ECONOMIC EVALUATION OF PAVEMENT OVERLAY DESIGN STRATEGIES

(KADUNA-ABUJA ROAD AS A CASE STUDY)

BY

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CERTIFICATION

This thesis entitled "THE ECONOMIC EVALUATION OF PAVEMENT OVERLAY DESIGN STRATEGIES (KADUNA-ABUJA ROAD AS A CASE STUDY)" by ADEGBESAN, Joseph Folorunso, meets the regulations governing the degree of Master of Science of Ahmadu Bello University Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This work is dedicated to my wife

(Mrs M.K. ADEGBESAN) and my son

(Master OMOYEMI ADEGBESAN).

DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree.

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The above declaration is confirmed.

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ABSTRACT

There are two main phases to this work. The first dealt with the overlay thickness design while the second considered economic appraisal of overlay design strategies.

Pavement overlay design on Kaduna - Abuja road was carried out based on elastic layer and traffic estimate theories, as well as field and **-Laboratory** observations. The road was statistically divided into 8 homogenous sections.

A computer program 'LAYER 5' was developed and used for the calculation of horizontal and vertical strain, vertical stress and fatigue remaining life of the pavement based on Odemark, Burminster and Boussinesq equations.

The economic appraisal of the design was based on a cost model that considers all costs incurred over a period of 20 years. A total of 10 strategies involving design periods ranging from 2 years to 20 years at an incremental rate of 2 years were considered for the different thicknesses of the overlays. Relationships were developed for both the maintenance and users costs as functions of overlay thickness and design period. All cost items were subjected to sensitivity analyses.

The results of the economic appraisals showed that those strategies that require frequent overlays are more expensive than these with fewer overlays. However, differences in total costs diminish as from the design period of 14 years onwards. Also, it was found that on the basis of present physical conditions of the road, the stretch spanning 2,3km - 8.0 km from Kaduna is the strongest.

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CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND INFORMATION

The need for detailed appraisal of design practices in Nigeria pertaining to roads and their overlays has become very essential given the downturn in the economy. Optimum utilization of resources demands that this should, infact, be the case. The very prohibitive high costs of road construction in the country clearly indicates that resources have hitherto not been optimally utilized.

The premature failure of flexible pavements seems to be a common feature in Nigeria for all types of roads. This failure is possibly caused by poor design of the roads which has characterised design practices in the country. Therefore, there is a need for improvement in design practices especially in Nigeria that the highways constitute about 60-70% of the total means of transportation of people and freight (Onakomaya (1985)).

It is the purpose of this study to carry out detailed appraisal of overlay design strategies so as to obtain an optimum overlay thickness that minimises the associated sum total of construction, user and maintenance costs. For the purpose of the work, Kaduna - Abuja road has been chosen as the

case study.

The Kaduna-Abuja road is a single carriageway that connects the cities of Kaduna in Kaduna state and Suleja in Niger State. It is a main gateway to the new Federal Capital city of Nigeria. It is therefore of immense importance. Besides its importance, some data on the road can readily be obtained from the Pavement Evaluation Unit, Kaduna and hence its choice for this study. The road has an approximate length of 157 kilometres. It was first constructed as a surface dressed road in the late seventies. Later it was reconstructed as a two lane asphalt concrete pavement between 1982 and 1985 probably in direct consequence of changing of the Federal Capital from Lagos to Abuja.

1.1 STATEMENT OF PROBLEM

Nigeria, like most other developing countries invest a substantial portion of her annual budgets to provision of infrastructures, of which road development takes a prominent position. Hence it is necessary that all issues connected with road development be given due attention. Among the intractable problems that have surfaced in road development is the high costs of construction. It is now obvious in the face of dwindling resources that unless avenues for reducing construction costs are explored, high costs of construction may constitute a constraint to further development.

The above described general problem is what has been tackled in this project. The specific aspect of the problem that has been focussed on is the derivation of an optimum overlay design strategy. Several options exist to the designer and policy makers in solving this problem.

At the one extreme, very thick overlays could be provided and this would ensure that minimal maintenance is needed and further overlays would not be required for quite a long time. The main drawback of this approach, however, is that very high initial costs would be incurred. The other extreme is to have very thin overlays as a design policy. Its advantage would be low initial costs but high maintenance costs and frequent overlays would be necessary. One would expect that an optimum solution exists, probably somewhere between the two extremes. The main problem tackled in this thesis is to derive that optimum strategy for the specific case of Kaduna - Suleja road.

1.2 OBJECTIVES OF THE STUDY

Against the background of the problem defined for this work, the following are the main objectives of the study:

(i) To formulate a rational design method for pavement overlay with a view to isolating the effect of thickness.

(ii) To identify the major cost items that can be affected by the overlay design strategy

(iii) To formulate rational methodologies for quantifying the cost items identified in (ii)

(iv) To undertake a parametric variation of the overlay thickness which is the main design factor of interest to this work, with a view to assessing its influence on the total construction, maintenance and users' costs

(v) To determine which design option(s) give minimum total costs.

1.3 SCOPE OF THE STUDY

The project consists of two interrelated parts viz:-

(a) Pavement Overlay Design

(b) Economic appraisal of the overlay design.

These have been undertaken for each of the scientifically determined typical sections of Kaduna-Abuja road.

1.3.1 Pavement Overlay Design

The level of pavement serviceability declines gradually and continuously over time, and if no remedial action is taken it will fail functionally. The decline in present serviceability index with age for a typical pavement is shown in Fig. 1.1.

Pavements may become functionally and structurally inadequate either because the traffic loading is greater than what was forecasted at the design stage or because there was an under-design of facility. Regardless of the cause of the road's inadequacy, an immediate action is needed to restore the serviceability of the road once the inadequacy occurs.

One of the techniques used to restore the level of serviceability is the application of an overlay which increases the structural strength of the pavement as shown in Fig. 1.2.

A major thrust of the pavement study is to review the pavement overlay design strategy as reflected in the timing of strengthening and degree of strengthening undertaken at overlay. The field work is based on Kaduna-Abuja road. Different trial thicknesses corresponding to various life spans will be tried. The overlay design method used incorporates a mechanistic prediction of pavement

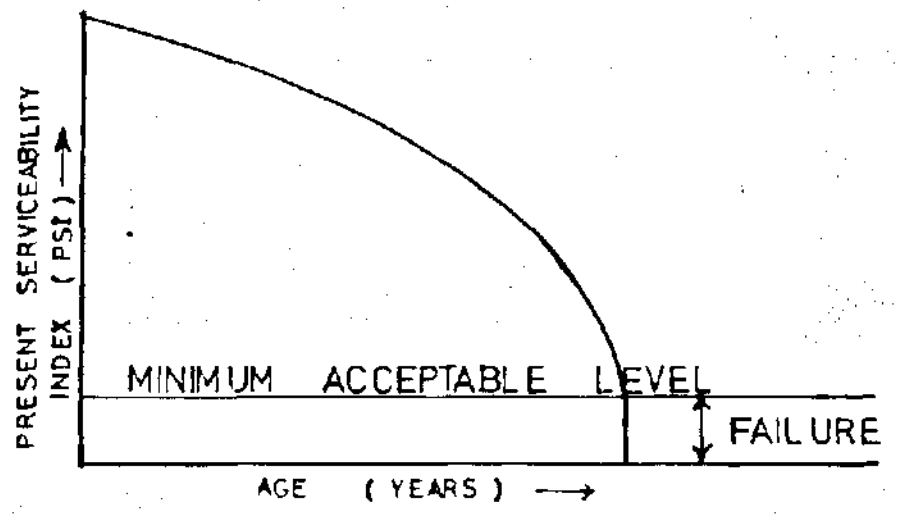


FIG. 1-1 TYPICAL PAVEMENT PERFORMANCE PROFIFE.

