An -Najah National University

Faculty of Higher Studies

Three Dimensional Finite Element Modeling for Thin Layer of High Performance Portland Cement Concrete Pavements

(Analysis and Design)

By

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This Thesis was defended successfully on Wednesday (6 - 2 - 2002) and approved by: -

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Chapter (1)

Introduction

There are many methods to design pavements, which depend on opinions regarding suitability of design, which vary from local to local.

Materials that are available for construction of pavements have major influence in design. The design of airport and highway pavements involves a study of soils and paving materials, their behavior under load, and the design of pavement to carry that load under all climatic conditions. All pavements derive their ultimate support from the underlying subgrade.

Flexible pavements were classified by pavement structure having relatively thin asphalt wearing coarse with layers of granular base and subbase, being used to protect the subgrade from being over stressed.

The goal that must be satisfied by any design method is to achieve the most economical section that will serve the analysis period with acceptable serviceability.

A flexible pavement is a type of pavement design was primarily based upon empiricism or experience. In the design of flexible pavements, the pavement structure is usually considered as a multi-layered elastic system. The material in each layer is characterized by certain physical properties.

Rigid pavements consist of thin slabs of Portland Cement Concrete (PCC) poured on subgrade or base-course. Because of its rigidity and high Modulus of Elasticity, concrete pavements tend to distribute the applied load over a relatively wide area of subgrade. Thus the slab itself supplies the major portion of the structural capacity, this is on the contrary of flexible pavements, where the strength of the pavement is brought by building up relatively thick layer of subbase, base and surface.

Thin layer specialized of the single high performance cement concrete of rigid pavements on the contrary of thick multi layers of flexible pavements (asphalt layer, base & subbase layers), as shown in figures (1.1,1.2). Where a thick layer of rigid pavements needs when we using an ordinary concrete instead of the thin one of high performance concrete.

The major factor that is considered in the design of rigid pavements is the strength of the concrete itself, where the variation of subgrade or base strength have little influence on the structural capacity of the pavement. Stresses in rigid pavements can result from several cases including volumetric changes in the subgrade and / or subbase, restrained, temperature, movement caused by changes in moisture and wheel load.

The existing methods for designing rigid pavements depend on empirical formulas. These formulas deal with the analysis of rigid pavements, the stresses include factors that may be placed in several categories, including restrained temperature and moisture deformations and externally applied loads, and volume changes of the supporting materials including frost action, and continuity of the subgrade support through pumping.

The purpose of this thesis is to derive a theoretical model for the thickness design of rigid concrete pavements using High Performance Portland Cement Concrete.

The basis of this research is dependent on a stress-strain analysis for three-dimensional finite element analysis of rigid concrete pavements.

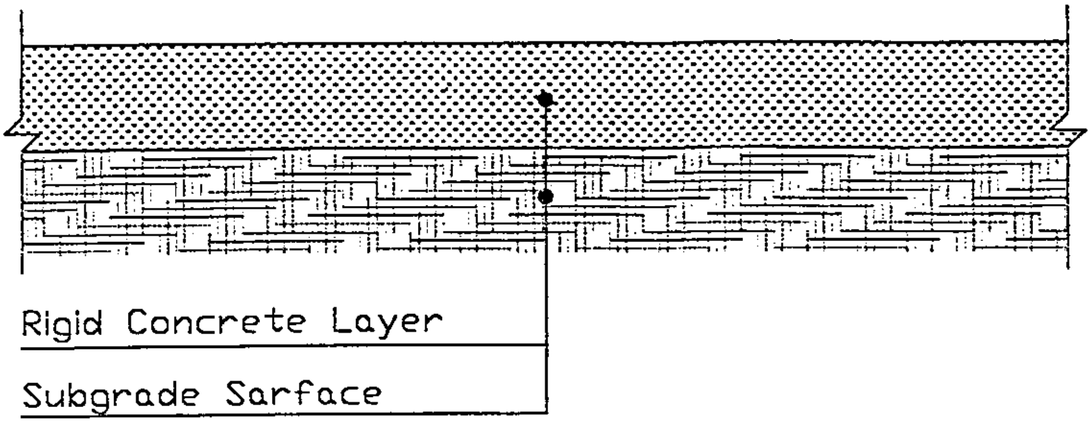
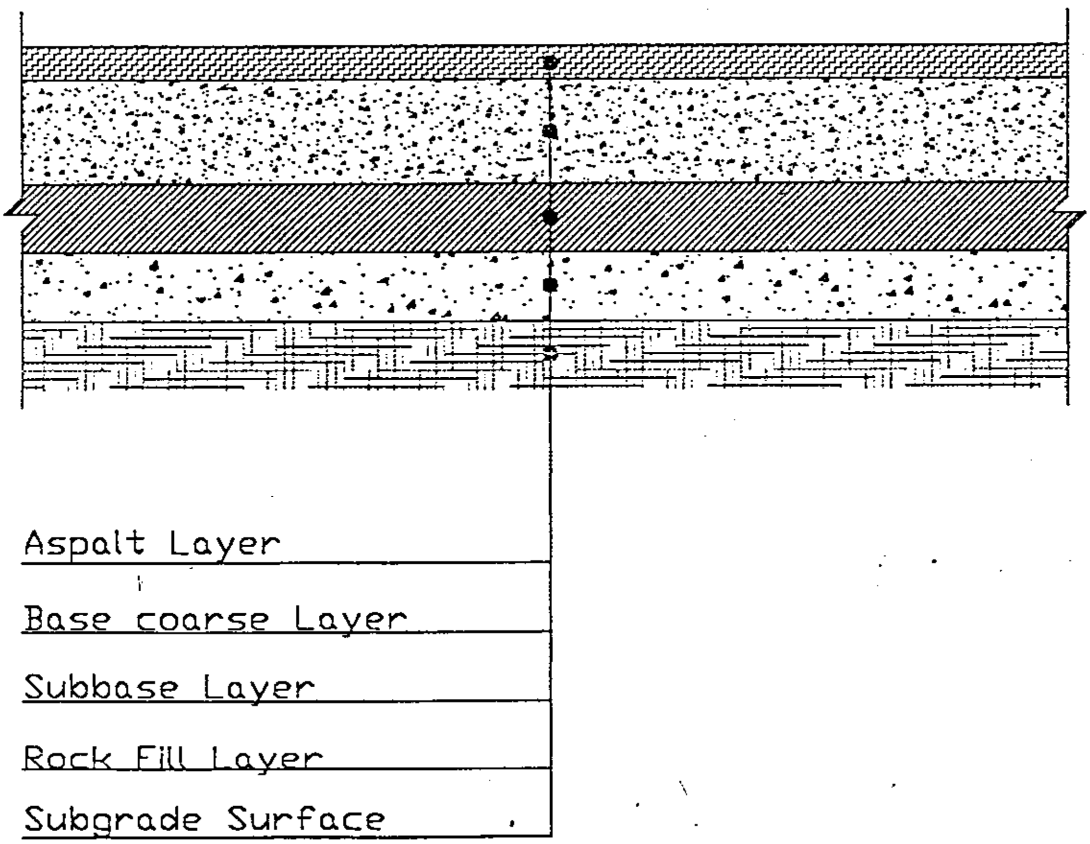


Fig (1.1) (section in rigid concret pavemente)



Fig(1.2) (Section in flexible pavement)

Different variables are considered as input values for the proposed model; as soil classification of subgrade modulus of rupture (MR) for Portland Cement Concrete, California bearing ratio test (CBR), modulus of subgrade reaction (k), modulus of elasticity (E), traffic volume (number of repetitions of 18 Kip. Single axle load), temperature, and concrete compressive strength (fc) which depend on the use of high performance concrete characteristics with or without supplementary cementitiouse materials. The dimensions of the proposed theoretical model are presented in the following chapters, chapter (2) deals with the history of the rigid pavement design, by pointing out on all contributing factors which deals with rigid pavement design and analysis, it also include the state of the art in that regard. Chapter (3) gives a short summary and several methods of analyzing rigid pavements.

Chapter (4) deals with methodology of working and finite element method for analysis of rigid concrete pavements.

Chapter (5) deals with model formulation and analysis and regression to get the required formula.

Chapter (6) gives conclusions and recommendations.

Chapter (2)

Literature review

Introduction

Until now there has been a very little research done which deals with 3D finite element modeling of rigid pavements which does not reach to a final concluding model, however several research papers discussed this issue and will be presented in this chapter.

San Helwany &Joe Leidy deal with Finite Element Analysis of Flexible Pavements. They used an analytical model to calculate primary response load equivalent factor, utilizing deflections based or strain based equivalency factor methods. The method is capable of simulating the observed responses of Pavements subjected to axle loads with different configurations and axle loads travelling at different speeds. A variety of materials constitutive models such as linear elastic, nonlinear elastic, and viscoelastic are employed in the analysis to describe the behavior of the pavement materials. Finite Element modeling of pavements can be extremely useful, because it can be used directly to estimate primary response parameters without resorting to potentially costly field experiments.

This study illustrates the benefits of such method in the analysis of three layered pavement systems subjected to different types of loading. This method was able to simulate the observed responses of pavements subjected to axle loads of different tire pressure, axle loads of different speeds.

- Donald D.N. GEOFFROY .P.E are discussed the thin surfaced pavements, they recommend for continuing the studying of three dimensional finite element modeling for rigid concrete pavements. Donald reached to a conclusion that there is no a thin surfaced pavement structural or thickness design methodologies suitable for use in the United States. Consideration should be given to modeling any effort of this nature on some of the very successful programs provided by the technology transfer center. All the procedures currently in use are adoption of the Corps of Engineer's Method that had its beginning as an airfield pavement design during World War Two. ((5), Synthesis of highway practice 260 /thin surfaced pavement.)

- The conference held in the Embassy Suites Hotel, Charleston, West Virginia on November 8-10/1998 discussed 3D finite element modeling for pavement design and analysis. The conference recommends continuing research & study of three dimensional finite element modeling for rigid pavement analysis and design. ((1), 3D finite element modeling for pavement analysis and design.)
- The second international symposium 3D finite element for pavement Analysis and Design and Research which held between 11-13 October 2000 in Charleston west Virginia, Embassy suite hotel. The steering committee invited authors to submit original contributions that describe the development and /or application of 3D finite element modeling in any area related to highway pavements or airports runway, the following topics were welcomed:-

a. Response and or performance modeling of flexible, rigid or

b. Composite pavement or airport runway.

c. Development / verification of 3Dfinite element software for pavement.

This symposium aims to provide an exchange of ideas between practicing pavement specialists and researchers, in this respect the symposium presentation will not be limited to theoretical and experimental research, but will be extended to presentation of field problems presented by highway and airport runway engineers.

Worldwide developments in the field of using 3D finite element in investigating pavement structural problems and developing new design techniques were discussed. ((1), 3D finite element modeling for pavement analysis and design.)

- Banan R. Jadallah & Fawz K. Kobari discussed Feasibility of Finite Element Modeling in the Design of Flexible Pavements, They reached to a conclusion that the stress distribution below the load decrease as the pavement thickness increases. Also an increase in the number of repetition of the load will bring an increase in the severity of deflection problem, which in its role needed more thickness in pavement. But they could not reach to a regression equation to simulate the thickness of flexible pavement dependant to some variables as the number of repetitions of loads and modulus of subgrade reaction. ((13), Transportation Research Record no. 1629 (design rehabilitation pavements 1998).)

- Gutierrez PA. Canovas MFACI made an experiment program, which has been carried out to establish specifications for constituent materials of high performance concrete (HPC) mixtures.

Many general recommendations can be found in the bibliography, but not enough to determine precisely how to specify cement, aggregates and admixtures for high performance concrete, cement has to be selected not only according to its strength, but also its water demand and setting time. Suitable aggregates are those having good mechanical properties, controlled by the loss angles coefficient, in addition, water demand of the aggregate must be low. ((6), ACI Materials Journal, September- October /1996.)

- Bowser JD Krause GL. Tadrose MK. discussed Mechanical Properties of High Performance Concrete, they reach to a developed information about mechanical properties of high performance concrete, high-performance concrete with 56- day compressive strength of 65 to 120 Mpa. with or without silica fume, were studied , results and discussion are presented regarding compressive strength gain with time , effect of type cement , effect of drying , specimen size effect, static modulus of elasticity, poison's ratio, tensile splitting strength and modulus of rupture.

This next chapter deals with all factors related to rigid pavement variables and gives a notation for relation of the thickness of rigid pavements and determines these factors. Also it discuss the basic principles of rigid pavement analysis and design. ((8), Journal of Transportation Engineering, September-October)

Chapter (3)

Rigid Pavement Design

3.1 Introduction

The calibrated mechanism design procedure involves the application of structural models to calculate pavement responses, the development of distress models to predict pavement distresses from structural responses and the calibration of the predicted distress with the observed distress on in-service pavement. The structural models for rigid pavement analysis are more advanced than the distress models. Several finite element programs can be used as structural models, but most of the distress models are regression equations derived empirically with a large scatter of data. The major types of distress to be modeled include fatigue cracking, pumping, faulting and joint deterioration for jointed concrete pavement and punch-outs for continuous reinforced concrete pavement. To accurately analyze rigid pavements, the structural models used must have the following capabilities: -

- To analyze slab of any arbitrary dimensions.

- To analyze system with two layers (slab and subbase), either bonded or unbonded with the same or different material properties.
- To analyze slab system with either uniform or non-uniform support, hence the loss of support due to erosion or other causes can be taken into account.
- To analyze slab system on either liquid or solid subgrade.
- To analyze multiple slabs with load transfer across the joint.
- To consider slab warping and curling simultaneously with load response.
- To analyze slab with variable crack spacing for design.
- To analyze slab with any arbitrary loading conditions including single or multiple wheels, variable tire pressure and loads applied at arbitrary assigned distances from cracks, joints, or slab edges.
- To analyze pavement systems with arbitrary shoulder condition including asphalt shoulders, tie concrete shoulders, and extended driving lanes with asphalt or concrete shoulders beyond the extended slab.

- To analyze system with non-uniform slab or shoulder thickness.

The fatigue cracking models are similar to flexible pavements, the accumulation of fatigue damage can be expressed as a summation of damage ratios defined as the ratio between predicted and allowable number of load repetitions. However, instead of relating to tensile strain, the allowable number of load repetitions is related to the stress ratio, which is the ratio between the flexural stress and the modulus of rupture. The fatigue of concrete can cause both transverses cracking, which initiates at the pavement edge midway between transverse joints, and longitudinal cracking, which initiates in the wheel paths at transverse joint, usually at the wheel path nearest the slab centerline. Due to lateral distribution of traffic, wheel loads are not applied at the same location, so only fraction of the load repetitions need to be considered for fatigue damage.

((11), PRINCIPLES OF PAVEMENT DESIGN.)

3.2 Subgrade modulus

As a slab deflects under load it induces reactive pressure between the slab and supporting medium.

It is commonly assumed that the amount of reactive pressure bears a direct linear relationship to the magnitude of deflection, the degree of resistance offered by subgrade depends upon its stress- strain properties. The modulus of subgrade reaction (k) has been often refered to as the spring constant and it is determined by means of the plate-bearing test.

Typical values are in the range, which are justified for design of highway pavements as shown in table (3.1):

Table (3.1) modulus of subgrade reaction (k) in pound per cubic inches (pci).

Soil type	k (pci)
Plastic clays	50-100
Silts and silty clays	100-200
Sands, clayey gravels	200-300
Gravels	>300
CTB or ATB	>400

The thickness of highway concrete pavement is relatively insensitive to the modulus of subgrade reaction (k).

Easily we can get the approximate value of modulus of subgrade reaction (k) by using the nomograme shown in Fig (3.1).

((11), PRINCIPLES OF PAVEMENT DESIGN,(12) Feasibility of Finite –Element Modeling in the Design of Flexible Pavement.)

