Comparison study on flexible pavement design using FAA (Federal Aviation Administration) and LCN (Load Classification Number) code in Ahmad Yani international airport’s runway.

S E Santoso1, D Sulistiono2, A F Mawardi2
1 Civil Infrastructure Department. Institut Teknologi Sepuluh Nopember, Menur 127, Surabaya Indonesia.
2 Lecturer at Civil Infrastructure Department. Institut Teknologi Sepuluh Nopember, Menur 127, Surabaya Indonesia

E-mail: shelvysantoso@gmail.com

Abstract. FAA code for airport design has been broadly used by Indonesian Ministry of Aviation since decades ago. However, there is not much comprehensive study about its relevance and efficiency towards current situation in Indonesia. Therefore, a further comparison study on flexible pavement design for airport runway using comparable method has become essential.
The main focus of this study is to compare which method between FAA and LCN that offer the most efficient and effective way in runway pavement planning. The comparative methods in this study mainly use the variety of variable approach. FAA code for instance, will use the approach on the aircraft’s maximum take-off weight and annual departure. Whilst LCN code use the variable of equivalent single wheel load and tire pressure. Based on the variables mentioned above, a further classification and rated method will be used to determine which code is best implemented. According to the analysis, it is clear that FAA method is the most effective way to plan runway design in Indonesia with consecutively total pavement thickness of 127cm and LCN method total pavement thickness of 70cm. Although, FAA total pavement is thicker that LCN its relevance towards sustainable and pristine condition in the future has become an essential aspect to consider in design and planning.

1. Introduction
Pavement structure is a structure consisting of one or more layers of processed materials. A pavement consisting of a mixture of bituminous material and aggregate placed on high quality granular materials is referred to as flexible pavement [1]. Airfield pavement is intended to provide a smooth and safe all weather riding surface that can support the weights of such heavy objects as aircraft on top of the natural ground base. Airfield pavements are typically designed in layers, with each layer designed to a sufficient thickness to be adequate to ensure that the applied loads will not lead to distress or failure to support its imposed loads [1].

1 Corresponding author. Tel: +62 856 48904890
Email: shelvy13@mhs.ce.its.ac.id (S E Santoso)
2 Corresponding author. Tel: +62 812 3212190, +62 812 34082635
Email: djoko_sulistiono@ce.its.ac.id (D Sulistiono), amaliafmawardi@gmail.com (A F Mawardi)
2. Research significance
By comparing two methods, it is very possible to project which method has significant benefits and drawbacks. A smaller number in pavement’s thickness and heavy load carriage could yield into a cheaper and more efficient design. In another hand, a thick and less load carriage pavement could be a significant draw back that people should avoid. Therefore, knowing each code in detail will help the society to determine the best way to design Airport pavement.

3. Pavement design codes which are compared in this study.
There are two main codes which are being compare in this study. Those codes are FAA and LCN pavement design codes. Each code has its distinguish approach to determine the runway’s total pavement thickness which will be explain on the next section.

3.1. FAA (Federal Aviation Administration) Code Design.
FAA code is originally generated by the US Ministry of Aviation. This code has a specific approach on the aircraft’s annual departure, main landing gear configuration, maximum take-off weight (MTOW) and number of tires in order to determine the total thickness of runway pavement. Each approach represents a significant factor which contributed to the runway’s design \[1\]. In order to calculate the pavement’s thickness, FAA code use this following equations:

\[
\log R_1 = \log R_2 \left( \frac{W_2}{W_1} \right)^{\frac{1}{2}} \] \quad \text{equation (3.1)}
\]

\[
\log R_1 = \log R_2 \left( \frac{W_2}{W_1} \right) \] \quad \text{equation (3.2)}
\]

\[
\log R_2 = \log R_2 \left( \frac{W_2}{W_1} \right) \] \quad \text{equation (3.3)}
\]

\[
R_1 = 10^{\log R_1} \] \quad \text{equation (3.4)}
\]

\[
R_2 = \text{Annual Departure} \times \text{tire configuration converted factor into dual wheel gear} \] \quad \text{equation (3.5)}
\]

\[
W_1 = \text{Wheel load of the design aircraft} \] \quad \text{equation (3.6)}
\]

\[
W_2 = \text{Maximum value of } W_2 \text{ column} \] \quad \text{equation (3.7)}
\]

