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A PROPOSED PAY ADJUSTMENT METHOD FOR HIGHWAYS CONSTRUCTION

طريقة لحساب نسبة الخصم فى انشاء الطرق

By

HAZEM A. SAKR

الخلاصة – تؤثر خواص مكونات الطبقات السطحية الأسفلتية تأثيرا مباشرا وهاما على مستوى خدمة الطريق . ومما لا شك فيه أن خواص باقى طبقات الرصف (الأساس – الأساس المساعد – التربة الحاملة) ذات تأثير كبير على مستوى الخدمة المتوقع الا أنه قد يكون من الممكن علاج هذه الطبقات فى وقت مبكر أثناء عملية الانشاء وذلك بضبط المحتوى المائى أو بزيادة عملية الضغط أو بأى طريقة أخرى وصولا لأفضل النتائج . أما بالنسبة للطبقات السطحية والتى يعمل الأسفلت فيها كمادة أسمنتية رابطة فانه بمجرد اتمام عملية الدمك وهبوط درجة حرارة الخلطة يصبح من المستحيل اجراء أى تعديلات فى الخواص التى ترتبط ارتباطا مباشرا بمقاومتها للأحمال التكرارية . ومن الخواص الهامة التى تؤثر فى عمر الطبقة السطحية نسبة الفراغات الهوائية ، النسبة المئوية للأسفلت ، الخواص الريولوجية للأسفلت ، نسبة البودرة بالاضافة الى نوع وتدرج الركام المستخدم فى الخلطة . وفى كثير من الأحيان فان نسب المواد المكونة للطبقات السطحية لا تكون مطابقة للمواصفات بالزيادة أو بالنقصان . وفى مثل هذه الأحوال فان مهندس المالك يقوم بتطبيق عقابا ماديا على المقاول وذلك بخصم نسبة من تكلفة المشروع نظير النقص فى نسبة المواد (كوزن الأسفلت أو البودرة) وعادة لا يطبق أى عقاب فى حالة زيادة هذه النسب . وهذه الطريقة ليست مبنية على أسس هندسية دقيقة ولا تمثل دائما مبلغا يعتمد عليه لتعويض الخسارة المتوقعة فى مستوى خدمة الطريق . لذلك فقد كان الهدف من اعداد هذا البحث هو اعداد طريقة هندسية لحساب نسبة الخصم على مستحقات المقاول بوسيلة تعكس الخسارة المتوقعة فى مستوى خدمة الطريق فى المستقبل . وقد تم قياس مستوى الخدمة باستخدام مقياس خدمة الطريق المعروف فى طريقة اتحاد الولايات الأمريكية للطرق والنقل . أما حساب معامل الخصم فقد تم تحديدها كنسبة من أكبر قيمة خصم يمكن توقيعها وهى القيمة المالية اللازمة لانشاء طبقة سطحية جديدة ذات سمك كاف لرفع مستوى خدمة طبقات الرصف للمستوى التصميمى وبطريقة تتناسب طرديا مع مقدار الخسارة الفعلية المتوقعة فى مستوى الخدمة . كذلك فقد تم ايجاد علاقة بيانية بين معامل الخصم وبين الرقم الانشائى لطبقات الرصف وذلك لتسهيل مهمة مهندس المالك فى ايجاد نسبة الخصم الهندسى .

ABSTRACT:

The influence of variations in asphalt concrete mix properties on pavement performance during its life is a critical factor in highways construction. Although other pavement's layers; base course, subbase and subgrade have also important effects on performance; however, they can easily be adjusted early during the construction. Shortly after being laid the asphalt concrete surface layer hardens; therefore, no

adjustment can be applied. An asphalt concrete surface layer can be characterized by its percent air voids, percent asphalt content, asphalt properties, percent filler and aggregate type and gradation.

Quite often material quality does not meet specification requirements. The effect of this nonconformation on the pavement serviceability has not been established; however, it results in reduced payments to contractors. The pay adjustment methods currently used in Egypt is based mainly on discounting the present cost of materials lost out of the mix from the contractor's payment. This method of penalizing the contractor is not based on sound engineering principles. Thus, it is not always a reliable measure of pavement's reduced serviceability.

The purpose of this study is to develop a pay adjustment method that is based on the actual serviceability of pavement. It was based on the serviceability of pavement defined in the ASSHTO method of thickness design. It was assumed that the maximum penalty a contractor can ever pay was equivalent to an adjusted cost of an overlay which upgrads the pavement to its design serviceability. The actual penalty was; then, computed based on the actual loss of serviceability experienced over time. Summary tables and figures that facilitate presenting the method and its application through a simple example are included.

