CHAPTER FIVE

CASE STUDY

5.1 Site of Khartoum New International Airport (KNIA)

There were three proposed sites for a new airport in Khartoum, Omdurman, North Khartoum and Khartoum. Designers select Site of Omdurman (SALEHA South Omdurman). Moreover, if we notice that the new airport away from the center of Khartoum 40 km, that space is not too long compared with spaces of Other available, as that area of 77 km. making it capable of expansion in the runways, where it starts now at least a length of 4000 meters and a width of 60 meters and runway spacing 2 km. depending on the designs, which were developed by the German company (Dorsch), we noticed that it was designed with the latest requirements of airports around the world. Which accommodate large aircraft such as airbus380, also with a capacity of 7.4 million passengers per year and ranging up to 10 million a year.

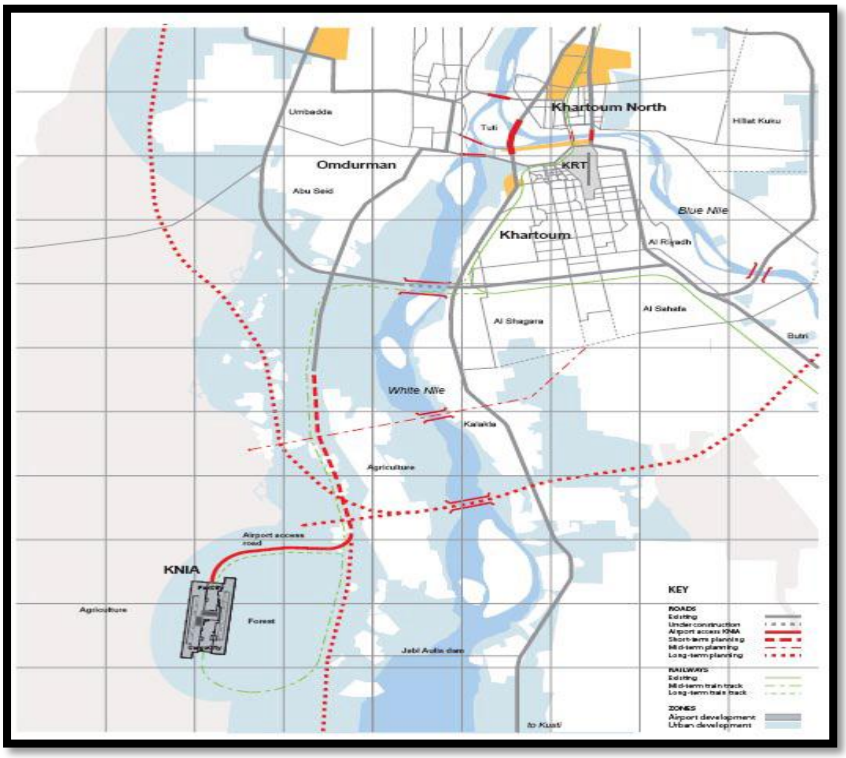

Figure (5-1) primary proposed sites of KNIA

5.2 GEOMETRIC DESIGN

5.2.1 Runway Length

The following procedures show the design information and the steps followed for the design.

- **Design Data:**
  - Runway length required for landing at sea level in standard atmospheric conditions 2700 m
  - Runway length required for take-off at a level site at sea level in standard atmospheric conditions 3000 m
  - Aerodrome elevation 400 m
  - Aerodrome reference temperature 43°C
  - Temperature in the standard atmosphere for 400 m 12.60°C
  - Runway slope 1.0%
- **Design steps:**

A: Corrections to runway take-off length:

1) Runway take-off length corrected for elevation =

□□□□□□□□□□□□□□□□ $\frac{400}{300}$ □□□□□□□□□□□□ **□□□□□m**

2) Runway take-off length corrected for elevation and temperature =

□□3280 * (43 – 12.60) x 0.01 □□□□3280 □□**4277.12 m**

3) Runway take-off length corrected for elevation, temperature and slope

□□□4277.12* 1.0 * 0.10 □□□□4277.12□□**4704.83 m**

B: Correction to runway landing length:

Runway landing length corrected for elevation =

$$(2700 * 0.07 * \frac{400}{300}) + 2700 = \mathbf{2952\ m}$$

C: Actual runway length:

= 4704.83 m ≈ **4700 m**

5.2.2 Runway Width

The following procedures show the design information and the steps followed for the design.

- **Design Data:**
  - Code Letter F
  - Code Number 4

*From table (3-1) the width is **60m**

5.2.3 Orientation:

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

The following procedures show the design information and the steps followed for the design.

Design Data:

Table (5-1) Wind Data of (KNIA)

Direction	Percentage of wind				
	0-4	5-7	8-10	11 and over	Total
N	8	12	9	6	35
NEN	0	0	0	0	0
NE	0	1	2	0	3
ENE	0	0	0	0	0
E	0	0	0	0	0
ESE	0	0	0	0	0
SE	0	0	0	0	0
SES	0	0	0	0	0
S	0	3	5	1	9
SWS	0	0	1	0	0
SW	2	9	14	1	26
WSW	0	1	0	0	1
W	0	1	2	0	3
WNW	0	0	0	0	0
NW	2	9	6	1	18
NWN	0	1	3	0	4
Total					100%

- **Output data:**

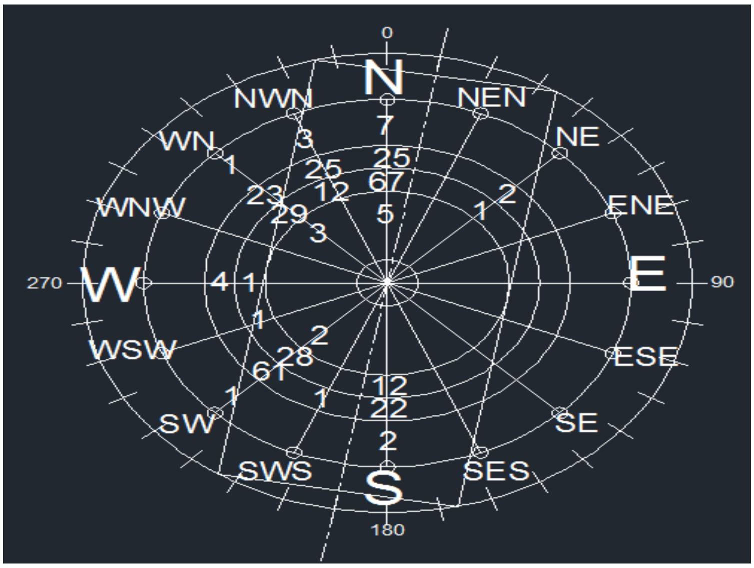

Figure (5-2) Orientation Runway for KNIA

5.3 STRUCTURAL DESIGN

5.3.1 KNIA Soil Investigation

The area has rocky land characterized by high consistently and twice the capacity. Indicated all tests conducted by the unity of the new Khartoum Airport and Engineering airports that good natural resistance to the ground where they found that the CBR is equal to 10%.where that mean the natural soil can be used for the different pavement layers.

5.3.2 MAAT for KNIA

Temperature has great influence on the stress-strain distributive characteristics of full-depth asphalt pavement and surface layer; thicknesses are increased as the mean annual air temperature gets warmer and Table (5-2) shows the average annual air temperature in Khartoum for any month in the year

Table (5.2) Average temperature in the year

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average °C	30.8	33.0	36.8	40.1	41.9	41.3	38.4	37.3	39.1	39.3	35.2	31.8

Then MAAT =41° C

5.3.3 KNIA Design traffic mix

The following table shows the aircraft type , annual departure and expected annual rates of increase for any aircraft expected on KNIA

Table (5-3): Traffic mix information

Aircraft	Gear	type	Departure	Passes	Annual growth %
A-300	2D	international	203	406	7.7
A-310	2D	international	22	44	7.7
A-319	D	international	347	694	7.7
A-320	D	domestic	3996	7992	13.3
A-320	D	international	395	790	7.7
A-321	D	international	675	1350	7.7
A-330	2D	international	984	1968	7.7
A-340	2D	international	91	182	7.7
A-380*	2D/3D2	international	141	282	0
B-737	D	international	3331	6662	7.7
B-747	2D/2D2	international	188	376	7.7
B-757	2D	international	4	8	7.7
B-767	2D	international	58	116	7.7
B-777	3D	international	318	636	7.7
E190	S	international	43	86	7.7
F50	S	domestic	27	54	13.3
F50	S	international	395	790	7.7
T204	D	international	32	64	7.7
AN 32	S	international	4	8	7.7
IL62	D	international	5	10	7.7
Q400	D	international	57	114	7.7
MD83	D	international	8	16	7.7
AN 26	D	domestic	953	1906	13.3
IL76	2D	domestic	1112	2224	13.3
CRJ200	D	domestic	2032	4064	13.3
YAK42	2D	domestic	1781	3562	13.3
DC8	2D	domestic	1143	2286	13.3
TU134	2D	domestic	635	1270	13.3
AN 12	2D	domestic	445	890	13.3
AN 24	D	domestic	191	382	13.3

5.3.4 Flexible Airports Pavement Design Process

1. KNIA Flexible Pavement Design by Asphalt Institute Method (Analytical):

The following procedures show the design information and the steps followed for the design:

- **Design information**
  - Sub-grade CBR = 10%
  - Mean Annual Air Temperature (MAAT) = 41 C

- Traffic mix groups with the types of aircraft in the charts and tables of this method

Table (5-4): Traffic Mix Groups

Type	G1(2D/2D2)	G2(2D)	G3(D)	G4(S)
AIRCRAFT DESIGN	**B-747**	**DC 8-63**	**B-737-200C**	**DC-9-41**
AIRCRAFT	A380 B-777 B-747	A300,YAK42 A310,DC8 A330,TU134 A340,AN12 B-757 B-767 IL76	A319,MD83 A320,AN26 A321,CRJ200 B-737,AN24 T204 IL62 Q400	E190 F50 AN32 DC-3

Compute equivalent departure for each group by multiplying aircraft departure by equivalent factors. And then determine total passes for design life as shown:

Total passes for design life	**B-747**	**DC-8-63**	**B737-200C**	**DC-9-41**
	77940	2699000	4236520	91070

- **Design steps**

Step (1): determine allowable thickness (T_A) for repetitions and distress for fatigue and deformation criterion from figures (B-1), (B-2), for MAAT = 41 C and form equation (3-1) E_S = 1500*10 = 15000 psi. Tables (5-5), (5-6) showing values of (T_A)

Table (5-5) T_A values by fatigue criteria

	Number of strain repetitions (N_f)				
	100	1000	10000	100000	1000000
T_A (in)	5.5	8.2	12.6	18	26

Table (5-6) T_A values by deformation criteria

	Number of strain repetitions (N_f)				
	100	1000	10000	100000	1000000
T_A (in)	12.2	15	17	18	19.5

Step (2): Summarize the asphalt concrete tensile strain (f_{ix}) values from Table (B-3) and fatigue values $f_{ih}$from table (B-5) summarize them for all design aircraft in the traffic mix. Tables (5-7) and (5-8) show that.

Table (5-7) f_{ix} values (asphalt concrete tensile strain)

	Interval form taxiway centerline						
Aircraft	0-1ft	4-5ft	8-9ft	12-13ft	16-17ft	20-21ft	24-25ft
B-747	0.45	0.68	0.62	0.45	0.68	0.59	0.18
DC-8-63F	-	0.15	0.48	0.48	0.15	-	-
B-737-200C	0.05	0.30	0.56	0.30	0.04	-	-
DC-9-41	0.07	0.29	0.46	0.21	0.02	-	-

Table (5-8) fatigue F_{ih} values

Aircraft	h_1=10 in	h_1=20 in	h_1=30 in	h_1=40 in	h_1=50 in
B-747	0.392	0.876	1.970	2.158	2.393
B-737-200C	0.126	0.047	0.024	0.015	0.013
DC-8-63F	1.0	1.0	1.0	1.0	1.0
DC-9-41	0.264	0.076	0.037	0.022	0.015

Step (3): Summarize the sub-grade vertical strain (f_{ix}) values from Table (B-4) and deformation f_{ih} regression constants from Table (B-6) summarize them for all design aircraft in the traffic mix. Tables (5-9) and (5-10) show that.

Table (5-9) f_{ix} values (sub-grade vertical strain)

Interval form taxiway centerline							
Aircraft	0-1ft	4-5ft	8-9ft	12-13ft	16-17ft	20-21ft	24-25ft
B-747	0.58	1.02	0.90	0.58	1.02	0.88	0.22
B-737-200C	0.03	0.21	0.45	0.28	0.05	-	-
DC-8-63F	0.01	0.28	0.83	0.71	0.17	-	-
DC-9-41	0.05	0.25	0.40	0.18	0.02	-	-

Table (5-10) deformation F_{ih} regression constants

	h_1=10 in		h_1=20 in		h_1=30 in		h_1=40 in	
Aircraft	C	A_1	C	A_1	C	A_1	C	A_1
B-747	0.606	-0.335	0.667	-0.364	0.716	-0.404	0.769	-0.460
B-737-200C	0.789	-0.680	0.876	-0.881	0.860	-0.879	0.884	-0.931
DC-8-63F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DC-9-41	0.894	-0.626	0.899	-0.736	0.583	-0.844	0.041	-0.992

Step (4): Determine the Equivalent DC-8 repetitions (n_{ex}) for fatigue analysis from equation (5-1).

$$\text{Nex} = \sum_{j=1}^{j} \mathbf{p_j} \cdot \mathbf{f_{jx} F_{jh}} \qquad \_\_\_\_\_\_\_\_\_ \ (5\text{-}1)$$

Where:

N_{ex}= Equivalent dc-8 repetitions

f_{ix}= asphalt concrete tensile strain

F_{jh} = fatigue values

P_j = no. of passes

Using **P1=77940**, **P2=2699000**, **P3=4236520** and **P4=91070.** For f_{ix} and F_{jh} see tables (5-6) and (5-7) respectively. Table (5-10) shows the Equivalent DC-8 repetitions for fatigue analysis.

Step (5): Determine the Equivalent DC-8 repetitions (n_{ex}) for deformation analysis from equation (5-)

$$n_{ex}= \sum_{j=1}^{j} 10^{c}\left(p_j . f_{ix}\right)^{A1+1} \qquad \text{\_\_\_\_\_\_ (5-2)}$$

Where:

n_{ex} = Equivalent DC-8 repetitions.

P_j = no. of passes.

f_{ix} = sub-grade vertical strain.

