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Modeling of the Stability and Flow of Asphalt Mixes Using Optimum Asphalt Content

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ABSTRACT

The main aim of this study was to evaluate the asphalt mixture properties for samples that were taken from different sites and plants: Amanat Baghdad, Faluja municipality, and Baghdad Governorate, which almost produced in private plants. Forty seven asphalt mixtures samples were tested following Marshall Test. The tested properties were: Marshall Stability, Marshall Flow, specimen density, and air voids. Asphalt extraction was carried out according to quantative extraction of bitumen from paving mixtures test.

A statistical analysis of the collected field data was performed and a prediction model was built. The variables such as asphalt content, stability and flow data were analyzed using computer software. The statistical analysis includes four stages: data extraction and evaluation, verification, calibration, and validation.

Results of this study indicate that both of Marshall Stability and Marshall Flow correlate positively with asphalt content, but with different degree. Asphalt content affect Stability property much more than flow property of the asphalt mixes.

Keywords: Statistical Modeling; Marshall Stability; Marshall Flow; Asphalt content

نمذجة الثبات والزحف للخلطات الإسفلتية باستعمال النسبة المثلى للأسفلت

الخلاصة

ان الهدف الرئيسي من هذا البحث هو تقييم بعض خواص الخلطات الاسفلتية لنماذج تم اخذها من معامل ومواقع مختلفة مثل امانة بغداد, بلدية الفلوجة ومحافظة بغداد والتي غالبا يتم انتاجها في معامل القطاع الخاص. تم فحص سبعة واربعون نموذج باختبار مارشال المستخدم في تصميم الخلطة الاسفلتية. وكانت الخواص المفحوصة هي ثباتية مارشال, زحف مارشال, كثافة النموذج والفراغات الهوائية علما ان فصل مكونات الخلطات الاسفلتية تم طبقا لفحص الاستخلاص الكمي لمكونات الخلطات الاسفلتية.

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تم اجراء تحليل احصائي للبيانات التي تم جمعها ومن ثم موديل تنبؤ احصائي وذلك باستخدام برنامج حاسوبي واستخدام متغيرات ثباتية مارشال والمحتوى الاسفلتي والزحف. تضمن التحليل الاحصائي اربعة مراحل هي جمع وتقييم البيانات, التحقق من هذه البيانات ومعايرتها واثباتها.

بينت نتائج البحث بان كلا من ثباتية مارشال وزحفها لهما علاقة ارتباط قوية مع المحتوى الاسفلتي وبدرجات مختلفة حيث ان المحتوى الاسفلتي يؤثر بالثباتية اكثر من تاثيره بزحف مارشال للخلطات الاسفلتية.

INTRODUCTION

Prithvi (1) stated that earliest studies have shown that the repeatability of Marshall stability, flow, and air voids content measurements on 6-in.(152.4mm) diameter specimens of large stone mixes is better than the repeatability on 4-in.(101.6mm) diameter specimens. A round robin study involving twelve participating laboratories was conducted to provide information for developing a precision statement for the ASTM Test Method for Resistance to plastic Flow of Bituminous Mixtures Using Marshall Apparatus (6inch-Diameter Specimen) (D5581). Difference two-sigma (d2s) limits were developed to determine acceptable single and multi-laboratory differences for bulk specific gravity, percent voids, Marshall Stability, and Marshall Flow measurements. Analysis of other data collected during the study indicated that stability and flow measurements are not sensitive to minor differences in various 6-in.(152.4) diameter breaking heads currently in use.

LARRY (2) concluded that the HMA properties compacted at various temperatures was evaluated. This study has determined the Marshall properties of ACW14 and ACW20 when compacted at 85ºC, 100Cº, 115ºC, 130ºC, 145ºC, and 160ºC.

The study has achieved its objective of evaluating the Marshall properties of ACW14 and ACW20 mix design when compacted at various temperatures. Study indicates that temperature has a tremendous effect on HMA Marshall Properties and indirect tensile strength.

Even though compaction temperatures range from 160ºC to 85ºC, the different between two temperatures in the data is 15ºC. This could make the data gained from experiment less accurate, but six different compaction temperature used in the reseaech studied can generally represented the HMA performance in real situation at site.

