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Damaging Effect of Static and Moving Armoured Vehicles with Rubber Tires on Flexible Pavement

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Abstract

The damaging effect of military armoured vehicles with rubber tires on flexible pavements was studied. Two types of military armoured vehicles with rubber tires were considered, namely CM32 four-axle and CM32 triple-axle. A measure of the damaging effect of military armoured vehicles with rubber tires loads was achieved by correlating their equivalent loads with the AASHTO equivalency factors. The equivalent load was developed on the basis of mechanistic - empirical approach. It was found that the damaging effect of the studied loads of CM32 four-axle military armoured vehicle with rubber tires is 0.262-2.853 times the damaging effect of the standard 18 kips (80 kN) axle load depending on the thickness of asphalt layer. It was found that the damaging effect of the studied loads of CM32 triple-axle military armoured vehicle with rubber tires is 0.933-4.880 times the damaging effect of the standard 18 kips (80 kN) axle load depending on the thickness of asphalt layer. It was found that the damaging effect of the braking forces of CM32 four-axle military armoured vehicle with rubber tires is 40 times the damaging effect of the CM32 four-axle military armoured vehicle weight only. It was found that the damaging effect of the braking forces of CM32 triple-axle military armoured vehicle with rubber tires is 5 times the damaging effect of the CM32 triple-axle military armoured vehicle weight only.

Key Words: Military Armoured Vehicles, Four-axle, Triple-axle AASHTO Equivalency Factors, Flexible Pavements, Braking Forces and Damaging Effect.

1. Introduction

1.1 General

The growth in truck traffic volumes as observed over the past few decades, combined with increasing commercial vehicle weights and dimensions, is causing the anticipated lifespan of many roadways to decrease (World Road Association, 2004). Consequently projected maintenance and preservation costs increase. Pavement deterioration is further intensified by an incentive for overweight trucks due to economic benefits of an increased payload (Paxson and Glickert, 1982). Faced with decreasing lifespan of their infrastructure, roadway agencies are investigating low-cost but effective methods of monitoring and enforcement (SDHT, 2005). The effect of the traffic using these roads should be focused upon carefully from the standpoint of pavement structural design. Yoder and Witczak (1975) reported that this effect includes among other considerations, the expected vehicle type and the corresponding number of repetitions of each type during the design life of the pavement. The effect of various types of vehicles (axles) on the structural design of road pavement is considered by means of the approach of axle load equivalency factor. In this approach, a standard axle load is usually used as a reference and the damaging effect of all other axle loads (corresponding to various types of axles) is expressed in terms of number of repetitions of the standard axle. The AASHTO standard axle is the 18 kips (80 kN) single axle with dual tires on each side (Yoder and Witczak' 1975). Thus, the AASHTO equivalency factor defines the number of repetitions of the 18 kips (80 kN) standard axle load which causes the same damage on pavement as caused by one pass of the axle in question moving on the same pavement under the same conditions. The AASHTO equivalency factor depends on the axle type (single, tandem, or triple), axle load magnitude, structural number (SN), and the terminal level of serviceability (pt). The effect of structural number (SN) and the terminal level of serviceability (pt) is rather small; however, the effect of axle type and load magnitude is pronounced (Razouki and Hussain, 1985). There are types of vehicle loads that not included in the AASHTO road test such as the heavy military rubber-tire armoured vehicles that move on paved roads occasionally during peace times and frequently during war times. **The effect of the military rubber-tire armoured vehicle loads on flexible pavement is not known, and not mentioned in the literature up to the capacity of the author's knowledge**. Therefore, this research was carried out to find the damaging effect in terms of AASHTO equivalency factors of military rubber-tire armoured vehicles that move frequently on our roads network (even on small local paved streets) on daily bases for more than six years up to now.

1.2 Static analysis

There are two main approaches used by researchers to determine the equivalency factors, the experimental and the mechanistic (theoretical) approach. A combination of two approaches was also used by Wang and Anderson (1979). In the mechanistic approach, some researchers adopted the fatigue concept analysis for determining the destructive effect (Havens et al., 1979), while others adopted the equivalent single wheel load procedure for such purposes (Kamaludeen,1987). The mechanistic empirical approach is used in this research depending on fatigue concept. Following Yoder and Witczak (1975), AASHTO design method recommended the use of 18 kips (80 kN) standard axle with dual tires on each side, thus, AASHTO equivalency factor F_j is:

$$F_j = \left(\frac{\varepsilon_j}{\boldsymbol{\varepsilon_s}}\right)^{\mathbf{c}} \ldots. \quad (1)$$

where, ε_j , ε_s = the maximum principal tensile strain for the jth axle and the 18 kips standard single axle respectively, and c represent regression constant. Yoder and Witczak (1975) reported that both laboratory tests and field studies have indicated that the constant c ranges between 3 and 6 with common values of 4 to 5.Van Til et. al. (1972) and AASHTO (1986) recommended two fatigue criteria for the determination of AASHTO equivalency factors namely, the tensile strain at the bottom fiber of asphalt concrete and the vertical strain on sub-grade surface. AASHTO (1986) reported a summary of calculations for tensile strain at the bottom fiber of asphalt concrete (as fatigue criterion) due to the application of 18 kips standard axle load on flexible pavement structures similar to that of original AASHTO road test pavements. Also, AASHTO (1986) reported a summary of calculations for vertical compressive strain on sub-grade surface (as rutting criterion) due to the application of 18 kips standard axle load on flexible pavement structures similar to that of original AASHTO road test pavements. The AASHTO (1986) calculated strains are function of the structural number (SN), the dynamic modulus of asphalt concrete, the resilient modulus of the base materials, the resilient modulus of roadbed soil, and the thickness of pavement layers. These reported AASHTO (1986) strains which represent (ε_s) in equation (1) above in addition to Van Til et. al. (1972) & Huang (1993) reported experimental values for the constant c in equation (1) above for different pavement structures. Huang (1993) reported that in fatigue analysis, the horizontal minor principal strain is used instead of the overall minor principal strain. This strain is called minor because tensile strain is considered negative. Horizontal principal tensile strain is used because it is the strain that causes the crack to initiate at the bottom of asphalt layer. The horizontal principal tensile strain is determined from:

$$\varepsilon_r = \frac{\varepsilon_x + \varepsilon_y}{2} - \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + (\gamma_{xy})^2} \quad \ldots\ldots (2) \qquad 2$$