A = regression constants.

c = regression constants

Using, **P1=77940, P2=2699000, P3=4236520**and**. P4=91070** For f_{ix} and (A,c)see tables (5-8) and (5-9) respectively. Table (5-11) shows the Equivalent DC-8 repetitions for deformation analysis

Table (5-11) the Equivalent DC-8 repetitions for fatigue analysis

	Aircraft	x=0-1ft	x=4-5ft	x=8-9ft	x=12-13ft	x=16-17ft	x=20-21ft	x=24-25ft
T_A=10 in	B-747	137848.616	20775.686	18942.54	137848.616	20775.686	18025.963	5499.446
	DC-8-63F	0	404850	1295520	1295520	404850		
	B-737-200C	26690.076	160140.456	298928.8512	160140.456	21352.0608		
	DC-9-41	1682.974	6972.32	11059.541	5048.92	480.85		
	SUM	166221.666	592738.462	1624450.932	1598557.992	447458.5968	18025.963	5499.446
T_A=20 in	B-747	30723.948	46427.299	42330.77	30723.948	46427.299	40282.5096	12289.5792
	DC-8-63F	0	404850	1295520	1295520	404850		
	B-737-200C	9955.822	59734.932	111505.2064	59734.932	7964.6576		
	DC-9-41	484.4924	2007.1828	3183.8072	1453.4772	138.4264		
	SUM	41164.2624	513019.4138	1452539.784	1387432.357	459380.383	40282.5096	12289.5792
T_A=30 in	B-747	69093.81	104408.424	95195.916	69093.81	104408.424	90589.662	27637.524
	DC-8-63F	0	404850	1295520	1295520	404850		
	B-737-200C	5083.824	30502.944	56938.8288	30502.944	4067.0592		
	DC-9-41	235.8713	977.1811	1550.0114	707.6139	67.3918		
	SUM	74413.5053	540738.5491	1449204.756	1395824.368	513392.875	90589.662	27637.524
T_A=40 in	B-747	75687.534	114372.2736	104280.6024	75687.534	114372.2736	99234.7668	30275.0136
	DC-8-63F	0	404850	1295520	1295520	404850		
	B-737-200C	3177.39	19064.34	35586.768	19064.34	2541.912		
	DC-9-41	140.2478	58.0266	921.6284	420.7434	40.0708		
	SUM	79005.1718	538344.6402	1436308.999	1390692.617	521804.2564	99234.7668	30275.0136
T_A=50 in	B-747	83929.689	126827.0856	115636.604	83929.698	126827.0856	110041.1478	33571.8756
	DC-8-63F	0	404850	1295520	1295520	404850		
			16522.428					
	B-737-200C	2753.738		30841.8656	16522.28	2202.9904		
	DC-9-41	95.6235	396.1545	628.383	286.705	273.21		
	SUM	86779.0505	548595.6681	1442626.853	1396258.683	534153.286	110041.1478	33571.8756

Table (5-12) the Equivalent DC-8 repetitions for deformation analysis

	Aircraft	x=4-5ft	x=8-9ft	x=12-13ft	x=16-17ft	x=20-21ft	x=24-25ft
T_A=10 in	B-747	7321.980958	6737.220317	5030.24452	7321.980958	6637.284871	2640.101134
	B-737-200C	492.8935532	629.0294343	540.4226386	311.3962404		
	DC-8-63F	755720	2240170	1916290	458830		
	DC-9-41	333.915008	398.0859158	295.3100946	129.8349438		
	SUM	763868.7895	2247934.336	1922155.977	466593.2121	6637.284871	2640.101134
T_A=20 in	B-747	6076.161724	5611.227169	4243.261718	6076.161724	5531.597795	2290.553502
	B-737-200C	38.36703145	42.00939153	39.70323623	32.34383647		
	DC-8-63F	755720	2240170	1916290	458830		
	DC-9-41	112.0292042	126.8291047	102.7228429	57.51048203		
	SUM	761946.558	2245950.066	1920675.688	464996.016	5531.597795	2290.553502
T_A=30 in	B-747	4331.266452	4019.923004	3093.800344	4331.266452	3966.439842	1736.093524
	B-737-200C	38.00639304	41.67799659	39.3526735	31.94798642		
	DC-8-63F	755720	2240170	1916290	458830		
	DC-9-41	18.31222829	19.70533902	17.39742862	12.34875664		
	SUM	760107.5851	2244251.306	1919440.55	463205.5632	3966.439842	1736.093524
T_A=40 in	B-747	2601.325568	2431.316917	1917.79319	2601.325568	2401.990358	1136.210673
	B-737-200C	19.70138556	20.76516099	20.09636654	17.84401458		
	DC-8-63F	755720	2240170	1916290	458830		
	DC-9-41	1.190854008	1.195340082	1.187728514	1.167033285		
	SUM	758342.2178	2242623.277	1918229.077	461450.3366	2401.990358	1136.210673

Step (6): At each interval, the sum of the equivalent repetitions represents the mix traffic effect expressed in terms of equivalent DC-8-63F repetitions.

Illustrates the highest passes for each thickness for permanent deformation and fatigue analysis with allowable thickness in Figure (5-6) respectively. The cross of curves presented the design thickness of criteria. Figures (5-4) and Figures (5-5) show that

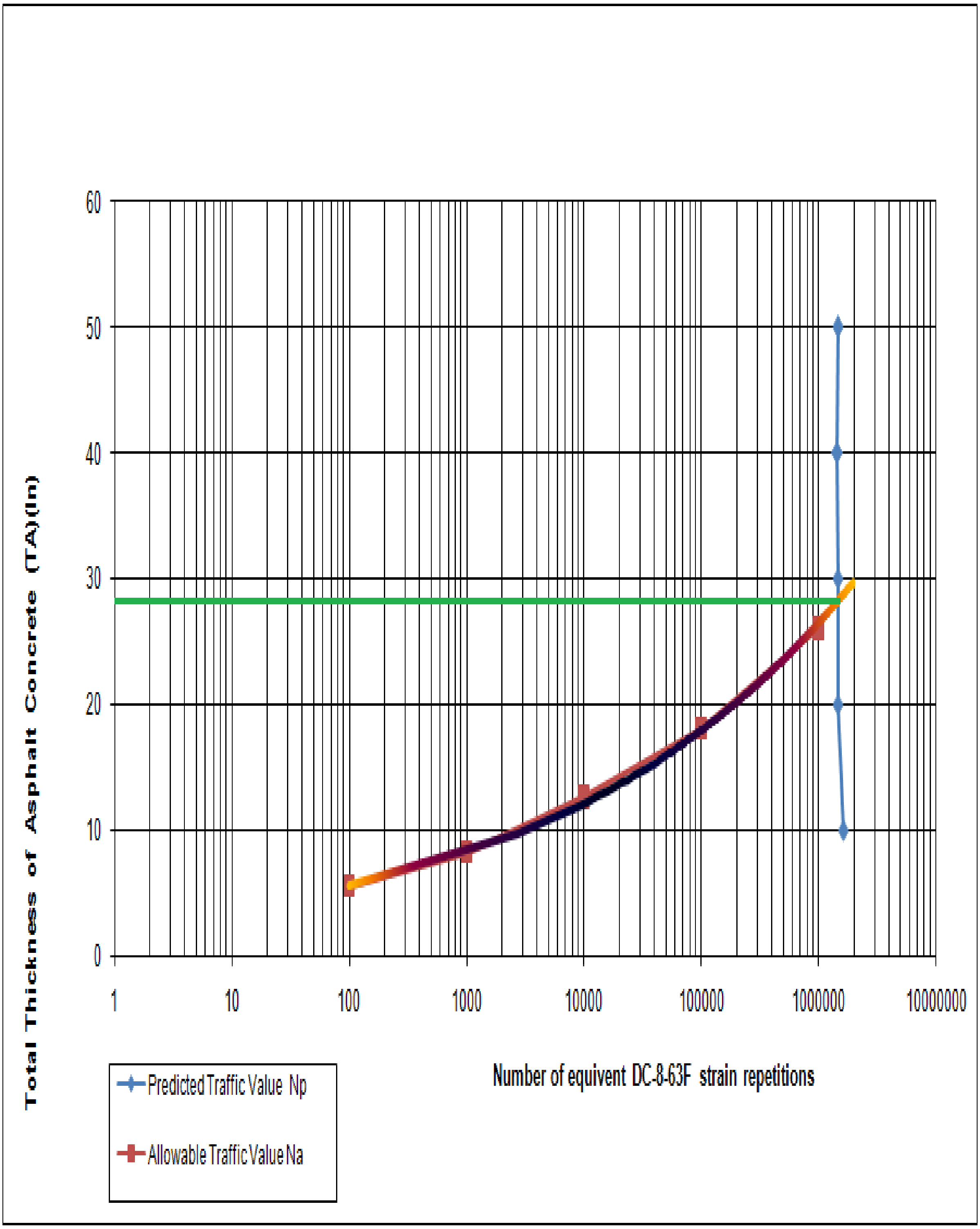

Figure (5-3) the cross of curves presented the design thickness of criteria.

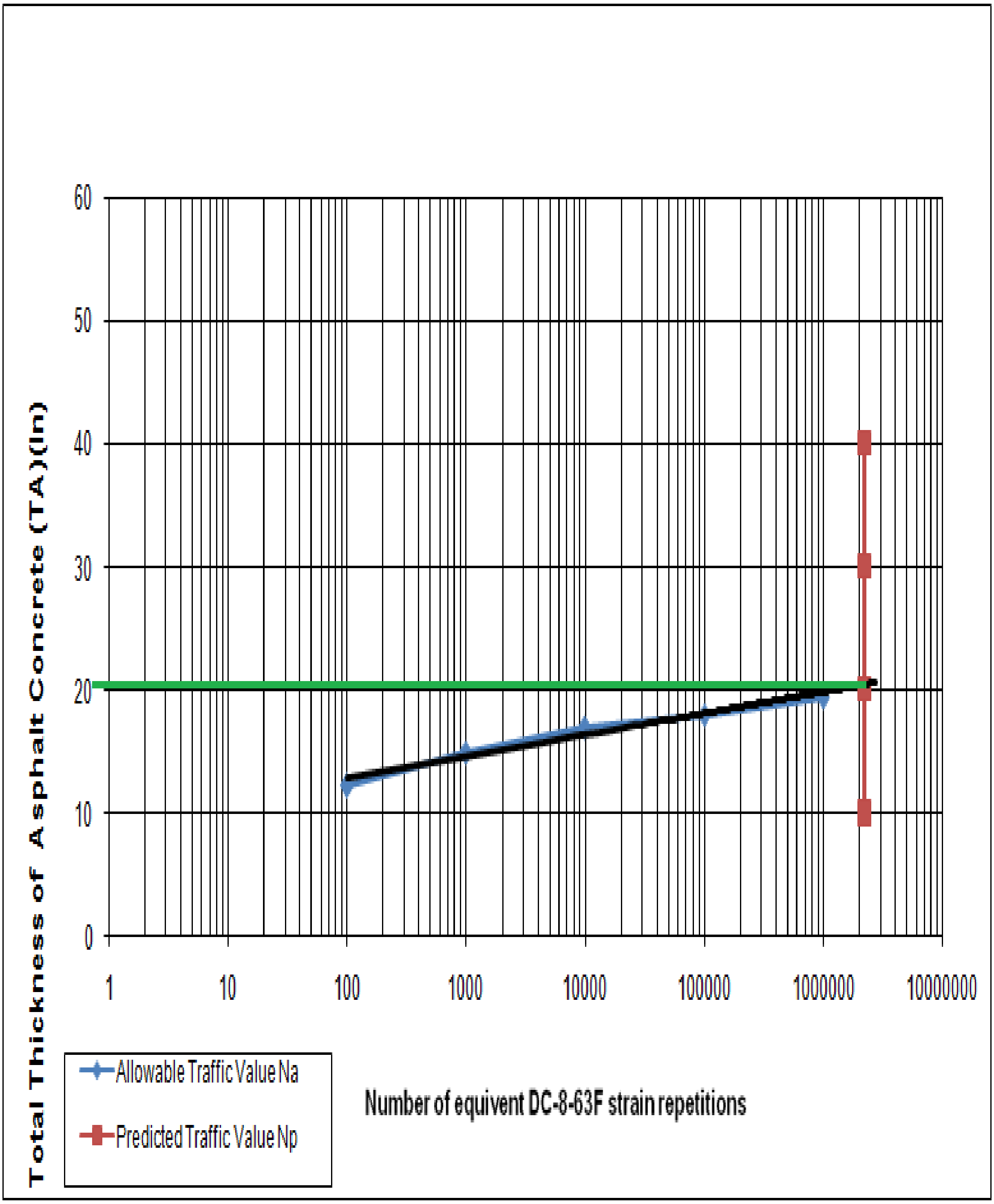

Figure (5-4) The cross of curves presented the design thickness of criteria.

Step (7): the design thickness is the maximum one of two criterions

The design thickness= 28 in full depth HMA. Figure (5-6) shows all details about pavement facilities

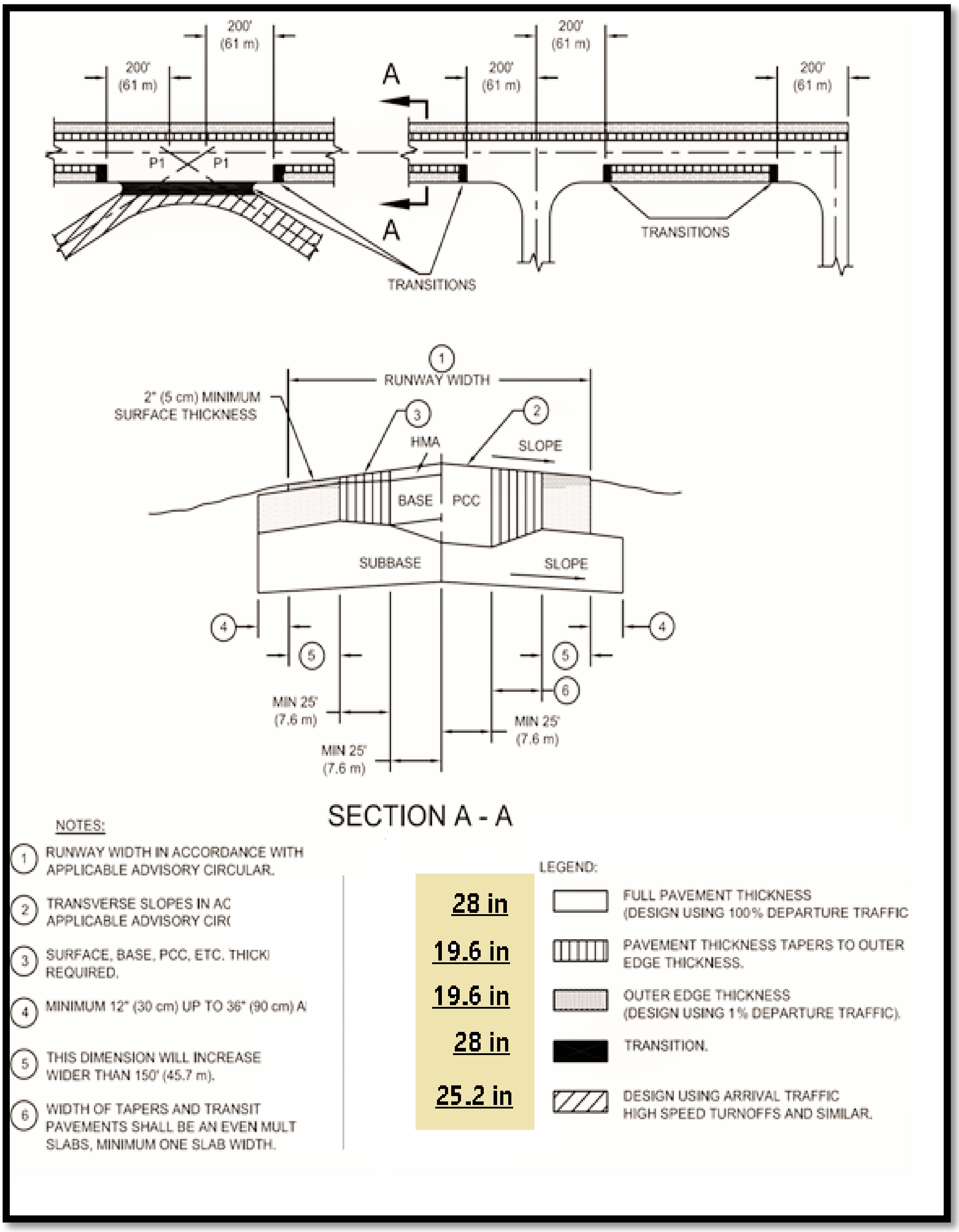

Figure (5-5) Typical Plan and Cross Section for KNIA Runway Pavement designed by AI method

2. KNIA Flexible Pavement Design by Asphalt Institute Method (Nomograph)

The following procedures show the design information and the steps followed for the design.

