Analysis of Pavement Dimension at The Hang Nadim International Airport in Batam City, Indonesia

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Abstract

It was acknowledged that, the Hang Nadim International Airport's aircraft movements increased significantly at recent 10 years period. The shift in aircraft dimensions and weights have raised questions whether or not the existing apron pavement dimensions are sufficient for accommodating the increase aircraft parking demands and to bear aircraft load changes. The purpose of this research is to evaluate and analyze the apron dimensions and pavement thickness at Hang Nadim Airport. This research was used two relevant methods as guidelines for calculating this apron dimension and thickness; ICAO (International Civil Aviation Organization) Anex 14 2013 and FAA (Federal Aviation Administration) 150/5320-6d. It was calculated that the apron dimension needs to be expanded to 1600 m x 150 m for accommodating 31 aircraft parking in 2025 (11 units B747- 300 + 16 units B737-900 + 4 units F27). The apron thickness would be 46.2 cm of base course and 10 cm of subbase course.

Keywords: Airport, Landing Movements, Runway, Taxiway, Apron, ICAO.

INTRODUCTION

Due to a huge increase in the air traffic over the past decade, and with further growth forecast, air traffic congestion on the airport surface is a major constraint on efficient use of airport resources [1]. The Hang Nadim International Airport's aircraft movements increased by an average of 7.30% every year started from 2007.

The capacity of an airport depends on the capacities of its landside and airside components [2]. Based on data from 2007 to 2016, the population, GDP and per capita income of Batam City have increased every year. GDP is the most sensible to air traffic growth in region where only international airports are located, that is for region that exhibit the highest level of development [3].

A runway is a rectangular area on the airport surface prepared for the takeoff and landing of aircraft. Taxiways are defined paths on the airfield surface which are established for the taxiing of aircraft and are intended to provide a linkage between one part of the airfield and another. Apron is an area where the aircraft instrument and engine operation can be checked prior to takeoff [4].

Hang Nadim International Airport is located in Batam City, Riau Archipelago, Indonesia. In 2016, Hang Nadim Airport has a single runway with dimensions of 4015m x 45m, 2 exit taxiways with dimensions of 150m x 23m and 2 rapid exit taxiways with dimensions of 300m x 23m. The existing apron has dimensions of 690.5 x 76.8m and 240m x 150m. This apron has a capacity of 13 aircrafts with the largest type of aircraft operating is Boeing 737-900, while Hang Nadim airport have to accommodate 19 aircrafts in 2016. Therefore, the existing apron has to be expanded.

Airport pavements should satisfy safe and regular aircraft operations thus, it is necessary to monitor these surfaces [5]. This research also designed the pavement thickness in the apron expansion for 2026.

METHOD

The Hang Nadim International Airport (coordinates of 01 '07 '15 "NL and 04°06'50" EL) is located in Batam City, Riau Archipelago, Indonesia which has a distance of ± 7 km from the downtown of Batam City. (Figure 1).


Figure 1. Hang Nadim International Airport

Figure 2. Hang Nadim International Airport (Google Maps)

