Mansoura Engineering Journal

Volume 33 | Issue 1 Article 1

3-1-2008

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Recommended Citation

Mohamady, Ahmed (2008) "Proposed Technique that Simulates the Actual Asphalt Mix Field Compaction.," *Mansoura Engineering Journal*: Vol. 33 : Iss. 1 , Article 1.
Available at: https://doi.org/10.21608/bfemu.2008.126802

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Mansoura Engineering Journal, (MEJ), Vol. 33, No. 1, March 2008. C. 1

PROPOSED TECHNIQUE THAT SIMULATES THE ACTUAL ASPHALT MIX FIELD COMPACTION

طريقة مقترحة لدمك الخلطات الأسفلتية تماثل الدمك الحقلى

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الملخص العربى

تحتاج صناعة الخرسانة الأسفلتية إلى تحديث وتطوير لمواصفات التصميم والتنفيذ لضمان أفضل أداء للرصف لمواكبة التحديات المستقبلية فى هذا المجال، وتعتبر عملية فرش ودمك الخلطات الأسفلتية عملاً مهما أثناء الإنشاء لأن طريقة الدمك فى الموقع تؤثر تأثيرا ملحوظاً على خصائص وأداء الرصف بالإضافة إلى عمره الزمنى. ويتم الدمك فى الموقع بأسلوب لا يتوافق مع ذلك الذى يتم فى المعمل عند التصميم بطريقة مارشال وبالتالى فإن التنبؤ بسلوك وخصائص الخلطة الأسفلتية المجهزة لاختبار مارشال قد لا يتوافق مع واقع الدمك الحقلى. وقد حاولت العديد من الدراسات السابقة استخدام أساليب دمك معملية مختلفة لمحاولة محاكاة ما يحدث فى الطبيعة لكى يتم التنبؤ بالسلوك الفعلى للخلطة تحت تأثير الأحمال المرورية.

وتهدف هذه الدراسة إلى تقديم طريقة دمك معملية جديدة تحاكى ما يحدث أثناء دمك الخلطة الأسفلتية فى الطبيعة وذلك باستعمال جهاز مارشال – CBR (نسبة تحمل كاليفورنيا) العادى. ويتم فى تلك الطريقة المقترحة وضع قرص حديدى أعلى العينة في قالب مارشال ثم الضغط بانتظام لحين الحصول على أبعاد العينة القياسية. وعلى ذلك فقد تم إختيار عشر خلطات مختلفة من طرق يتم تنفيذها بواسطة الهيئة العامة للطرق والكبارى، وتم إستخدام ثلاثة أساليب دمك مختلفة وحساب خصائص الخلطات الناتجة عن تلك الأساليب. الأسلوب الأول وهو استخدام طريقة مارشال التقليدية لتصميم الخلطة. والأسلوب الثانى هو نفس طريقة مارشال التقليدية مع إختلاف فقط فى أسلوب دمك العينة حيث تم إستخدام أسلوب الدمك المقترح لمحاكاة ما يحدث فى الطبيعة. أما خصائص الخلطة الأسفلتية التى تم دمكها فى الموقع باستخدام الأسلوب الثالث (طريقة الدمك العادية فى الموقع) فقد تم أخذ عينات من الخلطات المدموكة حديثا فى الطبيعة بجهاز الكور لنفس التصميمات السابقة، حيث تم إعتبار خصائص تلك الخلطات فى الطبيعة هى المرجع فى مقارنة نتائج أسلوبىَ الدمك المعملى.

وقد أظهر تحليل النتائج أن طريقة الدمك المعملى المقترحة تحقق خصائص تكاد تكون متطابقة مع الخصائص الفعلية فى الموقع لكل الخلطات التى تم اختبارها. أما طريقة مارشال التقليدية فهى تعطى خصائص غير معبرة بدرجات متفاوتة عن الخصائص الفعلية فى الواقع.

ABSTRACT

Future needs and challenges in the asphalt concrete industry should make use of developed and new techniques to attain the best field performance. Spreading and compacting fresh asphalt concrete mix is a very important job during pavement construction. The compaction mechanism in the field greatly affects the pavement characteristics, performance, and service life. Several studies tried to use different compaction techniques to simulate the actual field compaction in the laboratory. The purpose of this study aims at introducing an innovative compaction technique that simulates the actual field compaction conditions to a great extent as presented in the research results. The technique employs the traditional Marshall-CBR testing machine in compacting the asphalt mixes. A steel disc is placed over the sample, which is continuously compressed in the Marshall mould till reaching the required sample dimensions. Results obtained from the traditional Marshall and the proposed compaction techniques are compared with field results. Analysis of the results showed large coincidence between the proposed compaction technique and the field results. On the other hand, specimens compacted using the traditional Marshall technique showed larger deviation with the field results in almost all the tested properties.