INTRODUCTION:

Quality control during the construction of flexible pavements is considered critical in determining the service life of a highway. It normally happens that the quality of the materials used in construction are outside the specification tolerance limits. In some cases, specially during the early stages of construction, the materials that do not meet the specification requirements can be rejected and the contractor is responsible for replacement. However; in many situations, evaluation of the finished pavement layer has proved deviations from the design limits.

Worldwide, some agencies reject construction that do not meet specification limits, and do not pay contractors. Others, however; accept these deviations in thickness, asphalt content and properties, compaction, and gradation but apply a pay adjustment factor that penalizes the contractor by reducing his balance. In Egypt, the reduction is based on present material cost discount. For example if an asphalt concrete surface course constructed at less thickness that designed, the present cost of thickness difference is deducted from the total amount of the contract. Other factors such as a lower asphalt content, lack of filler or missing a portion of an aggregate size is cut from the contractors balance on the basis of weight cost of material lost.

Non of the previously mentioned approaches, for pay adjustment, have been based on sound engineering principles. Therefore, these factors are not considered measures of serviceability reduction of the pavement. Hence, many problems between the highways agencies and the contractors are presently experienced. In fact, the need for an actual engineering procedure for accepting or rejecting noncompliance work is warranted.

PURPOSE AND METHOD OF STUDY:

The main target of this analysis is to develop a sound method for setting a pay adjustment method for flexible pavements in Egypt. The condition of the constructed subgrade, subbase or base course layers can be adjusted to satisfy the specification requirements either by thickness increase, by additional compaction or by both of them. The surface course is responsible for 40.0 percent or more of the total serviceability and cost of pavement. Therefore, the proposed method should concentrate of finding a rational relation between the asphalt concrete quality and the total pavement serviceability. Whence it can be specified whether the work should be accepted or rejected and how much compensation the contractor would pay.

To satisfy this purpose, the major elements that affect the asphalt concrete properties are first determined. Then a predictive model which reflects these properties in one representative value is selected. The relation between pavement components and its serviceability over time is then based on the AASHTO method of design. The final step will, then, be responsible for determining the penalty or the pay adjustment factors.

MIX PROPERTIES VERSUS SERVICEABILITY:

The serviceability of a pavement can be defined as its ability to serve the traffic for which it is designed for. Apavement is designed to reach a predefined serviceability index (PSI) under a predefined traffic flow which is expected to occur during a specified period of time. The number of repitions of a standard axle, 18 kips (80Kn) single axle, has been related to the subgrade soil properties, environmental conditions and the pavement quality and structure in the AASHTO method of design (1). Since, in this study, we assumed that base and subbase courses are perfectly controlled, the surface course properties could have been directly related to the pavement serviceability index. Some major properties of the finished surface course are discussed in the following paragraphs

Air Viods:

Percentage air viods (Va) is the most dominant factor that determins an asphalt mix quality. Fatigue life of a bitumenous surface course is primarily affected by the level of compaction: a higher fatigue life of pavement is the result of a decreased percentage of air voids. From a mix design point of view; the asphalt content, aggregate grad ation, and percent filler are selected to obtain the smalles voids spaces posible so that bleeding will not occur. Research, elsewhere, has confirmed that fatigue life decreases sharply with increasing voids content of the mix (2).

Asphalt Properties and Content

When all other properties are fixed, the viscusity of asphalt cement affects the fatigue life of asphalt concrete. Low penetration asphalt cement imparts a lower fatigue life for the asphalt concrete than a higher penetration one (2).

The asphalt content is also a critical factor that rules all mix properties. The binder is the most expensive constituent of the mix, in addition, it controls the flexibility of surface course. The content of bitumen in mix is directly related to the percent air voids and affects aggregate interparticle friction which in turn influence the stability, durability, strength and fatigue life of mix.

Recent research, aimed to developing a mathematical model for prediction of the modulus of elasticity of asphalt concrete, has proved that not only the percent asphalt content (Pac) that effects the elastic modulus but also its deviation from the optimum value [Popt] (3). In the recent Asphalt Institute method of pavement design (4) the fatigue life of asphalt concrete has been found to be dependent on the modulus of elasticity and the level of elastic strain. In general, percent bitumen content and properties is a factor that interacts with all other mix components to determine the quality of asphalt concrete.

