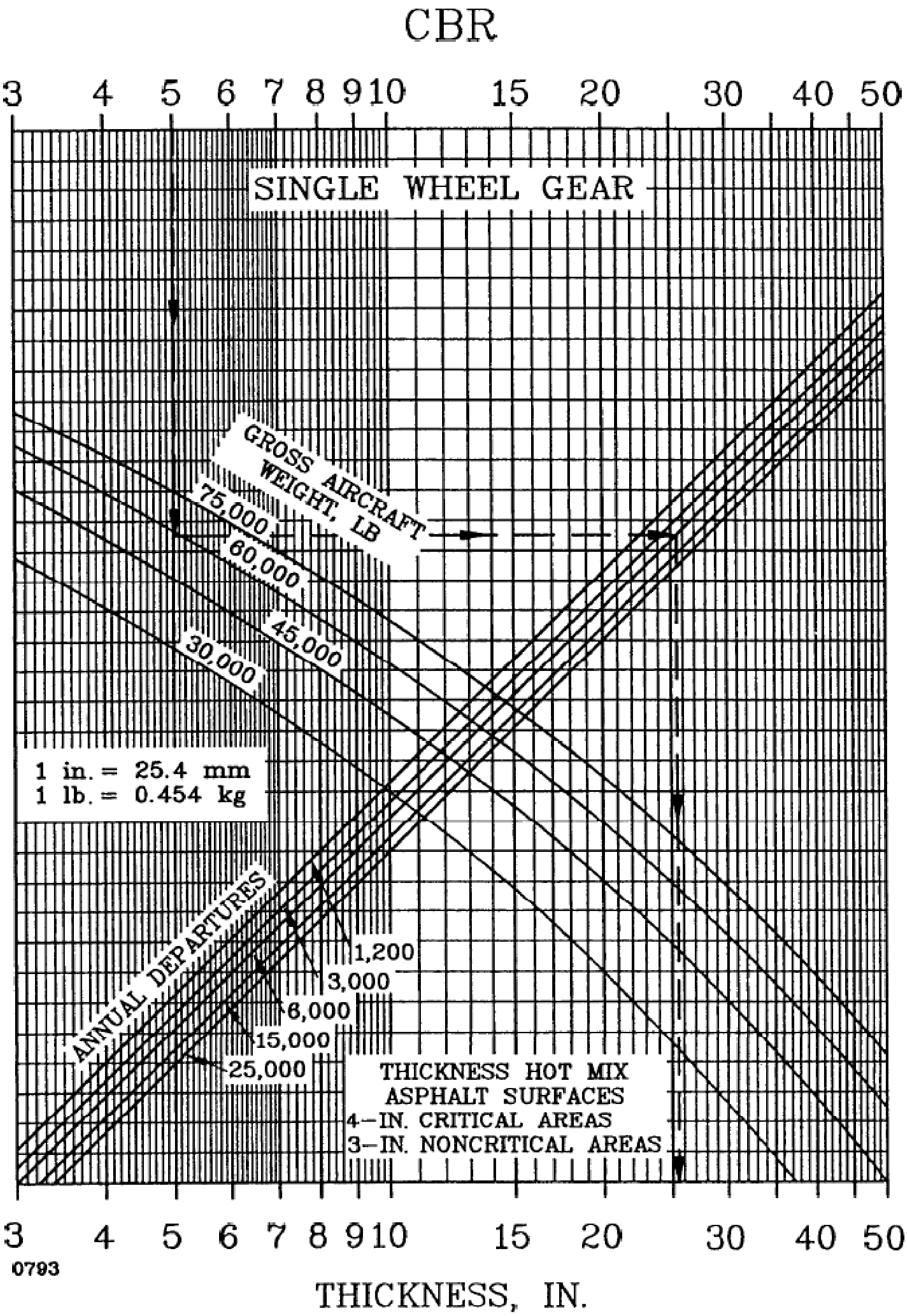


FIGURE 3-2 FLEXIBLE PAVEMENT DESIGN CURVES, SINGLE WHEEL GEAR

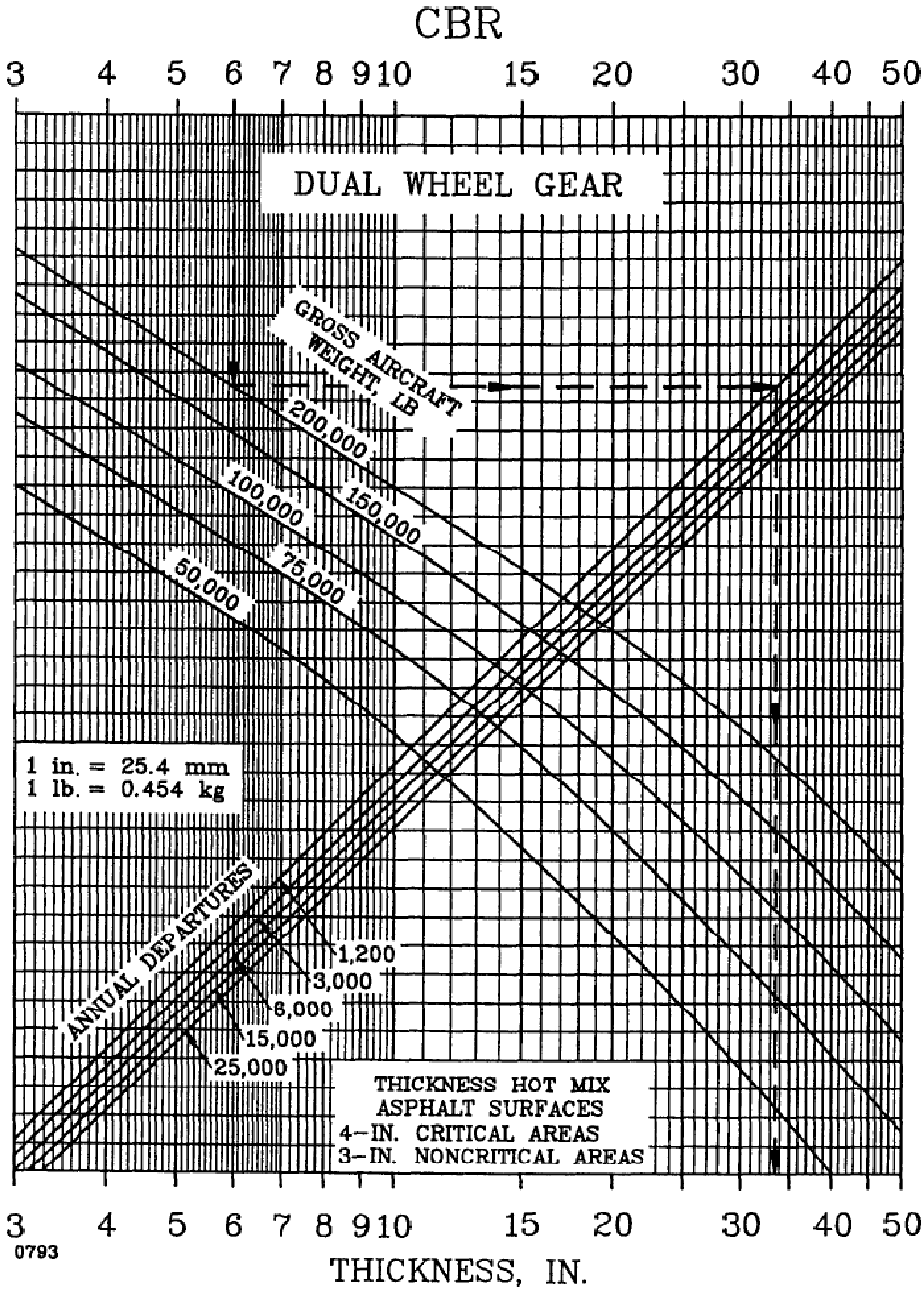


FIGURE 3-3 FLEXIBLE PAVEMENT DESIGN CURVES, DUAL WHEEL GEAR

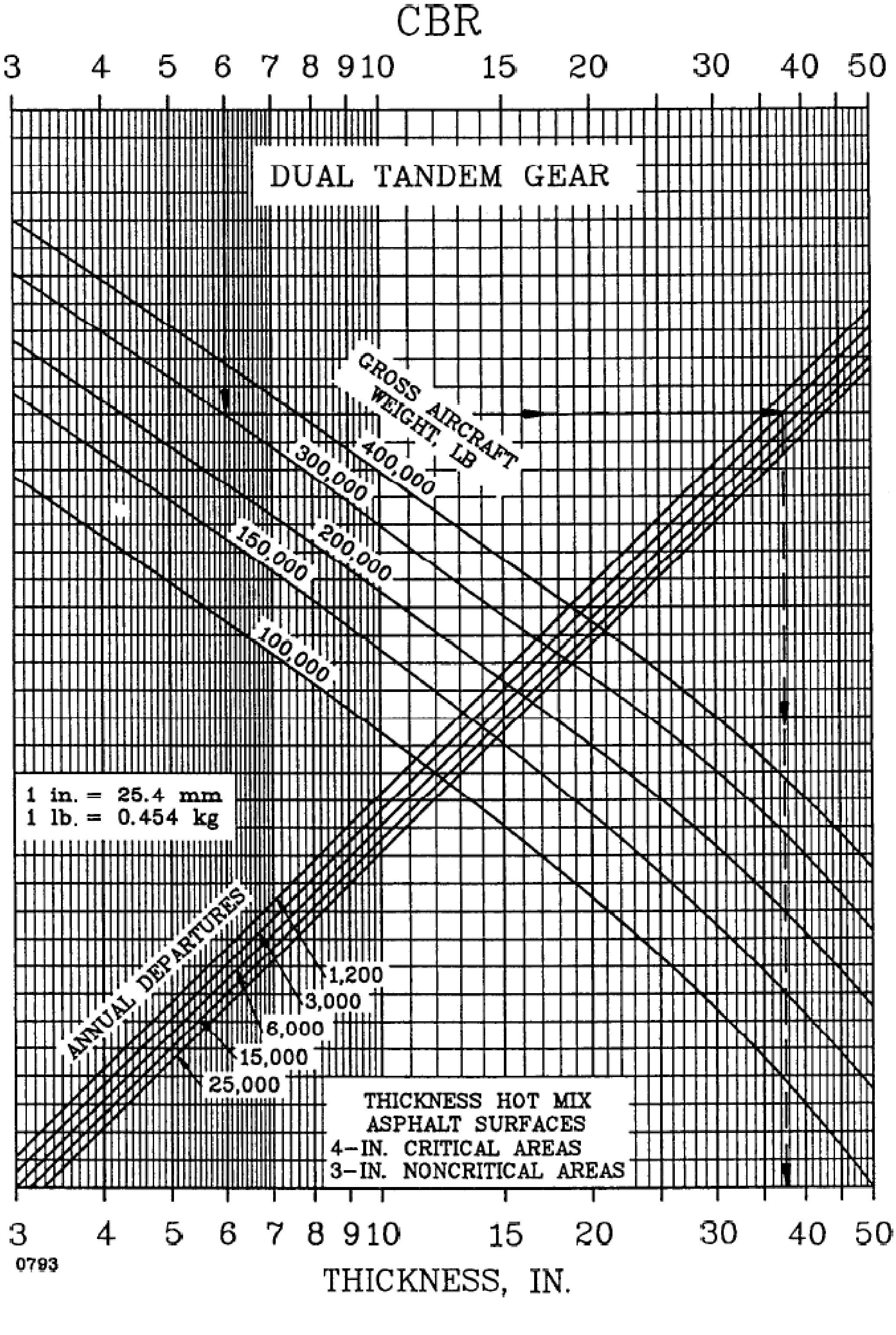


FIGURE 3-4 FLEXIBLE PAVEMENT DESIGN CURVES, DUAL TANDEM GEAR

DESIGN EXAMPLE:-

Design a flexible pavement for an airport for a dual gear aircraft 727-200 having a gross weight of 75,000 pounds (34 000 kg). Design CBR values for the subbase and subgrade are 20 and 6, respectively. The annual equivalent departure of the design aircraft is 6,000.

Solution :

1- Total Pavement Thickness.

The total pavement thickness required is determined from Figure 3-3. Enter the upper abscissa with the subgrade CBR value, 6.

Project vertically downward to the gross weight of the design aircraft, 75,000 pounds (34 000 kg). At the point of intersection of the vertical projection and the aircraft gross weight, make a horizontal projection to the equivalent annual departures, 6000. From the point of intersection of the horizontal projection and the annual departure level, make a vertical projection down to the lower abscissa and read the total pavement thickness; in this example - 23 inches (584 mm).

2- Thickness of Subbase Course.

The thickness of the subbase course is determined in a manner similar to the total pavement thickness. Using Figure 3-3, enter the upper abscissa with the design CBR value for the subbase, 20. The chart is used in the same manner as described in "1" above, i.e., vertical projection to aircraft gross weight, horizontal projection to annual departures, and vertical projection to lower abscissa. In this example the thickness obtained is 9.5 inches (241 mm). This means that the combined thickness of hot mix asphalt surface and base course needed over a 20 CBR subbase is 9.5 inches (241 mm), thus leaving a subbase thickness of 23 - 9.5 = 13.5 inches (343mm).

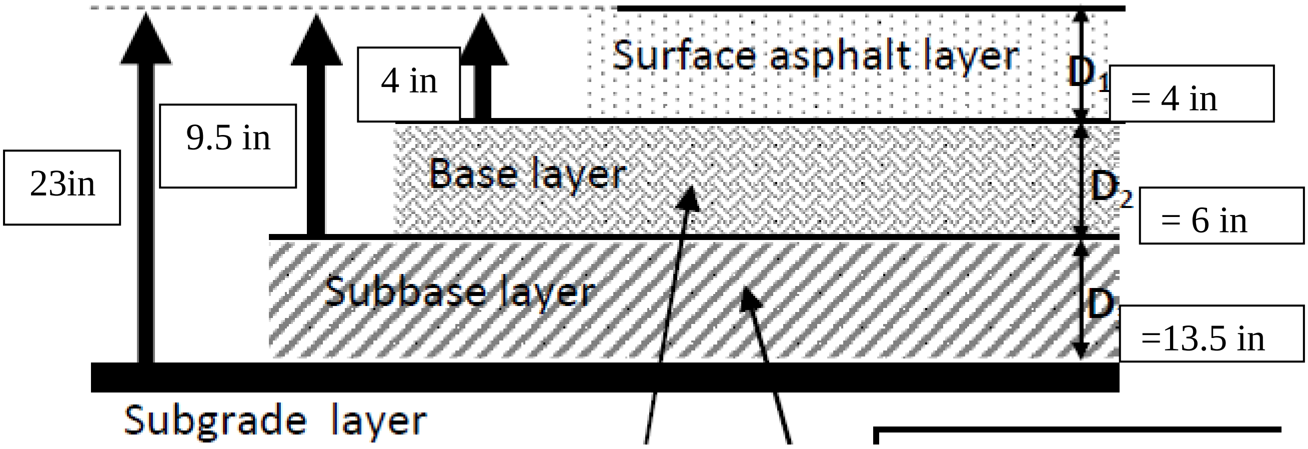
3- Thickness of Hot Mix Asphalt Surface.

As indicated by the note in Figure 3-3, the thickness of hot mix asphalt surface for critical areas is 4 inches (100 mm) and for noncritical, 3 inches (76 mm).

4- **Thickness of Base Course.**

The thickness of base course can be computed by subtracting the thickness of hot mix asphalt surface from the combined thickness of surface and base determined in