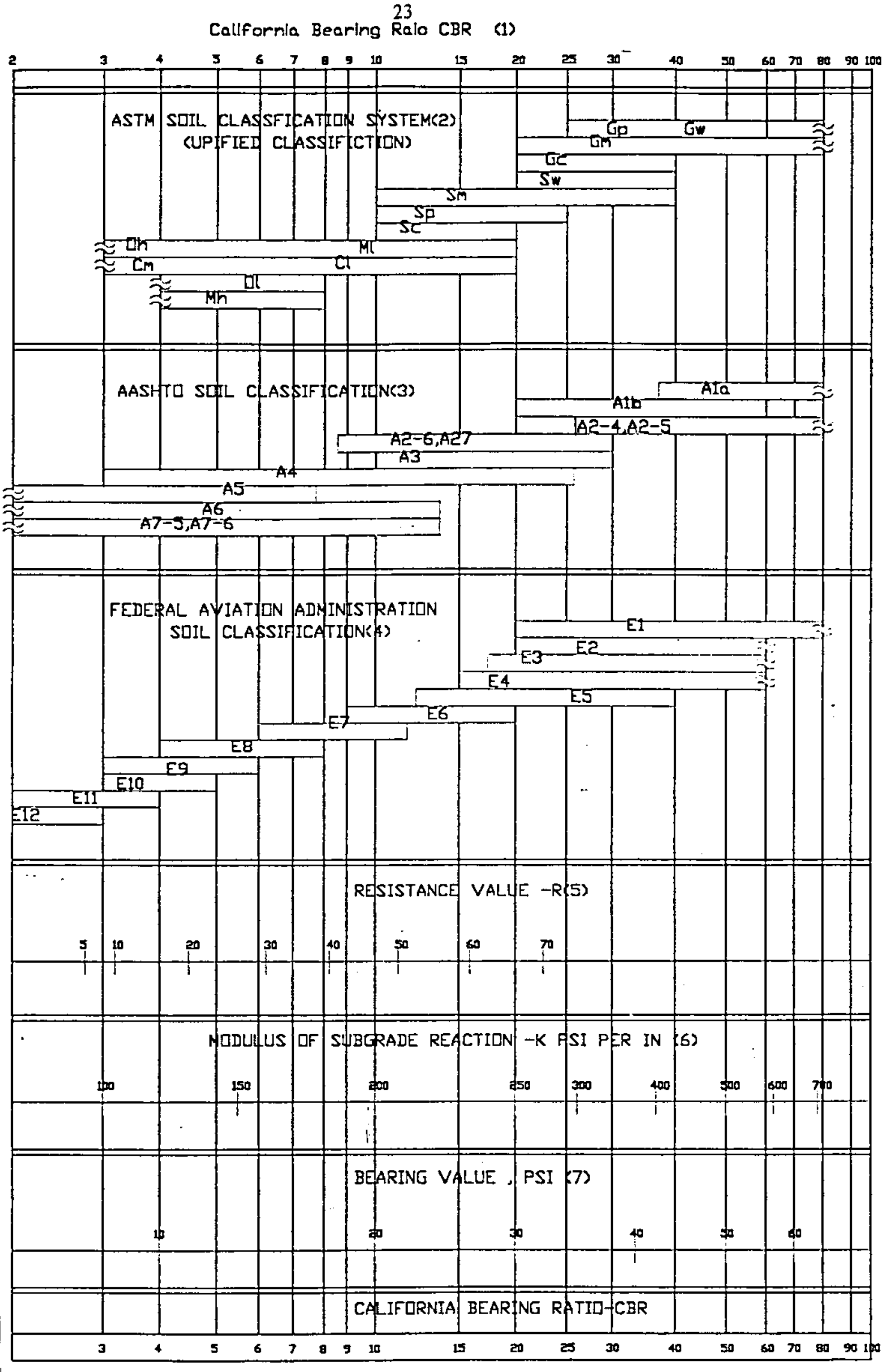


Fig. (3.1) Approximate interrelationships of soil classifications and bearing values

3.3 Fatigue criteria

Fatigue criteria is a failure criteria which is used in rigid pavement design that can be expressed in terms of allowable horizontal tensile stresses or strains at the bottom of the pavement layer. Research includes the results of an analytical study of the effect of tire loads on a thin layer of a rigid pavement, and the strain induced in pavement structure is evaluated. In this theoretical model the adoption of fatigue cracking criteria (phenomena of repetitive load- induced cracking due to a repeated stress- strain level below the ultimate strength of the material) was made as a failure criteria. This type of failure is referred to in terms of the horizontal tensile strain or stress at the bottom of the rigid concrete layer.

((11), PRINCIPLES OF PAVEMENT DESIGN,(12) Feasibility of Finite –Element Modeling in the Design of Flexible Pavement, (13) Transportation Research Record no. 1629 (design rehabilitation pavements 1998).

3.4 Existing Methods of Rigid Pavement Design

Most of rigid pavement design methods for highway have a bases with varying degrees of empiricism that have developed from each individual design agency correlating to their design method.

3.4.1 AASHTO Road Test

American Association of State Highway and Transportation Officials (AASHTO) road test has primary a purpose to determine the effect of the traffic upon the performance of concrete pavement. The experiment was setup as a factorial study in which a pavement of varying thickness was constructed and trucks having both single and tandem axles were run over them. The most important outcomes of AASHTO research project dealing with pavement serviceability and the relationships between change in serviceability and repetitions of load. Equations were developed which relate repetition of load to change in serviceability index.

The basic equations for concrete pavement design, which was developed by the AASHTO road test, are as follows: -

$$B = \frac{1+3.63(L1+L2)^{5.20}}{(D+1)^{8.46}L2^{3.52}} \qquad \text{eq. (3.1)}$$

$$P = \frac{10^{5.85}(D+1)^{7.35}L2^{3.25}}{(L1+L2)^{4.62}} \qquad \text{eq. (3.2)}$$

Where: B = slope of line of chart of relation between repetition of load &the serviceability index.

P = serviceability index (between 1&5).

L1 = single or tandem axle load (kip)

L2 = no. of axles in group.

D = thickness of concrete pavement (in)

A solution was prepared in the form of a nomograph chart, which relate all variables of design with the thickness of rigid concrete pavements as a substitute for using equations as shown in figure (3.2).

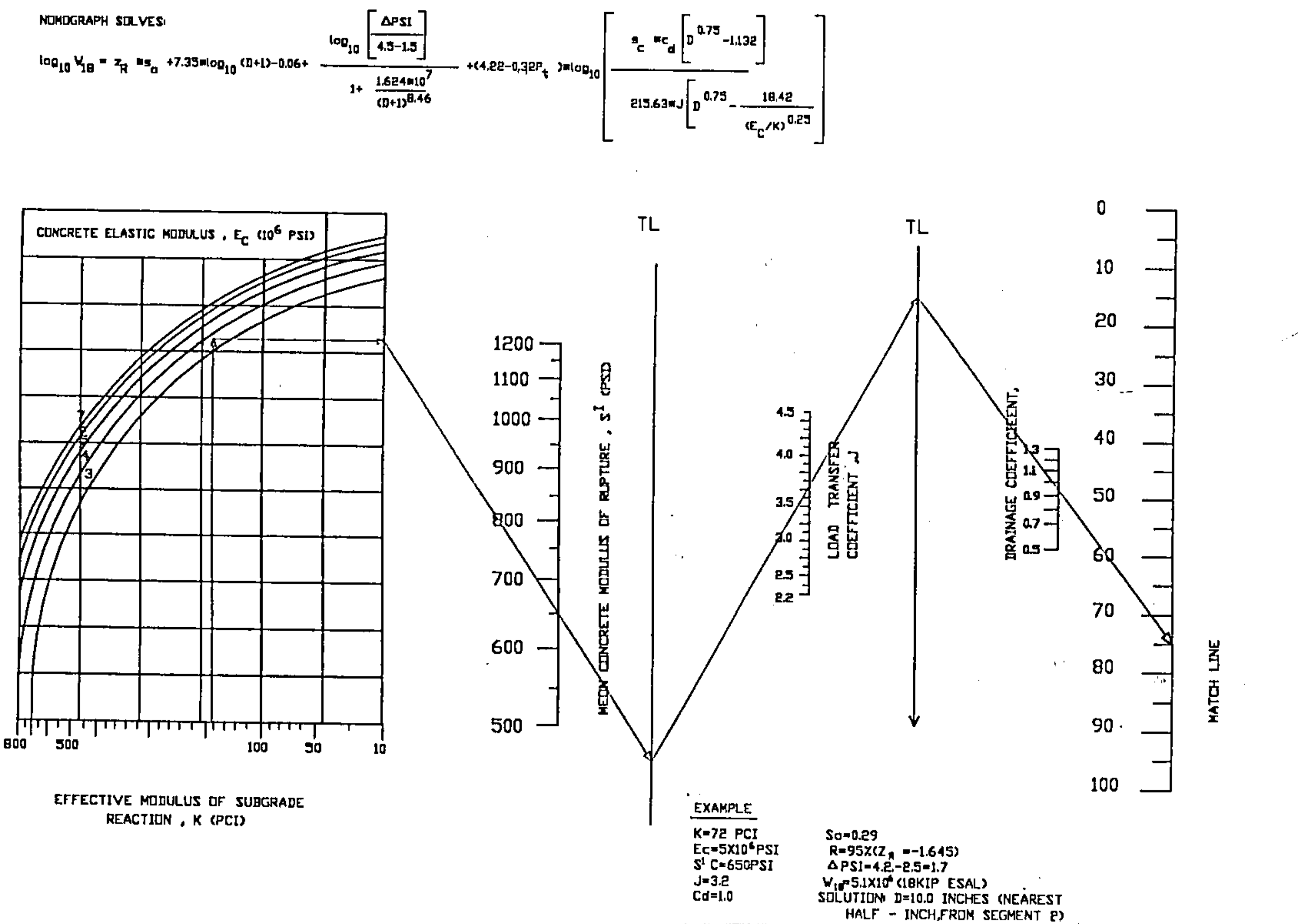
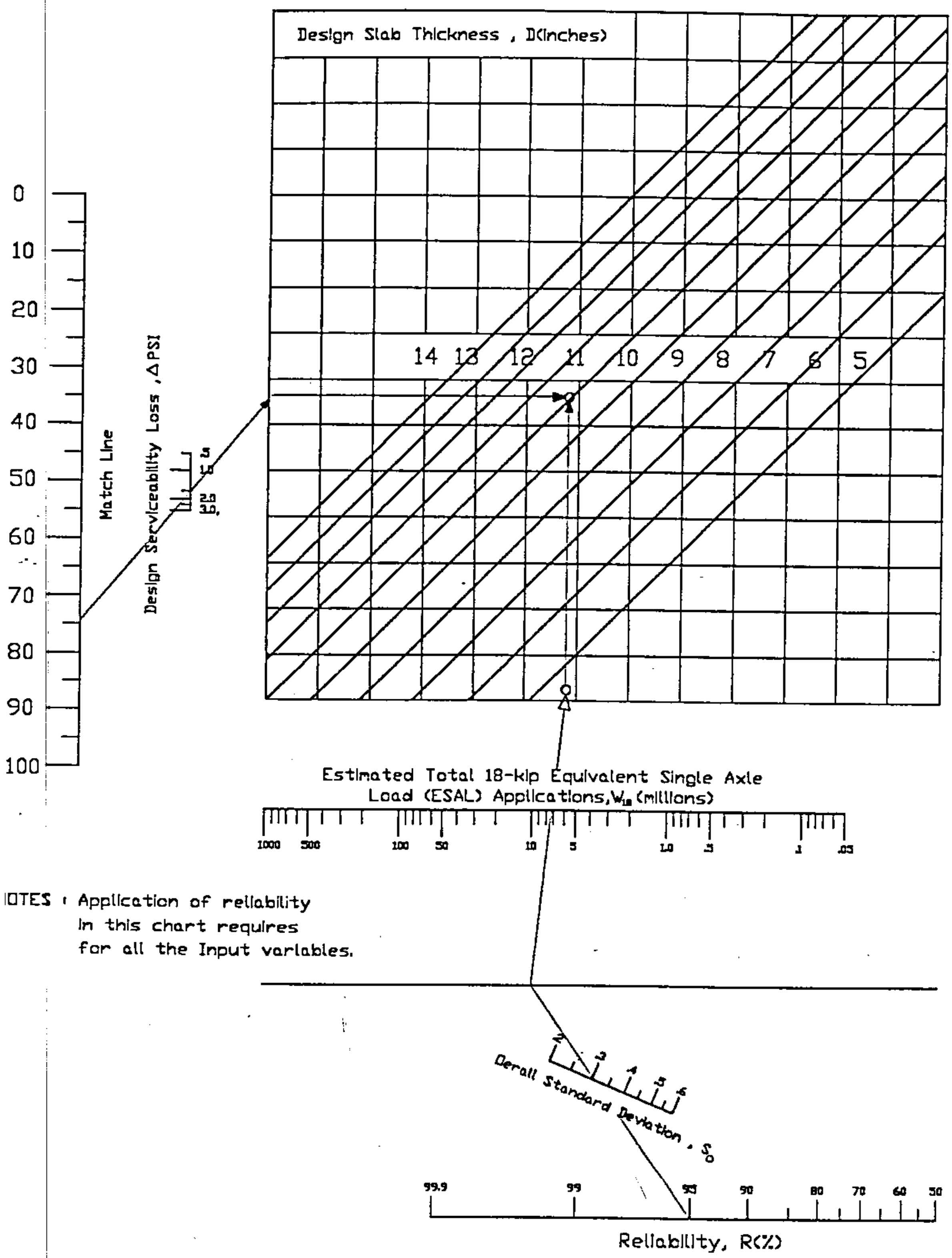


Figure 3.2 Design Chart for Rigid Pavement Based on Using Mean Values for Each Input Variable (Segment 1)



NOTES : Application of reliability in this chart requires for all the input variables.

Figure 3.2 Continued-Design Chart for Rigid Pavements Based on Using Mean Values for Each Input Variable (Segment 2)

The thickness of rigid pavement slab using AASHTO guide, is obtained through nomograph from the input variables which are: traffic load (in Equivalent 18 kip single axle load in repetitions), concrete working stress in pound per square inches, concrete modulus of elasticity, and modulus of subgrade reaction in pound per cubic inches (pci). The nomograph solves the equation:

$$\text{Log}(w18)=\frac{7.35\log(D+1)-0.06=\log(\frac{4.5-Pt}{3})}{3.0} / (1+\frac{1.624E7}{(D+1)^{8.46}}$$

$$+(4.22-0.32Pt).\log((ft/215.63J)*((D^{0.75}-1.132)/$$

$$(D^{0.75}18.42/(E/k)^{0.25}))). \qquad \text{eq. (3.3)}$$

Where:

W18: 18 kip equivalent single axle load repetitions

D: slab thickness in inches

Pt: serviceability index (1-5), 2.5 is used here

Ft: concrete elastic modulus in (psi) =Sc/FS;

Where: Sc: mean concrete modulus of rupture (psi),

FS: factor of safety

J: transverse joint modulus of subgrade reaction or load transfer coefficient (pci)

Ec: concrete modulus of elasticity (psi)

K: modulus of subgrade reaction (pci), when using base coarse then the combined modulus is used.

Cd: drainage coefficient

As an example by application on nomographs:

If :-

k =72 pci

Ec = 5E7 psi

Sc = 650 psi

J = 3.2

Cd =1

So = 0.29 (overall standard deviation)

R = 95% reliability

Psi = 4.2-2.5 =1.7 (design serviceability loss

W18 =5.1E6 (18 kip ESAL)

Solution: D=10 inches

((11), PRINCIPLES OF PAVEMENT DESIGN,(12) Feasibility of Finite –Element Modeling in the Design of Flexible Pavement,(4) Journal of Transportation Engineer, November &December /1998).

3.4.2 Maryland Road Test

It is a research project setup by the interregional council on highway transportation in year 1949 to study the effect of various wheel loads on rigid pavement performance. The purpose of the testing program was to determine the relative effect of various axle load and configuration on distresses of rigid pavements. The loads which where used were 18,000 and 22,400 pounds on single axle or 32,000 and 44,000 pounds on tandem axle. The results of testing program indicated that the progress of cracking was definitely related to the occurrence of pumping.

((11), PRINCIPLES OF PAVEMENT DESIGN.)

3.4.3 Portland Cement Association method (PCA)

The basis of Portland Cement Association design method is stress analysis techniques, which developed by Westergard, in which the thickness is dependent upon magnitude and number of repeated loads, and modulus of rupture or the modulus subgrade reaction.

The thickness of concrete pavement is relatively insensitive to the modulus of subgrade support. In the Portland Cement Association procedure use the stress ratio to account for fatigue of the concrete pavement (stress ratio is defined as the ratio of the actual stress in the pavement to the modulus of rupture). Design by the PCA method is accomplished through the use of a worksheet, tables, and nomographs. Design by this method is accomplished by trial and error. An assumed slab thickness is checked for both allowable fatigue and allowable foundation erosion, the input variables of PCA method are: traffic volume (repetitions), load safety factor, and 28-day concrete modulus of rupture, subgrade modulus, transverse joint design and the presence or lack of concrete shoulders adjacent to the traffic lanes. (11,12,4)

3.4.4 Ever FE (Ever Finite Element method)

Ever FE is a rigid pavement of three dimensional finite element analysis tool, In which the rigid pavement analysis program Ever FE has been developed, in an attempt to make three dimensional finite element analysis, more assessable to users in abroad range of setting, which makes it simple and practical to explore the effects of various factors on pavement behavior and to perform parametric studies to evaluate different designs.

This tool (ever FE) was formulated the basic relationships between stress and displacement across a discrete crack based on the representation of concrete as constituted by two separate materials; the cement and the aggregate which idealized as obeying a rigid - plastic stress- strain low. For the solution of the system equilibrium equations, Ever FE employs a high-performance multi grid preconditioned strategy, which is much more efficient than conventional direct solution methods in terms of both computational time and memory use. This permits realistic three-dimensional models to be run on modest desktop computer using Ever FE. ((13), Transportation Research Record no. 1629 (design rehabilitation pavements 1998).

3.5 A comparison of two rigid pavement design methods

A comparison of design of a rigid pavement slab by the ASSHTO method and the PCA method has been presented, the required slab thickness over a range of trucks volumes and axle weights has been compared as well as the change in slab thickness with subgrade modulus. When comparing required slab thickness, one method did not consistently give larger volumes over the entire range of traffic volumes and axle weights. In general, the PCA method produced thicker slabs in the high categories while the AASHTO slabs in the categories with high volumes. The PCA fatigue model allows an unlimited number of load applications if the concrete stresses are less than 45% of the modulus of rupture. If slab has been designed for high volume, additional volume may not cause a change in the design thickness. This could explain why two load categories, the slab thickness obtained by the PCA method for doweled joints is not very sensitive to the number of load applications. The rate of reduction of slab thickness for increasing subgrade modulus was found to be consistently greater than the PCA method. ((13) Transportation Research Record no. 1629 (design rehabilitation pavements 1998).

Chapter (4)

Methodology

4.1 Thesis Significant

Existing methods for rigid concrete pavement design depend on empirical formulas, which are in turn dependent on regression analysis.

The objective of this research is to derive a theoretical simple model to solve the issue of determination of the thickness of rigid pavement for a given condition, in parallel to the practical design methods. As an example, AASHTO design procedure for rigid concrete pavement is based on the AASHTO Road test as a pavement performance algorithm.

4.2 Methodology

The method used for the purpose of developing a model, which solves the problem of thickness of rigid highway pavement, is the three dimensional finite element analysis. The finite element model described here will simulate the rigid pavement in the field considering the constraints of the available resources; software

(SAP 2000 program), and developing failure criteria. The selection of a finite element for the purposes of this research depends on the kind and type of load, boundary conditions, and materials characteristics.

The members that are thin with a limited dimension in the third direction, (Z direction; the thickness or depth of the roadway of the rigid concrete pavement), compared with the members dimensions in the other two directions, X direction which is mainly the width of the road way pavement) & Y direction which represents the length of the roadway pavement)).

