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## FLEXIBLE PAVEMENT COMPONENTS FOR OPTIMUM PERFORMANCE IN RUTTING AND FATIGUE

مكونات الرصف المرن للأداء الأمثل في التآكل والكلال

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### الملخص العربي

ما زال الانهيار المبكر للأرصفت المرنة مشكلة الطرق المصرية في ظل الزيادة المطردة في أحمال محاور الشاحنات. وللحد من هذا الانهيار المبكر والاستفادة المثلى من مكونات الرصف في تصميم اقتصادي، يجب أن يوازن التصميم بين أنماط تدهور الرصف المتمثلة في التآكل والشروخ. لذلك تهدف هذه الدراسة إلى توضيح منهجية لتحقيق التوازن المرجو بين عمر الرصف في التآكل وعمره بالنسبة للشروخ. تعتمد هذه المنهجية على مفهوم تحليل الضرر للرصف والذي تم إجراءه باستخدام برنامج KENLAYER لتحليل العديد من القطاعات الإنشائية للرصف بالنسبة لكل من التآكل والشروخ. وكانت عناصر الرصف محل الدراسة هي سمك الطبقة الأسفلتية وطبقة الأساس ومعايير المرنة لهما إلى جانب معايير المرنة لطبقة التأسيس.

أوضحت نتيجة تحليل الرصف أن سمك طبقة الأساس ومعايير المرنة لطبقة التأسيس هي العناصر الرئيسية التي تتحكم في الموازنة بين عمر الرصف في التآكل وعمره بالنسبة للشروخ. هذا لأن زيادة أي منهما تزيد بشدة من عمر الرصف في التآكل في حين عدم تأثير عمر الرصف بالنسبة للشروخ بهما. استنتجت الدراسة أيضا أن عمر الرصف بالنسبة لكل من التآكل والشروخ يزيد بشدة بزيادة سمك الطبقة الأسفلتية، ويزيد باعتدال بزيادة كل من معايير المرنة لطبقة الأساس والطبقة الأسفلتية. وفي النهاية أوصت الدراسة بقيمة محددة لسمك طبقة الأساس (١٢ بوصة) وللمعايير المرنة لطبقة التأسيس (٨٠٠٠ رطل/البوصة المربعة) مع أي قيمة للمكونات الأخرى للحصول على قطاع متوازن بين عمر الرصف في التآكل وعمره بالنسبة للشروخ.

### ABSTRACT

Premature failure of flexible pavements has long been a problem in many Egyptians roads with the drastic increase in truck axle loads. To fully utilize each pavement material in an economic design, a pavement should generally have reasonably balanced design between the rutting and fatigue modes of distress. The purpose of this paper is to develop a methodology for achieving a reasonable balance between fatigue and rutting lives of flexible pavements. The methodology is based on the damage analysis concept which is performed for both fatigue cracking and rutting on different pavement sections using KENLAYER program. The investigated pavement components are; thickness ( $d_1$  and  $d_2$ ) and elasticity modulus ( $E_1$  and  $E_2$ ) for asphalt layer and base layer, respectively, and subgrade elasticity modulus ( $E_3$ ).

The results of pavement analysis showed that  $d_2$  and  $E_3$  are the key elements which control the equilibrium between fatigue and rutting lives ( $N_f$  and  $N_r$ , respectively). That is because, increasing  $d_2$  and  $E_3$  sharply increases  $N_r$ , and don't affect in  $N_f$ . The study also concluded that, increasing  $d_1$  significantly increases both  $N_f$  and  $N_r$ , while increasing  $E_2$  and  $E_1$  mildly increases  $N_f$  and  $N_r$ . Finally, the study has recommended pavement sections with any values of  $d_1$ ,  $E_1$  or  $E_2$  at  $d_2 = 12$ -in. along with  $E_3 = 8,000$  psi, for optimum utilization of pavement components with respect to fatigue and rutting.

**KEYWORDS:** Pavement life, Tensile strain, Compressive strain, and KENLAYER program.

## INTRODUCTION AND BACKGROUND

A field observation in Egypt [1, 2] for evaluation of pavement surface conditions of Egyptian roads network, showed that, rutting and fatigue cracking are considered the most important distresses surveyed due to high severity and density levels, and consequently their high effects on the pavement condition. Flexible pavements should be designed to provide a durable, skid resistance surface under in-service conditions. Also, it is essential to minimize cracking and rutting in flexible pavement layers. To fully utilize each pavement material in an economic design, a pavement should generally have reasonably balanced design between the rutting and fatigue modes of distress [3]. The increased rutting or decreased fatigue life of the flexible pavements may be attributed to the shortcomings of the application of flexible pavement analysis and the absence of attention to identify the pavement components that achieve a balanced section which gives equal pavement lives with respect to rutting and fatigue.