where, ε_r = the horizontal principal tensile strain at the bottom of asphalt layer, ε_x = the strain in the x direction, ε_y = the strain in the y direction, γ_{xy} = the shear strain on the plane x in the y direction. Therefore, (ε_r) of equation (2) represents (ε_j) of equation (1) and will be used in fatigue analysis in this research. These two criteria were used in this research to determine the AASHTO equivalency factors of military rubber-tire armoured vehicles. The tensile strains at the bottom fiber of asphalt concrete and vertical compressive strains on sub-grade surface of similar pavement structures to that of AASHTO road test as reported by AASHTO (1986) were calculated under military rubber-tire armoured vehicles in this research. Also, a comparison was made between different calculated three-direction strains under military rubber-tire armoured vehicles on the surface of flexible pavement and that of AASHTO 18 kips standard axle to study the damaging effect of these military rubber-tire armoured vehicles on the functional features of the asphalt layer. KENLAYER linear elastic computer program (DOS version, Huang (1993)) was used to calculate the required strains and stresses in this research at 400 points each time in three dimensions at different locations within AASHTO reported pavement structures under military rubber-tire armoured vehicles.

1.3 Moving Loads and Braking Forces

AASHTO equivalency factors are determined based on static vehicle loads (AASHTO, 1986). Huang (1993) found in his simplified closed form solution of moving loads on flexible pavement that the effect of moving load on flexible pavement is less than the effect of static load because the maximum value of the moving load is equal to the value of static load at a certain point of time (haversine function).Therefore, the maximum damaging effect of moving load on flexible pavement is less than the damaging effect of the same load in static condition. Garber and Hoel (2002) reported that the maximum braking force (F) of a vehicle moving on a level road is equal to the maximum frictional force, which equals to the product of the weight of the vehicle W times the coefficient of friction f :

F = W x f	3

where, F = maximum braking force, W= weight of vehicle, and f = coefficient of friction. They reported that AASHTO represents the friction coefficient as (a/g), where a = vehicle deceleration and g = acceleration of gravity (32.2 ft/sec^2) to ensure that the pavement will have and maintain the coefficient of friction (f).

F = W x (a/g)	4

They reported that AASHTO recommended that a comfortable deceleration rate of 11.2 ft/sec^2 should be used. Also they reported that many studies have shown that when most drivers need to stop in an emergency the deceleration rate is greater than 14.8 ft/sec^2. Substituting the value of deceleration rate of 11.2 ft/sec^2 in equation (4) gives a value of 0.348W for the allowed braking force (F) by AASHTO. In the same way, a maximum value of braking force can be found to be 0.46W for an emergency stop. Therefore, the maximum damaging effect of a moving vehicle trying to stop equals to the damaging effect of its static vertical weight plus an additional value of a static horizontal force of 0.496W at a certain point of time during braking process. These braking forces are tangential stresses in addition to the normal weight of the tank. Poulos and Davis (1974) reported closed form solution for uniform horizontal stresses applied on a circular area placed on two layers pavement structure. This closed form solution will be used in this study to evaluate the damaging effect of tank braking forces on the asphalt pavement in terms of AASHTO equivalency factors as mentioned in section 1-2 above. For the purpose of the analysis of braking force the modulus of the sub-grade layer will be chosen to be similar to the modulus of the base layer in order to use the two layer pavement structure as mentioned in section 1-2 above.

The damaging effect of braking force on the flexible pavement structure is not mentioned in the literature up to the capacity of the authors knowledge, therefore the damaging effect of braking force will be studied to determine the value of this damage in comparison with the damage caused by weight only.

2- Characteristics of the military armoured vehicles with rubber tires

The characteristics of military armoured vehicles with rubber tires which required in this research are their three dimensions (height, length, and width) in addition to the weight. These features were obtained from the brochure of their manufacturing company (Timoney Technology Group, 2010) and the website website (The Federation of American Scientists, 2010). Two types of military armoured vehicles with rubber tiers were taken for the purpose of this study as follows (see Figure (1)):

1- CM32 four-axle eight-wheel military armoured vehicle was chosen to represent the family of four-axle military armoured vehicles with rubber tiers because it is widely used and can be converted to any other type and purpose (see Figure (2)).

2- CM32 triple-axle six-wheel military armoured vehicle was chosen to represent the family of triple-axle military armoured vehicles with rubber tiers because it is widely used and can be converted to any other type and purpose (see Figure (3)).

3-1 AASHTO equivalency factors of military armoured vehicles

Three-layer pavement structure was taken as mentioned in the introduction above to simulate AASHTO original road test pavements as shown in Figure (2) and Figure (3). Only one set of values for the modulus of asphalt layer ($E_{1=}$1035.5 MPa), the base layer ($E_{2=}$103.5 MPa), and the sub-grade modulus ($E_{3=}$51.7 MPa) was taken from the original AASHTO road test because it is similar to the modulus values of local materials in practice (Kamaludeen,1987). AASHTO Poisson's ratios of 0.4 for asphalt layer, 0.35 for base layer, and 0.4 for sub-grade layer were taken for the purpose of this analysis. Two types of military armoured vehicles with rubber tires were studied, namely CM32 four-axle and CM32 triple-axle as shown in Table (1).

3-1-1 AASHTO equivalency factors of CM32 four-axle military armoured vehicle

CM32 four-axle eight-wheel multipurpose military armoured vehicle was used to represent the family of four-axle military armoured vehicles that is widely used world wide. Three-layer pavement structure was taken as mentioned in the introduction above to simulate AASHTO original road test as shown in Figure (2). The contact areas of the eight wheels were calculated using three values for tire pressure namely, 0.828, 0.69, and 0.552 MPa respectively to study the effect of tire pressure on the AASHTO equivalency factors of these military armoured vehicle loads. The combat weight of 14.67 tons was distributed equally on the eight wheels because these vehicles have load distribution mechanism on equal bases.