In order to limit the approximation during the solution of differential equation into a finite element program, the size of the three-dimensional element and the aspect ratio must be considered as small as possible (up to the certain limit) to maximize the number of nodes which maximize the number of finite elements of the rigid concrete pavement to the capabilities available in SAP 2000 program. The edge condition of rigid concrete pavement is chosen as being fully restrained as an ideal condition, which assumes the existence of stabilized shoulders, and also the case of unrestrained conditions when displacement is allowed, but real condition is represented by a combination of both cases.

The materials used are high performance concrete with or without adding supplementary cementitiouse materials to get a thin layer of rigid concrete pavement with comparison of normal concrete or non high performance concrete which need un-economical thickness for the layer of rigid pavements.

The goal is to conduct a method depending on three-dimensional finite element for a thin layer of rigid pavement, by depending on the strength of concrete and the modulus of subgrade reaction, in addition to the applied vehicular load. The Portland Cement Concrete can be strengthen by using high performance concrete, by adding supplementary cementitiouse materials and small iron segments.

4.3 Finite Element method

The Finite Element method is a tool of research of design and analysis, it is a numerical technique which gives an approximate solution to differential equations that modeled problems arising in physics and engineering.

The finite element method has become a powerful tool for the numerical solution of wide range of engineering problems. Application range from deformation and stress analysis of automotive, aircraft, building, and bridge structures to field analysis of heat flux, fluid flow, magnetic flux seepage, and other flow problems.

To defined any problem in the finite element, it is modeled by dividing it into an equivalent system of smaller bodies or units, which called (finite elements), internal connected at points common to two or more elements (nodal points or nodes) and for the boundary lines and/or surface (mesh).

In this technique, instead of solving the problem of the intire body in one operation, it formulates the equations for each finite element and combines them to obtain the solution for the whole body.

The solution of structural problems typically refers to determining the displacement of each node and the stresses within each element, making up the structure that is subjected to applied load.

After the advancement in computer technology, complex problems can be modeled with relative ease. Several alternative configurations can be tried out on a computer before the first prototype is built. All of this suggests that the need to keep space with these developments by understanding the basic theory, modeling technologies and computational aspects of the finite elements method. in this method of analysis, a complex region defining a continuum is discretized into simple generic shapes called Finite Elements. The material properties and the governing relationships are considered over these elements and expressed in terms of unknown values at element corners. An assembly process, duly considering the loading and constraints, results in a set of equations, solution of these equations gives us the approximate behavior of the continuum.

4.3.1 Finite Element Formulation

Several factors affect and support the choice of the finite element technique and form of the basis of this model. Finite element is an updated analytical method that has approximately accurate results. Many researchers are working nowadays using this method to modify their old results. The finite element model will simulate the rigid pavements in the field considering the constraint of the available resources.

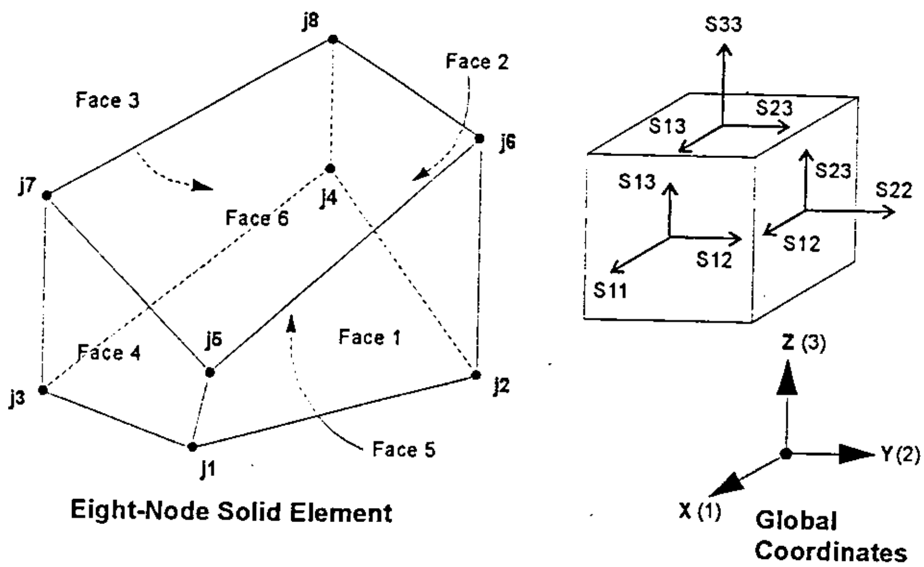
The major considerations in any finite element model are the selection of element type, kinds of loads, boundary conditions, and material characteristics.

4.3.2 Element type

Element type is an important factor in the analysis by finite element method since there are frame element, shell element, Asolid element, solid element, and plate element as shown in figures (4.1,4.2,4.3).

In this research the shell element is adopted since the kind of stresses govern the kind of finite element to be adopted, where the existing stresses her is compressive stresses, also there is a need to thin layer in rigid pavements as figure (4.3).

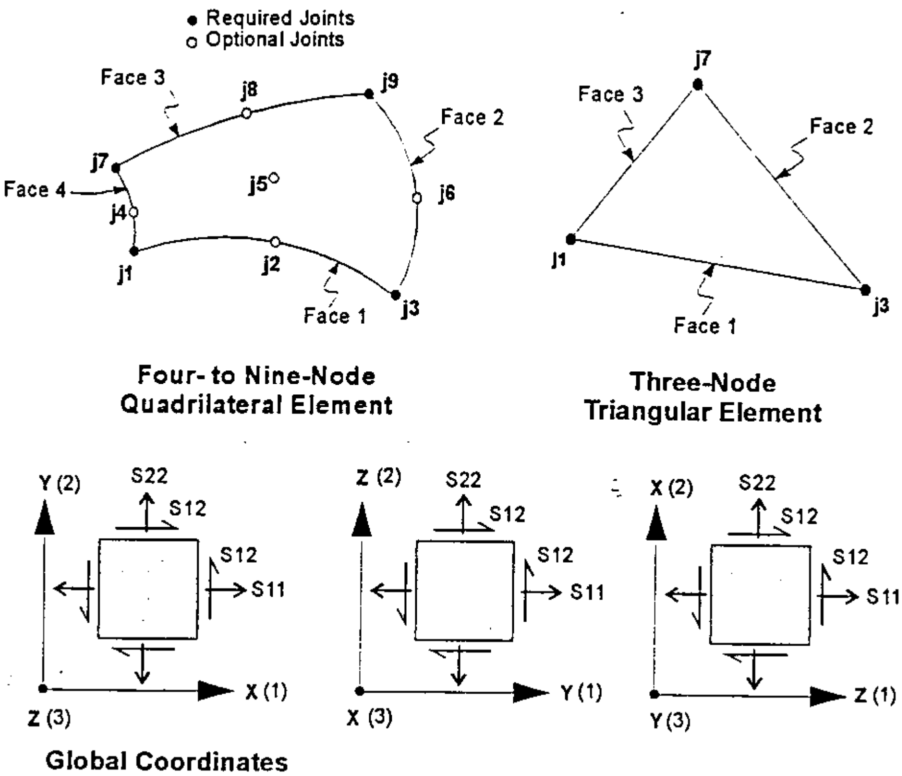
Solid Element



Solid Element Stresses

Fig. 4-1 Solid Element Stresses

Asolid Element



Plane and Asolid Element Stresses

SINT = F intermediate

SVM =√{1/2[(SMAX - SINT)^2+(SMAX - SMIN)^2+(SINT - SMIN)^2]}.

Also See: Von Mises Stress

Fig. 4-2 Plane and Asolid Element Stress

Shell Element

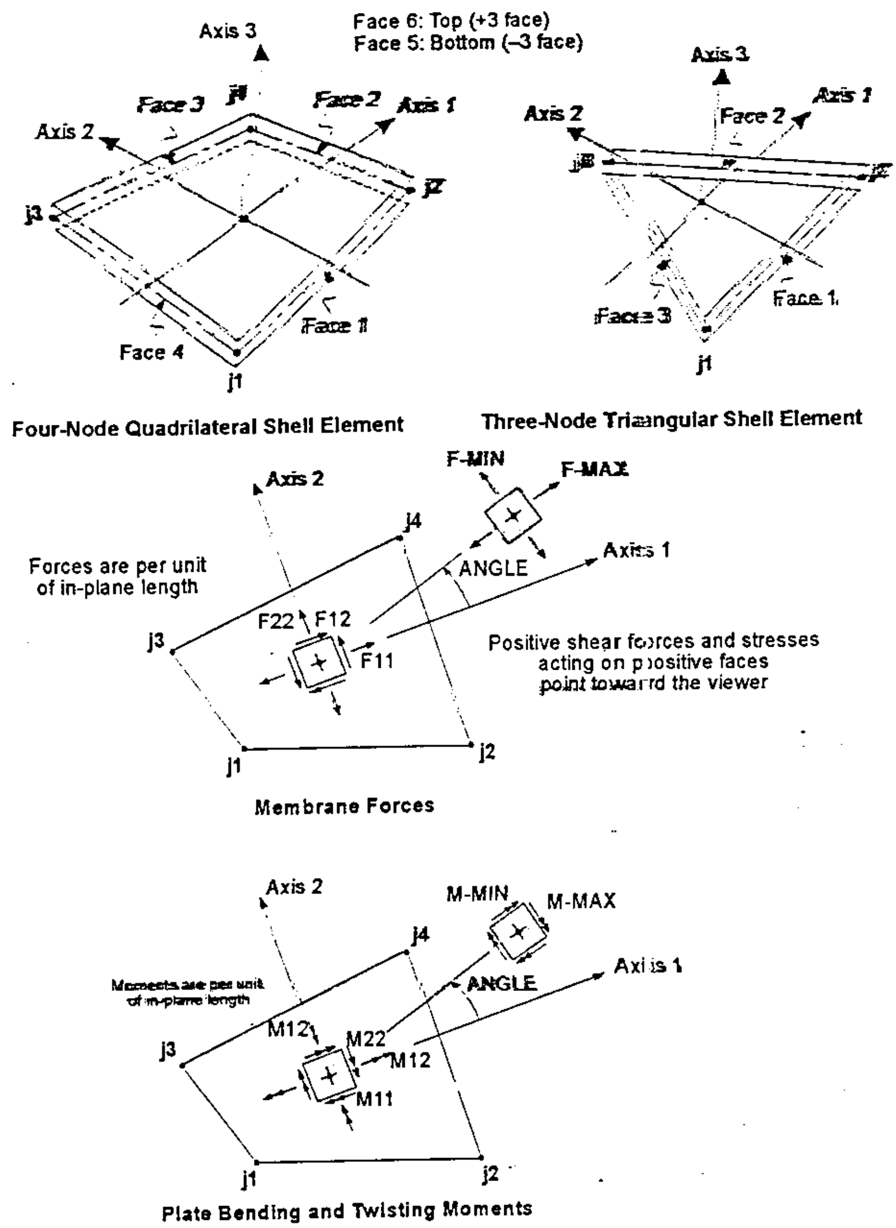


Fig. 4-3 **Shell Internal Forces**

FINT = F intermediate

FVM =√[1/2[(FMAX - FINT)^2+(FMAX - FMIN)^2+(FINT - FMIN)^2]].

Also See: Von Mises Stress

4.4 About SAP 2000 software program

SAP 2000 is the latest and most powerful version of the well-known SAP series of structural analysis programs.

SAP 2000 features powerful and completely integrated modules for design of both steel and reinforced concrete structures. The program provides the user with options to create, modify, analyze and design structural models, all from within the same user interface. The program provides an interactive environment to which the user can study the stress conditions, which make appropriate changes such as: members size revision, and update the design without reanalyzing the structure, members can be grouped together for design purposes. The output in both graphical and tabulated formats can be ready displayed and painted. The program is structured to support a wide variety of design codes for automated design.

The design is based upon the set of user specified loading combination, However the program provides a set of default loads combinations for each design code supported in SAP 2000. If the default load combinations are acceptable, no definition of additional load combinations is required. The presentation of the output is clear and concise, the information is in a form that allows engineers to take appropriate remedial measures in the event of member overstress, backup design information produced by the program is also provided for convenient verification of the results.

SAP 2000 structural analysis program offers the following features: -

- Static and dynamic analysis.
- Linear and nonlinear analysis including seismic analysis.
- Vehicles live load analysis for bridges.
- P- delta analysis.
- Frame and shell structural elements including beams, columns, truss, membrane, and plate behavior.
- Two and three-dimensional and axisymetric solid element.
- Nonlinear link and spring elements.
- Multiple coordinate system.
- Many types of constraints.
- A wide variety of loading options.
- Alpha numeric labels.

- Large capacity.
- And highly efficient and stable solutions algorithm.

SAP 2000 creates design output in three major different formats: graphical display, tabular output, and member specific detailed design information.

The graphical display of design output includes input and output design information. Input design information includes design section label, k- factors, and live load factor and other design parameters. The output design information includes longitudinal reinforcing, shear reinforcing and column capacity ratio. The tabular output can be saved in a file or printed, the tabular output includes most of the information, which can be displayed, and this is generated for added convenience to the designer.

The member specify detailed design information shows the detailed of the calculation from the designers point of view, it shows the design forces, design section dimensions, reinforcement, and some intermediate results for all the load combinations at all the design sections of specific frame member

Chapter (5)

Model formulation and analysis

5.1 Introduction

The section type, specified by the parameter type determines the behavior modeled by the corresponding element.

A shell section is a set of materials and geometric properties that describe the cross section of one or more shell elements and are assigned to the element.

Section type has one of three types as:

- Member Type; pure membrane behavior, only the in-plane forces and the normal drilling moment can be supported.
- Plate Type; pure plate behavior, only the bending moments and the transverse force can be supported.
- Shell Type; full shell behavior, a combination of membrane and plate behavior, all forces and moments can be supported.

5.2 Material properties

The material properties for each section are specified by the reference to a previously defined material, the material properties used by the shell section are the modulus of elasticity (E) and poisons ratio (μ) to compute the membrane and plate stiffness.

5.3 Thickness

Each section has a constant membrane thickness and a constant bending (t_h), The membrane stiffness for full shell and pure membrane sections.

The element volume for the element self-weight and mass calculations, the bending thickness ($t_{hb.}$) is used.

The plate- bending stiffness for full shell, and pure –plate section. Normally these two thicknesses are the same and (t_h) only need to be specified.

5.4 Joints and degree of freedom

The joints play a fundamental role in the analysis of any structure, joints are the points of connections between the elements, and they are the primary locations in the structure at which the displacements are known or are to be determined the displacement components (translations and rotations) at the joint are called the degrees of freedom.

5.5 Element type

The rigid pavement of roadway section, which used for applying a finite element analysis on it, is about 24 ft x24 ft with different various thickness divided to small plate parts to the limit that can be accepted by SAP 2000 program analysis. The principle stresses, which can be converted to horizontal strain (ϵh) by applying Hooks law:

$$\epsilon h = \frac{1}{E}(s1-\mu(s2+s3)) \qquad \text{eq.(5.1)}$$

Where:

ϵh: horizontal strain or critical strain which depends on fatigue criteria.

E: is resilient modulus of concrete layer.

μ: Poisons ratio of concrete material

s1,s2,s3: principle stresses in X,Y&Z directions

The tensile strength test usually shows a large scatter, a number of equations have been proposed in the literature. The following expressions given in the ACI code (14.15) may be used to obtain the lower bound estimates: -

Principle tensile strength = $0.4\ (fc)^{0.5}$

Flextural tensile strength = $0.6\ (fc)^{0.5}$

Where: - fc is expressed in terms of Miga Pascal (M Pa.)

Tables (5.1,5.2) define the critical strain of subgrade and rigid concrete layer, which will be used to find the suitable thickness of rigid concrete pavements by trial and error in solving thickness.

Using elastic theory computation, a relationship between the ratio of vertical subgrade strain at a given wheel load ∈hg was developed to various loads.

Table (5.1) defines the criteria relates the allowable strain ∈h9 value (∈h9 =240E-6 in/in) for a given number of 18-Kip axle load repetition, it should be noted for this criteria that:

- It assumes that assurance against deformation will be comparable for all traffic volumes.

- The development of limiting tensile strain criteria for fatigue cracking was based upon an analysis of existing fatigue results coupled with the theoretical results of the control section.

Fatigue data developed by Dorman & Metcalf where extrapolated to determine the allowable strain for a single load application.

Using linear relationship to interpret the analysis of predicted a stress- strain result to pavement structures for varies design ESAL, in between these limits. Variable adjustments in the thickness requirements for deformation are made these noval adjustment loads to the result that a greater degree of deformation may be allowable as the traffic volume is decreased.

