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Investigation of the Reasons for Alligator Cracks at Side of Flexible Pavement Roads

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ABSTRACT

Flexible pavement cracks are considered one of the significant distresses of asphalt pavement. Alligator cracks are considered one of the types of damage called crocodile cracks because their shape is like alligator skin. The common cause of this cracking is an overloaded, weak granular layer underneath the asphalt layer. This paper investigates the alligator cracks that appear at the side of the university of Baghdad campus road. The road does not pass over any heavy trucks, and cracks appear on one side of the road. Using a finite element approach through simulation of the road and applying the effect of temperature in these cracks. The results show that the high temperature leads to the appearance of these cracks with a brittle asphalt layer. the results illustrated that the expansion factor plays an essential role in producing the cracks at the side of the road by using three values of the expansion factor in the analysis, which are (2.44 $\times 10^{-5}$ per °C, 2.58$\times 10^{-5}$per °C, and 2.79$\times 10^{-5}$per °C). The results demonstrated that the increased expansion factor of the asphalt layer by 8.1% let increased thermal stresses, strain, and deformation by 14.36 %, 14.03 %, and 14.51%, respectively.

1. INTRODUCTION

The cracks in asphalt roads consider a common phenomenon. Alligator cracks are one of the significant cracks in asphalt pavement. The common cause of alligator cracks is the weak granular or subgrade layer also, the repeated load is one of these causes [1]. The structural integrity of pavement materials is likely to deteriorate over time due to repeated cyclic loading and changing environmental conditions. Numerous distress types that impact the rideability and safety of drivers and passengers are signs of such pavement deterioration. The term fatigue resistance/fatigue life refers to an asphalt mixture's capacity to withstand repeated traffic loading under environmental conditions without cracking [2].

Fatigue cracking is a common and significant issue with asphalt pavements. It is also referred to as alligator or reflected cracking. Fractures occur due to repeated vehicle loads, concentrating stress in the lower asphalt layer as a result of tensile strains induced by cyclic loading. The fissures progressively expanded upward, creating weblike patterns that resembled the skin of an alligator. Fatigue cracking can be influenced by a variety of factors, including loads from traffic, rest intervals, temperature changes, asphalt mixture qualities, and weather variables. This issue exacerbates with high traffic and temperature fluctuations, particularly in regions susceptible to freeze-thaw cycles. Engineers mitigate this by utilizing strategies such as sophisticated asphalt mix designs with additives and modifications, precise pavement designs that account for traffic loads and environmental factors, regular maintenance including crack sealing and patching, and the development of materials like polymer-modified binders and high-performance asphalt mixes. In order to prolong the lifespan and safety of asphalt roads, these programs concentrate on improving pavement durability and preventing fatigue cracking [3].

The road maintenance authority faces significant financial strain due to fatigue cracking, which raises maintenance costs because of the frequent and costly repairs needed to fix the expanding cracks. Often, this continuous upkeep takes funds away from important infrastructure initiatives like new road construction or public transportation systems. Additionally, the cyclical nature of maintenance due to recurring fatigue cracking impacts public budgets and raises fiscal uncertainty [4].

Fatigue cracking can also interfere with traffic, leading to delays and congestion. Repairing fatigue cracks usually necessitates lane restrictions and road closures, which can be extremely disruptive. In addition to being inconvenient for commuters, these disruptions have an impact on the economy because they hinder the flow of goods and services, interfere with supply chains, and raise fuel consumption due to traffic congestion [5].

The road of the University Baghdad is severe, with some portions with alligator cracks at the side of the road, as shown in Figure 1.

Most research considers the cycling traffic load as the main factor in fatigue damage and alligator crack, and the effect of temperature that induces pavement fatigue crack is not taken into consideration when designing flexible pavement [1, 6-13] although there is minor fatigue damage caused by cycling of temperature through day-night [14].

Figure 1. The alligator cracks on the side of the University of Baghdad campus road

Pavement fatigue cracking is greatly influenced by temperature changes, and the extent of damage varies depending on the location and climate. Large daily temperature differences cause high thermal stresses in hot, arid climates, while freeze-thaw cycles accelerate cracking in cold climates. The fatigue damage is less severe but still noticeable in temperate and tropical regions. In order to overcome these obstacles, pavement design needs to take climate-specific factors like material choice, structural modifications, and maintenance plans into account. Engineers can create pavement systems that are more resilient and economical while taking into account local conditions by comprehending the connection between temperature fluctuations and fatigue cracking.