There are various modes in which the pavement fails. Cracking of the surface layer and permanent deformation of the pavement system which manifests as rutting on the pavement surface [4]. Larger and more concentrated loads produce larger stresses and strains, with thicker layer carrying higher flexural stresses than thinner layers [5]. In pavement analysis, loads on the surface of the pavement produce two strains which are believed to be critical for design purposes. These are the horizontal tensile strain;  $\epsilon_t$  at the bottom of the asphalt layer and the vertical compressive strain;  $\epsilon_c$  at the top of the subgrade layer. If the horizontal tensile strain;  $\epsilon_t$  is excessive, cracking of the surface layer will occur, and the pavement distresses due to fatigue. If the vertical

compressive strain;  $\epsilon_c$  is excessive, permanent deformation occurs at the surface of the pavement structure from overloading the subgrade, and the pavement distresses due to rutting [6, 7, 8]. Damage analysis is performed for both fatigue cracking and permanent deformation as follows:

### Fatigue Criteria

The relationship between fatigue failure of asphalt concrete and tensile strain  $\epsilon_t$ , at the bottom of asphalt layer is represented by the number of repetitions as suggested by Asphalt Institute [9] in the following form:

$$N_f = 0.0796 (1/\epsilon_t)^{3.291} (1/EI)^{0.854} \quad (1)$$

Where:

- $N_f$  : number of load repetitions to prevent fatigue cracking.
- $\epsilon_t$  : tensile strain at the bottom of asphalt layer.
- $EI$  : elastic modulus of asphalt layer.

### Rutting Criteria

The relationship between rutting failure and compressive strain;  $\epsilon_c$  at the top of subgrade is represented by the number of load applications as suggested by Asphalt Institute [9] in the following form:

$$N_r = 1.365 * 10^{-9} (1/\epsilon_c)^{4.477} \quad (2)$$

Where:

- $N_r$  : number of load applications to limit rutting.
- $\epsilon_c$  : vertical compressive strain, at the top of subgrade

## STUDY OBJECTIVE

The main objective of this study is to investigate the effects of all pavement components; thickness and elasticity



modulus, on pavement life with respect to fatigue and rutting. That is, to recognize the key components of the pavement which achieve balanced sections having equal design lives between fatigue and rutting ( $N_f = N_r$ ).

### INVESTIGATED PAVEMENT CROSS SECTIONS

A typical cross section consists of asphalt layer thickness ( $d_1 = 4$ -in.) with elasticity modulus ( $E_1 = 400,000$  psi), and base layer thickness ( $d_2 = 12$ -in) with elasticity modulus ( $E_2 = 24,000$  psi), resting on subgrade with elasticity modulus ( $E_3 = 8,000$  psi) is considered a section with reference components. Different probable cross sections that may be used in Egyptian Roads are considered for analysis through varying the reference components by  $\pm 25\%$  and  $\pm 50\%$ . Four values of each component are considered plus the reference one. That is,  $d_1$  is varied from 2 to 6-in, while  $d_2$  is varied from 6 to 18-in.  $E_1$  is varied from 200,000 to 600,000 psi, while  $E_2$  is varied from 12,000 to 36,000 psi and  $E_3$  is varied from 4,000 to 12,000 psi. Varying these components with each other give various cross sections for analysis.

### PAVEMENT ANALYSIS

Flexible pavement is typically taken as a multi-layered elastic system in the analysis of pavement response. Materials in each layer are characterized by a modulus of elasticity ( $E$ ) and a Poisson's ratio ( $\mu$ ). Poisson's ratio;  $\mu$  is considered as 0.35, 0.40 and 0.45 for asphalt layer, base course and subgrade, respectively. Traffic is expressed in terms of repetitions of single axle load 18-Kip applied to the pavement on two sets of dual tires. The investigated contact pressure is 100 psi. The dual tire is approximated by two circular plates with

radius 3.78-in. and spaced at 13.60-in. center to center. The detrimental effects of axle load and tire pressure on various pavement sections are investigated by computing the tensile strain ( $\epsilon_t$ ) at the bottom of the asphalt layer and the compressive strain ( $\epsilon_c$ ) at the top of the subgrade by using computer program KENLAYER [10]. Then, damage analysis is performed using the two critical strains to compute pavement life for fatigue cracking and permanent deformation (rutting).

