NUMERICAL CALCULATION FOR EQUIVALENT SINGLE WHEEL LOAD (ESWL)

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Abstract

The flexible pavement layers attach at every hours during the day to hundred thousand from several traffic loading according to number of axles, number of wheel for each axles (Dual and Triple …,etc) and tire pressure.

These different types of above variable generate stresses, strains and defilations in the pavement layers (with overlap stresses and deflection) caused to fatigue of pavement to reduced pavement life. In order to design exchange these loads to Equivalent Single Wheel Load (ESWL).

Little programs are available to solve this problem as an exact solution. In this work using 3D finite element model make by SAP 2000 program based on the equal maximum vertical interface deflection for equal contact area concept. The results are compared with the analytical solution obtained from Kenlayer Computer program.

Keywords: ESWL, SAP 2000, Kenlayer Program, Michigan Pavement Model, Flexible Pavement.

الحساب العددي لحمل العجلة المكافئة المنفردة

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الخلاصة:-

تتعرض الخرسانة الإسفلتية يوميا" بل في كل ساعة خلال اليوم إلى مئات الآلاف من الأحمال المرورية المختلفة الأنواع من حيث عدد المحاور أو عدد الإطارات ضمن المحور الواحد وكذلك مختلف قيم ضغط الإطار.

هذه الأنواع المختلفة أعلاه تولد اجهادات وتشوهات وهبوط في طبقات التبليط الإسفلتي وحدوث تتداخل في هذه الاجهادات تسبب تعب او كلال التبليط وبالتالي تقليل العمر الخدمي له ولغرض التصميم الإنشائي للتبليط يتم التعويض عن هذه الأحمال المختلفة بحمل عجلة واحدة مكافئة.في هذا البحث تم بناء نموذج رياضي ثلاثي الأبعاد بطريقة العناصر المحددة وباستخدام برنامج SAP 2000 لغرض دراسة توزيع الاجهادات والتشوهات والهبوط الناتج بطبقات التبليط الإسفلتي المختلفة ومقارنتها بالطرق التحليلية التقليدية وباستخدام Kenlayer Computer Program

Introduction

The trend towards heavier truck speed aircraft, equipped with multiple wheel assemblies, has emphasized the need in pavement design for a method, whereby multiple-wheel loads can be related to a common standard irrespective of arrangement or configuration of the wheel.

In many cases, the conversion of multiple wheel loads to equivalent single wheel loads offers the designers of flexible and rigid pavements a convenient means for both the design and evaluation of highway and airfield pavements.

The interrelation of loading effects produced by single and multiple-wheel assemblies has been determined through theoretical analysis, laboratory investigations, accelerated traffic tests on prototype pavements and investigations of pavement performance (***Jones, 1962***).

Although further investigation, along these lines is needed the conversion methods presented here in will provide satisfactory solution to the problem of converting multiple wheel loads, equivalent single– wheel loads. The conversion for flexible pavement is naturally different from that for rigid pavements.

The thickness of a flexible pavement varies according to the qualities of the subgrade upon which it rests. A subgrade having a high supporting strength will required at thin pavement and the interaction of he loads on the subgrade caused by several wheels will be slight (***El-laithy, 1982***).

The study of ESWL for dual tires was first initialed during World War II when the B-29 bombers were introduced into combat missions because the design criteria for flexible airport pavements then available were based on single wheel load.

The ESWL is defined as the load on a single tire that will cause an equal magnitude of a reselected parameter (stress, strain and deflection or distress) at a given location within a specific pavement system so that resulting from a multiple –wheel load at the same location within the pavement structure.

Depending upon the procedure selected either the tire pressure or contact area of the ESWL may be equal to that of one tire of the multiple-gear assembly.

The ESWL can be determined from the theoretically calculated or experimentally measured stress, strain or deflection .it can be also be determined from pavement distress and performance such as the large , scale WASHO and AASHO road test.

Methods for Measuring (ESWL)

a) Exact Solution

1) Equal Vertical Stress Criterion.

Boyd and Foster (***Yader, 1975***), presented a semi-rational method for determining ESWL based on a theoretical consideration of the vertical stress in elastic half – space. This method assumes that the ESWL varies with the pavement thickness as shown in **Figure (1).**

1-For thickness ≤ d/2

The ESWL = $P_d/2$ (indicating that the subgrade vertical stresses caused by two wheels do not overlap).

2-For thickness > $2S_d$

The ESWL=P_d Total load (indicating that the subgrade vertical stresses due to the two wheels overlap completely).

3-The ESWL for any intermediate thickness can be easily determined by assuming a straight-line relationship between pavement thickness and wheel load on logarithmic scales. For mere convenient to compute the ESWL by

$$Log_{(ESWL)} = Log_{Pd} + \frac{0.301 * \log_{\left(\frac{2z}{d}\right)}}{\log_{\left(\frac{4S_d}{d}\right)}} \quad ..... \quad (1)$$

where P_d=the total load on the dual tire.

d= the clearance distance between dual tires ($d=S_d-2a_c$).
S_d= the center to center spacing between dual tires.
a_c= Radius of circular tire pavement contact area .