“2” above; in this example 9.5 - 4.0 = 5.5 (150 mm) of base course. The thickness of base course thus calculated should be compared with the minimum base course thickness required as solve in Table 3-4. Note that the minimum base course thickness is 6inches (150 mm) from Table 3-4. Therefore the minimum base course thickness from Table 3-4, 6 inches (152 mm), would control. If the minimum base course thickness from Table 3-4 had been less than the calculated thickness, the calculated thickness would have controlled.



Thickness of Noncritical Areas.

The total pavement thickness for noncritical areas is obtained by taking 0.9 of the critical pavement base and subbase thicknesses plus the required hot mix asphalt surface thickness given on the design charts. For the thinned edge portion of the critical and noncritical pavements, the 0.7T factor applies only to the base course because the subbase should allow for transverse drainage. The transition section and surface course requirements are as noted in Figure 3- 1.

THICKNESS REQUIREMENTS

	Critical in. (mm)	Non-Critical in. (mm)	Edge in. (mm)
Hot Mix Asphalt Surface (P-209 Base)	4 (100)	3 (75)	2 (50)
Base Course (P-209, or P-21 1)	6 (200)	5 (1`25)	4 (100)
Subbase Course (P-154)	14 (355)	13 (330)	10 (255)
Transverse Drainage Course (if needed)	0 (0)	3 (75)	8 (205)

Airport Drainage System

نظام تصريف مياه الإمطار في المطارات يجب أن يمتاز بالمميزات التالية (يحقق الأهداف التالية)

1- **Safety**

يتم أنشاء أنظمة تصريف مياه الأمطار لغرض الأمان وذلك بالتخلص منها للتقليل من حوادث الانزلاق وتقليل skip

2- **Efficiency** أنظمة تصريف مياه الإمطار يجب أن تكون كفوءة وجيدة في عملها

3- **Durability** أنظمة تصريف المياه يجب ان تكون مستمرة في عملها (ديمومة عملها مستمرة)

Important Principle الخطوات الرئيسية المهمة في تصميم نظام التصريف

1) **Estimation Runoff.**
2) **Design a Base Drainage System for Collection and Disposal of Runoff.**
3) **Prevision for Adequate Subsurface Drainage.**

1) Estimation of Runoff:-

في البداية يجب تخمين او تقدير كمية مياه الأمطار التي سوف تسقط وذلك من خلال المعلومات الإحصائية المتوفرة وهنالك عدة طرق يمكن استخدامها ومنها:-

Rational Method

Q = C *I* A

Where

C : Coefficient of runoff: is the ratio between quantity of runoff to the total precipitation area which falls on the drainage area.

I : Runoff intensity.

A : Catchment area.

النسبة بين كمية المياه الامطار التي تجري على السطح الى الكمية الكلية الساقطة .عند سقوط الامطار فان قسما منها سوف ينفذ داخل التربة وقسم اخر سوف يجري على السطح فالنسبة بينهما تمثل معامل الامطار

C = (H / Total)

وهذا المعامل يعتمد على العوامل التالية:

١- Slope ميل المنطقة يؤثر بصورة كبيرة حيث سوف يزيد من سرعة التصريف بالنسبة للميل الحالي ويقلل من H وبالتالي يقل C وبالعكس.