Arshad Hussain (3) stated that the use of Reclaimed Asphalt Pavement (RAP) has been enormously increased from the last two decades. In fact using RAP in pavement construction has now become common practice in many countries. Using RAP not only economical and environmental friendly but also preserve the natural resources and similar or even better in structural performance than virgin asphalt mixtures. The author presents an experimental study to evaluate the effect of various types and percentages of RAP on the properties of asphalt mixtures. Based on extensive laboratory evaluation of different Marshall Mixtures containing RAP concludes that the blending of virgin and RAP material overall improve the mixture properties. In laboratory the RAP mixtures designed using Marshall method perform the same or even better than the conventional mixtures. The Marshall stability increases linearly with increase in RAP contents. The stability of the 100% RAP mixtures is more than double the stability of the virgin mixtures and for the other RAP source also increases in the stability with 100% RAP. Hussain (4) studied a preventive maintenance techniques that apply to retard asphalt pavement deterioration and prolonged service lives. This study focuses on prepare good performance and flexible modified thin hot mix asphalt used as an overlay. Atactic poly-propylene (APP) at five contents (from 3 to7% by asphalt weight) were used either alone or mixed with one rubber percent [Styrene-butadiene rubber (SBR), tier rubber (R) and/or equal parts of SBR and R] to modify local asphalt penetration grade 60/70.

Properties of modified and un-modified asphalts [Softening point, penetration value at (5, 25 and 45°C), penetration temperature susceptibility (PTS), and penetration index (PI), Dynamic viscosity at 135 and 150°C and tensile strength at 25 and -7°C] were examined. Durability of modified and unmodified asphalt mixtures was evaluated through Marshall and Wheel Tracking Tests. Test results showed that all properties of the base asphalt binder and asphalt mixes were improved by the addition of the modifiers. The degree of improvement depends mainly on the characteristics of polymer and bitumen/polymer ratio. The best improvements in the modified binders and modified mixes were obtained at 6% APP/1% (1SBR:1R). Stiffness, PTS and tensile strength of APP modified asphalt binders were improved at low temperature when 1% rubber was introduced. Marshall stability and flow were increased by 35% and 11.7% respectively at 6% APP/1% (1SBR:1R). Resistant of the modified asphalt mixes to rutting was increased by 84.3% at the same modifier content.

EXPERMENTAL WORK

In order to find out and to evaluate the asphalt mixture properties that consider in this study and mixtures that were taken from different sites and plants belong to a different authorities like as Amanat Baghdad, Faluja municipality, and Baghdad Governorate which almost produced in private plants. Forty seven asphalt mixtures samples that taken from these sites, were tested following ASTM D1559 (5). The tested properties were: Marshall stability, Marshall flow, specimen density, and air voids. Asphalt extraction was done to samples according to ASTM D2172, “Quantitative Extraction of Bitumen from Paving Mixtures” (6), and the aggregate gradation for each mixture also obtained, furthermore, asphalt content for each mixture samples were implemented in the statistical and modeling analysis that considered the Marshall stability, Marshall flow and asphalt content as explained in the next section.

STATISTICAL ANALYSIS OF FIELD DATA

A statistical analysis of the field data was performed so that the reduced data could be used in the service life prediction model [7-9]. The variables such as asphalt content, stability and flow data were analyzed using computer software to determine their statistical distributions and cumulative distribution functions (cdf).Table(1) shows an example of the statistical description of asphalt content, Marshall Stability, and Marshall Flow data taken from different asphalt plant in Baghdad. A 95 percent probability of occurrence was considered for every data set; therefore, the lowest and highest 2.5 percent of the data were excluded in the modeling work. The whole process is grouped into four stages: data extraction and evaluation, verification, calibration, and validation.

DATA EXTRACTION AND EVALUATION

This stage involves the selection of input data for the inputs to be used in the calibration process. Fifty percent (50%) of the whole data were selected randomly to build the model and an analysis process is developed in order to observe the local dependency of bias and standard error. Table (2) presents the analysis for the collected data in this study. Figure (1) shows the scatter plot of the collected data.

There are three types of field test results that can be included in the calibration process, i.e., Asphalt Content, Marshall Stability, and Marshall Flow. The final step in this stage involves extraction and evaluation of the selected data by checking for reasonableness and any presence of irrational trends.