KEW WORDS: Asphalt concrete mix, Marshall test, Compaction technique, Mix unit weight, Mix stability, and Air voids.

Accepted March 31, 2008

1. INTRODUCTION AND BACKGROUND

Compaction is the process of maximizing the material unit weight through reducing the volume of air in an asphalt mix by the application of external forces. Therefore, the compaction process is an important factor in the design and subsequent production of asphalt mixtures [1]. Compaction is also the simplest and most economical method of improving the load carrying capability of pavements to sustain traffic loads, and different distresses such as rutting and Raveling [2, 3, 4]. When the compaction process is done during construction, it costs very little, and thus can significantly reduce future maintenance costs. Compaction also gives the road higher strength to support heavier loads, reduces settlement over the pavement lifetime, reduces its permeability to water and air, and its susceptibility to rutting [3]. In addition, the compaction degree and mechanism in the field greatly affects the pavement performance [5]. Several studies tries to use different compaction techniques in the laboratory to simulate the actual field compaction process [4, 5, 6, 7]. Although, superpave techniques for mix design use advanced compaction equipments, Egyptian laboratories still use the traditional Marshall technique, which depend on hammering the specimen to achieve the required mix compaction. This compaction technique is not simulating the actual field compaction. In addition, compaction by hammering may disintegrate the coarse aggregate particles gradation, and consequently, the mix gradation may change to the extent of failing achieve the specification requirements. In the field, compaction is done by rolling large weights over the compacted pavement. This compaction technique is a quasi-static compaction effort. So, the main objective of this study is concerned with the development of a compaction technique simulating the actual field compaction to be used in the Egyptian laboratories. To achieve this objective, a comprehensive experimental program was designed and carried out. The next section explain thoroughly this program.

2. PROPOSED LABORATORY COMPACTION PROCEDURE

A new compaction procedure is proposed in this paper to simulate the actual field compaction process. The traditional laboratory compaction test is performed by hammering the Marshall specimen according to the required specification [10]. Actually, the compaction through hammering cannot ever be performed in the field, where compaction by rolling large weights over the compacted area is done. The rolling weights are quasi-static compaction effort and not a dynamic one as in case of hammering. Therefore, the proposed compaction technique is believed to be more relevant and representative of the actual compaction in the field.

The standard Marshall mould is placed in the Marshall-CBR testing machine. A steel disc having an outer diameter equal to (or slightly less than) the inner diameter of the Marshall mould is placed over the specimen. The CBR plunger is used to press that steel disc over the compressed specimen at the same CBR testing rate (1 mm/min), as shown in Figure (1). Instead of hammering the specimens, as in the traditional procedure, a continuous compaction technique is proposed in which the specimen is subjected to continued pressure at the CBR test rate. The relatively slow compaction rate is very similar to the actual field compaction procedure.

The compaction procedure is performed as follows:

a- The asphalt mix specimen is prepared through the traditional mix procedure containing its common constituents.
b- The prepared specimens are placed in the Marshall mould with the normal dimensions of 4" diameter and 2.5" height.
c- The standard Marshall asphalt concrete mix specimen weighing 1200 gm is then pressed through the CBR-Marshall

testing machine at the specific rate of the CBR test.

d- The pressure application process is continued till assuring that the prepared specimen took the size of the standard Marshall mould.

In this case, it is believed that the obtained specimen would simulate the actual field specimen regarding the compaction process to a great extent.

3. EXPERIMENTAL TESTING PROGRAM

The focus of the current research is to develop a laboratory compaction technique that actually simulates the field compaction process. Knowing that the field compaction is performed by rolling heavy weight, thus compaction through steady compression is thought as a closer simulation technique than the traditional hammering.

Ten mix designs were selected on ten links representing both binder and surface courses. These links were selected from roads constructed by the Egyptian Roads and Bridges Authority (East Delta region). Table (1) presents the selected links and their construction dates as well as mix type (surface course or binder course). The Gradations of the investigated mixes and the Egyptian specifications are presented in Table (2). The mixes numbers 1, 3, 5, 7, 8 and 9 were designed to meet Egyptian specifications of the standard gradation 3D (binder course mixes). On the other hand, mixes with numbers 2, 4, 6 and 10 were designed according standard gradation 4C (surface course mixes).

The coarse aggregate used in all the investigated mixes were accepted according to Egyptian specifications. Results of qualification tests conducted for the coarse aggregates are presented in Table (3). Qualification tests were also conducted for asphalt cement 60/70 used in all mixes. Table (4) shows that the asphalt materials were accepted according to Egyptian specifications.