*Design Data

- The sub-grade modulus of elasticity (E=1500 psi)
- The mean annual air temperature(MAAT=37̊ C)
- Traffic mix is (B747, DC8-63F, B737-200, DC9-15) with total (**77940, 2699000, 4236520, 91070**) respectively.

- **Design Steps**

Step (1): Determine the allowable traffic value Na, for each strain criterion (εc and εt) from the design subgrade modulus of elasticity Es, and mean annual air temperature T, for the design location see table

Table (5-13): Allowable Traffic Value for Each Strain Criterion

	100	**1000**	**10000**	**100000**	**1000000**
εc	5.5	8	12	18	26
εt	12	15	17.5	18	19.5

Step(2): Determine the predicted traffic value Np ,from the projected aircraft mix forecast for the pavement selected design period , and the aircraft equivalency diagrams for specific strain criterion (horizontal tensile, εt or vertical compressive, εc) by using number of aircraft movement (passes) and lateral distance and table 5-13 and 5-14 illustrate that.

Step(3): Determine the full-depth asphalt concrete pavement thickness, needed to satisfy the strain criteria by using figure B-5 AND B-6 of the following figures(5-14 and 5-15) illustrate thickness design process . Then the design thickness =29 in

Table (5-14): Appropriate Traffic for the Fatigue Analysis

	Aircraft	X=5.5ft	X=9.5ft	X=13.5ft	X=17.5ft	X=21.5ft
Ta=10in	B747	8000	6500	5500	8000	6000
	B727-200C	550	600	500	250	0
	DC8-63F	1000000	1100000	1500000	2000000	0
	DC9-15	380	400	280	100	0
	Sum=	1008930	1007600	1506280	2008350	6000
Ta=20in	B747	6800	6000	5000	6800	5000
	B727-200C	110	120	100	60	0
	DC8-63F	1000000	1100000	1500000	2000000	0
	DC9-15	130	150	95	50	0
	Sum=	1007040	1106270	1505195	2006910	5000
Ta=30in	B747	3800	3400	3300	3800	3200
	B727-200C	38	40	36	28	0
	DC8-63F	1000000	1100000	1500000	2000000	0
	DC9-15	18	20	17	12	0
	Sum=	1003856	1103460	1503353	2003840	3200

Table (5-15) :Appropriate Traffic for the Permanent Deformation

	Aircraft	X=5.5ft	X=9.5ft	X=13.5ft	X=17.5ft	X=21.5ft
Ta=10in	B747	8000	6500	5500	8000	6000
	B727-200C	550	600	500	250	0
	DC8-63F	1000000	1100000	1500000	2000000	0
	DC9-15	380	400	280	100	0
	Sum=	1008930	1007600	1506280	2008350	6000
Ta=20in	B747	6800	6000	5000	6800	5000
	B727-200C	110	120	100	60	0
	DC8-63F	1000000	1100000	1500000	2000000	0
	DC9-15	130	150	95	50	0
	Sum=	1007040	1106270	1505195	2006910	5000
Ta=30in	B747	3800	3400	3300	3800	3200
	B727-200C	38	40	36	28	0
	DC8-63F	1000000	1100000	1500000	2000000	0
	DC9-15	18	20	17	12	0
	Sum=	1003856	1103460	1503353	2003840	3200
Ta=40in	B747	2800	2400	2200	2800	2300
	B727-200C	20	22	18	16	0
	DC8-63F	1000000	1100000	1500000	200000	0
	DC9-15	0	0	0	0	0
	Sum=	1002820	1102422	1502218	2002816	2300

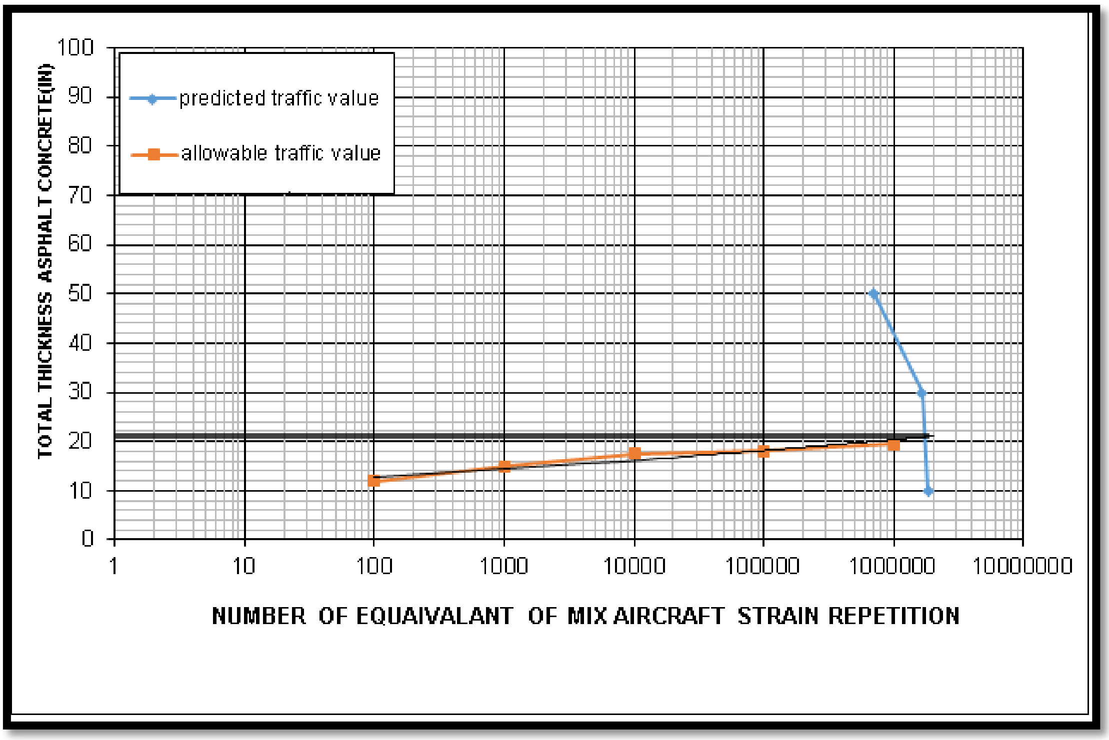

Figure (5-6): Allowable Traffic Value and Predicated Traffic Value Curves for Compressive Strain

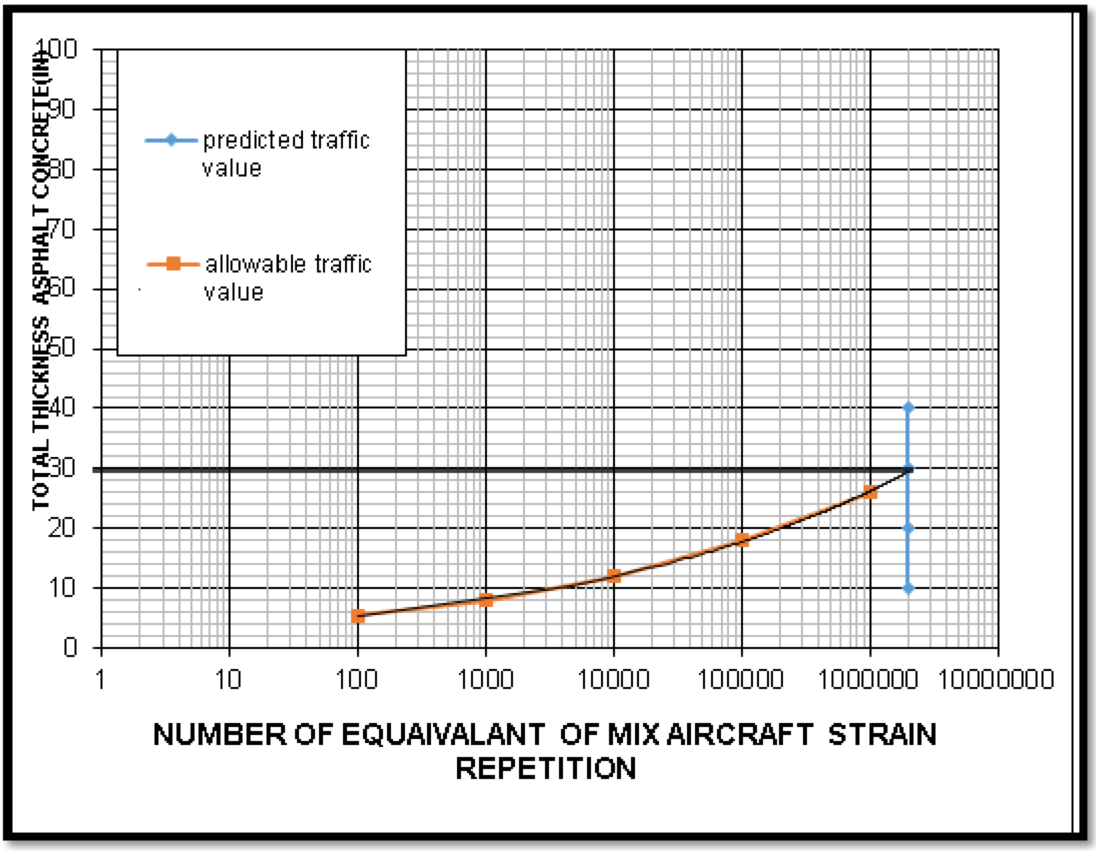

FIGURE (5-7): Allowable Traffic Value and Predicated Traffic Value Curves for Tensile Strain

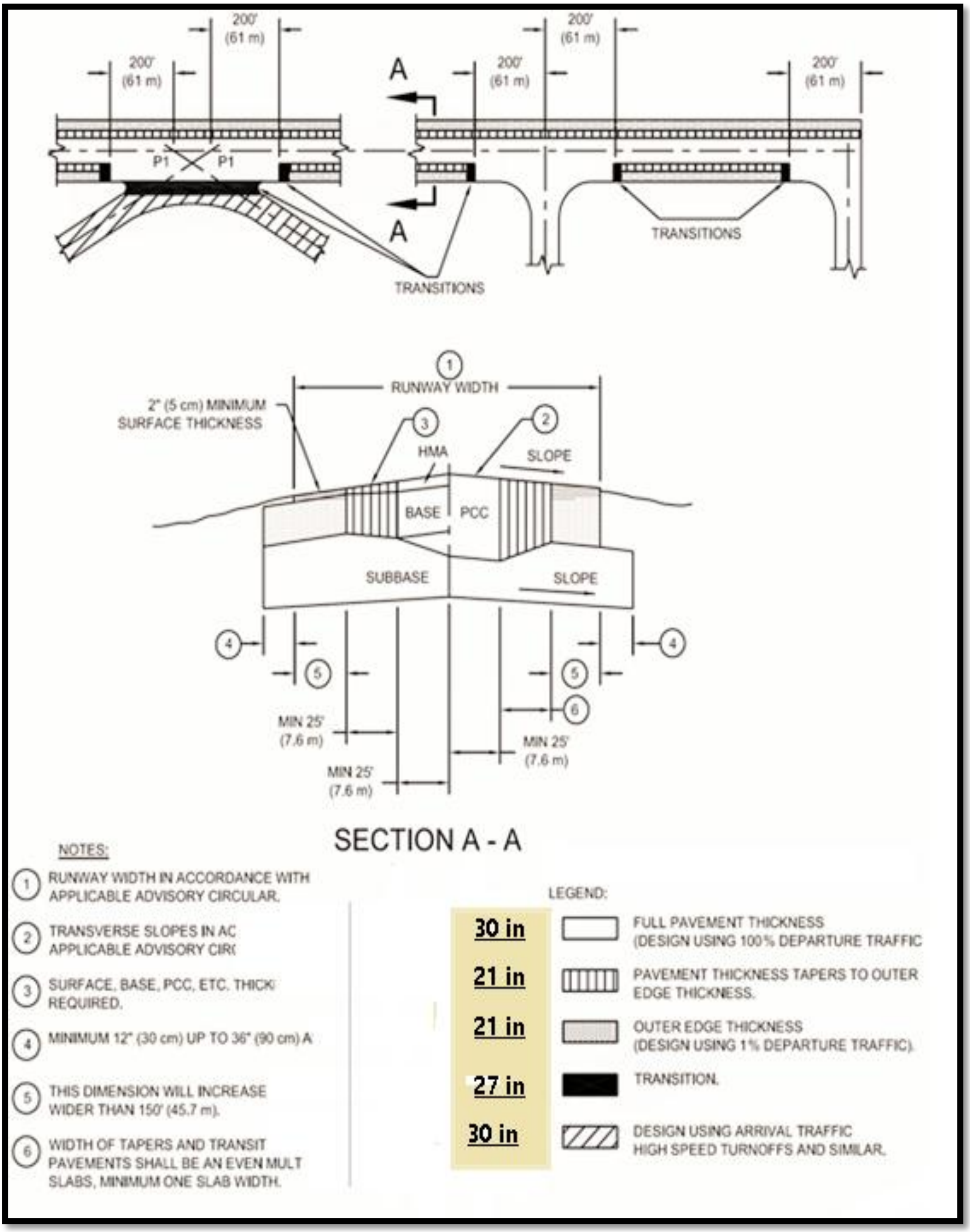

Figure (5-8) Typical Plan and Cross Section for KNIA Runway Pavement designed by AI (nomographs)

3. Design by FAARFIELD program

The following points show the design information and the steps followed for the design.