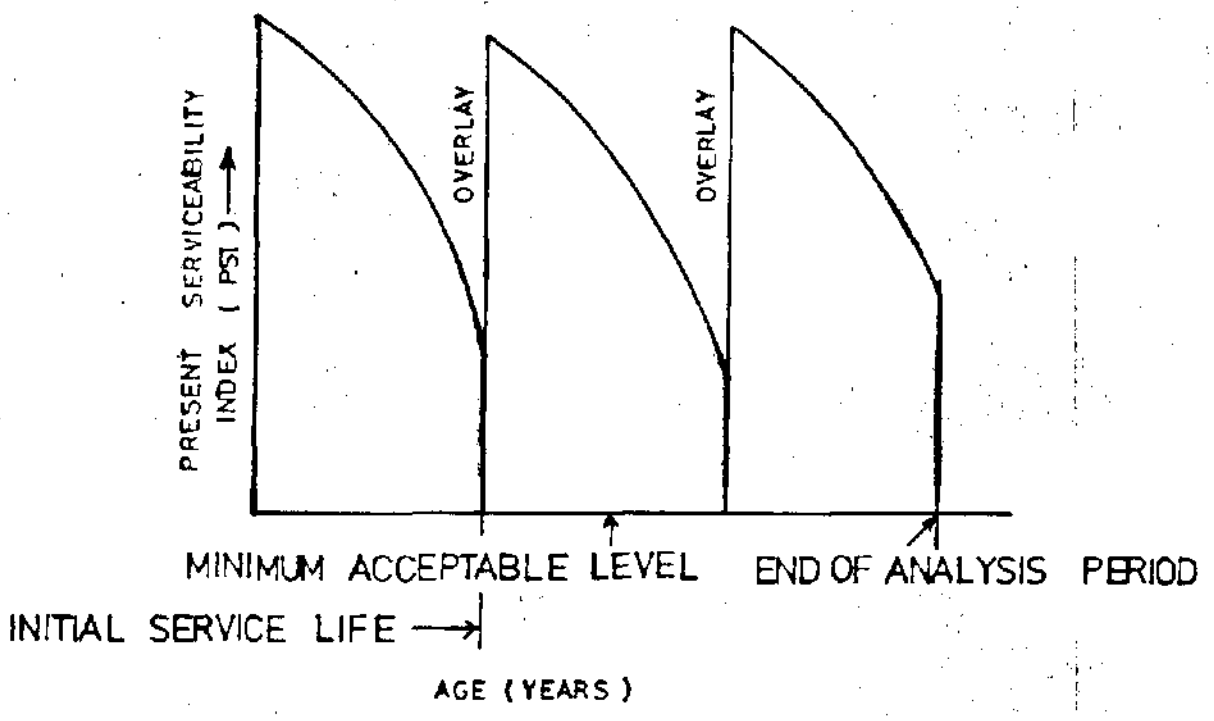


FIG. 1-2 PERFORMANCE PROFILE AS INFLUENCED BY OVERLAY.

strains using elastic layer theory and considers environmental factors such as temperature, and rainfall estimates of past and future traffic in terms of equivalent axle load, deflection measurements, roughness measurements, condition survey and material characterisation.

The weighted average of the overlay thicknesses obtained for different sections is then determined for each design period in order to obtain a uniform thickness for the entire road. For each overlay thickness so obtained, the total costs of construction, maintenance and vehicle operating are determined.

1.3.2 Economic Evaluation

The evaluation is to consider the relative desirability of the various design options on the basis of total costs. The total costs for each design strategy will then be related to the corresponding overlay thickness, so as to determine the most desirable. In this manner, the alternative investments will be compared in order to obtain the optimum overlay thickness that minimizes the associated total costs, including construction, maintenance, user's and vehicle operating costs.

1.4 ORGANISATION OF THESIS

This thesis has been split into six chapters for effective coverage of the study.

The introductory part of the work were discussed in chapter one. Chapter two covers all the previous researches carried out in this area. The theoretical approaches to the work came up in chapter three. Chapter four dealt with the methodology adopted for the work. The data analyses and discussion of results were carried out in chapter five while the conclusions and recommendations were stated in chapter six.

CHAPTER TWO

REVIEW OF LITERATURE

2.0 REVIEW OF DESIGN PRACTICE IN NIGERIA

Previously in Nigeria, overlay thickness had been selected on the basis of experience of the engineer or on the assigned budget for the overlay. In other cases, Federal Ministry of Works and Housing relied on empirical relationship involving maximum surface deflection such as the Transport and Road Research Laboratory (TRRL) method. Kennedy (1978) In the deflection method; the required overlay thickness is taken to be the thickness that assures reduction of the existing pavement deflection to a tolerable deflection.

Elkins and Hudson (1984) have enumerated the limitations of deflection model type methods for use in Nigeria to include the following:-

(a) No deflection method has been specially acclimatized to the Nigerian environmental, materials and traffic conditions.

(b) Surface deflection is the only measure of pavement strength used because in-situ material properties are not tested.

Therefore, the described design practice has long been considered unsatisfactory. This is hardly surprising since considerable information on pavement conditions and material characteristics have been obtained and stored by the Pavement Evaluation Unit in Kaduna. Obviously, there is sufficient basis for well grounded theoretical approaches to overlay design and analyses. Some uncoordinated efforts have already been made in this direction and the present work attempts to further this approach.

2.1 THEORIES OF ECONOMIC EVALUATION OF PAVEMENT OVERLAY STRATEGY

Phang and Slocum (1972) have proposed a simplified technique for the economic analysis of pavement/overlay design strategies. The technique is based on present and future construction and maintenance costs, pavement service life, discount rate and analysis period. These factors are combined in a formula which gives the total costs in present value as reflected in equation 2.1.

$$T_{cj} = C_o + \frac{C_{r_1}}{(1+R)^s} + \frac{C_{r_2}}{(1+R)^{s+t}} + \frac{C_{r_3}}{(1+R)^{s+2t}} + \cdots\cdots\cdots$$

$$+ \frac{C_{rm}}{(1+R)^{s+(m-1)t}} - (1-Y/t)\frac{C_{r_m}}{(1+R)^n} + \sum_{a=1}^{n}\frac{M_a}{(1+R)^n}$$

$$+ \frac{U_{C_{r1}}}{(1+R)^s} + \cdots\cdots + \frac{U_{C_{rm}}}{(1+R)^{s+(m-1)t}} \quad \ldots\ldots \quad 2.1$$

where T_{cj} = Total costs for alternative j

C_o = Initial construction cost

C_r = Resurfacing construction cost (including engineering, administration costs)

R = rate of discount

m = Number of resurfacing during the analysis period.

n = Analysis period

s = Lifespan of Initial surfacing

t = Lifespan of subsequent surfacing

Y = Number of years between the time of last resurfacing and the end of the analysis period.

(1-Y/t) = Residual-value coefficient

M_a = Annual Maintenance cost

U_{cr} = User's cost (including extra costs of time delay and vehicle operation costs)

Haas and Hudson (1978) reported other techniques for economic evaluation of pavement overlay. These

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by most people. It is easy to comprehend a return on investment because of the association and familiarity with normal business terms. It is particularly useful where the streams of the benefits associated with the various options under consideration differ. Nevertheless, situations do arise where the rate of return method gives ambiguous answers. It also entails cumbersome computations.

The particular problem investigated in this work indirectly assumes that the benefits are fixed regardless of the options. Hence, this method is not considered worthwhile.

(3) The benefit-cost ratio method has a major disadvantage on account of the abstract nature of the ratio, which is difficult to comprehend by itself. Another disadvantage is the possible confusion over whether maintenance cost reductions should be in the numerator or the denominator and whether cost reductions are benefits or negative costs and so on. Based on these disadvantages, the method has not been considered appropriate for the purpose of this study.

(4) The cost effectiveness method is used mainly where significant, non-monetary outputs are involved.

The cost-effectiveness method may not be the method most applicable to the pavement field, but it can be used to supplement other methods. For example, it is known that pavement appearance has an effect on users. If some measure of aesthetics or appearance were developed, this could be embo died in a cost effectiveness model with the results of the present value analysis. Hence, the method is not used for the present work.

(5) The present value method is generally preferred for economic evaluation of transportation projects or systems by several writers among whom are Wohl and Martins as claimed by Hudson and Hass (1978). Although there are certain limitations to the method, the advantages seem to outweigh the disadvantages. Thus, it is among the preferred approaches for evaluating alternative pavement strategies when public investments are involved.

The economic cost equation used in the study has the following advantages over other methods enumerated above

(a) The answer is given as a total payoff for the project.

(b) The method is computationally simple and straight forward. Hence, these justify its being chosen in undertaking the study.

2.2 THEORIES OF MECHANISTIC OF OVERLAY/PAVEMENT DESIGN

Burminster and Boussinesq's fundamental theory on elastic behaviour of multilayered flexible pavement forms the basis of the design procedure developed in this research. Actually, a similar procedure has highly been worked upon and has even been computerised by many researchers who assumed different degree of complexity and situations. Among such is Jerry Koole (1979) who schematised a pavement structure as a three layer model. The top layer was taken to represent the asphaltic or bituminous layer, the one beneath is the base layer and the third layer is the subgrade of original soil which is of infinite dimensions. Along the same view, Peattie (1982) discussed the possible subdivision of the top layer into wearing and base course, and the pavement base course underlain by a subbase layer of weaker granular material.