VERIFICATION

From the verification results shown in Figure (2), it can be observed that the measured Marshall Stability do not match the predicted Marshall Stability particularly well. This observation is attributed to the high level of the Standard Deviation and Sample Variance compared with Marshall Flow results. And, therefore, unless more Calibration processes are done, these measurement techniques cannot be used in the fitting process of the Stability vs. Asphalt content model. Thus, only linear regression was used for Flow vs. Asphalt content was used in the fitting process of the model see Figure (2b).

A null hypothesis test is performed on the verification results to check for the presence of bias. Bias here is indicated by the goodness of fit between the measured and predicted values. The null hypothesis here is that no significant differences exist between the measured and predicted values. A Chi-square test was performed as a part of this stage. Measured Chi-square (χ^2) -value less than tabled Chi-square (χ^2) -value signifies that no significant difference exists between the measured and predicted values and, hence, the hypothesis is accepted. From Table (3), it can be observed that the null hypothesis is accepted for both Marshall Stability model and Marshall Flow model. However, visual inspection indicate two points in the upper left zone of Figure (2a) deviate so much unlike other points and hence bias needs to be eliminated by recalibrating the Marshall Stability model.

CALIBRATION

Despite of the null hypothesis for the verification process of Marshall Stability model is accepted (from the previous stage), bias is needs to be either reduced or eliminated. To eliminate the bias, a 5% of the input data has been excluded which are having the highest deviation. Table (4) presents the standard error and Standard Deviation before and after the calibration effort of the Marshall Stability model.

Standard Deviation is obtained by taking the positive square root of the variance of the statistic.

The total standard error obtained after the calibration is comparable to the global standard error presented in Table (1). Figure (3a) and Figure (3b) show the comparison between the measured and predicted Marshall Stabilitybefore and after calibration respectively.

VALIDATION

For the purpose of validation, the remaining 50% of the data that were kept aside from the grouping stage to be used to verify the reasonableness of the final calibrated models. Table (5) presents the validation results for both models. For the Marshall Stability model results shown in Table (5), the observed standard deviation is similar to the local calibrated standard deviation see Table (2), as well as the global standard deviation Table as in (1). A Chi-square test is used to determine if there is any significant difference exists between the validation results and local calibration values and, hence, the null hypothesis is to be accepted or not. From the Chi-square test results presented in Table (6), it can be deduced that the validation check is successful and therefore the final calibrated Marshall Stability vs. Asphalt Content and Marshall Flow vs. Asphalt Content model can be used. Figure (4) shows the validation results for both models.

Finally, data collected from forgoing stage were used to build the model shown in Figure (5). The figure clearly indicate that both of Marshall Stability and Marshall flow correlate positively with Asphalt content, but with different degree. Since the slop of the regression line of Marshall Stability vs. Asphalt content is clearly more than that of Marshall Flow, then the conclusion that: Asphalt content affect Stability property much more than Flow property of the asphalt mixes, is being acceptable. This finding is in good agreement with reference [10].

CONCLUSIONS

The following conclusions were made from this study within the limits of the materials used:

• From the verification results, it is found that the Marshall Flow predicted values match very well with the measured values for the collected field data.

• From the calibration effort, it can be observed that the standard error and bias are reduced. The standard error from the local calibration effort is the same as the global standard error for both of the Marshal and flow prediction models.

• The null hypothesis test to check if the local calibrated standard error is significantly different from the global standard error shows that there is no significant difference between them and hence no further calibration is pursued to reduce the standard error in this study.

• The validation check performed on both the Marshal and flow prediction models using the Chi-square test shows that the validation is successful and hence the predictions are reasonable.

• The model clearly indicates that Asphalt content affect Stability property much more than Flow property of the asphalt mixes.

REFERENCES

[1].Prethvi, S. Kandhal"precision of Marshall stability and flow Test using 6-in.(152.4mm)Diameter specimens" journal of Testing and evaluation,JTEVA,vol.24,No.1,January 1996,pp-20-25.

[2].Larry ak silas tirau"evaluation of hot mix asphalt (hma) properties compacted at various temperatures"Faculty of Civil Engineering Universiti Teknologi Malaysia, 2005.