The testing program were carried out through three phrases:

a- The first phase is concerned with the design of asphalt concrete mixes using the traditional Marshall procedure. In this phase routine mix properties were determined and compared with Egyptian specifications.

b- The second phase is similar to the first one, but differing only in the compaction technique. Compaction procedure used in this phase is a closer simulation of the field compaction, as previously explained.

c- Finally, the third phase is the field one in which 60 field samples were extracted using core cutter apparatus; six samples from each mix compacted in the field and the average value was taken for each property. The core cutter samples were extracted after about 24 hours of the mix spreading and compaction. The specimens are taken according to ASTM D1587-00 [9], to minimize disturbance.

The main purpose of the last phase is to serve as a reference by correlating its results with that of the first two phases to make a decision about the confidence level in the proposed compaction technique.

4. RESULTS AND DISCUSSION

In this section, the results of experimental program will be presented and discussed. Tables (5) through (8) presents the results obtained for different tested mix properties. The tables show results of the three distinct compaction techniques presented as traditional Marshall compaction by hammering, proposed compaction simulation technique, and the actual field compaction by rolling high static weights. The tables also show percentage of the mix property obtained by the laboratory compaction techniques related to the reference field property value. The following subsections discuss the analysis of different mix properties and their relations with the applied compaction techniques.

4.1 Analysis of Unit Weight Results

The field collected samples are used to obtain the asphalt mix unit weight according to ASTM D2937-04 [11]. Table (5) presented the results of unit weights obtained from the two laboratory techniques; traditional Marshall (γ_M), and the compaction simulation (γ_s), as well as that obtained from the field and denoted by γ_f. Table (5) shows ratios of unit weights obtained by the traditional Marshall technique with the field unit weights (γ_M/γ_f). Somewhat large differences are noticed in this case with the unit weights ratio ranged from 101.53% up to 106.95%. On the other hand, great coincidence is noticed between the values obtained by the proposed compaction technique and those field values, ranging from 99.86% to 100.17%. It is also noted that the average γ_M/γ_f was 103.80 and γ_s/γ_f was 100.02, (with standard deviation of 2.22 and 0.11 for the two ratios respectively). The statistical results assured that the proposed compaction technique matches to the maximum extent the actual field compaction process.

Figure (2) represents the relation between field density (γ_f) and Marshall unit weight (γ_M). It is shown from the figure that the correlation coefficient (R^2) between the two parameters is 0.667, compared with $R^2 = 0.999$ which is the correlation coefficient between field unit weight (γ_f) and simulated one (γ_s), as shown in Figure (3). These results certify that the field unit weight has higher correlation with the simulated unit weight, and lower one with the Marshall compaction technique.

4.2 Analysis of Stability Results

The effect of the compaction technique on the asphalt mix stability is shown in Table (6). Based on the tabulated stability values, it can be noted that the compaction technique greatly affects the stability values. However, the mixes compacted using traditional Marshall compaction technique (hammering) has higher stability values than those compacted by the simulated technique (quasi-static) and field samples. This result indicated that the stability values are usually over-estimated when compacting by hammering, but in reality the actual (field) values are usually lower. The obtained values ranged from 102.51% up to 122.84%. One more time, the proposed compaction technique gave closer results of the stability numbers giving values ranging from 99.45% to 101.23% only. However, the mean value for $Stab_M/Stab_f$ was 113.84% and the mean value for $Stab_s/Stab_f$ was only 100.27%. Moreover, the standard deviation was 6.70 and 0.69 for the results of the two techniques respectively.

Profound analysis of stability data shows that, Marshall stability has higher values than that of simulated and field values by about 270 lbs in the average. This means that, the field stability values are decreased by about 14% in the average than that of Marshall values. This in turn means that the design is performed on high stability values, while in the field these values are never reached leading to premature failure of asphalt pavements. In addition, two mixes namely 1 and 8, as presented in Table (6), are in reality out of specifications giving acceptable stability values using traditional Marshall technique. Therefore, the lower limit of the accepted stability values as obtained from traditional Marshall technique should be elevated to reach 2070 lbs instead of 1800 lb [12] to assure successful field stability values.

Figure (4) shows the relation between field stability and Marshall stability with correlation coefficient, $R^2 = 0.77$. Figure (5) illustrates the relation of field stability versus simulated stability was $R^2 = 0.99$.