Koole (1979) further assumed that the materials of the separate layers behave in a linearly elastic nmanner characterised by their respective modulus/stiffness values. This particular approach has been adopted in this work.

Peattie and Brown (1982) also discussed the mechanistic behaviour of a multilayered elastic

pavement structure. They then suggested two main design criteria namely:-

(i) The tangential tensile strain below the asphalt layer, e_o, for fatigue cracking and

(ii) The vertical compressive strain on the top of the subgrade, e_v. for permanent deformation.

They proposed a simplified technique for determining the stresses, strains and deflections in a multilayered elastic pavement structure. The technique is based on Odemark, Burminster and Boussinesq's equations which are given as equations 2.2 to 2.5 using four layer pavement structure.

$$H_{e4} = \left[\left[h_1\left(\frac{E_1}{1-v_1^2}\right)^{1/3} + h_2\left(\frac{E_2}{1-v_2^2}\right)^{1/3} + h_3\left(\frac{E_3}{1-v_3^2}\right)^{1/3}\right]\left(\frac{1-v_4^2}{E_4}\right)^{1/3}\right] \quad \ldots \quad \ldots \quad 2.2$$

$$\sigma_x = \sigma_v = P_o\left[1 - \frac{1}{\left(1+(a/z)^2\right)^{3/2}}\right] \quad \ldots \quad \ldots \quad 2.3$$

$$e_z = e_v = \frac{P_o(1+v)}{E}\left[\frac{z/a}{\left(1+(a/z)^2\right)^{\frac{1}{2}}} - (1-2v)\left[\frac{z/a}{(1+(z/a)^2)^{\frac{1}{2}}} - 1\right]\right] \quad \ldots \quad \ldots \quad 2.4$$

$$e_o = 1/E \left[\frac{1-V}{2V} \left(\sigma_x - E\, e_z \right) - V\sigma_x \right] \quad \ldots\ \ldots\ 2.5$$

where:

$Z = H_{e4}$ = equivalent layer thickness (inches)

h_i = Layer i's thickness (inches)

V_i = Layer i's Poisson Ratio

E_i = Layer i's Modulus of Elasticity (PSI)

P_o = Contact stress (psi)

a = Contact area radius (inches)

σ_x = Vertical stress due to wheel load (PSI)

e_z = Compressive vertical strain on top of subgrade (PSI)

e_o = Tensile tangential strain at bottom of bituminous layer.(PSI)

Sharpe et al (1981) had reported the application of dynamic (vibratory) deflection measurements for the structural design and analysis of a flexible pavement in Kentucky State, U.S.A. This approach subjects the pavement to strenuous stress/strain analysis where the characteristics of individual components are fully considered. Something close to this has been accomplished, almost accurately, with the Finite element method (FEM), and method of equivalent thickness (MET). However, these approaches incorporated, heavily involved computer works. The former takes into account all the possible variations of material properties at all points and directions.

The author proposed a simpler and reasonably accurate method which is the introduction of a single value for base moduli to calculate the strains at critical points in the pavement, e_v, on the subgrade top and e_o at the bottom of the asphalt layer. These are the equivalent base modulus in both vertical and horizontal directions respectively.

The validity of such an approach to pavement analysis/design has been proved by comparison of its solutions with those of other methods - MCT, FEM and that of Maryland.

Singh and Akoto (1981) employed a similar approach for the design of a lime stabilised laterite road in the tropics. The critical tensile strain at the bottom of asphalt/bituminous surfacing and critical compressive strain on top of the subgrade were determined for elastic multilayered system.

As a general review of state- of-the -art in pavement design or overlay, the physical inputs to the design can be categorized as follows:-

(a) Traffic factors
(b) Environmental factors
(c) Material characterisation
(d) Roughness measurements
(e) Deflection measurements
(f) Condition survey factors

Details of the design methodology as well as the methods adopted for estimating the listed inputs in this study are presented at a later section.

2.3 THEORIES OF TRAFFIC ESTIMATE

Since the vehicular wheel loads to be sustained, estimate on the traffic is essential for good design. The standard procedure is to convert truck weights to equivalent single axle loads (ESAL). In this study 8,200kg equivalent single axle load is used as the standard load and 14,500kg equivalent single axle load for tandem. The equivalent factor relates the damage done by one pass of a given axle load to an equivalent number of standard axle load applications that would cause the same damage.

An approximate method of converting mixed traffic to ESAL was developed in a National Cooperative Highway Research Program (NCHRP) study as reported by Hudson (1978). It is based on categorising traffic into three basic groups:-

Passenger cars, single unit vehicles and Multi vehicles.

Highway traffic loads, as far as pavement design is concerned, are usually considered in terms of axle loads and the number of repetitions of these axle loadsthat the pavement must carry.

Elkins and Hudson (1984) have proposed a simplified technique for the conversion of traffic loads to ESAL. The technique is based on axle loads and number of Trucks as reflected in equation 2.6.

$$F_{Avg} = \sum_{j=1}^{NA} (1.02\ (L_j/L_s)^{3.8})/N_T \quad \ldots\ \ldots \qquad 2.6$$

where F_{Avg} = Number of 8,200kg single axle load. equivalent factor per truck

N_A = Number of axles

L_j = Axle load j, (kg)

L_s = Standard axle load as follows:

8,200kg for single axles

14,500kg for tandem axles.

N_T = Number of trucks.

CHAPTER THREE

THEORETICAL BACKGROUND

3.0 PREAMBLE

The application of economic evaluation techniques to transport projects, including investments on pavements, is essential in order to achieve the maximum returns from such investments.

In order to apply the principles of economic evaluation to the study the following are the theories involved:-

(a) Economic Model
(b) Overlay Design Model
(c) Traffic Estimate Model

3.1 ECONOMIC MODEL

The following factors are essential to the proper identification of economic costs:

(1) Present and future construction costs, maintenance costs, delay and vehicle operating costs during construction,

(2) Range of estimated service life expected from the pavement

(3) Discount rate to be used to discount future costs to present values.

(4) Analysis period over which the costs of various pavement/overlay designs can be compared.

Based on analysis by Phang and Slocum (1972), the four factors can be embodied within a realistic economic model as depicted in Fig. 3.1. These factors are incorporated in a formula (equation 2.1) to provide a rational basis for determining the economic costs of any pavement/overlay strategy.

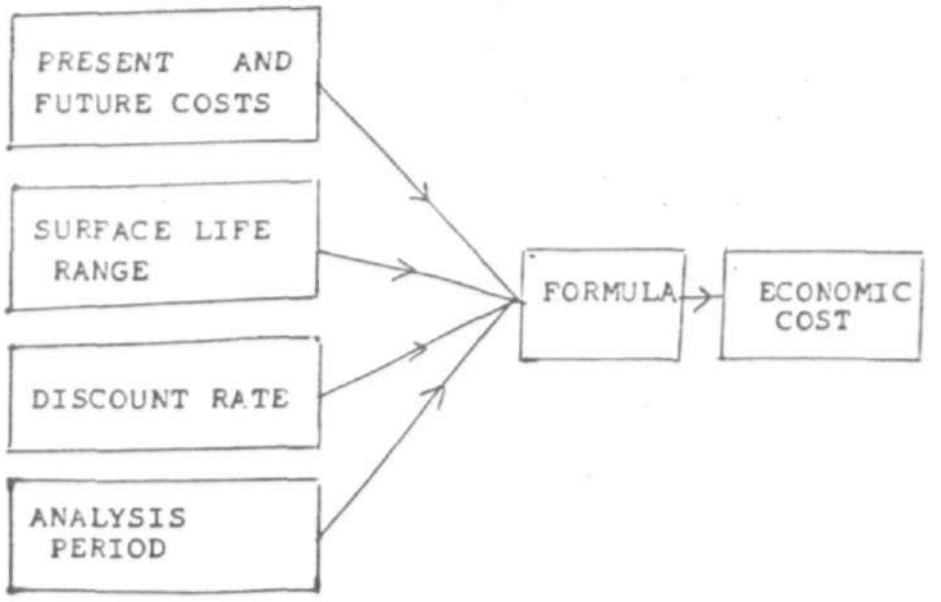


FIG. 3.1 ECONOMIC MODEL CHART

THE FORMULA:

The economic model depicted in Fig. 3.1 is represented by the formula given in equation 2.1. The inputs necessary for this formula are costs, service lives, discount rate and analysis period.