[3].ArshadHussain+ and QiuYanjun,"Evaluation of Asphalt Mixes Containing Reclaimed Asphalt Pavement for Wearing Courses" 2012 International Conference on Traffic and Transportation Engineering (ICTTE 2012),School of Civil Engineering, Southwest Jiaotong University, Chengdu, China.

[4]. Hussain, M.H.M. N.F. Ghaly and I.M. Ibrahim"Modified Hot Mix Asphalt for Road Maintenance"World Applied Sciences Journal 5 (2): 236-245, 2008.

[5].ASTM D1559-76"Resistance to plastic flow of Bituminous mixture using Marshall Apparatus"Vol.04.03.

[6].ASTM D2172-88, "Quantitative Extraction of Bitumen from Paving Mixtures"Vol.04.03.

[7].Montgomery, D.C. &Runger, G.C. "Applied statistics and probability for engineers" 3rd ed., John Wiley & Sons, 2003.

[8].Devore, J.I. "Probability and Statistics for Engineering and Sciences"; 7th Edition, 2008.

[9].NCHRP. 2003. b. "Refining the Calibration and Validation of Hot Mix Asphalt Performance Models: An Experimental Plan and Database". NCHRP Research Results Digest 284. NCHRP 9-30. National Cooperative Highway Research Program. Washington D.C.December.

[10].NCHRP. 2007. "Recommended Practice for Local Calibration of the ME Pavement Design Guide". NCHRP 1-40B Draft. National Cooperative Highway Research Program. ARA.

Table (1)Data description of field test.

Statistical value	Asphalt Content	Marshall Stability	Marshall Flow
Mean	4.440426	7.493617	3.097872
Standard Error	0.064782	0.233451	0.079224
Median	4.5	8.1	2.9
Mode	4.8	9.2	2.8
Standard Deviation	0.444121	1.600462	0.543135
Sample Variance	0.197243	2.56148	0.294995
Kurtosis	0.402009	-0.13542	1.449467
Skewness	-0.43971	-0.79736	1.267129
Range	2.1	6.8	2.4
Minimum	3.1	3	2.3
Maximum	5.2	9.8	4.7
Sum	208.7	352.2	145.6
Count (N)	47	47	47

Table (2) Data description of extracted test results.

Statistical value	Asphalt Content	Marshall Stability	Marshall Flow
Mean	4.45	7.308333	3.191667
Standard Error	0.08297	0.31149	0.132413
Median	4.5	7.95	2.9
Mode	4.6	8.4	2.8
Standard Deviation	0.406469	1.525983	0.648689
Sample Variance	0.165217	2.328623	0.420797
Kurtosis	-0.96757	-1.10876	0.531105
Skewness	0.002119	-0.54146	1.009197
Range	1.4	4.7	2.4
Minimum	3.8	4.5	2.3
Maximum	5.2	9.2	4.7
Sum	106.8	175.4	76.6
Count (N)	24	24	24

Table (3) Calibration Results - Null Hypothesis Test for Goodness of fit.

Statistical Results	Marshall Stability vs. Asphalt Content model	Marshall Flow vs. Asphalt Content model
Measured Chi-Square(χ^2)Statistic	5.46	2.97
Degrees of Freedom	23	23
N	24	24
Confidence level	95%	95%
Tabled *Chi-Square(χ^2) Statistic*	35.2>> 5.46	35.2>> 2.97
Null hypothesis	Accepted	Accepted

Table (4) Data description of Marshall Stability test.

Statistical value	Before	After
Mean	7.308333	7.509091
Standard Error	0.31149	0.302222
Median	7.95	8.15
Mode	8.4	8.4
Standard Deviation	1.525983	1.417546
Sample Variance	2.328623	2.009437
Kurtosis	-1.10876	-0.71354
Skewness	-0.54146	-0.73279
Range	4.7	4.7
Minimum	4.5	4.5

Maximum	9.2	9.2
Sum	175.4	165.2
Count (N)	24	22

Table (5) Validation Results – Summary of Statistics for the Marshall Stability and Marshall Flow data.