٢- Soil Condition نوعية التربة الموجودة بالمنطقة.

أ- نفاذة او غير نفاذة (النفاذية تقلل من H وتقل C).

ب- حالة التربة (مشبعة : لاتمتص الماء وبالتالي يزداد H ويزداد C او غير مشبعة: تمتص الماء وبالتالي يقل H ويقل C

ت- Vegetations النباتات الموجودة ونوعيتها وتاثيرها بالتقليل من H

ث- Land use استخدامات الارض حيث كلما تزداد الابنية سوف تزداد المساحات الغير نفاذة وبالتالي سوف يزداد H

Runoff Intensity:

Is the rate of rain which falls typically expressed by (in/hr)

1- Duration: الفترة الزمنية التي يستغرقها المطر حيث نلاحظ في بداية سقوط المطر تكون الشدة عالية وتقل بمرور الوقت

2- Frequency: فترة تكرار المطر (ما مدة عودة المطر)

Time of Concentration:

Is the time required for a particle of water to flow from most remote point of drainage area to point of investigated

الفترة الزمنية التي تستغرقها قطرة الماء للجريان من ابعد نقطة في المساحة الى نقطة الماخذ لنظام التصريف

- For design purpose the time of concentration is equal to duration of runoff لأغراض التصميم نفرض بان الزمن اللازم للوصول = فترة سقوط المطر
  1- Time of surface flow (inlet time, time of overload flow)
  2- Flow time within structural design system.

<u>الزمن اللازم للجريان السطحي يعتمد على العوامل التالية:</u>

١- **<u>Land slope</u>** : ميل السطح حيث نلاحظ بانه (في الميل العالي تزداد سرعة الجريان ويقل الوقت اما في الميل الواطىء تقل سرعة الجريان ويزداد الوقت)

٢- **<u>Type of surface</u>** : نوعية السطح (اذا صقيل يزيد سرعة الجريان ويقل الوقت اما اذا كان غير صقيل تقل سرعة الجريان ويزداد الوقت)

٣- **<u>Size and shape of drainage area</u>** : حجم منطقة التصريف (اذا كانت كبيرة تحتاج وقت اكبر مما اذا كانت صغيرة) اما شكل منطقة التصريف فتكون اما بسيطة او معقدة

- **<u>يمكن تخمين مقدار الوقت اللازم للتصريف السطحي من خلال العلاقة التالية:</u>**

1) $T = \dfrac{1.8\,(1.1 - C) * (D)^{1/2}}{(S)^{1/3}}$

Where: T ; Surface time flow.
C ; Coefficient of runoff.
S ; Slope %.
D ; Distance of most remote point.

2- Flow time within the structural drainage system $= \left(\dfrac{\text{length of structure drainage}}{\text{velocity of flow } (\frac{ft}{sec})}\right)$

2) Collection and disposal of runoff:

a- layout of the drainage system

1) Design of underground pipe system.
2) Design of open channel.
3) Inlets, Munhall, and others.

Pipes Design as Open Channels Based on Manning's Formula

- Manning Equation

<u>Design of Drainage</u>: هناك طريقتين لتصميم انظمة التصريف

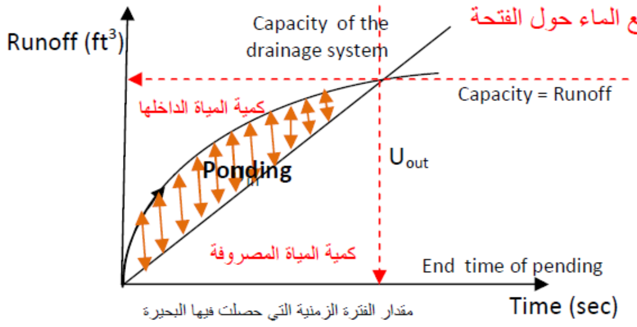
1- Without Ponding :

في هذه الطريقة يجب ان تكون كمية المياه المتجمعة حول الفتحة inlet ضمن قابلية او استيعاب الفتحة للتصريف بحيث لاتسمح بتكوين بركة من الماء

2- With Ponding

في هذه الطريقة يجب ان تكون كمية المياه المتجمعة حول الفتحة inlet اكبر من قابلية او استيعاب الفتحة للتصريف بحيث تسمح بتكوين بركة من الماء

في التصميم لايفضل النظام الذي يسمح بتكوين بركة يتجمع الماء حول الفتحة



في بداية سقوط الامطار تكون كميتها عالية وبالتالي فان الفتحة سوف تصرف حسب استيعابها مما يؤدي الى تكوين بركة من الماء حول الفتحة وهكذا باستمرار سقوط الامطار سوف تقل شدتها وكميتها وتقل البركة الى ان يصل الاستيعاب يساوي الساقط

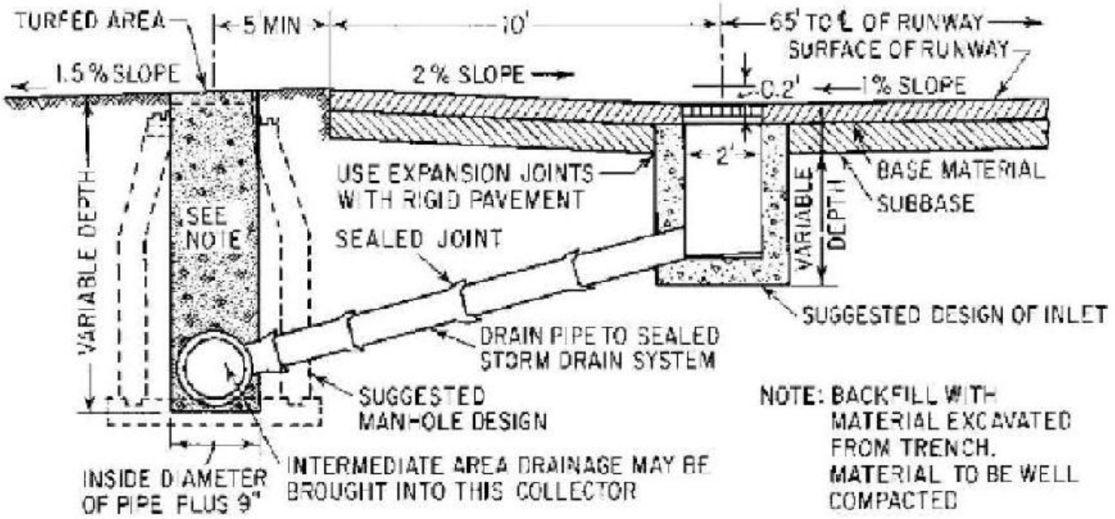
3- Surface Drainage System

a- Avoid saturation and weakening of pavement foundation layer

b- Control and prevent of danger of forstheart

في هذا النظام تكون عملية تصريف المياه من خلال استخدام خواص معينة (نفاذية باتجاه معين وغير قابلة للامتصاص)

- Sandy clay, sandy silt , clayly silt
- Subsurface drainage system (1- base and subgrade drains, 2- intercepting)



Drainage inlet at outer edge of runway in northern climates. (*Feder*

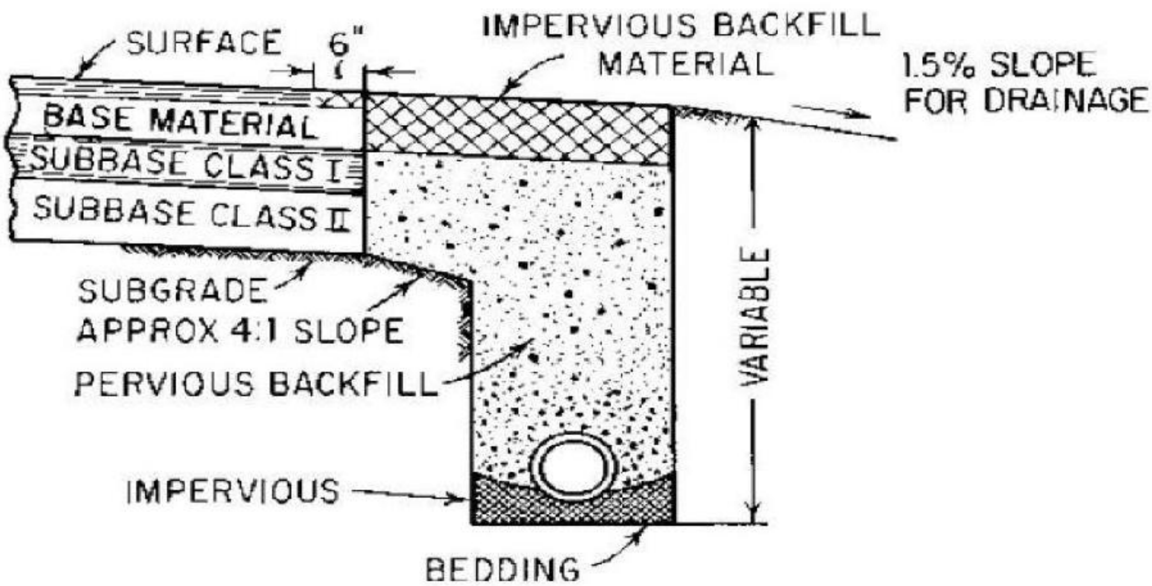


Fig. 18.14 Combined interceptor and base drain. (*Federal Aviation Administration.*)