Aggregate Gradation and Type

The gradation of an aggregate determines the amount of voids present to be filled with asphalt cement. The degree to which the voids are filled with bitumen influences the elasticty and fatigue life of mix. Also, the amount of voids, provided by the agregate, controls the fatigue life of finished mix.

Since different aggregate types have different capabilities as load-carrier thus it is expected that the fatigue life of mix differs by aggregate type. Shape, surface texture, durability and others are factors defining aggregate type. A recent study relating the number of load repetitions to failure with mix properties has substantiated that type of aggregate has an important consequences on fatigue life of asphalt concrete (2). They asserted that mixes composed of crushed stone have better fatigue life than those composed of crushed gravel.

Properties Predictive Model

The properties of surface course material is reflected in the AASHTO pavement design method through one variable called layer coefficient (a_1). This coefficient varies from 0.20 to 0.44 depending on the quality and type of asphalt mix. Based upon the NCHRP evaluation study of the AASHTO design guide (5), a relation between layer coefficient (a_1) and elastic modulus (E) has been proposed from a combined analysis of individual state highway results and a theoritical analysis, Fig.(1). A mathematical model relating the mix properties to its elastic modulus has been developed for use in the Asphalt Institute thickness design method (4). The model was based on measuring the modulus of elasticity of 369 asphalt concrete specimens made from crushed stone aggregates mixed at the optimum asphalt content. However, the model has recently been refined to include wider range of mix properties (3). The latest model was based on 1179 points and had a coefficient of determination (R^2) of 0.891. This excellent results created a highly accurate predictive equation that can reflect the properties of asphalt mix with only one dependent value. The model can be reduced for a temperature of 68°F (20°C) and a load frequency of 1.0 hertz to be:

$$\begin{aligned}\text{Log}\ (E) &= 6.485587 + 0.028829\ (P_{200}) - 0.03476\ (V_v) \\ &\quad + 2076.7\ (P_{ent})^{-2.194} - 0.457\ (P_{ac} - P_{opt} + 4.0)^{.5}\end{aligned} \qquad (1)$$

Where ;

E = elastic modulus, in psi.,
P_{200} = Percent material passing No. 200 sieve,
V_v = Percent air voids in the mix,
P_{ent} = Penetration of asphalt cement,
P_{ac} = Percent asphalt content, by weight of mix; and
P_{opt} = Percent optimum asphalt content, as found by Marshall.

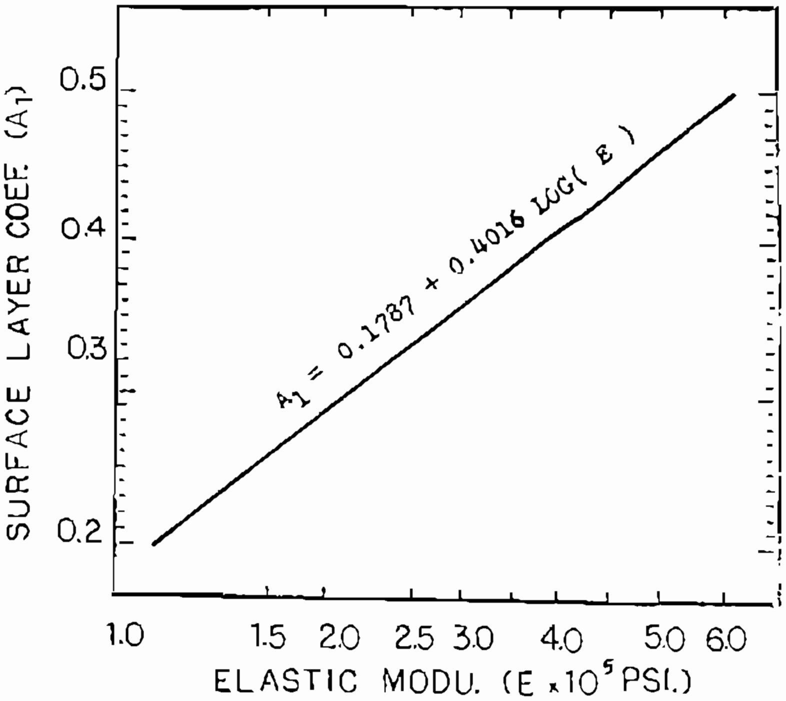

Fig. (1): Relation between modulus of elasticity and surface layer coefficient.

