DAMAGING EFFECT OF MOVING TANK LOADS ON FLEXIBLE PAVEMENT

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ABSTRACT

Presented in this paper is a new study of the damaging effect of the tank loads on flexible pavements. The equivalent load was developed on the basis of mechanistic - empirical approach. It was found that the damaging effect of the studied tank loads is 0.898 to 2.356 times the damaging effect of the standard 18 kips (80 kN) axle load. It was found that the damaging effect of tank braking forces is 2.375 times the damaging effect of tank weight only in terms of tensile stain (fatigue cracking). It was found that the damaging effect of tank turning maneuver is 1.216 times the damaging effect of tank weight only in terms of tensile stain (fatigue cracking). These loads have also severe damaging effects on the functional serviceability of the surface of asphalt layer.

KEY WORDS: Tanks, AASHTO, Equivalency Factors, Braking Forces, Turning Maneuver, Flexible Pavement, and Damaging Effect.

التأثير التخريبي لأحمال ألدبابات المتحركة على التبليط ألإسفلتي

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الخلاصة

دراسة جديدة للتأثير التخريبي لأحمال الدبابات المتحركة على التبليط الإسفلتي من خلال أبجاد معاملات آشتو المكافئة لها ولأول مرة وباستخدام طريقة الحل الميكانيكي – التجريبي. لقد وجد إن تأثير الأحمال التخريبية للدبابة التي تمت درستها يتراوح بين 0.898– 2.356 مرة تأثير حمل آشتو القياسي. ولقد وجد إن التأثير التخريبي لقوى التوقف للدبابة التي تمت درستها هو 2.375مرة بقدر التأثير التخريبي لوزن الدبابة و إن التأثير التخريبي لمناورة الدوران للدبابة التي تمت درستها هو 1.216 مرة بقدر التأثير التخريبي لوزن الدبابة إضافة إلى التأثيرات التخريبية الأخرى على الخواص الوظيفية لطبقة الإسفلت السطحية.

الكلمات الرئيسية: دبابات, آشتو, معاملات مكافئة, قوى الاحتكاك, مناورة الدوران, التبليط المرن, و التأثير التخريبي.

- INTRODUCTION

- Static Analysis

Road projects are considered the most important and expensive part of the civil infrastructure and the progress backbone of any nation's economy all over the world. The planning, design, construction, and maintenance of roads attracted and attracting more importance. 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 (and axles distribution) 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 (2). 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) are 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 tanks that move on paved roads occasionally during peace times and frequently during war times. **The effect of these tank loads on flexible pavements 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 equivalency factors based on AASHTO method and the damaging effect of T family of military tanks. 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, 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), the equivalent wheel load factor defines the damage per pass caused to a specific pavement by the vehicle in question relative to the damage per pass of an arbitrarily selected standard vehicle moving on the same pavement system:

$$\mathbf{EWLF} = \mathbf{F_j} = \left(\frac{\mathbf{d_j}}{\mathbf{d_s}}\right) = \left(\frac{\mathbf{N_{fs}}}{\mathbf{N_{fj}}}\right) \qquad \mathbf{(1)}$$

where, **EWLF** = $\mathbf{F_j}$ = equivalent wheel load factor, $\mathbf{d_j}$ = (1/ $\mathbf{N_{fj}}$), $\mathbf{d_s}$ = (1/ $\mathbf{N_{fs}}$), $\mathbf{d_j}$ & $\mathbf{d_s}$ = damage per pass for the **j**th vehicle and the standard vehicle respectively, and **Nfj** & $\mathbf{N_{fs}}$ = number of repetitions to failure for the **j**th vehicle and the standard vehicle respectively.
AASHTO (1986) design method recommended the use of 18 kips (80 kN) standard axle with dual tires on each side, thus, the AASHTO equivalency factor $\mathbf{F_j}$ becomes:

$$\mathbf{F_j} = \left(\frac{\mathbf{d_j}}{\quad}\right) = \left(\frac{\mathbf{N_{18}}}{\quad}\right) \qquad \mathbf{(2)}$$

d_s N_{fj}

where, N_{18} & N_{fj} = number of repetitions to failure for the 18 kips standard single axle and the **j**th axle respectively.

Following Yoder and Witczak (1975) fatigue results of asphalt concrete have shown that the number of repetitions to failure can be related to the tensile strain in the form of:

$$N_f = k_q \left(\frac{1}{\varepsilon_q}\right)^c \tag{3}$$

where, **ε** = the maximum principal tensile strain, **k** and **c** represent regression constants, and the subscript **q** is the test or pavement temperature (modulus).
Using this equation, the F_j in equation (2) above for any vehicle can be expressed by:

$$F_j = \left(\frac{\varepsilon_j}{\varepsilon_s}\right)^c \tag{4}$$

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 (4) above in addition to Van Til et. al. (1972) & Huang (1993) reported experimental values for the constant c in equation (4) 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:

$$\varepsilon_r = \frac{\varepsilon_x + \varepsilon_y}{2} - \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + (\gamma_{xy})^2} \tag{5}$$

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 (5) represents (ε_j) of equation (4) 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 T family of military tanks. 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 T-72 military tank in this research. Also, a comparison was made between different calculated three-direction strains under T-72 military tank at the surface of flexible pavement and that of AASHTO 18 kips standard axle to study the damaging effect of these tanks on the functional features of the asphalt layer. KENLAYER computer program (DOS version by 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 T-72 military tank.

- Dynamic Analysis

Moving Load and Braking Forces

AASHTO (1986) equivalency factors are determined based on static vehicle loads. 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**):

$$\mathbf{F} = \mathbf{W} \times \mathbf{f} \qquad (6)$$

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 9.81 m/sec^2 (32.2 ft/sec^2) to ensure that the pavement will have and maintain the coefficient of friction (**f**).

$$\mathbf{F} = \mathbf{W} \times (\mathbf{a}/\mathbf{g}) \qquad (7)$$

They reported that AASHTO recommended that a comfortable deceleration rate of 3.41 m/sec^2 (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 4.51 m/sec^2 (14.8 ft/sec^2). Substituting the value of deceleration rate of 3.41 m/sec^2 (11.2 ft/sec^2) in equation (7) gives a value of 0.348**W** for the allowed braking force (**F**) by AASHTO. In the same way, a maximum value of braking force can be found to be 0.46**W** 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 0.496**W** 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 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 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.

Turning Maneuver of a Tank

It was noticed that when a tank or any tracked vehicle tries to carry out a turning maneuver tangential stresses are applied to the surface of asphalt pavement. These stresses are generated by the relative movement of one side of the track while the other is not in movement (locked). These stresses are tangential stresses in addition to the normal weight of the tank. These stresses can be simulated by two opposite directions.

Poulos and Davis (1974) presented 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 turning maneuver on the asphalt pavement as mentioned in section 1 above. For the purpose of the analysis of turning movement 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 above. **The damaging effect of the tank turning movement on the flexible pavement structure is not mentioned in the literature up to the capacity of the authors,** therefore the damaging effect of turning movement forces will be studied to determine the value of this damage in comparison with the damage caused by tank weight only.