This equation (equation 2.1) can be modified further to allow for the effects of inflation rates, i_f as indicated in equation 3.1, i.e.

$$T_{C_j} = C_o + \frac{C_{r1}(1+i_f)^s}{(1+R)^s} + \frac{C_{r_2}(1+i_f)^{s+t}}{(1+R)^{s+t}} + \ldots\ldots +$$

$$+ \frac{C_{r_m}(1+i_f)^{s+(m-1)t}}{(1+R)^{s"(m-1)t}} + \frac{U_{C_{r_1}}(1+i_f)^s}{(1+R)^s} + \ldots\ldots$$

$$+ U_{C_{rm}} \frac{(1+i_f)^{s+(m-1)t}}{(1+R)^{s+(m-1)t}} - (1-Y/t)\frac{C_{rm}(1+i_f)^n}{(1+R)^n} +$$

$$\sum_{a=1}^{n} \frac{M_a(1+i_f)^n}{(1+R)^n} \quad \ldots\ldots \quad \ldots \quad 3.1$$

where

C_o, C_r, U_{Cr}, Y, t, M_a, n, R are as previous defined.

In estimating the total costs (equation 3.1) above, each parameter of the equation has to be determined. The procedure for obtaining these parameters are enumerated below:-

3.1.1 Initial Construction Costs (C_o)

This is the initial construction cost of the whole road and since this road is being divided into sections in this work, it is assumed that C_o is the same regardless of the strategy adopted for overlay. Therefore, it is omitted in the analyses.

3.1.2 Resurfacing Construction Costs ($Cr_1 \ldots Cr_m$).

These costs include the costs of materials, Labour, Engineering and administration. From the work of many researchers including Cross (1978), these costs can be combined in a sub-model to provide a rational basis for determining the resurfacing construction costs as given in equation 3.2.

$$C_r = M_c + L_c + E_c + A_c \quad \ldots \quad \ldots \quad \ldots \quad 3.2$$

where C_r = Resurfacing construction costs

M_c = Material costs

L_c = Labour costs (including equipment cost)

E_c = Engineering costs and

A_c = Administration cost

The Labour cost, Engineering cost and Administration cost are normally taken as a percentage of material costs. From many researchers work including Peurifoy (1975) and many Organizations including Federal Ministry of Works, the percentage varies from 30% to 50% of the costs of material. For the purpose of this work, these costs (i.e. labour cost, Engineering cost and administration cost) are subjected to sensitivity analyses.

3.1.3 Delay Cost During Resurfacing ($D_{cr}...D_{crm}$).

The delay costs depend on the volume of work done during resurfacing which in turn depends on the thickness of overlay applied and period at which the pavement is being put to use. Expressing this mathematically it gives:-

$$D_{Cr} = x\ (H_i\ N_i)\ i \qquad \ldots \qquad \ldots \qquad 3.3$$

where

D_{cr} = Delay costs in ₦/km for alternative i

x = Proportionality constant (₦/mm-yr-km)

H_i = Overlay thickness (mm) for alternative i

N_i = Analysis period (yr)

Several researchers including Haas and Hudson (1978) have indicated that values of x varies from ₦120.00 to ₦200.00 per mm-yr.

The process of obtaining H_i in equation 3.3 above is presented in section 3.2.

3.1.4 Maintenance Cost (Ma)

Maintenance costs are difficult to estimate because of inadequate data on independent effects of thickness, age and traffic. Because of this, maintenance costs are normally assumed to increase with design period for overlay design and also

inversely proportional to overlay thickness. Mathematically,

$$Ma_i = P\ (T_i/H_i)_i \quad \ldots \quad \ldots \quad \ldots \quad 3.4$$

where

Ma_i = Maintenance cost for alternative i (₦/km)

P = Proportionality constant (₦-mm/yr)

T_i = Pavement life (yr)

H_i = Overlay thickness (mm) for alternative i

From the literature including Phang and Slocum (1972) the values of P varies from ₦376,000 to ₦400,000 mm/yr .

3.2 Overlay Design Model

In estimating total construction costs, reliable information on thickness of overlay corresponding to the design strategy is required. The overlay thickness depends on the horizontal strain at the bottom of the existing pavement, vertical strain on top of the subgrade and allowable equivalent single axle load (ESAL) applications.

The overlay thickness required is obtained from a design curve which shows a relationship between allowable equivalent single axle load applications and overlay thickness. A typical example is shown in Fig. 3.2.

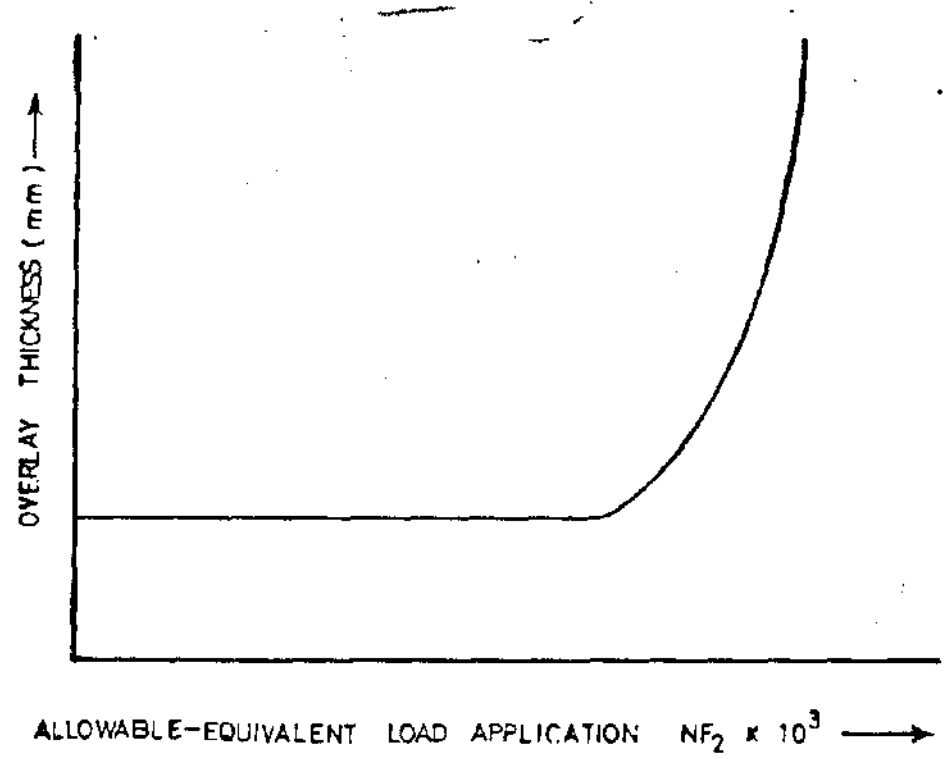


FIG. 3-2 SAMPLE OVERLAY THICKNESS DESIGN CURVE

In obtaining the above design curve, the following steps are taken:-

(a) The allowable equivalent load applications (horizontal axis) are obtained using the following expression:

$$NF_2 = \left[\frac{(9.727 \times 10^{15})}{24.5 \left(\frac{e_o}{10^{-6}}\right)^{3.291} \left(\frac{E_1}{10^3}\right)^{0.854}} \right] (LR) \quad \ldots \quad 3.5$$

where

NF_2 = Allowable 8,200kg ESAL applications

e_o = Horizontal tensile strain at the bottom of the existing pavement (PSI)

E_1 = Dynamic Modulus of the existing pavement (PSI)

LR = Pavement remaining fatigue life.

In estimating the allowable 8,200gk ESAL applications above, information on e_o, E_1 and LR are required.