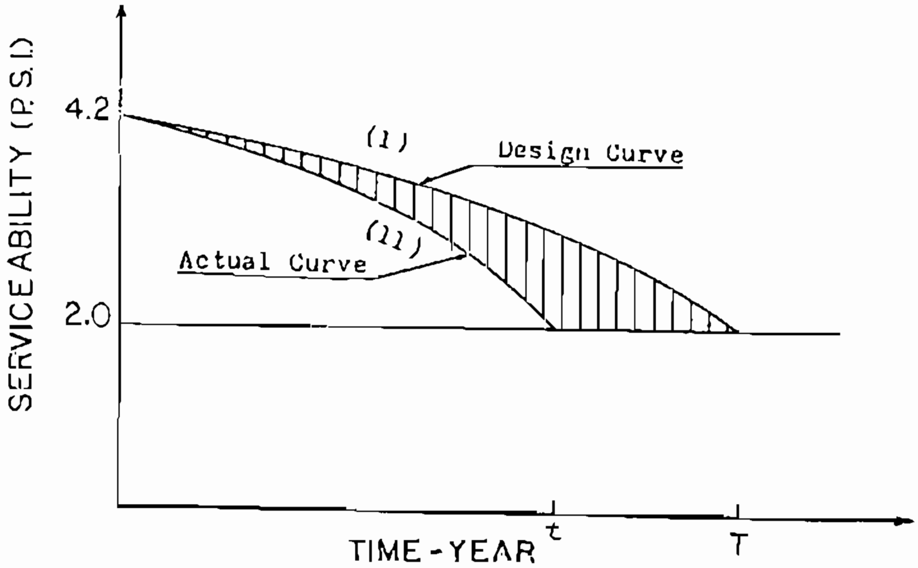

Fig. (2): Change in Serviceability (PSI) over time in years using the AASHTO procedure.

Hence; the major properties of finished mix can be reflected in one value, elastic modulus (E), which, in turn, can be used to determine any change in the serviceability of the pavement.

METHOD OF ANALYSIS

In this analysis the following assumptions were made:

1. Subgrade, subbase and base course are matching the design requirements, since any defect in any of these layers can be easily treated during construction.
2. A pavement is designed to serve an initial annual number of 18-Kips (80 Kn) single axle load repetitions (No) as well as their growth over a period of time (T-years) at a rate of (i) before it reaches a minimum serviceability index PSI = 2.0.
3. A pavement that has a minimum serviceability index of PSI = 2.0 is not worth zero cost value.

Thus, for a given pavement and based on the AASHTO method of design a relation between the total number of repetitions (N_f) and pavement variables can be reduced to the following equation:

$$\log (N_f) = -0.43 + 9.36 \log (SN + 1) + \frac{\log [(4.2 - PSI) / 2.7]}{0.4 + [1094/(SN + 1)^{5.19}} \qquad (2)$$

where; SN = Structure number of pavement
= $a_1 d_1 + a_2 d_2 + a_3 d_3$, and
N_f and PSI are as defined previously.

In equation (2), the regional factor (R) was given a value of 4.0 which was believed to reflect the environmental condition in the Egyptian Delta region, however; other values could be assumed changing only the constant value in the equation. Also, a soil support (S) value of 4.0 was considered reasonable for the nonstabilized clay present in the Delta area.

Therefore; for a given pavement structure that is designed to carry a limited number of equivalent load repetitions (N_f) during a time (T) the relation between the serviceability index (PSI) and time in years can be drawan as shown in Fig.(2), curve-I. The pavement under evaluation; however, will reach the minimum value of serviceability, PSI = 2.0, after a time (t) less than the design time (T) as shown in the same figure, curve-II. The dashed area shown in Fig.(2) represents the lost serviceability over time which will be experienced by the road users. If this imaginary area can be represented by cost units, rational pay adjustment or penalty factors can then be developed.

Maximum Penalty Pmax

Assuming we have two pavements both hold exactly the same structural components; however, one of them is new, i.e., it has a servieability index PSI=4.2 and the second is old and has allready reached the minimum serviceability of PSI=2.0. To upgrade the old pavement to its initial serviceability PSI=4.2, an overlay is added so that the structure number (SN) is shifted back to its original value. The cost of upgrading the old pavement is equal to the maximum penalty (Pmax) that a contractor should be charged for. A proposed method for computing maximum penalty is summarized below.