- CHARACTERISTICS OF T FAMILY OF MILITARY TANKS

The characteristics of T family of military tanks which required in this research are their three dimensions (height, length, and width) in addition to weight. The width and length of the tank track in contact with the surface of flexible pavement are required, also. These features were obtained from the brochure of the manufacturing company (Uralvagonzavod, 2009) and the website (Fas, 2009). The width and the length of the track in contact with the surface of asphalt pavement were measured from the available tank markings on the surface of asphalt concrete pavements at different locations. Figure (1) and Figure (2) were prepared to show the obtained characteristics of T family of military tanks. The combat weight of this tank of 41 tons was taken for the purpose of analysis as the gross tank load (Fas, 2009).

Figure (1): T-72 military tank (Uralvagonzavod, 2009).

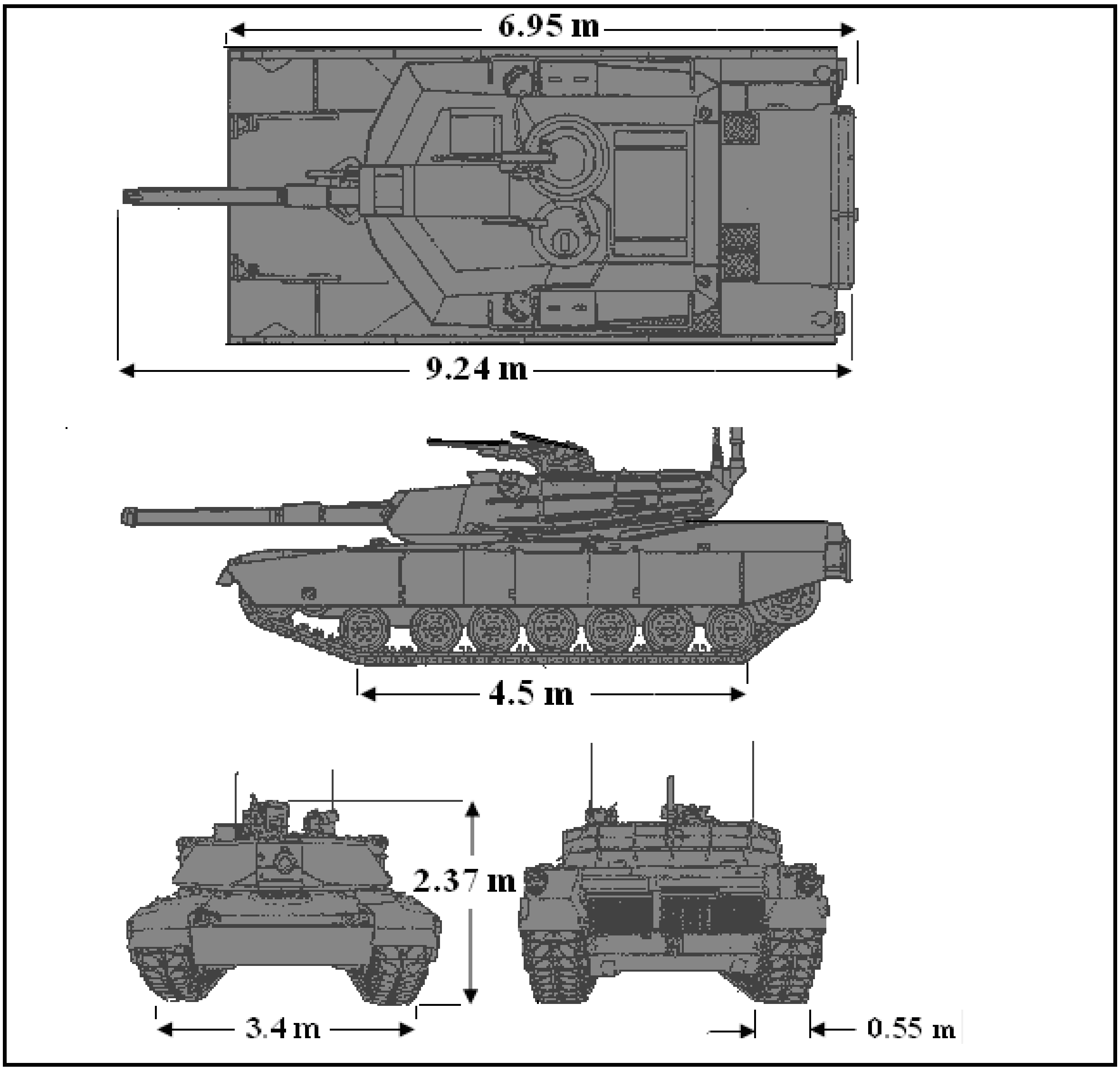

Figure (2): Dimensions of T-72 military tank (Fas, 2009).

- ANALYSIS METHODOLOGY

The simulation of T-72 military tank loads

T-72 military tank was used to represent T family of military tanks (main combat tank (Fas, 2009)) that is widely used. The length of the track of the tank that in direct contact with the ground was taken as 4.50 m as shown in Figure (2) above.

This length value was obtained from the brochure of the manufacturing company (Uralvagonzavod, 2009) and the website (Fas, 2009) in addition to that this width value was found to be almost equal to that measured from markings left on the surface of asphalt layer at different locations. The value for the width of the track of 0.55 m was taken in the analysis.

The simulation of tank loads in this analysis was taken as shown in Figure (3) which represents the (0.55 m x 4.50 m) track on each side of the tank. This track area was simulated by 9 circular areas on each side of the tank with a radius of (0.240 m) each to take the maximum contact width of the track into consideration and to keep the same tank load without change.

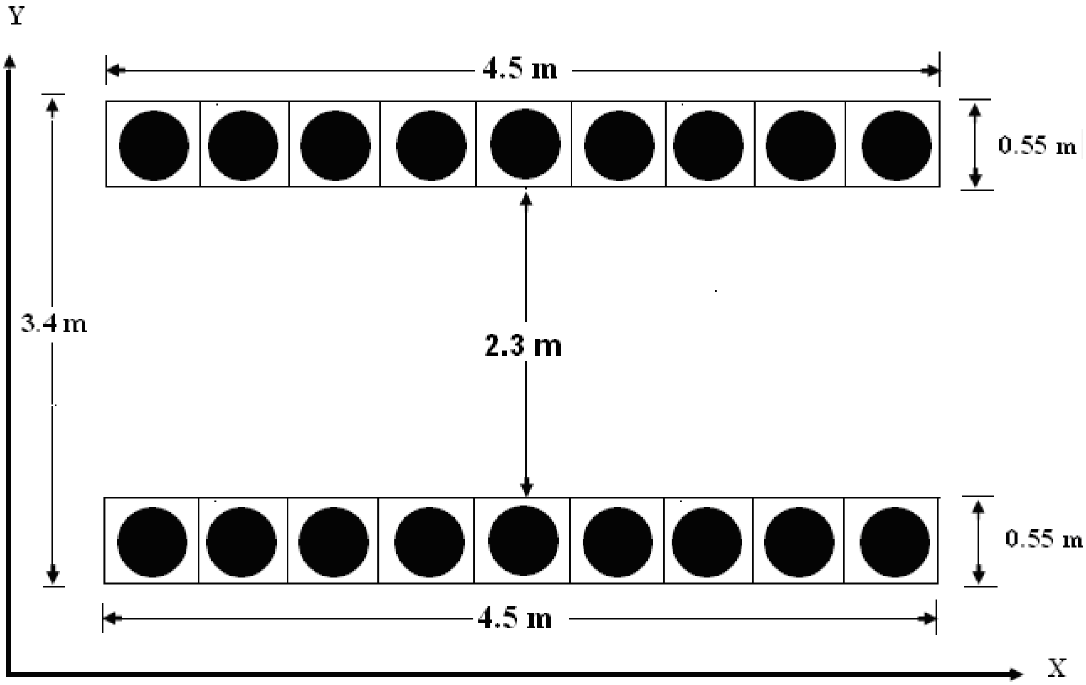

Figure (3): Simulation of the distribution of tank loads on the surface of flexible pavement for analysis purposes.