### ANALYSIS OF RESULTS

The results of the damage analysis which performed on the investigated pavement cross sections using the KENLAYER program are presented in Figures (1 through 5). Figure (1) shows the effect of  $d_1$  and  $d_2$  on pavement life with respect to fatigue ( $N_f$ ) and rutting ( $N_r$ ). As can be seen in the figure, both  $N_f$  and  $N_r$  increase as  $d_1$  increases at all values of  $d_2$ . It is also can be noticed that,  $N_f$  has no sensitivity with the variation of  $d_2$ , compared with  $N_r$  which is high sensitive to the variation of  $d_2$ . The fact which can not be ignored that,  $d_2 = 12$ -in. achieves balanced sections at all values of  $d_1$ , i.e. has equal lives with respect to fatigue and rutting ( $N_f = N_r$ ).

As shown in Figures (2 and 3),  $N_r$  sharply increases as  $d_2$  increases at all values of  $E_1$ , whereas  $N_f$  has no sensitivity with the variation of  $d_2$ . Also, both  $N_f$  and  $N_r$  mildly increase as  $E_1$  or  $E_2$  increases at all values  $d_2$ . Also, it can be noticed also, that  $d_2 = 12$ -in. achieves balanced sections at all values of  $E_1$  and  $E_2$ .

Figure (4) shows the effect of  $d_1$  and  $E_3$  on  $N_f$  and  $N_r$ . It can be seen in the figure that  $N_f$  and  $N_r$  increase as  $d_1$  increases at all values of  $E_3$ . It is also can be noticed that  $N_f$  has no sensitivity with the

variation of E3, compared with  $N_r$ , which is high sensitive to the variation of E3. The figure also, shows that, E3 = 8,000 psi. achieves balanced sections at all values of d1.

Figure (5) shows the effect of d2 and E3 on  $N_f$  and  $N_r$ . It can be seen in the figure that the smaller the E3, the bigger the d2 to achieves balanced sections between  $N_f$  and  $N_r$ . It is also can be noticed that,  $N_r$  has no sensitivity with the variation of d2, compared with  $N_f$ , which is high sensitive to the variation of d2.

Examining all figures together, it can be concluded that d2 and E3 are the key elements which control the equilibrium between  $N_f$  and  $N_r$ . That is because, increasing d2 and E3 sharply increases  $N_r$ , and don't affect in  $N_f$ . Also, increasing d1 sharply increases both  $N_f$  and  $N_r$ , while increasing E2 and E1 mildly increases  $N_f$  and  $N_r$ . That is, for obtaining balanced pavement sections with respect to fatigue and rutting, it is preferable to use any values of d1, E1 or E2 at d2 = 12-in. along with E3 = 8,000 psi, or pavement sections (d2 = 9-in with E3 = 12,000 psi or d2 = 15-in with E3 = 6,000 psi or d2 = 18-in with E3 = 4,000 psi. along with E1 = 400,000 psi and E2 = 24,000 psi)

### SENSITIVITY ANALYSIS

Sensitivity analysis is performed on the recommended sections to recognize the most effective component with respect to pavement life. Table (1) shows the relation between percent change in pavement life associated to the percent change in d1, E1 and E2 at key elements (d2 = 12-in, E3 = 8,000 psi). The percent change is related to the reference values of the typical cross section. As can be seen from the table, that d1 is the most effective component for increasing pavement life among other parameters, and E2 is more effective than

E1. That is, because 50% increase in d1 leads to 325% increase in pavement life compared to 80% and 50% for E2 and E1, respectively. Whereas, 50% decrease in d1 leads to 79% decrease in pavement life compared to 50% and 42% for E2 and E1, respectively. It can be also noticed that the benefit gained from 50% increase is about 4.2, 1.6 and 1.2 times the loss resulted from 50% decrease in d1, E2 and E1, respectively.

It can be said that, d1 is the most effective component in pavement structure for increasing pavement life in a balanced section, followed by E2. That is for superior pavement performance, it is preferable to use thicker asphalt layer rested on high quality base.