The occur of alligator cracks just on the side of campus road let to think about the cause of these cracks because the traffic load on this location is light, even the cause of it is traffic loads the cracks shout occur in the pathway of load or cover the whole area of the road because the strength of asphalt layer along the wheel path and the middle of the wheel path is almost equal [15].

Consequently, the one effect that can be thought about is the expansion and contraction of the asphalt layer due to various temperatures throughout the day and seasons.

The finite element approach is used to analyze the stresses, strains, and deformations that happen in the pavement when the temperature change by using the Abaqus finite element program, which is approved for its ability to simulate flexible pavement with a high level of accuracy [16-19].

This study will use three values of the expansion factor (2.44 $\times10^{-5}$ per °C, 2.58$\times10^{-5}$per °C, and 2.79$\times10^{-5}$per °C) to examine the impact of the asphalt layer's expansion factor, which represented measurement factors from the actual asphalt roads [20].

The value of the expansion factor of the asphalt layer based on the properties of the asphalt mixture and the temperature at which the expansion factor is measured, but its ranges from (1.98 $\times10^{-5}$ to 3.79$\times10^{-5}$ per °C) [21].

When designing long-lasting pavements, it is crucial to comprehend how expansion factors affect the formation of cracks. Engineers can reduce the chance of cracking and enhance pavement performance by choosing the right materials, refining layer designs, and taking environmental factors into account. These results highlight how crucial it is to customize pavement designs to particular site characteristics and material qualities in order to guarantee sustainability and economic viability.

Finite Element Mode l(FEM) for the university of Baghdad Road campus was built up using finite element program of Abaqus to examine the impact of the expansion factor of the asphalt mixture in stress, strain, and deformation in asphalt roads at the side as well as the effect of temperature variations during the day-night cycle.

The purpose of this study is to investigate the reasons of the alligator cracks that appear at the side of the University of Baghdad campus road.

2. MATERIAL AND METHODOLOGY

2.1 Finite element model

Finite element analysis is one type of numerical analysis used to approximate solutions to challenging engineering problems [22-24].

To know the behavior of the asphalt layer for Baghdad university road and to investigate the situation which let to occur the alligator crack at the side of pavement Abaqus program Ver. 6.14.4 is used to simulate the road behavior under thermal load.

2.2 Model geometry

The Abaqus program is used to create a 3D (FEM) that simulates the Baghdad University Road. The thickness of layers is asphalt 200 mm, 300 mm granular, and 400 mm subgrade; the length of a portion of the road used in the model is 5 m the width of the road is 5 m which represents a two-lane as shown in Figure 2.

Figure 2. The geometry of abaqus model and real road

2.3 Finite element type and mesh size

Three-dimensional domain, a 3D stress, 8-node linear brick continuum element, is used to generate the mesh in the simulation layers of the road [18] the road without reduced integration. Each of these elements is also referred to as C3D8 [25]. The mesh's approximate global size is 100 mm as shown in Figure 3.

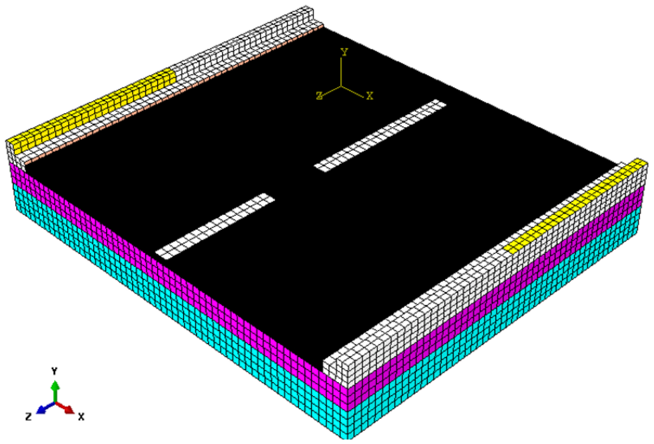


Figure 3. Mesh of model

2.4 Properties of material for finite element model

Viscoelastic properties are used to simulate the asphalt layer as viscoelastic behavior. Eqs. (1, 2, 3, 4, and 5) [16, 26] can use to calculate the Prony series parameters, which represent the viscoelastic properties.