AASHTO equivalency factors of T-72 military tank loads

Three-layer pavement structure was taken as mentioned in the introduction above to simulate AASHTO original road test pavements as shown in Figure (4).

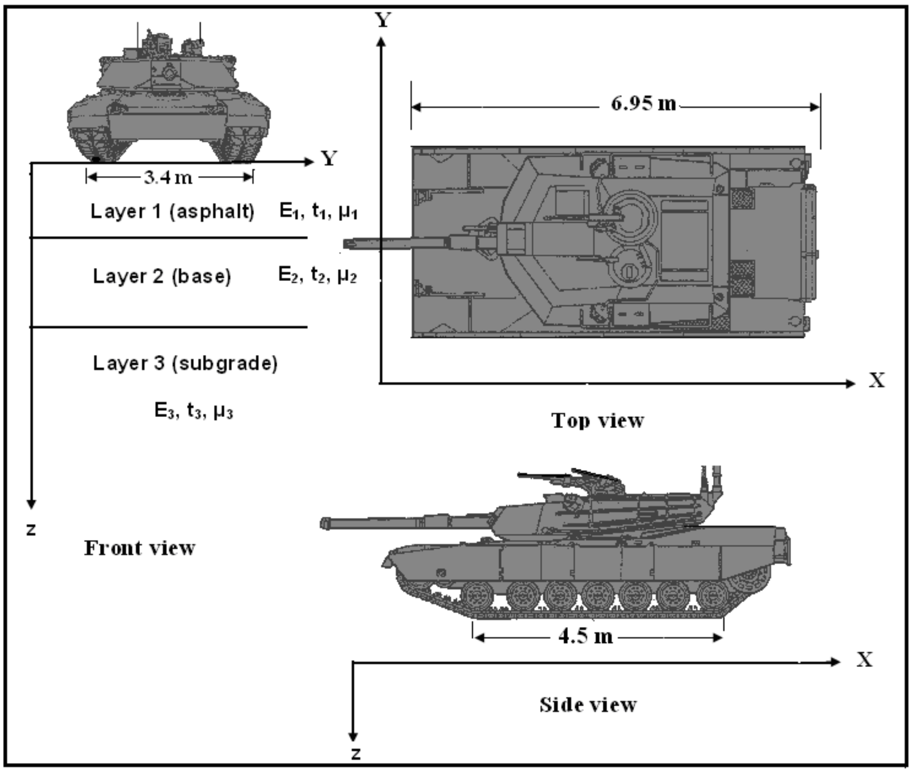

Figure (4): The layout of the tank on the pavement for analysis purposes.

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 ratio (**μ_1**) = 0.4 for asphalt layer, (**μ_2**) = 0.35 for base layer, and (**μ_3**) = 0.4 for sub-grade layer were taken for the purpose of this analysis (Yoder and Witczak, 1975).

Figure (5), Figure (6), and Figure (7) 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 the T-72 military tank. These calculated strains were for the AASHTO pavement structure shown in Figure (4) and for the simulation shown in Figure (3) above for the layout of T-72 tank loads. These strains were obtained for 400 calculating points for each one of these Figures using KENLAYER computer program (DOS version by Huang, 1993). Figure (8) was prepared to show the calculated vertical compressive strains on the surface of sub-grade layer of AASHTO pavement structure shown in Figure (4) under T-72 military tank. These strains were obtained for 400 calculating points using KENLAYER computer program (DOS version by Huang, 1993). It was found that the calculated vertical compressive strains on the surface of sub-grade layer under T-72 military tank are much more conservative than calculated tensile strains in the direction of x, y, and r at the bottom fiber of asphalt concrete layer in comparison with their similar type of strains reported by AASHTO (1986), as shown in Figure (5) to Figure (8). Therefore, the rutting criterion governed and was used to calculate the AASHTO equivalency factors of T-72 military tank.

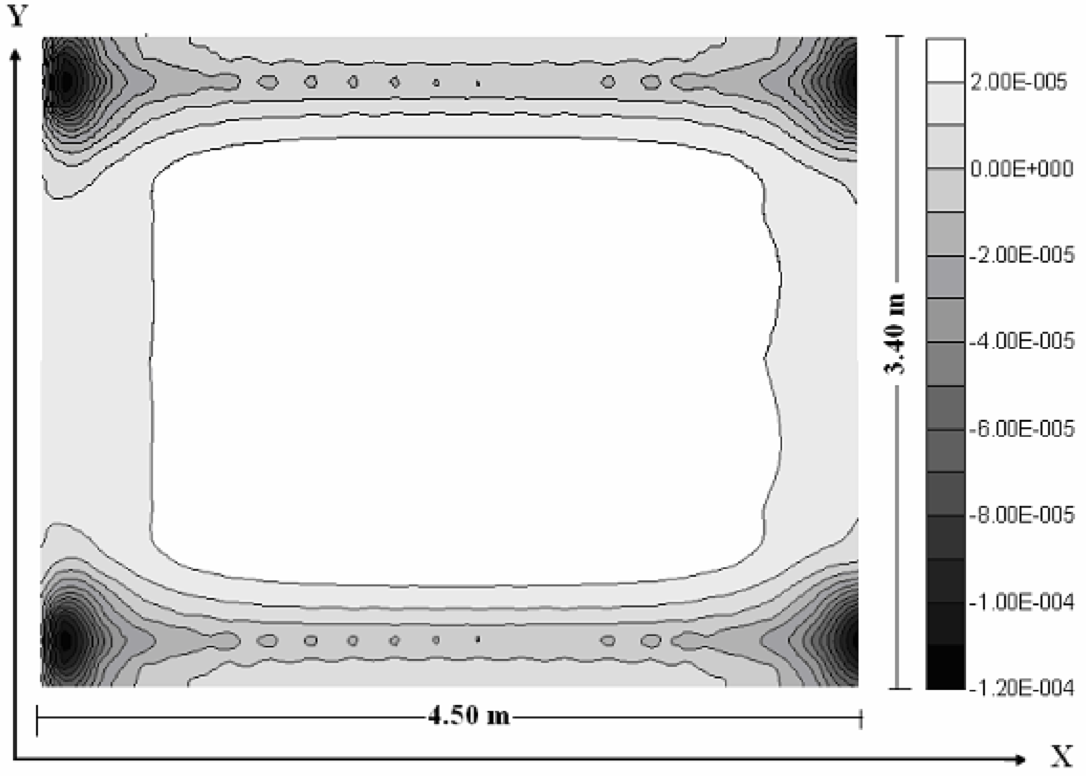

Figure (5): Tensile strain in the x direction (ε_x) at the bottom fiber of asphalt layer (t_1=7.6 cm and t_2=56.6 cm).