Figure (4), Figure (5), and Figure (6) were prepared to show the calculated tensile strains in the direction of x, y, and r at the bottom fiber of asphalt concrete layer respectively under CM32 four-axle military armoured vehicle. These strains were obtained for 400 calculating points for each one of these figures with a tire pressure of 0.828 MPa and using KENLAYER computer program (DOS version, Huang (1993))**.** Figure (7) was prepared to show the calculated vertical compressive strains on the surface of sub-grade layer of AASHTO pavement structure shown in Figure (1) under CM32 four-axle armoured vehicle with a tire pressure (contact pressure) of 0.828 MPa. These strains were obtained for 400 calculating points using KENLAYER computer program (DOS version, Huang (1993))**.** It was found that the calculated tensile strains in the direction of x, y, and r at the bottom fiber of asphalt concrete layer are much more conservative than calculated vertical compressive strains on the surface of sub-grade layer under CM32 four-axle military armoured vehicle in comparison with their similar type of strains reported by AASHTO (1986)**,** as shown in Figures (4) to (7). Therefore, the fatigue criterion governed and was used to calculate the AASHTO equivalency factors of CM32 four-axle military armoured vehicle. The maximum calculated horizontal principal tensile strains (ε_r) at the bottom fiber of asphalt concrete layer under CM32 four-axle military armoured vehicle for the AASHTO (1986) pavement structures are summarized in Table (2). The AASHTO (1986) reported maximum tensile strains (ε_t) at the bottom fiber of asphalt concrete layer for the AASHTO pavement structures under the standard 18 kips (80 kN) are shown also in Table (2). The values for the constant c of equation (4) for each of AASHTO (1986) pavement structure were obtained from the values of Asphalt Institute as mentioned by Huang (1993). The AASHTO equivalency factors of CM32 four-axle military armoured vehicle were calculated using equation (1) as shown in Table (2).

3-1-2 Effect of tire pressure of CM32 four-axle military armoured vehicle on AASHTO equivalency factors

The maximum tensile strains in the direction of x and y at the bottom fiber of asphalt concrete layer and the vertical compressive strains on the surface of sub-grade layer under CM32 four-axle military armoured vehicle for the AASHTO (1986) pavement structures were recalculated using different tire pressure values of CM32 four-axle military armoured vehicle to study the effect on strain values as shown Table (3). These strains were calculated using only one AASHTO pavement structure shown in Figure (2) above. It was found that the tire pressure has very small effect on the value of strain and later on the value of AASHTO equivalency factors of CM32 four-axle military armoured vehicle loads. This can be attributed to the high load magnitude and the interlocking of the effects of eight loaded tires in three dimensions.
The same procedure mentioned in paragraph 3-1 and 3-1-1 above to determine the AASHTO equivalency factors of CM32 four-axle load as shown in Table (2) was repeated to determine the AASHTO equivalency factors of CM32 triple-axle military armoured vehicle as shown in Table (4). The only exception is that the dimensions and weight of CM32 triple-axle military armoured vehicle were used instead of the dimensions and weight of CM32 four-axle. Table (4) was prepared following the same procedure in preparing Table (2) to show the AASHTO equivalency factors of CM32 triple-axle load respectively. Also, the fatigue criterion governed and was used to calculate the AASHTO equivalency factors of CM32 triple-axle military armoured vehicle load. The maximum calculated horizontal principal tensile strain (ε_r) at the bottom of asphalt layer under CM32 triple-axle vehicle load for load layout shown in Figure (3) above for the AASHTO (1986) pavement structure are summarized in Table (4).

3-1-4 Effect of tire pressure of CM32 triple-axle military armoured vehicle on AASHTO equivalency factors

The maximum tensile strains in the direction of x and y at the bottom fiber of asphalt concrete layer and the vertical compressive strains on the surface of sub-grade layer under CM32 triple-axle military armoured vehicle for the AASHTO (1986) pavement structures were recalculated using different tire pressure values of CM32 triple-axle military armoured vehicle to study the effect on strain values as shown Table (5). These strains were calculated using only one AASHTO pavement structure shown in Figure (3) above. It was found that the tire pressure has very small effect on the value of strain and later on the value of AASHTO equivalency factors of CM32 triple-axle military armoured vehicle loads. This can be attributed to the high load magnitude and the interlocking of the effects of eight loaded tires in three dimensions.

3-2 Damaging Effect of Braking Forces

It was mentioned in section 1-3-1 above that closed form solution of uniformly distributed horizontal load on a circular area on the two layers pavement structure (Poulos and Davis (1974)) will be used to study the effect of braking force of the vehicle on asphalt pavement structure. Figure (8) was prepared to simulate the distribution of CM32 four-axle and triple-axle vehicle braking forces on pavement structure. Three-layer pavement structure was taken as mentioned in the introduction above to simulate AASHTO original road test pavements as shown in Figure (2) and Figure (3). Only one set of values for the modulus of asphalt layer (E_1=1035.5 MPa), the base layer (E_2=103.5 MPa), and the sub-grade modulus (E_3=103.5 MPa) was taken from the original AASHTO road test because it is similar to the modulus values of local materials in practice [(8)] and allows the use of two layers closed form solution because $E_2 = E_3$. AASHTO Poisson's ratio of 0.5 was taken for asphalt layer, base layer, and for sub-grade layer for the purpose of this analysis (the effect of Poisson's ratio is very small on analysis results, Huang (1993).

3-2-1 Damaging Effect of CM32 four-axle Braking Forces

Figure (9) was prepared to show the horizontal principal tensile (ε_r) under the vehicle due to horizontal braking forces combined with vehicle weight. Figure (10) was prepared to show the maximum vertical strain (ε_v) under CM32 four-axle vehicle due to horizontal braking forces combined with vehicle weight. Table (6) was prepared to show the results of braking force analysis.

3-2-2 Damaging Effect of CM32 triple-axle Braking Forces

Figure (11) was prepared to show the horizontal principal tensile (ε_r) under the vehicle due to horizontal braking forces combined with vehicle weight. Figure (12) was prepared to show the maximum vertical strain (ε_v) under CM32 triple-axle vehicle due to horizontal braking forces combined with vehicle weight. Table (7) was prepared to show the results of braking force analysis.

4- Discussion of results and Conclusions

It was found that the military armoured vehicles with rubber tires have a pronounced damaging effect on flexible pavements in terms of AASHTO equivalency factors as follows:

1- The AASHTO equivalency factors of CM32 four-axle military armoured vehicle loads were found to be from 0.262 to 2.853 based on fatigue criterion. Increasing the thickness of the asphalt layer pavement decreases the AASHTO equivalency factors of CM32 four-axle military armoured vehicle loads. This means that the structural damaging effect CM32 four-axle military armoured vehicle load on flexible pavements of secondary and local roads is higher than its damaging effect on the flexible pavement of major roads and highways. It was found that increasing the tire pressure has very small effect on the AASHTO equivalency factors of CM32 four-axle military armoured vehicle load. From the theoretical point of view, this can be attributed to the high magnitude of CM32 four-axle military armoured vehicle loads. It was found that the ratio of the maximum horizontal strain (ε_r) of CM32 four-axle vehicle due to braking forces to the weight only is 2.29 as shown in Table (6). Taking into consideration that this value should be raised to the power of 4.48 as shown in Table (2) to find the damaging effect due to braking forces only. This means, that the damaging effect of CM32 four-axle vehicle due to braking forces is more than 40 times the damaging effect of CM32 four-axle vehicle due to weight only. This result is very serious, taking into consideration that the AASHTO equivalency factors of CM32 four-axle military armoured vehicle loads were found to be as high as 2.853 based on fatigue criterion due to weight only.