- **Design data (input data)**
  - Design life = 20 years.
  - Sub-grade CBR= 10%.
  - Traffic mix (see table 5-2).
  - P-401/P-403 HMA Surface course.
  - P-401/P-403 St (flex) base course.
  - P-209 Cr Ag sub-base course.

- **FARFIELD procedure:**

The design thickness for airfield flexible pavements using FAARFIELD can be determining by following steps:
Step (1): open program, create new job and select section type (flexible).
Step (2): press "structure" in main window and set design data.
Step (3): click "design structure" in structure window, when program stopped running Inspect design thickness of each layer.
Figure (5-7) show structure information by layer Top First, Then total thickness to the top of HMA = 29.50 in.

Pavement Structure Information by Layer, Top First

No.	**Type**	**Thickness in**	**Modulus psi**	**Poisson's Ratio**	**Strength R,psi**
1	P-401/ P-403 HMA Surface	5.00	200,000	0.35	0
2	P-401/ P-403 St (flex)	14.50	400,000	0.35	0
3	P-209 Cr Ag	10.00	38,236	0.35	0
4	Sub-grade	0.00	15,000	0.35	0

Total thickness to the top of the sub-grade = <u>29.50 in</u>

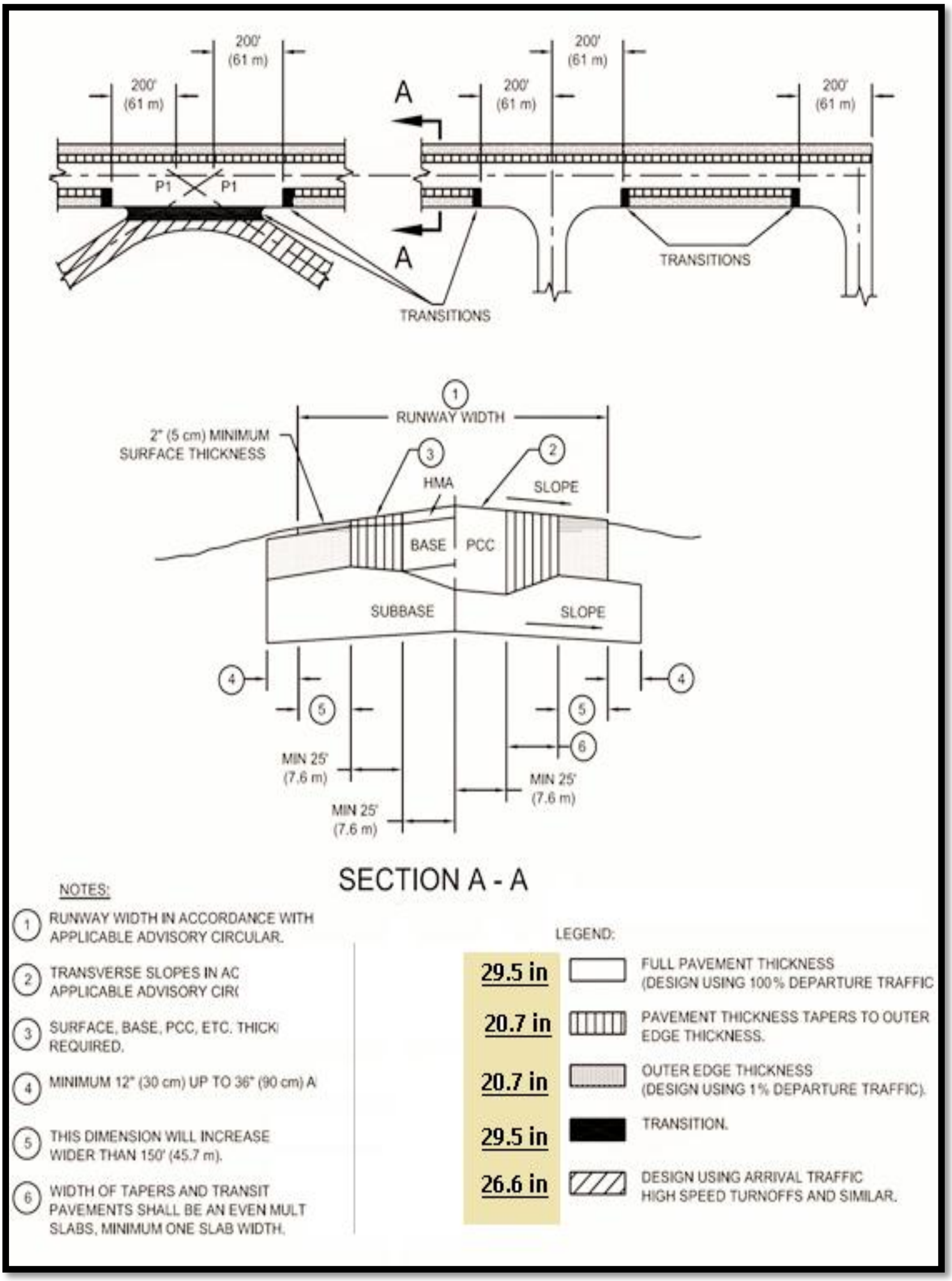

Figure (5-9) Typical Plan and Cross Section for KNIA Runway Pavement designed by FAARFIELD program

5.3.5 Design of rigid pavement of KINA

1. Portland Cement Association Method

The following points show the design information and the steps followed for the design.

- **Design data**

  - *K* value= 141.3 pci
  - Flexural strength = 650 psi
  - Traffic mix (Table 5-2).

Design Procedure

The *k* value in this research determined by the equation below:

$$K=\{\frac{1500 \times CBR}{26}\}^{\mathbf{0.7788}} \text{ pci} \quad ---- (5\text{-}3)$$

Factors of safety as recommended by Packard as follows:

- Aprons, taxiways, hard standing, runway ends, hangar floors-(1.7 to 2)
- Runways (central portion) high speed exit taxiways –(1.4 to 1.7

Determine the working-stress for each aircraft by dividing the modulus of rupture of concrete by the safety factor chosen and from the design chart for the specific aircraft then determine the pavement thickness for the working stress determined for base (P-306 Econcorete) and sub-base (P-209 Cr Ag) thickness equal 6 in. From table (5-12) the design PCC thickness is 20.2 in.

Table (5-16) PCA Slab Thickness Calculation.

AIRCRAFT	GEAR LOAD (lb)	OPERATION	pavement facility					
			taxiway and runway ends			runway ,central portion		
			safety factor	working stress (psi)	slab thickness (in)	safety factor	working stress (psi)	slab thickness (in)
A300	180746.05	occasional	1.9	342.11	11.5	1.5	433.33	11.5
A319	71628.1	occasional	1.9	342.11	11.8	1.5	433.33	10.5
A320	82099.95	frequent	2	325	12.5	1.7	382.35	12.5
A321	98331.65	frequent	2	325	14	1.7	382.35	14
A330	244938.97	frequent	2	325	13.3	1.7	382.35	13.15
A380	356200	occasional	1.9	342.11	13.6	1.5	433.33	13.6
B737	66500	frequent	2	325	9	1.7	382.35	8
B747	929100	occasional	1.9	342.11	20.2	1.5	433.33	17
B767	214225	frequent	2	325	14.5	1.7	382.35	11.4
B777	369075	occasional	1.9	342.11	15	1.5	433.33	13
IL62	25127.5	frequent	2	325	15.6	1.7	382.33	9.9
IL76	179070.25	frequent	2	325	16	1.7	382.33	16
CRJ200	25175	frequent	2	325	14	1.7	382.33	14
DC 8	170050	frequent	2	325	11	1.7	382.33	11
YAK42	60213.37	frequent	2	325	11.6	1.7	382.33	11.6
AN26	25127.5	frequent	2	325	16	1.7	382.33	16

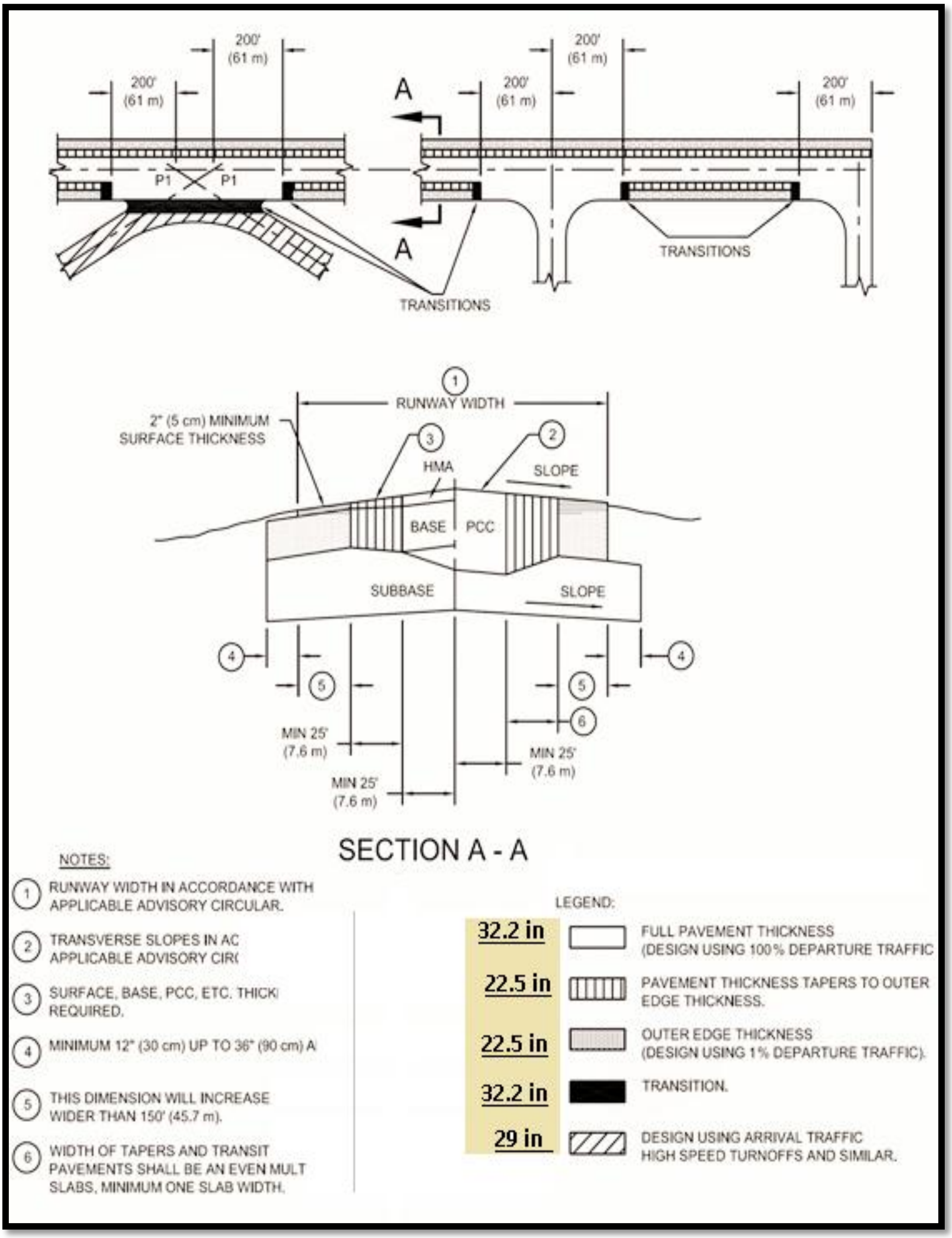

Figure (5-10) Typical Plan and Cross Section for KNIA Runway Pavement designed by PCA method

2. Design by FAARFIELD program

The following points show the design information and the steps followed for the design.

- **Design Information (input data)**
  - Design life = 20 years.
  - Sub-grade CBR= 10%.
  - Traffic mix (see table 5-2).
  - PCC surface course.
  - P-306 Econocrete base course.
  - P-209 Cr Ag sub-base course.
  - K= 141.3
- **FAARFAILED procedures**

The design thickness for airfield flexible pavements using FAARFIELD can be determining by following steps:

Step (1): open program, create new job and select section type (flexible).

Step (2): press "structure" in main window and set design data.

Step (3): click "design structure" in structure window, when program stopped running Inspect design thickness of each layer.

Figure (5-9) show structure information by layer Top First, Then total thickness to the top of HMA = 28.15 in.

Pavement Structure Information by Layer, Top First

No.	Type	Thickness in	Modulus psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	16.15	4,000,000	0.15	700
2	P-306 Econocrete	6.00	700,000	0.20	0
3	P-209 Cr Ag	6.00	35,429	0.35	0
4	Sub-grade	0.00	15,000	0.40	0

Total thickness to the top of the sub-grade = 28.15 in

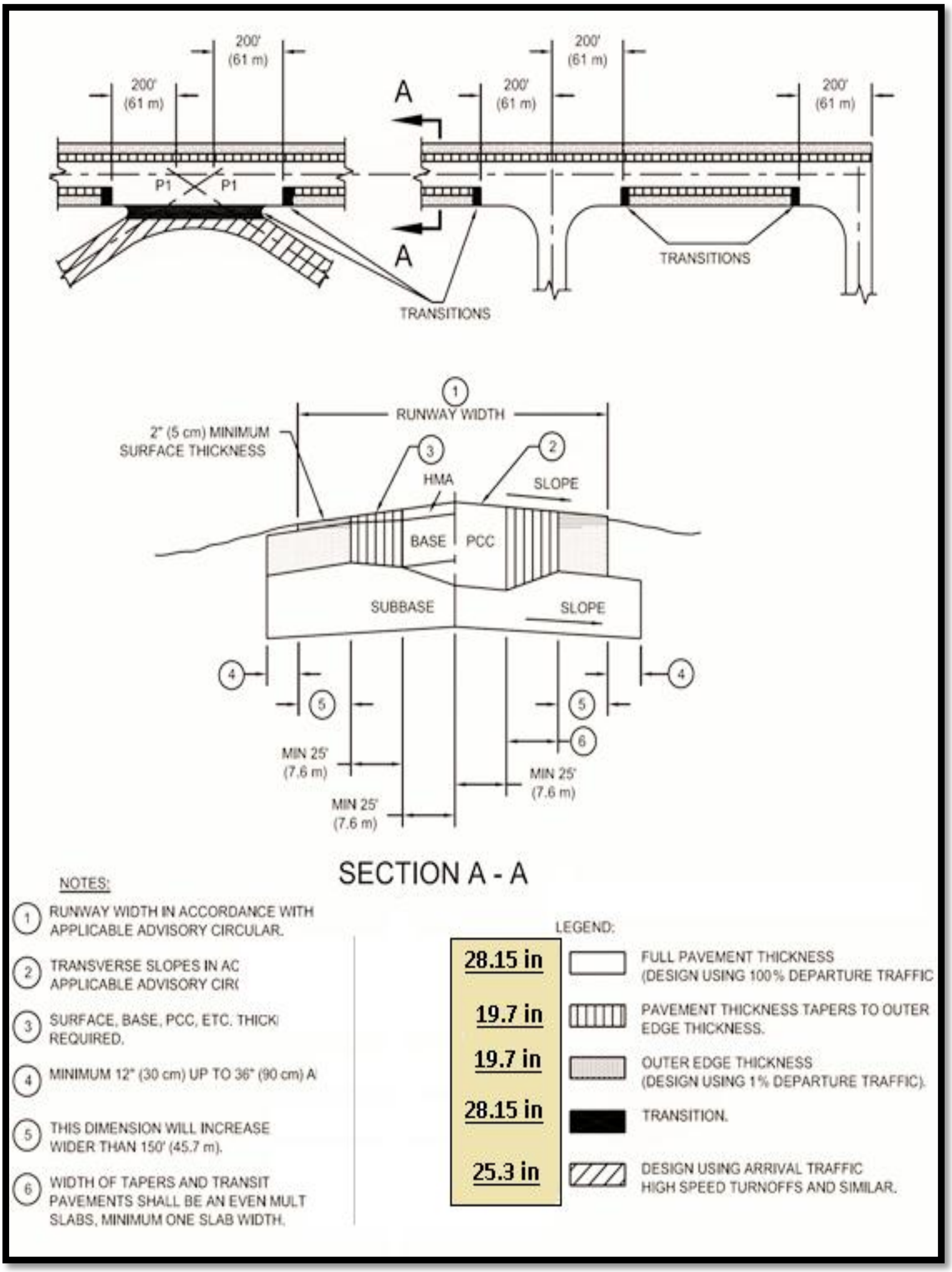

Figure (5-11) Typical Plan and Cross Section for KNIA Runway Pavement designed by FAARFIELD program