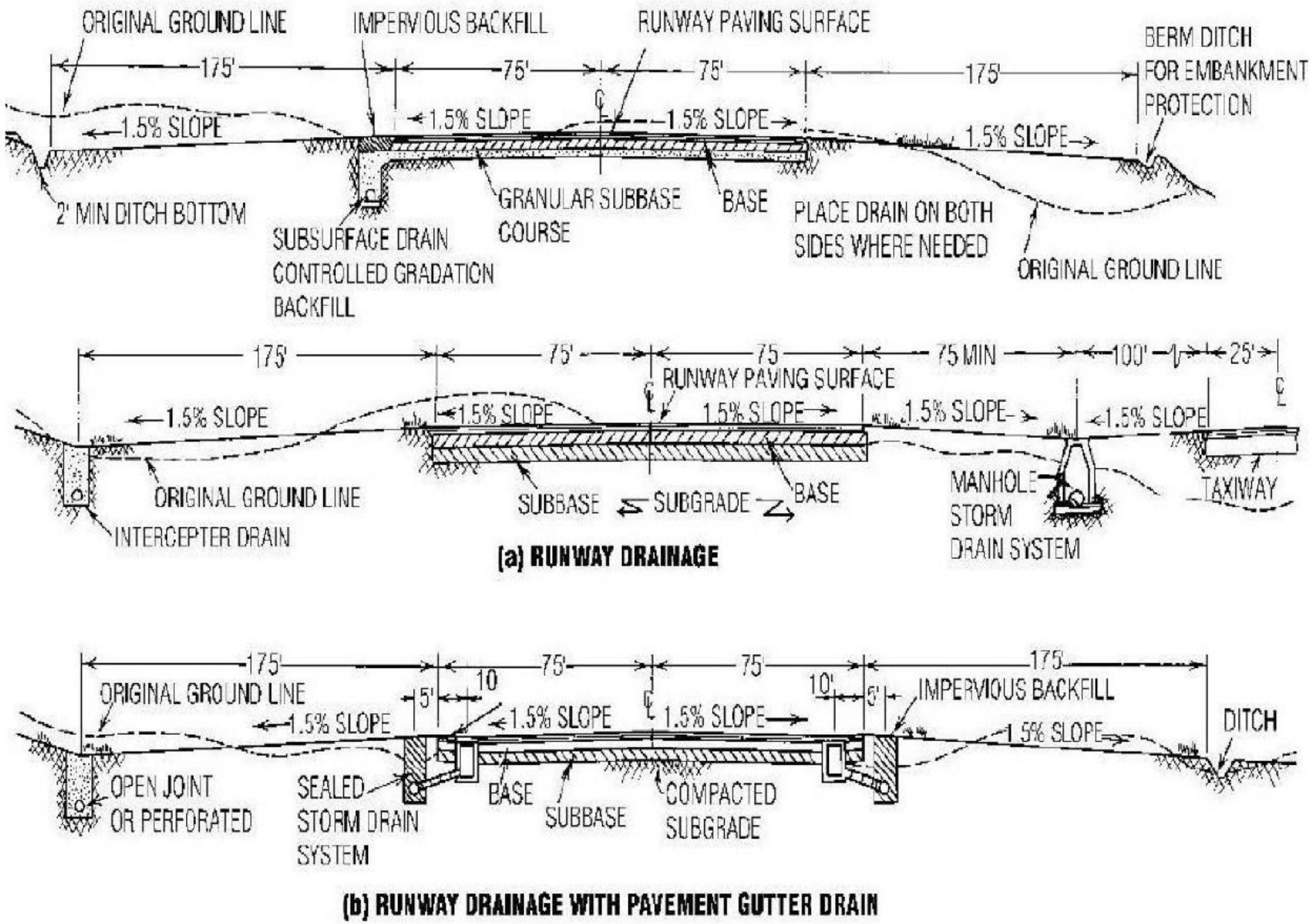


Fig. 18.12 Runway cross sections showing typical provisions for drainage.

Railway Engineering

Introduction

Railway is basically built for three reasons:

- i- Economy.
- ii- Safety.
- iii- Military.

ان الغرض الأساسي من انشاء خط السكة الحديدية الأسباب التالية :

1- اقتصادية (عملية نقل البضائع تكون اكثر اقتصادية بأستخدام خط السكة الحديدية وذلك لأنخفاض الكلفة مقارنة مع وسائل النقل الأخرى).

2- الأمان (عملية النقل بأستخدام خط السكة الحديدية اكثر امانا مقارنة مع وسائل النقل الأخرى).

3- عسكرية (نقل المعدات العسكرية الثقيلة).

<u>Traffic on railway:</u>

1- Fright traffic = 90% (tons/ mile).
2- Passenger traffic = 10% (passenger / mile).

<u>Classification of Transport Systems on the basis of :</u>

1- Surface of Transport
   - a- Land Transport
   - b- Water Transport
   - c- Air Transport

2- Degree of Freedom
   a- System of one degree of freedom.
   b- System of Two degree of freedom.
   c- System of three degree of freedom.

Water Transport: provide facilities for transport of heavy and bulk commodities where time may not be of movement importance.

Air Transport: obtains maximum utility where safely of time is almost importance rather than the others.

Land Transport: door to door service.

**** Railway Transport:** have the greatest utilization in the transport of large volumes of heavy and bulk commodities over long distance.

<u>Revenues & Cost:</u>

- Capital Expenditure:
  1- Road & Equipment (R &E).
  2- Additions & Betterment.
  3- Depreciation & Renewals.
- Operation Expenditure:
  1- Maintenance
     a- Way. b- Structure. 20%
     b- Equipment 25%
  2- Transportation 45%
  3- Administration 10%
- Operation Revenues:
  Mainly revenues is from fright traffic > 95%
  And the other revenues is from passengers < 5%
  ** Operation ratio = Operation Expenditure / Operation Revenues
  The ratio should be in minimum value

<u>Railway Network in Iraq:</u>

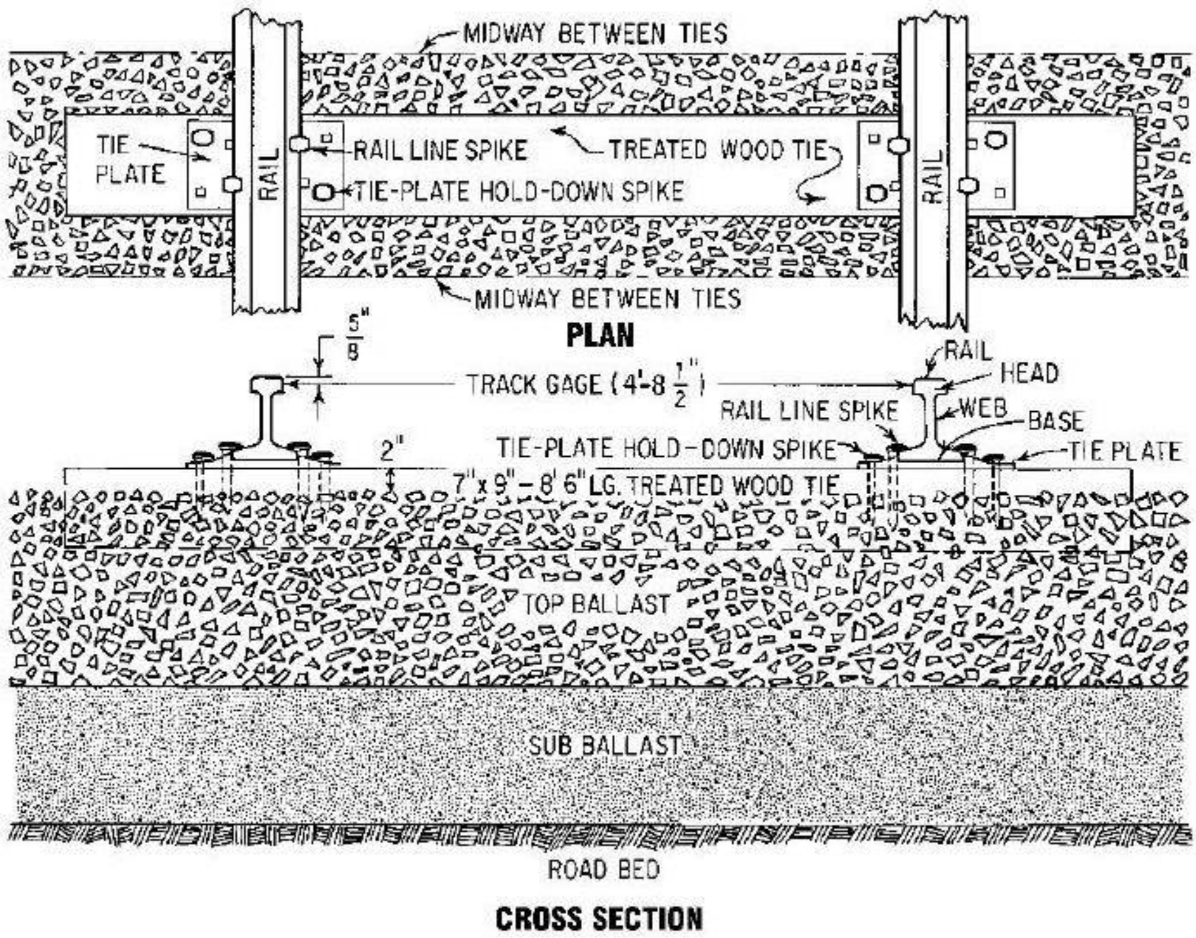
Baghdad – Mosul	412 km
Mosul – Rabi	112 km
كركوك – حديثة – بيجي	272 km
Baghdad – Basrah	542 km
بغداد – شعيبة	576 km
القائم – عكاشات	150 km