The maximum calculated vertical compressive strains on the surface of sub-grade layer under T-72 military tank for the AASHTO (1986) pavement structures are summarized in Table (1). The AASHTO (1986) reported maximum vertical compressive strains on the surface of sub-grade layer for the AASHTO pavement structures under the standard 18 kips (80 kN) are shown also in Table (1). The values for the constant c of equation (4) for each one of AASHTO (1986) pavement structures were obtained from Van Til et. al. (1972). The AASHTO equivalency factors of T-72 military tank were calculated using equation (4) are shown in Table (1).

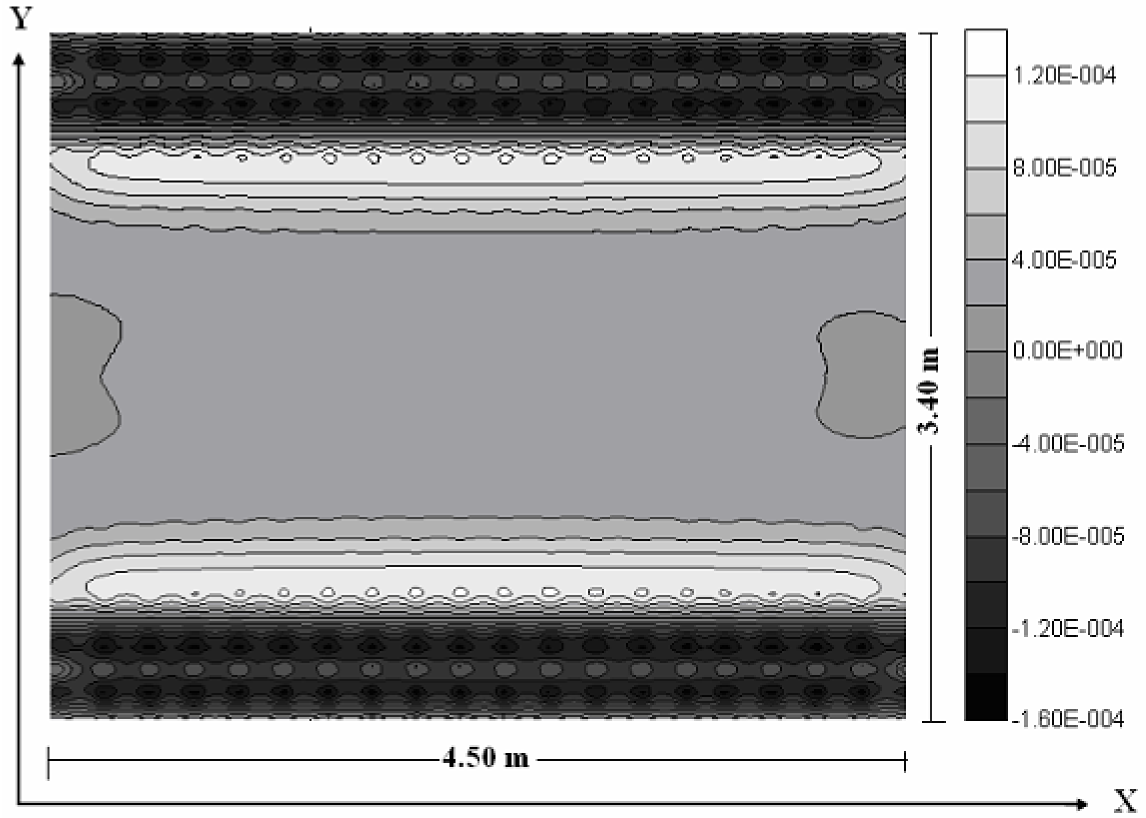

Figure (6): Tensile strain in the y direction (ε_y) at the bottom fiber of asphalt layer (t_1=7.6 cm and t_2=56.6 cm).

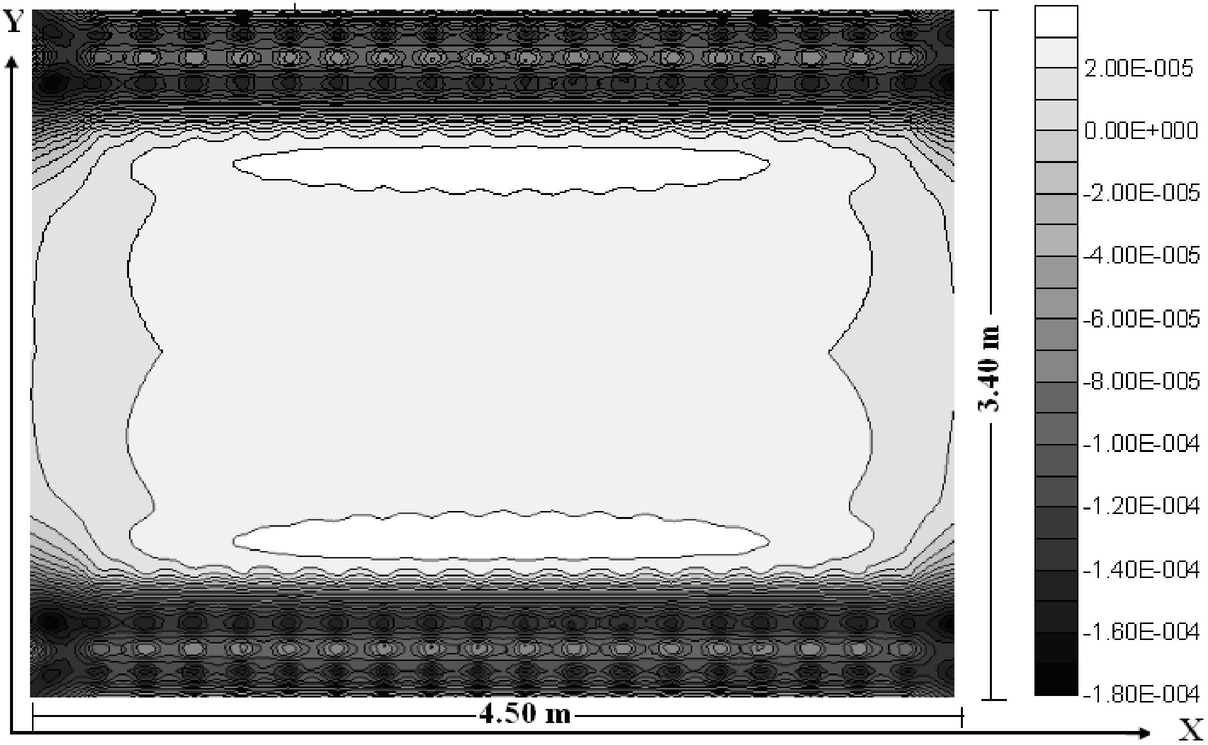

Figure (7): Horizontal principal tensile strain at the bottom of asphalt layer (ε_r) (t_1=7.6 cm and t_2=56.6 cm).