5.4 Site of MEROWI Airport.

- Merowe Airport is one of the largest projects that accompanied the establishment of Merowe Dam. This airport is located in the northern state east of the city of Meroe two kilometers from the old airport and overlooks the North Road artery that connects the city of Merowe dam body. And it is an important bridge quenched infrastructure of a modern airports in Sudan. The airport linking Africa, the Gulf and European countries and provides aircraft fuel and contributes to the recovery of tourism in Sudan has been designed on the landing and take-off large aircraft specifications, and the length of the runway about 4 kilometers aircraft and width of 60 meters and total area of the airport of 18 square kilometers along the 6 km, and currently 3 km.

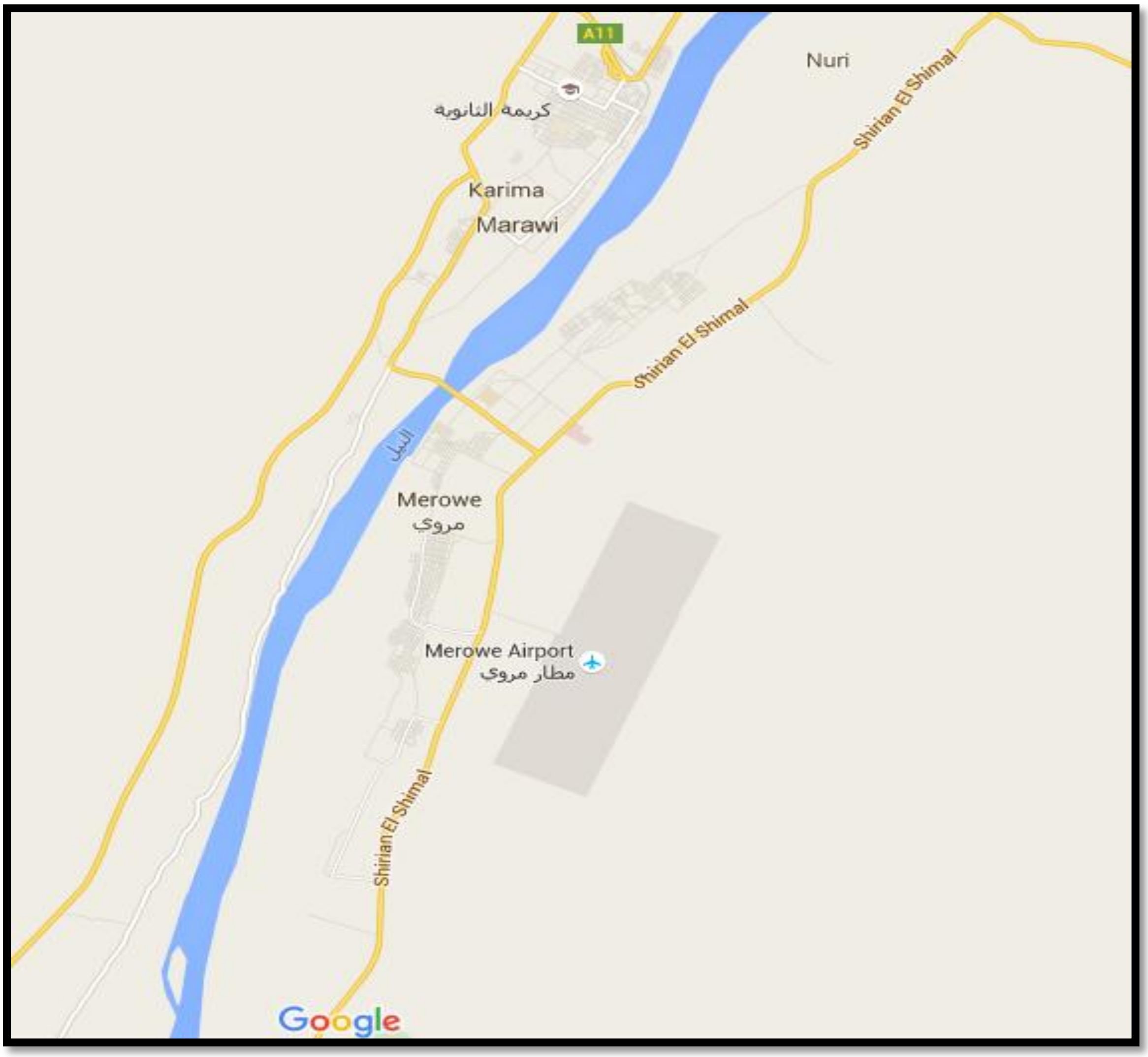

Figure 1-2 Location of Merowe Airport

4.2 Demand Analysis and Traffic Forecast

The demand for air transport is normally estimated from historical data. In the demand estimates for Khartoum new international airport, in this study we need to arrive at the estimated traffic based on Khartoum airport data analysis and the internationally accepted criteria for our estimation

5.5 Geometric Design

5.5.1 Runway Length

 # Design Data:

- Runway length required for landing at sea level in standard atmospheric conditions 2700 m

- Runway length required for take-off at a level site at sea level in standard atmospheric conditions 3000 m

- Aerodrome elevation 845 m

- Aerodrome reference temperature 45°C

- Temperature in the standard atmosphere for 400 m 9.51°C

- Runway slope 1.0%

 # Design steps:

A: Corrections to runway take-off length:

1) Runway take-off length corrected for elevation =

□□□□□□□□□□□□□□□□$\frac{845}{300}$□□□□□□□□□□□□**□□□□□□□m**

2) Runway take-off length corrected for elevation and temperature =

□□□□□□□□ * (45 – 9.51) x 0.01 □□□□□□□□□□□□**4866.12 m**

3) Runway take-off length corrected for elevation, temperature and slope =

□□4866.12* 1.0 * 0.10 □□□□4866.12□□**5352.73 m**

B: Correction to runway landing length:

Runway landing length corrected for elevation =

(2700 * 0.07 * $\frac{845}{300}$) + 2700 = **3232.35 m**

C: Actual runway length:

5352.73 m ≈ 5400 m

5.5.2 Runway Width

 # Design Data:

-Code Letter F

- Code Number 4

*From table (3-1) the widthis**60m**

5.5.3 Orientation:

 # Design Data:

Table (5-17) Wind Data for MEROWI AIRPORT

Direction	Percentage of wind				
	0-4	5-7	8-10	11 and over	Total
N	4	9	5	0	16
NEN	10	6	7	2	25
NE	0	0	0	0	0
ENE	0	11	3	0	14
E	0	0	0	0	0
ESE	0	0	0	0	0
SE	0	0	0	0	0
SES	0	0	0	0	0
S	2	4	1	0	7
SWS	0	0	0	0	0
SW	0	5	16	14	35
WSW	0	0	0	0	0
W	0	0	0	1	1
WNW	0	0	0	0	0
NW	0	7	1	3	11
NWN	0	0	0	0	0

Total	100%

 # Output data:

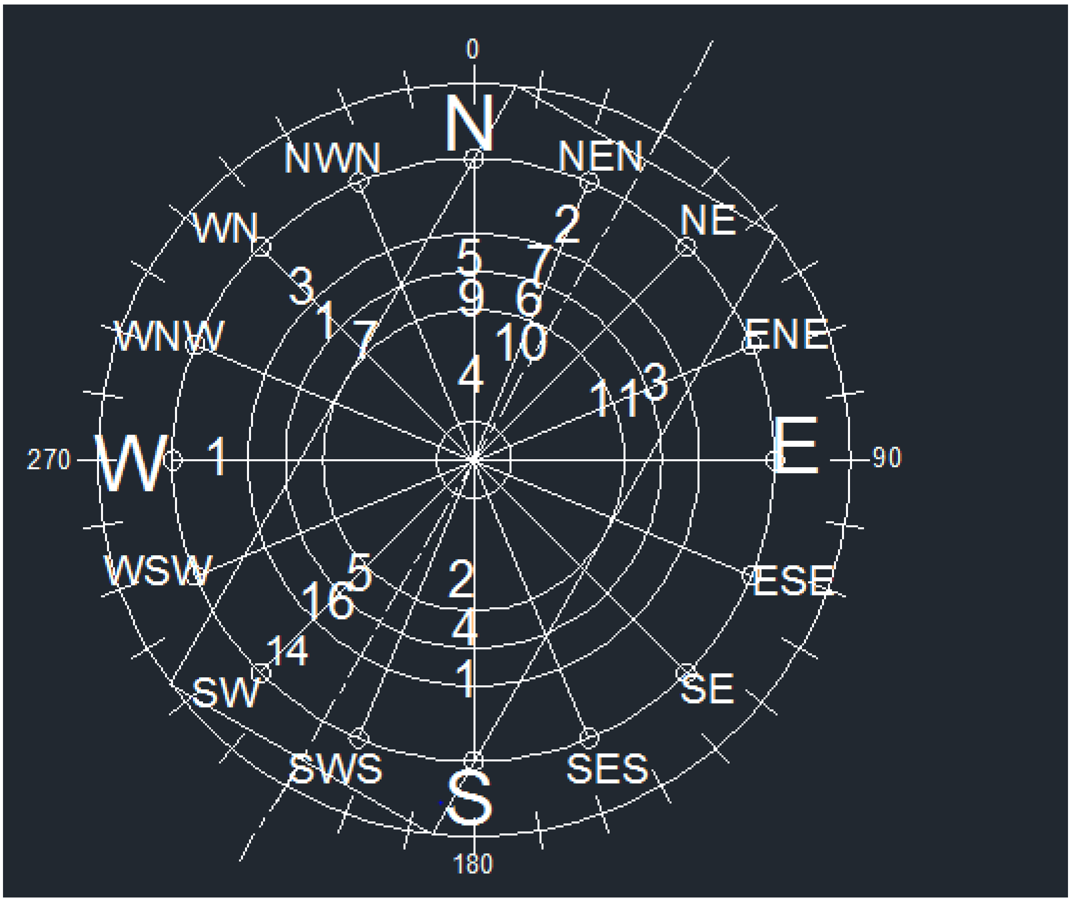

Figure (5-12) Orientation Runway for MEROWI AIRPORT

5.6 STRUCTURAL DESIGN

5.6.1 MEROWI Airport Design traffic mix

The following table shows the aircraft type, annual departure and expected annual rates of increase for any aircraft expected on MEROWI Airport.

Table (5-18): Traffic mix for MEROWI AIRPORT

Aircraft	Type of gear	Departure	Passes	Annual growth %
AN 26	D	14	28	6.5
AN 30	D	1	2	6.5
AN 32	D	7	14	6.5
AN 72	2D	3	6	6.5
AN 74	2D	6	12	6.5
B737	D	3	6	6.5
C208	S	4	8	6.5
BE30	S	4	8	6.5
F50	S	10	20	6.5
E135	D	1	2	6.5
L298	S	2	4	6.5
DC 8	2D	0	0	6.5

5.6.2Flexible Airport pavement Design process

1. **MEROWI Airport Flexible Pavement Design by Asphalt Institute Method (Analytical):**

The following procedures show the design information and the steps followed for the design.

- **Design information**
  - Sub-grade CBR = 10%
  - Mean Annual Air Temperature (MAAT) = 45 C
  - Traffic mix groups with the types of aircraft in the charts and tables of this method

Table (5-19): Traffic Mix Groups

Type	G1(2D)	G2(D)
AIRCRAFT DESIGN	**DC 8-63**	**B-737-200C**
AIRCRAFT	AN 72 , F50 AN74 BE 30 C 208 ,	AN 26. L 298 AN30 AN 32 E 135

Compute equivalent departure for each group by multiplying aircraft departure by equivalent factors. And then determine total passes for design life as shown:

Total passes for design life	**DC-8-63**	**B737-200C**
	2599	3891

 # Design steps

Step (1): determine allowable thickness (T_A) for repetitions and distress for fatigue and deformation criterion from figures (B-1), (B-2), for MAAT = 45 C and form equation (3-1) E_S = 1500*10 = 15000 psi. Tables (5-15), (5-16) showing values of (T_A)

Table (5-20) T_A values by fatigue criteria

	Number of strain repetitions (N_f)				
	100	1000	10000	100000	1000000
T_A (in)	5.5	8.2	12.6	18	26

Table (5-21) T_A values by deformation criteria

	Number of strain repetitions (N_f)				
	100	1000	10000	100000	1000000
T_A (in)	12.2	15	17	18	19.5

Step (2): Summarize the asphalt concrete tensile strain (f_{ix}) values from Table (B-3) and fatigue values $f_{ih}$from table (B-5) summarize them for all design aircraft in the traffic mix. Tables (5-22) and (5-23) show that.

Table (5-22) f_{ix} values (asphalt concrete tensile strain)

	Interval form taxiway centerline						
Aircraft	0-1ft	4-5ft	8-9ft	12-13ft	16-17ft	20-21ft	24-25ft
DC-8-63F	-	0.15	0.48	0.48	0.15	-	-
B-737-200C	0.05	0.30	0.56	0.30	0.04	-	-

Table (5-23) fatigue F_{ih} values

Aircraft	h_1=10 in	h_1=20 in	h_1=30 in	h_1=40 in	h_1=50 in
DC-8-63F	0.126	0.047	0.024	0.015	0.013
B-737-200C	1.0	1.0	1.0	1.0	1.0

Step (3): Summarize the sub-grade vertical strain (*fix*) values from Table (B-4) and deformation f_{ih}regression constants from Table (B-6) summarize them for all design aircraft in the traffic mix. Tables (5-24) and (5-25) show that.