2. Equal Vertical Interface Deflection Criterion:

Foster and Ahlvin (***Huang*** , *1993*), was developed a new method, in this method the pavement systems considered as a homogenous half–space and the vertical deflection at a depth equal to the thickness of pavement can be obtained from ***Boussinesq's*** solution. A single- wheel load that has the same contact radios ($a=a_e$) as one of the dual wheels and results in a maximum deflection equal to that caused by the dual wheels is the ESWL. Max interface deflection can be measured by using;

$$W = \frac{P * a}{E_1} * F_i \quad ....(2)$$

$$(W_o)_{max} = \frac{P * a}{E_1} * \left(\sum_{i=1}^{n} F_i \right)_{max} \quad ....(3)$$

where:

$(W_o)_{max}$ = Max. Interface deflection due to multiple wheel loads at the computation point (o).
F_i = Interface deflection factor corresponding to the i^{th} tire.

E_1 = Modulus of elastically of subgrade soil**.**
n = No. of tires in the multiple wheel assembly

$$(W_e)_{max} = \frac{Pe * ae}{E_1} * Fe_{\not\subset} \quad ... (4)$$

where:

$(W_e)_{max}$ = Max deflection due to ESWL at center of load.
P_e = Tire pressure corresponding to (ESWL).
a_e = Radios of circular tire pavement contact area for the (ESWL).

$F_{e\not\subset}$ =Interface deflection factor corresponding to (ESWL)

To obtain the same deflection $(W_o)_{max} = (W_e)_{max}$.

$$\frac{P * a}{E_1} * \left(\sum_{i=1}^{n} F_i \right) = \frac{Pe * ae}{E_1} * Fe_{\not\subset} \quad ... (5)$$

1) **<u>For equal contact area concept (a=a_e)</u>**

$$ESWL = P * \frac{\left(\sum_{i=n}^{n} Fi \right)_{max}}{Fe_{\not\subset}} \quad ... (6)$$

2) For equal contact pressure concept (P=Pe)

$$ESWL = P * \left[\frac{\left(\sum_{i=n}^{n} F_i \right)_{max}}{Fe_{\not\subset}} \right]^2 \qquad \text{.... (7)}$$

where:

P= Wheel load

The ESWL for layered systems is greater than that for a homogenous half-space , ***Huang ,1993*** suggested the use of layered theory and presented a simple chart for determining ESWL based on the interface deflection of two layered systems (See **Figure (2)**), the chart gives a load factor (L) defined as:

$$L = \frac{Total\ \ load}{ESWL} = \frac{2P_d}{P_s} \qquad \text{..... (8)}$$

$$ESWL = \frac{2P_d}{L} \qquad \text{....... (9)}$$

3) Kenlayer Computer Program.

Kenlayer computer program was developed at the ***Kentucky University*** by ***Huang H. Yang*** and was written in Fortran 77 and requires storage of 509 KB. In its present dimensions, it can be applied to a maximum of 19 layers with output at 10 different radial coordinates and 19 different vertical coordinates, or a total of 190 points. For multiple wheels in addition to the 19 vertical coordinates, solutions can be obtained at a total of 25 points by specifying the X and Y coordinates of each point creep compliance's can be specified at a maximum of 15 time duration's. Damage analysis can be made by dividing each year into a maximum of 24 periods each with a maximum of 24-load group's.

In this work used this program to analysis layered systems under single, dual, dual–tandem or dual-tridem wheels with each layer behaving different set of material properties. Each period can have a maximum of 24 load groups, either single or multiple. The damage caused by Fatigue cracking and Permanent deformation in each period over all load groups is summed up to evaluate the design life (***Huang, 1993***). Before running Kenlayer computer program, the input programs layerinp. Must be run first to setup a data file.

b) Numerical Solution by Finite Element Method

General.

The axisymmetric finite element computer program based on the structural analysis program (SAP2000) is developed in this study to analysis a multi-layer flexible pavement system. The developed SAP- Pave –Model (SPM) carries out displacements, strains and stresses analysis of any linear isotropic axisymmetric elastic system. The quadrilateral element is used.

Structural Analysis Programs (SAP2000) represent the research work conducted of the University of California, Barclay by Professor ***Edwan L. Wilson*** over the post 25 years. The program development is being conducted in the ANSI Fortran-77 subset environment, giving a problem size capacity about 4000 Joints with over 10000 equations and all numerical operations are executed in full 64-bit double precision .The program has static analysis and dynamic analysis operation these options may be activated together in the same run load combinations any include results from the static and dynamic analysis. Complete details of the developing of this model are given in the following steps;

General Parameters:

1 Mesh Selection:

The mesh used in the program for representing the structure were carefully selected, several trails have been made. These meshes have been modified several times in order to obtain an acceptable result and minimizing the time required for the analysis process. The meshes also selected to satisfy the aspect ratio (is the ratio of length /width, length /height and width / height) near critical positions (critical load, and where output results needed). Thee selection make in two steps;

1.1 Two Dimensional Mesh Selection;

Based on the ***Duncan et. al***. (1978) suggestion the boundary nodal points of a finite element mesh should be fixed at a depth of about 50 radii of load (50a) and to allowed to slide vertically at a radial distance of about 12 radii (12a) from the axis of symmetry. Two meshes were chosen at the same the above dimension as shown in **Figure (3).**

