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# Assessment of Analytical Techniques of Flexible Pavements by Final Element Method and Theory of Multi-Layer System

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## ABSTRACT

By development of the range of using Finite Element Method in road- construction industry during recent years, pavement construction engineers have tried to adapt this method to analyze pavements. Finite Element Method is able to analyze stability, time- dependent problems and those problems with non-linear properties for the material; although, this method is widely used for several sciences, but one of its weak points is in that it takes a lot of time for analysis on pavement as well as its requirement for advanced code- writing. In this research paper, a great number of the prevalent pavements have been analyzed by means of two techniques: Finite Element Method and Theory of Multi-layer System. Eventually, from statistical viewpoint, the results of analysis on these two techniques have been compared by significance parameter and correlation coefficient. Results of this study indicate that results of analysis on finite elements are most appropriately complied with results came from theory of multi-layer system and there is no significant difference among the mean values in both techniques.
**KEYWORDS**: Flexible Pavement, Analysis, Finite Element (Method), ABAQUS

## 1. INTRODUCTION

During the several years before World War II, road- pavement construction was mainly designed empirically and based on judgment by road- construction engineers. As a result, by 1940 there was no certain reference for thickness design of flexible pavements. By introducing soil classification systems (Casagrande and AASHTO i.e. *American Association of State Highway & Transportation System*), the first step was taken concerning to design technology of flexible pavements. By ever- increasing traffic trend in highways in terms of volume and weight of passage routes and through introducing analytical methods for pavement design followed by computation advancements, empirical techniques were gradually substituted by mechanistic- experiential methods of pavement design. In the models which are used for analysis and design in this technique, some simplification hypotheses are often employed such as considering materials' elastic behavior as well as their isotropic nature etc. By daily development of science in pavement industry, these structures were analyzed numerically and as finite element. In numerical analysis, one may adapt pavement better and closer to reality and by using more realistic hypotheses and analyze the responses more precisely and close to reality.

## 2.General Definition of Problem

The main objective in this paper is to compare the results came from critical responses predicted in elastic linear analyses resulting from Theory of Multi-layer Systems with correspondent results from Finite Element Method. To analyze finite elements in pavement, ABAQUS [1], powerful software may be used while KENLAYER software [2] has been employed for analysis based on multi-layer systems. In order to compare the results of pavement analysis by means of Theory of Multi-layer system with the results came from Finite Element Method, a wide range of the prevalent pavements was modeled. The modeled pavements include Hot Mix Asphalt (HMA) Layer, Base Layer, Sub-Base Layer and Subgrade Layer. Figure -1 indicates the modeled cross- sectional type. Finally by means of some statistical software like Minitab [3] and CURVEEXPERT [4], modeling results have been statistically examined and assessed.

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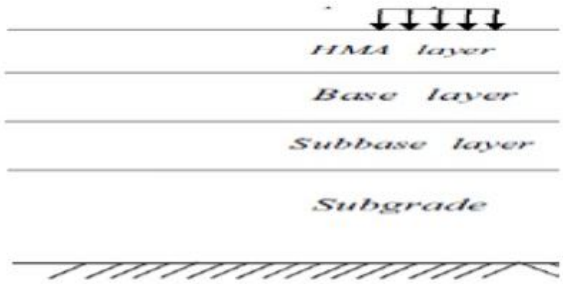


**Fig.1**: The modeled cross-sectional type.

**A review on used scientific topics**

Since the current paper is intended to compare pavement critical responses by means of different analyses and behavioral models, so in the following behavioral models have been purposed in terms of various scientific and theoretical perspectives.

**3.1. Multi-layer System**

Boussinesq is one of the first researchers, who introduced some formulae for analysis on single-layer isotropic pavement [5]. Gazetas introduced a formula (foundation stiffness) that was correspondent to Boussinesq's equation for linear anisotropic materials [6]. For the first time in 1942, Burmister purposed equilibrium equations for double- layer pavement by assuming homogeneity in materials. Several years later by invention of computer, these formulae were generalized to triple- layer and then to multi-layer pavement systems [7]. The basic hypotheses which were used in these equations by Mr. Burmister included [8]:

- Layers are homogeneous and isotropic.
-Behavior is elastic and linear in materials.
- Materials are massless.
- Regardless of subgrade layer, thickness of layers is limited to a certain and constant value.
- Load is exerted widely and uniformly over a circular plane.
- Boundary conditions were considered in such a way that in contact point of two layers, the exerted shear tension, vertical tension, vertical and radial displacements are identical for both layers.

After purposing these equations, some diagrams and tables were given to determine tension, strain and displacement in multi-layer systems [8]. In this essay, KENLASYER software [2] has been used for pavement modeling by application of Theory of Multi-layer System.