### CONCLUSIONS

Based on the methodology and analysis of results of this study, the following conclusions are drawn:

1. Both  $N_f$  and  $N_r$  increase as d1 increases.
2. E3 and d2 are the key elements which control the balance between  $N_f$  and  $N_r$ .
3.  $N_r$  has high sensitivity to the variation in d2 and E3, while  $N_f$  has no sensitivity to d2 and E3.
4. E2 and E1 have mildly effect on both  $N_f$  and  $N_r$ .
5. The value of d2 = 12-in and E3 = 8,000 psi are the optimum values which achieve balanced sections at all values of d1, E1 and E2.
6. It is recommended to use a pavement section with d2 = 12-in, and E3 = 8,000 psi at all values of d1, E1 and E2, for optimum utilization of pavement components with respect to fatigue and rutting.



7. For superior pavement performance, it is preferable to use thicker asphalt layer rested on high quality base.
8. It is also, recommended to complete this work by conducting economical analysis to define the optimum pavement components from economic point of view.

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**Table 1: Change in pavement life with change in its components**

Change in pav. components (%)	Change in pavement life (%)		
	d1	E2	E1
-50	-79	- 50	- 42
-25	-56	- 26	- 22
0	0	0	0
25	125	35	24
50	330	80	50

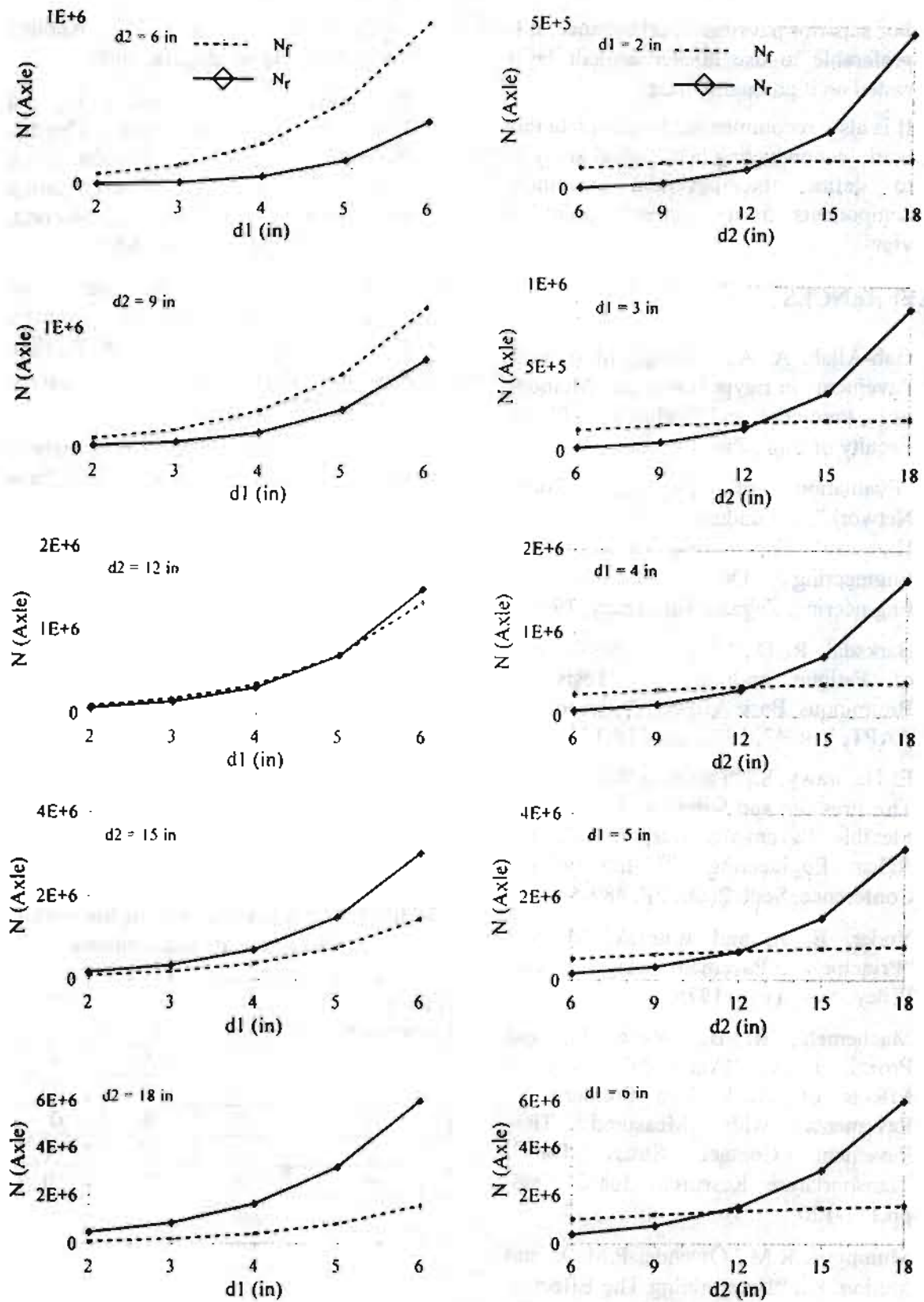


Figure 1 : Effect of d1 and d2 on pavement life with respect to fatigue ( $N_f$ ) and rutting ( $N_r$ ).

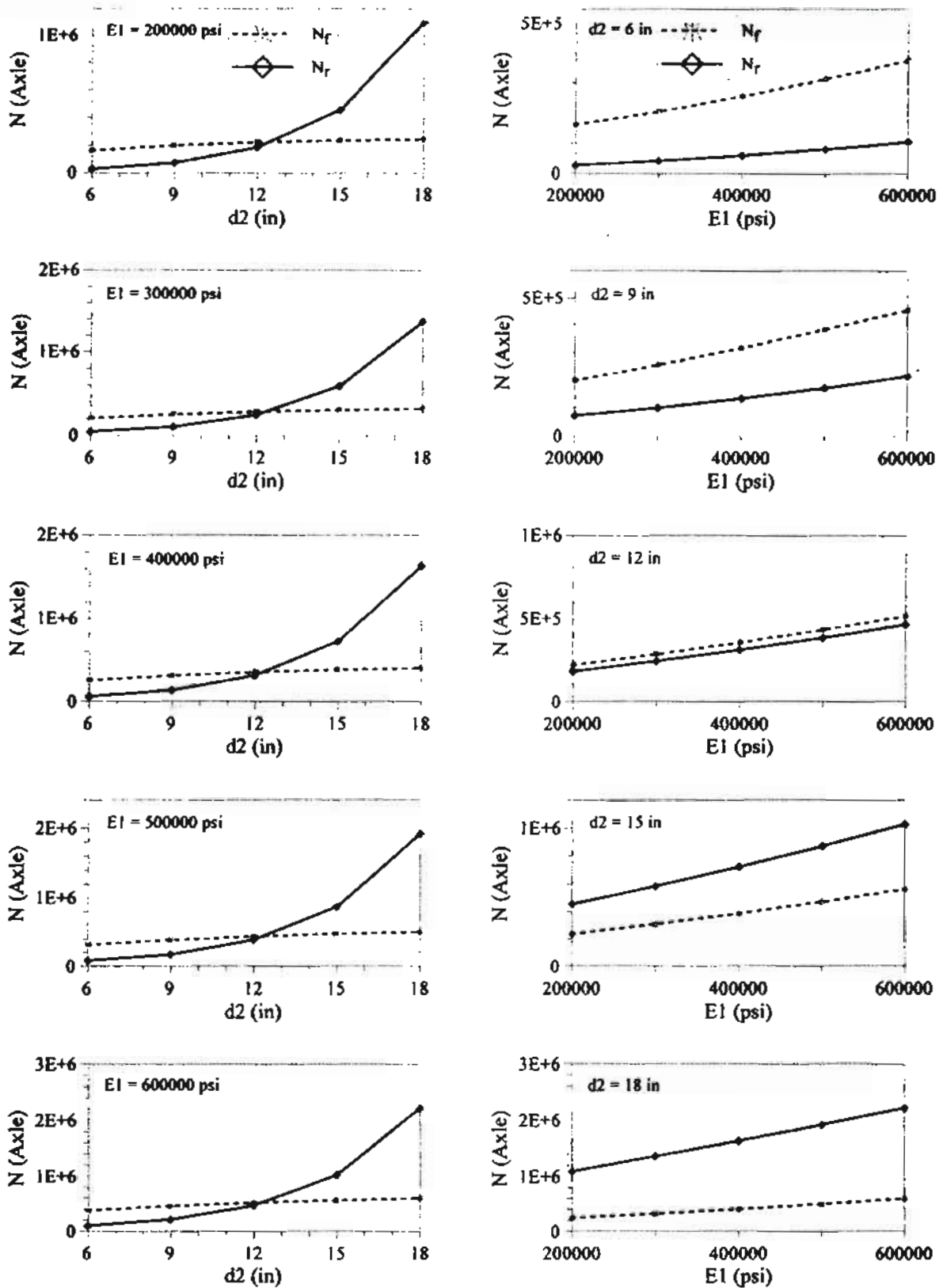


Figure 2: Effect of  $d_2$  and  $E_1$  on pavement life with respect to fatigue ( $N_f$ ) and rutting ( $N_r$ ).