Harichandran et. al. 2000, which developed a new non linear layers analysis model at the *Michigan state of University* , is very similar to ILLI – Pave program**,** used the same methods to characterize granular materials and fine – grained soils and the same Mohr-coulomb failure criteria to adjust the slate of stresses. Mich.-Pave suggest fixed at a depth of about (62 in≈1575 mm), and be allowed to slide vertically at a radial distance of about 10 radii (10a) but the in this study using (12a) for checking effect of boundary condition as shown in **Figure (4a).**

The use of a flexible boundary greatly reduces the number of finite element required, especially those oblong elements at the bottom. Consequently, the storage requirement is significantly reduced and the program can be implemented on personal computers, the fewer number of simultaneous equations's to be solved and the elimination of those oblong elements also yields more accurate results. So that for this reason the Mich.-Pave mesh model and modified Mich.-Pave is used in this study as shown in **Figure (4b).**

1.2 Three Dimensional Mesh Selection:

The time is very important matters to be taken in consideration in problem solving and those exactly the matters I insist on in comparing between those ***2D Duncan et-al*** mesh model and the use of 2D-Mich.-Pave meshes(first trial analysis).

To use the ***2D Duncan et al*** *1978* mesh model to determine the premium benefit of this type of mesh needs more time to solved about 45 minute for each trial that is about the time and about the storage requirement it was taking about (22MB) and the number of equations are needed to be solved are about (11000) greater than the program capacity, and is comparison with the application of 2D Mich.-Pave meshes this way it takes less time, storage capacity and number of equations. All of these parameters are going to be less than it times in first trial. And for that reasons the application of 2D Mich.-Pave-Model is more practically reasonable the use of the ***Duncan et al*** as shown in Table (1).

For calculating the (ESWL) to assembly of wheel using another type of mesh based on the Mich.-Pave Model and used the symmetric between the assemblies as shown in **Figure (5).**

2 Load Calculation:

In this study, the applied load assumed uniformly distributed over a circular tire pavement contact area with radius (a) defined at the joints so that we are need to find each joint load around the radius (a) specially in the 3D finite element model.

1. **Load Compute for Deflection Calculation.**
   Figure (6a), shows the method used for calculation of the applied load for each joint in order to simulate the behavior of load.
2. **Load Compute for ESWL Calculation.**
   Figure (6b), shows the method used for calculation of the applied load for each joint in the regular shape approximately to the nearly shape and calculate the area.

Boundary Conditions:

In purpose of choosing the boundary condition for analyzing the pavement structure, we use the following models

1. Duncan et.al Mode*:*
Depending on the results computed by ***Duncan et. al 1978*** ,which resumed that the boundary nodal points for the finite element mesh are fixed at a depth of about 50 radii (50a)from the center of loaded area and so he suggest to allowed that slide vertically at a radial distance of about 12 radii (12a) from the center of loaded area(axis of symmetry) as it shown in **Figure**. **(3).**

2. Mich.- Pave Model .
Depending on the developed model in Mich**.** University, the major improvement is the use of the flexible boundary, which it takes limited depth beneath the surface of subgrade. ***Yandell*** , 1985 explain benefit behind this way to greatly reduce the required number of finite elements which are needed to be solved, especially these oblong elements at the bottom. In this way these flexible boundaries includes the fixation at a certain depth which is theoretically protested at about (62 inch=1575 mm) and gives the freedom to be allowed to slide vertically at a radial distance of about 10 radii (10a) from the axis of symmetry as shown in **Figure (4b).**

3. SAP-Pave Model:

In this study many trials have been carried out in order to investigate the boundaries conditions, which developed in SAP-Pave Model as it is explained.

a) At start we use the ***Duncan et-al model***. We noticed that the use of this type of models needs more time, more storage and more required the number of equation to solve the problem, which are in deed going out of the range of program capacity because of the huge number of the joints used to solve in this model, the results were far away from the exact solution. as it is shown in Table (2)
b) In the application of the ***Mich.-Pave Model***, this model needs less time, less storage and so as the required equation, are less to decrease the number of joints used in this model and this model can be application at any personal computers, and reduced the number of simultaneous equation to be solved and the elimination of those oblong elements also yield more accurate results.

c) Through the results which has been calculated for used and for the purpose of getting nearby exact solution by using SAP program many trials been ran to change the boundaries condition in the ***Mich.-Pave Model*** in the coming way:
   1) Changing the dimension of the used section by increasing radial distance by 12-20 radii, in purpose of finding the effect of radial distance in the stiffness matrix, through those successive trials, we recognize that through out these trials the behavior of stress, strain and deflection distribution are change far away increasingly from the exact solution. So that we are suggesting that the neglecting of the increased radial distance from (12a) to give nearby results to the exact solution the following trials.
   2) Changing the boundary condition developed by Mich. –Pave Model.

   In this study we proposed and change the condition used in Mich.-pave- Model in this following matter:
   a) Slide vertically (which is here in the z-direction only) at the axis at symmetry of the applied load.
   b) Slide vertically and horizontally at the radial distance equal to (12a) from the center of the applied load or axis of symmetry.
   c) In order to investigate the wanted depth to be fixed, many trials have been done, we suggest the use of the same conditions of Mich.-Pave model, which are the fixing at a depth of 62 inch≈1575 mm.

