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Developing Multi Linear Regression Models for Estimation of Marshall Stability

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Abstract*—Nowadays, asphalt roads are exposed to increasing traffic loads in recent times. It is important to obtain a quality and healthy asphalt road covering when considering the conditions of our country where freight and passenger transportation are carried out by roads. One of the most important issues in asphalt road design is the determination of the optimum percentage of bitumen. The Marshall stability test is utilized for optimum percent bitumen determination. In our work, instead of the long and laborious Marshall experiment process, Multi Linear Regression (MLR) Models are developed as an alternative. Models were developed for Marshall experiment result for Marshall stability prediction. In order to construct stability estimation models, pre-made test parameters are used. These parameters are; the bitumen penetration (P),weight of the sample in the weather (H), the temperature (C), the bitumen weight (G), the sample heights (Y), the bitumen percentage (W), weight of the sample in water (S), the stability (ST). In the performance evaluation of the models, the correlation coefficient (R), the mean percentage errors (MPE) and the meansquare errors (MSE) are used. It is seen that the model with the highest performance value is composed of six variable model in this study formed by the MLR. The R value of the best model is 0.571.The MSE value of the best model is 14841,81. The MPE value of the best model is 9.58.*

***Keywords*—Marshall Stability Experiment, Multi LinearRegression, MSE, MPE,**

I. INTRODUCTION

Highway transportation is becoming increasingly common all over the world and due to the increase in population in our country, the increase of transportation demands and the environmental factors. Due to this reason, studies are being carried out in order to obtain better quality asphalt roads. Bituminous hot mix is used to obtain a healthy and high quality top structure in asphaltroad construction[1]. Asphalt road damages occur more frequently in the binder and wear layers than in the base and sub base layers. Deformations in the asphalt roads are deformation such as surface cracks, pits, subsidence, and breakage[2].The stability and flexibility that asphalt shows in long-term short-term freight transit is of great importance. The performance of roadway coating is crucial for the road to be long lasting. The coating performance is determined by the stability of the asphalt concrete. Many of the deformations that occur in the coating is due to the low stability of the asphalt concrete [3]. The stability of asphalt concrete depends on properties such as bitumen hot mix, bitumen content, bitumen viscosity, softening point, asphalt construction conditions and climate [4]. Fatigue fractures occur due to the effect of repetitive loads during highway coating. These cracks are one of the important deteriorations [5]. The percentage of asphalt bitumen is of great importance for the healthy design of asphalt roads. In the use of bituminous hot blending methods, the importance of engineering and project engineers is important [6]. Much research has been done on Marshall experiment and regression analysis. Yıldız ve Gökdemir [7] the asphalt concrete abrasion layer was subjected to regression analyzes using Marshall design method and SPSS 11.0 package program to obtain optimum mix design. As a result, the results obtained with these two methods are consistent. However, it is necessary to try the Marshall in accordance with the specifications. Namlı, Kuloğlu [8] they compared the Superpave and Marshall experiments. Asphalt concrete samples were prepared and applied in accordance with the rules for both tests. Özgan, Serin, Kap [9] have investigated the effect of hot mixture parameters on Marshall stability. The parameter bitumen ratio, which is the most positive correlation with Marshall Stability, was determined. The temperature was found to be the least relevant parameter. Konak [10] have prepared hot asphalt mixtures with different impact numbers. Marshall ratio is determined. The evaluation of the results determined by the regression analysis is done. Deniz, Lav [11] investigated the effect of granular sulfur on the stability of bituminous asphalt. In order to obtain quality asphalt mixtures, it is also important to use modified

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materials that are reinforced with additives as well as quality materials.

II. MATERIAL AND METHODS

In this study, variables with Marshall Experiment parameters are examined as dependent and independent variables. Independent variables; weight of the sample in the weather, bitumen penetration, the temperature, the bitumen weight, the sample heights, bitumen percentage, weight of the sample in water. Stability value is dependent variable. Regression models are formed by these dependent and independent variables. In this study,1050 experimental data are used.

Multiple Linear Regression Methods for Marshall Stability Estimation

Regression analysis has been one of the most used techniques to determine the relationship between variables in research[12].There are many types of regression. There are linear, nonlinear, simple, multiple, parametric, nonparametric, logistic, etc. regression models [13, 14, 15].The MLR model we use in this study is as in Equation 1.

$$y(x) = \beta_0 + \sum_{i=0}^{N} \beta_i x_i + \sum_{i<j}^{N} \beta_{ij} x_i x_j + \sum_{i=0}^{N} \beta_{ii} x_i^2 + \varepsilon \quad (1)$$

In this form, x_i and x_j (i = 1, ..., N) (j = 1, ..., N) represent independent variables. The y in the equation represents the dependent variable, β represents the regression coefficients, and ε represents the error. The dependent variable y is modeled as a combination of fixed, linear, interactive, and second order terms consisting of auxiliary variables. The coefficients of the model are estimated by MLR analysis[16, 17].