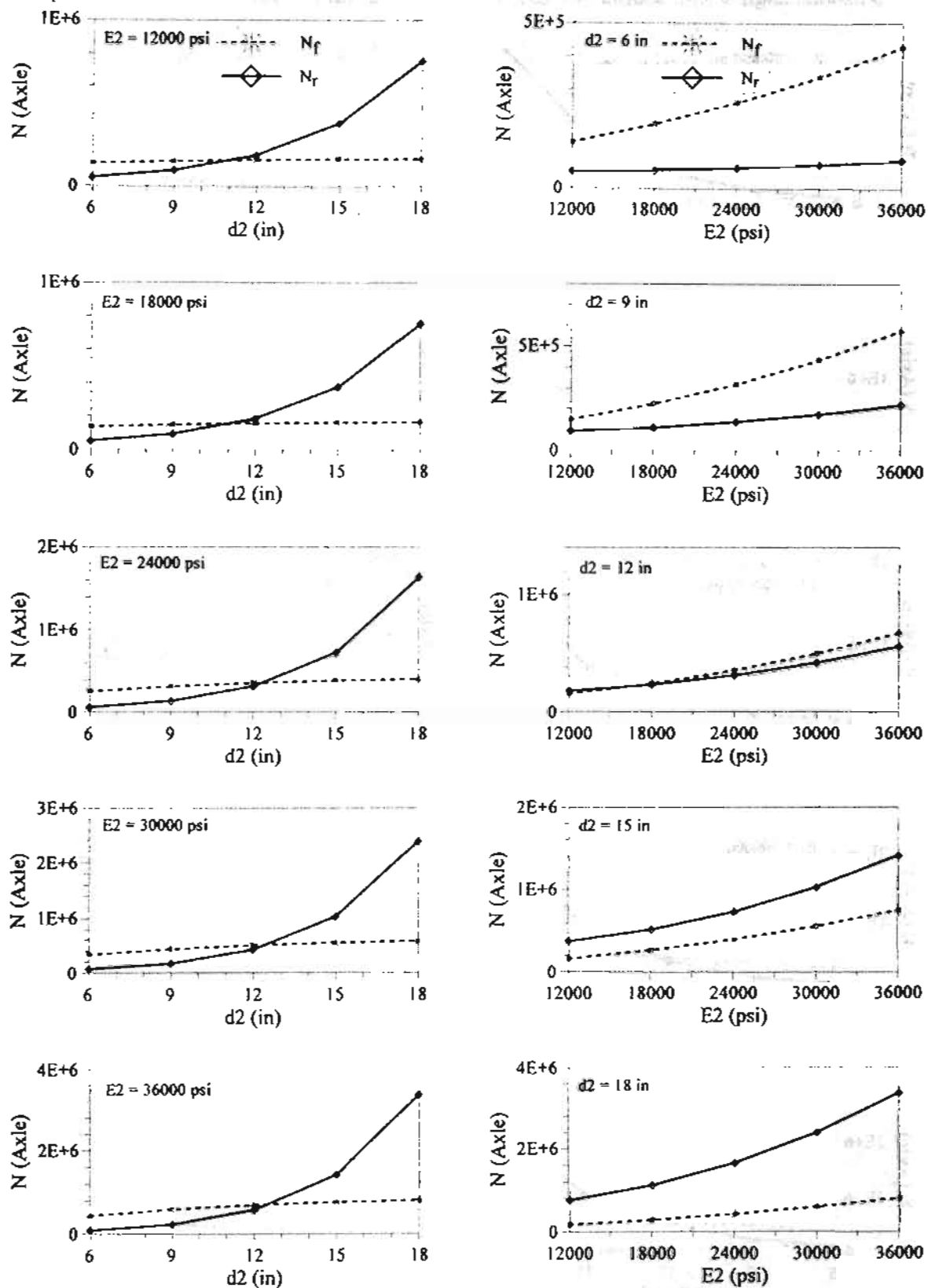


Figure 3: Effect of d2 and E2 on pavement life with respect to fatigue ( $N_f$ ) and rutting ( $N_r$ ).