To get a results more exactly near to the selected section and investigating from the previous theories that uses the axis symmetric finite element, we have tried many trial on a base supposed a plain strain finite element by evaluation of the deflection value in points which lies at distance of 12 radii (12a) from the center of the applied load and at the same time watching the effect of the increment in the radial distance , we recognize the effect of the use of the plain strain finite element to decrease the degree of freedom for the structure of the points in which the values of the deflection are known. Thus, we notice that the behavior of deflection keeps fixed as same those values in the previous trials out it goes for enough from the correct or the exact solution. So, we suggest that the theory of axis symmetric finite element it more practically correct to be used and neglecting the effect of the radial distance which increases further from 12 radii (12 a) from the axis of symmetry for the applied load, as it shown in **Figure (7).**

Results and Discussions

Figure (8) shows an elastic three-layer system under a set of duel –tandem tires each tires has a contact radius of (4.52 in) and contact pressure of (70 psi) and a center to center spacing (S_d) of (13.5 in). **Figure (9)** which show the three-dimension SAP-Pave-Model in order to simulate case study based on the assumption of this model. They suggested that the bottom rigid boundary should be located at a depth of at least 62 in beneath the surface and radial external boundary located at least 12 radii from the centerline of the loaded area.

a) Exact solution:

The exact solution shown in **Table (2),** which obtained from Kenlayer program. The location of the maximum stress under dual wheels is not known and can be determined by comparing the stresses.

* Fe⊄= deflection factor under the center line of a Single tire, the values are only a function of the depth radii ratios and give by (38):

$$Fe_{\not\subset} = \frac{1.5}{\left[1+(Z/a)^2\right]^{1/2}} \qquad \text{....(10)}$$

from Table (2) shows the max vertical deflection occurs under the tire No. (1), so that the ESWL=3555 lb.

b) 3D – Finite Element Analysis:

Used the Back-SAP-Pave-Model (BSPM), shown in **Figure (9)** for solved this problem and the results are shown in Table (3).

Table (4) shows the value of ESWL for the case study defined on each joint under the equivalent applied load (ESWL) equal to = 3590 lb. the max. discrepancy between numerical and exact solution.

where Max. Discrepancy = (Exact – Numerical)/ Exact

Conclusion

From the theoretical study of this research work and the results obtained, the following conclusions are drawn.

- The SAP 2000 program is used to analyze the multi-layered pavement system can include all these effective factors and can be solved with the finite element method for stresses, strains and displacements.
- The stress, stain and deflection have a more influence on the properties of each layer. (Modulus of elasticity, Poisson's ratio and this properties are various in all direction around these elements and the strain produces from this stress is not equal around this element and the deflection accurse below this layer not uniformly but basin (contour line connect this values of deflection).
- The kenlayer computer program used in this study for exact solution based in *Burmisters* layered theory are not exact and involve the numerical integration of an infinite series because the accuracy of the solutions depends on the interval and tolerance specified for the integration.
- Three-dimensional simulation of a structure will cover most of pavement variables than two dimension modeling.
- One of the most important steps can be benefit the back calculates available by SAP 2000 program to study the ESWL because the results of this program (stress, strain and deflection) and can be used the deflection results for calculate the ESWL by (BSPM).
- Solid element (brick element) used in the analysis is a suitable one when modeling structured multi-layered system. This is obvious from the previous verifications shown in this research this for 2D finite element. A three-dimensional modeling gives and advances step for simulation real structure.
- By used (Back-SAP-Pave-Model (BSPM) can be determined ESWL for multi-layer system based on the Equal Max Vertical Interface Deflection with equal contact area concept.
- From the several trail for selection the best mesh can be used for the (**SPM**), there are several possibilities that may cause in accurate results in the finite element method.

a) The shape of finite elements has a significant effect on the accuracy obtained .The necessity of simulating layer systems by using oblong elements can yield in accurate results.

b) The stresses and strains can be evaluated most accurately at center of elements to valuations at element boundaries, particularly of element corneas, are more prone to error.

c) The stresses at layer interfaces one obtained by linear extrapolation from those at the two joints. These procedures can lead to error if the mesh is not fine enough.

References

1. Bathe, K., J.,"*Finite Element Procedures*", Prentice Hall International Editions, New York, 1996.
2. Brown, S., F., and Stock, A., F., and Pell, P., P., "*The Structural Design of Asphalt Pavement by Computer*", the Highway Engineers, Vol. 27, No. 3, London, PP. 2-11, 1980.
3. Dawson, A., R., and Brown, S., F., and Barksdal, R., V., "*Pavement Foundation Developments*", Highway and Transportation, Vol. 36, No. 3, London, PP. 27-34, March 1989.
4. Duncan, J., M., and Monismith, C., L., and Wilson, E., L., "*Finite Element Analysis of Pavements* ", HRR, No. 228, PP. 18-23 1978.
5. El-laithy, A., M., "*Finite Element Analysis of Bimodular cress Anisotropic Multi-Layered"*, Ph.D.Sc. theses, Collage of Civil Engineering, University of Ohio state, 1982.
6. Harichandran, R., S., and Baladi, G., Y., "*MICHPAVE Use's Manual (Version 1.2 for DOS*", Michigan State University, January 2000.
7. Huang, Y., H.," *Pavement Analysis and Design*", Prentice Hall Inc. 1993.
8. Huang, Y., H.,"*Finite Element Analysis of Slabs on an Elastic Solids*", ACE Journal of Transportation Engineering, Vol. 100, Te. 2, May. 1974.
9. Huang, Y., H.,"*Computation of Equivalent Single Wheel Load using Layered System*", Highway Research Board, HRR, No. 291, 1969.
10. Jones, A.,"*Tables of Stresses in Three -layer Elastic System* ", Highway Research Board, No. 342, 1962.
11. Wilson, E., L. and Habibullah, A., "*SAP 90- Sample Example and Verification Manual Computers and Structures* ", Inc. Berkeley, Californian 1988.
12. Wilson, E., E., "*Solid SAP a Static Analysis Program for Three Dimensional Solid Structures* ", Structural Engineering Laboratory, Report No. UCSEC M71-19, 1971-Revised Dec. 1972.
13. Wilson, E., L., and Bathe, K., J., and Peterson, F., E., "*SAP2000 – A Structural Analysis Program for Static and Dynamic Response of Linear Systems"*.
14. Yader, E., J., and Witezak, M., W., "*Principles of Pavement Design*", John Wiley & Sons, Inc, 2nd edition, New York, 1975.
15. Yandell, W., D., "*New Method of Simulating Layered Systems of Unbound Granular Material"*, TRB, No. 1022, 1985.

