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Laboratory Investigation of the Pavement Condition in Lebanon: Implementation of Reclaimed Asphalt Pavement in the Base Course and Asphalt Layer

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***Abstract*—**The road network in the north of Lebanon is a prime example of the lack of pavement design and execution in Lebanon. These roads show major distresses and hence, should be tested and evaluated. The aim of this research is to investigate and determine the deficiencies in road surface design in Lebanon, and to propose an environmentally friendly asphalt mix design. This paper consists of several parts: (i) evaluating pavement performance and structural behavior, (ii) identifying the distresses using visual examination followed by laboratory tests, (iii) deciding the optimal solution where rehabilitation or reconstruction is required and finally, (iv) identifying a sustainable method, which uses recycled material in the proposed mix. The asphalt formula contains Reclaimed Asphalt Pavement (RAP) in the base course layer and in the asphalt layer. Visual inspection of the roads in Tripoli shows that these roads face a high level of distress severity. Consequently, the pavement should be reconstructed rather than simply rehabilitated. Coring was done to determine the pavement layer thickness. The results were compared to the American Association of State Highway and Transportation Officials (AASHTO) design methodology and showed that the existing asphalt thickness is lower than the required asphalt thickness. Prior to the pavement reconstruction, the road materials were tested according to the American Society for Testing and Materials (ASTM) specification to identify whether the materials are suitable. Accordingly, the ASTM tests that were performed on the base course are Sieve analysis, Atterberg limits, modified proctor, Los Angeles, and California Bearing Ratio (CBR) tests. Results show a CBR value higher than 70%. Hence, these aggregates could be used as a base course layer. The asphalt layer was also tested and the results of the Marshall flow and stability tests meet the ASTM specifications. In the last section, an environmentally friendly mix was proposed. An optimal RAP percentage of 30%, which produced a well graded base course and asphalt mix, was determined through a series of trials.

***Keywords*—**Asphalt mix, reclaimed asphalt pavement, California bearing ratio, sustainability.

I. Introduction

PAVEMENT evaluation is a procedure filled with standardized tests and visual inspection. Evaluating the existing pavement conditions is required to guarantee a feasible maintenance and rehabilitation. Pavement evaluation requires the determination of pavement distress. Some manuals use the visual inspection [1], while others use the Pavement Condition Index (PCI) [2].

The dynamic modulus is directly related to the structural capacity of the pavement and it affects the pavement weakening and deterioration. A comparison between field and laboratory testing conducted on a newly built highway (riksväg 40) close to the town of Ulricehamn, Sweden shows little discrepancies in the dynamic modulus (between 0.5% and 6.4%), showing high potential for faster quality assurance and quality control (QA/QC) in the future where non-contact field measurements could be used [3].

Lebanon is one of the countries having limited funds devoted to pavement rehabilitation. Therefore, a management system could be better and more efficient than a simple maintenance. Because the pavement management system determines the appropriate rehabilitation and maintenance techniques, it indicates also the appropriate time for the maintenance by predicting future pavement behavior. Therefore, this system helps in determining the maintenance priority for each section [4].

After identifying the distress and determining its severity, a pavement reconstruction or rehabilitation will be performed. The overlay thickness is affected by the condition of the existing pavement. Therefore, while designing an asphalt overlay, the design procedure is similar to designing a new pavement except that the remaining life of the existing pavement is taken into consideration in this case [5]. The existence of distress decreases the structural capacity of the asphalt layer and hence a thicker overlay is needed. The popular methods and formulas used to determine the overlay thickness do not take into consideration the condition of the existing asphalt layer. Therefore, an asphalt thickness correction factor (f_{ac}), function of the ratio of the area affected by the selected distresses to the area affected by all distresses, was introduced to enhance the accuracy of the overlay thickness calculation [6].

Many methods could be used to calculate the overlay thickness:

- The overlay thickness could be determined by using the Benkelman beam deflection measurements and graphs from the Asphalt Institute method,
- The overlay thickness is assumed to be the difference between the existing asphalt thickness and the effective thickness determined if a new pavement was constructed [7].
- The overlay thickness is estimated using the difference between the Structural Number (SN) required to support

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overlay traffic and the SN of the existing pavement before the application of an overlay [8].

In Lebanon, the method used for determining the overlay thickness is based on the engineering judgment and experience.

In the pavement rehabilitation, milling of the existing pavement is required, this results in an excess of asphalt, called RAP.

