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Mathematical Modelling of Airport Pavement Layer Thickness

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Abstract

In this study, a mathematical model has been developed in order to avoid possible chart and reading errors of the abacas used to determine the thickness of the airport concrete pavement slab layer. The least squares method was used for the established model. R^2 was calculated as 0.91 in the model developed with 1450 abaca reading data obtained by the literature. Because of the study, it was observed that the model established to determine the thickness of airport concrete pavement slab layer has a high regression coefficient. With the developed model the thicknesses of the layer were modelled with an average error of 3.5% using the strength in psi unit of the concrete used for the pavement, the subgrade reaction modulus coefficient, the number of takeoffs per year and the design plane weight parameters.

Keywords: *Airport pavement design, Least squares method, Concrete layer thickness.*

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Havaalanı Üstyapı Tabaka Kalınlıklarının Matematiksel Olarak Modellenmesi

Öz

Bu çalışmada, havaalanı üstyapı beton plak tabaka kalınlıklarının belirlenmesi amacıyla kullanılan abakların olası abak ve okuma hatalarının önüne geçmek amaçlı olarak matematiksel bir model geliştirilmiştir. Kurulan model için en küçük kareler yönteminden faydalanılmıştır. Literatür tarafından elde edilen 1450 abak okuma verileri ile birlikte kurulan modelde R^2 0.91 olarak hesaplanmıştır. Yapılan çalışma sonucunda havaalanı üstyapı beton plak tabaka kalınlıklarını belirlemek için kurulan modelin yüksek bir regresyon katsayısına sahip olduğu görülmüştür. Elde edilen model ile birlikte; havaalanı üstyapısı için kullanılan betonun psi biriminden dayanımı, doğal zemin yatak katsayısı, yıllık kalkış sayısı ve tasarım uçak ağırlığı parametrelerine bağlı olarak beton plak tabaka kalınlıkları ortalama %3.5 hata ile modellenebilmiştir.

Anahtar kelimeler: *Havaalanı üstyapı tasarımı, En küçük kareler yöntemi, Beton plak tabaka kalınlığı.*

1. Introduction

Airport pavement are very important buildings since very expensive air vehicles use them. Any deflection on the pavement can cause a very serious crash. Therefore, the pavement's parameter should be calculated correctly and the pavement should build without any mistake. The vehicles using the pavement are very heavy objects and therefore rigid pavements are preferred.

During the 1st World War, the importance of the airport pavement design method has been increased. To take off and land the planes, paved ground is needed. So, the highway pavements are used after the needed tests. When the planes weight increased, the pavement type changed to rigid pavement. To design the thickness of the pavement, airport pavement design graphs are obtained based on plane weights, gear geometries, environmental factors and grounds specifications (Okur, 2008; Yoder & Witczak, 1975).

Airport pavement design methods are divided into two methods: (*i*) empirical and (*ii*) analytical. The empirical methods are based on experience and experimental test results. Based on these, tables, charts and graphs are prepared to determine the thickness of the pavement slab layer. Analytical methods instead, take into account especially the mechanical properties of the materials used for the construction, in addition the estimated traffic load and environmental conditions, and based on these parameters, the slab layer thickness is obtained with the help of a computer program (Okur, 2008).

The oldest known design method is the CBR method. The design method changed in time like Portland Cement Association (PCA), Canadian Department of Transportation (CDOT), Federal Aviation Administration (FAA) methods (Okur, 2008; Kök, 2008). Nowadays, the development of the design method more shifted to artificial intelligence. For example, Küçükçapraz (2019) in his thesis, used fuzzy logic to determine the airport pavement slab layer thickness.

Any abaca to determine the layer thickness is very useful. However, while using the abaca, there can occur some possible mistakes because of the abaca plotting mistakes or while reading the abaca. In addition, it is very time consuming and needs a lot of attention. Therefore, Küçükçapraz's (2019) study is very useful because the probability of occurrence of the mistakes are reduced. Nevertheless, it still takes time to train and use it. Moreover, it needs many data.

This study focusses on the development of a mathematical formula for calculating the layer thickness of the airport pavement slab. Therefore, the data set of the Küçükçapraz's (2019) thesis are used. As a result, a global useable formula is obtained.