4.3 Analysis of Air Voids Results

Table (7) shows the results of the air voids for the different tested specimens compacted using the different compaction techniques for the binder and surface courses. These mixes are classified into two groups, the first group is concerned with binder course mixes (No. 1, 3, 5, 7, 8 and 9). The second group is related to surface course mixes (No. 2, 4, 6 and 10). Based on the data illustrated in the table it can be noticed that, the traditional compaction procedure involved in Marshall test achieve lower air voids than that of obtained by both the simulated compaction technique and the actual field compaction. The voids ratio in this case $A.V_M/A.V_f$ ranged from 76.74% up to 92.11% indicating larger field voids than that of the traditional Marshall technique (with mean value of 82.98% and standard deviation of 5.04). This is mainly due to a simple fact, compaction by hammering gave slightly higher unit weight, but noticeably lower voids ratio. However, the ratio of $A.V_s/A.V_f$ ranged from 96.08% up to 105.26% indicating closer representation of the proposed compaction technique to the actual field compaction technique. Moreover, the mean value was 99.35% and the standard deviation was 2.99.

Increasing the air voids content in either the binder or surface courses may lead to aging or oxidation and consequently decreasing flexibility that result in raveling. In addition, increasing the air voids may cause penetration of water in the underneath courses which may cause swelling and in turn pavement cracking. This situation can be obviously noticed in mix number 2 in which the field air voids is 5.2%, exceeding the upper limit of 5% for surface course layer [12], despite giving an acceptable value of 4.2% from traditional Marshall technique. Based on air voids analysis it can be concluded that the simulated compaction technique has higher correlation with the field air voids than Marshall technique. Therefore, the simulated compaction technique can be considered representative and realistic than Marshall technique. It is worth mentioning that the average value of field air voids are greater than that of common Marshall method and simulated technique by 0.774 and 0.04 respectively. Based on this result, it can be suggested that the specifications must limit the acceptable air voids percent up to 7.2% and 4.2% for binder and surface course layers respectively, instead of the currently used values of 8.0% and 5.0% [12] when using traditional Marshall technique.

Figure (6) shows the relation between air voids in the field and the corresponding design values obtained by Marshall test. The correlation coefficient for this relation is $R^2 = 0.82$ compared with $R^2 = 0.97$ which is the correlation coefficient for the relation between field and simulated air voids, as shown in Figure (7).

4.4 Analysis of Flow Results

The flow values presented in Table (8) shows that, both the simulated and field techniques gave higher mix flow values than those obtained using Marshall technique. Although all the flow values are within the acceptable range, the values obtained by the simulated technique are pronouncedly closer to the field values. The ratio of $M.F_M/M.F_f$ is ranging from 86.61% up to 99.21% with an average value of 93.70% and standard deviation of 3.95. On the other hand, the ratio of $M.F_s/M.F_f$ is ranging from 98.15% up to 101.89% with an average value of 100.17% and standard deviation of 1.12. Observation of the results showed very close representation of the simulated technique to the field compaction.

The correlation coefficient $R^2 = 0.87$ for the relation between field and Marshall flow values is shown in Figure (8), whereas $R^2 = 0.99$ for field and simulated flow values as illustrated in Figure (9). The higher flow values decrease the pavement capability to sustain traffic loads and environmental conditions.

5. CONCLUSIONS

Referring to the analysis of the study results, the following conclusions can be obtained:

1- The unit weights of the specimens compacted using the proposed compaction simulation technique are almost identical with those values obtained from the field, with almost perfect correlation ($R^2 = 0.999$). Although higher unit weights are obtained when using the traditional Marshall compaction technique but the judgment in this case should be based on the actual field values, with low correlation coefficient equals 0.667.

2- Lower stability values are obtained using the simulated technique compared to those of the traditional Marshall procedure. However, field stability values are approximately the same as those of the simulated compaction technique with high correlation coefficient ($R^2 = 0.99$). On the other hand, lower correlation was found between field and Marshall stability values ($R^2 = 0.77$).

3- Marshall stability has an average of about 270 lbs higher than that of the proposed compaction simulation technique and field samples. This may explain the premature failure of some asphalt pavements.

4- Air voids obtained from both field and proposed technique samples are higher than that obtained with common Marshall test. A strong correlation is found between field and simulated air voids values with ($R^2 = 0.97$) compared by the correlation between field and Marshall values with ($R^2 = 0.83$).

5- The average air void values in the field are greater than that of the common Marshall test procedure and simulated procedure by about 0.8% and 0.04% respectively.

6- The compaction simulation technique has approximately the same flow values obtained from field samples ($R^2 = 0.99$), whereas the common Marshall test achieved lower and different flow values when compared with field values ($R^2 = 0.87$).

