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Original Research

Evaluation of structural properties of Baghdad-Baquba road pavements

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ABSTRACT

Structural evaluation of the road pavements is an essential concept to ensure their efficiency to carry traffic loads and to archive the data for future usage especially in major highways. Baghdad-Baquba is an important interstate highway as it connects the capital of Iraq with Diyala governorate which is one of the biggest governorates in Iraq. In addition, this highway connects Baghdad city with several governorates in the north of Iraq. However, this highway exhibits low serviceability due to poor condition of its pavements. Therefore, the structure of the pavements must be evaluated to specify the causes those lead to the decrease in its serviceability and to propose the suitable rehabilitation methods. This study aims to adopt a field survey to extract a number of samples from selected section in this highway to evaluate the structural properties of the pavements based on laboratory testing. Four cores and one pit with 1×1 m dimensions were extracted from the pavements in the field. Several tests were implemented on these tests based on standard methods. The results of the tests were adopted to evaluate the capacity of the pavement based on AASHTO 1993 method. The results exhibited that the estimated applied traffic load exceeded the calculated allowable traffic load by more than 12 times which reflect the disastrous situation. Therefore, the study proposed to rehabilitate the pavements by reconstruction. The study proposed to construct three layers: asphaltic layer with thickness of 240 mm, granular base with thickness of 250 mm, and granular subbase with a thickness of 250 mm. The study stated that all layers must have superior quality with high elastic modulus to resist the predicated traffic load.

Keywords: Road pavements, Distresses, Rehabilitation, Structural evaluation, Layers.

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1. Introduction

Distress of flexible pavements may occur due to several causes [1, 2] such as unstable subgrade [3-5], insufficient subbase or base thickness [6-8], poor mix design of the asphaltic layers, high traffic loading, excessive axel loads, and environmental effects [9, 10]. These distresses can reduce the serviceability of the pavements and cause severe damages in the vehicles which lead to large losses in money for the persons and community which results in huge losses to the country's economy [11-15]. In addition, poor pavements condition can cause dangerous traffic accidents that lead to injury or death of road users as well as damages in vehicles and road properties [16-18]. Moreover, poor pavements condition cause delay as it interrupts the traffic movement and reduces the speed of the vehicles and consequently it results in additional money losses due to fuel consumption, vehicles' parts exhausting and lost in time [19-21]. Furthermore, poor pavements condition cause inconvenience driving which make the road users nervous and annoyed [22, 23]. Over that, maintaining such pavements require a huge amounts of materials, efforts, energy, and money [24]. Additionally, all these effects increase the environmental pollutions in direct or in indirect ways [25, 26]. In Iraq, the highway pavements with poor conditions represent a serious problem due their wide spread and severity level in a, relatively, extended sections of the highways. In some Iraqi highway sections, poor pavements condition takes severe, serious, and dangerous levels due to combination among different types of distresses such as rutting, cracking, waving, corrugation, and/or batching. In such sections, driving is a very dangerous and cause severe damages in the vehicles' parts. These problems are related to insufficiency of the structural capacity of the road pavements to accommodate the applied traffic load. Although that, the number of researches in this domain still limited. In addition, most of the researches adopted laboratory approaches which ignore the field conditions in most of the cases. Therefore, adopting case studies that apply field surveys in Iraqi highways are highly demanded. Bagdad-Baquba highway can be considered as one of the most important interstate highways as it connect the capital of Iraq (Baghdad) with one of the biggest governorates in Iraq (Diyala) that incorporate population of about 1640000 person. In addition, this highway connects Baghdad with other governorates in north of Iraq via Diyala governorate. Therefore, this study aims to adopt a case study in a selected section at Baghdad-Baquba road to evaluate the structural properties of its pavements in purpose of rehabilitation to fill the research gap in the domain mentioned and to provide the records of the specialized institutions with required data.

2. Research methodology

This study investigated the structural properties of the selected section by extracting samples from the pavements in the field. The samples includes 4 cores extracted from different locations and a number of samples extracted from a pit with dimensions of 1×1 m with full depth of the pavements including the asphaltic layers, the granular subbase, and the subgrade. Figure 1 shows the location of the study area and Figure 2 shows the locations of the extracted samples within the study area.