$$D(t) = \frac{1}{Eo}\left(1 + \frac{1}{To}\right) + \frac{1}{E1}\left(1 - \exp\left(-\frac{t}{T1}\right)\right) \quad (1)$$

where, *D(t)* is creeping compliance, *Eo* is the modulus of instantaneous, *E1* is the modulus of long-term, *to* is the relaxation time, *T1* is the retardation time, *t* is the time.

$$k(t) = ko\left[1 - \sum_{k=1}^{N} K_K^{-P}\left(1 - \exp(-\frac{t}{t_k})\right)\right] \quad (2)$$

$$G(t) = Go\left[1 - \sum_{k=1}^{N} g_K^{-P}\left(1 - \exp\left(-\frac{t}{t_k}\right)\right)\right] \quad (3)$$

where, *K(t)* is the bulk modulus, *G(t)* is the shear modulus as a function of time, *Ko* is the initial bulk modulus, *Go* is the initial shear modulus, *t* is time, K_K^{-P}, g_K^{-P} and t_k are Prony series parameters obtained by fitting the bulk and shear modulus with Eqs. (4) and (5).

$$K(t) = \frac{E(t)}{3(1-2vo)} \quad (4)$$

$$G(t) = \frac{E(t)}{2(1+vo)} \quad (5)$$

Table 1. The viscoelastic input parameters of Abaqus

Viscoelastic Model Parameters	Asphalt Layer
g. Prony	0.208
k. Prony	0.211
tau. Prony	5.69

The viscoelastic input parameters of Abaqus, which are used in the simulation [27], shown in Table 1. These characteristics are employed for the asphalt layer.

Table 2 illustrates the mechanical properties of Asphalt, granular, subgrade layers of pavement, and concrete gutter.

The Finite Element model's thermal properties are given in Table 3.

Table 2. The input properties of pavement layers

Layer	Elasticity Modulus (Mpa)	Density (kg/m^3)	Poisson's Ratio (υ)
Asphalt	4000	2320	0.35
Granular	600	2150	0.45
subgrade	140	1800	0.4
Concrete of gutter[26]	24422	2330	0.15

Table 3. Thermal parameters inputs in the finite element model

Particulars	Amount
Thermal Conductivity	2.2 (W/m-°C)
Specific Heat	1400 (J/Kg-°C)

2.5 Temperature loading

The temperature in Baghdad varies day and night. The pavement temperature in the hottest month arrives at 70°C to cover more effect of temperature in the asphalt layer, so the thermal loads applied in the model started from 10°C to 70°C.

3. RESULTS AND DISCUSSION

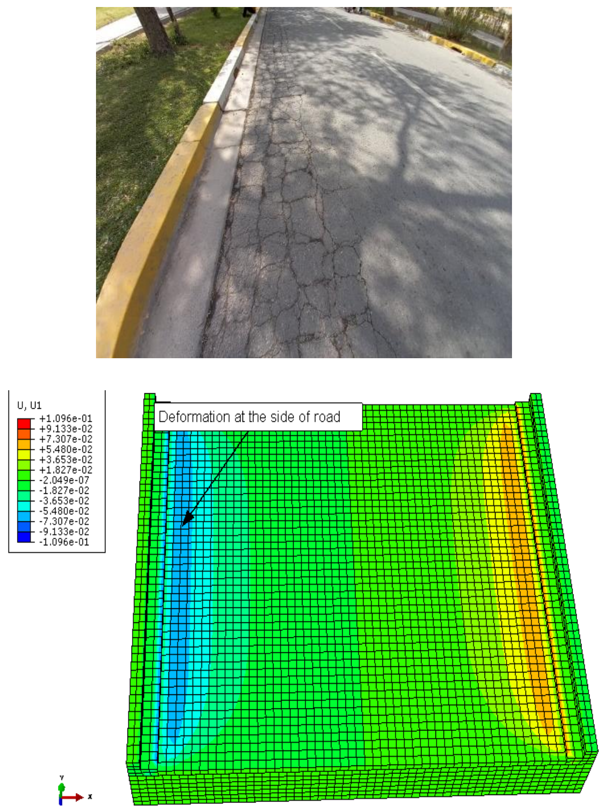
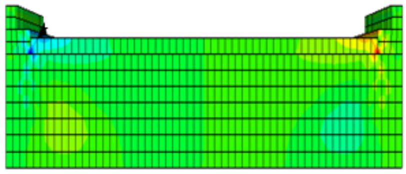
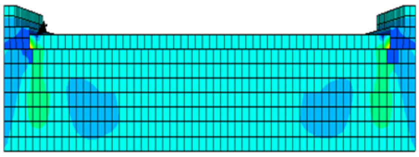