7- Despite giving better properties in all cases, compaction using the traditional Marshall technique could not ever be achieved in the field. Therefore, the proposed laboratory compaction simulation technique is much more relevant to the actual field compaction process.

6. RECOMMENDATIONS

Based the study analysis and conclusion the following can be presented:

1- It is recommended to use the proposed compaction simulation technique for asphalt concrete mix compaction instead of common hammering technique when designing asphalt mixes using Marshall procedure .

2- If the traditional Marshall compaction technique is used in the asphalt mix compaction, the accepted values of mix stability should not less than 2070 lbs to ensure best pavement performance in the field.

3- When using the traditional Marshall technique for asphalt mix compaction the permitted air voids percent must not be more than 7.2% for binder and 4.2% for surface courses respectively.

4- A Comprehensive experimental testing program is recommended to study the effect of the proposed compaction simulation technique on the asphalt mix properties under several mix conditions, testing procedures, and larger number of mixes.

5- Advanced testing equipments including new compaction techniques must be introduced in Egyptian laboratories to increase the reliability of the testing and consequently design procedures.

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Table (1): Links of the Investigated Mixes.

Mix No	Mix type	Link Name	Construction Date
1	Binder course	Belbeis – 10th of Ramdan	4/2003
2	Surface course	El-Abassa – Ezbet Bata	3/2005
3	Binder course	El Sinbelaween – Abu-Kapeer- Abu-El-Shokok	1/2006
4	Surface course	El-Sinbelaween – Abukpeer- Abu-El-Shokok	1/2006
5	Binder course	Zagazig Streets	3/2006
6	Surface course	Zagazig Streets	3/2006
7	Binder course	Domiate- Ras El-Barr	1/2007
8	Binder course	Zagazig – 10th of Ramadan	3/2007
9	Binder course	Ismailia – Port Said	7/2007
10	Surface course	Dekernes – El-Mansoura	12/2007

Table (2): Gradations of the Investigated Mixes.

Sieve Size	Mix No										Specification limits	
	1	2	3	4	5	6	7	8	9	10	3D	4C
1"	100	100	100	100	100	100	100	100	100	100	100	100
3/4"	97.62	96.7	99.6	99.8	96.72	98	93.1	90.7	97.9	93.9	75-100	80-00
1/2"	72.71	87.55	78.83	89.16	76.22	85.5	72.82	73.15	76.92	80.3	-	-
3/8"	47.53	73.78	59.84	77.88	65.8	78.12	63.25	60.85	65.6	71.4	45-70	60-80
N0.4	31.01	49.19	34.21	49.	35.03	49.2	36.16	32.72	31.05	48.4	30-50	48-65
N0.8	23.01	38.22	26.28	39.9	26.99	40.67	23.8	25.8	25.41	42.2	20-35	35-50
N0.30	18.97	26.14	18.24	29.33	17.97	28.89	17.35	18.7	18.3	30.1	5-20	19-30
N0.50	7.67	13.71	9.46	17.29	8.91	16.68	9.74	10.11	7.89	17.1	3-12	13-23
N0.100	2.72	7.55	3.03	8.38	3.07	9.59	3.15	3.21	2.85	8.9	2-8	7-15
N0.200	1.35	6.81	1.15	5.34	2.53	6.55	0.59	1.02	1.946	5.5	0-4	3-8

Table (3): properties of Coarse Aggregate.

Test NO	Test	Designation	1		2		3		4		5		6		7		8		9		10		Specif. Limits
			B.1	B.2	B.1	B.2	B.1	B.2	B.1	B.2	B.1	B.2	B.1	B.2	B.1	B.2	B.1	B.2	B.1	B.2	B.1	B.2	
1	Specific gravity - Bulk	AASHTO T-85	2.452	2.448	2.386	2.394	2.397	2.340	2.397	2.340	2.386	2.394	2.386	2.394	2.386	2.394	2.593	2.472	2.452	2.448	2.386	2.404	-
	- Saturated surface dry	AASHTO T-85	2.508	2.505	2.470	2.80	2.483	2.436	2.483	2.436	2.470	2.80	2.47	2.80	2.47	2.80	2.662	2.546	2.508	2.505	2.467	2.470	-
	- Apparent	AASHTO T-85	2.596	2.597	2.604	2.619	2.572	2.587	2.572	2.587	2.604	2.619	2.604	2.619	2.604	2.619	2.786	2.670	2.596	2.597	2.594	2.574	-
2	Water absorption (%)	AASHTO T-85	3.4	3.7	3.8	4.3	3.6	4.1	3.6	4.1	3.5	3.6	3.5	3.6	3.2	3.3	2.7	3	2.3	2.5	3.5	2.8	≤ 5
3	Los Angles abrasion,500 Revolutions (%)	AASHTO T-96	7	8	8	8	7	7	7	7	7	7	7	7	6	5	4	5	6	6	8	7	≤ 40
4	Stripping (%)	AASHTO T-182	> 95																				> 95

Table (4): Properties of Asphalt Cement.