Table (5-24) f_{ix} values (sub-grade vertical strain)

Interval form taxiway centerline							
Aircraft	0-1ft	4-5ft	8-9ft	12-13ft	16-17ft	20-21ft	24-25ft
B-737-200C	0.03	0.21	0.45	0.28	0.05	-	-
DC-8-63F	0.01	0.28	0.83	0.71	0.17	-	-

Table (5-25) deformation F_{ih} regression constants

	h_1=10 in		h_1=20 in		h_1=30 in		h_1=40 in	
Aircraft	C	A_1	C	A_1	C	A_1	C	A_1
B-737-200C	0.789	-0.680	0.876	-0.881	0.860	-0.879	0.884	-0.931
DC-8-63F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Step (4): Determine the Equivalent DC-8 repetitions (n_{ex}) for fatigue analysis from equation (5-1).

$$\text{Nex} = \sum_{j=1}^{j} \mathbf{p_j} \cdot \mathbf{f_{jx} F_{jh}} \qquad \text{\_\_\_\_\_\_\_\_\_ (5-1)}$$

Where:

N_{ex}= Equivalent dc-8 repetitions

f_{ix}= asphalt concrete tensile strain

F_{jh} = fatigue values

P_j = no. of passes

Using **P1=2599**, **P2=3891**, for f_{ix} and F_{jh}see tables (5-24) and (5-25) respectively. Table (5-26) shows the Equivalent DC-8 repetitions for fatigue analysis

Table (5-26) the Equivalent DC-8 repetitions for fatigue analysis

	Aircraft	x=0-1ft	x=4-5ft	x=8-9ft	x=12-13ft	x=16-17ft	x=20-21ft	x=24-25ft
	B-737-200C	194.55	1167.3	2178.96	1167.3	155.64	0	0
TA =10in	DC-8-63F	0	49.12	157.18	157.18	49.12	0	0
	SUM	194.55	1216.42	2336.14	1324.48	204.76	0	0
TA=20in	B-737-200C	194.55	1167.3	2178.96	1167.3	155.64	0	0
	DC-8-63F	0	18.32	58.63	58.63	18.32	0	0
	SUM	194.55	1185.62	2237.59	1225.93	173.96	0	0
TA=30 in	B-737-200C	194.55	1167.3	2178.96	1167.3	155.64	0	0
	DC-8-63F	0	9.35	29.94	29.94	9.35	0	0
	SUM	194.55	1176.65	2208.9	1197.24	164.99	0	0
TA=40 in	B-737-200C	194.55	1167.3	2178.96	1167.3	155.64	0	0
	DC-8-63F	0	5.84	18.71	18.71	5.84	0	0
	SUM	194.55	1173.14	2197.67	1186.01	161.48	0	0
TA=50 in	B-737-200C	194.55	1167.3	2178.96	1167.3	155.64	0	0
	DC-8-63F	0	5.07	16.22	16.22	5.07	0	0
	SUM	194.55	1172.37	2195.18	1183.52	160.71	0	0

Step (5): Determine the Equivalent DC-8 repetitions (n_{ex}) for deformation analysis from equation (5-)

$$N_{ex}= \sum_{j=1}^{j} 10^{c}\left(p_j . f_{ix}\right)^{A1+1} \qquad \text{\_\_\_\_\_\_ (5-2)}$$

Where:

N_{ex} = Equivalent DC-8 repetitions.

P_j = no. of passes.

f_{ix} = sub-grade vertical strain.

A = regression constants.

c = regression constants

Using, **P1=2599, P2=3891,** For f_{ix} and (A,c)see tables (5-24) and (5-25) respectively. Table (5-27) shows the Equivalent DC-8 repetitions for deformation analysis

Table (5-27) the Equivalent DC-8 repetitions for deformation analysis

	Aircraft	x=0-1ft	x=4-5ft	x=8-9ft	x=12-13ft	x=16-17ft	x=20-21ft	x=24-25ft
TA =10	B-737-200C	28.217	52.59	67.12	57.66	33.23	0	0
	DC-8-63F	25.99	727.72	2157.17	1845.29	441.83	0	0
	SUM	54.207	780.31	2224.29	1902.95	475.06	0	0
TA=20	B-737-200C	13.24	16.69	18.28	17.28	14.07	0	0
	DC-8-63F	25.99	727.72	2157.17	1845.29	441.83	0	0
	SUM	39.23	744.41	2175.45	1862.57	455.9	0	0
TA=30 in	B-737-200C	17.03	16.31	17.88	16.89	13.71	0	0
	DC-8-63F	25.99	727.72	2157.17	1845.29	441.83	0	0
	SUM	43.02	744.03	2175.05	1862.18	455.54	0	0
TA=40 in	B-737-200C	10.63	12.16	12.82	12.4	11.02	0	0
	DC-8-63F	25.99	727.72	2157.17	1845.29	441.83	0	0
	SUM	36.62	739.88	2169.99	1857.69	452.85	0	0

Step (6): At each interval, the sum of the equivalent repetitions represents the mix traffic effect expressed in terms of equivalent DC-8-63F repetitions.

Illustrates the highest passes for each thickness for permanent deformation and fatigue analysis with allowable thickness in Figure (5-15) respectively. The cross of curves presented the design thickness of criteria. Figures (5-13) and Figures (5-14) show that

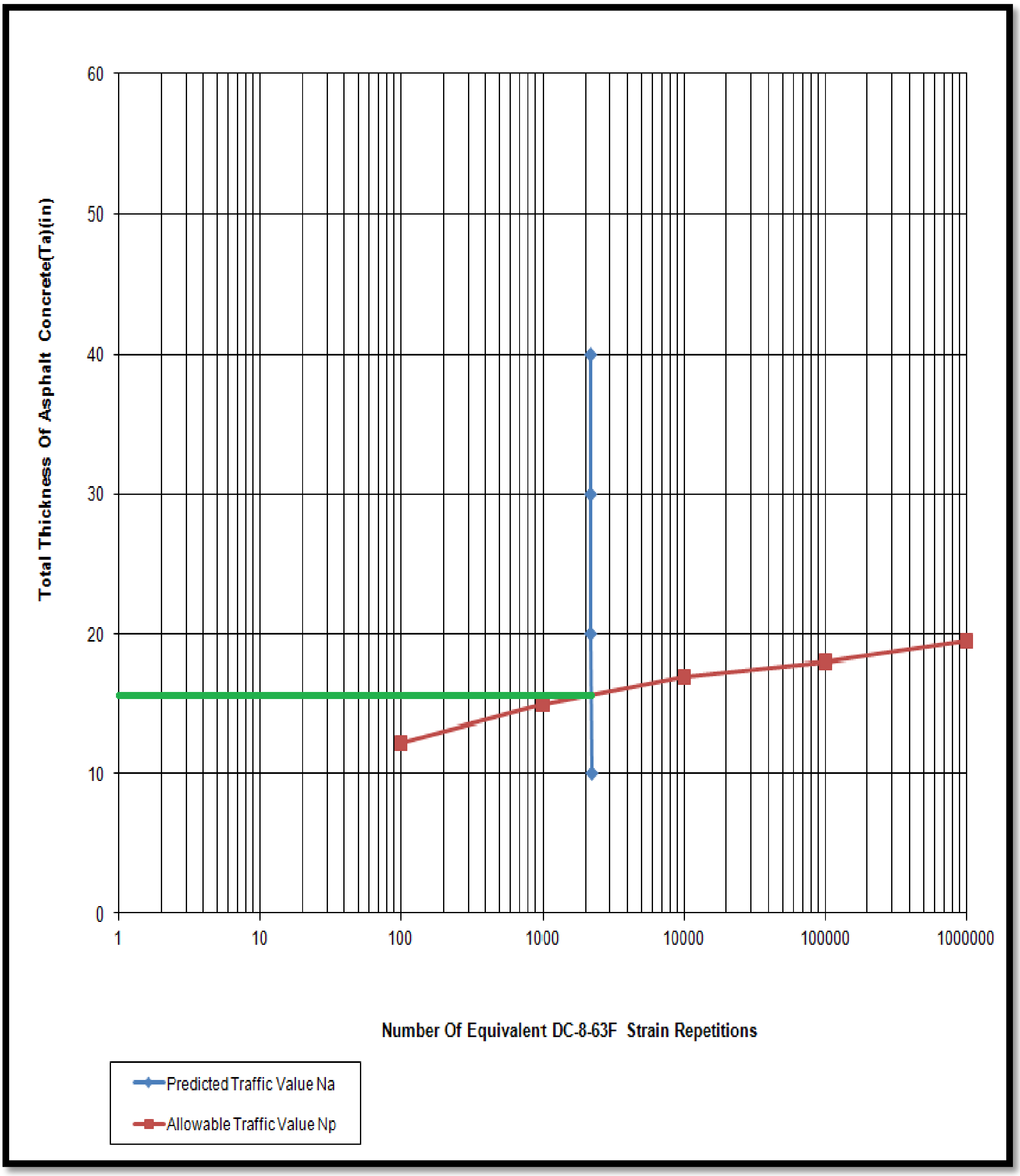

Figure (5-13) the cross of curves presented the design thickness of criteria.

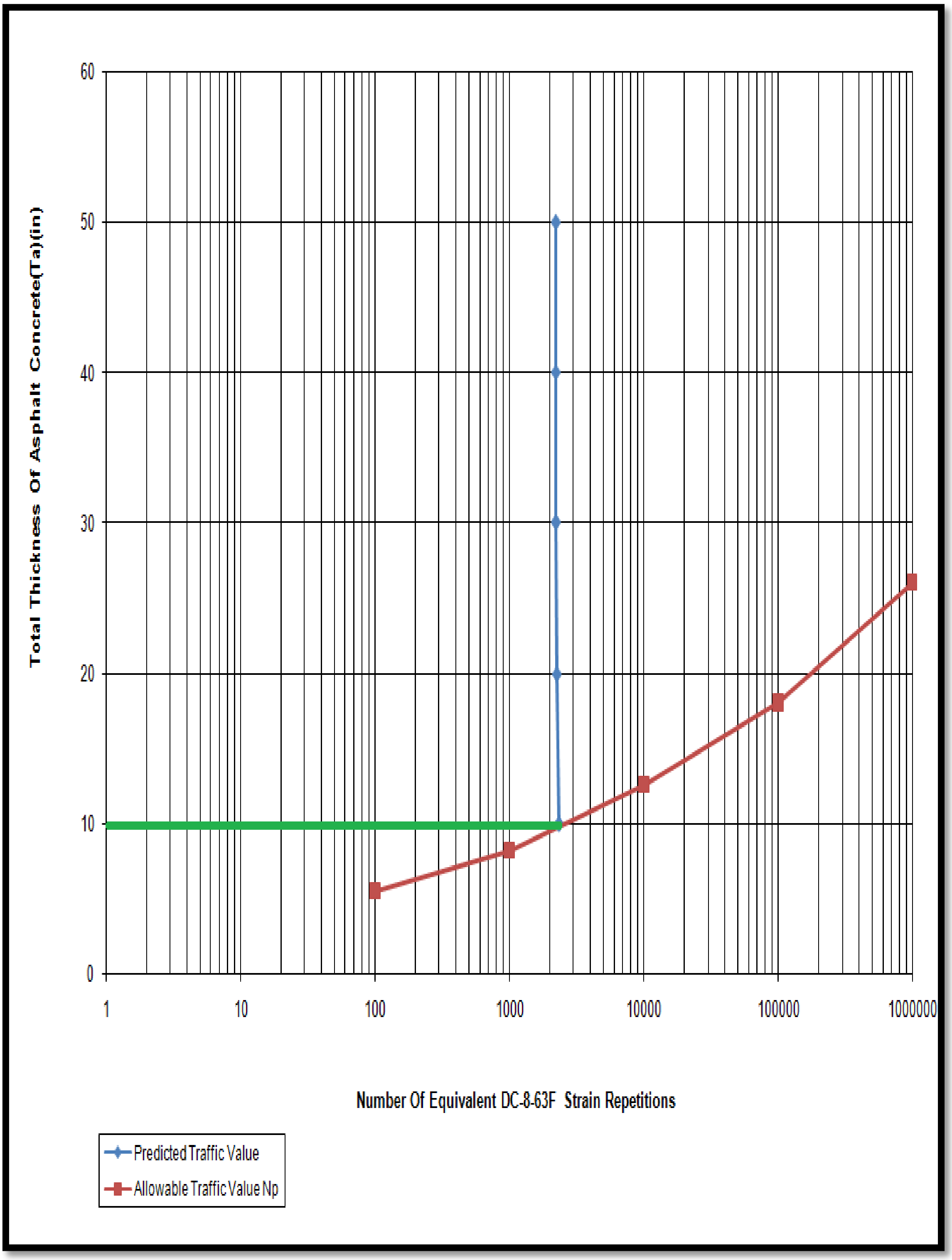

Figure (5-14) The cross of curves presented the design thickness of criteria.