There are four steps to determine the pavement dimension. First, forecasting of the airport capacities in the future using linear and multi linear regression. Second, evaluating the existing landing movement area. Third, analyzing and planning the requirement of the landing movement area in the future. Fourth, designing the pavement dimensions and thickness.
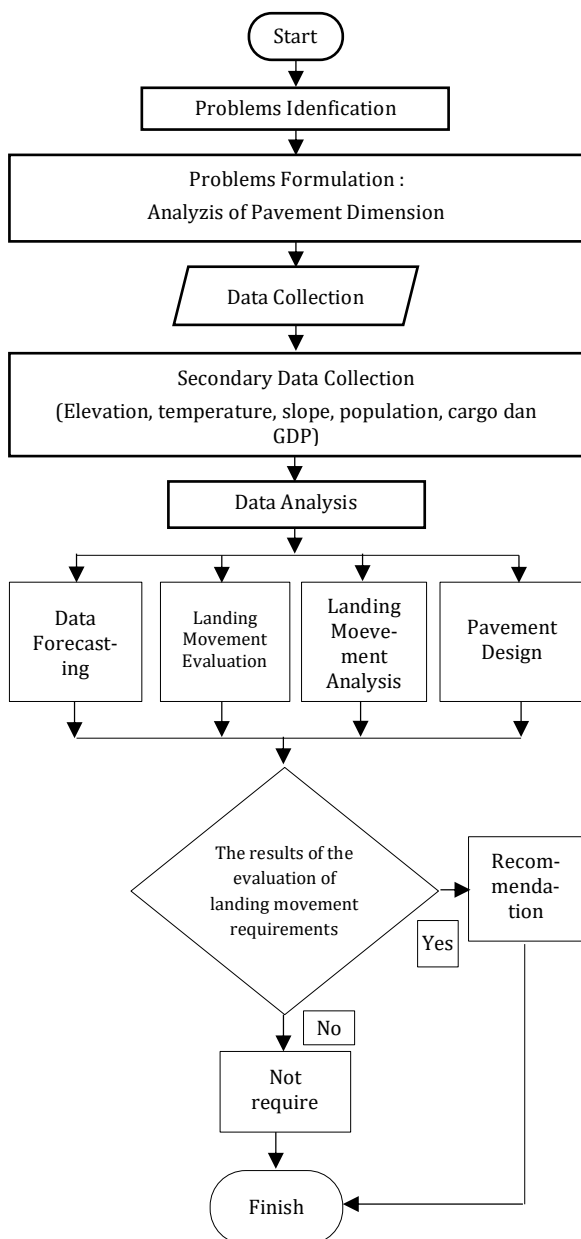
Figure 3. Methodology flowchart

Forecasting

Forecasting is a process of predicting some future event or events [6]. In planning and decision making processes, prediction of future events is very critical and forecasting can help in making rational decisions [7]. Therefore, forecasting is required for the development of air facilities. Airside facilities forecasting include passengers, aircraft movements, population, GDP, per capita income, and cargo. The data of this forecasting are shown in the table below:

Table 1. Data of Hang Nadim Airport and Batam City

Years	Passenger (people)	Aircraft Movements (unit)	Population (people)
2007	2.835.662	27.367	695.739
2008	2.682.181	25.823	824.964
2009	2.910.554	25.380	885.503
2010	3.358.369	26.089	954.450
2011	3.385.628	27.414	1.000.661
2012	3.918.427	32.838	1.047.534
2013	4.361.504	37.367	1.094.623
2014	4.944.291	41.554	1.141.816
2015	5.199.019	43.184	1.188.985
2016	6.299.699	50.290	1.236.399

Years	GDP (Rp)	Percapita Income (Rp)	Cargo (Kg)
2007	47.297.634,49	34.556.694,01	22.961.924,00
2008	52.624.417,00	36.836.279,69	24.535.161,00
2009	57.645.949,75	40.588.181,66	22.584.306,00
2010	63.640.191,41	42.379.608,73	24.693.029,92
2011	74.181.300,30	44.171.035,79	25.831.274,00
2012	83.751.112,92	46.266.613,81	31.296.794,21
2013	96.661.045,01	49.548.888,22	32.547.984,59
2014	107.219.525,72	52.588.078,64	29.778.905,00
2015	121.168.686,28	55.034.822,60	36.265.619,00
2016	130.734.768,94	59.892.929,89	40.360.336,00

The passengers and aircraft movement in 2026 are projected with the multi-linear and linear regression approaches. It was shown that the number of passengers increased 300 times, and aircraft movements increased by 200% in 10 years

Linear Regression

Linear regression analysis is one of the most commonly used statistical methods for modeling cross section data. In regression modeling there are two kinds of variables, dependent variable (variables that are influenced or value depend on other variables) and independent variable (variable that is suspected to affect dependent variable) [8]. The linear regression shown in the equation below:

$$Y = A + BX \qquad (1)$$

Where: Y = dependent variable
A = constant (the intersection to the Y axis)
B = regression coefficient
X = independent variable