Table (1): Effect of Type of Mesh on the Running Time.

Mesh type	Trail No.		Running time minutes	Storage capacity (MB)	Number of Joint	Number of element	Number of equation to be solved	Notes
2D	1		2	2.5	238	208	1157	
	2		2	2	180	90	1057	
	3		3.5	8.250	882	806	4469	
	4		4	=11	1071	992	5766	Accurate Case
3D	1		cancel	cancel	3042>3000	2592		Neglect out of capacity
	2		19	=43	2448	1936	9704<10000	Out range of program
	3		8	21.297	1885	1242	7688	
	4	Forward	8	21.297	1885	1242	7688	Accurate Case
		Back	8	21.297	1885	1242	7688	Accurate Case

Table (2): Exact Solution for Case Study.

Trial No.1=assume max vertical interface deflection at point (o) , as shown in Figure (10).							
Z/a	Fi factor calculated from Kenlayer program				Fi	Fe⊄ *	ESWL P*(Sum Fi max)/Fe lb
	Trail No.1	Trail No.2	Trail No.3	Trail No.4			
6/4.52	٠.١٧٧١٥	٠.١٧٧١٥	٠.١٧٧١٥	٠.١٧٧١٥	٠.٧٩٨٦	٠.٩٠٢٥٥٣٨	3527.5=3528
Trial No.2 = assume max vertical interface deflection at center of tire No. (1), as shown in Figure (10),							
Z/a	Fi factor calculated from Kenlayer program				Fi	Fe⊄ *	ESWL P*(Sum Fi max)/Fe lb
	Trail No.1	Trail No.2	Trail No.3	Trail No.4			
6/4.52	٠.٠٤٨٥٦٥٢	٠.٠٤٨٥٦٥٢	٠.٢٤٧١٥٤	٠.٣٦٩٩١٢٩	٠.٧١٤١٩٣٦	٠.٩٠٢٥٥٣٨	٣٥٥٥.٢٢=3555

Table (3): Printout of Result of SPM Program for Case Study.

STRUCTURAL ANALYSIS PROGRAMS NONLINEAR VERSION 7.21			
Copyright (C) 1984-2000 EDWARD L. WILSON			
ABDUL HAQ- 3 LAYER SYSTEM(Case study ESWL FOR 3D SOLID)			
LOAD CONDITION 1 - FORCES "F" AND MOMENTS "M"			
JOINT	F(X)	F(Y)	F(Z)
1059	-.1231E-10	.1933E-11	-.2178E-09
1060	-.4100E-11	-.2677E-10	-.1314E-09
1061	.9351E-11	-.2507E-10	.1039E-09
1149	.1307E-11	.2439E-10	.7368E-11
1150	-.3780E-11	.2501E-11	-.2398E-10
1151	-.8896E-11	-.9948E-11	-.2554E-10
1152	.0000E+00	-.1461E-10	-.2017E-10
1153	.2547E-10	.0000E+00	-.4826E-10
1239	.2319E-10	-.1495E-10	.4334E-10
1240	-.4945E-11	-.4121E-11	.7180E-10
1241	-.1978E-10	-.2160E-11	.4799E-10
1242	-.2092E-10	-.6935E-11	-.4647E-10
1243	.1199E-10	-.6139E-11	-.1507E-10
1244	.2456E-10	.3382E-11	.7002E-10
1245	.1330E-10	-.3439E-11	-.1844E-10
1330	-.8583E-11	.0000E+00	-.1261E-09
1331	.8924E-11	.5372E-11	-.1009E-10
1332	.4320E-11	-.1256E-10	.8146E-10
1333	.0000	.0000	-3589.7533
1334	.9436E-11	.5059E-11	-.1117E-10
1335	.4832E-11	-.9237E-11	-.5821E-10
1336	.9351E-11	-.3638E-11	.1063E-09
1421	-.9152E-11	.1975E-11	.8909E-10
1422	-.1415E-10	.1185E-10	.3202E-10
1423	-.2126E-10	-.1296E-10	.4970E-10
1424	-.1643E-10	.8583E-11	.1012E-09
1425	-.8413E-11	.4604E-11	-.1110E-09
1426	-.2780E-10	-.2325E-10	.9545E-10
1427	-.3467E-11	.4821E-11	.1671E-09

1513	-.9607E-11	.0000E+00	-.8263E-10
1514	.5116E-11	-.5798E-11	-.7834E-11
1515	.1134E-10	-.2558E-11	.1541E-10
1516	-.9123E-11	.1734E-10	.4913E-10
1517	.1344E-10	.1421E-10	-.1356E-09
1605	.6501E-11	-.1256E-10	.1252E-10
1606	-.8185E-11	-.1262E-10	-.6051E-10
1607	.7915E-11	.1117E-10	.9447E-10
TOTAL	-.1802E-10	-.8568E-10	-.3590E+04

Table (4): Max. Discrepancy between Trials.