Figure 4. The similarity between the pattern of distress on the road and the Abaqus finite element model



(a)



(b)

Figure 5. Distress at the side of the road: a - Deformation at the side of the road, b - Strain at the side of the road

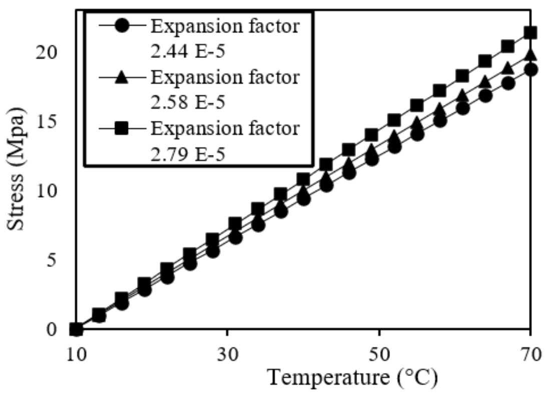


Figure 6. The relationship between temperature and stresses for expansion factors

The results of finite elements illustrated that the Abaqus outputs were good in a simulation of the pattern of the stresses, strains, and deformations, similar to the actual pattern of the asphalt layer of Baghdad university road distresses. The analysis shows that the stresses, strain, and deformation in the transfer direction concentrated at the sides of the pavement, which represented the actual distress, strains, and deformation at the sides of the pavement, as illustrated in Figure 4. Also Figure 5 shows a cross-section of the road, and the deformation and strain in the transfer direction, which demonstrates the concentrated distress at the side of the road, as the actual road distress which appeared at the side of university road.

Figure 6 illustrated that the asphalt layer of the road with an expansion factor of 2.79×10^{-5} per °C produces thermal stresses at the side of the road more than the roads with an Asphalt layer expansion factor of 2.58×10^{-5} per °C, and 2.79×10^{-5} per °C, also the figure shows that thermal stresses increase as temperature increases. Figure 7 shows the relationship between the stresses and expansion factors at a constant temperature of 70°C, we noticed that as the expansion factor of the Asphalt layer increases, the stresses at the side of the asphalt layer increase.

Figure 8 demonstrated that the asphalt layer of the road with an expansion factor of 2.79×10^{-5} per °C produces thermal strains at the side of the road more than the roads with an Asphalt layer expansion factor of 2.58×10^{-5} per °C, and 2.79×10^{-5} per °C, also the figure shows that thermal strain increases as temperature increases, the same behavior observed by Islam and Tarefder in their studies [20, 28]. Figure 9 shows the relationship between the strains and expansion factors at a constant temperature of 70°C, the figure shows that the strains at the side of the asphalt layer increase as the asphalt layer's expansion factor increases.

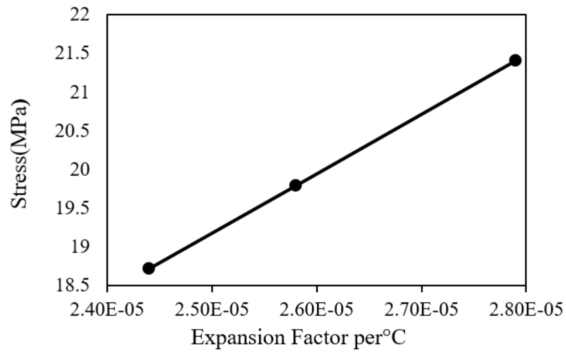


Figure 7. The relationship between expansion factors and stresses in the asphalt layer