Where
\[
R_1 = \text{Equivalent annual departures by the design aircraft.} \\
R_2 = \text{Annual number of departures by an aircraft in terms of design aircraft landing gear configuration.} \\
W_1 = \text{Wheel load of the design aircraft.} \\
W_2 = \text{Wheel load of the aircraft being converted.} \\
\]

In order to get all aircraft’s tire configuration converted in one single form, below (Table 1) is the table guide for factors for converting annual departures by aircraft to equivalent annual departures by design aircraft:

| To Convert from     | To          | Multiply Departure By |
|---------------------|-------------|-----------------------|
| 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                   |
3.2 LCN (Load Classification Number) Code Design

LCN code is originally generated by the British Air Ministry Directorate of General Work. This code has a specific approach on the aircraft’s annual departure, main landing gear configuration, equivalent single wheel load, tire pressure and number of tires in order to determine the total thickness of runway pavement. Each approach represents a significant factor which contributed to the runway’s design [11]. In order to achieve the proper strength during the service period, the LCN number of the runway’s pavement need to be greater or at least equal than the LCN number of the aircraft itself.

4. Data

There are two main data which provided by PT. Angkasa Pura I Semarang, the government owned aviation corporation in Indonesia. Those data including the aircraft’s annual departure from 2011 up to 2016 (Table 2) along with the runway’s cross section data which also show the detail CBR percentage of certain layer of the pavement (Figure 1).

| No | Aircraft Type | 2011 Arrive | 2011 Depart | 2012 Arrive | 2012 Depart | 2013 Arrive | 2013 Depart | 2014 Arrive | 2014 Depart | 2015 Arrive | 2015 Depart | 2016 Arrive | 2016 Depart | Total Arrive | Total Depart |
|----|---------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1  | A 320         | 150         | 149         | 657         | 657         | 886         | 886         | 974         | 972         | 1319        | 1319        | 2579        | 2579        | 6,565       | 6,562       |
| 2  | ATR 72-600    | 1314        | 1313        | 1557        | 1558        | 1759        | 1759        | 2408        | 2407        | 3138        | 3138        | 3754        | 3754        | 13,930      | 13,929      |
| 3  | B 738         | 2697        | 2696        | 3240        | 3239        | 3291        | 3291        | 3728        | 3730        | 4834        | 4836        | 4939        | 4940        | 22,729      | 22,732      |
| 4  | B 739         | 1658        | 1657        | 2827        | 2827        | 3371        | 3372        | 3237        | 3236        | 2716        | 2715        | 2378        | 2377        | 16,187      | 16,184      |
| 5  | C 172         | 519         | 519         | 1601        | 1590        | 1345        | 1327        | 1506        | 1473        | 2274        | 2285        | 1866        | 1875        | 9,111       | 9,069       |
|    | Total         |             |             |             |             |             |             |             |             |             |             |             |             |             |             |
|    | Total         |             |             |             |             |             |             |             |             |             |             |             |             | 22,729      | 22,732      |

Figure 1. runway’s cross section
### International Flight

| No. | Aircraft Type | 2011 Arrive | 2011 Depart | 2012 Arrive | 2012 Depart | 2013 Arrive | 2013 Depart | 2014 Arrive | 2014 Depart | 2015 Arrive | 2015 Depart | 2016 Arrive | 2016 Depart | Total Arrive | Total Depart |
|-----|---------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1   | A 319         | 118         | 118         | 0           | 0           | 0           | 45          | 45          | 95          | 95          | 30          | 30          | 288         | 288         |
| 2   | A 320         | 50          | 51          | 396         | 396         | 521         | 521         | 581         | 582         | 468         | 468         | 556         | 556         | 2,572       | 2,574       |
| 3   | B 733         | 31          | 30          | 13          | 13          | 0           | 0           | 0           | 0           | 0           | 0           | 0           | 0           | 44          | 43          |
| 4   | B 734         | 0           | 0           | 0           | 0           | 15          | 15          | 0           | 0           | 0           | 0           | 0           | 0           | 15          | 15          |