For a perfectly constructed pavement that was designed to have a structure number (SNp), then;

$$SN_p = a_1 d_1 + a_2 d_2 + a_3 d_3 \tag{3}$$

If this pavement has been used untill a serviceability of PSI = 2.0 is reached, before being overlaid to gain a structure number (SNo), therefore;

$$SNo = a_1 d_o + (d_1 + d_2) a_2 + a_3 d_3 \tag{4}$$

where; d_o = thickness of overlay

Equating SN_p to SNo or equation 3 to equation 4, then;

$$d_o = d_1 \left(1 - \frac{a_2}{a_1} \right) \tag{5}$$

In developing equation: 4, 5 it was assumed that the old surface course layer would be considered as an additional base course with a layer coefficient of a_2 (1). The total cose of overlay (Co), allowing 20.0 percent extra cost for batching and preparing old surface will therefore be:

$$Co = 1.2\, Cs\, d_1 \left(1 - \frac{a_2}{a_1} \right) \tag{6}$$

where; Cs is the unit thickness cost of surface layer. As introduced previously the cost of overlay (Co) is equal to the maximum penalty (Pmax) that a contractor will be obliged to pay, under the assumption of this analysis. Since it is not expected that a new constructed pavement will reach minimum serviceability in the first day of opening then; the amount of penalty will lie between zero and (Pmax).

PAY ADJUSTMENT PROCEDURE

It is proposed that the pay adjustment is applied as a penalty that a contractor has to pay to compensate the user for the loss of serviceability he will experience during the pavement design life. The concept is that a pavement constructed within design thickness and mix specification are accepted with full payment. Adeviation, from mix specifications and/or design thickness may reduce the level of service offered to user overtime, Fig.(2). Therefore; a new term is introduced in this study called the integrated time service (TTS). The (ITS) is defined as the area under the service-time curve between PSI=4.2 and PSI=2.0. In a mathematical form, the integrated time-service (ITS) can be represented by;

$$ITS = \mathop{}_{t=0}^{T} \mathop{}_{PSI\,=\,2.0}^{4.2} (\,PSI\,).\,dt \tag{7}$$

For a design period (T), an initial annual number of load repetitions (No), a traffic growth rate (i) and a design structure number (SN)d the integrated time service (ITS) will have its design value. When the ITS is equal to its design value the pay adjustment factor will be equal to unity, or the penalty is zero Egyptian Pounds. However; the ITS will be zero if the constructed pavement has enough deviation from the design specifications so that its serviceability is minimum, i.e.; PSI =2.0. Therefore, for any pavement which has an integrated time service (ITS) act, the penalty can be computed as follows:

$$P = K . P_{max} \qquad (8)$$

where; K is the penalty coefficient and equal to

$$\frac{(ITS)_{des} - (ITS)_{act}}{(ITS)_{des}} \qquad (8)$$

Figure (3), shows the service time curves for a pavement which was assumed to have a design structure number (SN = 3.6) as well for the same pavement when its structure number was reduced. Detailed data for each one curve are also given in Table-1 for comparison. It can be noticed, in the same figure, that a reduction in the pavement structure number from SN = 3.6 to SN = 3.5 results in reducing its design life from 20.0 years to about 18 years. In addition, the serviceability, as measured by PSI, is less than expected during all the reduced time of 18 years. Using the proposed method, it was found that the contractor should pay a penalty of 8.75 percent out of the maximum penalty (Pmax) as a compensation. Assuming a 40-in thickness surface course of a design layer coefficient a_1 = .44, then; a reduction of 0.10 in SN will happen when a_1 is reduced to a value of 0.415. This reduction can be the result of an increase of the percent air voids of 1.0 percent, a reduction in the percent filler of 1.35 percent, or any other equivalencies of combined deviations.

As shown in Figure (4) the relation between the penalty coefficient (K) and the structure number of pavement is linear. The slope of this line is equal to the difference between the minimum and the design structure number, i.e.: (slope = (SN) min-(SN)des). This finding will facilitate the use of the proposed method. The engineer, knowing (SN) des, needs only to compute the (SN)act using equation (1) and Fig.(1) as well as (SN)min; or the structure number of the pavement when the surface layer has a coefficient equivalent to the base course layer coefficient. A relation similar to that shown in figure(4) is drawn and the penalty coefficient can be found. Knowing the penalty coefficient, the total penalty can be calculated as given in previous section.