Trail No.	Exact	3D-FEM Sap Pave Model	Max. Discrepancy
1	3528	3590	2 %
2	3555	3590	1 %

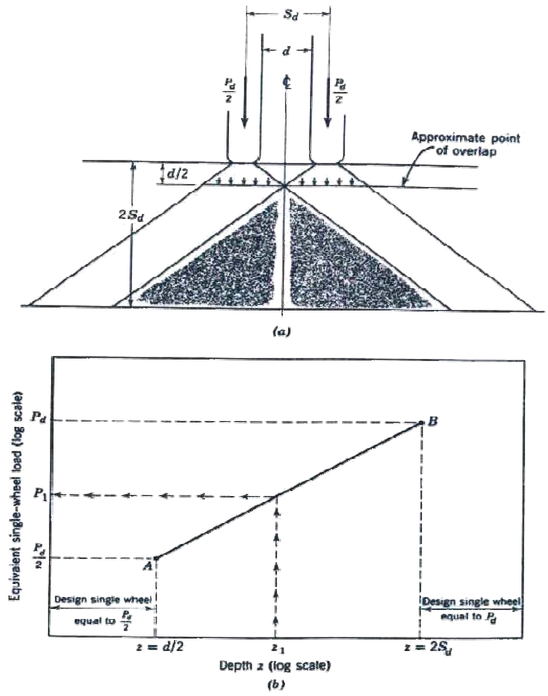

Figure (1); shown ESWL based on the Equal Vertical Subgrade Stress.

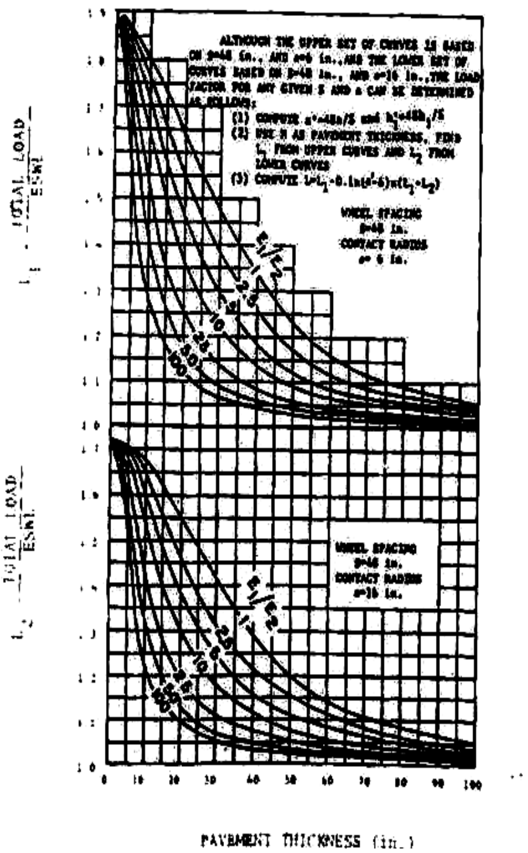

Figure (2): Chart for Determining ESWL for Layered System.

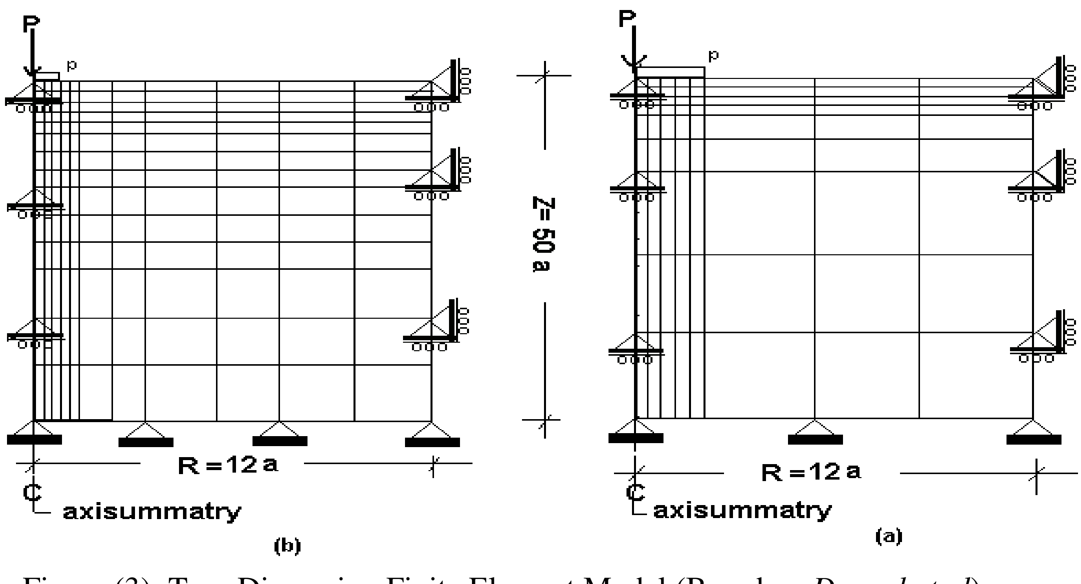

Figure (3): Two-Dimension Finite Element Model (Based on *Duncal et.al*)