Multi-Linear Regression

Regression models with one dependent variable and more than one independent variables are called multilinear regression [9]. The multilinear regression shown in the equation below:

$$Y = A + B_1X_1 + B_2X_2 + \cdots + B_ZX_Z \qquad (2)$$

Where: Y = dependent variable
Xi ... Xz = independent variable
A = constant
Bi ... Bz = regression coefficient

Landing Movement Area

Aircraft characteristics have an important role on airport planning. Both the airport airside and landside planning are based on operating characteristics of the aircraft which will be operated at the airport according to the available pavement strength especially the dimension of the apron thickness [10]. The airport's airfield component includes all the facilities located on the physical property of the airport to facilitate aircraft operations [11].

Apron

An apron will accommodate number of aircrafts according to the calculation of the amount of each type of aircraft movements during peak hours [12]. Area of apron are planned depend on the wingspan and the length of each type of aircraft referring to ICAO Annex 14 2013.
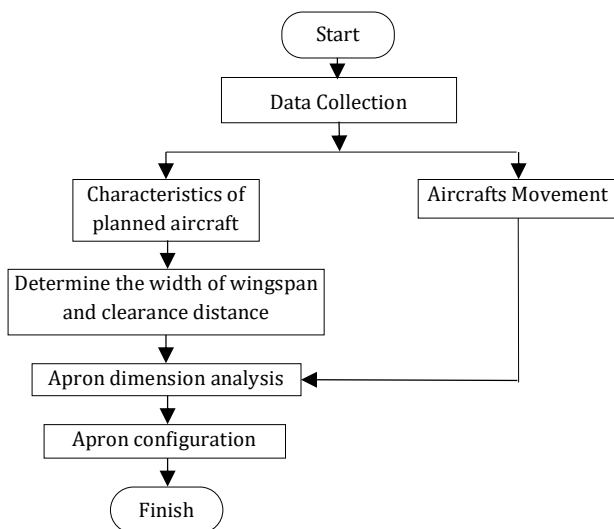
Figure 4. Apron analysis flowchart

The apron must have sufficient slope so there is no waterlogging on the surface of the apron. According to ICAO, the maximum allowable slope is 1%.

An aircraft stand should provide the following minimum clearances between an aircraft using the stand and any adjacent building, aircraft on another stand and other objects:

Table 2. The minimum clearance distance

Code letter	Clearance
A	3 m
B	3 m
C	4,5 m
D	7,5 m
E	7,5 m
F	7,5 m

Table 3. Apron clearance requirement

Description	Ref. Code				
	A/I	B/II	C/III	D/IV	E/V
Clearance distance between parked aircraft and taking off aircraft (A) (m)	10	10	10	15	15
The distances between parallel aircraft in the apron with other buildings (B) (m)	4,5	4,5	7,5	7,5	10
The clearances between parked aircraft with aircraft in the taxi lane and other obstructions (C) (m)	4,5	4,5	7,5	7,5	10
Distances between aircraft to the terminal building (D) (m)	4,5	4,5	7,5	7,5	10
Clearance distance between aircraft and gas fuel (E) (m)	15	15	15	15	15

Pavements

The application of concrete pavements for apron in this airport has been rigid pavement slabs. This rigid pavement slab spreads and distributes the overall aircraft wheel load over the pavement layer more efficiently.

The concentrated wheel load of an airplane is spread out over a large area keeping pressure on the subgrade low. A subbase at least 4 in. Thick is recommended for airport pavements. The principal factors that affect concrete thickness of airport pavements are gross weight and type of landing gear of aircraft, concrete strength, soil support [13].

The pavement design consists of flexible pavement (high quality asphalt and aggregate) and rigid pavement (concrete slabs).