In the work, the technique for obtaining e_o is based on Odemark, Burminster and Boussinesq's equations (equations 3.6 to 3.9). In this technique a range of overlay thicknesses are imposed on the existing pavement as shown in Fig. 3.3. Then the e_o is obtained as follows:

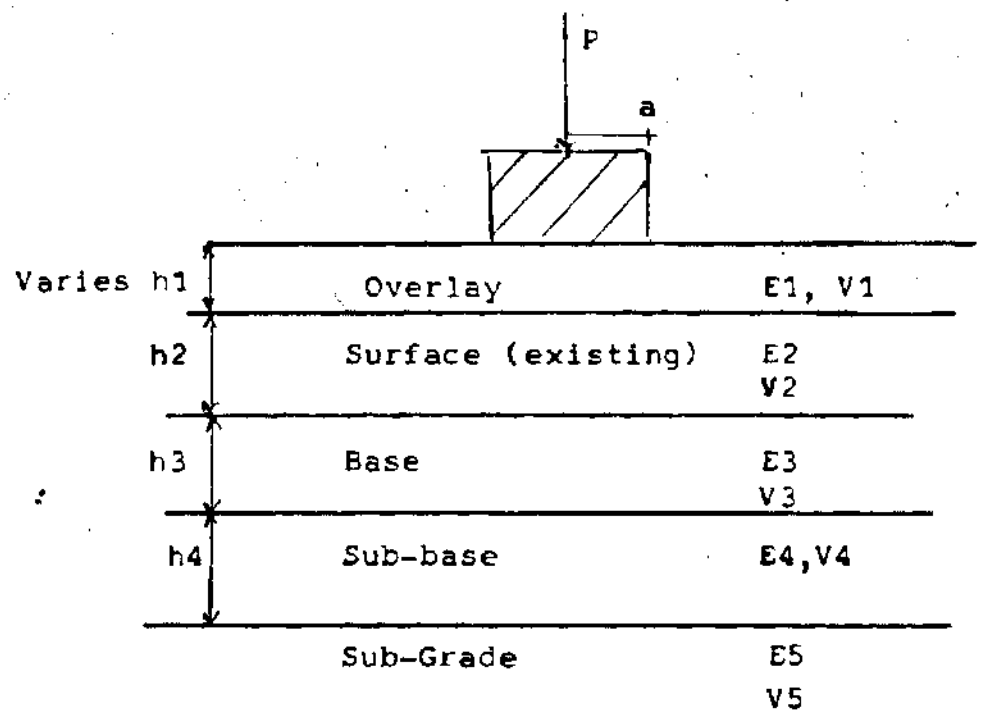


Fig. 3.3 Pavement with imposed overlay.

$$e_o = \frac{1}{E_5}\left[\left(\frac{1-V_5}{2\,V_5}\right)\left(\sigma_x - E_5\, e_z\right) - V_5\,\sigma_x\right] \quad \ldots 3.6$$

$$e_z = P_o \frac{(1 + V_5)}{E_5} \left[\frac{\frac{H_{e5}}{a}}{\left(1+\left(\frac{H_{e5}}{a}\right)^2\right)^{3/2}} - (1-2V_5) \left[\frac{\frac{H_{e5}}{a}}{\left(1+\left(\frac{H_{e5}}{a}\right)^2\right)^{1/2}} - 1 \right] \right] \quad \ldots 3.7$$

$$\sigma_x = P_o \left[1 - \frac{1}{(1+(a/He_5)^2)^{3/2}} \right] \quad \ldots 3.8$$

$$H_{e5} = \left[h_1 \left(\frac{E_1}{1-V_1^2}\right)^{1/3} + h_2 \left(\frac{E_2}{1-V_2^2}\right)^{1/3} + h_3 \left(\frac{E_3}{1-V_3^2}\right)^{1/3} + h_4 \left(\frac{E_4}{1-V_4^2}\right)^{1/3} \right] \left(\frac{1-V_5^2}{E_5}\right)^{1/3}$$

where $\ldots \ldots$ 3.9

$Z = H_{e5}$ = equivalent layer thickness (inches)

h_i' = = Thickness of Layer i (inches)

V_i' = Poisson ratio of layer i

E_i' = Modulus of Elasticity of layer i (PSI)

P_o = Contact stress (PSI)

a = Contact area radius (inches)

σ_x = Vertical stress due to wheel load (PSI)

e_z = Compressive vertical strain on top of subgrade (PSI)

e_o = Tensile tangential strain at bottom of bituminous Asphalt layer (PSI).

Each parameter in equations 3.6 - 3.9 is obtained as follows:-

h_1 (overlay thickness) varies and for this project it is taken to be 50mm, 100mm, 150mm and 200mm.

h_2 to h_4 are obtained from direct field measurements.

V_1 to V_5 are obtained from a standard table which is reproduced in this thesis as Appendix B.

E_1 is taken as 2.76 MP_a (400,000 PSI) based on Elkins and Hudson (1984) work

E_2 is obtained from Dynamic Laboratory tensile test of the core of existing pavement.

E_3 to E_5 are estimated from empirical relationship due to Elkins and Hudson (1984) which are given in equations 3.10 - 3.12.

$$E_3 = 1585\ FLDCBR \quad \ldots \quad \ldots \quad 3.10$$

$$E_4 = 1000\ FLDCBR \quad \ldots \quad \ldots \quad 3.11$$

$$E_5 = 5054\ (S_5)\ 0.88645 \quad \ldots \ldots \quad 3.12$$

where

E_3 = Base layer modulus (PSI)

E_4 = Sub base modulus (PSI)

E_5 = Sub grade modulus (PSI)

FLDCBR = California bearing ratio value obtained directly from field tests.

S_5 = Sensor five deflection (mills), obtained

on field dusing deflection measurement instrument.

The contact area radius (a) and contact stress (P_o) are based on the standard values of the deflection measurement instrument. Their values are taken as 157mm (6.18 inces) and 517.13P_a (75PSI) respectively.

The remaining life (LR) of the existing pavement which is defined as the remaining fatigue resistance of the pavement is estimated using equation 3.13.

$$LR = 1 - LU \quad \ldots \quad \ldots \quad 3.13$$

where

LR = Remaining fatigue life

LU = Fatigue life consumed and is given in equation 3.14

$$LU = N_p/N_f \quad \ldots \quad \ldots \quad \ldots \quad 3.14$$

where

N_p = Cumulative 8,200kg ESAL from initial construction/overlay to the beginning of design life assumed (this is given by equation 3.16).

N_f = Past number of allowable 8,200kg ESAL applications.

The past number of allowable 8,200kg (ESAL) application (N_f) is obtained from an expression derived by Elkins and Hudson (1984). It is given in equation 3.15.

$$\text{Log } N_f = 15.988 - 3.291 \log \frac{e_o}{10^{-6}} - 0.854 \log \frac{E_2}{10^3} \quad \ldots 3.15$$

where e_o and E_2 are as previously defined.

Here we are concerned with the past number of applications on the existing pavement, therefore assumed overlay thickness h_1 in equation 3.9 is zero. Hence the value of e_o is obtained as given in equations 3.6 to 3.9. The existing pavement structure is shown in Fig. 3.4 where

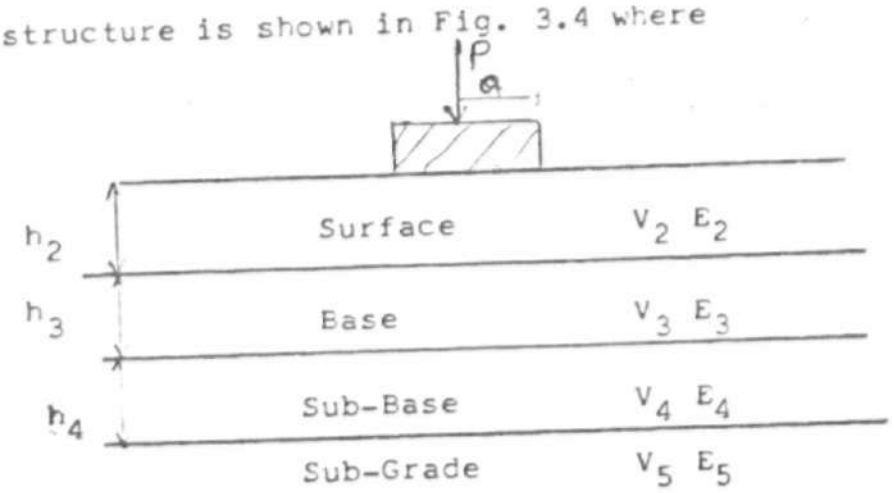


FIG. 3.4: Existing pavement structure.

h_1, h_2, h_3, E_1, ... E_4, V_1 ....V_4 are as previously defined.

3.3 TRAFFIC ESTIMATES MODEL

In obtaining overlay thickness, reliable information on traffic volumes is required. Normally, traffic flow data is estimated on two premises. These are:-

(1) Past traffic carried by the existing pavement since the application of the last overlay.

(2) The design traffic (i.e. future traffic/ applications).

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These estimates are expressed in terms of 8, 200kg Equivalent single axle loads (ESAL) by using the formulae given by equations 3.16 and 3.19.