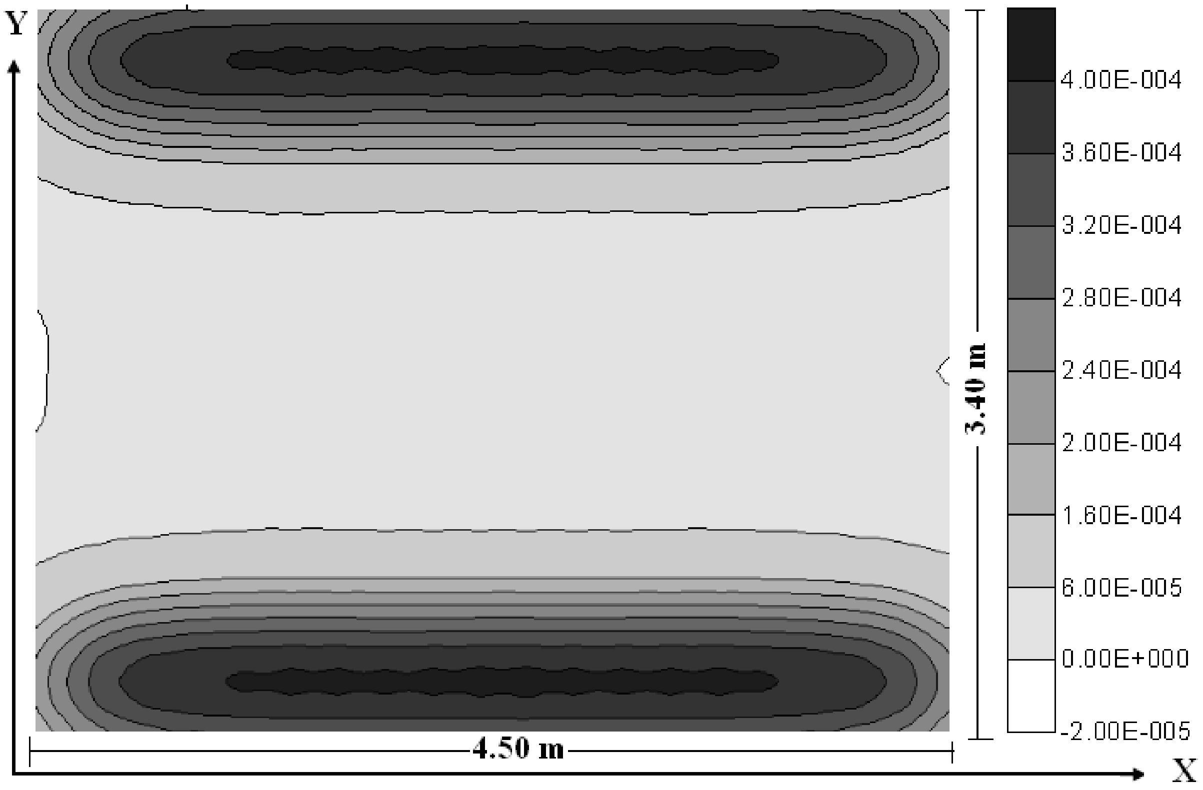

Figure (8): Vertical strain in the z direction (ε_z) on the surface of sub-grade layer (t_1=7.6 cm and t_2=56.6 cm).

Table (1): AASHTO equivalency factors of T-72 tank using rutting criterion and for tank load simulation (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 = 51.7 MPa, μ_3 = 0.40						
Thickness Layer 1 cm	**Thickness Layer 2 cm**	**Source of Data**	**Vertical strain (ε_z) on sub-grade**	**SN**	**c**	**Tank AASHTO Equivalency Factor**
7.62	**56.64**	**AASHTO**(1)	**0.0004330**	**4**	**3.54**	0.898
7.62	**56.64**	Calculated(2)	0.0004200	**4**	**3.54**	0.898
10.16	**47.50**	**AASHTO**(1)	**0.0005280**	**4**	**3.43**	0.600
10.16	**47.50**	Calculated(2)	0.0004550	**4**	**3.43**	0.600
12.70	**59.18**	**AASHTO**(1)	**0.0003420**	**5**	**3.43**	1.397
12.70	**59.18**	Calculated(2)	0.0003770	**5**	**3.43**	1.397
15.24	**50.04**	**AASHTO**(1)	**0.0003740**	**5**	**3.43**	1.280
15.24	**50.04**	Calculated(2)	0.0004020	**5**	**3.43**	1.280
20.32	**52.58**	**AASHTO**(1)	**0.0002940**	**6**	**4.29**	2.356
20.32	**52.58**	Calculated(2)	0.0003590	**6**	**4.29**	2.356

(1)AASHTO (1986) maximum vertical strain (ε_z) on the sub-grade surface under the standard 18 kips (80 kN) axle load for terminal of serviceability (Pt) of 2.0.

(2) Calculated maximum vertical strain (ε_z) on the sub-grade surface under the T-72 military tank for simulated layout of tank loads as shown in Figure (3) above.

Damaging Effect of Braking Forces

It was mentioned in section 1-2-1 above that closed form solution of uniformly distributed horizontal load on a circular area on the two layers pavement structure (10) will be used to study the effect of braking force of the tank on asphalt pavement structure. Figure (9) was prepared to simulate the distribution of tank braking force 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 (4).

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 (Kamaludeen, 1987) 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).

Figure (10) was prepared to show the horizontal principal tensile (ε_r) under the tank due to horizontal braking forces combined with tank weight. Figure (11) was prepared to show the maximum vertical strain (ε_v) under the tank due to horizontal braking forces combined with tank weight. Table (2) was prepared to the results of braking force analysis.