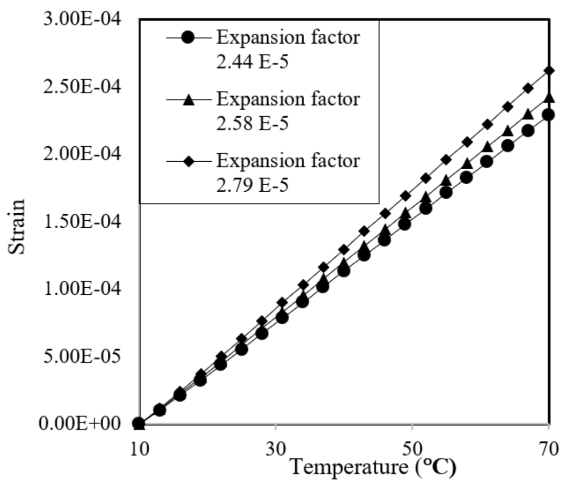


Figure 8. The relationship between temperature and strains for expansion factors

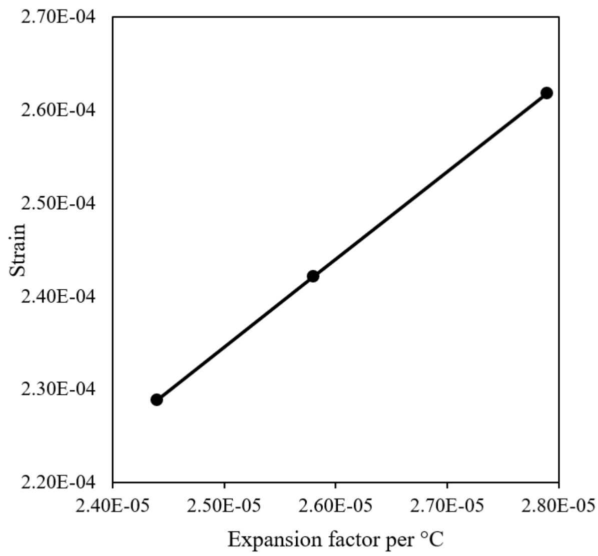


Figure 9. The relationship between expansion factors and strain in the asphalt layer

Figure 10 shows that the asphalt layer of the road with an expansion factor of 2.79×10^{-5} per°C produces thermal deformation at the side of the road more than the roads with an Asphalt layer expansion factor of 2.58×10^{-5} per°C, and 2.79×10^{-5} per°C, also the figure shows that thermal strain increases as temperature increases. Figure 11 shows the relationship between the deformation and expansion factor at a constant temperature of 70°C, the figure shows that the deformation at the asphalt layer's sides increases as the asphalt layer's expansion factor increases.

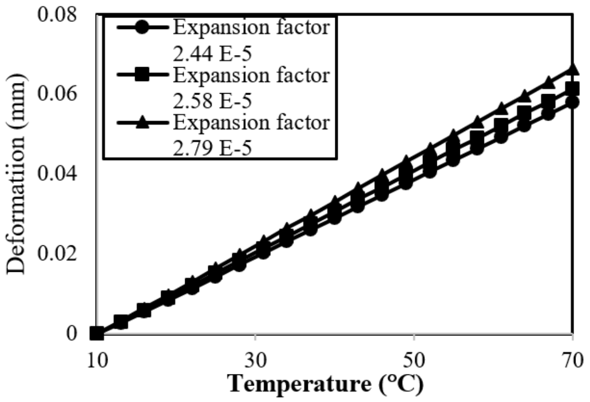


Figure 10. The relationship between temperature and deformation for expansion factors

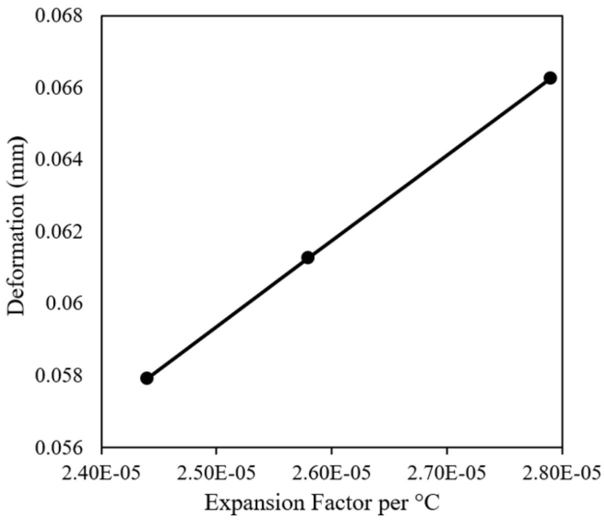


Figure 11. The relationship between expansion factors and deformation in the asphalt layer

The results demonstrated that the increased expansion factor of the asphalt layer by 8.1% let increased thermal stresses, strain, and deformation by 14.36 %, 14.03 %, and 14.51%, respectively.

4. CONCLUSIONS

The research studied the reasons for alligator cracks on the side of the road, using a finite element approach by Abaqus program. Based on the results of the study.