**3.2. Finite Element Method**

Engineers and physicists usually describe a physical effect by means of system of ordinary and/ or partial differential equations that apply to certain region (limit) and boundary and primary apt conditions. In fact, a differential equation with its needed boundary and primary conditions is a perfect mathematical model of an effect. In order to find distribution of the given variables which their relation is expressed in differential equations by the given dominant equation, the aforesaid equation should be solved so that to obtain numerical values of any related quantity at the given point. Finite Element Method is a numerical instruction to solve physical problems described by differential equations. This method has two characteristics that make it distinct from other numerical techniques:

- In this method, an integral formulation is employed to create an algebraic equations system.
- At this technique, smooth functions are continually used to estimate unknown values.

Instead of calculation of analytical response of equation for all continuous points in Finite Element Method, the approximated response of equation is computed only in limited number of concrete points in this range. In fact, by application of such points, continuous range of this model is converted into a concrete region [8]. These points are simply called nodes. Some part of a continuous region that is limited among some nodes is called element. Although, arising of this technique is ambiguous, but its privileges are obviously visible. This technique is able to analyze stable problems, time-dependent problems and those problems with non- linear properties for material(s).

Some advance computerized programs have been written in these fields that are comprehensive and independent from a certain problem and/ or specific to certain user. Moreover, such users may use subsidiary programs to create network in order to identify form geometry and graphic analysis on results. Finite Element Method is basis for many Computer- Aid-Designs (CADs). Since different properties of pavement may be modeled in this method; therefore, this technique is a very

appropriate technique for pavement analysis. In this paper, ABAQUS 6.11[1] i.e. power software is used for modeling of pavement.

## 4. Collection of Information

In this paper, ABAQUS 6.11 and KENLAYER computer programs are used for analysis of flexible pavements. The input parameters needed for these computer programs include layers thickness, modulus of elasticity, poison ratio, etc. This category of information has been selected based on a wide range of prevalent pavements derived from domestic and foreign valid papers and researches and some of reports given by consulting engineers.

## 5. MODEL

Details of modeling process in finite element software are given in the following:

### 5.1. Definition of Model

In this paper, symmetric geometry, which shown in Fig.2, is employed where in this model, with respect to their execution structure, width of all layers in pavements is identical and considered as 2m.

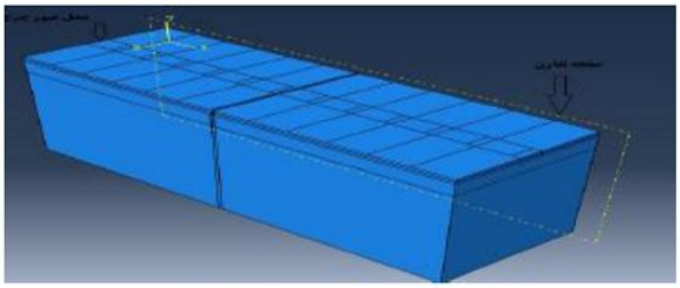

**Fig. 2**: Geometry of model.

Elastic behavior has been considered for HMA Layer, and materials in Base and Sub base layers; and in order to make load value closer to dynamic conditions quasi- static solution plus dynamic explicit operator are used; and also standard equivalent axial load (8.2ton) has been exerted on this model. The area of effective force that is exerted by wheel on pavement has been shown in Fig.3 [8]. This area is calculated as follows:

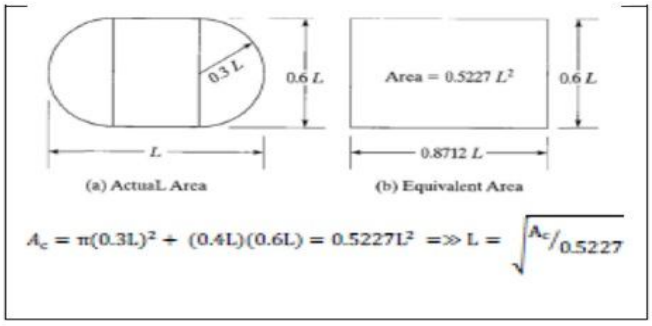


**Fig.3:**Area of effectiveforce on pavement[8]

$$6.0L=31.5\text{cm} \Rightarrow L=315/0.6=50\text{cm} \Rightarrow 0.8712*50=43.5$$

Thus, loading area is a quadrangle with dimensions (43.5 × 31.5). In order to obtain the pressure that is exerted by wheel of vehicle on pavement the following formula is used:

$$[(40 \times 10^3) / (0.315/0.435)] = 291917$$

In analysis and prevalent designs of flexible pavement, tensile strain of asphalt sub base and compressive strain on subgrade of pavement bed are considered as the effective parameters on design while the results came from some software like Minitab [3] and CURVEEXPERT [4] have been used for statistical analysis.