Test No.	Test	Designation	Result for Mix No.										Specif. limits
			1	2	3	4	5	6	7	8	9	10	
1	Penetration (0.1 mm, 25°C, 100 gm, 5 sec.)	AAHTO T-49	68	67	69	69	67	76	67	69	67	68	60-70
2	Kinematic viscosity (centistokes, 135 °C)	AAHTO T-201	255	381	420	420	398	398	288	398	372	360	≥ 320
3	Flash point (°C)	AAHTO T-48	260	266	267	267	268	268	267	267	256		≥ 250
4	Softening point ring and Ball test (°C)	AAHTO T-53	47	53	52	52	53	53	53	53	51	.	45-55

Table (5): Results of Unit Weights Using the Different Traditional and Proposed Compaction Techniques Compared with the Field Results.

Mix No.	AC, (%)	Unit Weight (t/m^3)			γ_M/γ_f (%)	γ_s/γ_f (%)
		γ_M	γ_s	γ_f		
1	5.15	2.250	2.210	2.213	101.67	99.86
2	5.50	2.290	2.151	2.149	106.56	100.09
3	5.00	2.247	2.100	2.101	106.95	99.95
4	5.40	2.334	2.300	2.298	101.57	100.09
5	5.00	2.275	2.151	2.150	105.81	100.05
6	5.35	2.307	2.178	2.179	105.87	99.95
7	5.00	2.340	2.272	2.270	103.08	100.09
8	4.95	2.339	2.282	2.280	102.59	100.09
9	5.03	2.311	2.254	2.257	102.39	99.87
10	5.23	2.328	2.297	2.293	101.53	100.17

Notes: M: Marshall, s: Simulated, and f: Field compaction techniques.

Table (6): Results of Stability Using the Different Traditional and Proposed Compaction Techniques Compared with the Field Results.

Mix No.	Stability (lb)			$Stab_M/Stab_f$ (%)	$Stab_s/Stab_f$ (%)
	$Stab_M$	$Stab_s$	$Stab_f$		
1	1840	1690	1680	109.52	100.60
2	2150	1940	1930	111.40	100.52
3	2200	1910	1920	114.58	99.48
4	2450	2380	2390	102.51	99.58
5	2320	2180	2160	107.41	100.93
6	2540	2320	2300	110.43	100.87
7	2190	1810	1820	120.33	99.45
8	1990	1640	1620	122.84	101.23
9	2560	2100	2110	121.33	99.53
10	2350	2000	1990	118.09	100.50

Table (7): Results of Air Voids Using the Different Traditional and Proposed Compaction Techniques Compared with the Field Results.

Mix No.	Air Voids (%)			$A.V_M/A.V_f$ (%)	$A.V_s/A.V_f$ (%)
	$A.V_M$	$A.V_s$	$A.V_f$		
1	4.20	4.90	5.00	84.00	98.00
2	4.20	5.10	5.20	80.77	98.08
3	4.30	4.90	5.10	84.31	96.08
4	3.11	3.60	3.50	88.86	102.86
5	4.00	5.00	5.10	78.43	98.04
6	3.50	4.00	3.80	92.11	105.26
7	3.80	4.50	4.40	86.36	102.27
8	3.60	4.40	4.50	80.00	97.78
9	3.05	3.80	3.90	78.21	97.44
10	3.30	4.20	4.30	76.74	97.67

Table (8): Results of Mix Flow Using the Different Traditional and Proposed Compaction Techniques Compared with the Field Results.

Mix No.	Mix Flow (0.01")			$M.F_M/M.F_f$ (%)	$M.F_s/M.F_f$ (%)
	$M.F_M$	$M.F_s$	$M.F_f$		
1	9.40	9.80	9.90	94.95	98.99
2	12.70	13.40	13.4	94.78	100.00
3	11.90	12.80	12.90	92.25	99.22
4	10.20	10.60	10.80	94.44	98.15
5	11.40	11.80	11.70	97.44	100.85
6	10.40	11.50	11.50	90.43	100.00
7	10.70	11.10	11.00	97.27	100.91
8	9.70	11.30	11.20	86.61	100.89
9	12.60	12.80	12.70	99.21	100.79
10	9.50	10.80	10.60	89.62	101.89