Step (7): the design thickness is the maximum one of two criterions

The design thickness= 16 in full depth HMA. Figure (5-15) shows all details about pavement facilities

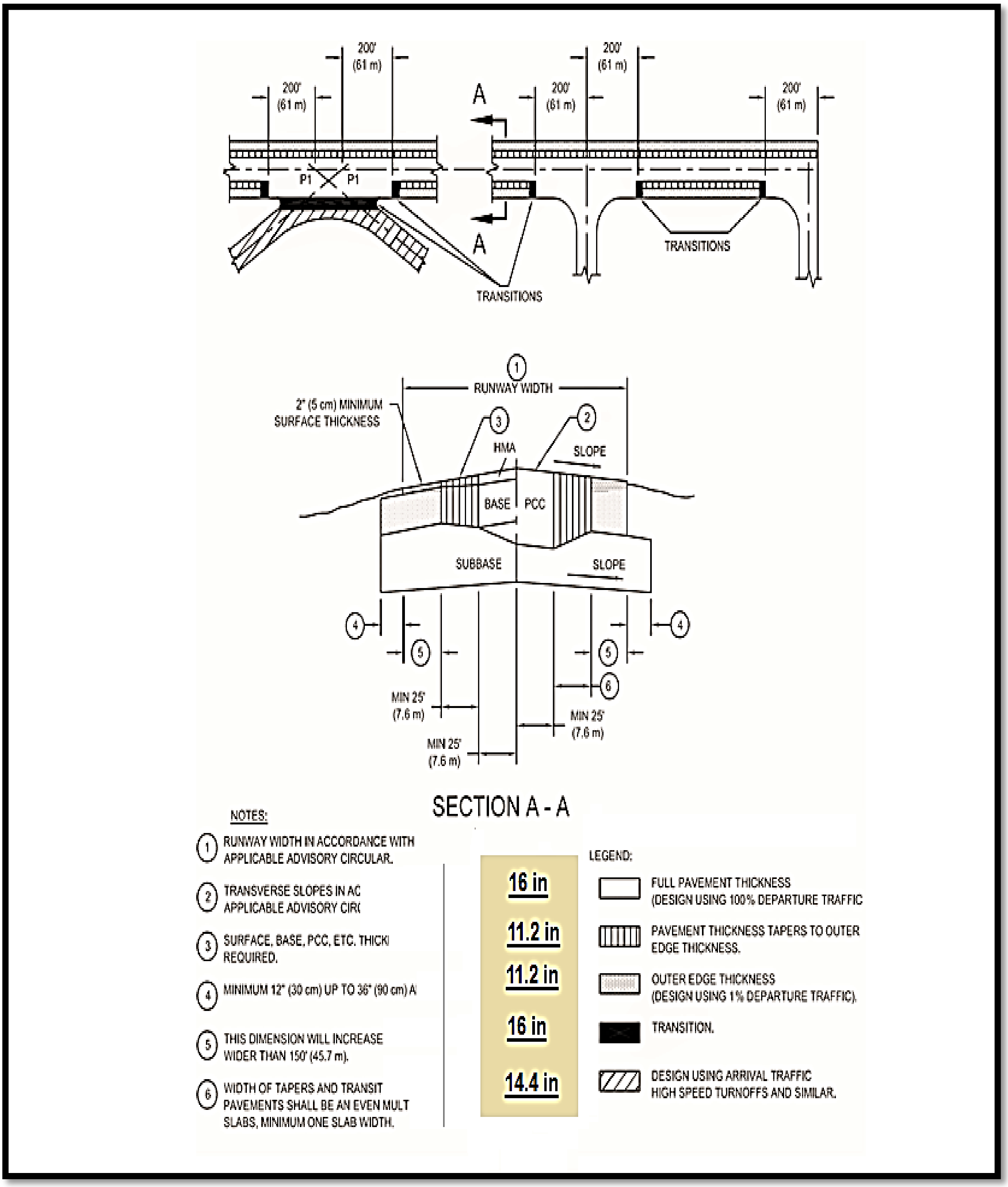

Figure (5-15) Typical Plan and Cross Section for MEROWI AIRPORT Runway Pavement designed by AI method

2. MEROWI Flexible Pavement Design by Asphalt Institute Method (nomographs)

The following procedures show the design information and the steps followed for the design.

- **Design Data**
  - The sub-grade modulus of elasticity (E=1500 psi)
  - The mean annual air temperature(MAAT=37̊ C)
  - Traffic mix is (DC8-63F,B737-200,) with total (,2599 ,3891)
- **Design Step**

  Step (1): Determine the allowable traffic value Na,for each strain criterion (εc and εt)from the design subgrade modulus of elasticity Es, and mean annual air temperature T,for the design location see table

Table (5-28): Allowable Traffic Value for Each Strain Criterion

	100	1000	10000	100000	1000000
Ec	5.5	8	12	18	26
Et	12	15	17.5	18	19.5

Step(2): Determine the predicted traffic value Np ,from the projected aircraft mix forecast for the pavement selected design period , and the aircraft equivalency diagrams for specific strain criterion (horizontal tensile, εt or vertical compressive, εc) by using number of aircraft movement (passes) and lateral distance and table 5-26 and5-27 illustrate that.

Step(3): Determine the full-depth asphalt concrete pavement thickness, needed to satisfy the strain criteria by using figure B-5 AND B-6 of the following figures(5-18) illustrate thickness design process . Then the design thickness=15in

Table (5-28): Appropriate Traffic for the Fatigue Analysis

	AIRCRAFT	5.5	9.5	13.5	17.5
TA=10in	B737	40	150	25	1.2
	DC	700	60	1200	220
	SUM	740	210	1225	221.2
TA=30in	B737	200	300	120	5
	DC	700	150	1200	220
	SUM	900	450	1320	225
TA=50in	B737	20	30	9	0.5
	DC	700	1500	1200	220
	SUM	720	1530	1209	220.5

Table (5-29): Appropriate Traffic for the Permanent Deformation

	AIRCRAFT	5.5	9.5	13.5	17.5
TA=10in	B737	160	70	60	27
	DC	300	3000	700	300
	SUM	460	3070	760	327
TA=20in	B737	29	20	27	18
	DC	0300	300	700	300
	SUM	2903	320	727	318
TA=30n	B737	17	18	27	13
	DC	300	3000	700	300
	SUM	317	3018	727	313
TA=40in	B737	13	14	12	10
	DC	300	3000	700	300
	SUM	313	3014	712	310

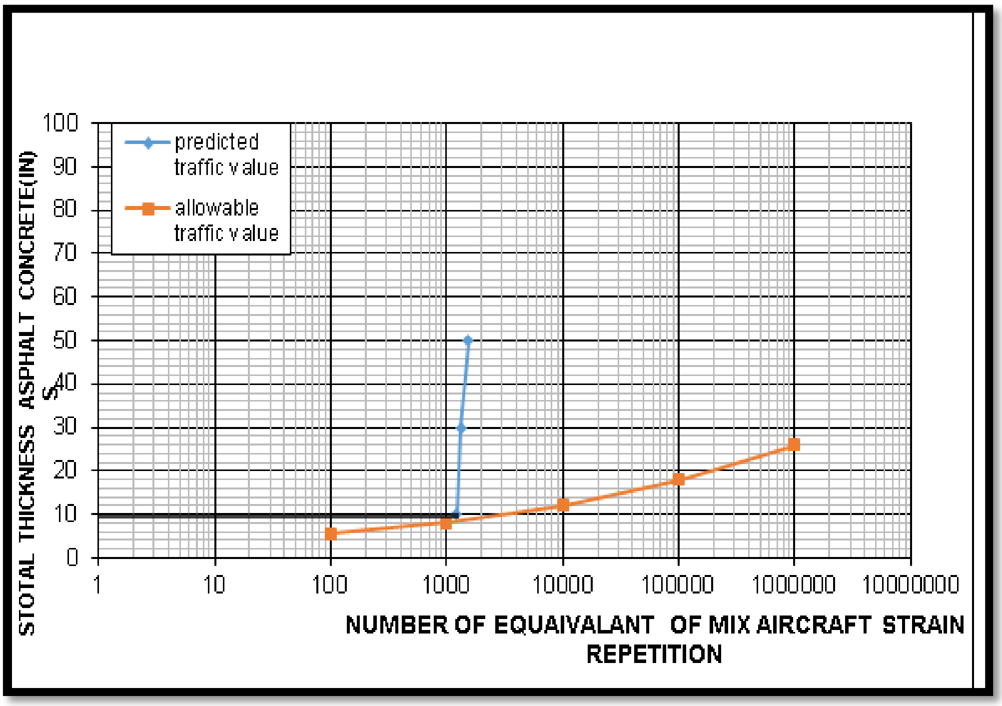

FIGURE (5-16): Allowable Traffic Value and Predicated Traffic Value Curves for Compressive Strain

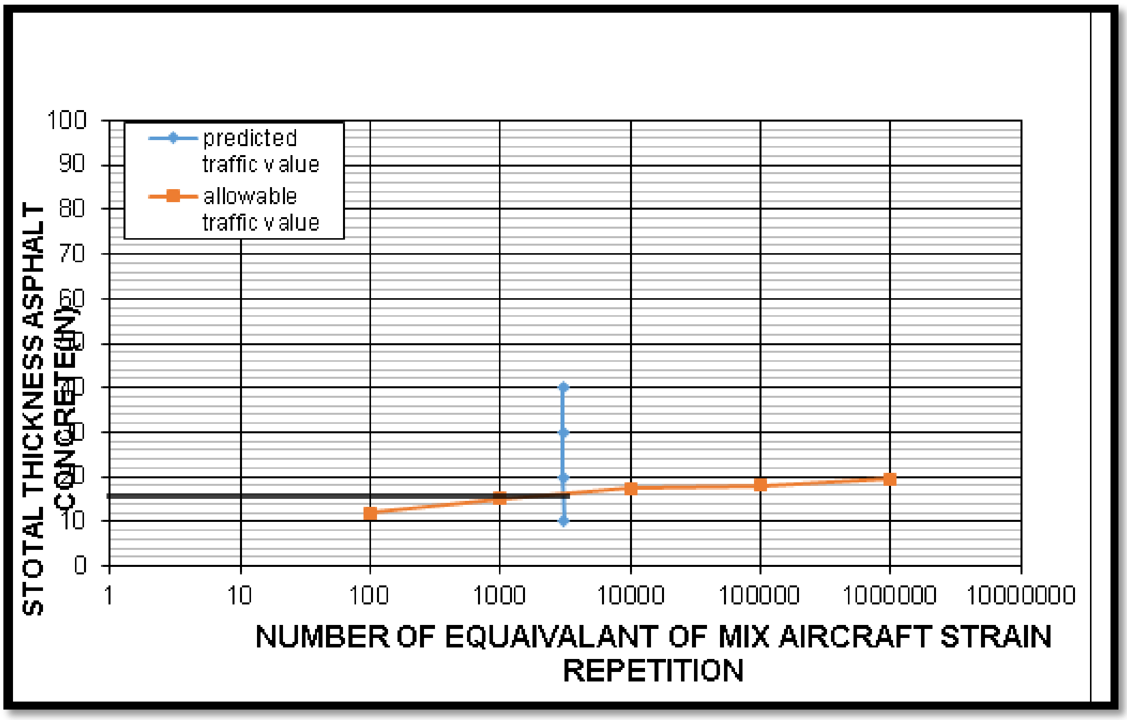

FIGURE (5-17): Allowable Traffic Value and Predicated Traffic Value Curves for Tensile Strain

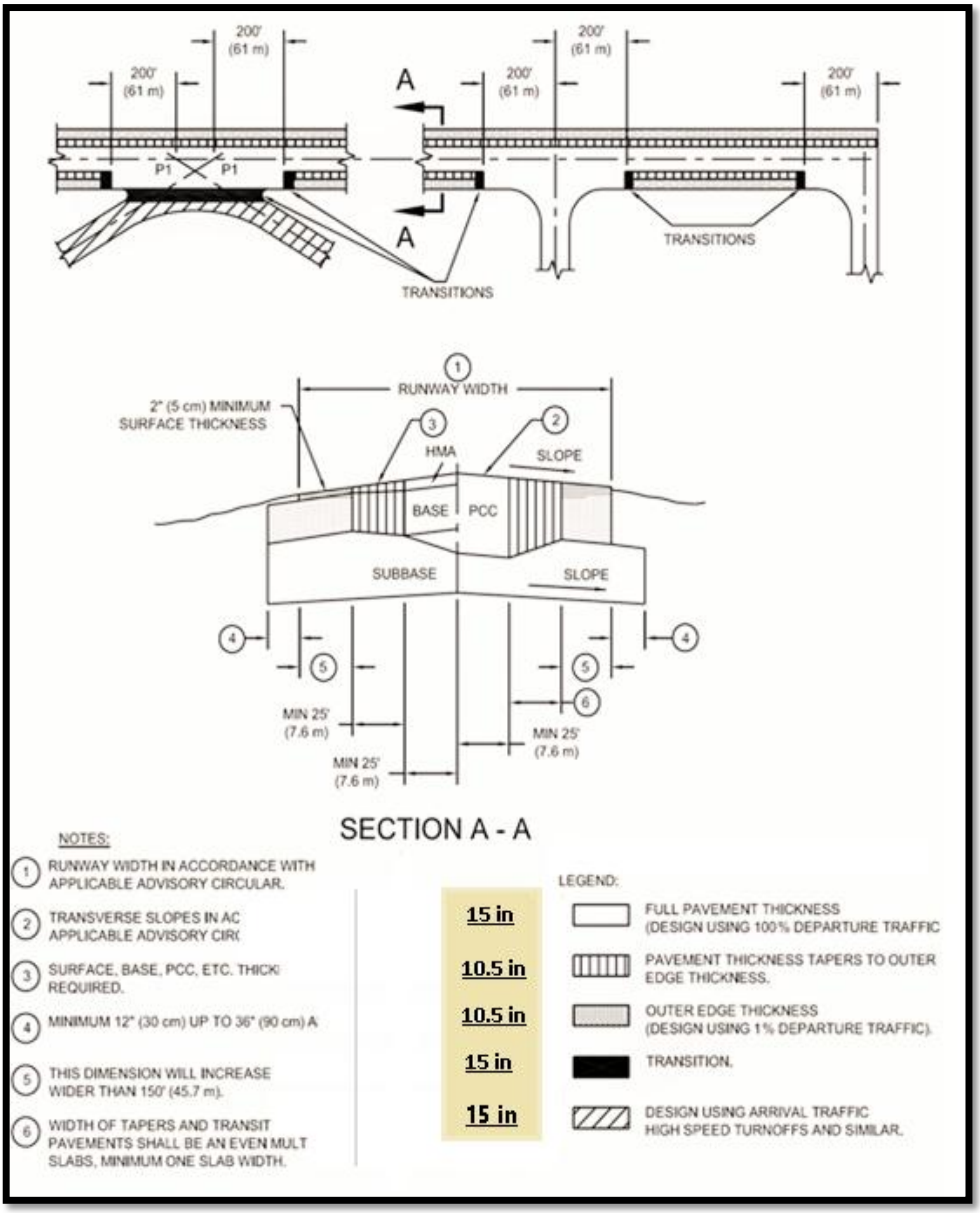

Figure (5-18) MEROWI flexible Pavement Design by Asphalt Institute Method (nomographs)

3. Design by FAARFIELD program

The following procedures show the design information and the steps followed for the design.

#Design data (input data)

- Design life = 20 years.
- Sub-grade CBR= 10%.
- Traffic mix (see table 5-13).
- P-401/P-403 HMA Surface course.
- P-401/P-403 St (flex) base course.
- P-209 Cr Ag sub-base course.

#Design procedure

The design thickness for airfield flexible pavements using FAARFIELD can be determining by following steps:
Step (1): open program, create new job and select section type (flexible).
Step (2): press “structure” in main window and set design data.
Step (3): click “design structure” in structure window, when program stopped running Inspect design thickness of each layer.
Total thickness to the top of HMA = 23 in.