Baghdad Line (Istanbul- Baghdad) 2400 km 1903-1940

<u>Capacity:</u>

2009 Iraq passenger per traffic is 187772 p/year.
Fright traffic 708678 ton/year.

Railway track elements



Typical cross-section of a railway track permanent way

Permanent way:

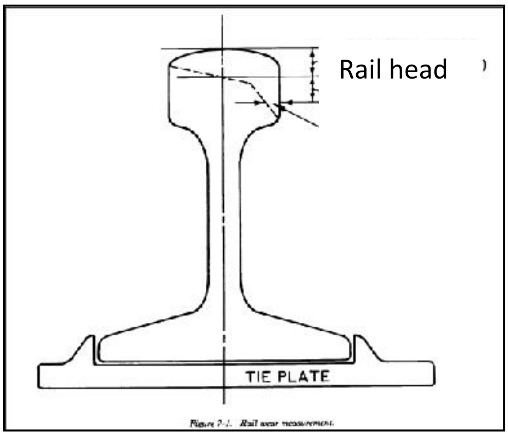
The permanent way or railway track consist generally of two lines of parallel steel rails which bear and guide the flanged wheel of cars and locomotive and which are support on tie plates, ties (sleepers), resting on ballast and subgrade.

1- RAILS:

a- General.

Rails are steel girders which provide the hard and smooth surface for movement of wheels of a locomotive and railway vehicles. They are made of high carbon steel to withstand wear and tear. Flat – footed rails are mostly used in railway track.

b- Functions.



1- Rails provide a hard smooth and un-changing surface for passage of heavy moving loads with a minimum friction between the steel rails and steel wheels.
2- Rails bear the stresses developed due to heavy vertical loads, lateral and braking forces and thermal stresses.
3- The rail material is such that it gives minimum wear to avoid replacement charges and failures of rails due to wear.
4- Rails transmit load to sleepers and consequently reduce pressure on ballast and formation.

c- Types of rail sections:

1- Double headed rails (D.H. Rails).
2- Bull headed rails (B.H. Rails).
3- Flat footed rails (F.F. Rails).

d- Selection of rails.

A rail is designated by its weight per unit length. The various important factors to be considered in deciding the weight of rails to be used are the following:

1- Speed of train.
2- The gauge of the track.
3- The axle load and nature of traffic.
4- Type of rails whether D.H. or B.H. or F.F. rails.

5- Spacing of sleepers or sleeper density.
6- Maximum permissible wear on top of rails. (5 percent of the weight of rail is allowed).
** In Iraq use rail 132 RE =132 Ib/yard = 60 kg/m.

e- Length of rails.

The rails of larger length are preferred to smaller length of rails, because they give more strength and economy for a railway track. The weakest point of track is the joint between two rails. Lesser the number of joints, lesser would be the number of fish plates and this would lead to less maintenance cost, smooth running of trains and comfort to the passengers. Length of rail jointed shall not be less than 15 m long and desirable length is 36m.

2- Tie Plates (Bearing Plates):

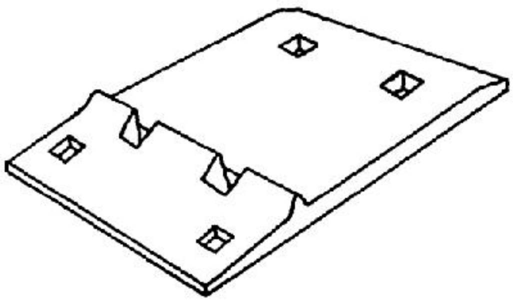


Figure 6-1. Single shoulder tie plate.

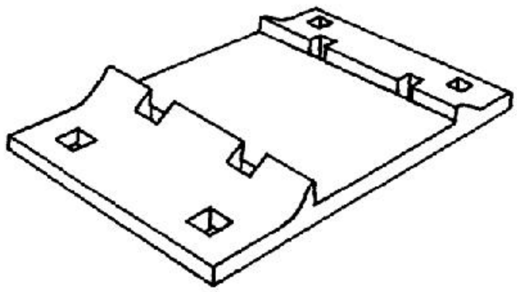


Figure 6-2. Double shoulder tie plate.

a- General.

Bearing plates are rectangular plates are used below rails to distribute the load on a larger area of sleepers.

b- Functions.

1- Provide a large bearing surface on the tie (sleeper) reducing the intensity of bearing pressure.
2- Protect the rail from the longitudinal defects and lateral movement of the rail base.
3- Make spike more effective in holding the rail gauge.
4- Better maintenance of gauge, is possible, if bearing plates are used.

3- BALLAST:

a- General.

Ballast is the granular material packed under the sleepers to transport load from sleepers to subgrade. It helps in providing elasticity to the track. (crashed gravel, crashed limestone).

b- Function of Ballast.

1- Distribute loads uniformly over the subgrade.
2- To hold track structure to line and grade, (prevent or reduce possibility of buckling).
3- To reduce the excess pore water pressure developed in clay subgrade.
4- To provide good drainage of track structure.
5- To reduce dust.
6- To prevent growth of brash and weeds.
7- Reduce frost heave.
8- Simplify the maintenance operations.

c- **Selection criteria.**
   1- Size and gradation.
   2- Shape (angularity).
   3- Weight.
   4- Strength.
   5- Durability.
   6- Cleanliness.
   7- Economics.

d- **Types of ballast.**
   1- Crushed stone.
   2- Prepared gravel.
   3- Sand.
   4- Other material.

<u>Ballast subgrade system:-</u>

According toTelbots formula:

$$h_{min.} = [\frac{16.8\ P_t}{P_s}]^{4/5}$$

Where:

$h_{min.}$= Minimum depth of ballast (and sub ballast if any below the bottom of the tie and over the subgrade (in).

P_t = Allowable bearing pressure over the bearing area of the tie (psi).

P_s = Bearing capacity of subgrade .

<u>Assume:</u>

P_s = 20 psi (average allowable bearing capacity of a normally fine subgrade soil).

P_t = 65 psi (maximum desirable unit tie pressure especially for ballast at less that top quality)

P_t = 85 psi for concrete ties is allowable

For P_t = 65 psi, P_s = 20 psi then $h_{min.} = [\frac{16.8*65}{20}]^{\frac{4}{5}} = 24.5\ in$

For P_t = 85 psi, P_s = 20 psi then $h_{min.} = [\frac{16.8*85}{20}]^{\frac{4}{5}} = 30.41\ in$

$$P_t = \frac{P\ (wheel\ load)}{Tie\ bearing\ area}$$

Where:

$P_{s,bc}$ = Pressure in pound per square inch under the tie center line.

P_t = Uniform distributed pressure over the tie face.

5- Ties (Sleepers):

a- General.

Sleepers are members generally laid transverse to the rail, on which the rails are supported and fixed, to transfer the loads from rails to the ballast and subgrade below.

b- Functions.

1- To hold the rails to proper gauge.
2- To hold the rails in proper level or transverse tilt.
3- To interpose an elastic medium between the ballast and rails.
4- To distribute the load from rails to the ballast underlying it or to the girders in case of bridges.
5- To support the rails at a proper level in straight tracks and at proper superelevation on curves.
6- Sleepers also add to the general stability of the permanent track on the whole.

c- Classification of sleepers:

Sleepers can be classified according to the material uses in their construction, in the following:

1- Wooden sleepers.
2- Metal sleepers.
    a- Cast-iron sleepers.
    b- Steel sleepers.
3- Concrete sleepers.
    a- Reinforced concrete sleepers.
    b- Prestressed concrete sleepers.

1- Timber or wooden sleepers:

Wooden sleepers are regarded to be best as they fulfill almost all the requirements of an ideal sleeper. The life of timber sleepers depends on their ability to resist wearing, decay, attack by vermin i.e., white ants, and quality of the timber used. Following are the advantages and disadvantages of using wooden sleepers.

- **Advantages:-**
  1- Fittings for wooden sleepers are few and simple in design.
  2- These sleepers are able to resist the shocks and vibrations due to heavy moving loads and give less noisy track.
  3- Wooden sleepers are easy to lay, relay, pack, lift and maintain.
  4- These wooden sleepers are suitable for all types of ballast.
  5- They are best for track-circuited operations as wooden sleepers are over all economical.
- **Disadvantages:-**
  1- The sleepers are subjected to wear, decay, attack by white ants, cracking and splitting, rail cutting, etc.
  2- It is difficult to maintain the gauge in case of wooden sleepers.
  3- Track is easily disturbed i.e., alignment maintenance is difficult.
  4- Wooden sleepers have got minimum life (12 to 15 years) as compared to other types of sleepers.
  5- Maintenance cost of wooden sleepers is highest as compared to other sleepers.

2- Metal sleepers:-

Metal sleepers are either of steel or cast-iron. Cast-iron is in greater use than steel for sleepers because it is less prone to corrosion.