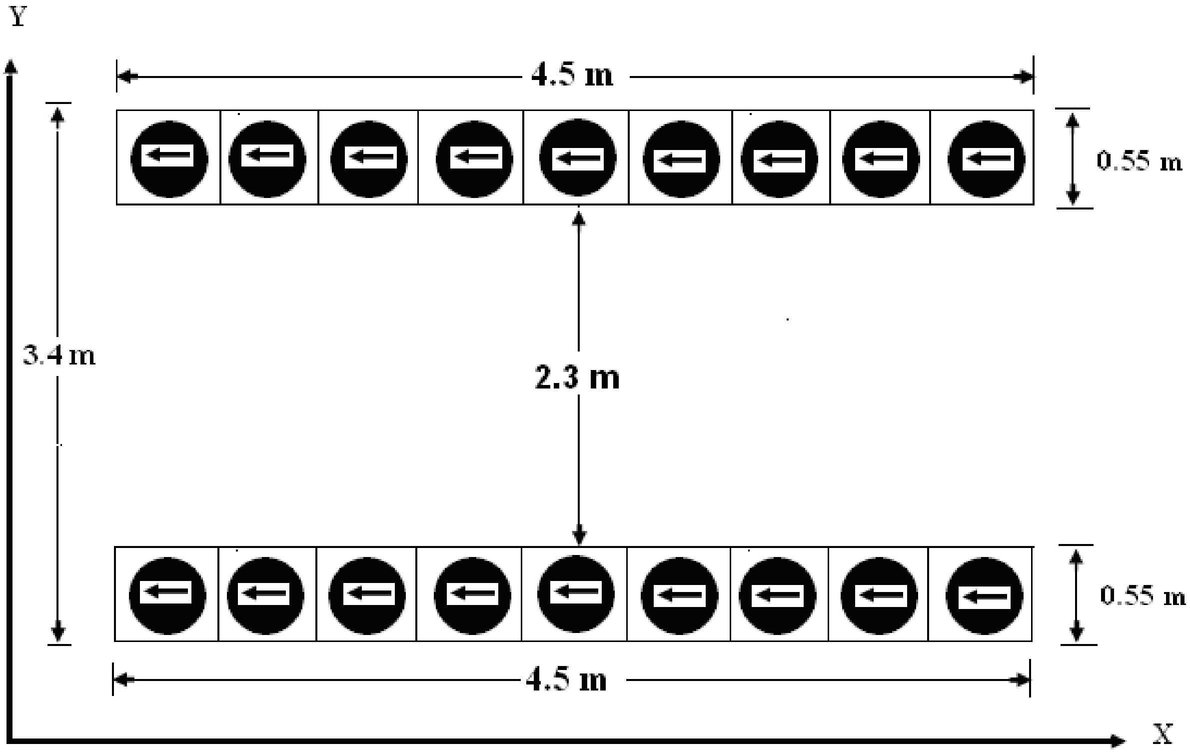

Figure (9): Simulation of tank braking forces distribution for analysis purposes.

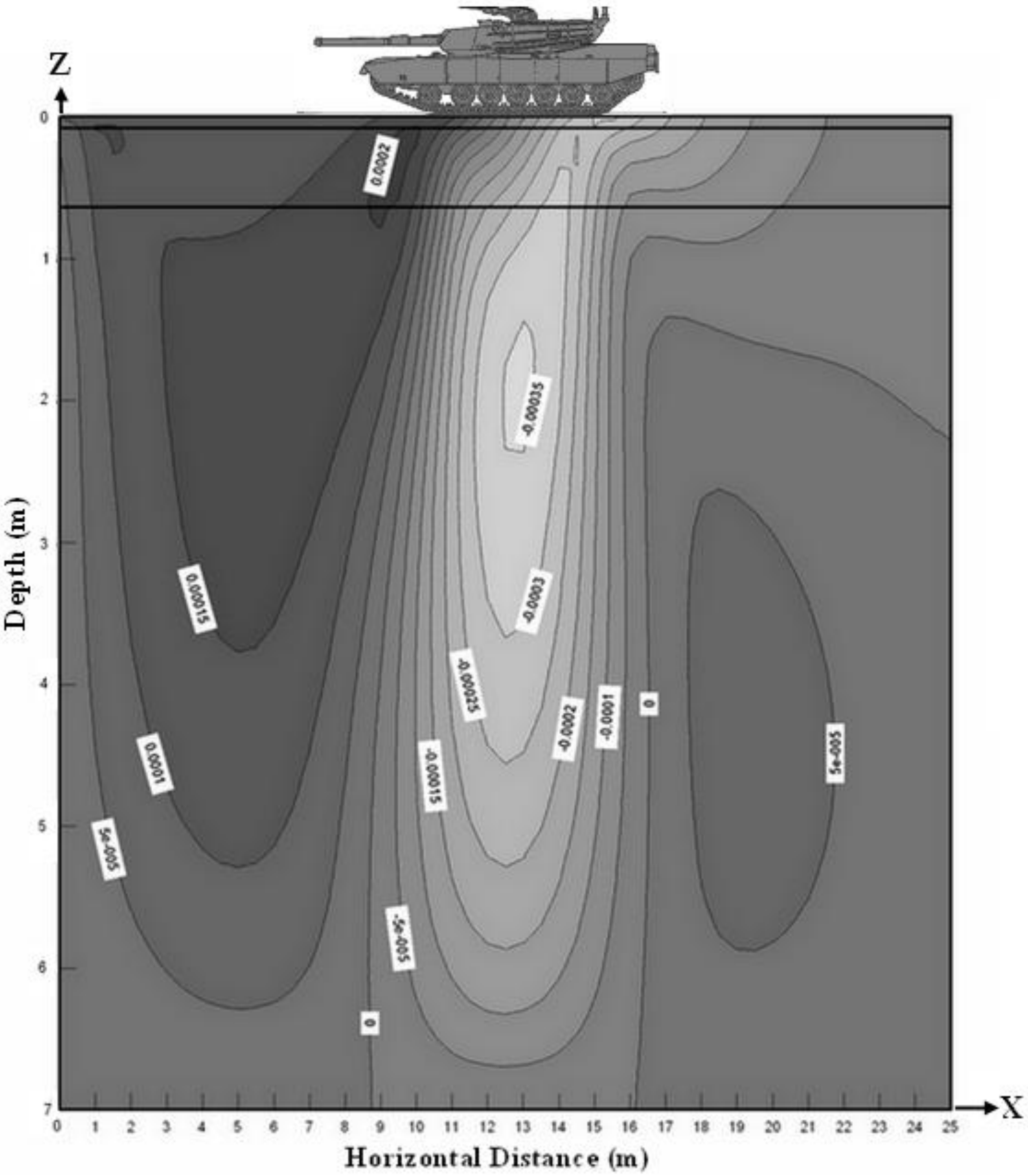

Figure (10): Horizontal principal tensile strain (ε_r) due to braking force combined with tank weight as shown in figure (9),(t_1=7.6 cm and t_2=56.6 cm).

Damaging Effect of Tank Turning Maneuver

It was mentioned in section 1-2-1 above that closed form solution of uniformly distributed horizontal load on a circular area on the two layers pavement structure [(10)] will be used to study the effect of tank turning maneuver on asphalt pavement structure. Figure (12) was prepared to simulate the distribution of tank turning maneuver force 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 (4).

Table (2): Effect of tank braking force.