Computing the penalty using the method discussed above is considered a rational way of compensating the users for the serviceability they are going to loose over time.

Although it may result in higher or even lower penalty values than the methods currently used in Egypt, it is offering a fair compromise both for government agencies and contractors.

Table -1 Summary of the Example Data

Present (SN)	Life Time (t - year)	ITS[b]	K[c]	Serviceability Model (PSI)[a]
3.6	20	24.48	0.00	$4.2-0.78\,(1.08^{t} - 1)^{0.8}$
3.5	18.1	22.67	0.088	$4.2-0.863\,(1.08^{t} -1)^{0.845}$
3.4	16.2	20.5	0.175	$4.2-0.97\,(1.08^{t} -1)^{0.9}$
3.3	14.5	18.47	0.256	$4.2-1.107\,(1.08^{t} -1)^{.964}$
3.0	9.53	12.8	0.485	$4.2-2.0\,(1.08^{t} -1)^{1.22}$
2.8	5.64	8.14	0.670	$4.2-5.94\,(1.08^{t} -1)^{1.63}$

a Example assumesgrowth rate of 8.0 percent
b ITS = Area under time-serviceability curve (2 PSI 4.2)
c k = Penalty Coefficient

CONCLUSIONS

1. Initial deviation of surface mix properties from specifications can cause a high reduction in the pavement's serviceability over time.

2. Pay adjustment factors should be based on the deviation of mix air voids percent as well as other factors currently used.

3. The Asphalt Institute modified model for asphalt concrete elastic modulus prediction is an excellent tool for measuring the relative change in mix characteristics.

4. Pay adjustment using the maximum penalty as a reference is based on sound engineering principles and the penalty computed using the proposed method represents the actual compensation for a lower service during pavement's life time.

5. A more practical pay adjustment method can be settled if a relation between serviceability index (PSI) and the present worth of pavement's rehabilitation cost is developed.

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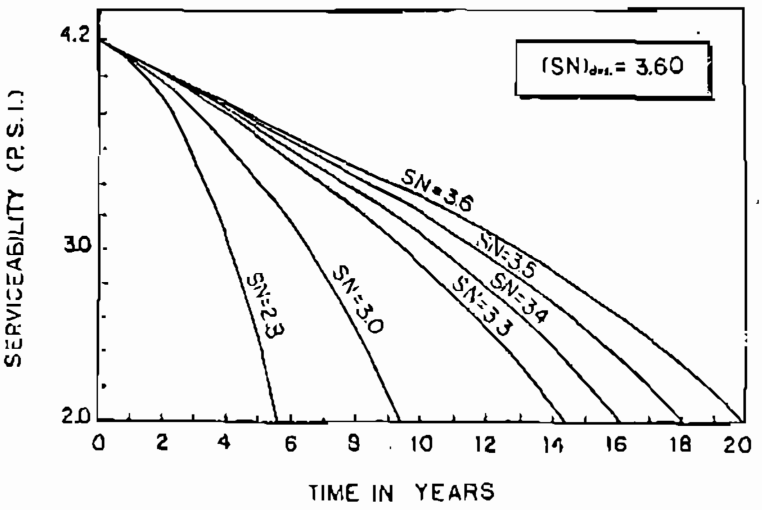

Fig. (3): Effect of Pavement structure number on serviceability over time.

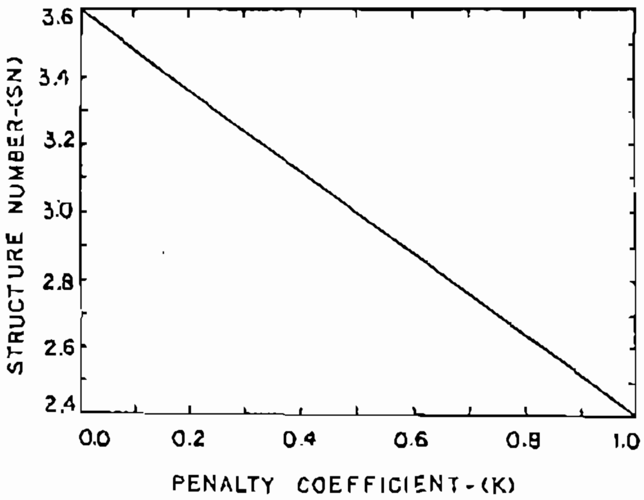

Fig. (4): Structure number versus penalty coefficient (K).

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