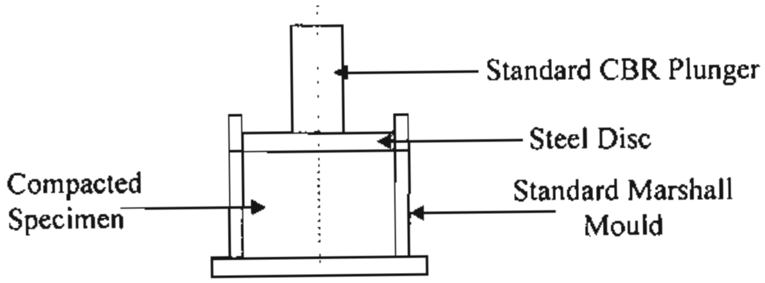

Figure (1): Schematic Presentation of the Proposed Marshall Compaction Technique.

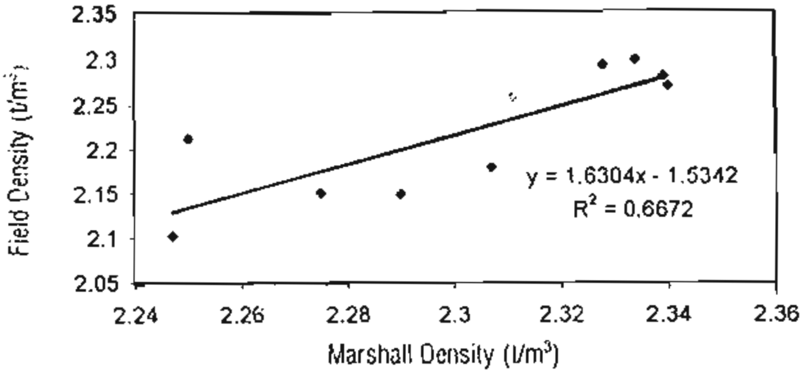

Figure (2): Relation between Field Density and Marshall Density

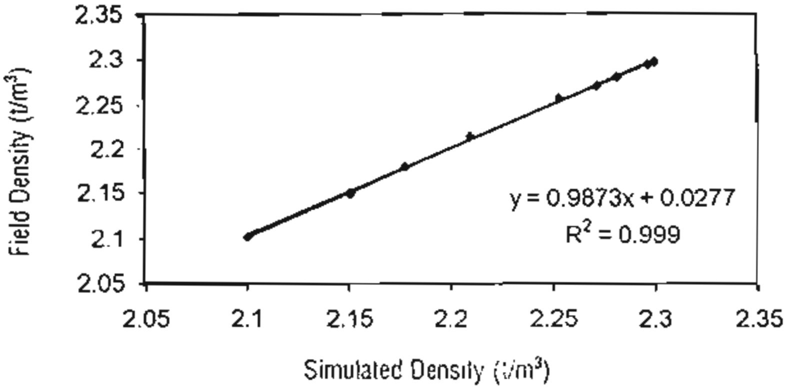

Figure (3): Relation between Field Density and Simulated Density

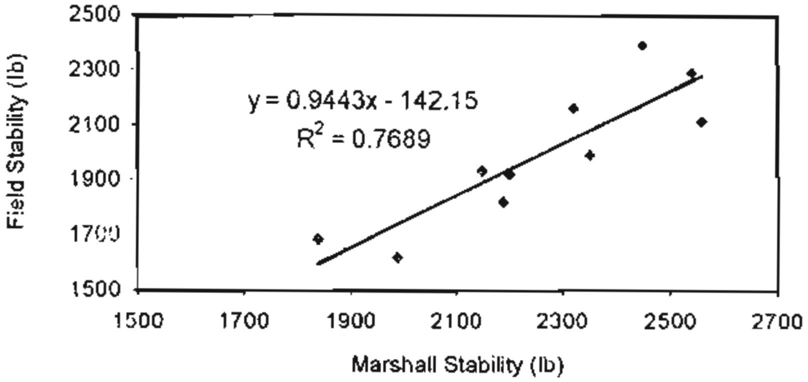

Figure (4): Relation between Field Stability and Marshall Stability

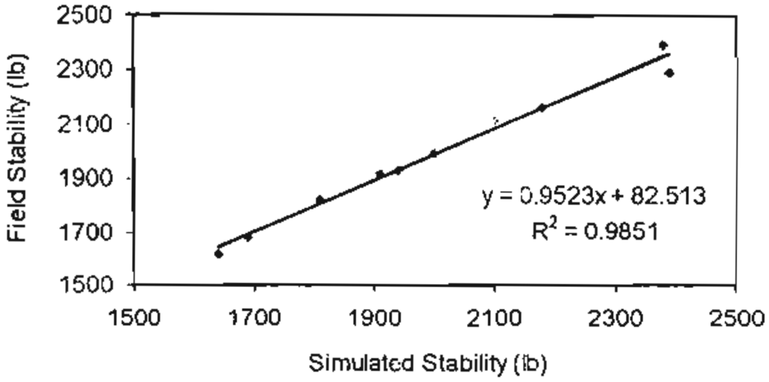