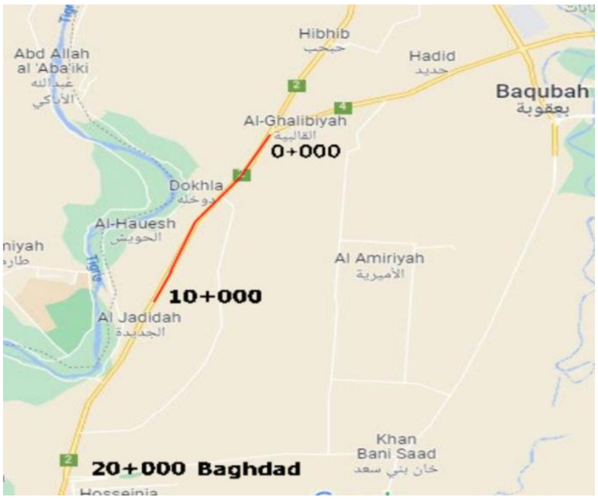

Figure 1. The selected section in the study area

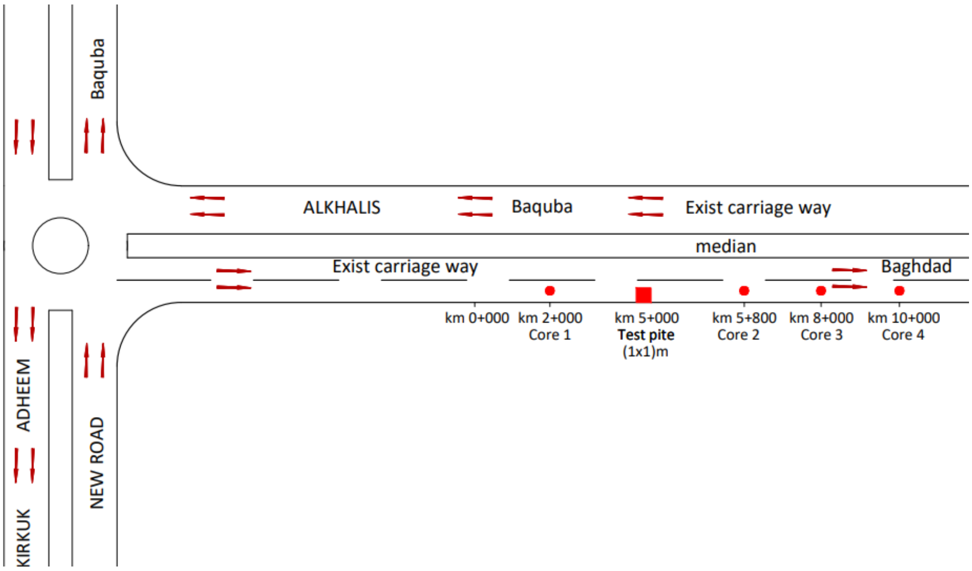

Figure 2. The locations of the samples extracted from field in the study area

After extracting of the samples, their thicknesses were measured and a number of tests were implemented to determine their properties in order to evaluate the structural properties of the pavements. The testing program is abstracted in Table 1, and Table 2.

The methodology also included the estimation of traffic loading in the study area based on previous studies. In addition, the methodology adopted structural analysis and design based on AASTHO method to analyze the structural capacity of the pavements and to propose the rehabilitation method. This method, basically, involved calculation of the thickness of the main layers in the pavements system based on two major equations “Equation (1) and “Equation (2)” [27] and predetermined conditions when the traffic load is known. In case of analysis, the parameters in the equations must be known to determine the traffic load.