2- The AASHTO equivalency factors of CM32 triple-axle military armoured vehicle loads were found to be from 0.933 to 4.880 based on fatigue criterion. Increasing the thickness of the asphalt layer pavement decreases the AASHTO equivalency factors of CM32 triple-axle military armoured vehicle loads. This means that the structural damaging effect CM32 triple-axle military armoured vehicle loads on flexible pavements of secondary and local roads is higher than its damaging effect on the flexible pavement of major roads and highways. It was found that increasing the tire pressure has very small effect on the AASHTO equivalency factors of CM32 triple-axle military armoured vehicle loads. From the theoretical point of view, this can be attributed to the high magnitude of CM32 triple-axle military armoured vehicle loads. It was found that the ratio of the maximum horizontal strain (ε_r) of CM32 triple-axle vehicle due to braking forces to the weight only is 1.47 as shown in Table (7). Taking into consideration that this value should be raised to the power of 4.48 as shown in Table (4) to find the damaging effect due to braking forces only .This means, that the damaging effect of CM32 triple-axle vehicle due to braking forces is more than 5 times the damaging effect of CM32 triple-axle vehicle due to weight only. This result is very serious, taking into consideration that the AASHTO equivalency factors of CM32 triple-axle military armoured vehicle loads were found to be as high as 4.880 based on fatigue criterion due to weight only.

5- Recommendations

Based on the results of this study, an economic evaluation for the cost of damage that had been caused by the frequent movement of CM32 military armoured vehicles with rubber tires on the whole national road network during the last six years is required. Also, another study is necessary to determine the damaging effect of military armoured vehicles with rubber tires on the national road network during summer seasons.

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Notations

a vehicle deceleration.
c regression constant.
E_1 the modulus of asphalt layer.
E_2 the modulus of the base layer.
E_3 the modulus of subgrade layer.
f coefficient of friction.
F_j AASHTO equivalency factor.
F maximum braking force.
g acceleration of gravity.
t_1 thickness of asphalt layer.
t_2 thickness of base layer.
W weight of vehicle.

Greek letters

ε_j the maximum principal tensile strain for the jth axle.
ε_s the maximum principal tensile strain for the 18 kips standard single axle.
ε_r the horizontal principal tensile strain at the bottom of asphalt layer.
ε_x the strain in the x direction.
ε_y the strain in the y direction.
γ_{xy} the shear strain on the plane x in the y direction.
ε_v compressive strain on the top of subgrade soil.
ε_t tensile strain at the bottom of asphalt layer.
μ_1 Poisson's ratio of asphalt layer.
μ_2 Poisson's ratio of the base layer
μ_3 Poisson's ratio of subgrade layer.

Table (1): Features of the two studied military armoured vehicles.		
Features	**Type of military armoured vehicle**	
	CM32 Four-axle	**CM32 Triple-axle**
Length (m)	6.35	6.57
Width (m)	2.7	2.23
Height (m)	2.23	2.70
Combat Weight (ton)	14.67	14.67

Table (2): AASHTO equivalency factors of CM32 four-axle military armoured vehicle using fatigue criterion and for load layout in Figure (2).

Modulus Layer 1 = 1035.5 MPa, μ_1 = 0.40						
Modulus Layer 2 = 103.5 MPa, μ_2 = 0.35						
Modulus Layer 3 = 51.724 MPa, μ_3 = 0.40						
Thickness Layer 1 cm	**Thickness Layer 2 cm**	**Source of Data**	**Asphalt Tensile strain (ε_t)**	**SN**	**c**	**CM32 AASHTO Equivalency Factor**
7.62	**56.64**	**AASHTO**(1)	**0.0006212**	**4**	**4.48**	2.853
7.62	**56.64**	Calculated(2)	0.0007850	**4**	**4.48**	2.853
10.16	**47.50**	**AASHTO**(1)	**0.0005395**	**4**	**4.48**	1.516
10.16	**47.50**	Calculated(2)	0.0005920	**4**	**4.48**	1.516
12.70	**59.18**	**AASHTO**(1)	**0.0004561**	**5**	**4.48**	0.950
12.70	**59.18**	Calculated(2)	0.0004510	**5**	**4.48**	0.950
15.24	**50.04**	**AASHTO**(1)	**0.0003897**	**5**	**4.48**	0.262
15.24	**50.04**	Calculated(2)	0.0002890	**5**	**4.48**	0.262
20.32	**52.58**	**AASHTO**(1)	**0.0002854**	**6**	**4.48**	0.338
20.32	**52.58**	Calculated(2)	0.0002240	**6**	**4.48**	0.338

(1) AASHTO maximum horizontal strain (ε_t) at the bottom fiber of asphalt layer under the standard 18 kips (80 kN) axle load for terminal of serviceability (Pt) of 2.0.

(2) Calculated maximum horizontal principal tensile strain (ε_r) at the bottom of asphalt layer under CM32 four-axle for load layout shown in Figure (2) above.

Table (3): Effect of tire pressure of four-axle military armoured vehicles on strains(*).

Tire Pressure MPa	**Max. Tensile Strain (ε_x)**	**Max. Tensile Strain (ε_y)**	**Max. Compressive Strain (ε_v)**
0.828	**0.0007850**	**0.0007850**	**0.0002150**
0.690	**0.0007070**	**0.0007070**	**0.0002130**

(*): Maximum strains ε_x, ε_y, and ε_z were calculated for the pavement structure shown in Figure (2), (E_1=1035.5 MPa, E_2=103.5 MPa, E_3=51.7 MPa, t_1=7.6 cm, t_2=56.6 cm, μ_1=0.4, μ_2=0.35, and μ_3=0.4).

Table (4): AASHTO equivalency factors of CM32 triple-axle military armoured vehicle using fatigue criterion and for load layout in Figure (3).