Table (5.1) Limiting subgrade strain

Traffic curve	No. of 18kip ESAL repetition	Wheel load (kip)	∈hN/∈h9 in./in.	∈hN (accepted strain (in.))
IA	5E3	25.5	2.837	6.809E-4
	7.81E3	24.5	2.726	6.542E-4
	1E4	24	2.664	6.394E-4
I	1.56E4	23	2.553	6.127E-4
II	3.12E4	21.4	2.381	5.714E-4
	5E4	20.4	2.263	5.431E-4
III	6.25E4	19.9	2.208	5.299E-4
	1E5	18.8	2.091	5.018E-4
IV	1.25E5	18.3	2.038	4.891E-4
V	2.,5E5	16.8	1.863	4.471E-4
VI	5E5	15.2	1.690	4.056E-4
VII	1E6	13.7	1.518	3.643E-4
VIII	2E6	12.1	1.346	3.230E-4
IX	4E6	10.6	1.172	2.813E-4
	5E6	10.1	1.117	2.681E-4

Traffic curve	No. of 18kip ESAL repetition	Wheel load (kip)	∈hN/∈h9 in./in.	∈hN (accepted strain (in.))
X	8E6	9.0	1.000	2.400E-4
	1E7	8.5	0.944	2.266E-4
XI	1.6E7	7.5	0.824	1.978E-4
XII	3.2E&	5.9	0.654	1.570E-4
	5E7	4.9	0.543	1.303E-4
	1E8	3.3	0.371	0.899E-4

from Havens, Deen and Southgate.(11,12)

Table (5.2) Limiting concrete tensile strains

Traffic curve	No. of 18kip ESAL repetition	Limiting concrete tensile strain (in.)			
		Concrete compressive strength psi.			
		3000	3500	4000	5000
IA	5E3	3.69E-4	4.92E-4	6.03E-4	7.03E-4
	7.81E3	3.37	4.55	5.64	6.62
	1E4	3.2	4.36	5.43	6.4
I	1.56E4	2.91	4.03	5.08	6.03
II	3.12E4	2.5	3.57	4.58	5.5
	5E4	2.27	3.28	4.26	5.17
III	6.25E4	2.17	3.14	4.11	5.0
	1E5	1.96	2.89	3.82	4.7
IV	1.25E5	1.87	2.78	3.69	4.56
V	2.,5E5	1.62	2.46	3.22	4.17
VI	5E5	1.4	2.18	3.0	3.81
VII	1E6	1.22	1.94	2.71	3.48
VIII	2E6	1.05	1.72	2.45	3.18
IX	4E6	0.91	1.52	2.2	2.89
	5E6	0.87	1.46	2.12	2.8

Traffic curve	No. of 18kip ESAL repetition	Limiting concrete tensile strain (in.)			
		Concrete compressive strength psi.			
		3000	3500	4000	5000
X	8E6	0.79	1.35	1.97	3.63
	1E7	0.75	1.29	1.91	2.56
XI	1.6E7	0.68	1.19	1.78	2.41
XII	3.2E&	0.59	1.06	1.61	2.2
	5E7	0.56	0.98	1.5	2.07
	1E8	0.46	0.87	1.36	1.9

from Havens, Deen and Southgate.(11,12)

5.6 Applied load and the required data

In order to formulate a model, there is a need to change the dynamic load to an equivalent single axle load. And, in turn it must be changed to a vehicle load, which defined in lists through the software. These vehicle loads are given in a lot of styles as shown in figures (5.1,5.2) by using the existing template in the software (plate type) with the need for data as follows:

Number of spaces along X direction =12 spaces

Number of spaces along Y direction =12 spaces

Space width along X direction =24ft, width of two lanes.

Space width along Y direction =24ft, length equal to the width of two lanes to be squared section.

Middle strip width along X direction = 12ft

Middle strip width along Y direction = 12ft

This can be shown in fig. (5.3a, 5.3b).

This mean that the dimensions of the model is =24x24 ft^2, and it has 144 finite elements, and 169 points or nods which represent as the springs compressive forces as shown in fig. (5.3a, 5.3b).

By using a defined list to specify the materials specifications of existing subgrade and the concrete which may be used.

These specifications as mass per unit volume, weight per unit volume and modulus of elasticity (E), the value of poisons ratio (μ), and all other specifications of the two mentioned materials.

Also the section itself must be defined as a shell section of a plate type with variable thickness, choosing this type of element (shell element) is due to the kind of stresses established in rigid concrete layer, which is only compressive stresses. And in turn determined by trial and error method for each section. Also defining static loads if it exists by defining the dead load of the concrete pavement itself.

Also dynamic load must be defined by using standard vehicles as shown in figure (5.1) and by changing it to the equivalent 18 kip. Single axle load, which adopted in other method of rigid pavement design and analysis.

Thus our model is resulted from using standard loads, which clarified in SAP2000 software,

In parallel, we could use a point load instead of standard vehicles to represent the applied load. Using point load representation to the applied load is amore conservative method, which means that the thickness getting from the point load representation is greater than that of the standard vehicles for the same variables of (ESAL, k, and fc), which due to neglecting overlapping stresses due to other tire in the same axle.

As the data is collected the design thickness of rigid pavement is achieved and relating the input data of modulus of subgrade reaction (k), number of equivalent single axle load in repetitions (No. E.S.A.L), and the compressive strength of concrete (crushing force (fc)), to the required thickness (t) which resulted from applying the finite element method on the SAP 2000 software.

By running the SAP 2000 program with different values of the selected variables to achieve the design thickness for each alternative of variables, the resulted data can be gathered as shown in table (5.3), page (70).

To formulate the proposed model a linear regression analysis is performed, this regression can be done by applying (SPSS) software with the resulted thickness of concrete rigid pavement design from finite element method.

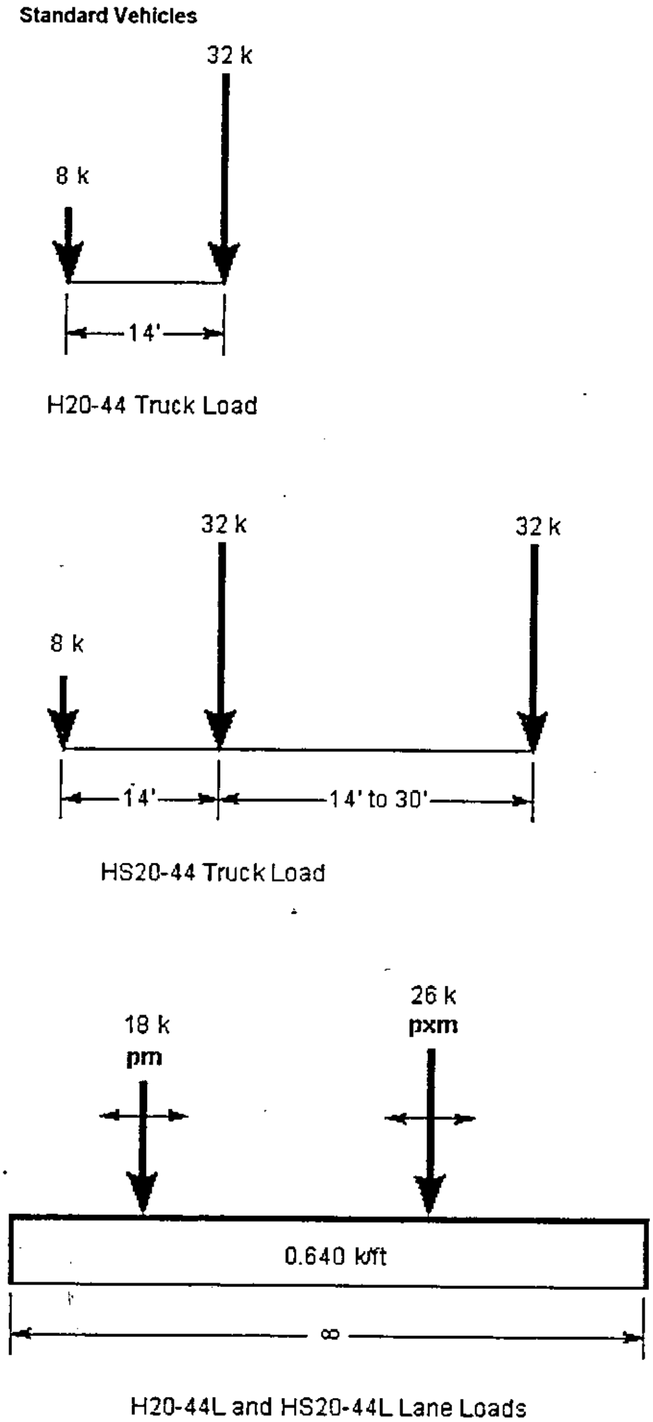
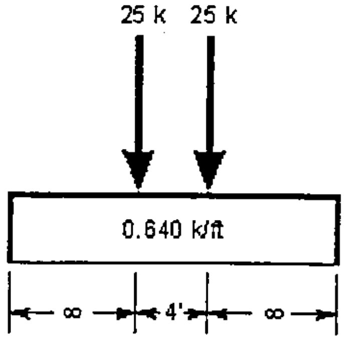
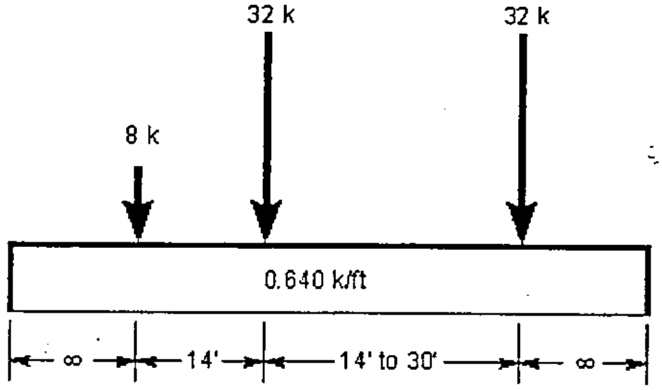


Fig. 5-1 Standard Vehicles

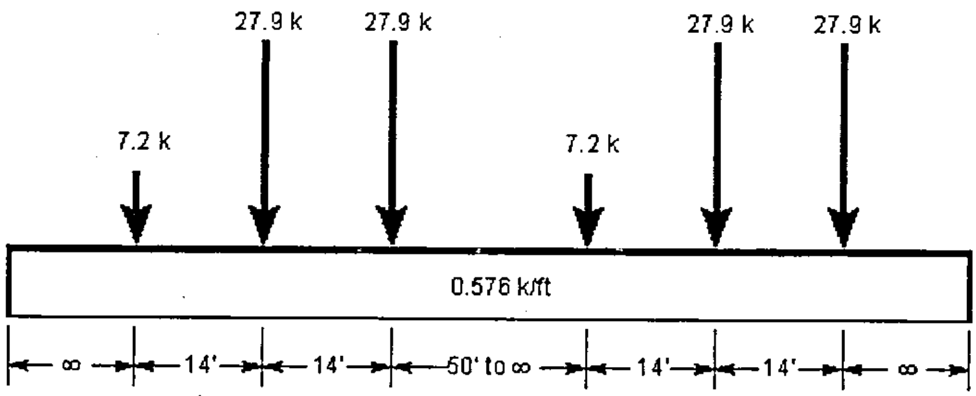


HL-93K Tandem and Lane Load

Note: All point loads will be increased by the dynamic load allowance, **im**, expressed as a percentage



HL-93K Truck and Lane Load



HL-93S Truck and Lane Load for Negative Moment and Reactions at Interior Piers

Fig. 5-1(continued) Standard Vehicles

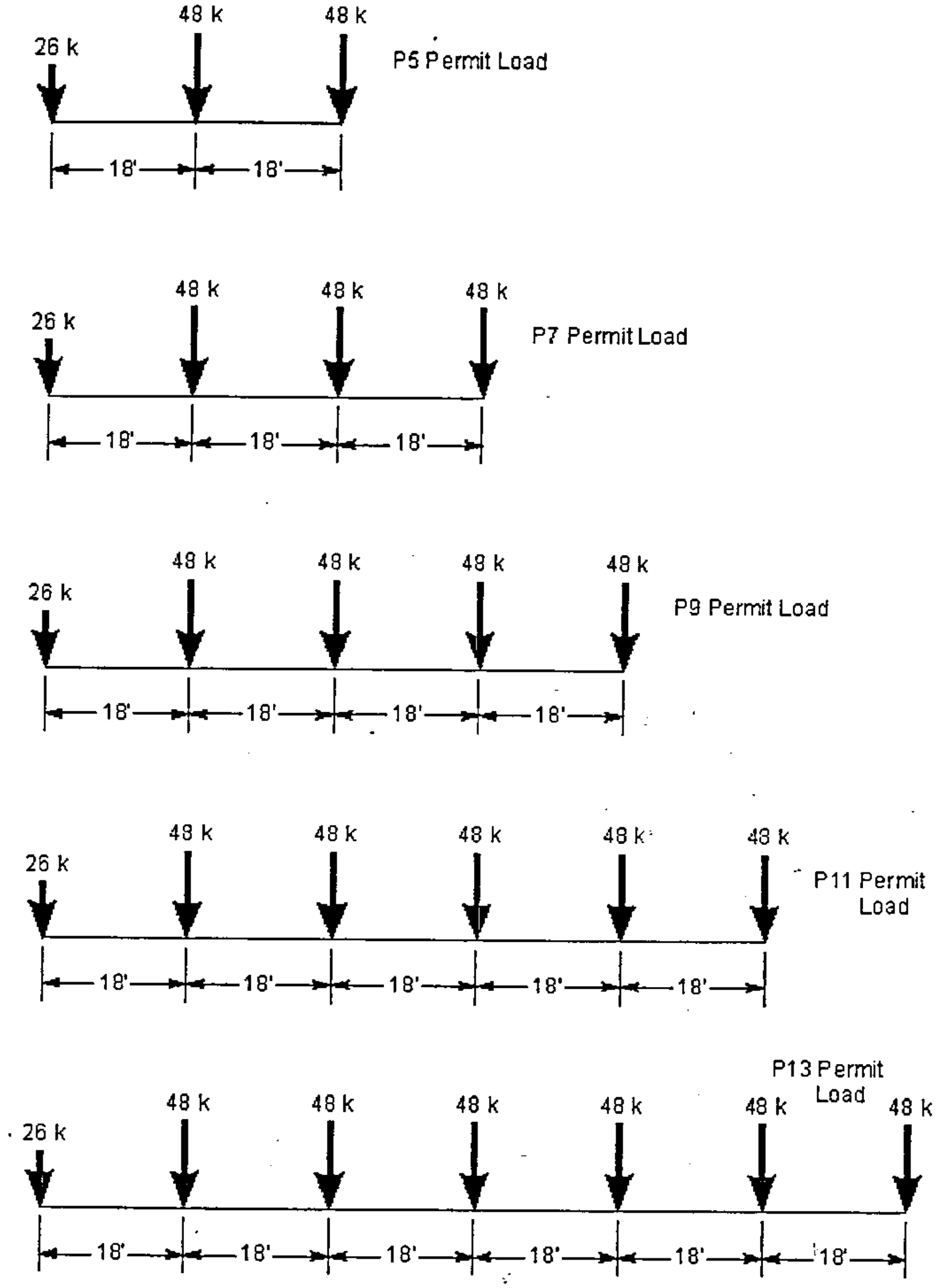


Fig. 5-1(continued) Standard Vehicles

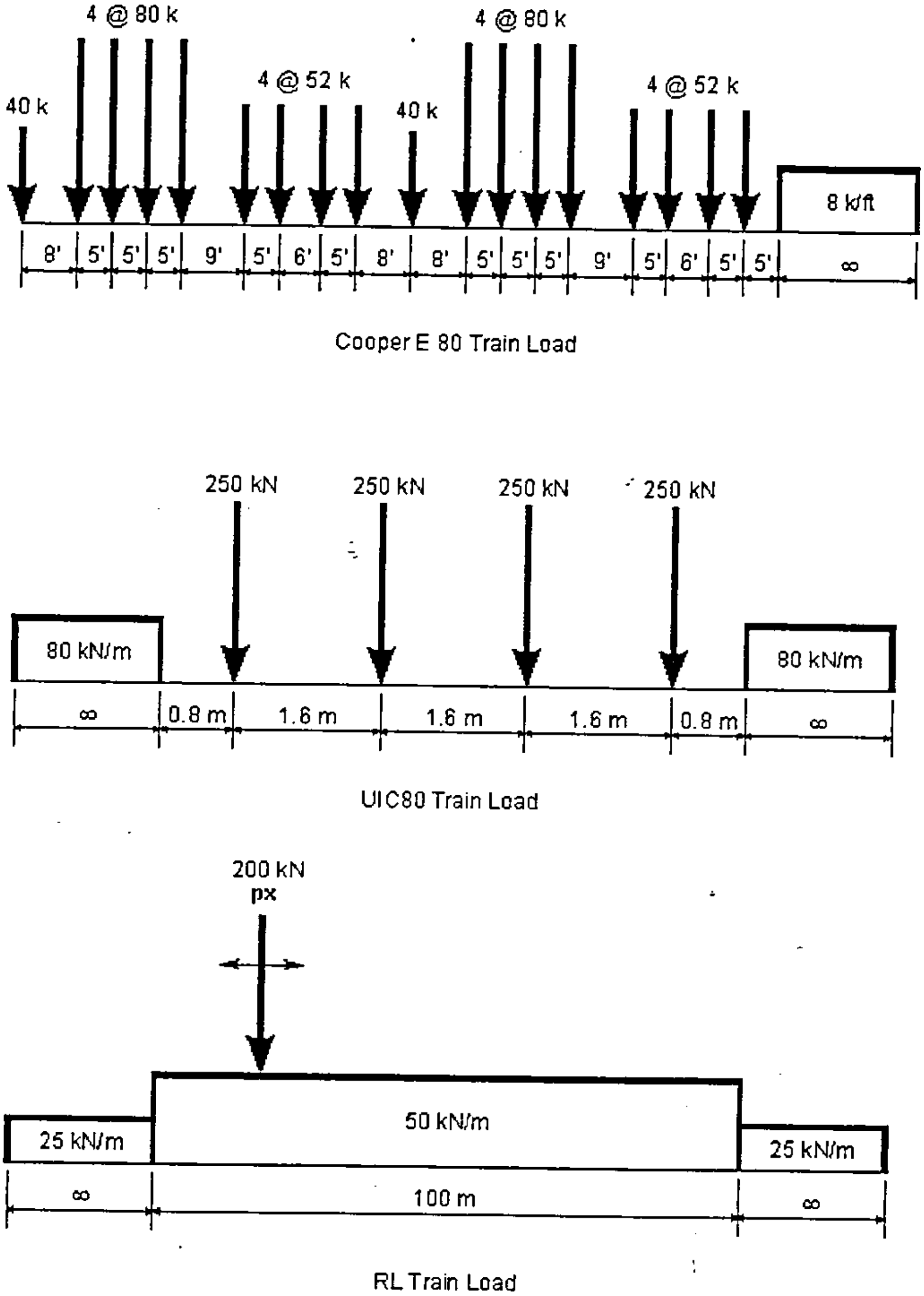
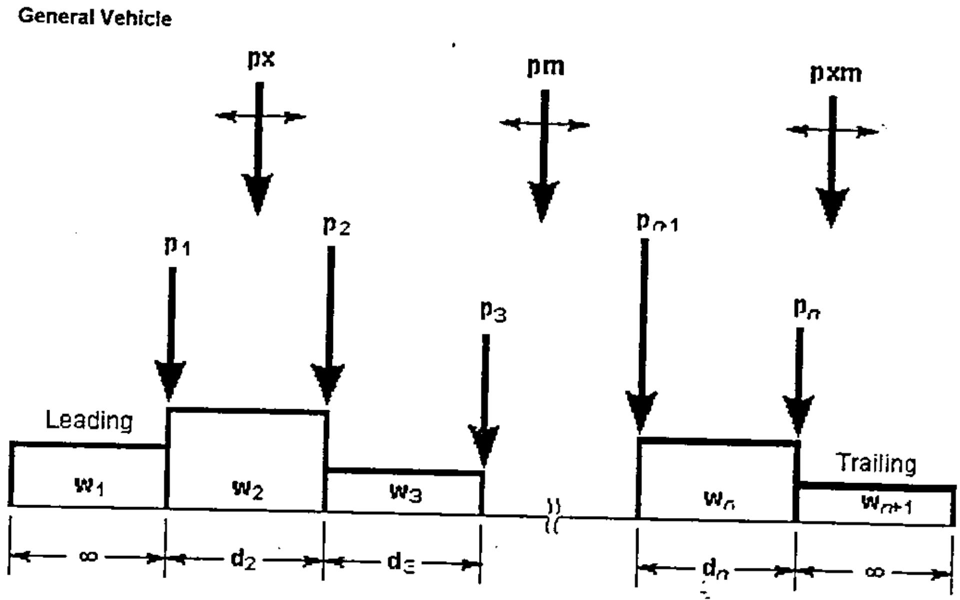


Fig. 5-1(continued) Standard Vehicles



Notes:

(1) All loads are point loads or uniform line loads acting on the Lane center line

(2) Any of the point loads or uniform line loads may be zero

(3) The number of axles, n, may be zero or more

(4) One of the inter-axle spacings, $\mathbf{d_2}$ through $\mathbf{d_n}$, may vary over a specified range

(5) The locations of loads **px**, **pm**, and **pxm** are arbitrary

Fig. 5-2 General Vehicles

The general vehicle may represent an actual vehicle or notational vehicle used by a design code. Most trucks and trains can be modeled by the SAP 2000 as general vehicle.