Evaluating the suitability of the RAP as a sub-base or base course material in the flexible pavement, shows that RAP, when mixed with crushed stone aggregates (CSA) and stabilized with a small percentage of cement, is suitable for using it as sub base or as a base for flexible pavement [9].

Noferini et al. tested the interaction between virgin and RAP bitumen. Asphalt mixes were provided including different percentages of RAP (10%, 20% and 30%) added to a common asphalt concrete which was used as the reference mix [10]. Results from the laboratory tests proved that the impacts of the RAP bitumen on the final combination varied proportionally to the RAP content: Using up to 10% of RAP in the mix, RAP can be added without the obligation to make any further laboratory tests on the recovered binder. Above 20% RAP content, it is extremely advised to conduct laboratory investigations on the recovered binder similar to the method done in the study of [10]. Therefore, in this research the efficiency of using 20% of RAP in the base course material is tested.

II. Methodology

The analysis of the current state of the roads in Tripoli, North of Lebanon is performed using visual inspection and laboratory testing of the asphalt and the underlying layers.

The results of test pits obtained from Advanced Construction Technology Services (ACTS) Laboratory are used to compare the existing thickness to the thickness calculated using the AASHTO design methodology. Then, the base course aggregates and the asphalt layer are tested. At the end, the efficiency of mixing the base course aggregates or the asphalt layer with RAP is tested and analyzed.

III. Site Inspection

Figs. 1 (a)-(f) illustrate the state of the road network situated in Tripoli. The distresses identified on asphalt concrete-surfaced pavements (ACP), and according to [1] are summarized in Table I. The high severity level of distresses shown in these photos, indicates that the pavement should be reconstructed rather than being simply rehabilitated using an asphalt overlay. Therefore, the new material that will be used to reconstruct the pavement layers should be tested.

IV. Test Pit Results of The Roads in Tripoli

Coring was done by ACTS laboratory to determine the pavement layer thickness. The results were compared to the AASHTO design methodology, and showed that the existing asphalt thickness is lower than the required asphalt thickness. Coring results of the soil tests are presented in Tables II, III and Fig. 2.

Fig. 1 Distress identified from Tripoli's roads (a. transverse crack, b. raveling (loss of coarse aggregates), c. potholes, d. bleeding and rutting, e. raveling and bleeding, f. fatigue/alligator cracks)

TABLE I
Distress Identification Using Visual Inspection

Distress	Severity
Transverse Cracks	High
Raveling	Not applicable
Potholes	High
Rutting	Not applicable
Alligator Cracks (fatigue)	High
Bleeding	Not applicable

TABLE II
Asphalt Layer Thickness for ''Sabsabie" Road

Location	Abou Samra Sabsabie Phase II			
Core Ref.	1	2	3	4
Layer	1	1	-	1
Thickness 1 (mm)	91	99.55	109.25	94.1
Thickness 2 (mm)	91.8	104.37	114.37	90.5
Thickness 3 (mm)	90.8	105.52	116.83	96.1
Thickness 4 (mm)	97.1	101.47	116.53	97
Average Thickness (mm)	92.7	102.73	114.2	94.4
Average (mm)	**101**			

Table II summarizes the asphalt thickness for the "Sabsabie" road [11]. Fig. 2 represents the results of the test pit survey pertaining to "Nejmeh" road. The different layers identified from this test are:

- First asphalt layer with a thickness of 6 cm. This layer contains stones with a maximum gradient of 19 mm
- Second asphalt layer with a thickness of 7 cm. This layer contains stones with a maximum grade of 12.5mm.
- Base-course layer with a thickness of 10 cm.

- A layer of black basalt stone with a thickness of 15cm.
- Natural soil layer (dust, sand, rubble).

Table III shows a comparison between the layer thickness of the newly constructed roads in Tripoli and the minimum thickness as per AASHTO requirements.

The results summarized in Table III clearly indicate that the thickness of the soil layers in Tripoli roads is lower than the ones calculated using AASHTO design methodology. This could be a possible reason for the poor conditions of Tripoli's roads.