Modulus Layer 1 = 1035.5 MPa, μ_1 = 0.40						
Modulus Layer 2 = 103.5 MPa, μ_2 = 0.35						
Modulus Layer 3 = 51.724 MPa, μ_3 = 0.40						
Thickness Layer 1 cm	**Thickness Layer 2 cm**	**Source of Data**	**Asphalt Tensile strain (ε_t)**	**SN**	**c**	**CM32 6X6 AASHTO Equivalency Factor**
7.62	**56.64**	**AASHTO[1]**	**0.0006212**	**4**	**4.48**	4.880
7.62	**56.64**	Calculated[2]	0.0008850	**4**	**4.48**	4.880
10.16	**47.50**	**AASHTO[1]**	**0.0005395**	**4**	**4.48**	3.010
10.16	**47.50**	Calculated[2]	0.0006900	**4**	**4.48**	3.010
12.70	**59.18**	**AASHTO[1]**	**0.0004561**	**5**	**4.48**	2.110
12.70	**59.18**	Calculated[2]	0.0005390	**5**	**4.48**	2.110
15.24	**50.04**	**AASHTO[1]**	**0.0003897**	**5**	**4.48**	1.550
15.24	**50.04**	Calculated[2]	0.0004300	**5**	**4.48**	1.550
20.32	**52.58**	**AASHTO[1]**	**0.0002854**	**6**	**4.48**	0.933
20.32	**52.58**	Calculated[2]	0.0002810	**6**	**4.48**	0.933

(1) AASHTO maximum horizontal strain (ε_t) at the bottom fiber of asphalt layer under the standard 18 kips (80 kN) axle load for terminal of serviceability (Pt) of 2.0.

(2) Calculated maximum horizontal principal tensile strain (ε_r) at the bottom of asphalt layer under CM32 for load layout shown in Figure (3) above.

Table (5): Effect of tire pressure of triple-axle armoured vehicles on strains (*).

Tire Pressure MPa	**Max. Tensile Strain (ε_x)**	**Max. Tensile Strain (ε_y)**	**Max. Compressive Strain (ε_v)**
0.828	0.0008850	0.0008850	0.000282
0.690	0.0007820	0.0007820	0.000280

(*): Maximum strains ε_x, ε_y, and ε_z were calculated for the pavement structure shown in Figure (3), (E_1=1035.5 MPa, E_2=103.5 MPa, E_3=51.7 MPa, t_1=7.6 cm, t_2=56.6 cm, μ_1=0.4, μ_2=0.35, and μ_3=0.4).

Table (6): Effect of CM32 four axle vehicle braking forces.

Type of Vehicle Load	**Max Horizontal Strain (ε_r)**	**Max Vertical Strain (ε_v)**
weight only	0.00002802	0.00008141
weight +Braking	0.0000770	0.00009999
Braking only	0.00006415	0.00003230

Table (7): Effect of CM32 triple axle vehicle braking forces.		
Type of Vehicle Load	**Max Horizontal Strain (ε_r)**	**Max Vertical Strain (ε_v)**
weight only	0.00002886	0.00005823
weight +Braking	0.00003869	0.00007459
Braking only	0.00004253	0.00002312

CM32 four-axle **CM32 triple-axle**

Figure (1): CM32 military armoured vehicles with rubber tiers.

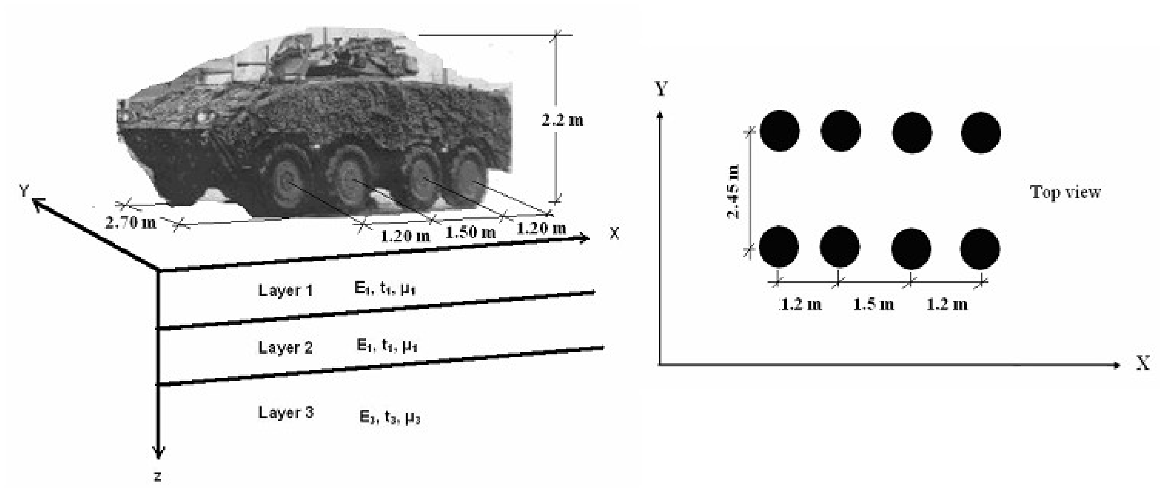

Figure (2): CM32 four-axle armoured vehicle with rubber tiers

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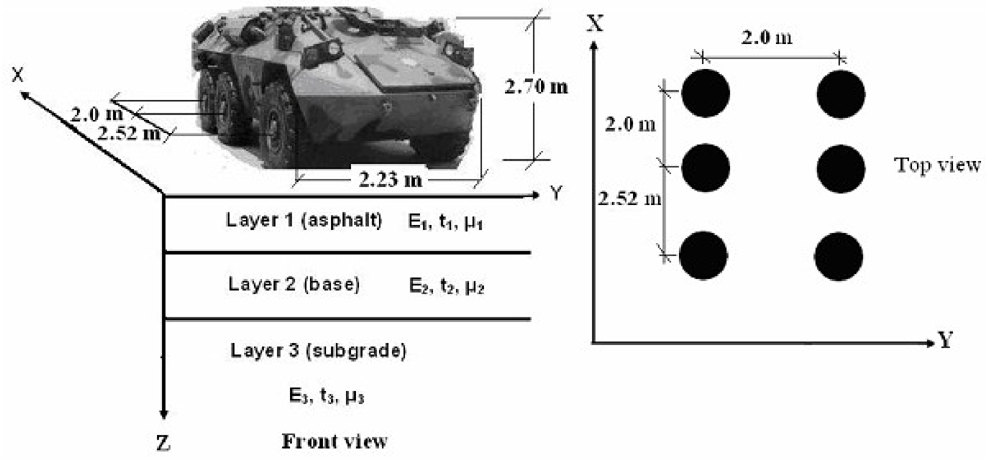

Figure (3): CM32 triple-axle armoured vehicle with rubber tiers

.