2. Data Set and Method

2.1. Data set

The data used for this study is obtained from Küçükçapraz (2019) thesis. The data set consists of five parameters. Four of them were used as input parameter and the last one, as the output parameter, was the slab layer thickness. The input and output parameters are obtained using the single wheel gear abaca (Figure 1) reading. The abaca seen in Figure 1 start with determining the concrete's flexural strength (1 psi is equal to 6.89 kPa). After determining the strength, the subgrade reaction modulus coefficient (1 pci is equal to 271.45 kN/m^3) is obtained by drawing a straight line to right. When the coefficient is obtained, a straight line to up or down based on the plane weight (1 lbs is equal to 0.45 kg) is drawn. Last of all, a straight line to right is drawn till the annual departure line is crossed. Moreover, the reading obtained at last is the slab layer thickness (1 in is equal to 2.54 cm).

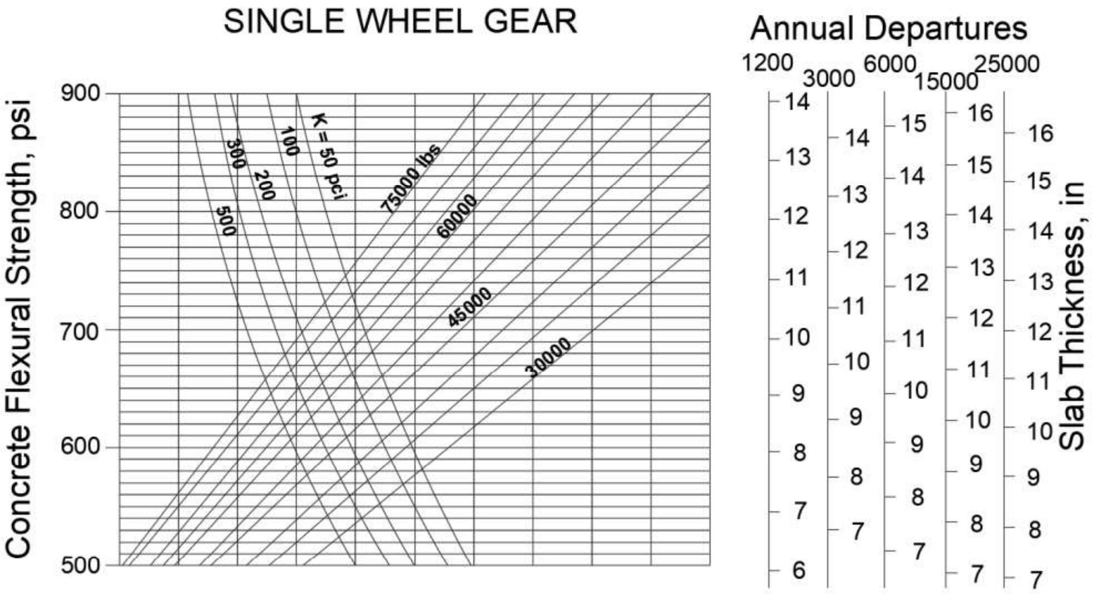

Figure 1. Slab thickness determining abaca for single wheel gear (FAA, 1995)

To create the data set, the concrete strength value is random selected between 500 and 900. The ground coefficient is random selected between 50 and 500. 10 different design plane weights are determined and used as 13620, 15890, 18160, 20430, 22700, 24970, 27240, 29510, 31780 and 34050 kg. Last of all five different annual departure counts are used as readable from the abaca as 1200, 3000, 6000, 15000 and 25000. All the created data is random combined and 1450 random selected data set is obtained by Küçükçapraz (2019). 80% of the obtained data set were used as training data and the rest 20% were used for testing data. In this study, the mathematical model is also developed based on the Küçükçapraz's (2019) training data and tested using the test data set. To develop of the mathematical model, least squares method is used.