1. The concentration of stresses, strain, and deformation in transfer direction at the side of the road.
2. The concentration of distresses at the side of the road clarifies the cause of alligator cracks at the side of the road.
3. The expansion factor of the asphalt mixture effects the value of thermal stresses.
4. The increase in the expansion factor of the asphalt mixture increases the strain, stresses, and deformation.
5. Thermal stresses, strains, and deformations in the asphalt layer increases as temperature increases.
6. The effect of the expansion factor of asphalt mixture properties must be considered during the design asphalt mixture.
7. The temperature plays an essential role in producing the stress at the side of the road.
8. To reduce the effect of the expansion factor, can make an expansion joint at the side of the road to give the asphalt layer space to expand.
9. A comprehensive strategy that incorporates appropriate material selection, optimized design, high-quality construction techniques, and proactive maintenance is needed to mitigate the effects of thermal stresses on alligator cracks. Pavement engineers can greatly lower the incidence of alligator cracking and increase the pavement's service life by addressing the underlying causes of thermal stresses and putting climate-specific solutions into place.
10. The pavement's resistance to temperature changes is further improved by cutting-edge technologies and creative materials, guaranteeing long-term performance and durability.
11. For the future work can be use the road of university of Baghdad a acase stydy for practical work to investigate the reasons of the alligator cracks that appear at the side of the campus road and make as simulation with the numerical model.

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REFERENCES

[1] Setiawan, D.M. (2024). Fatigue cracking behaviour and characteristics of flexible pavement subjected to freight coal-truck loading. International Journal of Sustainable Construction Engineering and Technology,15(2): 76-89. https://doi.org/10.30880/ijscet.2024.15.02.007

[2] Sudarsanan, N., Kim Y.R. (2022). A critical review of the fatigue life prediction of asphalt mixtures and pavements. Journal of Traffic and Transportation Engineering (English Edition), 9(5): 808-835. https://doi.org/10.1016/j.jtte.2022.05.003

[3] Alnaqbi, A.J., Zeiada, W., Al-Khateeb, G., Abttan, A., Abuzwidahet, M. (2024). Predictive models for flexible pavement fatigue cracking based on machine learning. Transportation Engineering, 16: 100243. https://doi.org/10.1016/j.treng.2024.100243

[4] Moins, B., France C., Audenaert A. (2020). Implementing life cycle cost analysis in road engineering: A critical review on methodological framework choices. Renewable and Sustainable Energy Reviews, 133: 110284. https://doi.org/10.1016/j.rser.2020.110284

[5] Hashim, I.H., Badawy, R.M., Heneash, U. (2023). Impact of pavement defects on traffic operational performance. Sustainability, 15(10): 8293. https://doi.org/10.3390/su15108293