Figure (5): Relation between Field Stability and Simulated Stability

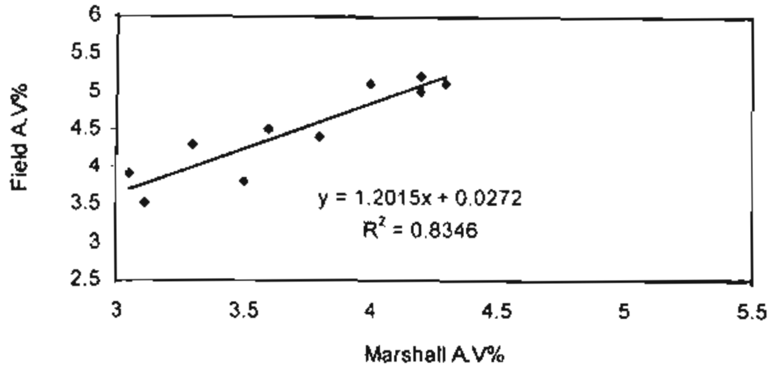

Figure (6): Relation between Field Air Voids and Marshall Air Voids

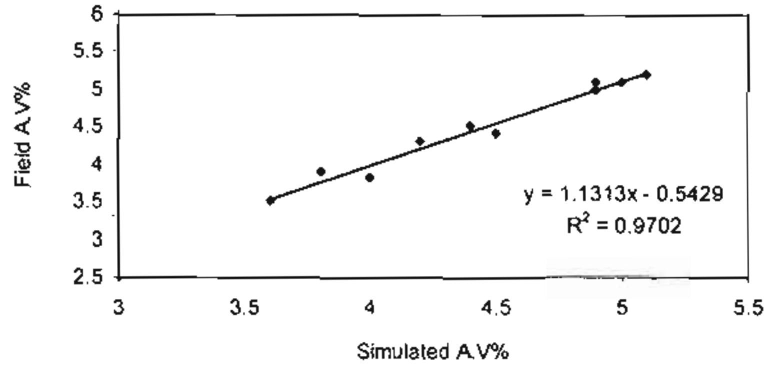

Figure (7): Relation between Field Air Voids and Simulated Air Voids

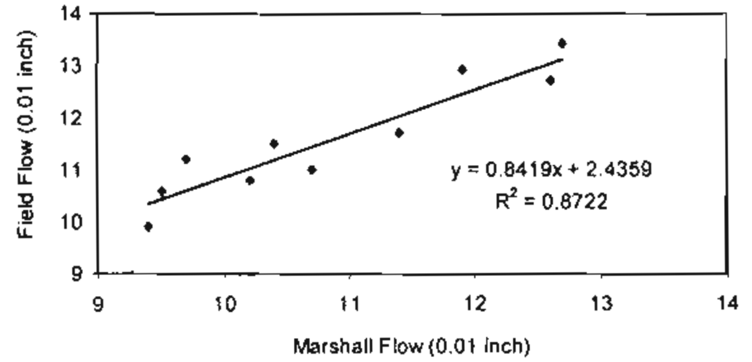

Figure (8): Relation between Field Flow and Marshall Flow

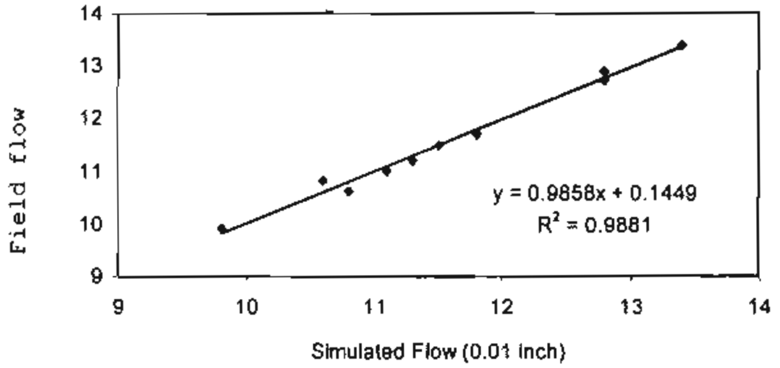

Figure (9): Relation between Field Flow and Simulated Flow