- **Advantages:-**
  1- Metal sleepers are uniform in strength and durability.
  2- In metal sleepers, the performance of fitting is better and lesser creep occurs.
  3- Metal sleepers are economical, as life is longer and maintenance is easier.
  4- Gauge can be easily adjusted and maintained in case of metal sleepers.
- **Disadvantages:-**
  1- More ballast are required than other type of sleepers.
  2- Fittings are greater in number.
  3- Metal, C.I. or steel are liable to rust.
  4- Metal being good conductor of electricity interferes with track circuiting.

5- Metal sleepers are unsuitable for bridges, level crossing and in case of points and crossings.
6- Metal sleepers are only suitable for stone ballast.

3- <u>Concrete sleeper:-</u>

These sleepers are mainly of two types

a- Reinforced concrete sleepers.
b- Pre-stressed concrete sleepers.
Experiments have been proved that concrete is an ideal material for the sleepers for the following reasons:
They are made of a strong homogeneous material, impervious to effect of moisture, and is unaffected by the chemical attack of atmospheric gases or sub-soil salts.

- **Advantages :-**

1- These sleepers free from natural decay and attack by insects.
2- They have maximum life compared with the other sleepers. And life under normal conditions is (40 to 60 years).
3- This is not affected by moisture, chemical action of ballast, and sub-soil salts.
4- There is no difficulty in the circuiting.
5- The high weight of sleepers helps in minimizing joint maintenance by providing longer welded lengths, greater stability of the track and better resistance against temperature rise.
6- The sleepers have higher elastic modulus and can resist the stresses introduced by fast and heavy traffic.

- **Disadvantages:-**

1- The weight of concrete sleeper is as high as 2.5 to 3 times of wooden sleeper.
2- These sleepers require pads and plugs for spikes.
3- They damage the bottom edge during the packing.

Gauge in Railway Track:

The gauge of a railway track is defined as
Track gauge is the clear distance between the inside heads of rail 5/8 in below the top of rail.
The distance between the inner faces of a pair of wheels is called **Wheel gauge**.
The different gauges types are:

1- Standard gauge = 1435 mm or 1451mm.
2- Broad (wide) gauge = 1676 mm ,1600mm, or 1524mm.
3- Meter gauge = 1000 mm or 1069mm.
4- Narrow gauge = 762mm or 610 mm

Gauge (mm)	% Length of World Network
1000	9
1069	7.8
1435	61.6
1524	8.8
1600	1.3
1676	6.1
21 other	5.4
	$\sum = 100\%$

***Standard Gauge Track on Tangent
Gauge:

a- Track gauge
b- clearance gauge: (structure gage & loading gauge)

Loading gauge is a limit above and to both sides of the track, which no part of rolling stock or their loads are allowable to encroach upon.

Structure Gauge:

1. Structure Gauge (I).
2. Structure Gauge (II).
3. Structure Gauge (III).

Structure gauge is the limit above and to both side of track within which permanent structure or installation is permitted to be built.

Structure Gauge I: no structure / installation of any type are permitted within this gauge. This gauge is the exceptional minimum clearance.
First isolated structure like signal in between track where structure gauge.

Structure Gauge п: recommended minimum clearance for isolated structures such as signals, columns and posts. It is the exceptional minimum clearance for other structure.

Structure Gauge ш: it is recommended within clearance for all other structures.

Structure Gauge in Tunnels: this shall be determined individually for each case taking into account all relevant factors such as speeds, No. of tracks, (both present and future), length of tunnels, geotechnical features, …. etc.

Geometric Design of the track

1- **Gradient and Grade Compensation.**

A: Gradient: any departure of the track from the level is known as grade or gradient. Gradient is measured either

i- By the extent of rise / fall in 100 units horizontal distance, or

ii- The horizontal distance travelled for a rise / fall in 1 unit.

Gradient are provided on the tracks due to the following reasons:-

i- To provide a uniform rate of rise or fall as far as possible.

ii- To reach the various stations at different elevations, and

iii- To reduce the cost of earth work.

Various gradients used on railway tracks can be classified under the following heads:

1- **Ruling gradient**.

It is the maximum gradient allowed on the track section. Steep gradients necessitate more powerful locomotives, smaller train load, lower speed and costly haulage. Not only the amount of gradient that will come into play but also the length of the gradients and its position. (a train is able to climb a rising gradient more easily if this rising gradient follows a falling gradient).

The extra pull force required by the locomotive to climb a grade = $w * \sin\theta \approx w * \tan\theta \approx w *$ gradient

Example: - if a train weighing 500 tons travels a slope of rising 1 m in 100 m, the additional force required is 1/100 * 500 = 5 tones. If the same height 1 m is a lined in 200 m, the additional force required is 1/200*500= 2.5 ton.

2- **Momentum gradient.**

Those gradients are on a section with values higher than the ruling gradient. Normally trains need sufficient momentum to climb the momentum grade. For example, in valleys a falling gradient is usually followed by a rising gradient. A train while coming down falling gradients acquires sufficient momentum. This momentum gives additional kinetic energy to the moving train which would enable the train to overcome a steeper rising gradient than the ruling gradient. The rising gradient is called as momentum gradient.

Note: - trains must be not stopped where it acquires the momentum; otherwise this gradient is changed to be the ruling gradients.

3- **Pusher or helper gradient.**

If the ruling gradient is sever the train for a large portion of its journey will have unused capacity for carrying higher loads. But if the grade is concentrated in a specific section such as mountainous section, instead of limiting the train load, it may be more economical to run the train on the basis of load that the engine can carry on other section and use another or assisting engine for the portion where the gradient is severe. Such gradient is known as pusher or helper gradient.

4- **Gradients at station yards.**

Low gradients are preferable at station due to the following reasons:-

i- To prevent the movement of standing vehicle on the track due to effect of gravity.

ii- To prevent additional resistance due to grade on starting vehicles, gradient of 1 in 1000 m is recommended.

B: Grade Compensation on Curve: if a curve lies on a ruling gradient, the resistance due to gradient is increased by that due to curvature. In order to avoid resistance beyond the allowable limits, the gradients are reduced on curves and this reduction in gradients is known as grade compensation for curves. The curve resistance is expressed as a percentage per degree of the curve.
Note: - the curve resistance is greater at lower speed.

Compensation for curvature:
B.G. =0.04% per degree of curve
M.G. =0.03%
N.G. =0.02%

Ex. 1:- if the ruling gradient is 1 in 150 on a particular section of broad gauge and at the same time a curve of 4 degrees is situated on this ruling gradient, what should be the allowable ruling gradient?

Solution: From table of grade compensation of B.G. = 0.04 percent per degree of curve.

Then compensation for 4 ^{o} curve = 0.04 *4 = 0.16 percent

Ruling gradient 1 in 150 = 1/150*100 = 0.67percent

So allowable gradient or actual gradient to be provided

= 0.67-0.16= 0.51 percent

=0.51/100 =1/100/0.51= 1 in 196.

Ex. 2:- what should be the actual ruling gradient

a- If the ruling gradient is 1 in 200 on a B.G.

b- A curve of 3^{o} is superimposed on the above track section of B.G.

Solution:- assume grade compensation on B.G.= 0.04 percent per degree of curve.

Then compensation for 3 ^{o} curve = 0.04 *3 = 0.12 percent

Ruling gradient 1 in 200 = 1/200*100 = 0.5percent

So allowable gradient or actual gradient to be provided

= 0.5-0.12= 0.38 percent

=0.38/100 =1/100/0.38= 1 in 264.

2- Speed of the train.

The speed of the train depends upon the strength of the track and the power of the locomotive.

Safe speed: safe speed for all practical purpose means a speed which is safe from the danger of overturning and derailment with a certain margin of safety. This speed; to negotiate curve safely, depends upon the following factors:

i- The gauge of the track.

ii- The radius of the curve.

iii- The distance at which the resultant of the weight of vehicle and its centrifuged force acts from the center of the track.

iv- Amount of superelevation provided.

v- The existence or absence of transition curves at the ends of the circular curve.

The following formula may be used for the safe speed on curve:-

a- Where transition curves exist.

1- For B.G. & M.G the safe speed V in kmph is given:

$$V = 4.4\sqrt{R-70}$$ ……………. **A** R= m

2- For N.G. the safe speed V in kmph is given:

$$V = 3.65\sqrt{R-60}$$ ……………. **B** R=m

b- Where transition curves are absent.

1- For B.G. & M.G. V= 4/5 th of speed calculated in A above.

2- For N.G. V=4/5 th of speed calculated in B above.

c- For high speeds:-

$$V = 4.58\sqrt{R}$$

Where:-

V = speed in (kmph)., R = radius of the curve in (m).

3- Radius or degree of the curve.

Curves on the railway are generally circular i.e. each curve should have the same radius on every portion of it.

Degree of curvature is defined as the angle subtended at the center by an arc of 30 m length

$$\frac{D}{30} = \frac{360}{2\pi R} \Longrightarrow D = \frac{1720}{R}$$

Where:

R: radius of curve in meters.

D: degree of curvature. ; it is also may be defined as the angle subtended at the centre by a chord of 100 feet or 30.48 meter.

Note: normally curves on railway are not recommended as they may cause speed reduction, no heavy locomotive and limitation on train length. Moreover derailment and accident may occur.

$$v = 12.5\frac{c^2}{R}$$

C= chord in meter
R= radius in meter
V= versine in cm

4- Superelevation or cant.