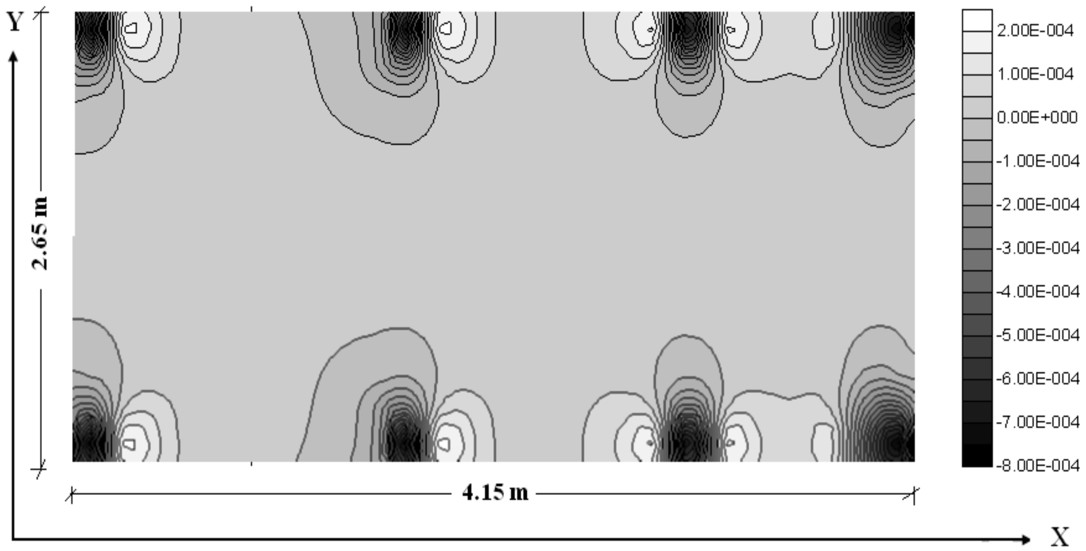

Figure (4): Tensile strain in the x direction (ε_x) at the bottom fiber of asphalt layer (t_1=7.6 cm and t_2=56.6 cm).

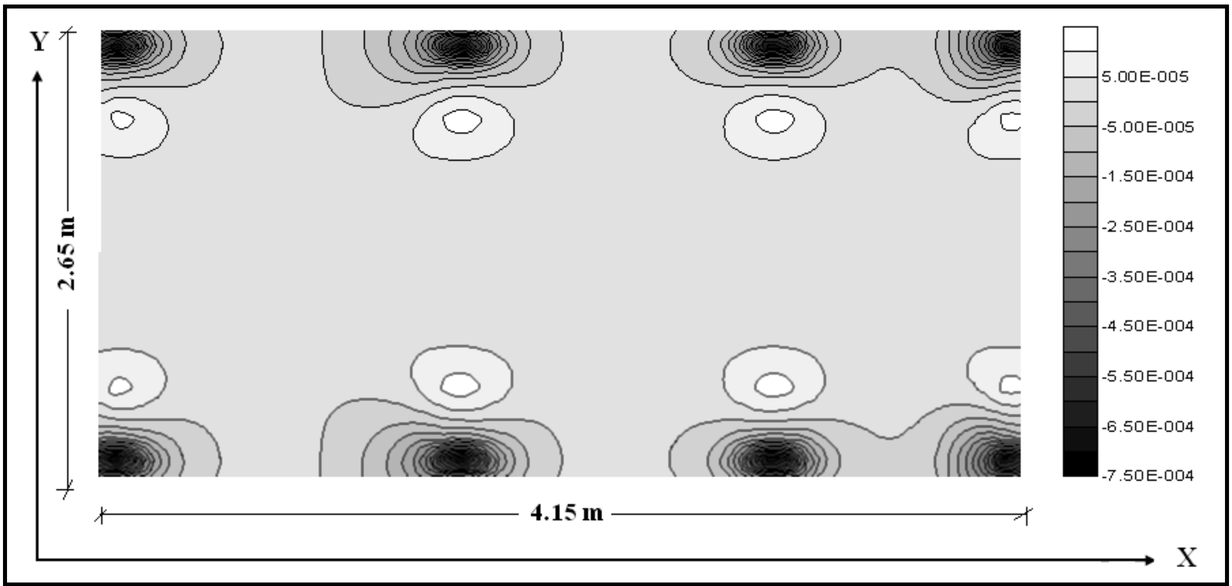

Figure (5): Tensile strain in the y direction (ε_y) at the bottom fiber of asphalt layer (t_1=7.6 cm and t_2=56.6 cm).