**Total**

|          | 2,919        | 2,920       |

### Table 3. Planning Objectives

| Objective | Description |
|-----------|-------------|
| **Total Pavement Thickness** | Overall thickness of the pavement. Measure from the surface, base course, subbase course and subgrade. |
| **Subgrade Thickness** | The thickness of the very bottom layer in the pavement structure. |
| **Surface Thickness** | The thickness of the very top layer in the pavement structure. |
| **Cost estimation** | The cost that will be spent to construct the whole pavements. |

This table describes the planning objectives used in this evaluation framework.

### Analysis

The analysis in this study is done based on each code references and different approach. FAA code will have the analysis based on the aircraft’s annual departure, main landing gear configuration, maximum take-off weight (MTOW) and number of tires in order to determine the total thickness of runway pavement. While LCN code will have the aircraft’s annual departure, main landing gear configuration, equivalent single wheel load, tire pressure and number of tires in order to determine the total thickness of runway pavement.

6.1 **FAA Codes Design Analysis**

FAA design code has a specific approach on the aircraft’s annual departure, main landing gear configuration, gross aircraft weight (lbs.) and number of tires in order to determine the equivalent annual departures by the design aircraft. Then the calculated of the equivalent annual departures by the design aircraft will be used to design the total thickness of runway pavement [11]. This approach has been calculated and put into an equation (Equation 3.1) which is broadly addressed in this following table (Table 3).
Table 4. FAA equivalent annual departures by the design aircraft analysis.

| Aircraft’s Type | Main Landing Configuration | Gross Aircraft Weight (lbs.) | Annual Departure | Number of Tires | Factor for Converting Dual Wheel | W2 | R2 | W1 | Log R2 | Log R1 | R1 |
|-----------------|---------------------------|-----------------------------|------------------|----------------|---------------------------------|----|----|----|--------|-------|----|
| ATR 72-600      | Dual Wheel                | 50,705                      | 13,929           | 4              | 1.0                             | 12,043 | 13,929 | 44,698 | 4.14   | 2.15  | 142 |
| B 737-800 (B-738) | Dual Wheel              | 174,700                     | 22,732           | 4              | 1.0                             | 41,491 | 22,732 | 44,698 | 4.36   | 4.20  | 15,757 |
| B-727-900 (B-739) | Dual Wheel                | 188,200                     | 16,184           | 4              | 1.0                             | 44,698 | 16,184 | 44,698 | 4.21   | 4.21  | 16,184 |
| C 172           | Dual Tandem wheel         | 2,552                       | 9,099            | 8              | 1.7                             | 303   | 15,468 | 44,698 | 4.19   | 0.34  | 2   |
| A 320           | Dual Tandem wheel         | 158,730                     | 2,574            | 8              | 1.7                             | 18,849 | 4,376  | 44,698 | 3.64   | 2.36  | 231 |
| B 737-300 (B-733) | Dual Tandem wheel       | 140,000                     | 43               | 8              | 1.7                             | 16,625 | 73     | 44,698 | 1.86   | 1.14  | 14 |
| B 737-400 (B-734) | Dual Tandem wheel       | 150,500                     | 15               | 8              | 1.7                             | 17,872 | 26     | 44,698 | 1.41   | 0.89  | 8   |
| Total           |                           |                             |                  |                |                                 | 32,382 |        |      |        |       |     |

Right after the calculation of the equivalent annual departures by the design aircraft. Then the result will be plotted into the following curve in order to acquire the total pavement of the runway. Prior to 2008, the FAA’s standard method for flexible pavement design was known as the CBR method. The CBR method was based on approximation charts that factored in the CBR value of the subgrade and the number and gross weight of equivalent annual departures of the design aircraft. Separate approximation charts were provided by the FAA for different generic aircraft landing gear configurations, and for aircraft greater than 300,000 lbs. maximum gross weight, specific individual aircraft [1]. Figure 2 provides an illustrative example of the CBR method. The example nomograph found in Figure 2 represents the historical method of estimating the total thickness of flexible pavement for a Boeing 737-900. The arrow within the nomograph represents the example for an aircraft subgrade with CBR value of 3 (Figure 1), a 188,200-lbs. aircraft gross weight (Table 4), and 32,382 annual equivalent departures (Table 4), resulting in a required total pavement of 50 in thickness.