2.2. Least squares method

Estimation methods are generally based on mathematical and statistical methods. Tendency analysis is the expression of the trend defined as the long-term trend of a time series with a line or a curve (Yalçınöz et al., 2000). Here the trend of a data set is obtained based on least squares method. Least squares method aims to find the best solution by minimising the sum of the squares of the errors (Equation 1).

$$S = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \tag{1}$$

Where, S is the sum of the errors square, y_i is the real data and $\hat{y}_i$ is the obtained data (Chapra & Canale, 2003; Akdeniz, 2002). In this study, the linear approach given below is used. The linear approach based on that the relation between the variables and can be formulated using Equation 2 (Chapra & Canale, 2003; Akdeniz, 2002; Hengirmen, 1999).

$$y = ax + b \tag{2}$$

When the least squares method is used to zero the error than the Equation 3 and 4 is obtained. In addition, by solving the equations, the a and b coefficients can be obtained.

$$an + b\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} y_i \tag{3}$$

$$a\sum_{i=1}^{n} x_i + b\sum_{i=1}^{n} {x_i}^2 = \sum_{i=1}^{n} x_i y_i \tag{4}$$

3. Mathematical Model

The slab layer thickness can be obtained based on (*i*) design plane characteristics, (*ii*) annual departures, (*iii*) concrete flexural strength and (*iv*) subgrade reaction modulus coefficient (Bayram, 2006).

When the abaca in Figure 1 examined, concrete flexural strength, plane weights, annual departures and layer thickness are linear. However, the subgrade reaction modulus is polynomial. So, the main form of the excepted formula is shown in Equation 5.

$$y = \begin{Bmatrix} a_0 + a_1x_1 + a_2x_2 \\ +{a_3}^2x_2 + {a_4}^3x_2 + a_5x_3 + a_6x_4 \end{Bmatrix} \tag{5}$$

Where, y is the layer thickness in cm, x_1 is the concrete flexural strength in psi, x_2 is the subgrade reaction modulus in pci, x_3 is the plane weights in kg and x_4 is the annual departure counts. a_i $\{i = 0 \dots 6\}$ is the coefficients. As mentioned above, because subgrade reaction modulus is polynomial, the coefficient is third order polynomial predicted. With the help of EXCEL software's solver tool, the least squares method was able to be applied. As a result, Equation 6 is obtained for calculating the layer thickness.

$$y = \begin{Bmatrix} 24.747 - 0.019x_1 - 0.03x_2 \\ +0.0719^2x_2 + 0.2305^3x_2 \\ +0.0005x_3 + 0.0001x_4 \end{Bmatrix} \tag{6}$$

As seen from Equation 6, annual departure counts have the less impact on the layer thickness. The comparison of the calculated thickness values using Equation 6 and obtained thickness values from abaca are shown in Figure 2 and 3.

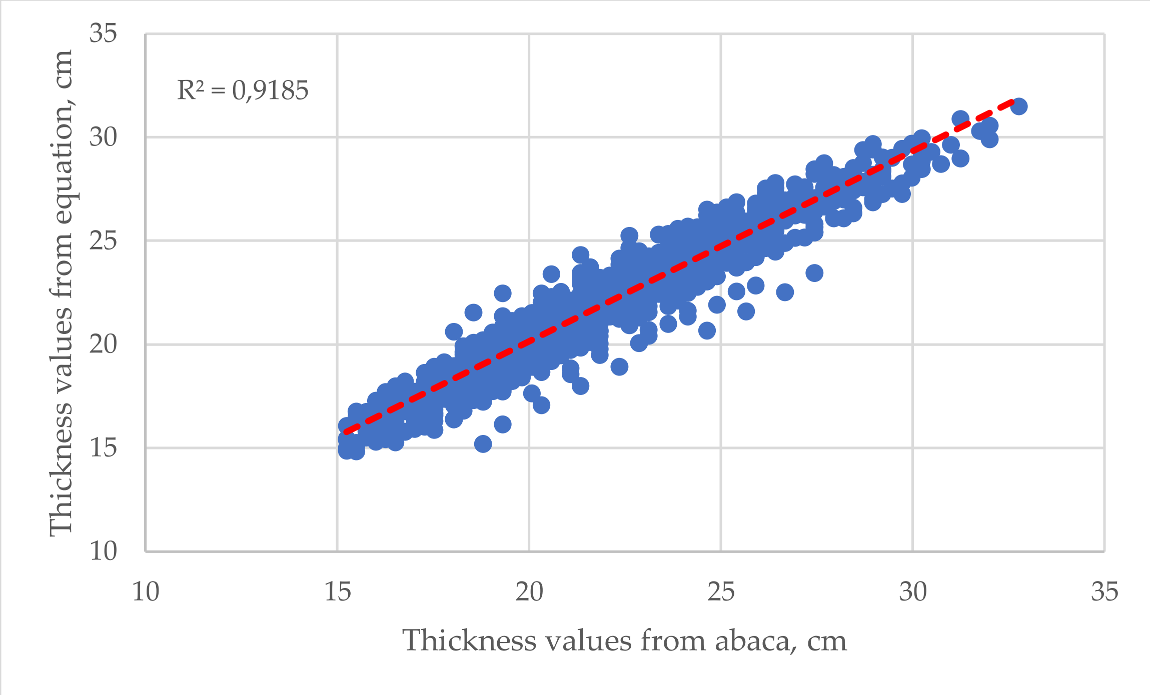

Figure 2. The regression value between calculated and abaca obtained thickness values for training data set