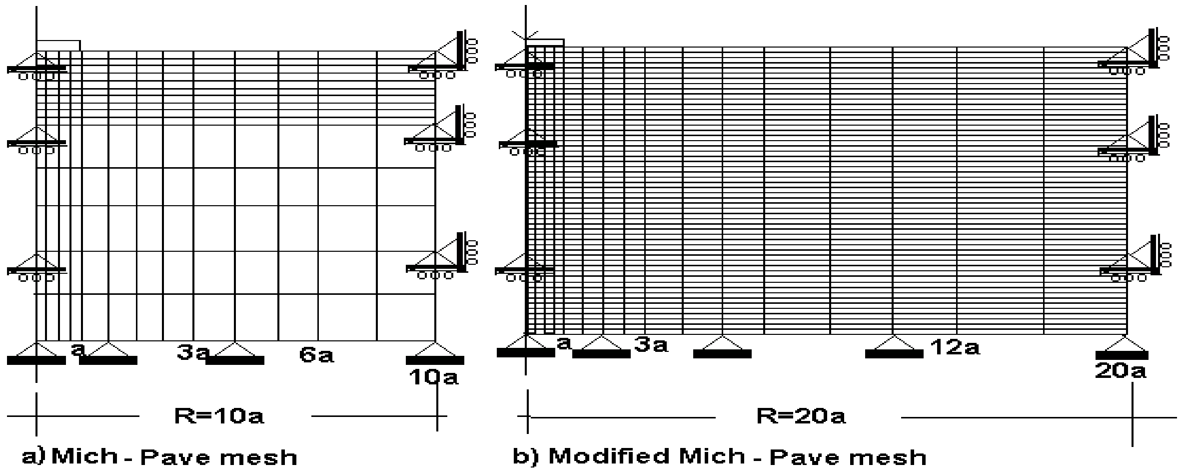

Figure (4) Two-Dimension Finite Element Model (Based on Mich.-Pave Model)

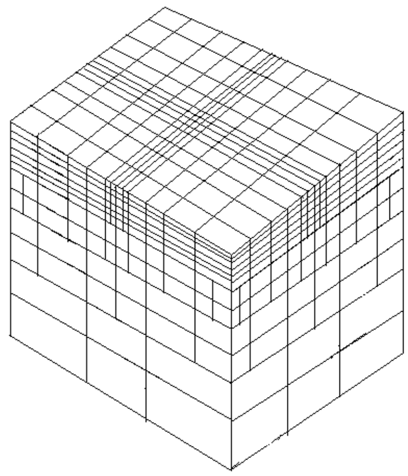

Figure (5) 3D Mich.-Pave Model for mesh type showed in Figure (4a).

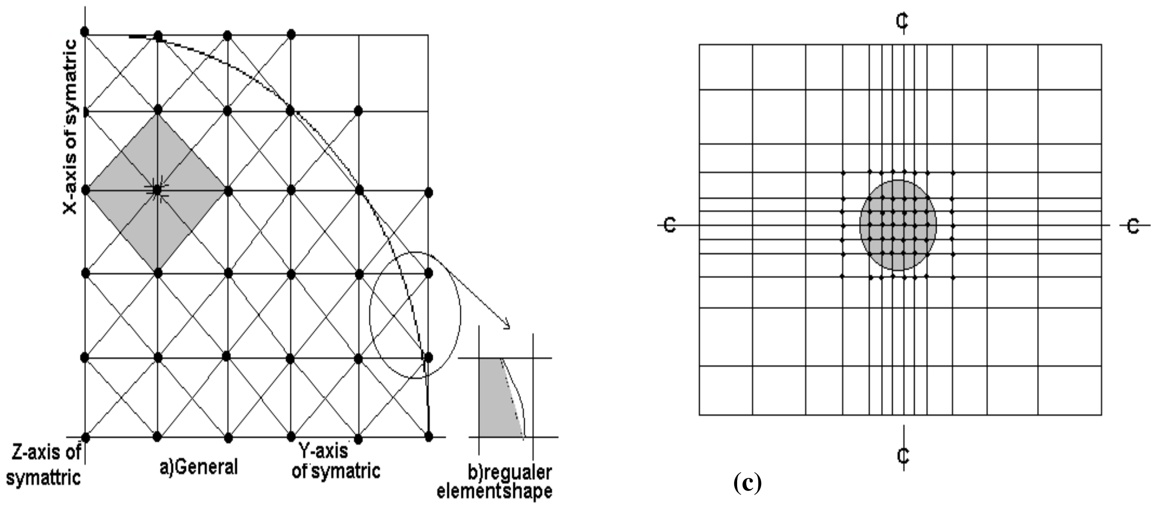

Figure (6) Symmetric Uniformly Distribution load
a) General. b) Regular Element Shape. (c) Uniformly Distribution Load for ESWL Calculation.