Statistical value	Asphalt Content%	Marshall Stability kN	Marshall Flow mm
Mean	4.430435	7.686957	3
Standard Error	0.102041	0.351693	0.082692
Median	4.5	8.1	2.8
Mode	4.5	9.2	2.8
Standard Deviation	0.489373	1.68666	0.396576
Sample Variance	0.239486	2.844822	0.157273
Kurtosis	1.12903	1.118165	0.371012
Skewness	-0.70119	-1.14073	1.139814
Range	2.1	6.8	1.4
Minimum	3.1	3	2.5
Maximum	5.2	9.8	3.9
Sum	101.9	176.8	69
Count (N)	23	23	23

Table (6) Validation Results - Null Hypothesis Test for Goodness of fit.

Statistical Results	Marshall Stability vs. Asphalt Content model	Marshall Flow vs. Asphalt Content model
Measured Chi-Square(χ^2)Statistic	0.163	0.07
Degrees of Freedom	22	23
N	23	24
Confidence level	95%	95%
Tabled *Chi-Square(χ^2) Statistic*	33.9 >> 0.163	33.9 >> 0.07
Null hypothesis	Accepted	Accepted

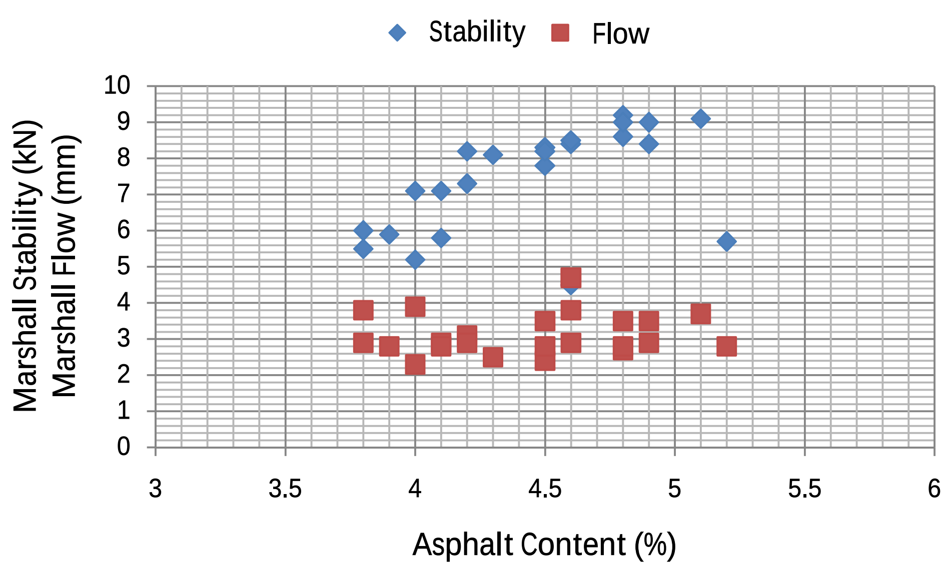
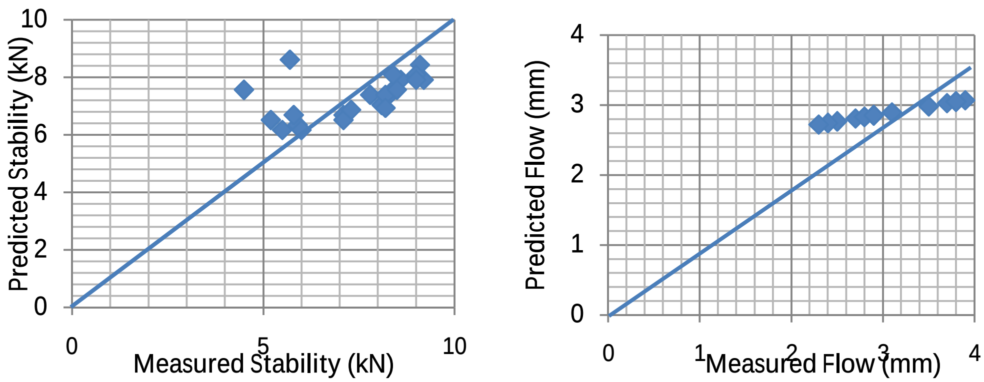
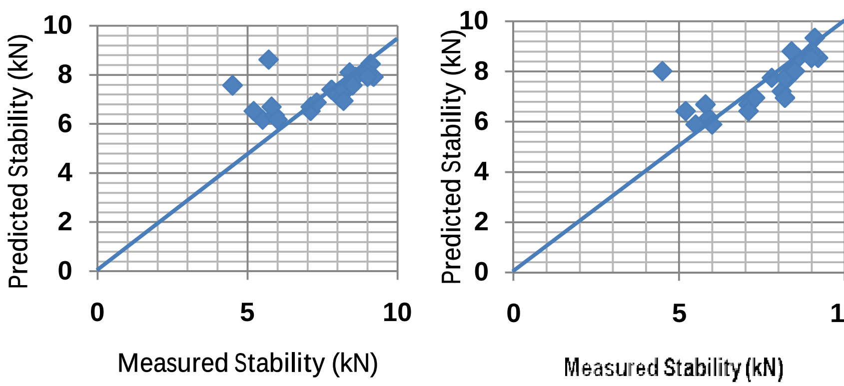