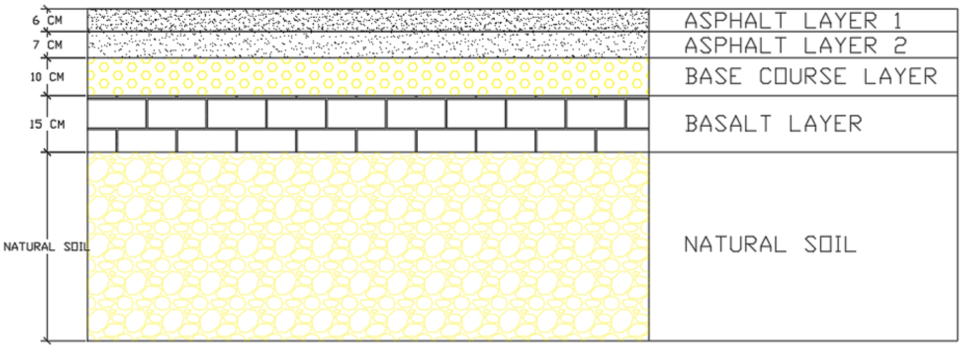

Fig. 2 Results of the test pit survey obtained for "Nejmeh" Road

TABLE III
COMPARISON OF THICKNESSES OF LAYERS IN SITU WITH THOSE OBTAINED BY THEORETICAL STUDY (AASHTO DESIGN METHOD) FOR DIFFERENT NEW CONSTRUCTED FLEXIBLE PAVEMENTS IN TRIPOLI

Road's Name	Thicknesses as executed in Reality			Thicknesses determined with AASHTO design method		
	Subgrade (embankment)(cm)	*Base course layer (cm)*	*Asphalt layer (cm)*	*Subbase (cm)*	*Base course layer (cm)*	*Asphalt layer (cm)*
Ibn Sina- Al Qobbah	50	30	8.1	30	11	12
Sabsabie 1-Abou Samra	200	30	10	30	11	12
Sabsabie 2-Abou Samra	70	30	10	30	11	12
Sabsabie 3-Abou Samra	50	30	10	30	11	12
Fatimah – Abou Samra	50	30	10.5	30	11	12
Nejmeh	40	30	9.8	30	11	12
Al Amal	150	30	9.9	30	11	12
Bostani – Al Qobbah	70	30	8.3	30	11	12

V. LABORATORY TESTING

Due to the high level of distress severity and the results of the test pits, the pavement should be reconstructed. Therefore, base course aggregates and asphalt layer are tested and test results are summarized in this section.

A. Base Course Aggregate Characteristics

A sieve analysis is performed in accordance with [12]-[14] to determine the characteristics of each soil layer. Results of the sieve analysis show a well graded material, and the gradation curves of the sample with the ASTM specification limits are illustrated in Fig. 3.

Tests to determine the Atterberg limits are done in accordance with the Standard Test Method for determining Liquidity Limit (LL), Plasticity Limit (PL), and Plasticity Index (PI) of soils specified by [15]. The Liquidity Limit is 16% as presented in Fig. 4. The PL test shows a non-plastic material, therefore, according to AASHTO soil classification table, this soil is Class A.1.a (Stone Fragments Gravel and Sand). So, this soil type could be used as base sub-base or subgrade after compaction.

The Los Angeles (LA) Abrasion test is carried out in accordance with [16]. LA value is lower than 50% as shown in Table IV which indicates a good soil.

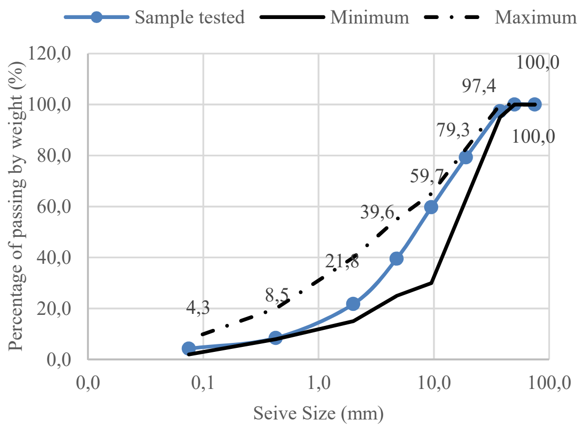

Fig. 3 Percentage of passing by Weight of the sample compared with requirement limits of the ASTM Standards

The compaction characteristics and the maximum dry density are determined by performing Modified Proctor test using the Standard test methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (2,700 KN-m/m^3) as specified by [17]. Results shown in Fig. 5 indicate a maximum dry density of 2.2 and an optimum moisture content of 8.2%.