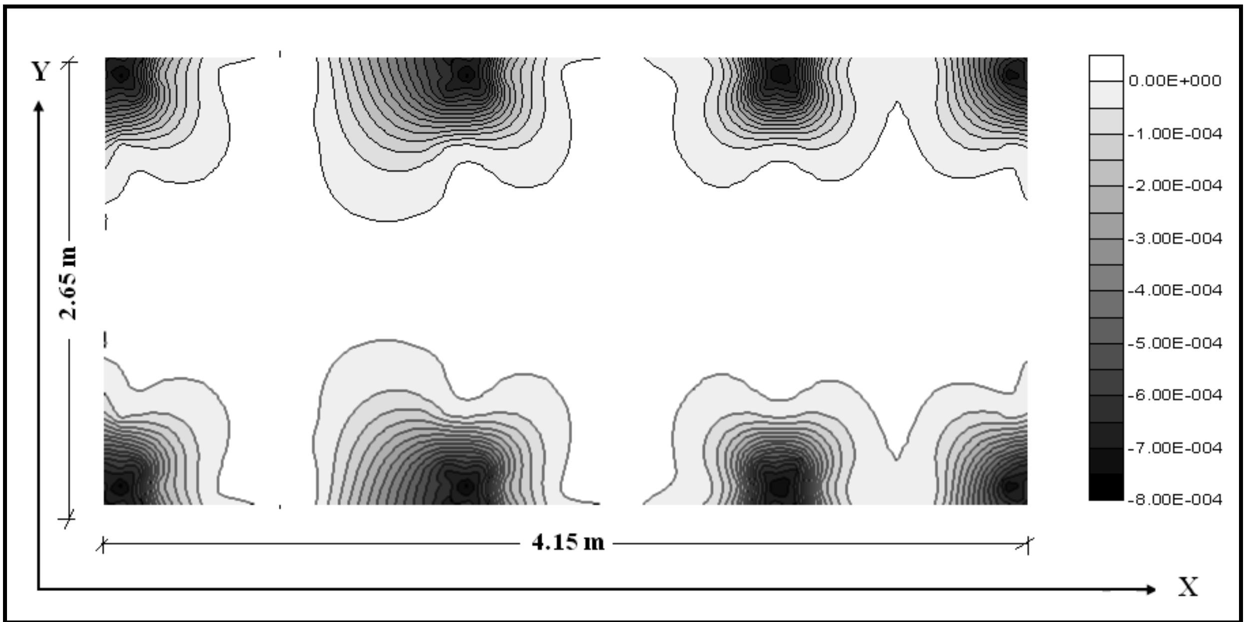

Figure (6): Horizontal principal tensile strain at the bottom of asphalt layer (ε_r) (t_1=7.6 cm and t_2=56.6 cm).

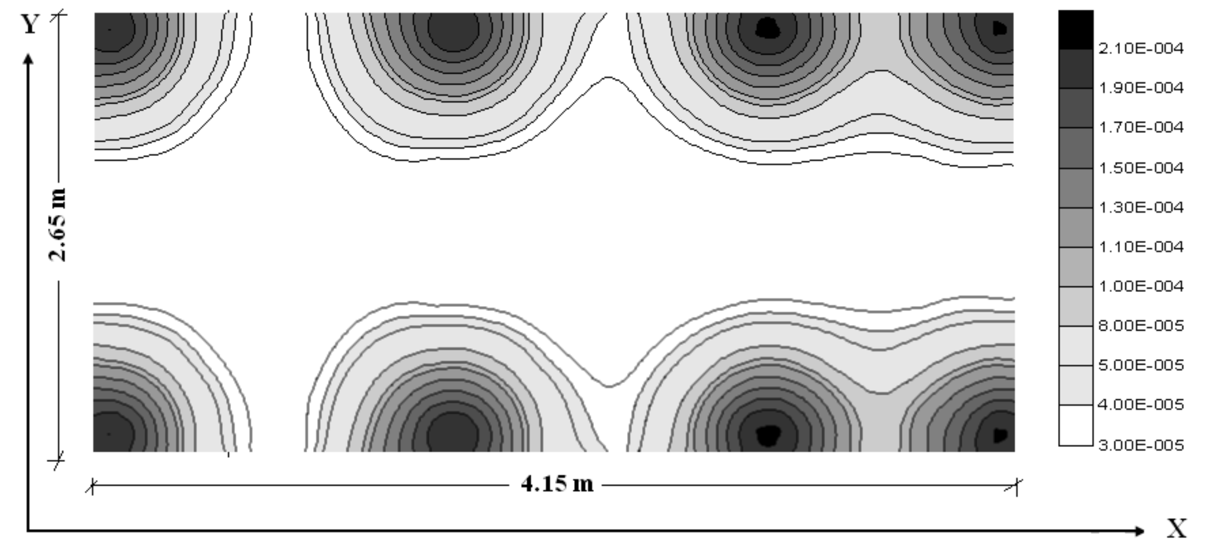

Figure (7): Vertical strain in the z direction (ε_z) on the surface of sub-grade layer (t_1=7.6 cm and t_2=56.6 cm).

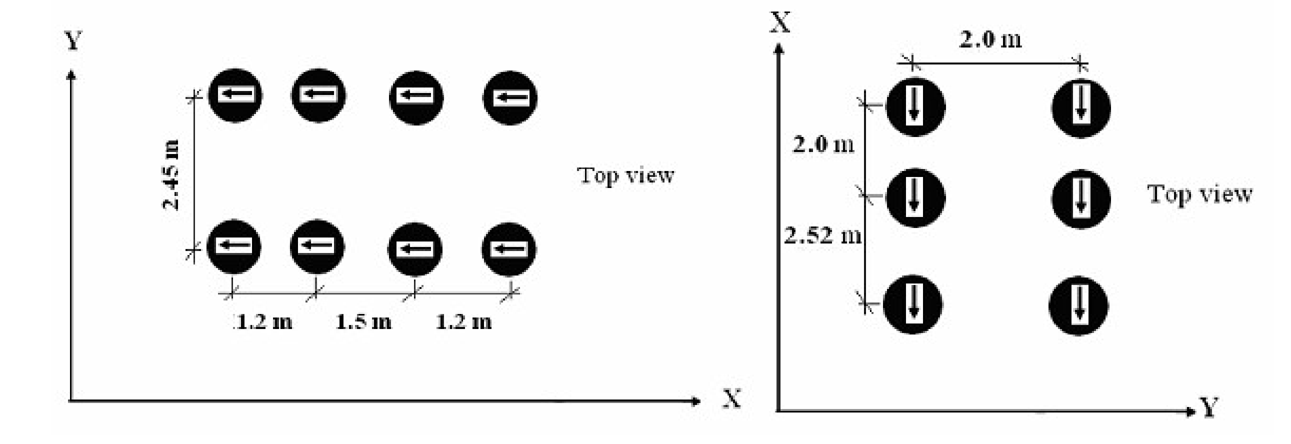

Figure (8): The layout of braking forces of four-axle and triple-axle military armoured vehicles on the pavement for analysis purposes.

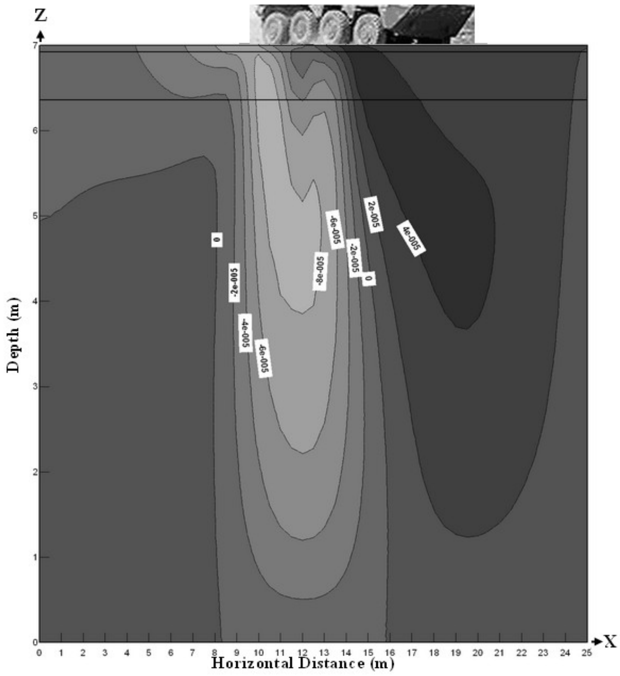

Figure (9): Horizontal principal tensile strain (ε_r) due to braking force combined with vehicle weight of CM32 four-axle as shown in Figure (8),