Table 1. Abstract of testing program for asphaltic materials extracted from the field

Test Designation	Purpose	Applied
ASTM D3549	Thickness Determination	1
ASTM D2726	Density Determination	1 and 2
ASTM D6927	Determination of Marshall Stability and Flow	1 and 2
ASTM D6307	Asphalt Content Determination	2
ASTM D2041	Determination of Maximum Density of Asphalt Mixture	2
ASTM D5444	Determination of Size Analysis of Extracted Aggregate	2
ASTM D5821	Determination of Fractured Particles in Coarse Aggregate	2

1 Tests on cores including Wearing, Binder, and AC Base courses; 2 Tests on asphaltic mixture obtained from square sample (1mx1m) including Wearing, Binder, and AC Base courses

Table 2. Abstract of testing program for subbase and subgrade materials extracted from the field

Test Designation	Purpose	Applied
ASTM D1556	Determination of Density in place	1
ASTM D1557	Determination of Compaction Characteristics	1 and 2
ASTM D1883	Determination of CBR	1 and 2
ASTM D4318	Determination of Liquid Limit, Plastic Limit, and Plasticity Index	1 and 2
ASTM C131	Determination of Resistance to Degradation	1
ASTM C136	Sieve Analysis of Fine and Coarse Aggregates	1
ASTM D2937	Determination of Density in place	2
ASTM D422-63	Particle-Size Analysis	2

1 Subbase; 2 Subgrade

$$SN = a_1 \times D_1 + a_2 \times D_2 \times m_2 + a_3 \times D_3 \times m_3 \quad (1)$$

$$log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times log_{10}(SN+1) - 0.2 + \frac{log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.4+\frac{1094}{(SN+1)^{5.19}}} + (2.32 \times log_{10}(M_r) - 8.07) \quad (2)$$

Where:
SN: Structural number indicative of the total pavement thickness
a_1, a_2, a_3: Layer coefficient of asphaltic layer, base layer, and subbase layer respectively
D_1, D_2, D_3: Layer thickness of asphaltic layer, base layer, and subbase layer respectively
m_2, m_3: Drainage coefficient of base layer and subbase layer respectively
W_{18}: predicted number of 80 KN (18,000 lb) equivalent single axle loads (ESALs)
Z_R : Standard normal deviation
S_o : combined standard error of traffic prediction and performance prediction
M_r: Resilience modules
ΔPSI: Difference between the initial design serviceability index and the design terminal serviceability index = $p_o - p_t$; where: p_t is the terminal serviceability index and p_o denotes the initial design serviceability index

3. Results and discussions

Based on the data collected from previous studies, the traffic loading in terms of ESALs in the year 2021 (the year when this study was implemented) was estimated to be 9758000.

The results show significant variance among the thickness values of the asphaltic layers attained from different samples in different locations. This variance can be attributed to the rehabilitation processes by overlaying implemented over different periods without planning. Table 3 abstracts the main properties of the asphaltic samples extracted from the field. The worst case was selected to be adopted and presented in this paper which is the case in the location No. 2 as it exhibit the lowest overall thickness (163 mm). The other properties of the samples extracted from this location area presented in Table 4. Using "(1)" and "(2)" the satiable inputs, the allowable traffic load was found to be 800000 in terms of W_{18} ($ESAL_{allowable}$) as shown in Table 5. It is important to reveal that the input data can be classified into three categories. First, know inputs which attained directly from measuring or testing. This category includes the thicknesses of the layers and CBR values. Second, estimated values which were estimated based on know values and using charts and equations from previous studies. This category includes the elastic modules of the layers. Third, assumed inputs those cannot be measured or estimated. This category includes the other inputs shown in Table 5.

The value of allowable traffic load (800000) is very small compared to that applied (9758000). This means that the applied traffic load represents more than 12 times than the allowable; this is a huge exceeding. A number of probable reasons may justify this huge difference (why the applied load extremely exceeded the allowable traffic load?) as shown in the following points:

1. No control on the maximum axle loads of the heavy vehicles. This reason is likely as no control stations are available on this route.
2. No control on the types of heavy vehicles that use this road. This reason is likely as no control stations are available on this route.
3. No control on routing of the heavy vehicles. This reason is likely as no control stations are available on this route.
4. Changing of routing (the drivers prefer to use this road) after 2014 as a result to the security problems in other parallel routs such as the road that connects Baghdad by Saladin Governorate. This reason is likely as the security risks were a problem for the drivers of the trucks after 2014 in the war areas.
5. Expanding of transportation in the study area due to expanding of different activities (economical, social, residential, and/or educational activities) in the area as a result to security problems in Saladin Governorate. This reason is likely as the security risks were a problem for the drivers of the trucks after 2014 in the war areas.