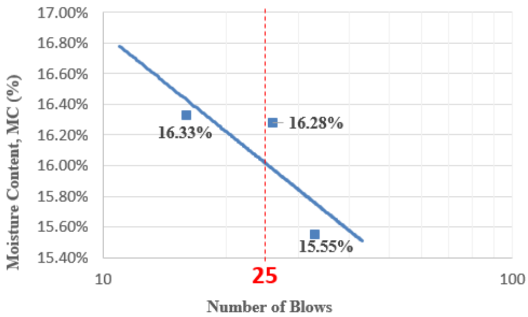

Fig. 4 Moisture Content vs. Number of Blows

A CBR test is performed to determine the sample penetration resistance using the Standard test method for CBR -Laboratory- Compacted Soils as specified by [18]. Fig. 6 illustrates the variation of the penetration resistance with respect to the penetration rate of the base course aggregates sample. The CBR value is 72%, which is higher than 70%. Therefore, this material can be used as base course when well compacted (compaction rate on field > 98%). By performing these tests, it can be concluded that the base course aggregate sample at hand material can be used as base course material.

TABLE IV
LOS ANGELES ABRASION TEST RESULTS

Number of spheres	12
Original dry sample weight (g)	5000
Weight after test retained on sieve #12 (g)	3680
LA Abrasion Value	26.40%

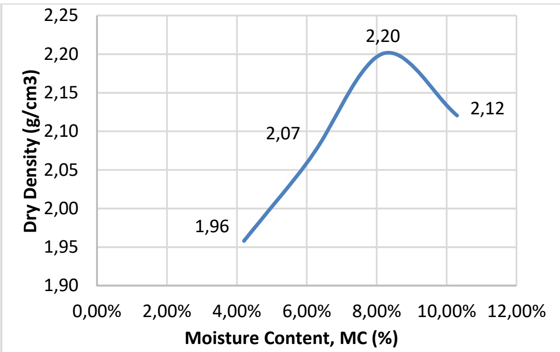

Fig. 5 Modified Proctor test results

B. Asphalt Mix Testing

An extraction test was carried out to determine the bitumen content then following this test; the oven-dried sample is sieved. Table V summarizes the bitumen extraction test results and indicates that the bitumen percentage by weight present in the asphalt sample is 4.4%. Table VI shows the gradation of the aggregates present in this asphalt sample and compares this gradation to the specification of [14]. The sieve analysis shows that the aggregates gradation meets ASTM specification.

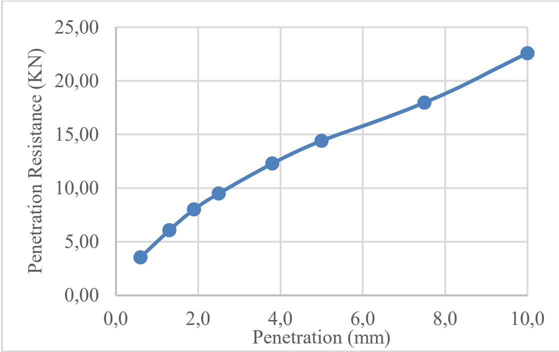

Fig. 6 Penetration Resistance vs. Penetration Rate during CBR Test

A Marshall stability and flow test of bituminous mixtures is executed in accordance with [19] to determine the stability and the flow of the bituminous layer. The results of this test show that the average corrected stability obtained is 1092 Kg and the average flow is 3 mm. These results meet the specifications.

TABLE V
BITUMEN EXTRACTION TEST RESULTS

Weight of Sample Before Test (g)	820.8
Weight of Sample After Test (g)	782.1
Weight of Filter Paper Before Test (g)	17.8
Weight of Filter Paper After Test (g)	20
Increase in Weight of Filter Paper (g)	2.2
Weight of Total Mineral Aggregates (g)	784.3
Weight of Bitumen in Sample (g)	36.5
Bitumen By Weight of Mix (%)	**4.4**

TABLE VI
SIEVE ANALYSIS RESULTS

Sieve Size	**Weight Retained (g)**	**Cumulative Weight Passing (g)**	**% Passing**	**Specification % Passing * Min.**	**Max.**
1 1/2" / 37.5mm					
1" / 25.4mm	0	784.3	100	100	100
3/4" / 19mm	0	784.3	100	90	100
1/2" / 12.7mm	78	706.3	90.1		
3/8" / 9.5mm	90	616.3	78.6	56	80
No. 4 / 4.75mm	193	423.3	54	35	65
No. 8 / 2.36mm	179	244.3	31.1	23	49
No. 50/0.30mm	181	63.3	8.1	5	19
No. 200/0.075mm	25	38.3	4.9	2	8
Pan	2				