FAARFAILED (Output data)

Pavement Structure Information by Layer, Top First

No.	Type	Thickness in	Modulus psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	5.00	200,000	0.35	0
2	P-401/ P-403 St (flex)	8.00	400,000	0.35	0
3	P-209 Cr Ag	10.00	75,000	0.35	0
4	Sub-grade	0.00	15,000	0.35	0

Total thickness to the top of the sub-grade = <u>23 in</u>

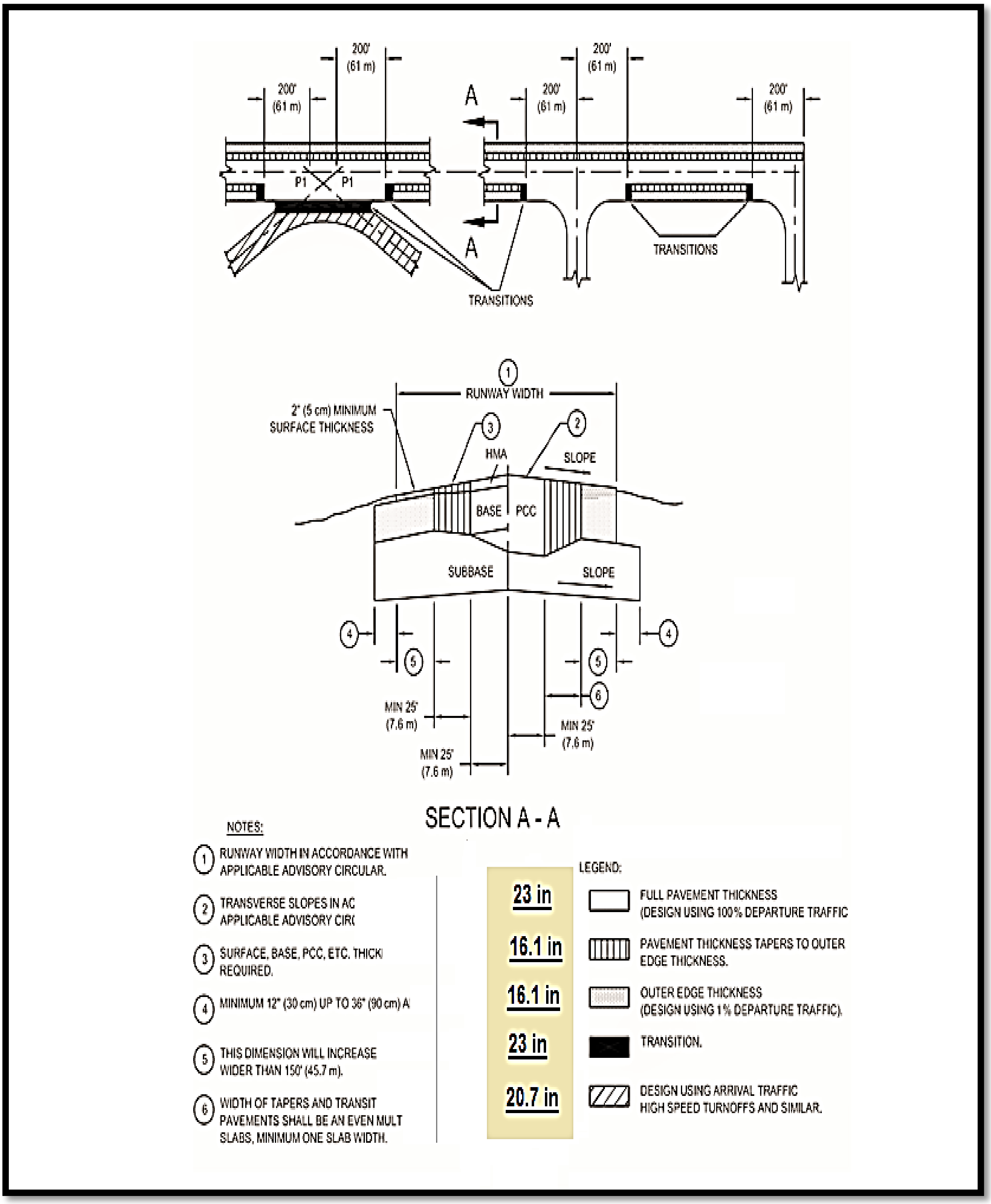

Figure (5-19) Typical Plan and Cross Section for MEROWI AIRPORT Runway Pavement designed by FAARFIELD program

5.6.3 Design of rigid pavement of MEROWI AIRPORT

The following procedures show the design information and the steps followed for the design.

1. Portland Cement Association Method

- **Design data**
  - *K* value= 141.3 pci
  - Flexural strength = 650 psi
  - Traffic mix (Table 5-13).

 # Design Procedure

The *k* value in this research determined by the equation below:

$$K = \{\frac{1500 \times CBR}{26}\}^{\mathbf{0.7788}} \text{pci} \qquad \text{- - - (5-3)}$$

Factors of safety as recommended by Packard as follows:

- Aprons, taxiways, hard standing, runway ends, hangar floors-(1.7 to 2)
- Runways (central portion) high speed exit taxiways –(1.4 to 1.7)

Determine the working-stress for each aircraft by dividing the modulus of rupture of concrete by the safety factor chosen and from the design chart for the specific aircraft then determine the pavement thickness for the working stress determined for base (P-306 Econcorete) and sub-base (P-209 Cr Ag) thickness equal 6 in. From table (5-23) the design PCC thickness is 12.6 in.

Table (5-23) PCA Slab Thickness Calculation.

AIRCRAFT	GEAR LOAD (lb)	OPERATION	pavement facility					
			taxiway and runway ends			runway ,central portion		
			safety factor	working stress (psi)	slab thickness (in)	safety factor	working stress (psi)	slab thickness (in)
AN 26	25127.5	occasional	1.8	361.11	12.6	1.5	433.33	12.7
AN 30	24150	occasional	1.8	361.11	11	1.5	433.33	10.4
AN 32	28350	occasional	1.8	361.11	9.7	1.5	433.33	9.3
AN 72	36225	occasional	1.8	361.11	10	1.5	433.33	9.8
AN 74	36229	occasional	1.8	361.11	12	1.5	433.33	10.7
B737	89359	occasional	1.8	361.11	9	1.5	433.33	8
C208	48876	occasional	1.8	361.11	7.9	1.5	433.33	8
BE30	60128	occasional	1.8	361.11	11.6	1.5	433.33	9.3
F50	18430	occasional	1.8	361.11	9.5	1.5	433.33	9.2
E135	25305	occasional	1.8	361.11	5	1.5	433.33	4.4
L298	5032.65	occasional	1.8	361.11	8	1.5	433.33	7.3
DC 8	178552.5	occasional	1.8	361.11	11.6	1.5	433.33	11.5

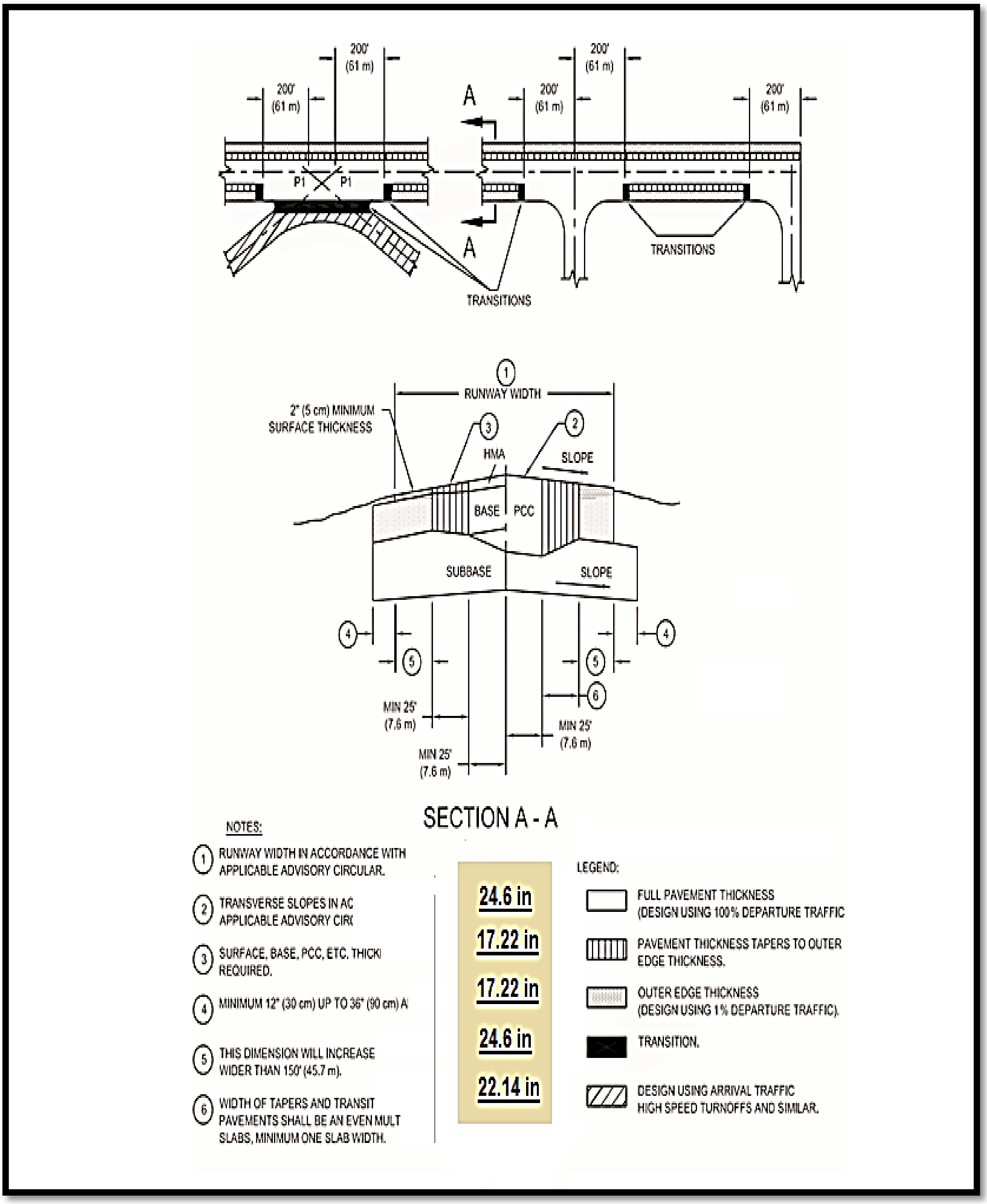

Figure (5-20) Typical Plan and Cross Section for MEROWI AIRPORT Runway Pavement designed by PCA method

2.Design by FAARFIELD program

The following procedures show the design information and the steps followed for the design.

Design Information (input data)

- Design life = 20 years.
- Sub-grade CBR= 10%.
- Traffic mix (see table 5-2).
- PCC surface course.
- P-306 Econocrete base course.
- P-209 Cr Ag sub-base course.
- K= 141.3

FAARFAILED (Output data)

Pavement Structure Information by Layer, Top First

No.	Type	Thickness in	Modulus psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	10.00	4,000,000	0.15	700
2	P-306 Econocrete	6.00	700,000	0.20	0
3	P-209 Cr Ag	5.00	75,000	0.35	0
4	Sub-grade	0.00	15,000	0.40	0

Total thickness to the top of the sub-grade = 21.00 in

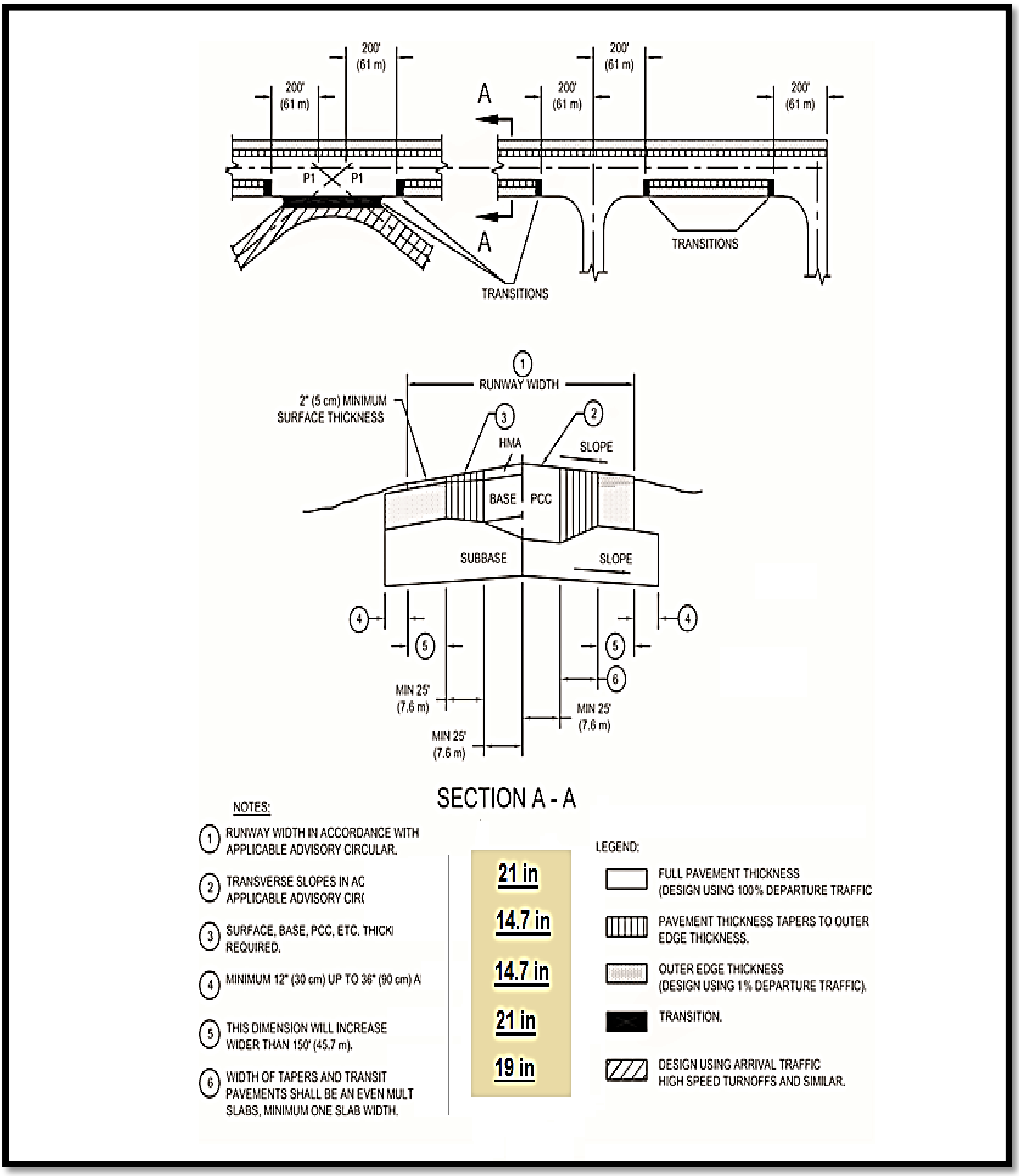

Figure (5-21) Typical Plan and Cross Section for MEROWI AIRPORT Runway Pavement designed by FAARFIELD program