Subgrade

The subgrade is an important part in the design of the runway because this layer is the lowest layer that supports construction and loads. Investigation of subgrade is needed to determine the type of soil and soil bearing capacity.

Subbase Course

Subbase course is a part of runway pavement construction between the subgrade and base course.

Base Course

Base course (high quality split stone) is a course between the surface course and the subbase course.

Surface Course

Surface course is in direct contact with the aircraft wheel load. This course should have high stability, waterproof, and be able to distribute the loads to the base course.

Subgrade Modulus (K)

Subgrade is one of the important factors in the pavement structure. Compaction is needed to obtain a good quality of subgrade. The strength of the bearing capacity of the subgrade in a rigid pavement structure is expressed by the modulus of the subgrade reaction (K) through plate bearing testing.

Table 4. Soil classification based on AASHTO

CBR	General rating	Uses	Classification System	
			Unifed	**AASHTO**
0-3	*Very poor*	*Subgrade*	OH, CH, MH, OL	A5, A6, A7
3-7	*Poor to fair*	*Subgrade*	OH, CH, MH, OL	A4, A5, A6, A7
7-20	*Fair*	*Subbase*	OL, CL, ML, SC, SM, SP	A2, A4, A6, A7
20-50	*Good*	*Base, Subbase*	GM, GC, SW, SM, SP, GL	A1b, A2-5, A3, A2-6
50	*Excellent*	*Base, Subbase*	GW, GM	A1a, A2-4, A3

According to the AASHTO T222-86 method the test is carried out on an area that represents the foundation material that will support the pavement. If the K value in the plan cannot be measured, then the K value from the correlation with the CBR value can be used, but this correlation value must be tested again in the field. Subgrade modulus (k) is determined using the formula below:

$$K = \left(\frac{1500 \, x \, CBR}{26} \right)^{0,7788}$$

Where :
K   = Subgrade modulus
CBR = California bearing ratio

Flexural Strength

The required thickness of concrete pavement is related to the strength of the concrete used in the pavement. Concrete strength is assessed by the flexural strength, as the primary action of a concrete pavement slab is flexure. Concrete strength is not only expressed in compressive strength but in flexural strength, which is the tensile strength needed to overcome the stresses caused by wheel loads from planned traffic. Unless expedited construction is required, the strength specified for material acceptance during construction should be specified as a 28 day strength and be 5 percent less than the strength used for thickness design. The calculation of the rupture modulus is shown in the equation below :

$$MR = k\sqrt{fc}$$

Where :
MR   = Modulus of Rupture (Psi)
k   = Constants
fc = Compressive strength of concrete

To establish the flexural strength for the thickness design the designer needs to consider several factors, such as:
A. Capability of the industry in a particular area to produce concrete at a particular strength
B. Flexural strength vs. cement content data from prior projects at the airport
C. The need to avoid high cement contents, which can affect concrete durability
D. Whether early opening requirements necessitate using a lower strength than 28-day.

Maximum Take Off Weight

Maximum Take Off Weight (MTOW) value is required to determine the thickness of the concrete slab. The MTOW will determine the aircraft that has the largest MTOW to be used as the planned aircraft.

Equivalent Annual Departure

Equivalent Annual departure (EAD) value is the annual departure of the planned aircraft, which is the aircraft with the largest MTOW.

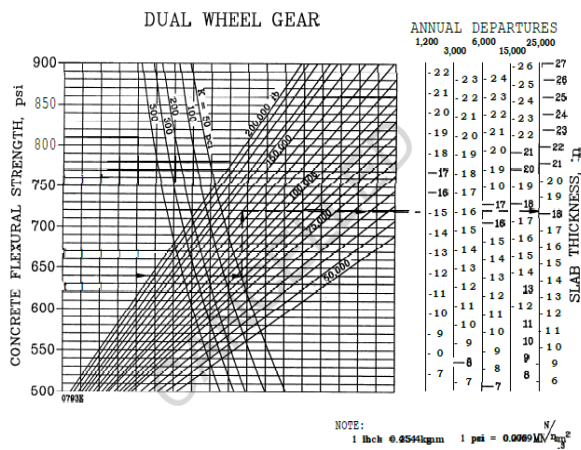The slab thickness is determined based on the curves below:

Figure 5. Curve of Slab Thickness (based on the Advisory Circular 150/5320-6d)
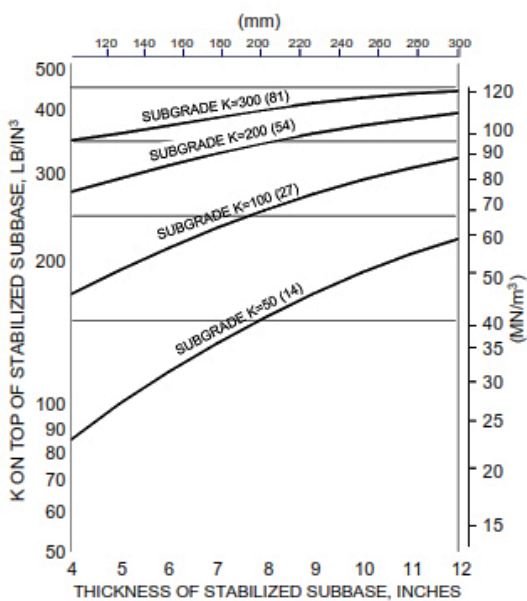

Figure 6. Curve of K modulus (subbase)

RESULTS AND DISCUSSION

The results will be discussed in 3 subsections, including forecasting results, evaluation and projection of the movement area, and pavement.

Forecasting Results

The forecasting results are shown in the table below:

Table 5. Forecasting of passengers, aircraft movements, population and aircraft peak hours, GDP, percapita income, and cargo.

Years	Passenger (people)	Aircraft Move-ments (unit)	Population (people)	Aircrafts in Peak Hours (unit)
2017	6.073.036	48.663	1312503	20
2018	6.451.855	51.378	1368036	21
2019	6.830.674	54.093	1423570	22
2020	7.209.493	56.807	1479103	24
2021	7.588.311	59.522	1534637	25
2022	7.967.130	62.237	1590171	26
2023	8.345.949	64.952	1645704	27
2024	8.724.767	67.667	1701238	29
2025	9.103.586	70.382	1756771	30
2026	9.482.405	73.097	1812305	31

Years	GDP (Rp)	Percapita Income (Rp)	Cargo (Kg)
2017	136.400.608	60.820.273	39.346.342
2018	146.020.270	63.480.993	41.212.557
2019	155.639.933	66.141.713	43.078.772
2020	165.259.596	68.802.433	44.944.986
2021	174.879.259	71.463.153	46.811.201
2022	184.498.921	74.123.874	48.677.416
2023	194.118.584	76.784.594	50.543.630
2024	203.738.247	79.445.314	52.409.844
2025	213.357.909	82.106.034	54.276.059
2026	222.977.572	84.766.754	56.142.273

The increase in the number of passengers and aircraft movements from 2017 to 2026 indicate that air-side facilities require to be developed.

Movement Area

Movement area is the part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, consisting of the maneuvering area and the apron [14]. The characteristics of operating aircrafts at Hang Nadim International Airport are shown in the table below:

Table 6. The characteristics of operating aircraft

Type of Aircraft	REF CODE	Characteristics			
		ARFL (m)	Wingspan (m)	OMGWS (m)	Length (m)
A 320	3C	2090	34,1	8,70	37,6
ATR 725	3C	1220	27,0	4,78	27,2
B 737-200	4C	1990	28,4	5,91	30,53
B 737-300	4C	1940	28,9	5,91	33,4
B 737-500	4C	1830	28,9	6,40	31
B 737-800	4C	2256	34,3	6,40	39,5
B 737-900	4C	2240	34,3	6,40	42,1
CRJ-1000	4C	2079	26,2	5,25	39,1

This research uses two types of operating aircraft. First, B 737-800, the operating aircraft with the longest ARFL, which has a runway length requirement of 2256 m. Second, B 747 – 300, the assumed aircraft in 2026 with the longest ARFL where the runway length needs 3320 m.