## 5.2. ANALYSIS OF MODEL RESULTS

As two important criteria, vertical compressive strain on subgrade layer of pavement and horizontal tensile strain on asphalt sub base layer are considered in construction of asphaltic pavements. The results came from the quantities that have been derived from pavement are statistically exploited by application of ABAQUS [1] and KENLAYER software. The statistical analysis has been conducted separately by means of Minitab [3] and CURVEEXPERT [4] software.

### 5.2. 1. Statistical Analysis by Minitab [4]

At first step, Minitab [3] statistical software was employed to examine and analyze the relationship among the results came from Finite Element Method and techniques of layers theory. The estimated (fitting) formula is in Figs of 4 and 5 in this software so that with respect to estimated expression (Y) as well as parameter R, it may be concluded that the fitting formula is a very appropriate relation and has the acceptable accuracy in terms of statistics.

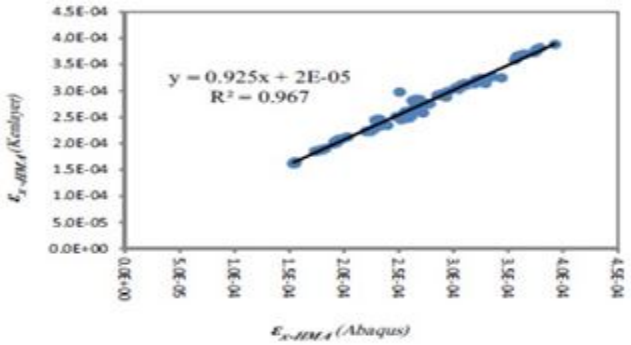


**Fig.4:**Horizontal tensile strain at the bottom of asphalt surface layer.

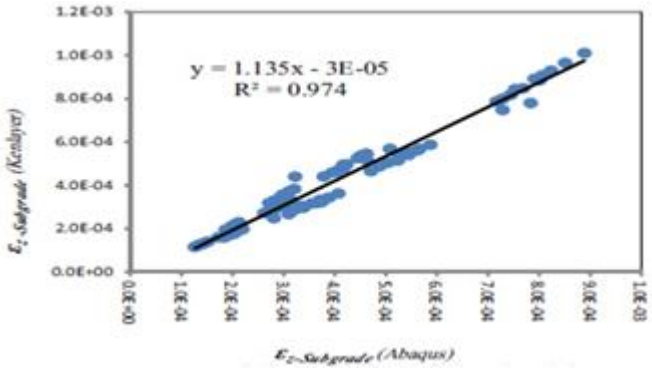


**Fig.5:** compressive strain on top of subgrade.

In order to determine the significance of results from testing, hypothesis of two dependent means (T-Test) has been adapted. The results of T-Test are given as follows:

**Results of T-Test on criterion of horizontal tensile strain on asphaltic subgrade**

**Paired T-Test and CI: Et (abaqus); Et (Kenlayer)**

```
Paired T for Et(abaqus) - Et(Kenlayer)

                N        Mean      StDev   SE Mean
Et(abaqus)     90    0.000262   0.000060   0.000006
Et(Kenlayer)   90    0.000266   0.000058   0.000006
Difference     90   -0.000004   0.000009   0.000001


95% CI for mean difference: (-0.000006; -0.000002)
T-Test of mean difference = -0.000004 (vs not = -0.000004): T-Value = 0.05
     P-Value = 0.960
```

**Results of T-Test on criterion of vertical compressive strain on pavement sub base layer**

**Paired T-Test and CI: Et (abaqus); Et (Kenlayer)**

```
Paired T for Et(abaqus) - Et(Kenlayer)

                N       Mean     StDev   SE Mean
Et(abaqus)     90   0.000262  0.000060  0.000006
Et(Kenlayer)   90   0.000266  0.000058  0.000006
Difference     90  -0.000004  0.000009  0.000001


95% CI for mean difference: (-0.000006; -0.000002)
T-Test of mean difference = -0.000004 (vs not = -0.000004): T-Value = 0.05
     P-Value = 0.960
```

Since parameter *p* is greater than 0.05 (P>0.05) at certainty level 95%, so one can conclude that there is no significant difference in both criteria of design and means at two methods. As a result, hypothesis of equality is rejected; in other words, both methods are appropriately compliance with each other.

### 5.2. 2. Statistical Analysis by CURVEEXPERT [5]

In statistical analyses done for controlling this model, some parameters are used including parameter *R* as correlation coefficient, parameter *S* as rate of error, and function *Y* as fitting equation (estimation). Figures 4 and 5 indicate these parameters in statistical analysis by means of CURVEEXPERT software [4].