3.3.1 Past Traffic

The past no of 8,200kg ESAL applications of vehicular load since last overlay is given by equation 3.16

$$N_p = \sum_{i=1}^{M} \frac{ADT_p}{(1+R)^t} \quad (FTG) \quad (DD) \quad (LD) \quad (P_t) \quad (F_{Avg}) \qquad .. \; .. \; 3.16$$

where

N_p = Past number of 8,200kg ESAL application.

m = Period between the analysis period and the period the last overlay was applied.

ADT_p = Present average daily Traffic

DD = Directional Distribution factor

R = Growth rate

t = Number of years in this period

FTG = Future Total Growth factor.

P_t = Percent trucks

LD = Lane Distribution factor

FA_{vg} = Average 8,200kg single axle load equivalence factor per truck (i.e. conversion factor to ESAL).

The future total Growth (FTG) and Percent truck (P_t) in equation 3.16 are estimated as follows.

FTG is given in equation 3.17 based on Elikins and Hudson (1984) work as

$$FTG = \frac{365\ (1+R)^n - 1}{1_n\ (R+1)} \quad \ldots\ \ldots \quad 3.17$$

where

FTG = Future total growth

R = As previously defined

n = Design period

1_n = Log to base e i.e. $\log_e$

The percent truck (P_t) is obtained as

$$P_t = \frac{\text{No of trucks in } ADT_p}{ADT_p} \times 100 \quad \ldots\ \ldots \quad 3.18$$

P_t, ADT_p are as previously defined.

The value of number of years in the period, t, in equation 3.16 is taken as 4 since the last overlay was done in 1984.

The average 8,200kg single axle load equivalence factor (F_{Avg}) is determined for all axles as given in equation 2.6 and dividing by the total number of trucks weighed on the field.

3.3.2 Design Traffic

The design number of ESAL applications (traffic) for alternatives j; $W_{8.2j}$ is obtained from equation 3.19

$$W_{8.2j} = ADT_p\ (DD)\ (LD)\ (P_t)\ (FTG)\ (F_{AVS}) \quad \ldots\ \ldots \quad 3.19$$

where:

$W_{8.2j}$ = Design number of 8,200kg ESAL application for alternative j.

ADT_p = Present Average Daily traffic.

DD = Directional distribution factor

LD = Lane distribution factor

P_t = Percent trucks

F_{AVg} = Average Equivalence Factor

The process of estimating the above parameters have been enumerated in section 3.3.1.

CHAPTER FOUR

METHODOLOGY

4.0 PREAMBLE:

The primary objective of this study is to undertake a detailed appraisal of overlay design strategy using Kaduna-Abuja road as a case study.

An application of overlay is meant to increase the structural strength of the pavement, so that the pavement's level of serviceability can be enhanced. A number of choices as regards overlay thickness is open to the designer but each choice brings about certain ramifications as regards maintenance and vehicle operating costs. For example a thin overlay thickness will result into low construction cost but might entail high maintenance cost and frequent resurfacings. The opposite is the case for large thickness. In between these extremes, there could very well be an optimum thickness which gives minimum total costs. The main thrust of this study is to establish such optimum state if, infact, it exists. Thus the project has two main components namely:-

(1) Economic appraisal of the pavement overlay design, and

(2) Pavement overlay design.

Appropriate methodologies, therefore, had to be devised to tackle the two facets of the defined problem.

4.1 BASIC ASSUMPTIONS

In undertaking the study, the following assumptions were made to simplify the problem.

(a) Analysis period is 20 years

(b) Boundaries for feasible thickness is as follows:-

Lower Limit - 50mm. Overlay thickness below this will be very difficult to construct.

Upper limit - 200mm. If a design gives an overlay thickness that is more than 200mm, it is more economical to do total reconstruction than applying overlay to the pavement.

(c) The actual service life is taken as same as the design life.

(d) The pavement homogenous sections are assumed to wear out at a uniform rate.

(e) The labour strength is taken to be the same for all strategies.

4.2 METHODOLOGY ADOPTED FOR COST ESTIMATES

The estimates of total costs comprises several subunits as indicated in equation 3.1. These subunits are further investigated in the subsequent sections.

4.2.1 Present and future construction costs

These costs include the costs of materials, labour, engineering and administration. In order to obtain the costs of materials, the volume of work to be done is estimated and a market survey is undertaken so as to know the current price of materials. Having done these, the volume of materials is then multiplied by its corresponding unit cost to obtain the costsof materials to be used in each instance. Besides the costsof materials to be used for work, labour, engineering, and administration costsare estimated from findings gathered from current literature. In addition, a sensitivity analysis about the range of values obtained from literature is undertaken.

4.2.2 Delay costs during resurfacing

These include the extra costs of time delay and vehicle operation during the process of overlay. The delay costs are basically estimated by using equation 3.3. The overlay thickness, H is directly derived from design model while the design period, N is parametrically varied from 2 years to 20 years in incremental steps of 2 years. Again, the range of values of the constant X is derived from the literature but subjected to sensitivity analyses about these values.

For example if the overlay thickness, H corresponding to design period of 20 years is 150mm. Using equation 3.3.

If X = 60(₦/yr -mm)

DC_r = 60(150 x 20)

= ₦180,000/length = ₦4724/km.

4.2.3 Maintenance Costs

Mainterance costs are difficult to estimate because of inadequate data on independent effects of thickness, age and traffic. For this study, the maintenance costs are estimated using equation 3.4.

For the purpose of this study, the maintenance costs are subjected to sensitivity analyses about the range of values stated in section 3.1.4. The values of P chosen are 190000, 376000, 40 0000 and 800,000 all in ₦-mm/yr.
For example, using the same example used for delay costs for the pavement life of 1yr.

H = 150mm, N = 1 yr

For P = ₦190,000mm/yr.

M_a = ₦190,000 (1.0/150)

= ₦1266.67/km.

4.2.4 Estimated Service Life

The estimated service life of a pavement is not necessarily the same as the design life of pavement. This may be due to some factors. For example if the volume of traffic plying the road increased tremendously or the road lack proper maintenance, the pavement will wear out quickly. As a result the service life won't be the same as the design life.

For the purpose of this project, the estimated service life is taken as same as the design life.

4.2.5 Discount and Inflation rates

The debate among economists still continues regarding an appropriate rate for the discounting of public investment streams. There is no question that future values should be discounted. Delayed benefits are not so attractive as present benefits, and present costs are not so attractive as delayed costs. Hence, the discounting process is needed to reduce both future benefits and future costs to present values.

The rate of discount should reflect society's time preference for early benefits versus late benefits. However an acceptable premise for choosing discounting rate is yet to be found. Hence, in the present work, discount rate has been subjected to sensitivity analyses covering a reasonable spectrum than a single value.

As for inflation rates, no exact or standard technique make allowance for future inflation, nor indeed would such a technique be valid as inflation rates cannot be predicted with any degree of certainty. Hence in this work, inflation rates are also subjected to sensitivity analyses.

4.2.6 Salvage Value

The salvage value is a function of construction cost, analysis period and time of last resurfacing. The cost is estimated as

$$(1-Y/t)\ \frac{C_{rm}\ (1+i_f)}{(1+R)^n}$$, as given in equation 3.1.

4.2.7 Analysis Period

The analysis period should correspond to the functional design life of the pavement concerned. Because geometric changes, reflecting advancing technology, and highways typically require rebuilding, in many instances, in less than 30 years, longer analysis period would be unrealistic. The period used in the study is 20 years.

By comparing the present value of cost for design strategies over the same analysis period, one will have a meaningful measure of the costs of providing essentially the same benefit.

After obtaining all the associated costs enumerated above, they are discounted, and then added together to obtain the total discounted costs for each strategy.

4.3 METHODOLOGY ADOPTED FOR OVERLAY DESIGN

For a meaningful cost estimation, a reliable information on overlay thickness is required. The overlay thickness design method adopted for this study requires input from the following areas:-

(1) Deflection testing factor
(2) Condition survey factor
(3) Roughness testing factor
(4) Traffic data factor
(5) Material characterisation factor.

4.3.1 Deflection Testing Factor

The deflection data is normally obtained in the form of a profile for the length of the road as shown in Appendix F, subsequently it is sub-divided into sections that are reasonably homogenous as in table 4.1.