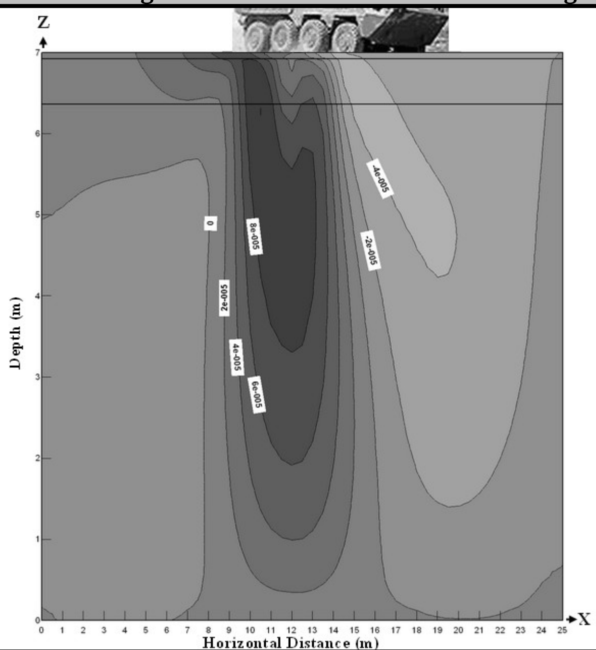

Figure (10): Vertical strain (ε_v) due to braking force combined with vehicle weight of CM32 four-axle as shown in Figure (8).

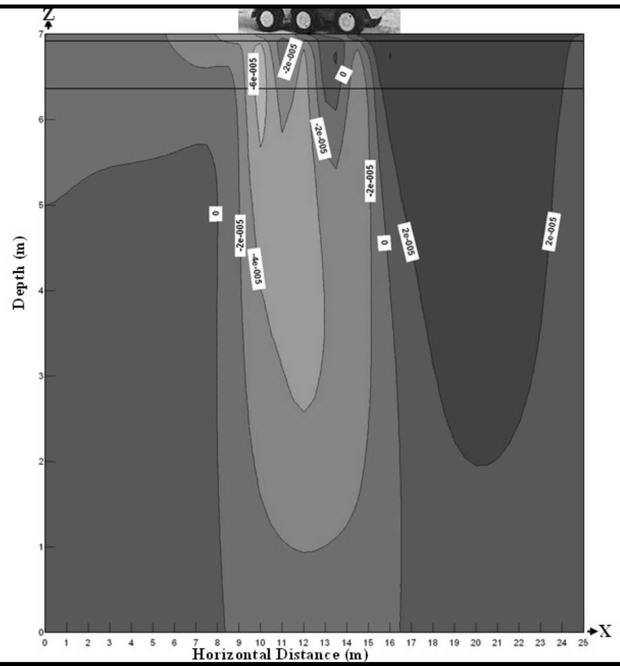

Figure (11): Horizontal principal tensile strain (ε_r) due to braking force combined with vehicle weight of CM32 triple-axle in Figure (8).

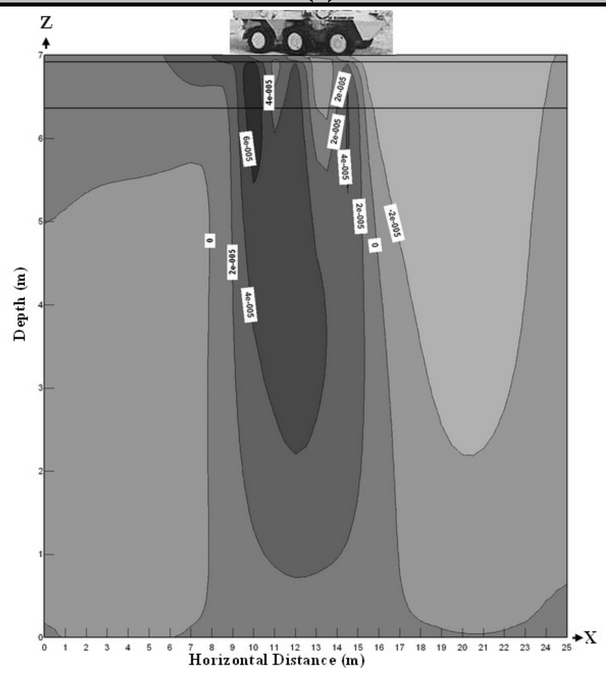

Figure (12): Vertical strain (ε_v) due to braking force combined with vehicle weight of CM32 triple-axle as shown in Figure (8).

التأثير التخريبي لأحمال ألعجلات المدرعة الساكنة والمتحركة ذات الإطارات المطاطية على التبليط ألإسفلتي

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الخلاصة

تمت دراسة التأثير التخريبي لأحمال ألعجلات المدرعة ذات الإطارات المطاطية رباعية وثلاثية المحاور على التبليط الإسفلتي من خلال أبجاد معاملات آشتو المكافئة لها ولأول مرة وباستخدام طريقة الحل الميكانيكي – التجريبي. لقد وجد إن التأثير التخريبي لأحمال العجلات المدرعة رباعية المحاور ذات الإطارات المطاطية التي تمت دراستها يتراوح من **0.262** إلى **2.853** مرة تأثير حمل آشتو القياسي حسب سمك طبقة الإسفلت. . لقد وجد إن التأثير التخريبي لأحمال العجلات المدرعة ثلاثية المحاور ذات الإطارات المطاطية التي تمت دراستها يتراوح من**0.933** إلى **4.880** مرة تأثير حمل آشتو القياسي حسب سمك طبقة الإسفلت. لقد وجد إن التأثير التخريبي لقوى الفرملة للعجلات المدرعة رباعية المحاور ذات الإطارات المطاطية هو **40** مرة بقدر التأثير التخريبي لوزن نفس العجلات فقط. لقد وجد إن التأثير التخريبي لقوى الفرملة للعجلات المدرعة ثلاثية المحاور ذات الإطارات المطاطية هو **٥** مرات بقدر التأثير التخريبي لوزن نفس العجلات فقط.