Linear, Interaction, Quadratic and Purequadratic MLR methods were used in our study. It is seen that the best model among the created models is six variable models. The beta coefficients of the model were obtained at the end of the analysis in the MATLAB program. The linear regression model of this model is shown in Equation 2.

$$ST = -905{,}2378314 + 5{,}388874025 * H - 4{,}342171288 * P + 9{,}301123242 * C - 33{,}57871985 * Y - 72{,}1825 * W - 4{,}429639906 * S \quad (2)$$

Equation 3 of the interaction regression model is seen.

$$ST = -1076{,}034481 - 11{,}51577899 * H + 92{,}69293196 * P - 143{,}0209243 * C - 282{,}6862705 * Y + 220{,}8074527 * W + 69{,}30927451 * S + 0{,}276126182 * H * P - 0{,}042548775 * H * C + 0{,}401606147 * H * Y - 1{,}251214819 * H * W - 0{,}018546838 * H * S - 0{,}329144805 * P * C - 1{,}253213817 * P * Y - 0{,}60228875 * P * W - 0{,}424118338 * P * S + 2{,}317337895 * C * Y + 1{,}416000019 * C * W + 0{,}102508531 * C * S + 5{,}295628482 * Y * W - 0{,}737332781 * Y * S + 0{,}977486549 * W * S \quad (3)$$

The coefficients of the quadratic regression are shown in equation 4.

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$$ST = +18054{,}48354 - 9{,}067259718 * H + 29{,}37620757 * P - 346{,}8691251 * C - 63{,}91968259 * Y + 898{,}8133477 * W + 33{,}5450474 * S + 0{,}338978055 * H * P - 0{,}060892258 * H * C + 0{,}741417288 * H * Y + 0{,}173132269 * H * W - 0{,}029464774 * H * S - 0{,}189360359 * P * C - 1{,}649029683 * P * Y - 1{,}407600681 * P * W - 0{,}487389052 * P * S + 1{,}95442971 * C * Y + 1{,}241707794 * C * W + 0{,}227220653 * C * S - 8{,}24161665 * Y * W - 0{,}965717554 * Y * S - 0{,}76027346 * W * S - 0{,}010074251 * H^2 + 0{,}347384307 * P^2 + 0{,}532139852 * C^2 - 2{,}570864781 * Y^2 - 24{,}91495593 * W^2 + 0{,}04086942 * S^2$$

(4)

The results of the Purequadratic regression are shown in equation 5.

$$ST = -1507{,}569095 + 10{,}98246856 * H - 66{,}05557092 * P - 108{,}2193999 * C - 177{,}1409938 * Y + 92{,}71018452 * W + 30{,}01804932 * S - 0{,}002177812 * H^2 + 0{,}512588536 * P^2 + 0{,}403104664 * C^2 + 1{,}139821409 * Y^2 - 17{,}69735793 * W^2 - 0{,}025567309 * S^2$$

(5)

III. RESULTS AND DISCUSSION

In this study, a total of 107 ST prediction models are constructed including one variable, two variables, three variables, four variables, five variables, six variables and seven variables. Models are subjected to four different regression techniques (Linear, Interaction, Quadratic and Purequadratic) to obtain the performance values of 428different model results. As a results of the analyzes made, the performance of the models is compared. When the performance comparison is made, the correlation coefficient, the mean square errors, and the mean percentage error values are compared. The model with the best performance is the model with six different variables. The best model is the Quadratic regression model. The correlation coefficient is 0.57, the mean square errors is 14841.81, the mean percentage errors is %9.58(Table 1).

Table 1: Comparison of Multiple Linear Regression Methods for ST Estimation

	R	MSE	MPE
Linear model	0,510	16288,44	10,04
İnteraction model	0,553	15281,68	9,70
Quadratic model	0,571	14841,81	9,58
Pure Quadratic model	0,542	15543,28	9,76

The comparison of the actual stability value with the stability value of the regression model is given in Figure 1.

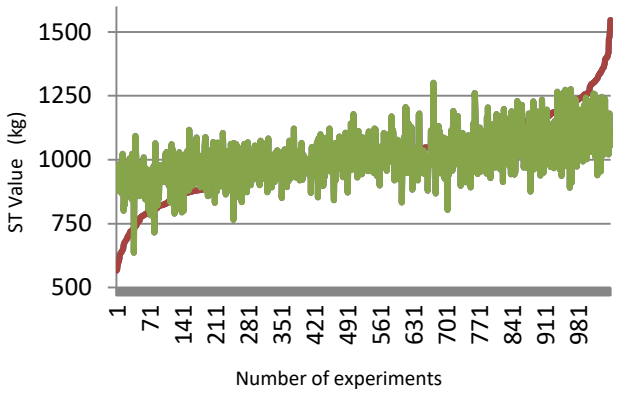

*Fig.1:*Comparison of actual value and best MLR results for stability value

IV. CONCLUSION

- In this study has benefited MLR techniques that are Linear, Interaction, Quadratic and PureQuadratic regression techniques.
- The independent variables are weights of the sample in the weather, bitumen penetration, the temperature, the bitumen weight, the sample heights, bitumen percentage, weight of the sample in water.
- The value of Marshall Stability is used in the regression models as the dependent variable.
- To find the best regression model, 428 MLR models were fitted.
- The best MLR model has been a six-variable with quadratic regression method.
- The R value of the best MLR model is 0.571.
- The best MSE for the model is 14841,81.

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- The best model has the MPE value of 9.58.
- It is seen that there is a weak interaction between the independent variables and the dependent variables by MLR techniques.
- However, artificial intelligence techniques can be used to achieve better results than regression models in further studies.

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