Those sections for which measured characteristics are not statistically different are combined to form a homogenous section, beginning from one end of the road to the other using students' t-distribution test as in tables 4.2 and 4.3. The students' t-distribution test is actually meant for testing mean deflection of one section against another. For

TABLE 4.1 TYPICAL SUB-SECTIONS IDENTIFIED FROM DEFLECTION TEST RESULTS

SUB-SECTIONS	LENGTH (KM)	Observations from Visual Surveys of Section.
1	0-2.3	Moderately cracked, few pot holes, moderate alligator cracks and roughness values.
2	2.3-8.0	Moderately cracked and very low roughness values.
3	8.0-13.10	Moderately cracked, few pot holes and patches.
4	13.10-16.10	Moderately cracked, few pot holes and patches.
5	16.10-19.10	Moderately cracked
6	19.10-27.60	Moderately cracked few pot holes and patches.
7	27.60-35-70	Severely cracked fragile pot holes and patches.
8	35.70-38.70	same as subsection 7
9	39.70-44.50	Severely cracked Fragile pot holes and patches. (Km 41.00-42.00 TOTAL pavement failure.)
10	44.50-51.20	Severely cracked, sum of pot holes and patches.
11	51.20-55.00	Moderately cracked.

TABLE 4.2 INITIAL ZONING OF DEFLECTION GROUPS.

SECTION	MEAN DEFLECTION	STANDARD DEVIATION DEFLECTION
1	0.916	0.292
2	0.823	0.146
3	0.903	0.241
4	0.832	0.194
5	0.741	0.127
6	0.865	0.210
7	0.977	0.217
8	0.989	0.219
9	1.023	0.310
10	0.893	0.203
11	0.818	0.141

TABLE 4.3 RESULTS OF STUDENT- T ANALYSIS USED FOR COMPARING SUBGROUPS.

SECTION	Vs SECTION	PASS/FAIL
1	2	FAIL
2	3	FAIL
3	4	PASS
4	5	FAIL
5	6	FAIL
6	7	FAIL
7	8	PASS
8	9	PASS
9	10	FAIL
10	11	FAIL

TABLE 4.4. FINAL DESIGN SUB-SECTIONS

DESIGN SUB-SECTIONS	LENGTH (Km)	DEFLECTION MEAN	DEFLECTION STANDARD DEVIATION
1	0-2.3	0.916	0.292
2	2.3-8.0	0.823	0.146
3	8.0-16.1	0.809	0.132
4	16.1-19.1	0.741	0.127
5	19.1-27.6	0.865	0.210
6	27.6-44.5	0.997	0.227
7	44.5-51.2	0.893	0.203
8	51.2-55.0	0.818	0.141

each subsection, the design deflection is obtained and also treated as an individual problem.

Fig. 4.1 shows the steps for selecting design sections. Table 4.4 indicates the final design sub-sections.

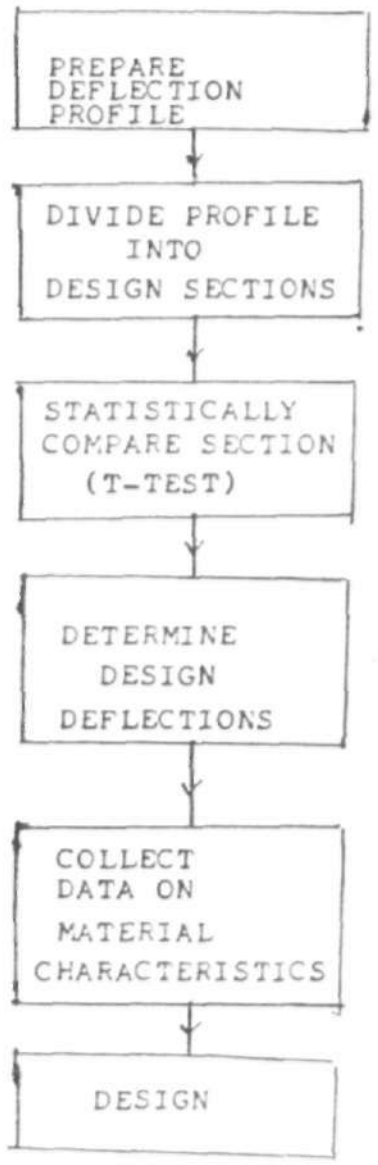


FIG.4.1 PROCEDURE FOR SELECTION OF DESIGN SECTIONS

4.3.2 Condition Survey Factor

The pavement surface condition survey performed includes each of the distresses used as design criteria (cracking, deformation and disintegration). Cracking is classified using AASHTO severity method. Rut depth measurements in the wheel path give an estimate of the level-up thickness required on the existing surface prior to overlay.

The following procedure is used for computing the composite condition survey rating scores (CCSRS).

(1) For alligator cracking, the total extend ratings in each severity class are added together over all sample sections.

(2) For surface separations, potholes, patches, and drop off categories, the total extent ratings in each severity class are added together over all sample sections.

(3) For rut depth, the rut depth readings over all the sample sections are averaged.

(4) For edge cracking, revelling, bleeding and base shear, the total extent ratings in each severity class are added together over all sample sections.

In computing the composite condition survey rating score, the ratings for each sample section are considered separately. Appendix H presents the deduct values to be assigned to each distress category, severity level and extent rating. The appendix is used by locating the deduct value for each extent rating assigned to the distress severity level. For example, if a section has class III alligator cracking rated as 3, then from Appendix H, the assigned deduct value is 13. The deduct values for all distresses are obtained in the same manner. These values are added together to compute the total deduct points for the sample section.

The composite condition rating score is computed as:

$$CCRSi = 100 - DP_i \quad \ldots \quad \ldots \quad 4.1$$

where

CCRSi = Composite condition rating score for sample section i, and

DP_i = Total deduct points for sample section i.

Table 4.5 gives the summary of the condition survey results. The results are used in conjunction with deflection measurement and roughness measurement results for dividing the road into reasonable homogenous sections.

4.3.3 Roughness Testing Factor

Pavement roughness can be considered as the distortions and variations of the road surface.

In this work, the device used for roughness measurements is Maysmeter. The values from the Maysmeter are converted to quarter - Car Index, QI, which is the standard roughness scale used in the world Bank's model for the prioritization of highway maintenance and rehabilitation in developing countries.

The QI values for each section are calculated from empirical relationship developed by Elkins and Hudson (1984), which are given in this work as equations 4.2a to 4.2c.

$$QI = 8.454 + 0.0703(mc) \quad \text{(For Maysmeter speed of 30kph).} \quad \text{4.2a}$$

$$QI = 3.666 + 0.0881\,(Mc) \quad \text{(for Maysmeter speed of 50kph)} \quad \text{4.2b}$$

$$QI = 3.517 + 0.0902\,(Mc) \quad \text{(for Maysmeter speed of 80kph)} \quad \text{4.2c}$$

where

QI = Quarter - car Index

M_c = Maysmeter reading on the field

The summary of the roughness values is presented in table 4.6. The results are used for dividing the roads into reasonable sections.

4.3.4 Traffic Data

Traffic information is required for the design procedure in terms of 8,200kg ESAL. The procedure for obtaining traffic information is enumerated in section 4.5. Traffic prior to overlay design (equation 3.16) is determined for use in remaining life analysis. The future traffic (equation 3.19) is determined also. Directional and lane distribution factors are applied.

4.3.4 Material Characterisation

Materials characterisation such as field CBR and asphalt concrete dynamic indirect tensile test results were obtained from Pavement Evaluation Unit (P.E.U) Kaduna. These results are used for calculating elastic moduli of the pavement structure using basin matching (equation 3.10 to 3.12).

The basin matching is actually meant for calculating the deflection basin that will match

the measured deflection on the field. A computer program called DYNFIT (written by PEU) is used in undertaking this task.

The results from the basin matching with the structure poisson ratio are then used as input into a computer program titled LAYER 5 for calculation of vertical compressive strain on top of the subgrade (e_z) and horizontal tensile strain (e_o) at the bottom of the pavement. The program is actually based on equations 3.5 to 3.19. The computations are done for a range of overlay thicknesses.

The values of e_o and e_z are, then used for obtaining allowable 8,200kg ESAL applications in equations 3.5 and 3.15.

4.3.5 Overlay Thickness Selection

A plot of overlay thickness (range of overlay thicknesses chosen above i.e. 50mm, 100mm, 150mm and 200mm) versus corresponding allowable traffic obtained above (i.e. equation 3.5) is made for each sub section. Appendix A1-A7 give an illustration.

The design traffic (values obtained from equation 3.19) is then entered into the figures mentioned above projected vertically to the curve and then horizontally to the overlay thickness curve. The thickness obtained is selected as the overlay design thickness. The identical strategy from each section are then combined using weighted average in order to obtain a uniform thickness throughout the whole length of the road.