The general vehicle consists of (n) axles with specified distances between them. Concentrated loads may exist at the axles, uniform loads may exist between pairs of axles, in front of the first axle and behind of the last axle. The distance between any one pair of axles may vary over a specified range, the other distances are fixed. The leading and trailing uniform loads are of infinite extent. Additional floating concentrated loads may be specified that are independent of the position of the axle.

Because the applied loads never decrease the severity of the computed response, a longer vehicle that includes the same loads and spacing as the longer vehicle captures the effect of a shorter vehicle. Only longer vehicles need to be considered in such cases.

To define a vehicle you may specify; -

- (n-1) positive distance (d) between the pairs of axles, one inter-axle distance may be specified as a range from ($d_{min.}$)to ($d_{max.}$) where 0< ($d_{min.}$) < $d_{max.}$).

- (n) Concentrated loads, (p) at the inter-axle load and the trailing load.
- Floating concentrated loads; either :-
  - A single floating load (p_x) for all response quantities, or
  - A pair floating load:
    - Load (p_m) for span moments in the lane element.
    - Load (p_{xm}) for all response quantities except span moments in the lane element.
- whether or not this vehicle is to be used for:-
  - Negative moments over the supports in the lane elements.
  - Vertical forces in interior pairs and or interior support.
  - Response quantities.

These parameters are illustrated in fig. (5.1), (5-2) pages (60-64). When vehicle is applied to a traffic lane, the axles are moved along the length of the lane to where the maximum and minimum values are produced for every response quantity in every element, usually this location will be different for each response quantity.

1	13	25	37	49	61	73	85	97	109	121	133
2	14	26	38	50	62	74	86	98	110	122	134
3	15	27	39	51	63	75	87	99	111	123	135
4	16	28	40	52	64	76	88	100	112	124	136
5	17	29	41	53	65	77	89	101	113	125	137
6	18	30	42	54	66	78	90	102	114	126	138
7	19	31	43	55	67	79	91	103	115	127	139
8	20	32	44	56	68	80	92	104	116	128	140
9	21	33	45	57	69	81	93	105	117	129	141
10	22	34	46	58	70	82	94	106	118	130	142
11	23	35	47	59	71	83	95	107	119	131	143
12	24	36	48	60	72	84	96	108	120	132	144

Fig.(5-3a) Shape of Rigid Pavements &numbered finite elements

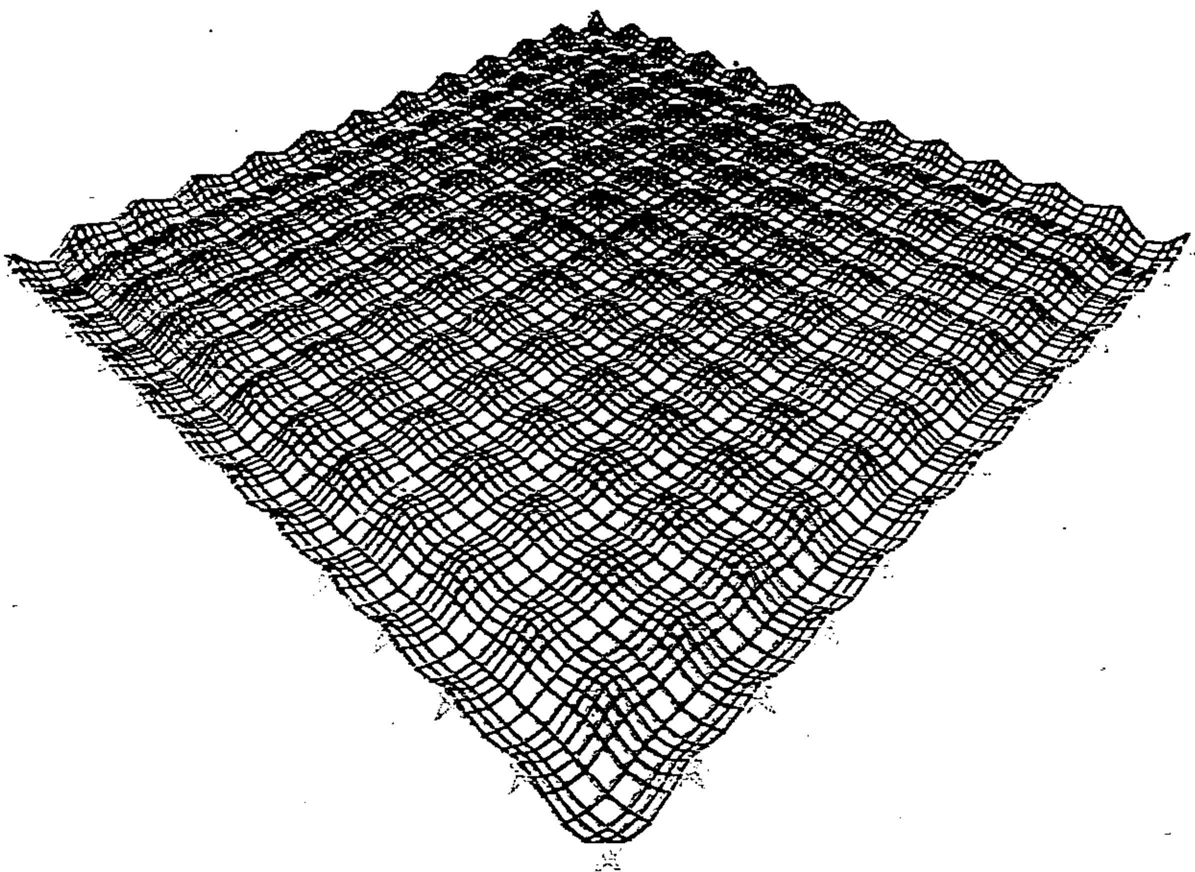


Fig.(5-3b) Displaced Shape of Rigid Pavements & finite elements

SAP2000 v6.11 - File:fff - Deformed Shape (LOAD1) - Kip-in Units

Finite Element method allowed the displaced shape of the system to be viewed as a wire frame in three dimensions, fig. (5.3a, 5.3b) on pages 67 & 68 shows the finite elements of rigid pavement and the displaced shape of the current model subjected to axle loading. Note that the slab here is lifted off the base layer.

Several options are available to the user when viewing the displacement. The displaced and / or undisplaced shapes of any combination of the slabs may be viewed, as usually the displaced and / or undisplaced shapes of the subgrade.

The graphical user interface in finite element in SAP 2000 allowing users to rapidly and intuitively generate and solve finite element models of rigid pavement systems and interpret their results.

The efficiency and ease of use of the graphical user interface allow users to easily test different designs, perform parameters studies, and analyze as built or retrofitted configurations.

5.7 Running SAP2000 for rigid pavements thickness

Taking all the above variables mentioned into account in designing the thickness of layer of rigid concrete pavements.

These variables are:

1. Equivalent 18 Kip single axle load (ESA),
2. Modulus of subgrade reaction (k),
3. The compressive strength of concrete (fc),

Then running the SAP 2000 program to get the required thickness of rigid pavement design, by using Finite Element Method with trial and error method to determine the thickness of the layer of rigid pavements, as shown in table (5.3).

Table (5.3) the resulted thicknesses by running SAP 2000 software.

ESAL equivalent 18 kip single axle load (repetition)	K modulus of subgrade reaction (pci)	Fc (compressive strength of concrete (psi))	T(the needed thickness by F.E method (inch))
100000	100	3000	5
100000	100	4000	4.5
100000	100	5000	4
100000	100	7000	3.5
250000	100	3000	7
250000	100	4000	5.5
250000	100	5000	4.5
250000	100	7000	4
500000	100	3000	7
500000	100	4000	6.5
500000	100	5000	5.5
500000	100	7000	5
750000	100	3000	7.5

ESAL equivalent 18 kip single axle load (repetition)	K modulus of subgrade reaction (pci)	Fc (compressive strength of concrete (psi))	T(the needed thickness by F.E method (inch))
750000	100	4000	7
750000	100	5000	5
750000	100	7000	4.5
1000000	100	3000	8
1000000	100	4000	7
1000000	100	5000	6
1000000	100	7000	5.5
2500000	100	3000	8.5
2500000	100	4000	7.5
2500000	100	5000	6
2500000	100	7000	5
5000000	100	3000	9
5000000	100	4000	8
5000000	100	5000	7
5000000	100	7000	6.5

ESAL equivalent 18 kip single axle load (repetition)	K modulus of subgrade reaction (pci)	Fc (compressive strength of concrete (psi))	T(the needed thickness by F.E method (inch))
10000000	100	3000	10
10000000	100	4000	9.5
10000000	100	5000	9
10000000	100	7000	8.5
100000	200	3000	4.5
100000	200	4000	4
100000	200	5000	4
100000	200	7000	3.5
500000	200	3000	8
500000	200	4000	6
500000	200	5000	5
500000	200	7000	4
1000000	200	3000	7
1000000	200	4000	6.5
1000000	200	5000	6

ESAL equivalent 18 kip single axle load (repetition)	K modulus of subgrade reaction (pci)	Fc (compressive strength of concrete (psi))	T(the needed thickness by F.E method (inch))
1000000	200	7000	5
5000000	200	3000	9
5000000	200	4000	8
5000000	200	5000	7
5000000	200	7000	6.5
10000000	200	3000	10
10000000	200	4000	9
10000000	200	5000	6.5
10000000	200	7000	7.5
100000	300	30000	5
100000	300	4000	4
100000	300	5000	3.5
100000	300	7000	3
500000	300	3000	7
500000	300	4000	6

ESAL equivalent 18 kip single axle load (repetition)	K modulus of subgrade reaction (pci)	Fc (compressive strength of concrete (psi))	T(the needed thickness by F.E method (inch))
500000	300	5000	5
500000	300	7000	4
1000000	300	3000	8
1000000	300	4000	6
1000000	300	5000	5
1000000	300	7000	4
5000000	300	3000	9
5000000	300	4000	8
5000000	300	5000	6.5
5000000	300	7000	6
10000000	300	3000	10
10000000	300	4000	8.5
10000000	300	5000	8
10000000	300	7000	7
100000	400	3000	5

ESAL equivalent 18 kip single axle load (repetition)	K modulus of subgrade reaction (pci)	Fc (compressive strength of concrete (psi))	T(the needed thickness by F.E method (inch))
100000	400	4000	4
100000	400	5000	4
100000	400	7000	3
500000	400	3000	7
500000	400	4000	6
500000	400	5000	4.5
500000	400	7000	4
1000000	400	3000	7
1000000	400	4000	6
1000000	400	5000	5
1000000	400	7000	3.5
5000000	400	3000	9
5000000	400	4000	8
5000000	400	5000	7
5000000	400	7000	6

ESAL equivalent 18 kip single axle load (repetition)	K modulus of subgrade reaction (pci)	Fc (compressive strength of concrete (psi))	T(the needed thickness by F.E method (inch))
10000000	400	3000	10
10000000	400	4000	9
10000000	400	5000	8.5
10000000	400	7000	6.5

High performance high –strength concrete (HPHSC) is defined as concrete that meets special performance uniformity requirements that cannot always be achieved by using only the conventional materials and normal mixing, placing, and curing practices.

High- performance requirements may include ease of placement and compaction without segregation, enhanced short – term and long- term mechanical properties.

High – performance concrete is usually proportioned with low water to cementitious materials ratio, and has a high compressive strength in the range of (3 to 15 Ksi.).

The supplementary cementitious materials may include blast furnace slag, fly ash, or silica fume, which are used either as cement placement or additives to the concrete mixture.

5.8 Regression analysis for thickness design

To find a statistic that measures how well, a multiple regression model to fit a set of data, we use the multiple regression equivalent of R^2, the coefficient of determination for the straight line model, the definition of the multiple coefficient dependent on determination of R^2, which relating to a squares of data relationships as:-

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - y_{esi})^2}{\sum_{i=1}^{n} (y_i - y)^2}$$

Where: -

y_{esi} is the predicted value of y for the model

Also the F static for testing the utility of the model as: -

$$F = \frac{R^2/k}{(1 - R^2)/(n - (k+1))}$$

Where

n :- number of data points

k :- number of parameters

By using the above data as input data on SPSS program for a linear regression analysis the following is done: -

Regression

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Compressive strength of concrete pavement (psi), modulus of subgrade reaction (pci), and no. of equivalent single axle load (repetition)	.	Enter

Where dependent Variable is the required thickness of rigid concrete pavement expressed in inches.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.923	.852	.847	.7333

Predictors: (Constant), Compressive strength of concrete pavement (expressed in psi), modulus of subgrade reaction (expressed in pci), and no. of equivalent single axle load expressed in repetition. Where R^2 is a sample statistic that tells us how well the model fits the data, and thereby represents a measure of the adequacy of the model. If $R^2 = 0$ implies complete lack of fit of the model to the data, and if $R^2 = 1$ implies a perfect fit with the model passing through every data point, in general, the larger the value of R^2, means the better the data fits in model. The error component is normally distributed and the assumption is most important when the sample size is small, the mean of standard error (Sig. column in table page 82) is zero.

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	272.605	3	90.868	169.001	.000
	Residual	47.316	88	.538		
	Total	319.921	91			

Predictors: (Constant), Compressive strength of concrete pavement (expressed in psi), modulus of subgrade reaction (expressed in pci), and no. of equivalent single axle load (expressed in repetition).

Where $$F = \frac{R^2/k}{(1-R^2)/(n-(k+1))}$$

Where n is the number of data points and k is the number of parameters in the model.

The F statistic test becomes large as the coefficient of determination R^2 becomes large.

Dependent Variable: the required thickness of rigid concrete pavement (expressed in inches)

Coefficients table

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	8.643	.303		28.515	.000
	no. of equivalent single axle load (repetition)	3.988E-07	.000	.772	18.753	.000
	modulus of subgrade reaction (pci)	-2.24E-03	.001	-.139	-3.376	.001
	Compressive strength of concrete pavement (psi)	-6.38E-04	.001	-.506	-12.341	.000

Where the dependent Variable is the required thickness of rigid concrete pavement (expressed in inches).

Where t is the statistic values related to the mean of standard error (Sig. col.) where when the value of the mean of standard error becomes small or equal to zero then the values of (t) and the resulted coefficients are approach from the exact values.

This table determines the coefficients of independent variables of the equation: -

$Y = B_0 + B_1 x_1 + B_2 x_2 + B_3 x_3 + \ldots + \ldots,$

Which determine the equation relating the above variables to the thickness of rigid concrete pavements. These tables are determined by SPSS with applying the least square approach.

Depending on the output of linear regression analysis tables of SPSS software for the designed thickness of rigid concrete pavement as above, which depends on the chosen independent variables (k, ESAL, fc), the following linear equation is developed as: -

T=8.643 + 3.988 E-07 (ESAL) –2.24 E-03 (k) –6.38 E-04 (fc)

Where: -

T: the required thickness of rigid concrete pavement (expressed in inches)

ESAL: - the equivalent 18 kip. Single axle load

(expressed in repetitions)

k:- modulus of subgrade reaction (expressed in pci)

fc:- compressive strength of rigid concrete or crushing force of concrete (expressed in psi).

This equation is logically related to choosing three dependent variables, which means that the required thickness of rigid concrete pavement is directly related to the applied vehicle load (as the no. of equivalent 18 kip single axle load increase then the required thickness increase). But it is inversely related to the two other variables, as modulus of subgrade reaction and compressive strength of concrete increases, then the required thickness decreases.

This equation points that the most sensitive factor in determining the thickness of rigid concrete pavements in this formulated equation, is the modulus of subgrade reaction (k), which is an effective factor in determining the required thickness of concrete pavements. This means that if a treatment added to subgrade layer as spraying a new layer of selected material or base course materials, (increasing the value of modulus of subgrade reaction, or improve the subgrade) then a decrease in the required thickness will occurs.

Secondly the compressive strength of the cemented concrete is effecting on determine the thickness of rigid concrete pavements. This means that by increasing the compressive strength of concrete, by using small pieces of iron or metals or using cementatious materials, the required thickness of rigid concrete pavements will decrease.