Based on the results of analysis, an immediate rehabiltaion must be implemented. The suitable rehabilitation must be by reconstruction. This study prepared a proposal for design on new pavements system based on AASHTO 1993 method as abstracted in Table 6. The design assumed that the reconstruction is implemented in 2022 and continue in service for 20 years (until 2042). The calculations exhibited that the proposed design for the flexible pavements consists of subbase layer of 250 mm thickness, granular base of 250 mm thickness, and asphaltic layer of 240 mm thickness. The asphaltic layer must be constructed as three courses: asphaltic base, binder, and wearing. All layers must be of superior quality to provide high elastic modules as shown in the Table 6.

Table 3. Abstract of the main properties attained from testing of the asphaltic samples extracted from the field.

Core No.	Layer thickness (mm)				Stability and Flow values of the layers			
	Wearing	Binder	Base	Overall	Layer	Stability (kN)	Flow (mm)	Stiffness (kN7mm)
1	54	57	101	212	Wearing	17.9	3.4	5.3
2	48	54	61	163	Binder	22.9	2.3	9.9
3	52	47	7	169	Base	19.2	3.8	5.1
4	67	48	52	167	Stability and Flow were attained from square sample			

Table 4. The properties of the asphaltic sampled in location 2

layer	Field density (gm/cm^3)	Lab density (gm/cm^3)	Relative compaction (%)	Asphalt content (%)	Air void (%)
Wearing	2.297	2.312	99	4.8	3.8
Binder	2.292	2.322	99	4.4	4.1
Base	2.291	2.331	98	3.8	4.5

Table 5. The input-output data for pavements structural analysis in location 2

Description	Layer Coefficient	Drainage Coefficient	CBR (%)	Elastic Modulus, psi	Thickness (mm)
Wearing Layer	0.40	-	-	370000	48

Description	Layer Coefficient	Drainage Coefficient	CBR (%)	Elastic Modulus, psi	Thickness (mm)
Binder Layer	0.44	-	-	450000	54
Base Layer	0.39	-	-	350000	61
Granular Subbase	0.12	0.8	40	16000	250
Subgrade	-	-	4.5	6750	-
Constant data; p_i=4.5, p_t=2.5; ΔPSI = 2; S_o=0.45; Z_R= -1.645					
W_{18}=800000					

Table 6. The input-output data for pavements structural design for rehabilitation proposal

Description	Layer Coefficient	Drainage Coefficient	CBR (%)	Elastic Modulus, psi	Thickness (mm)
Asphaltic Layers	0.44	-	-	450000	240
Granular Base Layer	0.14	0.9	100	31000	250
Granular Subbase	0.13	0.8	60	17000	250
Subgrade	-	-	4.5	6750	-
Constant data; p_i=4.5, p_t=2.5; ΔPSI = 2; S_o=0.45; Z_R= -1.645					
W_{18}= 39500000					