Figure 2. Cross section of FAA design
The nomograph above also provides the necessary thickness for the surface layer, at 4 in thick for critical areas and 3 in thick for noncritical areas, such as pavement shoulders. The same process applied to determine the thickness of the subbase course. The arrow within the nomograph show the value of subbase course with CBR value of 20 (Figure 1.), a 188,200 –lbs. aircraft gross weight (Table 4), and 32,382 annual equivalent departures (Table 4), resulting in a required subbase course of 18 in thickness.
6.2 LCN Codes Design Analysis

6.2.1 LCN for Aircrafts

According to procedure by the British Air Ministry Directorate of General Work, LCN design code has a specific approach on the aircraft’s annual departure, main landing gear configuration, equivalent single wheel load, tire pressure and number of tires in order to determine the equivalent annual departures by the design aircraft. Then the calculated of the equivalent annual departures by the design aircraft will be used to design the total thickness of runway pavement [41]. This approach will be broadly addressed in this following table (Table 5).

Table 5. LCN data analysis based on the approach variable.

| Aircraft’s type | Main Landing Configuration | MTOW (lbs) | Wheel Number | Tire Pressure (Psi) | Gear Loads (lbs) | Tire’s Contact Area (inch²) |
|-----------------|----------------------------|------------|--------------|---------------------|-----------------|-----------------------------|
| ATR 72-600      | Dual Wheel                 | 50,705     | 4            | 55                  | 12042           | 219                         |
| B 737-800       | Dual Wheel                 | 174,700    | 4            | 204                 | 41491           | 203                         |
| B-727-900       | Dual Wheel                 | 188,200    | 4            | 204                 | 44698           | 219                         |
| A 319           | Dual Tandem wheel          | 141,095    | 8            | 200                 | 16755           | 84                          |
| A 320           | Dual Tandem wheel          | 158,730    | 8            | 200                 | 18849           | 94                          |
| B 737-300       | Dual Tandem wheel          | 140,000    | 8            | 166                 | 16625           | 100                         |
| B 737-400       | Dual Tandem wheel          | 150,500    | 8            | 177                 | 17872           | 101                         |
| **Maximum**     |                            | **204**    |              | **44698**           |                 | **219**                     |
In order to determine the pavement thickness, the LCN number has to be found first. The arrow within the nomograph represents the calculation of the equivalent single wheel load and aircraft’s tire pressure. Above is the nomogram (Figure 4.) shown that the adequate LCN number which suit the needs of all aircraft type is 40. Due to a safety reason the result should be multiple by 1.5. Therefore, the final LCN number is 60.

Figure 4. Curve to determine LCN number
6.2.2 **LCN for Pavement**

According to the LCN method which use soil parameter as the main approach, the method was based on approximation charts that factored in the CBR value of the subgrade and LCN category of the aircraft [4]. Figure 5 provides an illustrative example of the method. The example nomograph found in Figure 5 represents the historical method of estimating the total thickness of flexible pavement. The arrow within the nomograph represents the calculation for a subgrade modulation (K) of 300 Pci and flexural strength 350 Psi, resulting in a required total pavement of 700mm of thickness (Figure 6). The nomograph also provides the necessary thickness for the surface layer, at 100mm thick, base course layer of 500mm and subbase course layer of 100mm. According to this data, it is then concluded that the LCG of the pavement was categorized as the LCG III.

![Figure 5 Flexible Pavement design curve using LCN method](image)
Please bear in mind that the LCN pavement should surpass the LCN of aircrafts in order to well serve the heavy load carried from the airlines traffic. Therefore, the check of this matter has become essential. Based on the previous calculation, it was noted that the LCG of the pavements was categorized as LCG III.