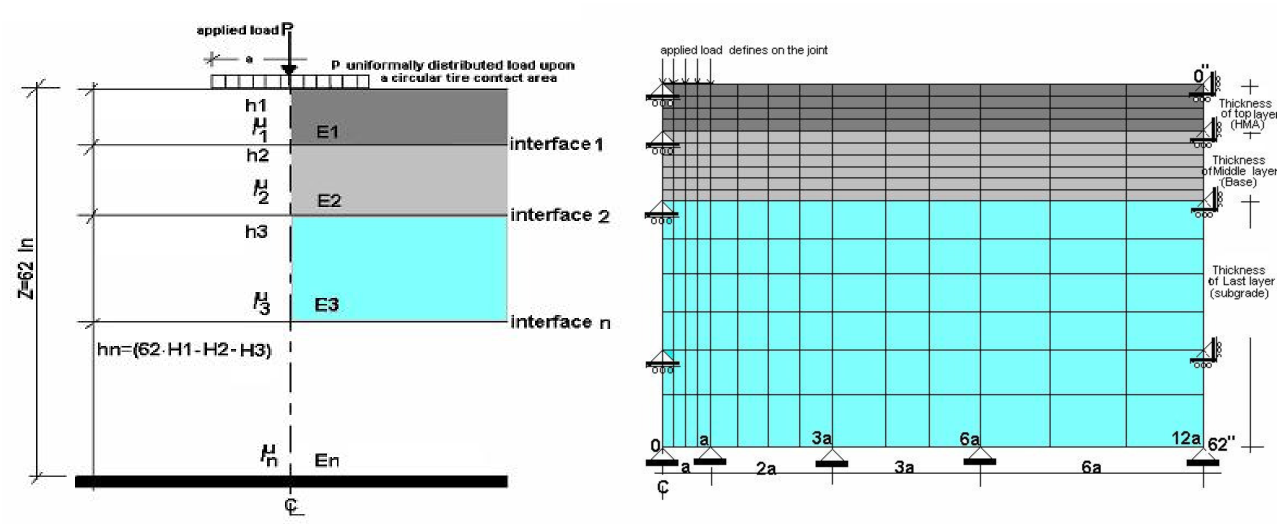

Figure (7): Numerical Model Description.

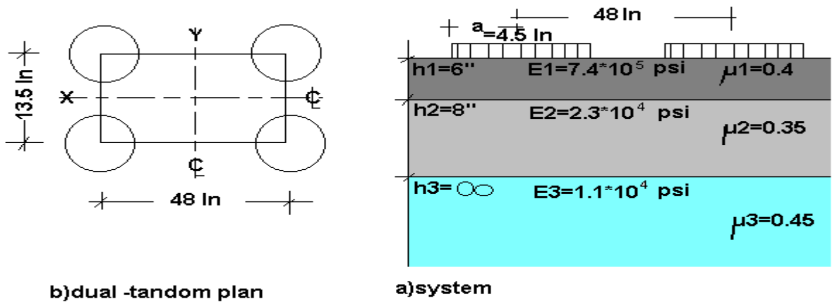

Figure (8) Case study for determine ESWL

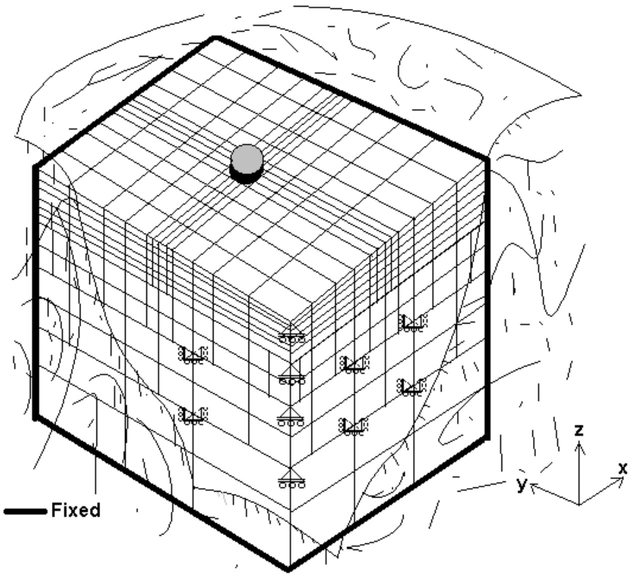

Figure (9): 3D Simulation of Pavements for Case Study.

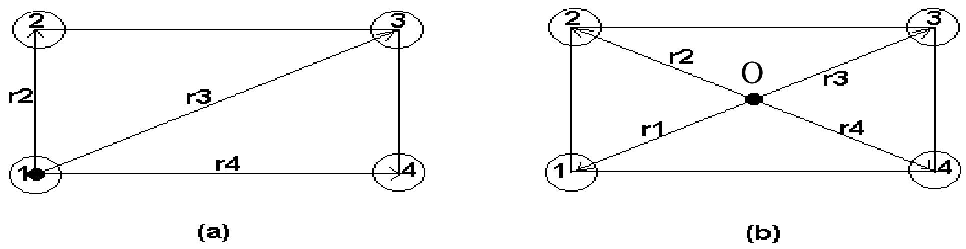

Figure (10): Trials for Determining the Location of Max. Interface Deflection.