Finally the third factor affecting the formulated equation in determining the required thickness of rigid concrete pavements is the load or equivalent 18 kip. single axle load.

5.9 Model Calibration

By comparing the theoretical model developed with the other existing models as AASHTO design method, the following results shown in table 5.5 express the comparison.

Table (5.5) model calibration

ESAL(rep.)	K (pci)	Fc (psi)	Thickness (in) by F.E[a]	Thickness (in) by AASHTO
1.00E5	100	3000	6.6	6
5.00E5	200	3000	6.5	8
1.00E6	100	3000	6.9	8.5
5.00E6	300	3000	8.1	12
1.00E7	100	3000	10.5	14

(a): by applying Finite Element model as follows :-

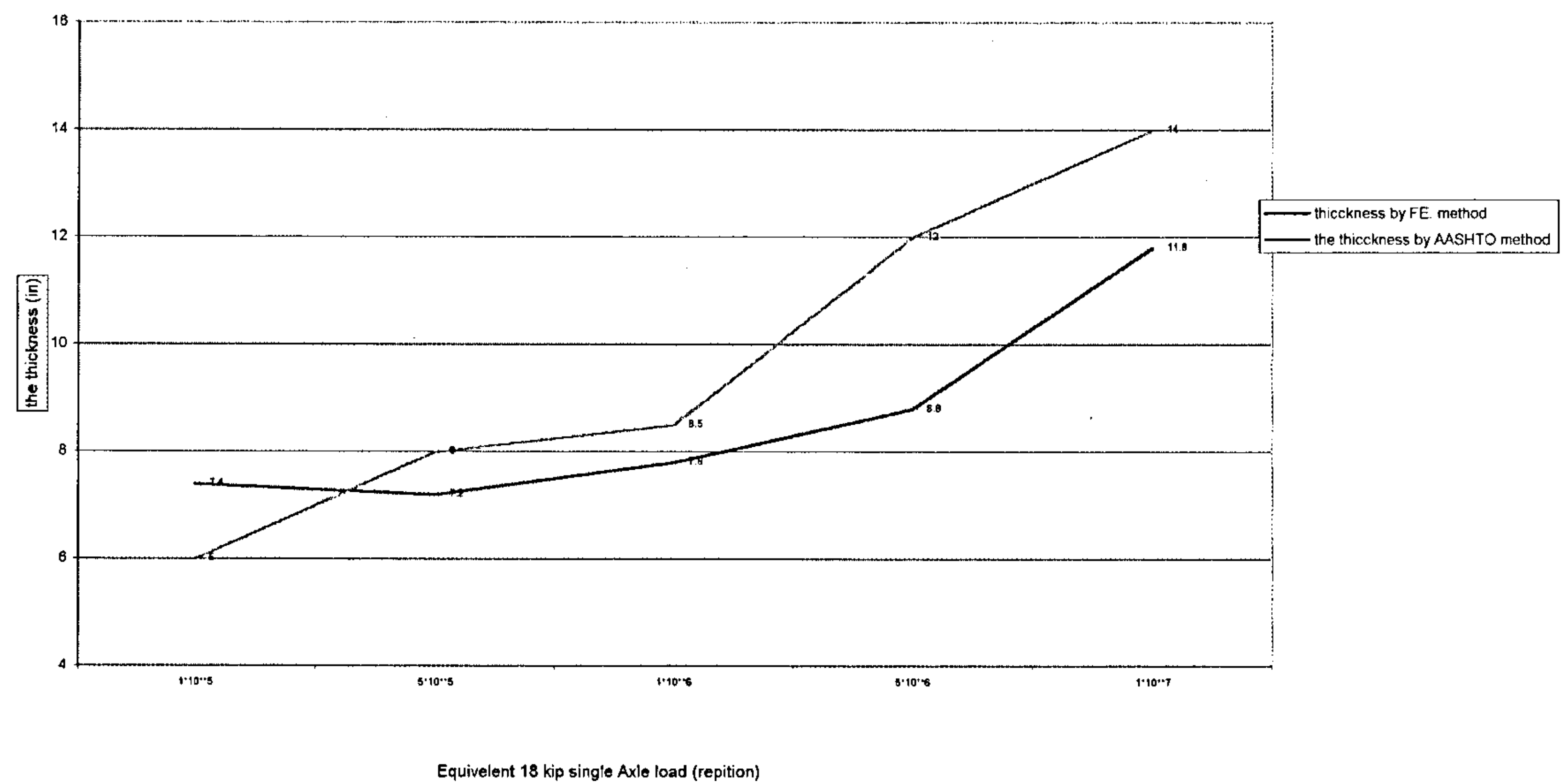
T =8.643 + 3.988 E-7 (ESAL) −2.24E-3(k) −6.38E-4(fc)

From these data we note that the thickness resulted from Finite Element method, is greater than or approach to that of the thickness resulted from AASHTO road test method for small loads, on the contrary, the Finite Element method thickness is less than that of AASHTO road test method for large and heavy loads, as shown in fig. (5.4).

Since Finite Element method for the thickness design of rigid concrete pavement is considered economical method for designing roads with heavy axles which needs a less thickness of rigid concrete pavements than other methods, especially in large and heavy trucks which need large thickness.

The difference between the curves of Finite Element method and AASHTO method are clarified in fig. (5.4), which shows that these difference's reach to 35% less than that needs by using AASHTO method especially when the road is designed for heavy trucks and large vehicles.

Fig .5-4 Model calibration



Chapter (6)

Conclusion and Recommendations

Depending on the results of research the following can be concluded: -

1. Three Dimensional Finite Element Method for the thickness of a thin layer of rigid concrete pavement is an economical method to simulate the thickness, which need a large thickness of pavements for heavy traffics and loads and large trucks, but for relatively light traffics the AASHTO method still the economical one.
2. Using selected materials or basecourse materials layer over subgrade face under the rigid concrete, improves the behavior of concrete layer and decrease the required thickness of rigid concrete pavement, to be more economical than constructing a rigid concrete layer directly on existing subgrade, especially when the subgrade material are very bad materials as clay or silty clay, thus changing materials of the face of subgrade with good selected material or with basecourse is encouraged before constructing rigid concrete pavements layer.

3. Using good materials of concrete or using small iron segments or pieces in concrete mixture reduces the thickness required, since using additives which strengthen the concrete by increasing the resistance force of concrete fc are more economical in designing rigid concrete pavements.
4. These data and the predicted formula, which resulted from regression analyses are for plain concrete, without using any steel reinforcement

- From the above conclusions the recommendation is to continue the research of three- dimensional finite element of rigid pavement by using steel reinforcement.

References

The following are some of the references considered: -

1. Dr. Sameer N. Shoukry (1998, November). 3D finite element modeling for pavement analysis and design. Discussed in the dialogue of the conference, which held in Embassy Suites Hotel. Charleston, West Virginia, documents on http://wwwccmr.wvu.edu/-3dfem/
2. Peter H. Emmons, Alexander M &Thomas. (1998). High performance, High strength concrete Design recommendation. Journal of Concrete International, November /1998, (page 163).
3. Laszio Duaszegi (1998). Strengthening concrete structure & high performance in the confederation Bridges. Journal of Concrete International, April /1998, (page 66).
4. Raj V. Sid. Jian yao & Peter E. (1998). Pavement strain from moving dynamic 3D load distribution. Journal of Transportation Engineer, November &December /1998, (page 557).

5. Donald D.N. GEOFFROY. P.E. (1998) Synthesis of highway practice 260 /thin surfaced pavement National Academy Press, Washington D.C. 1998.

6. Surendra P. Shah, W. Josson Weiss & Wei yang, (1996) Mechanical properties of high performance concrete, ACI Materials Journal, September- October /1996, (page 53).

7. Charles K. Nmai, Tony Schlagbaum, (1996), high performance concrete- requirement for constituent material and mix proportioning, ACI Materials Journal, May-June /1996, (, (page 45).

8. Sam Helwany, John dyer & Joe Leidy , (1998), Finite Element Analysis of Flexible Pavements, Journal of Transportation Engineering, September-October /), (page 491).

9. Tirupathir Chandrupatla, Ashok D. Bellegunda. (1993) Introduction to Finite Elements in Engineering, 2nd edition. U.S.A.New Jersey

10. YANG H. HUANG. (1993) , Pavement Analysis and Design 2nd edition. U.S.A. New Jersey

11. ELDON J.YODER , (1975), PRINCIPLES OF PAVEMENT DESIGN, 2nd edition, Copyright @ by John Wiley &Sons,Inc.,Canada.

12. Banan R. Jadallah& Fawz K. Kobary , (1997),Feasibility of Finite –Element Modeling in the Design of Flexible Pavement, Nablus, West Bank , Palestine.

13. William David, George Turkiyyah, & Joe Mahoney , (1998), EverFE Rigid Pavement Three –Dimensional Finite Element Analysis Tool. Transportation Research Record no. 1629 (design rehabilitation pavements 1998), (page 41).

These appendix form a sample for output tables of Finite Element for rigid pavements design by running SAP 2000 software, also clarifies the matrices of computer solutions.

Light

J O I N T   D I S P L A C E M E N T S

JOINT	LOAD	UX	UY	UZ	RX	RY	RZ
7	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	HIST1 MAX	0.0000	0.0000	1.179E-06	0.0000	0.0000	0.0000
7	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	COMB1 MAX	0.0000	0.0000	10.5789	-0.0756	-0.1654	0.0000
7	COMB1 MIN	0.0000	0.0000	10.5799	-0.0756	-0.1654	0.0000
8	LOAD1	0.0000	0.0000	-2.091E-04	2.116E-06	4.894E-06	0.0000
8	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	HIST1 MAX	0.0000	0.0000	1.074E-06	0.0000	0.0000	0.0000
8	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	COMB1 MAX	0.0000	0.0000	9.6429	-0.0586	-0.1309	0.0000
8	COMB1 MIN	0.0000	0.0000	9.6429	-0.0586	-0.1309	0.0000
9	LOAD1	0.0000	0.0000	-1.789E-04	7.780E-06	8.826E-06	0.0000
9	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	COMB1 MAX	0.0000	0.0000	7.5030	-0.3999	-0.2189	0.0000
9	COMB1 MIN	0.0000	0.0000	7.5030	-0.3999	-0.2189	0.0000
10	LOAD1	0.0000	0.0000	-1.233E-04	1.098E-05	9.292E-06	0.0000
10	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	COMB1 MAX	0.0000	0.0000	6.1630	-0.4745	-0.2149	0.0000
10	COMB1 MIN	0.0000	0.0000	6.1630	-0.4745	-0.2149	0.0000
11	LOAD1	0.0000	0.0000	-1.321E-04	7.153E-06	1.198E-05	0.0000
11	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	COMB1 MAX	0.0000	0.0000	4.9207	-0.4401	-0.2950	0.0000
11	COMB1 MIN	0.0000	0.0000	4.9207	-0.4401	-0.2950	0.0000
12	LOAD1	0.0000	0.0000	-5.263E-05	1.197E-05	1.398E-05	0.0000
12	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	COMB1 MAX	0.0000	0.0000	3.0021	-0.5556	-0.3315	0.0000
12	COMB1 MIN	0.0000	0.0000	3.0021	-0.5556	-0.3315	0.0000
13	LOAD1	0.0000	0.0000	-1.011E-04	2.691E-06	1.416E-05	0.0000
13	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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J O I N T   D I S P L A C E M E N T S

JOINT	LOAD	UX	UY	UZ	RX	RY	RZ
13	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	COMB1 MAX	0.0000	0.0000	2.4759	-0.3573	-0.3537	0.0000
13	COMB1 MIN	0.0000	0.0000	2.4759	-0.3573	-0.3537	0.0000
14	LOAD1	0.0000	0.0000	0.0000	2.842E-06	1.341E-05	0.0000
14	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	COMB1 MAX	0.0000	0.0000	0.0000	-0.3768	-0.4687	0.0000
14	COMB1 MIN	0.0000	0.0000	0.0000	-0.3768	-0.4687	0.0000
15	LOAD1	0.0000	0.0000	-1.003E-04	-2.029E-06	1.221E-05	0.0000
15	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	COMB1 MAX	0.0000	0.0000	0.7310	-0.2255	-0.3222	0.0000
15	COMB1 MIN	0.0000	0.0000	0.7310	-0.2255	-0.3222	0.0000
16	LOAD1	0.0000	0.0000	-1.905E-05	-6.441E-06	1.436E-05	0.0000
16	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	COMB1 MAX	0.0000	0.0000	-1.4099	-0.1425	-0.3517	0.0000
16	COMB1 MIN	0.0000	0.0000	-1.4099	-0.1425	-0.3517	0.0000
17	LOAD1	0.0000	0.0000	-1.185E-04	-3.425E-06	9.279E-06	0.0000
17	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	COMB1 MAX	0.0000	0.0000	-0.3040	-0.1270	-0.2617	0.0000
17	COMB1 MIN	0.0000	0.0000	-0.3040	-0.1270	-0.2617	0.0000
18	LOAD1	0.0000	0.0000	-5.919E-05	-6.317E-06	1.005E-05	0.0000
18	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	COMB1 MAX	0.0000	0.0000	-2.0043	-0.0625	-0.2990	0.0000
18	COMB1 MIN	0.0000	0.0000	-2.0043	-0.0625	-0.2990	0.0000
19	LOAD1	0.0000	0.0000	-1.448E-04	0.0000	6.470E-06	0.0000
19	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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J O I N T   D I S P L A C E M E N T S

JOINT	LOAD	UX	UY	UZ	RX	RY	RZ
346	LOAD1	0.0000	0.0000	-1.096E-06	0.0000	0.0000	0.0000
346	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
346	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
346	HIST1 MIN	0.0000	0.0000	-1.099E-06	0.0000	0.0000	0.0000
346	COMB1 MAX	0.0000	0.0000	33.3275	-0.6932	2.8594	0.0000
346	COMB1 MIN	0.0000	0.0000	33.3275	-0.6932	2.8594	0.0000
347	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
347	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
347	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
347	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
347	COMB1 MAX	0.0000	0.0000	21.7054	-6.4659	3.6866	0.0000
347	COMB1 MIN	0.0000	0.0000	21.7054	-6.4659	3.6866	0.0000
348	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
348	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
348	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
348	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
348	COMB1 MAX	0.0000	0.0000	10.8164	-7.7558	4.9437	0.0000
348	COMB1 MIN	0.0000	0.0000	10.8164	-7.7558	4.9437	0.0000
349	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
349	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
349	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
349	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
349	COMB1 MAX	0.0000	0.0000	0.0000	-5.8187	6.4242	0.0000
349	COMB1 MIN	0.0000	0.0000	0.0000	-5.8187	6.4242	0.0000
350	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
350	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
350	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
350	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
350	COMB1 MAX	0.0000	0.0000	-6.2296	-3.0587	5.5500	0.0000
350	COMB1 MIN	0.0000	0.0000	-6.2296	-3.0587	5.5500	0.0000
351	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
351	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
351	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
351	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
351	COMB1 MAX	0.0000	0.0000	-9.9642	-1.9629	4.8308	0.0000

light

J O I N T   D I S P L A C E M E N T S

JOINT	LOAD	UX	UY	UZ	RX	RY	RZ
351	COMB1 MIN	0.0000	0.0000	-9.3642	-1.9699	4.8308	0.0000
352	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
352	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
352	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
352	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
352	COMB1 MAX	0.0000	0.0000	-12.8873	1.041E-03	4.2700	0.0000
352	COMB1 MIN	0.0000	0.0000	-12.8873	1.041E-03	4.2700	0.0000
353	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
353	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
353	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
353	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
353	COMB1 MAX	0.0000	0.0000	-9.9596	1.9718	4.9292	0.0000
353	COMB1 MIN	0.0000	0.0000	-9.9596	1.9705	4.9292	0.0000
354	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
354	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
354	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
354	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
354	COMB1 MAX	0.0000	0.0000	-6.2255	3.0574	5.5772	0.0000
354	COMB1 MIN	0.0000	0.0000	-6.2255	3.0574	5.5772	0.0000
355	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
355	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
355	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
355	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
355	COMB1 MAX	0.0000	0.0000	0.0000	5.9139	6.4202	0.0000
355	COMB1 MIN	0.0000	0.0000	0.0000	5.9139	6.4202	0.0000
356	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
356	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
356	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
356	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
356	COMB1 MAX	0.0000	0.0000	10.8067	7.7484	4.9407	0.0000
356	COMB1 MIN	0.0000	0.0000	10.8067	7.7484	4.9407	0.0000
357	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
357	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
357	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Light

J O I N T   D I S P L A C E M E N T S

JOINT	LOAD	UX	UY	UZ	RX	RY	RZ
357	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
357	COMB1 MAX	0.0000	0.0000	21.6849	6.4591	3.6945	0.0000
357	COMB1 MIN	0.0000	0.0000	21.6849	6.4591	3.6945	0.0000
358	LOAD1	0.0000	0.0000	-1.086E-06	0.0000	0.0000	0.0000
358	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
358	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
356	HIST1 MIN	0.0000	0.0000	-1.099E-06	0.0000	0.0000	0.0000
358	COMB1 MAX	0.0000	0.0000	33.2941	0.6922	2.9534	0.0000
358	COMB1 MIN	0.0000	0.0000	33.2941	0.6922	2.9534	0.0000
359	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
359	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
359	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
359	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
359	COMB1 MAX	0.0000	0.0000	24.2547	-6.0023	4.6601	0.0000
359	COMB1 MIN	0.0000	0.0000	24.2547	-6.0023	4.6601	0.0000
360	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
360	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
360	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
360	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
360	COMB1 MAX	0.0000	0.0000	13.8711	-8.8817	6.6923	0.0000
360	COMB1 MIN	0.0000	0.0000	13.8711	-8.8817	6.6923	0.0000
361	LOAD1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
361	SPEC1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
361	HIST1 MAX	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
361	HIST1 MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
361	COMB1 MAX	0.0000	0.0000	0.0000	-9.5653	9.5628	0.0000
361	COMB1 MIN	0.0000	0.0000	0.0000	-9.5653	9.5628	0.0000