Apron

Hang Nadim Airport has an apron with capacities of 13 aircrafts including B747-SP, B737-900, dan F27 while the apron has to accommodate 19

aircrafts. Calculation of existing apron requirements is shown in the table below:

Table 7. Calculation of existing apron requirements

a. Clearances	= 4.5m
b. The distances between parallel aircraft in the apron with other buildings	= 10 m
c. The clearances between parked aircraft with aircraft in the taxi lane and other obstructions	= 10 m
d. Distances between aircraft to the terminal building	= 9 m

Category I (B747-SP)
wingspan = 59,6 m and *length* = 56,30 m

Length of apron (wingspan + a)	= 74,6 m
Width (aircraft length + d + wingspan + c)	= 134,90 m

Category II (B737-900)
wingspan = 34,3 m and length = 42,1 m

Length of apron (wingspan + a)	= 38,8 m
Width (aircraft length + d + wingspan + c)	= 92,90 m

Category III (F27)
wingspan = 29,00 m and length = 25,1 m

Length of apron (wingspan + a)	= 33,50 m
Width (aircraft length + d + wingspan + c)	= 70,6 m

Existing Apron Requirements (19 aircrafts)

Length of Apron	= (4 x category I) + (12 x category II) + (3 x category III) + (2 x c)
	= (4 x 74,60) + (12 x 38,80) + (3 x 33,50) + (2 x 10)
	= 884,50 m
Width of Apron	= 134,90 m
Area of Apron	= 119.319,05 m²

Existing Apron Capacities (13 aircrafts)

Area of Apron	= 690.5m x 76.8m + 240m x 150m
	= 89.039,40 m2

According to the forecasting of the aircraft's peak hours in 2026, the apron planned to accommodate 31 aircraft. Calculation of apron requirements in 2026 is shown in the table below:

Table 8. Calculation of apron requirements in 2026

a. Clearances	= 4.5m
b. The distances between parallel aircraft in the apron with other buildings	= 10 m
c. The clearances between parked aircraft with aircraft in the taxi lane and other obstructions	= 10 m
d. Distances between aircraft to the terminal building	= 9 m

Category I (B747-SP)
wingspan = 59,6 m and *length* = 56,30 m

Length of apron (wingspan + a)	= 74,6 m
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wingspan = 34,3 m and length = 42,1 m

Length of apron (wingspan + a) =	= 38,8 m
Width (aircraft length + d + wingspan + c)	= 92,90 m

Category III (F27)
wingspan = 29,00 m and length = 25,1 m

Length of apron (wingspan + a) =	= 33,50 m
Width (aircraft length + d + wingspan + c)	= 70,6 m

Existing Apron Requirements (31 aircrafts)

Length of Apron	= (11 x category I) + (16 x category II) + (4 x category III) + (2 x c)
	= (11 x 74,60) + (16 x 38,80) + (4 x 33,50) + (2 x 10)
	= 1595.40 m
Width of Apron	= 134,90 m
Dimensions of planned apron	= 1600 m x 150 m

Pavements

1. Subgrade modulus

In this design, a CBR number has been determined of 8%.. The CBR will be converted to a number of subgrade modulus.

$$K = (\frac{1500 \ x \ CBR}{26})^{0,7788}$$
$$K = (\frac{1500 \ x \ 8}{26})^{0,7788}$$
$$K = 118,8 \ pci$$

2. Flexural strength

The compressive strength of the concrete design is K 400. This compressive strength has been designed for 28 days concrete test results, while the FAA suggested the 90 days concrete test results. According to Basuki, if there is no 90 days flexural strength test results, it is recommend to use 110% x 28 day concrete test results.