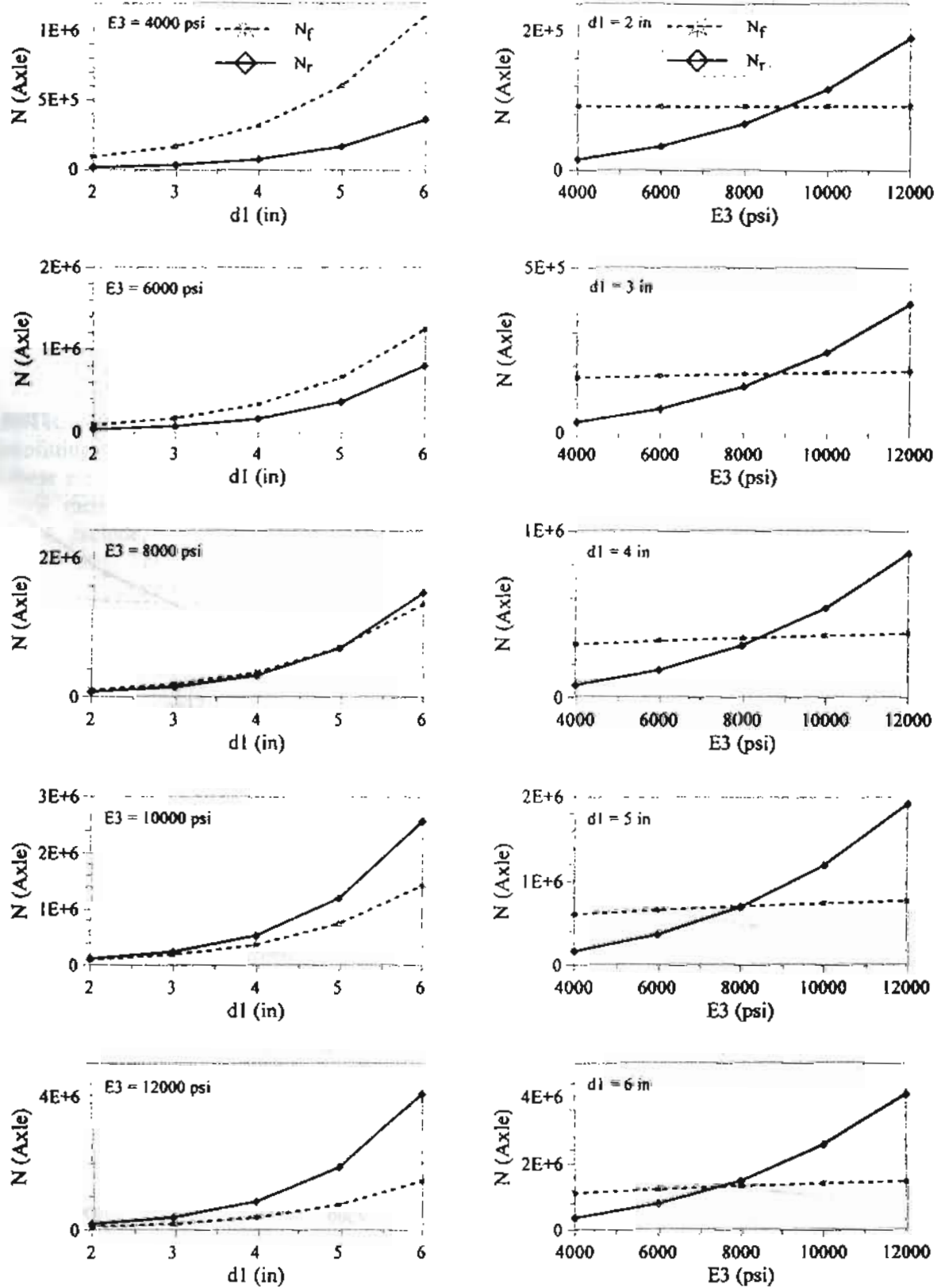


Figure 4: Effect of  $d_1$  and  $E_3$  on pavement life with respect to fatigue ( $N_f$ ) and rutting ( $N_r$ ).