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Light

S H E L L   E L E M E N T   S T R E S S E S

SHELL	LOAD	JOINT	S11-BOT	S22-BOT	S12-BOT	S11-TOP	S22-TOP	S12-TOP	S13-AVG	S23-AVG
		360	-180.75	-16808.86	-18135.27	180.75	16808.86	18135.27	-7244.47	-6704.73
		341	-12386.92	-12469.36	-13959.17	12386.92	12469.36	13959.17	-7244.47	-8148.59
324	LOAD1									
		341	4.738E-04	4.738E-04	5.270E-04	-4.738E-04	-4.738E-04	-5.270E-04	2.964E-04	2.964E-04
		360	1.005E-05	6.734E-04	6.096E-04	-1.005E-05	-6.734E-04	-6.096E-04	2.964E-04	4.795E-04
		361	-2.567E-05	-2.567E-05	6.922E-04	2.567E-05	2.567E-05	-6.922E-04	4.795E-04	4.795E-04
		342	6.734E-04	1.005E-05	6.096E-04	-6.734E-04	-1.005E-05	-6.096E-04	4.795E-04	2.964E-04
324	SPEC1									
		341	1.052E-06	1.052E-06	1.366E-06	1.052E-06	1.052E-06	1.366E-06	0.00	0.00
		360	0.00	1.453E-06	1.540E-06	0.00	1.453E-06	1.540E-06	0.00	1.036E-06
		361	0.00	0.00	1.714E-06	0.00	0.00	1.714E-06	1.037E-06	1.036E-06
		342	1.453E-06	0.00	1.540E-06	1.453E-06	0.00	1.540E-06	1.037E-06	0.00
324	HIST1 MAX									
		341	4.078E-04	4.076E-04	5.291E-04	0.00	0.00	0.00	2.587E-04	2.586E-04
		360	7.712E-06	5.630E-04	5.965E-04	0.00	0.00	0.00	2.587E-04	4.016E-04
		361	0.00	0.00	6.640E-04	2.071E-05	2.072E-05	0.00	4.016E-04	4.016E-04
		342	5.631E-04	7.713E-06	5.966E-04	0.00	0.00	0.00	4.016E-04	2.586E-04
324	HIST1 MIN									
		341	0.00	0.00	0.00	-4.078E-04	-4.076E-04	-5.291E-04	0.00	0.00
		360	0.00	0.00	0.00	-7.712E-06	-5.630E-04	-5.965E-04	0.00	0.00
		361	-2.071E-05	-2.072E-05	0.00	0.00	0.00	-6.640E-04	0.00	0.00
		342	0.00	0.00	0.00	-5.631E-04	-7.713E-06	-5.966E-04	0.00	0.00
324	COMB1 MAX									
		341	-12365.36	-12361.57	-16045.57	12365.36	12361.57	16045.57	-7844.75	-7842.14
		360	-233.86	-17074.37	-18090.49	233.86	17074.37	18090.49	-7844.75	-12178.24
		361	629.16	629.30	-20135.89	-629.16	-629.30	20135.89	-12179.76	-12178.24
		342	-17076.94	-233.90	-18090.97	17076.94	233.90	18090.97	-12179.76	-7842.14
324	COMB1 MIN									
		341	-12365.36	-12361.57	-16045.57	12365.36	12361.57	16045.57	-7844.75	-7842.14
		360	-233.86	-17074.37	-18090.49	233.86	17074.37	18090.49	-7844.75	-12178.24
		361	629.16	629.30	-20135.89	-629.16	-629.30	20135.89	-12179.76	-12178.24
		342	-17076.94	-233.90	-18090.97	17076.94	233.90	18090.97	-12179.76	-7842.14

light

S H E L L   E L E M E N T   S T R E S S E S

SHELL	LOAD	JOINT	S11-BOT	S22-BOT	S12-BOT	S11-TOP	S22-TOP	S12-TOP	S13-AVG	S23-AVG
		340	0.00	0.00	0.00	-3.477E-04	-7.245E-04	-2.596E-04	0.00	0.00
322	COMB1 MAX									
		339	-8940.98	-27744.57	-3539.40	8840.98	27744.57	3539.40	-5142.69	-1924.37
		358	-63.15	-31273.40	-3952.05	63.15	31273.40	3952.05	-5142.69	-2136.63
		359	97.63	-24953.93	-8283.65	-97.63	24953.93	8283.65	-6592.72	-2136.63
		340	-10544.53	-21970.91	-7871.01	10544.53	21970.91	7871.01	-6592.72	-1924.37
322	COMB1 MIN									
		339	-6840.98	-27744.57	-3539.40	8840.98	27744.57	3539.40	-5142.69	-1924.37
		358	-63.15	-31273.40	-3952.05	63.15	31273.40	3952.05	-5142.69	-2136.63
		359	97.63	-24953.93	-8283.65	-97.63	24953.93	8283.65	-6592.72	-2136.63
		340	-10544.53	-21970.91	-7871.01	10544.53	21970.91	7871.01	-6592.72	-1924.37
323	LOAD1									
		340	3.935E-04	7.836E-04	3.269E-04	-3.935E-04	-7.836E-04	-3.269E-04	2.072E-04	2.041E-04
		359	9.631E-06	9.931E-04	3.699E-04	-9.631E-06	-9.931E-04	-3.699E-04	2.072E-04	2.236E-04
		360	7.866E-06	6.625E-04	4.874E-04	-7.866E-06	-6.625E-04	-4.874E-04	2.717E-04	2.236E-04
		341	4.747E-04	4.782E-04	4.444E-04	-4.747E-04	-4.782E-04	-4.444E-04	2.717E-04	2.041E-04
323	SPEC1									
		340	0.00	1.834E-06	0.00	0.00	1.834E-06	0.00	0.00	0.00
		359	0.00	2.264E-06	1.042E-06	0.00	2.264E-06	1.042E-06	0.00	0.00
		360	0.00	1.430E-06	1.288E-06	0.00	1.430E-06	1.288E-06	0.00	0.00
		341	1.054E-06	1.061E-06	1.188E-06	1.054E-06	1.061E-06	1.188E-06	0.00	0.00
323	HIST1 MAX									
		340	3.450E-04	7.107E-04	3.649E-04	0.00	0.00	0.00	1.892E-04	2.028E-04
		359	7.678E-06	8.774E-04	4.037E-04	0.00	0.00	0.00	1.892E-04	2.211E-04
		360	5.961E-06	5.543E-04	4.991E-04	0.00	0.00	0.00	2.338E-04	2.211E-04
		341	4.085E-04	4.112E-04	4.603E-04	0.00	0.00	0.00	2.338E-04	2.028E-04
323	HIST1 MIN									
		340	0.00	0.00	0.00	-3.450E-04	-7.107E-04	-3.649E-04	0.00	0.00
		359	0.00	0.00	0.00	-7.678E-06	-8.774E-04	-4.037E-04	0.00	0.00
		360	0.00	0.00	0.00	-5.961E-06	-5.543E-04	-4.991E-04	0.00	0.00
		341	0.00	0.00	0.00	-4.085E-04	-4.112E-04	-4.603E-04	0.00	0.00
323	COMB1 MAX									
		340	-10460.71	-21551.80	-11066.33	10460.71	21551.80	11066.33	-5705.79	-6148.59
		359	-232.85	-26606.32	-12243.43	232.85	26606.32	12243.43	-5705.79	-6704.73
		360	-180.75	-16808.86	-15135.27	180.75	16808.86	15135.27	-7244.47	-6704.73
		341	-12386.92	-12469.36	-13958.17	12386.92	12469.36	13958.17	-7244.47	-6148.59
323	COMB1 MIN									
		340	-10460.71	-21551.80	-11066.33	10460.71	21551.80	11066.33	-5705.79	-6148.59
		359	-232.85	-26606.32	-12243.43	232.85	26606.32	12243.43	-5705.79	-6704.73

Light

S H E L L   E L E M E N T   S T R E S S E S

SHELL	LOAD	JOINT	S11-BOT	S22-BOT	S12-BOT	S11-TOP	S22-TOP	S12-TOP	S13-AVG	S23-AVG
321	HISTI MAX									
		338	2.566E-04	5.071E-04	0.00	0.00	0.00	1.259E-04	1.555E-04	0.00
		357	0.00	5.536E-04	0.00	3.258E-06	0.00	1.411E-04	1.555E-04	0.00
		358	4.638E-06	1.044E-03	0.00	0.00	0.00	2.132E-05	1.762E-04	0.00
		339	2.910E-04	9.124E-04	0.00	0.00	0.00	7.071E-06	1.762E-04	0.00
321	HISTI MIN									
		338	0.00	0.00	-1.259E-04	-2.566E-04	-5.071E-04	0.00	0.00	-1.465E-04
		357	-3.258E-06	0.00	-1.411E-04	0.00	-5.536E-04	0.00	0.00	-1.796E-04
		358	0.00	0.00	-2.132E-05	-4.638E-06	-1.044E-03	0.00	0.00	-1.796E-04
		339	0.00	0.00	-7.071E-06	-2.910E-04	-9.124E-04	0.00	0.00	-1.465E-04
321	COMB1 MAX									
		338	-7780.10	-15378.58	3845.38	7780.11	15378.58	-3845.38	-4715.99	4444.08
		357	98.79	-16789.33	4277.38	-98.79	16789.33	-4277.38	-4715.99	5447.39
		358	-140.65	-31660.90	646.42	140.65	31660.90	-646.42	-5343.32	5447.39
		339	-8826.10	-27670.21	214.42	8826.10	27670.21	-214.42	-5343.32	4444.08
321	COMB1 MIN									
		338	-7780.11	-15378.58	3845.39	7780.10	15378.59	-3845.39	-4715.99	4444.08
		357	98.79	-16789.33	4277.38	-98.79	16789.33	-4277.38	-4715.99	5447.39
		358	-140.65	-31660.90	646.42	140.65	31660.90	-646.42	-5343.32	5447.39
		339	-8826.10	-27670.21	214.42	8826.10	27670.21	-214.42	-5343.32	4444.08
322	LOAD1									
		339	3.546E-04	9.057E-04	1.919E-05	-3.546E-04	-9.057E-04	-1.919E-05	2.029E-04	3.325E-05
		358	3.792E-06	1.067E-03	2.793E-05	-3.792E-06	-1.067E-03	-2.793E-05	2.029E-04	4.906E-05
		359	-4.391E-06	9.230E-04	2.078E-04	4.391E-06	-9.230E-04	-2.078E-04	2.425E-04	4.906E-05
		340	3.974E-04	9.027E-04	1.991E-04	-3.974E-04	-9.027E-04	-1.991E-04	2.425E-04	3.325E-05
322	SPEC1									
		339	0.00	2.361E-06	0.00	0.00	2.361E-06	0.00	0.00	0.00
		358	0.00	2.661E-06	0.00	0.00	2.661E-06	0.00	0.00	0.00
		359	0.00	2.124E-06	0.00	0.00	2.124E-06	0.00	0.00	0.00
		340	0.00	1.870E-06	0.00	0.00	1.870E-06	0.00	0.00	0.00
322	HISTI MAX									
		339	2.915E-04	9.149E-04	1.167E-04	0.00	0.00	0.00	1.696E-04	6.346E-05
		358	2.082E-06	1.031E-03	1.303E-04	0.00	0.00	0.00	1.696E-04	7.046E-05
		359	0.00	8.229E-04	2.732E-04	3.219E-06	0.00	0.00	2.174E-04	7.046E-05
		340	3.477E-04	7.245E-04	2.596E-04	0.00	0.00	0.00	2.174E-04	6.346E-05
322	HISTI MIN									
		339	0.00	0.00	0.00	-2.915E-04	-9.149E-04	-1.167E-04	0.00	0.00
		358	0.00	0.00	0.00	-2.082E-06	-1.031E-03	-1.303E-04	0.00	0.00
		359	-3.219E-06	0.00	0.00	0.00	-8.229E-04	-2.732E-04	0.00	0.00

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light

S H E L L   E L E M E N T   P R I N C I P A L S

SHELL	LOAD	JOINT	FMAX	FMIN	MMAX	MMIN	VMAX
321	LOAD1						
		338	0.00	0.00	5.751E-03	6.191E-04	2.167E-03
		357	0.00	0.00	5.282E-03	-1.496E-03	2.310E-03
		358	0.00	0.00	8.266E-03	-1.797E-04	2.072E-03
		339	0.00	0.00	7.678E-03	2.612E-03	1.935E-03
322	LOAD1						
		339	0.00	0.00	7.402E-03	2.890E-03	1.439E-03
		358	0.00	0.00	5.717E-03	2.497E-05	1.461E-03
		359	0.00	0.00	7.901E-03	-3.989E-04	1.732E-03
		340	0.00	0.00	7.220E-03	2.590E-03	1.713E-03
323	LOAD1						
		340	0.00	0.00	7.915E-03	1.699E-03	2.036E-03
		359	0.00	0.00	9.120E-03	-9.307E-04	2.134E-03
		360	0.00	0.00	7.833E-03	-2.087E-03	2.463E-03
		341	0.00	0.00	7.500E-03	2.617E-04	2.379E-03
324	LOAD1						
		341	0.00	0.00	9.173E-03	-4.349E-04	2.935E-03
		360	0.00	0.00	9.459E-03	-2.877E-03	3.946E-03
		361	0.00	0.00	5.447E-03	-5.863E-03	4.747E-03
		342	0.00	0.00	6.459E-03	-2.877E-03	3.946E-03

Light

S H E L L   E L E M E N T   P R I N C I P A L S

SHELL	LOAD	JOINT	FMAX	FMIN	MMAX	MMIN	VMAX
		350	0.00	0.00	3.547E-03	-5.712E-03	3.567E-03
		351	0.00	0.00	5.102E-03	-2.510E-03	3.212E-03
		332	0.00	0.00	5.439E-03	-1.022E-03	3.099E-03
315	LOAD1						
		332	0.00	0.00	4.678E-03	-1.429E-04	1.943E-03
		351	0.00	0.00	3.455E-03	-1.535E-03	2.035E-03
		352	0.00	0.00	5.321E-03	-9.975E-05	1.806E-03
		333	0.00	0.00	4.179E-03	2.625E-03	1.701E-03
316	LOAD1						
		333	0.00	0.00	4.179E-03	2.625E-03	1.701E-03
		352	0.00	0.00	5.321E-03	-9.975E-05	1.806E-03
		353	0.00	0.00	3.455E-03	-1.535E-03	2.035E-03
		334	0.00	0.00	4.678E-03	-1.429E-04	1.943E-03
317	LOAD1						
		334	0.00	0.00	5.439E-03	-1.022E-03	3.099E-03
		353	0.00	0.00	5.102E-03	-2.510E-03	3.212E-03
		354	0.00	0.00	3.547E-03	-5.712E-03	3.567E-03
		335	0.00	0.00	5.916E-03	-5.099E-03	3.457E-03
318	LOAD1						
		335	0.00	0.00	5.449E-03	-5.271E-03	4.323E-03
		354	0.00	0.00	4.431E-03	-5.297E-03	1.463E-02
		355	0.00	0.00	-2.647E-04	-2.379E-02	1.536E-02
		336	0.00	0.00	6.500E-03	-6.952E-03	6.390E-03
319	LOAD1						
		336	0.00	0.00	6.661E-03	-7.014E-03	6.499E-03
		355	0.00	0.00	-1.625E-04	-2.399E-02	1.598E-02
		356	0.00	0.00	5.290E-03	-5.210E-03	1.517E-02
		337	0.00	0.00	5.797E-03	-4.692E-03	4.477E-03
320	LOAD1						
		337	0.00	0.00	6.324E-03	-4.521E-03	3.907E-03
		356	0.00	0.00	4.369E-03	-5.591E-03	4.001E-03
		357	0.00	0.00	6.815E-03	-2.399E-03	3.683E-03
		338	0.00	0.00	6.536E-03	-2.814E-04	3.590E-03

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S H E L L   E L E M E N T   P R I N C I P A L S

SHELL	LOAD	JOINT	FMAX	FMIN	MMAX	MMIN	VMAX
		325	0.00	0.00	8.173E-03	-4.349E-04	2.835E-03
308	LOAD1						
		325	0.00	0.00	7.520E-03	2.617E-04	2.379E-03
		344	0.00	0.00	7.532E-03	-2.057E-03	2.463E-03
		345	0.00	0.00	9.120E-03	-9.307E-04	2.134E-03
		326	0.00	0.00	7.915E-03	1.639E-03	2.036E-03
309	LOAD1						
		326	0.00	0.00	7.220E-03	2.580E-03	1.713E-03
		345	0.00	0.00	7.901E-03	-3.989E-04	1.732E-03
		346	0.00	0.00	8.717E-03	2.497E-05	1.461E-03
		327	0.00	0.00	7.402E-03	2.890E-03	1.439E-03
310	LOAD1						
		327	0.00	0.00	7.679E-03	2.612E-03	1.935E-03
		346	0.00	0.00	8.966E-03	-1.797E-04	2.072E-03
		347	0.00	0.00	5.280E-03	-1.496E-03	2.310E-03
		328	0.00	0.00	5.751E-03	6.191E-04	2.187E-03
311	LOAD1						
		328	0.00	0.00	6.536E-03	-2.814E-04	3.580E-03
		347	0.00	0.00	6.815E-03	-2.399E-03	3.683E-03
		348	0.00	0.00	4.368E-03	-5.591E-03	4.001E-03
		329	0.00	0.00	6.324E-03	-4.591E-03	3.907E-03
312	LOAD1						
		329	0.00	0.00	5.797E-03	-4.692E-03	4.477E-03
		348	0.00	0.00	5.290E-03	-5.210E-03	1.517E-02
		349	0.00	0.00	-1.685E-04	-2.389E-02	1.598E-02
		330	0.00	0.00	6.661E-03	-7.014E-03	6.439E-03
313	LOAD1						
		330	0.00	0.00	6.600E-03	-6.952E-03	6.380E-03
		349	0.00	0.00	-1.647E-04	-2.379E-02	1.536E-02
		350	0.00	0.00	4.431E-03	-5.287E-03	1.463E-02
		331	0.00	0.00	5.449E-03	-5.271E-03	4.323E-03
314	LOAD1						
		331	0.00	0.00	5.916E-03	-5.098E-03	3.457E-03