$$MR = k\sqrt{fc}$$
$$MR = 0,7\sqrt{1,1 \ x \ 33,2}$$
$$MR = 4,32 \ Mpa$$
$$MR = 613,54 \ psi.$$

3. Maximum Take Off Weight

Maximum Take Off Weight (MTOW) is shown in the table below:

Table 9. MTOW in Hang Nadim International Airport

No	Type of Aircrafts	Ref. Code	MTOW	
			kg	Lbs
1	A 320	3C	73.500	162.068
2	ATR 725	3C	22.500	49.613
3	B 737-200	4C	52.400	115.542
4	B 737-300	4C	61.230	135.012
5	B 737-500	4C	60.560	133.535
6	B 737-800	4C	70.535	155.530
7	B 737-900	4C	66.000	145.530
8	B 737-900 ER	4C	66.000	145.530
9	CRJ-1000 ER	4C	40.284	88.826

Referring to the MTOW Table above, the apron pavement is designed using A320 aircraft, with MTOW of 162,068 lbs.

4. Equivalent Annual Departure

Equivalent Annual Departure is shown in the table below:

Table 10. Equivalent Annual Departure

Type of Aircraft	Aircraft Movements	Rn (i = 7,3%)	Convertion Factor
A 320	11.170	22.597	1
ATR 72-500	2.296	4.645	1
B 737 - 200	188	380	1
B 737 - 300	446	902	1
B 737 - 500	1.736	3.512	1
B 737 - 800	20.018	40.497	1
B 737 - 900	5.038	10.192	1
CRJ-1000	1.452	2.937	1

| R2	W2	W1	Log R1	R1
22596,98	38.491,15	38.491,15	4,35405	22596,98
4644,82	11.783,09	38.491,15	2,02888	106,88
380,33	27.441,23	38.491,15	2,17855	150,85
902,26	32.065,35	38.491,15	2,69739	498,18
3511,94	31.714,56	38.491,15	3,21834	1653,26
40496,54	36.938,38	38.491,15	4,51353	32623,24
10191,91	34.563,38	38.491,15	3,79825	6284,13
4349,46	34.563,38	38.491,15	3,4478	2804,16
2937,41	21.096,18	38.491,15	2,56741	369,33
Equivalent Annual Departure (ΣR1)				67087,01

The Equivalent Annual Departure (EAD) is calculated using the A320 aircraft. The Equivalent Annual Departure of A320 is 67,087.01 movements.

5. Thickness of The Rigid Pavement

Slab thickness is determined from Figure 2 by plotting flexural strength of 613.54 psi then being drawn horizontally until it intersects the subgrade modulus of 118.8 pci, from the intersection point of flexural strength and subgrade modulus then pulled vertically upwards to intersects the MTOW and then pulled horizontally again with annual departure 67,087.01.

Based on Figure 4, the slab thickness is determined of 17.15 inches. Because the annual departure result is more than 25,000, therefore the thickness of the pavement have to calculate the factor of pavement thickness of 1,054, so the designed slab thickness is determined as below:

H = 17,15 inch x 1,054
= 18,07 inch
= 46 cm
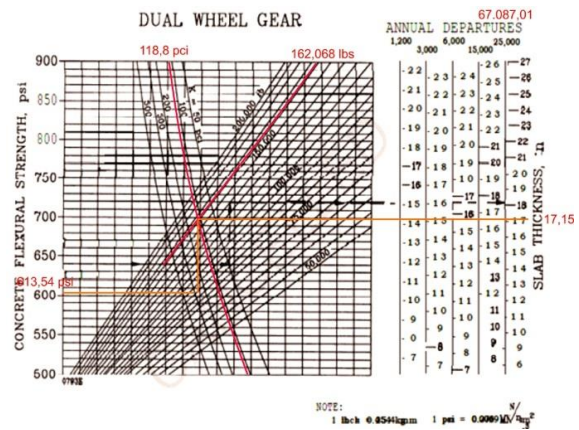
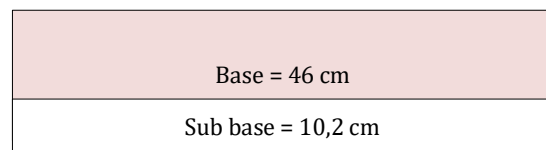**Figure 7.** Curve of slab thickness

The thickness of the subbase course for rigid pavement according to FAA AC No.150 / 5320 / 6D is 4 inches (10.2 cm). The K subbase determined by plotting the thickness of the subbase course, then draw a vertical line up to intersect the subgrade k modulus value, then draw a horizontal line to the left.