Figure (1) scatter plot of the extracted data.



(a) **(b)**

Figure (2) Verification Results: a- Measured Stability vs. Predicted Stability, b- Measured Flow vs. Predicted Flow.



(a) Before calibration **(b) After calibration**

Figure (3) Measured Stability vs. Predicted Stability before and after calibration.

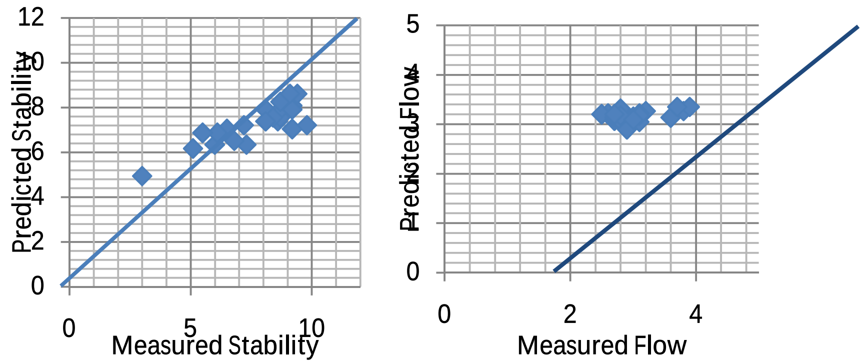


Figure (4) Validation results, measured vs. predicted values.

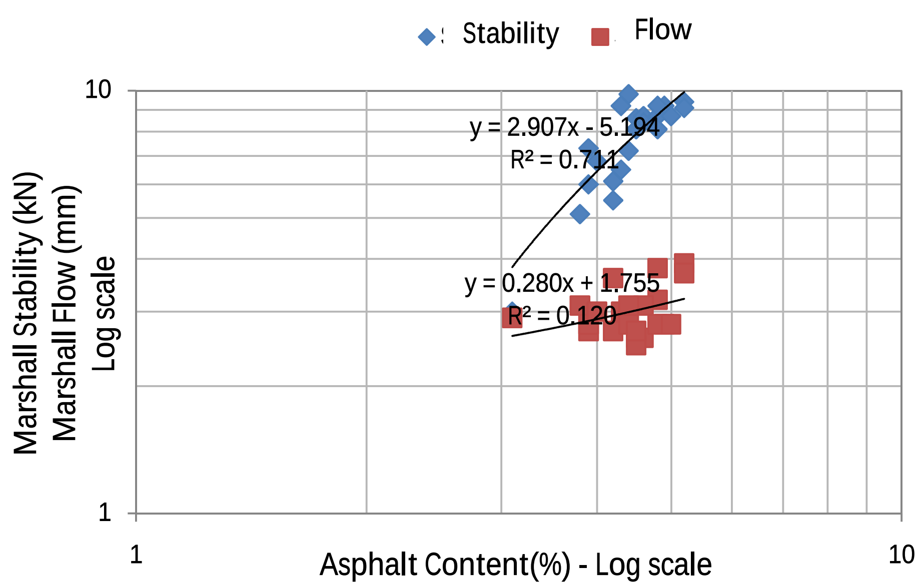


Figure (5) Stability & Flow vs. Asphalt Content Model.