### Table 6. LCN and LCG Correlation

| LCG | LCN Range |
|-----|-----------|
| I   | 101-120   |
| II  | 76-100    |
| III | 51-75     |
| IV  | 31-50     |
| V   | 16-30     |
| VI  | 11-15     |
| VII | 10 and under |

Source: Robert Horonjeff *Planning and Design of Airports* 5th Edition

Based on (Table 6.) it is concluded that the pavement LCN is in 51-75 range. Therefore, the design pavement has surpassed the LCN of aircraft of 60. In this case the design pavement successfully met the requirements.

### 7. Results and Discussion

The comprehensive study presented in this paper allowed us in the first hand to develop a performing methodology to offer an applicative solution towards major problem in pavement code decision. The analysis that we offer will help save materials, money, time and also a revenue generator for airport holdings. Having all the evaluation framework system will also increase the understanding of both ideas which will serve the best solution for everybody.

### Table 7. FAA (Federal Aviation Administration) code of pavement analysis.

| Objective          | Rating | Notes                                                                 |
|--------------------|--------|-----------------------------------------------------------------------|
| Cost Estimation    | 2      | The overall pavement thickness is 127cm. Which is considerably thick. |
| Method Result      | 4      | The variable approach used in this method is well represented and close to the actual condition. |
| Precision          |        | The way to calculate the total thickness of the pavement is quiet easy. The supporting data is easy to find as well. |
| Technical Calculation | 4     | The field construction is vary depends on the orders and procedures of every country. |
| Application Method | 3      |                                                                       |
| Total Score        | 13     |                                                                       |

Rating from 4 (best) to 1 (worst).
Table 8. LCN (Load Classification Number) code of pavement analysis.

| Objective          | Rating | Notes                                                                 |
|--------------------|--------|----------------------------------------------------------------------|
| Cost Estimation    | 3      | The overall pavement thickness is 70cm. Which is considerably thin.  |
| Method Result      | 2      | The variable approach used in this method is moderately represented  |
| Precision          |        | the actual variety of the airport environment.                       |
| Technical          | 3      | The way to calculate the total thickness of the pavement is slightly |
| Calculation        |        | complicated. It need more control variable which need to be verified |
| Application Method | 3      | The field construction is vary depends on the orders and procedures  |
|                    |        | of every country.                                                   |
| Total Score        | 11     | Rating from 4 (best) to 1 (worst).                                    |

According to the above analysis, it is clear that FAA method is the most effective way to plan runway design in Indonesia with consecutively total pavement thickness of 127cm and LCN method total pavement thickness of 70cm. Although, FAA total pavement is thicker that LCN its relevance towards sustainable and pristine condition in the future has become an essential aspect to consider in design and planning.

8. Acknowledgement
The author would like to express her gratitude to the department Civil Infrastructure Engineering of Institut Teknologi Sepuluh Nopember (ITS) and the head of the department Dr. Machsus for funding the conference.

9. Reference

[1] R. Horonjeff and F. Mc Kelvey, Planning and Design of Airports, vol. 5th Edition, United States: United States, 2010.
[2] H. Basuki, Merancang dan Merencana Lapangan Terbang, Bandung: P.T Alumni, 1986.
[3] Boeing, “Boeing 737 Airplane Characteristics for Airport Planning,” 2013. [Online].
[4] S. Khanna and M. Arora, Airport Planning and Design, Roorkee: Roorkee Press, 1979.
[5] FAA, “Airfield Pavement Design and Evaluation,” Advisory Circular AC 150/5320-6E, 2008.
[6] FAA, “Airport Pavement Analysis,” [Online]. Available: http://www.faa.gov..
[7] I. C. A. Organization, “Aerodrome Design Manual Part1: Runway,” International Civil Aviation Organization, Montreal, 1980.
[8] ICAO, “Aerodrome Design Manual, Annex 14 to the Convention on International Civil Aviation.,” International Civil Aviation Organization, Montreal, 1976.
[9] FAA, “Advisory Circular AC 150/5335-5:Standardized Method of Reporting Airport Pavement Strength-LCN,” US Department of Transportation., Washington, D.C., 1983.