Based on the 11 inch subbase course thickness with a 118.8 pci subgrade k modulus value, the subbase modulus k value is 322 lb / inch3 as shown in Figure 5.
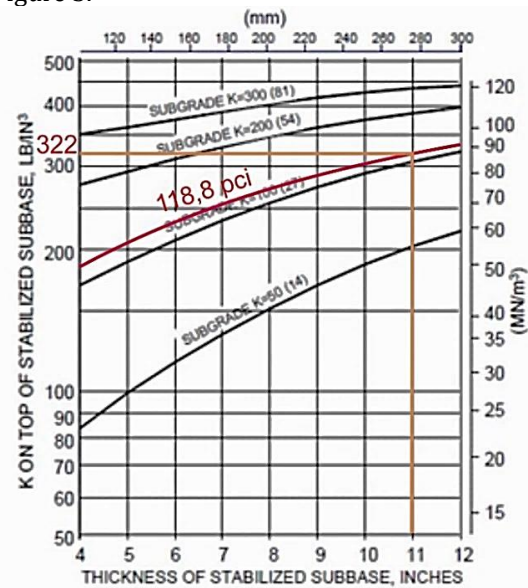
Figure 8. Curve of K modulus (subbase)

A subbase at least 4 in. (100mm) thick is recommended for airport pavements [15]. Therefore, the equivalent thickness of the rigid pavement is determined of 56,2 cm.

Base = 46 cm

Sub base = 10,2 cm

Figure 9. *layers of slab thickness*

Concrete slabs are connected by transverse joint reinforcement or dowel. The connection is in the centre of the plate thickness and parallel to the axis of the road. The dowel planning criteria are determined based on the thickness of the concrete slab plan as shown in the Table 11.

Table 11. Dimension and spacing of dowel joint

Thickness of Slab	Diameter	Length	Spacing
6-7 in (150-180 mm)	¾ in (20 mm)	18 in (460 mm)	12 in (305 mm)
8-12 in (210-305 mm)	1 in (25 mm)	19 in (480 mm)	12 in (305 mm)
13-16 in (330-405 mm)	1¼ in (30 mm)	20 in (510 mm)	15 in (380 mm)
17-20 in (430-510 mm)	1½ in (40 mm)	20 in (510 mm)	18 in (460 mm)
21-24 in (535-610 mm)	2 in (50 mm)	24 in (610 mm)	18 in (460 mm)

Based on Table 11, the thickness of the concrete slab (460 mm) requires dowels with specifications as below:
Diameter : 40 mm
Length : 510 mm
Spacing : 460 mm

Besides dowels, concrete slabs also require tie bars. Tie bars are profiled steel to tie the plates so the plates do not move horizontally. Based on FAA No.150 / 5320-6D the tie bar criteria are as follows:
Diameter : 5/8 inches (16 mm)
Length : 30 inches (760 mm)
Spacing : 30 inches (760 mm).

CONCLUSIONS

The evaluation results of Hang Nadim International Airport's apron dimensions (690,5 m x 76,8 m and 240 m x 150 m) has a capacity to accommodate 13 aircrafts require to be expanded to become 1600 m x 150 m in order to accommodate 31 aircraft in 2026 (11 units B747- 300 + 16 units B737-900 + 4 units F27). The apron thickness would be 46 cm of slab thickness and 10.2 cm of subgrade thickness.

ACKNOWLEDGMENT

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