* Specification Mix Designation "D4" according to [14]

VI. IMPLEMENTATION OF THE RAP IN THE DESIGN

A. Implementation of the RAP in the Base Course Layer

The performed mix is formed by using 20% of RAP and 80% of base course (BC). The value of 20% of RAP is chosen in accordance with the values obtained by [9] and [10]. The gradation curves visualized in Fig. 7 show that the gradation curves of the new mix fits the ASTM requirements.

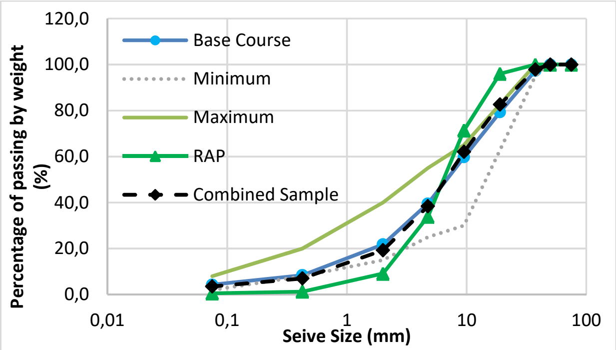

Fig. 7 Combined Sample according to the gradation specifications

CBR test at 100% compaction rate is done. Results of this test are illustrated in Table VII. These results show a CBR value of 67% close to 70% but not higher than the specifications (70%).

TABLE VII
CBR TEST RESULTS FOR THE COMBINED SAMPLE

Penetration mm	Penetration inch	Load kN	Load PSI	Corrected Load PSI	% CBR
0.0	**0.0**		**0.0**		
0.6	0.025	1.08	81		
1.3	0.050	2.56	192		
1.9	0.075	4.42	331		
2.5	0.100	6.45	483	600	**60.0**
3.8	0.150	9.73	729		
5.0	0.200	12.43	931	1000	**66.7**
7.5	0.300	16.11	1207		
10.0	0.400	20.15	1510		
CBR result after 4 days of soaking					**66.7**

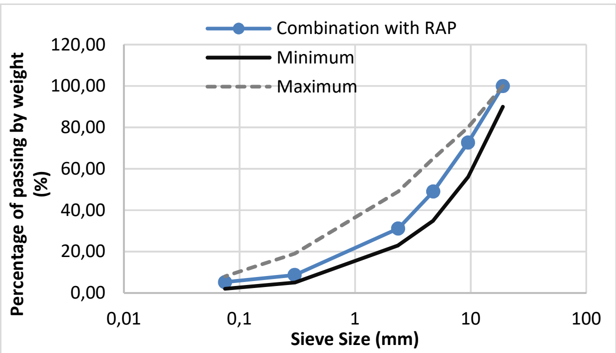

Fig. 8 New Asphalt Formula (Aggregates+30% RAP) Sieve results

B. Implementation of the RAP in the Asphalt Layer

Calculation of the optimum percentage needed to obtain a well graded mix shows that the proposed asphalt mix formula contains 25% coarse aggregates, 20% medium aggregates, 25% fine aggregates and 30% RAP. Fig. 8 indicates that the gradation curve of this asphalt formula mixed with RAP fits the specification requirements.

The most expensive element in the pavement design is the bitumen. By using a recycled material "RAP", the amount of bitumen to be added will decrease since the RAP contains bitumen. Calculations have shown a total decrease of 1.1 % of bitumen by mass which leads to a cost decrease.

To prove the calculation done in this paper, laboratory tests and trials should be carried out on samples containing different bitumen and RAP percentage.

VII. CONCLUSION

The road network in the North of Lebanon shows major distresses. The high severity level of distresses and coring test results indicate that the pavement should be reconstructed rather than being simply rehabilitated using an asphalt overlay. Therefore, an innovative sustainable material that will be used while reconstructing the pavement layers was tested.

Test results of the base course sample mixed with RAP indicate that this material is suitable to be used as a base course material. Testing the asphalt sample shows that the specification of the sample is in convergence with the specifications.

Further researches should be done to implement the use of an environmentally friendly asphalt formula along with a cost saving calculation to check the efficiency of the proposed asphalt formula.

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