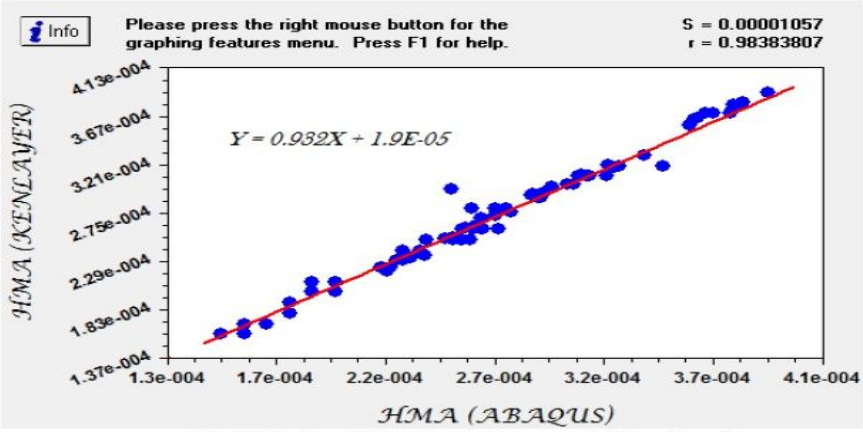


**Fig.6:** Horizontal tensile strain at the bottom of asphalt surface layer.

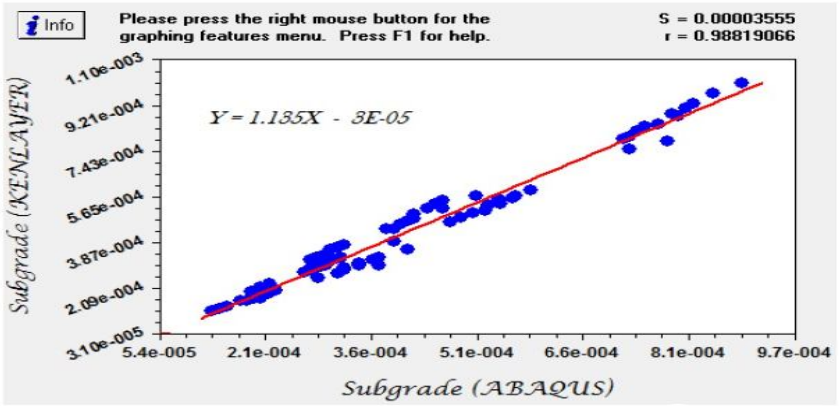


**Fig.7:** compressive strain on top of subgrade.

Table-1 also shows the value of these parameters. The value of parameter R, as one of the foremost criteria for measurement of dependency among parameters, is between 0 and 1. If this value is closer to unit (1), then there is more dependency among variables. According to Table-1, value of parameter R has been obtained as 0.98283807 for horizontal tensile strain in asphaltic subgrade. Thus, one may declare that tensile strain of asphaltic subgrade that resulted from KENLAYER [2] predicts tensile strain of asphaltic subgrade from ABAQUS software [1] at %98.283807. So this is an acceptable result. *R* value for criterion of vertical compressive strain over pavement sub base has been obtained as 0.98819066 as well so this value is also statistically acceptable result.

| Model | Y | S | R |
|---|---|---|---|
| Vertical tensile strain on asphaltic subgrade | Y = 0.932X + 1.9E-05 | 0.00001057 | 0.98283807 |
| Vertical Compressive strain on pavement sub base layer | Y = 1.135X – 3E-05 | 0.00003555 | 0.98819066 |

**Table. 1**: Results of statistical analysis by means of CURVEEXPERT software [5].

## 6. Conclusions and Suggestions

The result came from these two statistical analyses by the aid of Minitab [3] and of CURVEEXPERT [4] software is the same. The results which have been derived from the give analytical research are evaluated and classified as follows:

**1-** Fitting formula that given for the obtained results is a very appropriate relation and it has the acceptable accuracy from statistical view.

**2-** With respect to rate of error in statistical analysis, it can conclude that there is no significant difference among means in both methods. Results came from analysis on finite elements in flexible pavement are appropriately complied with the results of method concerning to theory of multi- layer systems. Thus, instead of employing costly and time- consuming Finite Element Method in elastic analysis on flexible pavements, one may adapt the simple and quick classic method of multi- layer theory.

However, since pavement different properties may be modeled in Finite Element Method, so this method is very appropriate for analysis on pavement when visco-elastic and anisotropic properties are intended in pavement materials. As a result, there is no alternative for Finite Element Method in analysis on such items.

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