4. Conclusions

1. Baghdad-Baquba Road is an important facility that connects Baghdad city (the capital of Iraq) with Diyala Governorates as well as the Governorates in the north of Iraq. Hundreds millions of persons and hundreds million tons of goods are transported every year on this road. This road can be considered an arterial interstate highway. It support the economic growth in the areas it links and in Iraq overall.
2. There is a lack in information about this road including traffic characteristics and maintenance records.
3. The traffic estimations show that the applied traffic loads in term of ESALs severely exceeded the allowable by more than 12 times until 2021. This number increases every year. It can reach 40 times in 2042.
4. The road was constructed with two layers (Surface asphaltic Layer, and Subbase) rested on a subgrade. The surface asphaltic layer consists of three courses: base, binder, and wearing. The following points were concluded from the investigations on the conditions of these layers:
5. All materials used conform to the Iraqi specifications requirements.
6. There is a significant variance among the thicknesses of the asphaltic courses (Base, binder, and wearing) in different locations. This refers to improper construction especially in mixture spreading process.
7. The subgrade has low strength which refers that it was not improved. Weak subgrade reduces the structural capacity of the pavements.
8. The subbase used has relatively low elastic modulus which reduces its strength and consequently reduces the capacity of the pavements.
9. The summation of thicknesses of the asphaltic courses is relatively low.
10. The structure of the pavements is capable to carry a medium traffic. However, it actually caries a heavy traffic that exceeded its capacity.
11. No records about investigations and predications related to the pavements design were found. This refers that the design was performed improvisational.
12. The reconstruction must be implemented immediately.
13. Improving the properties of the subgrade prior to or during reconstruction can reduces the required thicknesses of the pavements layers (subbase, base, and asphaltic layers) which reduces the construction cost.
14. An accurate design based on extended filed investigations and traffic studies must be prepared prior to reconstruction to avoid repeating the past problems.
15. Specifying and documentation of the causes of the distresses assists the domain engineers to avoid these causes and prevents the occurrence of the distresses or reducing them and elimination of their effects.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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References

[1] J. Li, T. Liu, X. Wang, and J. Yu, "Automated asphalt pavement damage rate detection based on optimized GA-CNN," Automation in Construction, Vol. 136, pp. 1-10, 2022.

[2] B. Yang, Z. Qin, Q. Zhou, H. Li, L. Li, and X. Yang, "Pavement damage behaviour of urban roads in seasonally frozen saline ground regions," Cold Regions Science and Technology, Vol. 174, pp. 103035, 2020.

[3] A. M. Mosa, A. H. Taher, and L. A. Al-Jaberi, "Improvement of poor subgrade soils using cement kiln dust," Case Studies in Construction Materials, Vol. 7, pp. 138-143, 2017.

[4] L. A. Salem, A. H. Taher, A. M. Mosa, and Q. S. Banyhussan, "Chemical influence of nano-magnesium-oxide on properties of soft subgrade soil," Periodicals of Engineering and Natural Sciences, Vol. 8, pp. 533-541, 2020.

[5] İ. Zorluer and S. GÜCEK, "Usage of Fly Ash and Waste Slime Boron for Soil Stabilization," Periodicals of Engineering and Natural Sciences (PEN), Vol. 5, pp. 51-54, 2017.

[6] A. M. Mosa, R. A. O. K. Rahmat, A. Ismail, and M. R. Taha, "Expert System to Control Construction Problems in Flexible Pavements," Computer-Aided Civil and Infrastructure Engineering, Vol. 28, pp. 307-323, 2013.

[7] A. M. Mosa, "Neural Network for Flexible Pavements Maintenance and Rehabilitation," Applied Research Journal, Vol. 3, pp. 114-129, 2017.

[8] A. M. Mosa, M. H. Al-Dahlaki, and L. A. Salem, "Modification of roadbed soil by crushed glass wastes," Periodicals of Engineering and Natural Sciences (PEN), Vol. 9, pp. 1038-1045, 2021.

[9] P. Di Mascio and L. Moretti, "Implementation of a pavement management system for maintenance and rehabilitation of airport surfaces," Case studies in construction materials, Vol. 11, pp. 1-11, 2019.

[10] G. Beyhan, "A comparative study on Soil Properties and Applications Review with EERA and NERA in İstanbul-MARMARAY Project between Kazlıçeşme to Sirkeci," Periodicals of Engineering and Natural Sciences(PEN), Vol. 5, pp. 65-80, 2017.

[11] A. M. Mosa, R. Atiq, M. Raihantaha, and A. Ismail, "Classification of construction problems in rigid highway pavements," Australian Journal of Basic and Applied Sciences, Vol. 5, pp. 378-395, 2011.