Right

SHELL ELEMENT RESULTANTS

SHELL	LOAD	JOINT	F11	F22	F12	M11	M22	M12	V13	V23
		360	0.00	0.00	0.00	-1476.16	-137272	-123605	-50711.31	-46933.09
		341	0.00	0.00	0.00	-101160	-101832	-113992	-50711.31	-43040.15
324	LOAD1									
		341	0.00	0.00	0.00	3.869E-03	3.669E-03	4.304E-03	2.075E-03	2.075E-03
		360	0.00	0.00	0.00	8.206E-05	5.500E-03	4.979E-03	2.075E-03	3.356E-03
		361	0.00	0.00	0.00	-2.097E-04	-2.097E-04	5.653E-03	3.356E-03	3.356E-03
		342	0.00	0.00	0.00	5.500E-03	8.206E-05	4.979E-03	3.356E-03	2.075E-03
324	SPEC1									
		341	0.00	0.00	0.00	8.594E-06	8.591E-06	1.115E-05	4.672E-06	4.672E-06
		360	0.00	0.00	0.00	0.00	1.137E-05	1.257E-05	4.672E-06	7.255E-06
		361	0.00	0.00	0.00	0.00	0.00	1.399E-05	7.255E-06	7.255E-06
		342	0.00	0.00	0.00	1.137E-05	0.00	1.257E-05	7.255E-06	4.672E-06
324	HISTI MAX									
		341	0.00	0.00	0.00	3.330E-03	3.329E-03	4.321E-03	1.811E-03	1.810E-03
		360	0.00	0.00	0.00	6.299E-05	4.599E-03	4.872E-03	1.811E-03	2.811E-03
		361	0.00	0.00	0.00	0.00	0.00	5.423E-03	2.811E-03	2.811E-03
		342	0.00	0.00	0.00	4.599E-03	6.299E-05	4.872E-03	2.811E-03	1.810E-03
324	HISTI MIN									
		341	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		360	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		361	0.00	0.00	0.00	-1.692E-04	-1.692E-04	0.00	0.00	0.00
		342	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
324	COMB1 MAX									
		341	0.00	0.00	0.00	-100984	-100953	-131039	-54913.22	-54894.96
		360	0.00	0.00	0.00	-1909.82	-139441	-147739	-54913.22	-85247.69
		361	0.00	0.00	0.00	5129.96	5131.10	-164443	-85258.35	-85247.69
		342	0.00	0.00	0.00	-139462	-1910.16	-147743	-85258.35	-54894.96
324	COMB1 MIN									
		341	0.00	0.00	0.00	-100984	-100953	-131039	-54913.22	-54894.96
		360	0.00	0.00	0.00	-1909.82	-139441	-147739	-54913.22	-85247.69
		361	0.00	0.00	0.00	5129.96	5131.10	-164443	-85258.35	-85247.69
		342	0.00	0.00	0.00	-139462	-1910.16	-147743	-85258.35	-54894.96

Light

S H E L L   E L E M E N T   R E S U L T A N T S

SHELL	LOAD	JOINT	F11	F22	F12	M11	M22	M12	V13	V23
		340	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
322	COMB1 MAX									
		339	0.00	0.00	0.00	-72201.30	-226581	-28905.13	-35998.82	-13470.57
		358	0.00	0.00	0.00	-515.69	-255399	-32275.07	-35998.82	-14956.39
		359	0.00	0.00	0.00	797.30	-203790	-67649.84	-46149.04	-14956.39
		340	0.00	0.00	0.00	-86113.63	-179429	-64279.90	-46149.04	-13470.57
322	COMB1 MIN									
		339	0.00	0.00	0.00	-72201.30	-226581	-28905.13	-35998.82	-13470.57
		358	0.00	0.00	0.00	-515.69	-255399	-32275.07	-35998.82	-14956.39
		359	0.00	0.00	0.00	797.30	-203790	-67649.84	-46149.04	-14956.39
		340	0.00	0.00	0.00	-86113.63	-179429	-64279.90	-46149.04	-13470.57
323	LOAD1									
		340	0.00	0.00	0.00	3.214E-03	6.400E-03	2.669E-03	1.481E-03	1.409E-03
		359	0.00	0.00	0.00	7.865E-05	8.110E-03	3.021E-03	1.481E-03	1.568E-03
		360	0.00	0.00	0.00	6.424E-05	5.411E-03	3.980E-03	1.302E-03	1.568E-03
		341	0.00	0.00	0.00	5.576E-03	3.905E-03	3.629E-03	1.302E-03	1.409E-03
323	SPEC1									
		340	0.00	0.00	0.00	7.270E-06	1.498E-05	7.691E-06	3.399E-06	3.663E-06
		359	0.00	0.00	0.00	0.00	1.849E-05	8.503E-06	3.399E-06	3.994E-06
		360	0.00	0.00	0.00	0.00	1.168E-05	1.052E-05	4.316E-06	3.994E-06
		341	0.00	0.00	0.00	8.509E-06	8.666E-06	9.701E-06	4.316E-06	3.663E-06
323	HIST1 MAX									
		340	0.00	0.00	0.00	2.817E-03	5.804E-03	2.980E-03	1.317E-03	1.419E-03
		359	0.00	0.00	0.00	6.271E-05	7.168E-03	3.297E-03	1.317E-03	1.549E-03
		360	0.00	0.00	0.00	4.868E-05	4.527E-03	4.076E-03	1.672E-03	1.549E-03
		341	0.00	0.00	0.00	3.336E-03	3.558E-03	3.759E-03	1.672E-03	1.419E-03
323	HIST1 MIN									
		340	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		359	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		360	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		341	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
323	COMB1 MAX									
		340	0.00	0.00	0.00	-85429.09	-176006	-90375.01	-39940.53	-43040.15
		359	0.00	0.00	0.00	-1901.61	-217285	-99988.02	-39940.53	-46933.09
		360	0.00	0.00	0.00	-1476.16	-137272	-123603	-50711.31	-46933.09
		341	0.00	0.00	0.00	-101160	-101933	-113992	-50711.31	-43040.15
323	COMB1 MIN									
		340	0.00	0.00	0.00	-85429.09	-176006	-90375.01	-39940.53	-43040.15
		359	0.00	0.00	0.00	-1901.61	-217285	-99988.02	-39940.53	-46933.09

Light

S H E L L   E L E M E N T   R E S U L T A N T S

SHELL	LOAD	JOINT	F11	F22	F12	M11	M22	M12	V13	V23
321	HIST1 MAX									
		338	0.00	0.00	0.00	2.096E-03	4.141E-03	0.00	1.08E-03	0.00
		357	0.00	0.00	0.00	0.00	4.521E-03	0.00	1.03E-03	0.00
		358	0.00	0.00	0.00	3.739E-05	9.526E-03	0.00	1.23E-03	0.00
		339	0.00	0.00	0.00	2.377E-03	7.452E-03	0.00	1.23E-03	0.00
321	HIST1 MIN									
		338	0.00	0.00	0.00	0.00	0.00	-1.036E-03	0.00	-1.026E-03
		357	0.00	0.00	0.00	-2.660E-05	0.00	-1.152E-03	0.00	-1.257E-03
		358	0.00	0.00	0.00	0.00	0.00	-1.741E-04	0.00	-1.257E-03
		339	0.00	0.00	0.00	0.00	0.00	-5.774E-05	0.00	-1.026E-03
321	COMB1 MAX									
		338	0.00	0.00	0.00	-63537.52	-125592	31403.96	-33011.92	31109.56
		357	0.00	0.00	0.00	806.78	-137113	34931.96	-33011.92	38131.73
		358	0.00	0.00	0.00	-1149.60	-258564	5279.11	-37403.21	38131.73
		339	0.00	0.00	0.00	-72079.55	-225973	1751.10	-37403.21	31109.56
321	COMB1 MIN									
		338	0.00	0.00	0.00	-63537.53	-125592	31403.96	-33011.92	31109.56
		357	0.00	0.00	0.00	806.78	-137113	34931.96	-33011.92	38131.73
		358	0.00	0.00	0.00	-1149.60	-258564	5279.11	-37403.21	38131.73
		339	0.00	0.00	0.00	-72079.55	-225973	1751.10	-37403.21	31109.56

SHELL	LOAD	JOINT	F11	F22	F12	M11	M22	M12	V13	V23
322	LOAD1									
		339	0.00	0.00	0.00	2.896E-03	7.396E-03	1.567E-04	1.420E-03	2.306E-04
		358	0.00	0.00	0.00	3.096E-05	8.711E-03	2.281E-04	1.420E-03	3.438E-04
		359	0.00	0.00	0.00	-3.586E-05	7.536E-03	1.697E-03	1.698E-03	3.438E-04
		340	0.00	0.00	0.00	3.245E-03	6.555E-03	1.626E-03	1.698E-03	2.306E-04
322	SPEC1									
		339	0.00	0.00	0.00	6.144E-06	1.928E-05	2.460E-06	3.064E-06	1.146E-06
		358	0.00	0.00	0.00	0.00	2.173E-05	2.747E-06	3.064E-06	1.273E-06
		359	0.00	0.00	0.00	0.00	1.734E-05	5.757E-06	3.927E-06	1.273E-06
		340	0.00	0.00	0.00	7.328E-06	1.527E-05	5.470E-06	3.927E-06	1.146E-06

SHELL	LOAD	JOINT	F11	F22	F12	M11	M22	M12	V13	V23
322	HIST1 MAX									
		339	0.00	0.00	0.00	2.391E-03	7.472E-03	9.532E-04	1.197E-03	4.442E-04
		358	0.00	0.00	0.00	1.701E-05	9.422E-03	1.064E-03	1.197E-03	4.932E-04
		359	0.00	0.00	0.00	0.00	6.720E-03	2.231E-03	1.522E-03	4.932E-04
		340	0.00	0.00	0.00	2.840E-03	5.917E-03	2.120E-03	1.522E-03	4.442E-04
322	HIST1 MIN									
		339	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		358	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		359	0.00	0.00	0.00	-2.629E-05	0.00	0.00	0.00	0.00

light

S H E L L   E L E M E N T   P R I N C I P A L   S T R E S S E S

SHELL	LOAD	JOINT	SMAX-BOT	SMIN-BOT	SVM-BOT	SMAX-TOP	SMIN-TOP	SVM-TOP	SVMAX-AVG
		325	1.001E-03	-5.325E-05	1.029E-03	5.325E-05	-1.001E-03	1.029E-03	4.192E-04
308	LOAD1								
		325	9.208E-04	3.204E-05	9.052E-04	-3.204E-05	-9.208E-04	9.052E-04	3.399E-04
		344	9.223E-04	-2.519E-04	1.071E-03	2.519E-04	-9.223E-04	1.071E-03	3.519E-04
		345	1.117E-03	-1.140E-04	1.178E-03	1.140E-04	-1.117E-03	1.178E-03	3.049E-04
		326	9.692E-04	2.079E-04	8.838E-04	-2.079E-04	-9.692E-04	8.838E-04	2.909E-04
309	LOAD1								
		326	8.841E-04	3.159E-04	7.760E-04	-3.159E-04	-8.841E-04	7.760E-04	2.448E-04
		345	9.674E-04	-4.884E-05	9.927E-04	4.884E-05	-9.674E-04	9.927E-04	2.474E-04
		346	1.067E-03	3.058E-06	1.066E-03	-3.058E-06	-1.067E-03	1.066E-03	2.067E-04
		327	9.063E-04	3.539E-04	7.911E-04	-3.539E-04	-9.063E-04	7.911E-04	2.056E-04
310	LOAD1								
		327	9.401E-04	3.198E-04	8.279E-04	-3.198E-04	-9.401E-04	8.279E-04	2.764E-04
		346	1.098E-03	-2.201E-05	1.109E-03	2.201E-05	-1.098E-03	1.109E-03	2.960E-04
		347	6.468E-04	-1.832E-04	7.553E-04	1.832E-04	-6.468E-04	7.553E-04	3.299E-04
		328	7.042E-04	7.581E-05	6.695E-04	-7.581E-05	-7.042E-04	6.695E-04	3.124E-04
311	LOAD1								
		328	8.003E-04	-3.446E-05	8.181E-04	3.446E-05	-8.003E-04	8.181E-04	5.115E-04
		347	8.345E-04	-2.925E-04	1.013E-03	2.925E-04	-8.345E-04	1.013E-03	5.261E-04
		348	5.349E-04	-6.846E-04	1.059E-03	6.846E-04	-5.349E-04	1.059E-03	5.716E-04
		329	7.744E-04	-5.609E-04	1.161E-03	5.609E-04	-7.744E-04	1.161E-03	5.591E-04
312	LOAD1								
		329	7.098E-04	-5.746E-04	1.114E-03	5.746E-04	-7.098E-04	1.114E-03	6.396E-04
		348	6.478E-04	-6.379E-04	1.113E-03	6.379E-04	-6.478E-04	1.113E-03	2.166E-03
		349	-2.064E-05	-2.924E-03	2.914E-03	2.924E-03	2.064E-05	2.914E-03	2.269E-03
		330	8.157E-04	-8.588E-04	1.450E-03	8.588E-04	-8.157E-04	1.450E-03	9.284E-04
313	LOAD1								
		330	8.081E-04	-8.513E-04	1.437E-03	8.513E-04	-8.081E-04	1.437E-03	9.115E-04
		349	-3.241E-05	-2.913E-03	2.897E-03	2.913E-03	3.241E-05	2.897E-03	2.194E-03
		350	5.425E-04	-6.474E-04	1.032E-03	6.474E-04	-5.425E-04	1.032E-03	2.089E-03
		331	6.672E-04	-6.454E-04	1.137E-03	6.454E-04	-6.672E-04	1.137E-03	6.176E-04
314	LOAD1								
		331	7.244E-04	-6.242E-04	1.169E-03	6.242E-04	-7.244E-04	1.169E-03	4.938E-04

light

S H E L L   E L E M E N T   P R I N C I P A L   S T R E S S E S

SHELL	LOAD	JOINT	SMAX-BOT	SMIN-BOT	SVM-BOT	SMAX-TOP	SMIN-TOP	SVM-TOP	SVMAX-AVG
		325	1.001E-03	-5.325E-05	1.029E-03	5.325E-05	-1.001E-03	1.029E-03	4.192E-04
308	LOAD1								
		325	9.208E-04	3.204E-05	9.052E-04	-3.204E-05	-9.208E-04	9.052E-04	3.398E-04
		344	9.223E-04	-2.519E-04	1.071E-03	2.519E-04	-9.223E-04	1.071E-03	3.519E-04
		345	1.117E-03	-1.140E-04	1.178E-03	1.140E-04	-1.117E-03	1.178E-03	3.049E-04
		326	9.692E-04	2.079E-04	8.838E-04	-2.079E-04	-9.692E-04	8.838E-04	2.909E-04
309	LOAD1								
		326	8.841E-04	3.159E-04	7.760E-04	-3.159E-04	-8.841E-04	7.760E-04	2.448E-04
		345	9.674E-04	-4.884E-05	9.927E-04	4.884E-05	-9.674E-04	9.927E-04	2.474E-04
		346	1.067E-03	3.058E-06	1.066E-03	-3.058E-06	-1.067E-03	1.066E-03	2.087E-04
		327	9.063E-04	3.539E-04	7.911E-04	-3.539E-04	-9.063E-04	7.911E-04	2.056E-04
310	LOAD1								
		327	9.401E-04	3.193E-04	8.279E-04	-3.193E-04	-9.401E-04	8.279E-04	2.764E-04
		346	1.098E-03	-2.201E-05	1.109E-03	2.201E-05	-1.098E-03	1.109E-03	2.960E-04
		347	6.468E-04	-1.832E-04	7.553E-04	1.832E-04	-6.468E-04	7.553E-04	3.299E-04
		328	7.042E-04	7.581E-05	6.695E-04	-7.581E-05	-7.042E-04	6.695E-04	3.124E-04
311	LOAD1								
		328	8.003E-04	-3.446E-05	8.181E-04	3.446E-05	-8.003E-04	8.181E-04	5.115E-04
		347	8.345E-04	-2.925E-04	1.013E-03	2.925E-04	-8.345E-04	1.013E-03	5.261E-04
		348	5.349E-04	-6.846E-04	1.059E-03	6.846E-04	-5.349E-04	1.059E-03	5.716E-04
		329	7.744E-04	-5.609E-04	1.161E-03	5.609E-04	-7.744E-04	1.161E-03	5.591E-04
312	LOAD1								
		329	7.098E-04	-5.746E-04	1.114E-03	5.746E-04	-7.099E-04	1.114E-03	6.396E-04
		348	6.478E-04	-6.379E-04	1.113E-03	6.379E-04	-6.478E-04	1.113E-03	2.166E-03
		349	-2.064E-05	-2.924E-03	2.914E-03	2.924E-03	2.064E-05	2.914E-03	2.269E-03
		330	8.157E-04	-8.588E-04	1.450E-03	8.588E-04	-8.157E-04	1.450E-03	9.284E-04
313	LOAD1								
		330	8.081E-04	-8.513E-04	1.437E-03	8.513E-04	-8.081E-04	1.437E-03	9.115E-04
		349	-3.241E-05	-2.913E-03	2.897E-03	2.913E-03	3.241E-05	2.897E-03	2.194E-03
		350	5.425E-04	-6.474E-04	1.032E-03	6.474E-04	-5.425E-04	1.032E-03	2.089E-03
		331	6.672E-04	-6.454E-04	1.137E-03	6.454E-04	-6.672E-04	1.137E-03	6.176E-04
314	LOAD1								
		331	7.244E-04	-6.242E-04	1.169E-03	6.242E-04	-7.244E-04	1.169E-03	4.938E-04