When a train moves round a curve, it is subjected to a centrifugal force acting horizontally at the centre of gravity of each vehicle radially away from the centre of the curve. This increases weight on outer rail.

To counteract the effect of centrifugal force, the level of the outer rail is raised above the inner rail by a certain amount to introduce the centripetal force. This raised elevation of outer rail above the inner rail at a horizontal curve is called " superelevation " .

$$\mathbf{e} = \frac{GV^2}{1.27R}$$

Where:

e = cant (superelevation) in (cm)
G =gauge of the track (m)
R = radius of the curve (m)
V= speed (kmph)
G for B.G. = 1.676m
M.G. = 1.000m
N.G. = 0.762m

$\mathbf{e} = 1.315\frac{V^2}{R}$ **…………………. for B.G.**

$\mathbf{e} = 0.8\ \frac{V^2}{R}$ **…………………… for M.G.**

$\mathbf{e} = 0.6\ \frac{V^2}{R}$ **…………………… for N.G.**

Limits of superelevation &cant deficiency.

There are limits to the amount of superelevation which may be provided safely. Normally, the maximum value of superelevation, according to the railway Board is $1/10^{th}$ of gauge to $1/12^{th}$ of gauge.

- Maximum superelevation for B.G.= 1/10*1.676=0.167m=16.7cm
- Maximum superelevation for M.G.= 1/10*1.000=0.1 m=10 cm
- Maximum superelevation for N.G. = 1/10*0.762=0.0762m=7.62cm

5- Cant deficiency.

The equilibrium cant is provided on the basis of equilibrium speed (average speed, or weighted average) of different trains. But this equilibrium cant or superelevation falls short of that required for the high speed trains. This shortage of cant is called "cant deficiency ".

In other words, cant deficiency is the difference between the cant necessary for the maximum permissible speed on a curve and the actual cant provided.

This cant deficiency is limited due to two reasons:-

i- Higher cant deficiency gives rise to higher discomfort to passengers.

ii- Higher cant deficiency means higher would be the balanced centrifugal forces and hence extra pressure and lateral forces on outer rails. This will require strong track and fastenings for stability.

Limits of cant deficiency

Gauge	Cant deficiency for speeds up to 100 kmph	Cant deficiency for speeds higher than 100 kmph
B.G.	7.6 cm (7.5 cm approx.)	10.0 cm
M.G.	5.1 cm (5.0 cm approx.)	Not specified
N.G.	3.8 cm	Not specified

<u>Negative superelevation:</u>

When the main line is on a curve and has a turnout of contrary flexture leading leading to a branch line (as shown in fig. 1) the superelevation necessary for the average speeds of trains running over the main line can not be provided.

AC which is the outer rail of the main line curve must be higher than inner rail BD or in other words, the point A should be higher than point B

For the branch line, however, BF should be higher than AE or the point B should be higher than point A.

These two contradictory conditions can not met within one layout. So instead of outer rail BF on branch line being higher, it is kept lower than the inner rail AE. In such cases, the branch line curve has a negative superelevation and therefore speeds on both tracks must be restricted, particularly on branch line.

The method, of working out the speeds on main line, branch line and negative superelevation on branch line, will be clear from the following steps:-

1- The equilibrium superelevation or cant on branch line is calculated by formula (e), after assuming a speed on branch line.
2- The permissible cant deficiency deducted from the equilibrium cant as obtained in step (1).
3- The difference obtained (equilibrium cant – permissible cant deficiency) will give the negative superelevation to be used on the branch line.
4- This negative superelevation is also equal to the maximum superelevation permitted on the main curved track.
5- The restricted speed on curved track is obtained by adding permissible deficiency to maximum cant on the main track and applying the formula (e).

Example no. 1:

if a 8^o curve track diverges from a main curve of 5^o in an opposite direction in the layout of a B.G. yard, calculate the superelevation and the speed on the branch line, if the maximum speed permitted on the main line is 45 kmph.

Solution:-

1- Equilibrium cant required for speed 45 kmph by equation (e):

$$\mathbf{e} = \frac{GV^2}{1.27R}$$

G=1.676 for B.G , V=45 kmph

D=1720/R

R=1720/5

e= 1.676*45*45/1.27*5/1720

e= 7.78 cm.

2- For broad gauge the cant deficiency for the main line =7.6cm permitted from table

3- So the cant for main track = 7.78 -7.6 = 0.18cm
4- Therefore the cant to be provided for branch track = -0.18 .
5- With cant deficiency of 7.6 cm which is permissible the speed of the train will be for a cant of 7.6+(-0.18)=7.42cm

   Hence permissible speed on branch line can be worked out from formula (e).

$$7.42=1.676*V^2/1.27 * 8/1720$$

$$V^2 = 7.42*1.27*1720/ 8*1.676$$

$$=1210$$

$$V = 34.7 \text{ kmph}$$

This is theoretical speed on branch line, because the maximum speed on branch line should not be more than 24 kmph.

<u>Example no. 2:</u>

Find the speed for which superelevation is to be maintained if the speeds of several trains running on a main curve track are as follows:

i- 15 trains at speed of 50 kmph.
ii- 10 trains at speed of 60 kmph.
iii- 5 trains at speed of 70 kmph.
iv- 2 trains at speed of 80 kmph.

Solution:

The " weighted average " of different trains at different speeds is calculated from equation.

$$weighted\ avg. = \frac{n1v1 + n2v2 + n3v3 + n4v4}{n1 + n2 + n3 + n4}$$

$$weighted\ avg. = \frac{15 * 50 + 10 * 60 + 5 * 70 + 2 * 80}{15 + 10 + 5 + 2}$$

$$weighted\ avg. = \frac{750 + 600 + 350 + 160}{32}$$

$$= 58.125 \text{ kmph}$$

The average speed = (50+60+70+80)/4=65kmph

<u>Example no. 3:</u>

What would be the equilibrium cant on a M.G curved track of 7^o for an average speed of trains 50 kmph ? also calculate the max. Permissible speed after allowing the maximum cant deficiency.(cant deficiency for M.G =5.0 cm).

Solution:

1- Equilibrium cant for M.G.

$$e = 0.8 \frac{V^2}{R}$$

R= 1720 /7

e= 0.80*50*50*7 /1720

e= 8.14 cm.

2- Theoretical cant = actual cant + cant deficiency

= 8.14 + 5.0 = 13.14 cm

3- Therefore, the max. permissible speed when theoretical cant of 13.14cm

$$V = \sqrt{\frac{13.14 * 1720}{0.8 * 7}}$$

$$V = \sqrt{4040}$$

V= 63.4 kmph

4- According to railway board speed formula

$$\mathbf{V = 4.4\sqrt{R - 70}}$$

$$V = 4.4\sqrt{245.7 - 70}$$

V= 58.325 kmph

So the maximum speed permissible for the train (lower of the two values) = 58.325 kmph

Speed from the length of transition curves.

This is the lesser value of the speed given by two following formula:

a- For normal speed up to 100 kmph

$$Vmax\frac{134 * L}{e}$$ or

L= length of the transition curve in (m).

e= superelevation in (mm).

$$Vmax\frac{134 * L}{D}$$

D= cant deficiency in (mm).

b- For high speed above 100 kmph.

$$Vmax\frac{198 * L}{e}$$ or

$$Vmax\frac{198 * L}{D}$$

Example no. 4:

Calculate the maximum permissible speed on curve of high speed B.G. track having the following particulars:

i- Degree of the curve =1^{o}

ii- Amount of superelevation = 8.0 cm

iii- Length of transition curve = 130 m

iv- Max. speed of the section likely to be sanctioned = 165 kmph

Solution:

Radius of the curve = 1720 /1 =1720 m.

i- Safe speed on the curve (for high speed)

$$\mathbf{V = 4.58\sqrt{R}}$$

$$= 4.58\sqrt{1720}$$

= 190 kmph

ii- Speed from superelevation

Actual superelevation = 8.0 cm

Max. cant deficiency for high speed B.G. track = 10.0 cm

Theoretical superelevation = 8.0+10.0=18.0 cm

Max. speed for this superelevation

$$18 = \frac{1.676 * V^2}{1.27 * 1720}$$

V= 153 kmph

iii- Speed of the length of transition curve

$$Vmax \frac{198 * L}{e}$$ e = 8.0 cm = 80 mm, L =130 m

V max = 320 kmph or

$$Vmax \frac{198 * L}{D}$$ D= 10 cm = 100 mm, L = 130 m

V max = 257 kmph

The max. permissible speed on the curve is the minimum of the following:

1- 190 kmph

2- 153 kmph

3- 257 kmph

4- 165 kmph,

Therefore max. permissible speed =153 kmph say 150 kmph

Curves:-

Thought it is desirable to have a straight track and it is the ideal condition but the use of curves becomes absolutely necessary for a change in the alignment (through horizontal curve) or gradient (through vertical curves). Simple curves are introduced to ease off the change.

Types of curves:-

Broadly speaking, the curves are of two types.

1- Horizontal curves: - these are provided whenever there is change in the alignment of the track. They are usually circular with parabolic transition curves at either end.

2- Vertical curves:- these are provided whenever there is change in the gradient i.e. either a rising gradient changes to a falling gradient or vice versa or a rising gradient or falling gradient is increased or decreased. They are usually parabolic curves.