[12] A. M. Mosa, R. Atiq, M. Raihantaha, and A. Ismail, "A knowledge base system to control construction problems in rigid highway pavements," Australian Journal of Basic and Applied Sciences, Vol. 5, pp. 1126-1136, 2011.

[13] A. M. Mosa, M. R. Taha, A. Ismail, and R. A. O. K. Rahmat, "A diagnostic expert system to overcome construction problems in rigid highway pavement," Journal of Civil Engineering and Management, Vol. 19, pp. 846-861, 2013.

[14] A. M. Mosa, M. R. Taha, A. Ismail, and R. A. O. K. Rahmat, "An Educational Knowledge-based System For Civil Engineering Students in Cement Concrete Construction Problems," Procedia - Social and Behavioral Sciences, Vol. 102, pp. 311-319, 2013.

[15] A. M. Mosa, N. N. Ismail, N. I. M. Yusoff, M. A. Mubaraki, N. A. Memon, M. R. Taha, and M. R. Hainin, "An expert system to remedy concrete imperfections and their effects on rigid pavements," Jurnal Teknologi, Vol. 76, pp. 105-119, 2015.

[16] A. A. Mohammed, K. Ambak, A. M. Mosa, and D. Syamsunur, "Classification of Traffic Accident Prediction Models: A Review Paper," International Journal of Advances in Science Engineering and Technology, Vol. 6, pp. 35-38, 2018.

[17] A. A. Mohammed, K. Ambak, A. M. Mosa, and D. Syamsunur, "Traffic Accidents in Iraq: An Analytical Study," Journal of Advanced Research in Civil and Environmental Engineering, Vol. 5, pp. 1-13, 2018.
[18] A. A. Mohammed, K. Ambak, A. M. Mosa, and D. Syamsunur, "A Review of the Traffic Accidents and Related Practices Worldwide," The Open Transportation Journal, Vol. 13, pp. 65-83, 2019.
[19] A. M. Mosa, L. A. Salem, and W. A. Waryosh, "New Admixture for Foamed Warm Mix Asphalt: A Comparative Study," Iranian Journal of Science and Technology, Transactions of Civil Engineering, Vol. 44, pp. 649-660, 2020.
[20] Q. S. Banyhussan, S. A. Tayh, and A. M. Mosa, "Economic and Environmental Assessments for Constructing New Roads: Case Study of Al-Muthanna Highway in Baghdad City," in AWAM International Conference on Civil Engineering AICCE2019, Penang, Malaysia, 2020.
[21] A. A. Mohammed, K. Ambak, A. M. Mosa, and D. Syamsunur, "Expert System in Engineering Transportation: A Review," Journal of Engineering Science and Technology, Vol. 14, pp. 229-252, 2019.
[22] A. Issa, H. Samaneh, and M. Ghanim, "Predicting pavement condition index using artificial neural networks approach," Ain Shams Engineering Journal, Vol. 13, pp. 1-11, 2022.
[23] M. A. Al-Neami, R. H. Al-Rubaee, and Z. Kareem, "J. Evaluation of Pavement Condition Index for Roads of Al-Kut City," International Journal of Current Engineering and Technology, Vol. 7, pp. 1461-1467, 2017.
[24] Z. Z. Hameed, Spatial Analysis of Urban Roadway Pavement Maintenance Management, University of Kerbala, 2021.
[25] Y. V. Trofimenko, V. I. Komkov, V. V. Donchenko, and T. D. Potapchenko, "Model for the assessment greenhouse gas emissions from road transport," Periodicals of Engineering and Natural Sciences, Vol. 7, pp. 465-473, 2019.
[26] A. N. Yakubovich, Y. V. Trofimenko, I. A. Yakubovich, and E. V. Shashina, "A forecast model for a road network's section traffic capacity assessment on a territory of the cryolithozone in conditions of the climate change," Periodicals of Engineering and Natural Sciences, Vol. 7, pp. 275-280, 2019.
[27] AASHTO, AASHTO Guide for Design of Pavement Structures, American Association of State Highways and Transportation Officials, 1993.