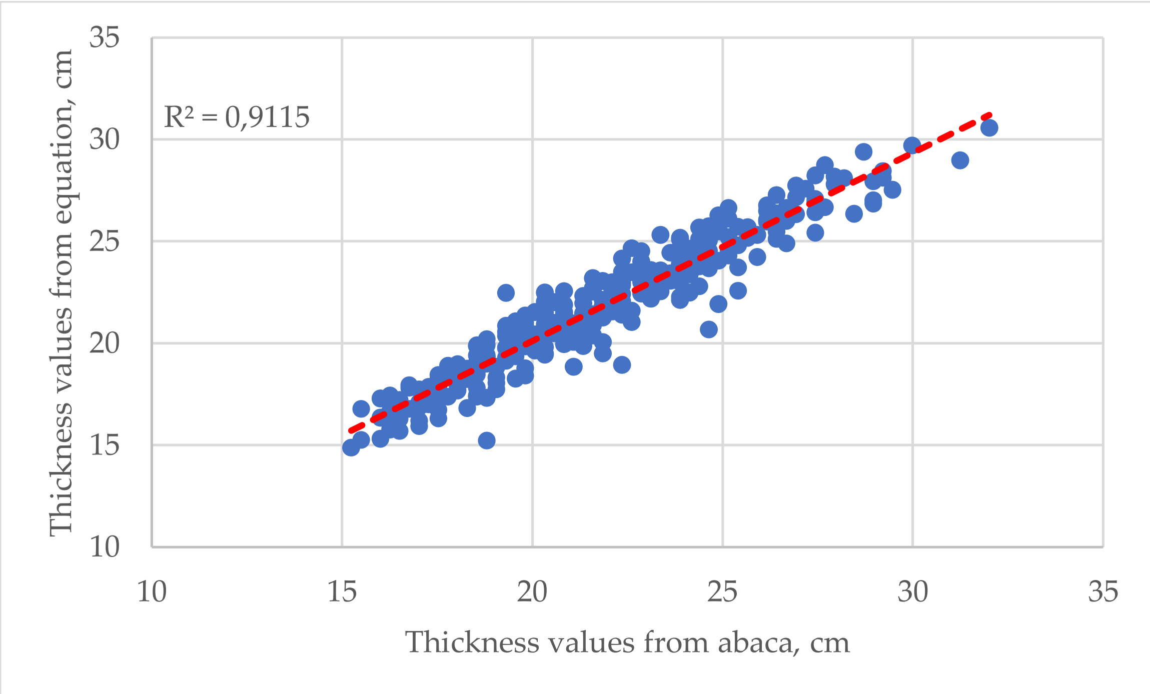

Figure 3. The regression value between calculated and abaca obtained thickness values for test data set

As seen in Figure 2 and 3, the thickness values are close to values obtained by abaca reading. In addition, for both, training and test data set, the regression between the data are very high, ~91%. Last of all, the error obtained from calculation has an average of 3.5% which is very low.

4. Conclusion

In this study, it is focused on developing a novel mathematical equation to calculate the layer thickness based on concrete flexural strength, plane weights, annual departures and subgrade reaction modulus. There is some abaca to determine the layer thicknesses but it is both time consuming and easy to make mistakes. So, suggesting a mathematical model can handle these handicaps.

For developing the equation, data set of Küçükçapraz (2019) has been used. As a result of the development, thickness values got close to the abaca read thickness values with a regression coefficient of 91.85%. After developing the equation using the training data set, the equation attempted for the test data set. Also using the equation for these data set gave a high regression value of 91.15%. The average mistake was 3.5% which is very low. So, the developed mathematical model could be used to determine the slab layer thickness for airport pavements.

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