[6] Ktari, R., Saint-Laurent, D., Hornych, P., Hammoum, F., Marsac, P., Nguyen, M.L. (2022). Effect of climate on asphalt pavement performance using two mechanistic-empirical methods. International Journal of Pavement Engineering, 23(5): 1433-1458. https://doi.org/10.1080/10298436.2020.1806276
[7] Ahmed, F., Thompson, J., Kim, D., Huynh, N., Carroll, E. (2023). Evaluation of pavement service life using AASHTO 1972 and mechanistic-empirical pavement design guides. International Journal of Transportation Science and Technology, 12(1): 46-61. https://doi.org/10.1016/j.ijtst.2021.11.004
[8] Singh, A.K., Sahoo, J.P. (2020). Analysis and design of two layered flexible pavement systems: A new mechanistic approach. Computers and Geotechnics, 117: 103238. https://doi.org/10.1016/j.compgeo.2019.103238
[9] Luo, Y., Wu, H., Song, W., Yin, J., Zhan, Y., Yu, J., Wada, S.A. (2023). Thermal fatigue and cracking behaviors of asphalt mixtures under different temperature variations. Construction and Building Materials, 369: 130623. https://doi.org/10.1016/j.conbuildmat.2023.130623
[10] Kotb, M.M. (2024). Prediction of distresses in pavement networks: A machine learning approach. Master's thesis, The American University in Cairo (Egypt).
[11] Harne, V.R., Tripathi, R.K., Guzzarlapudi, S.D. (2024). Effect of extrinsic and intrinsic parameters on fatigue performance of hot mix asphalt mixtures: A review. Journal of Building Pathology and Rehabilitation, 9(1): 53. https://doi.org/10.1007/s41024-024-00406-6
[12] Larsson, M., Niska, A., Erlingsson, S. (2022). Degradation of cycle paths—A survey in Swedish municipalities. CivilEng, 3(2): 184-210. https://doi.org/10.3390/civileng3020012
[13] Shaikh, S.G., Mahajan, D.U., Shaikh, M.N.S., Wadekar, A.P. (2022). Scientific study of asphalt road surface distress and their role in the design of flexible pavements. International Journal of Engineering Trends and Technology, 70(1): 220-232. https://doi.org/10.14445/22315381/IJETT-V70I1P227
[14] Fwa, T.F. (2005). The Handbook of Highway Engineering. CRC press.
[15] Islam, M.R., Tarefder, R., Ahmed, M.U. (2019). Backcalculated modulus of asphalt concrete. Journal of Civil Engineering and Construction, 8(4): 127-136. https://doi.org/10.32732/jcec.2019.8.4.127
[16] Hossain, M., Azam, M., Mehta, R., Shaik, N., Islam, M.R., Tarefder, R. (2016). Determining and validating thermal strain in asphalt concrete. Procedia Engineering, 145: 1036-1043. https://doi.org/10.1016/j.proeng.2016.04.134
[17] Al-Abdullah, S.F., Sofia, G.G., Teama, Z.T. (2016). Evaluation of using geosynthetic material and the process of grouting to improve pavement performance over sand dunes subgrade. In International Conference on Transportation and Development 2016, pp. 859-870. https://doi.org/10.1061/9780784479926.078
[18] Al-Abdullah, S.F., Sofia, G.G., Teama, Z.T. (2017). An approach in study behavior of sand dunes to use as a subgrade in pave road under moving loads. In Congress on Technical Advancement 2017, pp. 53-64.
[19] Al-Abdullah, S.F., Teama, Z.T., Aldahwi, S., Zaidn, M. (2022). Theoretical evaluation of sand subgrade behavior underneath the asphalt pavement with rutting deformation. In Geotechnical Engineering and Sustainable Construction: Sustainable Geotechnical Engineering, pp. 597-609. https://doi.org/10.1007/978-981-16-6277-5_48
[20] Islam, M.R., Tarefder, R.A. (2014). Determining coefficients of thermal contraction and expansion of asphalt concrete using horizontal asphalt strain gage. Advances in Civil Engineering Materials, 3(1): 204-219. https://doi.org/10.1520/ACEM20130101
[21] Mamlouk, M.S., Witczak, M.W., Kaloush, K.E., Hasan, N. (2005). Determination of thermal properties of asphalt mixtures. Journal of Testing and Evaluation, 33(2): 118-126. https://doi.org/10.1520/JTE12592
[22] Alani, Z., Mohammed, A.Q., Zaidan, M. (2023). Investigation of the most positions affected in rail track when the modulus of elasticity of the ballast layer is changed. Civil And Environmental Engineering Reports, 19(2): 568-574. https//doi.org/10.2478/cee-2023-0051
[23] Mohammed, A.Q. (2012). Finite element application for modified cam clay model to analyze silty clay soil under strip footing using MATLAB. Journal of Engineering and Sustainable Development, 16(2): 89-100.
[24] Obaid, A.Q., Ali, F.H., Mohammed, A.Q. (2011). Finite element analysis of strip footing resting on gibson-type soil by using matlab. Journal of Engineering, 17(1): 80-91.
[25] Abbas, S.R., Salih, M.M., Mohammed, A.Q., Abd, H.J. (2024). Assessing the impact of using (FRP) material for strengthening the holes in (RC) beams. Annales de Chimie Science des Matériaux, 48(4): 499-507. https://doi.org/10.18280/acsm.480407
[26] Islam, M.R., Faisal, H.M., Tarefder, R.A. (2015). Determining temperature and time dependent Poisson's ratio of asphalt concrete using indirect tension test. Fuel, 146: 119-124. https://doi.org/10.1016/j.fuel.2015.01.028
[27] Carvalho, R.L., Schwartz, C.W. (2006). Comparisons of flexible pavement designs: AASHTO empirical versus NCHRP project 1–37A mechanistic–empirical. Transportation Research Record, 1947(1): 167-174. https://doi.org/10.1177/0361198106194700116
[28] Islam, M.R., Tarefder, R.A. (2016). Developing temperature-induced fatigue model of asphalt concrete for better prediction of alligator cracking. Journal of Materials in Civil Engineering, 28(5): 04015193. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001477