Type of Tank Load	Max Horizontal Strain (ε_r)	Max Vertical Strain (ε_v)
weight only	0.0000940	0.0002898
weight +Braking	0.0003000	0.0003379
Braking only	0.0002233	0.0001243

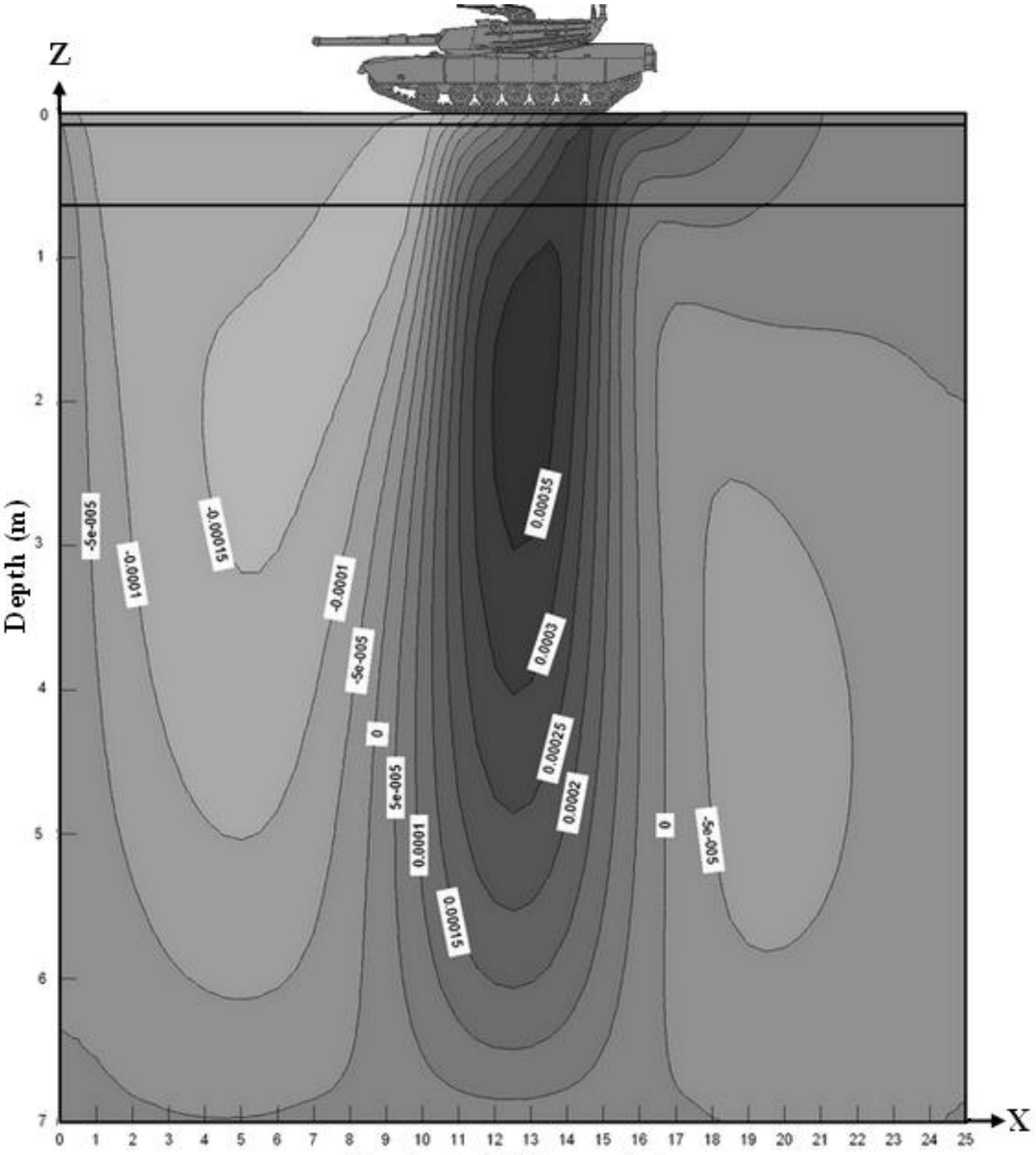

Figure (11): Vertical strain (ε_v) due to braking force combined with tank weight as shown in figure (9), (t_1=7.6 cm and t_2=56.6 cm).

Damaging Effect of Tank Turning Maneuver

It was mentioned in section 1-2-1 above that closed form solution of uniformly distributed horizontal load on a circular area on the two layers pavement structure [(10)] will be used to study the effect of tank turning maneuver on asphalt pavement structure. Figure (12) was prepared to simulate the distribution of tank turning maneuver force 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 (4). Only one set of values for the modulus of asphalt layer ($\mathbf{E_1}$=1035.5 MPa), the base layer ($\mathbf{E_2}$=103.5 MPa), and the sub-grade modulus ($\mathbf{E_3}$=103.5 MPa) was taken from the original AASHTO road test because it is similar to the modulus values of local materials in practice (Kamaludeen, 1987) and allow the use of two layers closed form solution because $\mathbf{E_2} = \mathbf{E_3}$. 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)). Table (3) was prepared to show the results of the damaging effect of the tank turning movement.

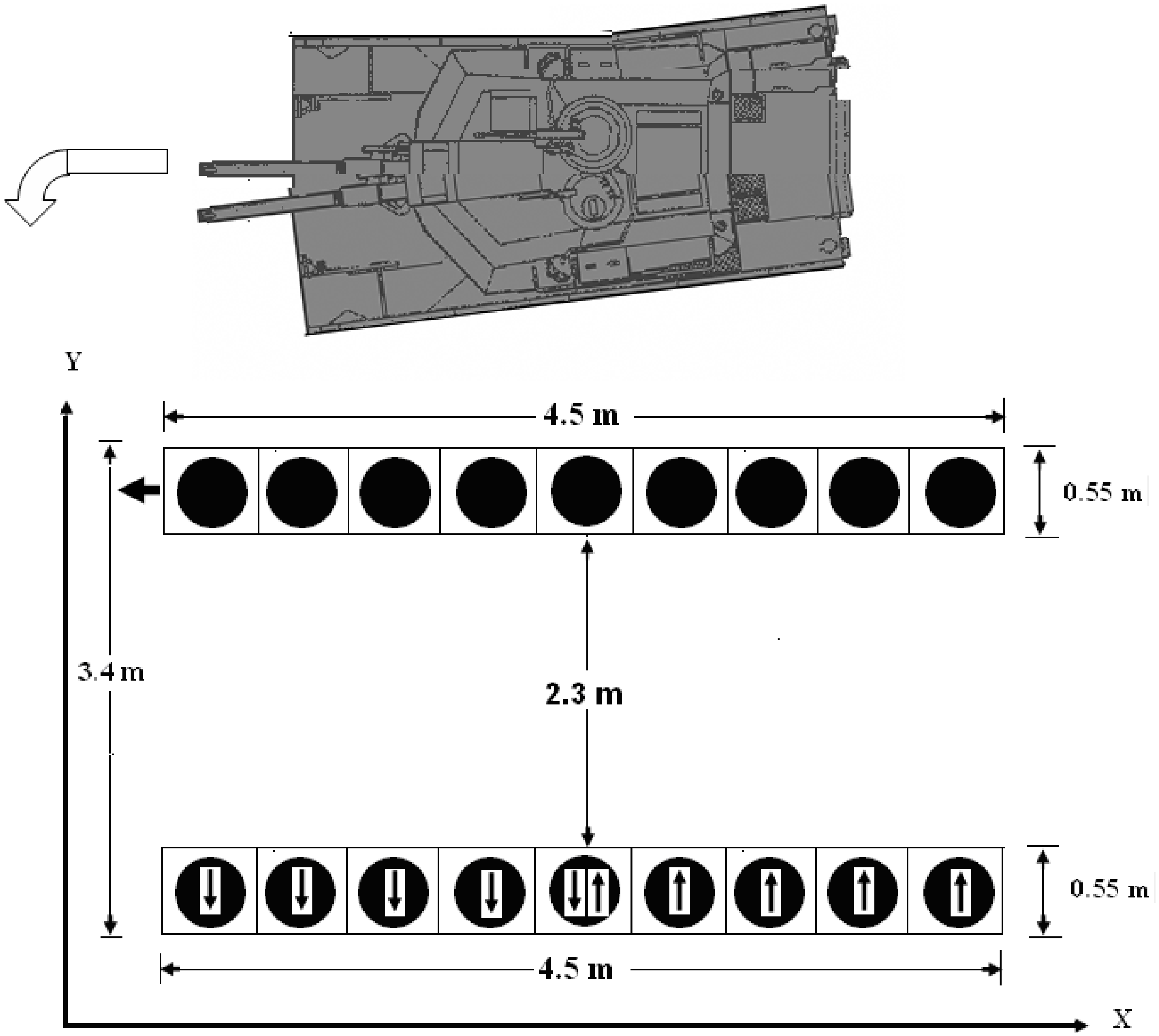

Figure (12): Simulation of tank turning maneuver loads distribution for analysis purposes.