The curves, in general, are classified under the following heads:-

a- Simple curves:- a simple curve is an arc of a circle. It is designed by the degree or by its radius. As already discussed D= 1720 / R. This curve may lie within two transitional curves or within two tangent lengths.

b- Compound curves:- these are the curves which are composed of two or more simple curves of different radii arranged in such a way that they are tangential to each other. They are used when compelled by the topography to avoid the obstructions like hard rocks, deep cuttings, and soft gradients.

c- Parabolic curves:- these curves have got the quality of being easily laid by the offset method. These are exclusively used as vertical curves in railway and highways. The equation of a parabolic curve is $y=k^2$.

d- Transitional curves:- transition curve is defined as a curve of parabolic nature which is introduced between a straight and a circular curve or between two branches of a compound curve. The transition curves are necessary to provide an easy change from a tangent (having infinite radius) to the radius selected for a particular curve.

Types of transition curves:-

There are following three types of transition curves,

i- Spiral curve.

ii- Cubic parabola.

iii- Bernoulli's lemniscate.

Length of transition curves:-

The length of the transition curve is a length along the centre line of the track from its meeting point with the straight to that with the circular curve. This length is inserted at the junction half in the straight and half in the curve as show in the Fig.(1).

Lets,

L= length of transition curve in metres.

e= actual cant or superelevation in cm.

D= cant deficiency for max. speed in cm, and

V=Max. speed in kmph.

Railways specify that greatest of the following lengths should be taken as the length of transition curve.

1- **L = 7.20 * e ……………..(1**

Where: e = actual superelevation in cm.

This is based on arbitrary gradient (1 in 720).

2- **L = 0.073 * D * Vmax ……………. (2**

Where: D = cant deficiency for max. speed in cm.

Vmax = Maximum speed in kmph.

This is based on the rate of change of cant deficiency.

3- **L = 0.073 * e * Vmax ………………(3**

This is based on the rate of change of superelevation.

Example:-

Find out the length of the curve for a B.G. curved track having 4^o and a cant of 12 cm. the maximum permissible speed on curve is 85 kmph.

Solution:- the length of curve will be max. out of the following three values:-

1- L = 7.20 * e ……………………….(1

= 7.20 * 12

= 86.4 m

2- L = 0.073 * D * Vmax ……………(2

= 0.073 * 7.6 * 85

= 47.3 m

3- L = 0.073 * e * Vmax …………….(3

= 0.073 * 12 * 85

= 74.5 m

L = 86.4 m ≈ 87 m max. of (1),(2), (3).

Say 90 m

Now equation of parabola is:

$$y = \frac{x^3}{6RL} = cx^3$$

$$c = \frac{1}{6RL}$$

R= 1720 /4 =430 m, L = 90

$$c = \frac{1}{6 * 90 * 430}$$

$$c = \frac{1}{232200}$$

Offset at 15 m = 1/ 232200 * $(15)^3$ * 100 = 1.45 cm.

Offset at 45 m = 1/ 232200 * $(45)^3$ * 100 = 39.24 cm.

Offset at 75 m = 1/ 232200 * $(75)^3$ * 100 = 181.63 cm.

Thus the offset at every 15 m are given in the table below:-

Chain age (m)	15m	30m	45m	60m	75m	90m
Offsets (cm)	1.45	11.63	39.24	93.02	181.68	313.95

Shift **$S = L^2/24\ R$ = 0.817 m**

Widening of gauge on curves:-

Due to rigidity of the wheel base, when the outer wheel of the front axle strikes against the outer rail, the outer wheel of the inner axle bears a gap with the outer rail. Provision should be made for this gap otherwise there is every possibility of tilting rails outwards. But this gauge widening should be just adequate, if it is more than required, the lateral play of the vehicles will be vigorous and may result in derailment. Extra width of gauge (d) in cm is given by the formula:

$$d = \frac{13(B+L)^2}{R}$$

B= rigid wheel base in meters for B.G.= 6m , for M.G.= 4.88 m

R= radius of the curve in meters.

L= lap of flange in meters.

$$L = 0.02\sqrt{h^2 + D * h}$$

h=depth of wheel flange below rail in cm.

D= diameter of wheel in cm.

Example:-

If the wheel base of a vehicle moving on a B.G. track is 6m, the diameter of wheel is 1.5m and the depth of flanges below the top of rail is 3.17 cm. determine the extra width required to be provided on gauge, if the radius of the curve is 160m.

Solution:-

Given h= 3.17 cm, D= 1.5 m = 150 cm, B= 6 m, R= 160 m.

$$\mathbf{L = 0.02\sqrt{h^2 + D * h}}$$

$$\mathbf{= 0.02\sqrt{(3.17)^2 + 150 * 3.17}}$$

$$\mathbf{= 0.02\sqrt{485.5}}$$

= **0.44m**

Extra width in cm:

$$\mathbf{d = \frac{13(6 + 0.44)^2}{160}}$$

= **3.38 cm**

Shift:-

Whenever a transition curves is to be fitted between the straight and circular tracks, the original curve is to be shifted inwards by a certain distance. This distance by which the circular curve is shifted to a new position is termed as "shift" and in case of cubic parabola which is mostly used in case of railways this shift is given by the formula:-

$$\mathbf{S = \frac{L^2}{24\,R}}$$

S= shift in m.

L= length of transition curve in m.

R= radius of circular curve in m.

Example:-

Calculate the shift and offsets at every 30 m of a transition curve. The transition curve of 90 m long is to be used to join the ends of a 4^o circular curve within the straight and circular curve.

Solution:-

R= radius of the curve = 1720/4=430 m.

$$S = \frac{L^2}{24\ R}$$

S= 90*90 / 24*430

= 0.817 m.

$$y = \frac{x^3}{6RL} = cx^3$$

$$c = \frac{1}{6RL}$$

1- Offset at 30 m = $(30)^3$/(6*90*430) *100

= 11.65 cm.

2- Offset at 60 m = $(60)^3$/(6*90*430) *100

= 93.1 cm.

3- Offset at 90 m = $(90)^3$/(6*90*430) *100

= 314 cm.

Vertical curves.

They are of two types:-

i- Crest (Summit) curves.

ii- Sag (Valley) curves.

As already discussed, whenever there is a change in the gradient of the track, an angle is formed at the junction of the gradients.

A parabolic curve is set out tangent to the two intersecting grades, with its apex at a level halfway between the points of intersection of the grade line and the average elevation of the two tangent points.

The length of the vertical curve depends upon the algebraic difference in grades i.e. as shown in fig (2) and determined by the rate of change at which it is decided to change the gradient of the line.

Example:-

If a sag curve is introduced between a down grade of 0.9 percent followed by an upgrade of 0.7 percent, determine the length of the parabolic vertical curve, the offsets at every 30m and the R.Ls of the various corresponding points on the curves. When given the R.Ls of the ground at the sag point is 30m and allowable rate of change of gradient is 0.2 percent.

Solution:-

Value "g" the algebraic difference of two grades.

g= g1 – g2

= -0.9 – (+ 0.7)

= - 1.6 %

As the rate of change of gradient is 0.2%, so the total length of the curve is = 1.6 / 0.2 = 8 chains.

If each chain is of 30m then,

The total length of the curve will be = 8 * 30 = 240 m.

Therefore, 120m on either side of the sag can be used.

R.L. of the ground at T = 30 + 120 * 0.9 %

= 30 + 1.08 = 31.08m.

R.L. of the ground at T1= 30 + 120 *0.7 %

= 30 + 0.84 = 30.84m

R.L. of H = mean of T &T1 = 31.08 + 30.84 / 2 = 30.96m

R.L. of M = mean of H & K= 30.96 + 30 / 2 = 30.48m

The offset at K = KM = 30.48 – 30 = 0.48m

From the property of parabolic curve, the offset at any point on the curve on the right of tangent point T or on the left of the tangent point T1, will vary as the square of the distance from the tangent point i.e. $y = x^2/L^2$.

Where:

y= the offset at any point on the tangent to the curve.

x= the corresponding distance to y along the tangent from tangent point.

L= length of the curve = 120m.

The offset at A, 30m from T= $30^2/ 120^2$ * 0.48 = 0.03m.

The offset at B, 60m from T= $60^2/ 120^2$ * 0.48 = 0.12m.

The offset at C, 90m from T= $90^2/ 120^2$ * 0.48 = 0.27m.

The offset at D = 0.27 m because 90m from T1.

The offset at E = 0.12 m because 60m from T1.

The offset at F = 0.03 m because 30m from T1.

The ground level at T= 31.08m as calculated at A will be 0.27m [1/4 * (1.08)] less 30.81m, at B = 30.54m and at C= 30.27m. Similarly the ground level at T1 = 30.84m, so the R.Ls at F will be 0.21 [1/4 * 0.84] less 30.63 and so on the results are provided in tabular form.

Point	**R.Ls on tangent line (m)**	**Vertical offsets (m)**	**R.Ls on curve (m)**
T	31.08m	0.0	31.08
A	30.81m	0.03	30.84
B	30.54m	0.12	30.66
C	30.27m	0.27	30.54
K	30.00m	0.48	30.48
D	30.21m	0.27	30.48
E	30.42m	0.12	30.54
F	30.63m	0.03	30.66
T1	30.84m	0.0	30.84