Table (3): Effect of tank turning maneuver forces

Type of Tank Load	Max Horizontal Strain (ε_r)	Max Vertical Strain (ε_v)
weight only	0.00002996	0.00009719
weight +Turning	0.00004142	0.00009906
Turning only	0.00003643	0.00001636

- COMPARISON OF T-72 TANK LOADS WITH OTHER MILITARY TANKS

In order to compare the damaging effect of T-72 military tank loads with other types of military tanks in the world, two families of tanks were considered. The first was the American family of Abrams M1 military tanks and the British family of Challenger military tanks. The most important features of the military tanks that affect on the magnitude of the AASHTO equivalency factors of any tank are the weight of the tank and the area of contact with the surface of pavement, in other words, the contact pressure. Table (4) was prepared to compare the weight, contact area of one side of tank track, and the contact pressure of different types of military tanks around the world (Fas, 2009). The contact pressure of T-72 military tank is the lowest and the damaging effect of its loads is the lowest too.

Table (4): Comparison between features of different tanks (Fas, 2009).

Tank Property	**Type of Tank**				
	Abrams M1A1	**Challenger 1**	**Challenger 2**	**T-72**	**T-90**
Track Length In contact (m)	5.35	6.13	5.20	4.5	4.3
Track Width In contact (m)	0.61	0.61	0.61	0.55	0.55
Combat Weight (ton)	69	62.5	62.5	41	46
Contact Pressure (MPa)	0.104	0.082	0.097	0.081	0.095

- DISCUSSION OF RESULTS AND CONCLUSION

It was found that T-72 military tank has a pronounced damaging effect on flexible pavements in terms of AASHTO equivalency factors. The AASHTO equivalency factors of T-72 military tank were found to be from 0.83 to 2.36 based on rutting criterion. Increasing the thickness of the asphalt layer pavement increases the AASHTO equivalency factors of T-72 military tank. This means that the structural damaging effect of T-72 military tank on flexible pavements of major highways and main principal roads is much more than its damaging effect on the flexible pavement of local and secondary roads.

It was found that the damaging effect of tank braking forces is 2.375 times the damaging effect of tank weight only in terms of tensile stain (fatigue cracking) as shown in table (2). It was found that the damaging effect of tank turning maneuver forces is 1.216 times the damaging effect of tank weight only in terms of tensile stain (fatigue cracking) as shown in table (3).It was found also, that T-72 military tank has a severe damaging effect on the functional serviceability of surface of asphalt layer in terms of deformation and strains due to the effect of metal track.

- RECOMMENDATIONS

- 1-Based on the results of this study, an economic evaluation for the cost of damage that had been caused by the frequent movement of T family of military tanks on the national road network is required.

- 2-Another study is necessary to determine the damaging effect of military tanks on the national road network during summer seasons.

- REFERENCES

- AASHTO, " AASHTO guide for the design pavement structures 1986", The American Association of State Highway and Transportation Officials, Washington D.C., 1986.

- Fas, Military Analysis Network, www.fas.org., Feb. 3rd, 2009.

- Garber, N. J., and Hoel, L. A. " Traffic & Highway Engineering", Int. Student Ed., Thomson Corporation, United States, 2002.

- Havens, J. H., Southgate, H.F., and Deen, R, C, "Fatigue damage to flexible pavements under heavy loads", TRB record 725, 1979.

- Huang, Yang H., "Pavement analysis and design", 1st. edition, Prentice Hall, Inc., New Jersey, USA, 1993.

- Kamaludeen, N. M., "Damaging effect of triple axle loads on flexible pavements", M.Sc. thesis, College of Engineering, University of Baghdad, Baghdad, 1987.

- Poulos, H. G., and Davis, E. H., "Elastic Solutions for Soil and Rock Mechanics", John Wiley and Sons, Inc., New York, 1974.

- Razouki, S. S., and Hussain, S. F., "Equivalency factors for floating tandem axle loads on flexible pavements", Proceedings, Iraqi Conference on Engineering, ICE 85, College of Engineering, University of Baghdad, vol. 1, Baghdad, 1985.

- Uralvagonzavod Co.,"T-72 brochure", Russian Federation, http://www.army-guide.com, Feb. 3rd, 2009.

- Van Til , C. J., McCullough, B. F., Vallerga, B. A., and Hicks, R. G., "Evaluation of AASHTO interim guides for design of pavement structures", Highway Research Board, NCHRP report 128, Washington D.C., 1972.

- Wang, M.C., and Anderson, R. P., "Load equivalency factors for triaxial loading for flexible pavements", TRB record 725, 1979.

- Yoder, E. J., and Witczak, M. W., "Principles of pavement design ", 2nd edition, John Wiley and Sons, Inc., New York, 1975.

- SYMBOLS

AASHTO: American Association of State Highway and Transportation Officials.
a : Vehicle deceleration.
c : Regression constant.
d_j : Damage per pass for the jth vehicle.
d_s : Damage per pass for standard vehicle.
F : Maximum braking force.
E_1 : The modulus of asphalt layer.
E_2 : The modulus of base layer.
E_3 : The modulus of subgrade layer.

F_j : Factor of equivalent wheel load..
f : Coefficient of friction.
g : Acceleration of gravity 9.81 m/sec^2.
k_q : Regression constant.
N_{18}: Number of repetitions to failure for the 18 kips standard single axle.
N_{fj} : Number of repetitions to failure for the jth axle.
N_{fs} : Number of repetitions to failure for the jth standard vehicle.
SN : Structural number .
t_1 : Thickness of asphalt layer.
t_2 : Thickness of base layer.
t_3 : Thickness of subgrade layer.
Pt : Terminal of serviceability.
W : Weight of vehicle.
ε : The maximum principal tensile strain.
ε_j : The strain for the jth vehicle.
ε_r : Maximum horizontal strain.
ε_s : The strain for standard vehicle.
ε_v : Maximum vertical strain.
ε_x : The strain in the x direction.
ε_y : The strain in the y direction.
μ_1 : Poisson's ratio of asphalt layer.
μ_2 : Poisson's ratio of base layer.
μ_3 : Poisson's ratio of subgrade layer.
γ_{xy} : The shear strain on the plane x in the y direction.