4.4 METHODOLOGY ADOPTED FOR TRAFFIC ESTIMATES

In obtaining overlay thickness, information on traffic estimates are required. In undertaking the study, two traffic estimates are made. They are:-

(1) The total past traffic that have used the pavement since last overlay up to the beginning of the analysis period.

(2) The future traffic which is going to use the highway over the design period.

These two estimates (equations 3.16 and 3.19) require input from the following factors.

(a) The present average daily traffic
(b) Growth factor
(c) Lane distribution factor
(d) Directional distribution factor
(e) The conversion factor to ESAL known as average 8,200kg single axle load equivalent factor

(f) Percent truck.

These factors are briefly reviewed as follows:

4.4.1 Present Average Daily Traffic (ADT_p)

The ADT_p is obtained on the field using mechanical counter or counting carried out manually. Then the total vehicular flow obtained over a range of period is divided by the period to obtain ADT_p.

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4.4.2 Growth Factor:

The growth factor is given as $(1+R)^n$. In order to obtain the total future growth factor, the growth factor is integrated with respect to time and multiplied by 365 (number of days in a year.), according to Hudson (1984). Thus

future growth factor (FTG) = $((1+R)^n - 1)/In\ (1+R)$

where

R,n, In are as defined previously.

The total past growth factor is obtained by dividing FTG by growth factor $(1+R)^n$ in order to back calculate the past traffic.

4.4.3 Lane and Directional Distribution Factors.

Both the total past traffic and future traffic are distributed using lane and directional

distribution factors.

In the study, the two lanes of the (Kaduna-Abgja road) are assumed to have equal number of vehicular flow. Therefore, the lane distribution factor is taken as 0.5. From the literatures including Elkins and Hudson (1984) the directional distribution factor varies from 0.8 to 1.0. For the purpose of this study, directional distribution factor is taken as 1.

4.4.4 Average 8,200kg single axle load equivalence factor.

This is used for converting the traffic estimates (past and future) to 8,200kg equivalent single axle load applications. The procedure for obtaining Average ESAL factor is as follows:

(a) The vehicle axle loads are weighed on the field (in kg).

(b) The weighed axle loads are divided by 8,200kg for mini buses, tippers etc

(c) The weighed axles loads are divided by 14,500kg for trailers, Luxurious bus etc.

(d) The average 8,200kg single axles loads equivalent factor is determined by summing the equivalence factor for all axles and dividing by the total number of trucks weighed as given in equation 2.6.

The equivalency factor is simply a convenient means for indexing the wide spectrum of actual axle loads to a selected value. The selected value for this study is 8,200kg equivalent single axle load.

After obtaining these parameters they are used as input into equations 3.16 and 3.19 for obtaining past traffic and future traffic.

CHAPTER 5

ANALYSIS AND DISCUSSION OF RESULTS

5.0 PREAMBLE

As discussed in chapter 4, this work has two main components namely:

(a) Overlay thickness design

(b) Economic appraisal of the overlay design strategies.

This chapter highlights the results obtained from these two components.

The strategies are obtained by designing overlay thickness corresponding to life spans of up to 20 years in incremental steps of 2 years. Therefore a total number of 10 alternatives are involved. The detailed appraisal of these overlay strategies were carried out. The first strategy has a life span of two years. Therefore a total number of ten overlays are required within the analysis period, while the last strategy has a life span of twenty years, as a result only one overlay is required within the analysis period. The other strategies fall in between these two extremes.

Figures 5.1A and 5.1B illustrate strategies 1 and 10 expected performance profiles.

Table 5.1 shows the number of overlays required for each strategy.

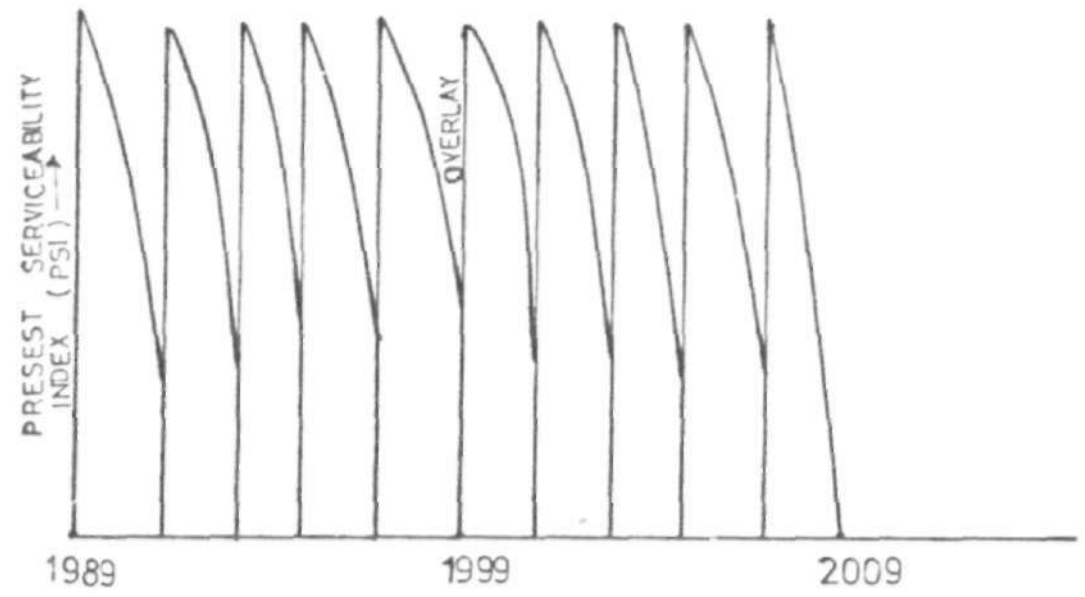


FIG. 5.1A

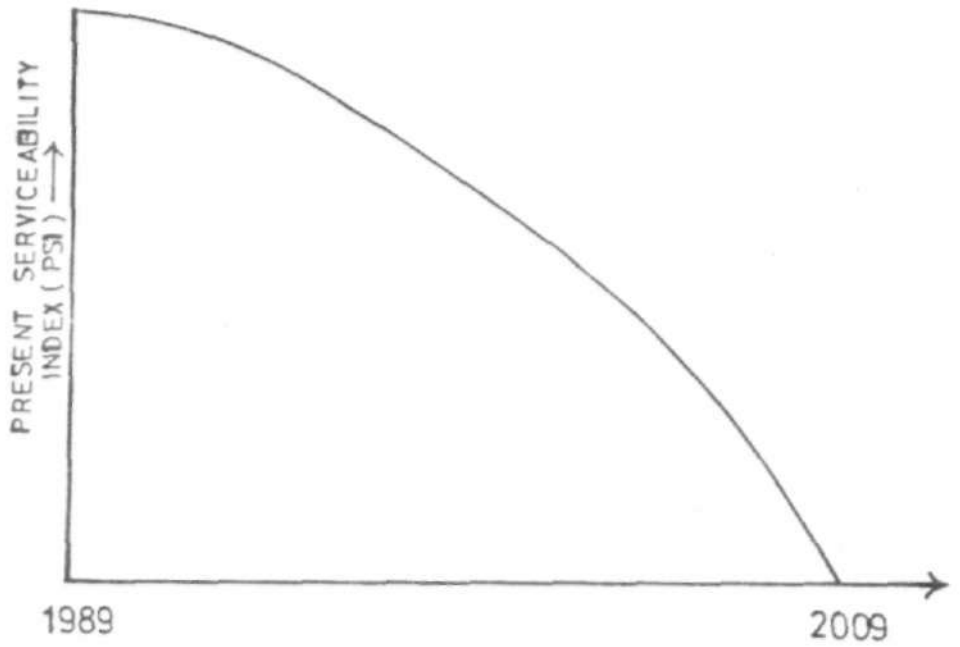


FIG. 5.1B

FIGS. 5.1A and 5.1B. EXPECTED PERFORMANCE PROFILES FOR STRATEGIES 1 AND 10.

TABLE 5.1 NUMBERS OF OVERLAYS REQUIRED FOR EACH STRATEGY AND THEIR YEARS OF CONSTRUCTION.

DESIGN STRATEGY	NO OF OVERLAYS REQUIRED	YEARS OF OVERLAY CONSTRUCTION
1	10	0, 2, 4, 6, 8, 10 12, 14, 16, 18
2	5	0, 4, 8, 12, 16
3	4	0, 6, 12, 18
4	3	0, 8, 16
5	2	0, 10
6	2	0, 12
7	2	0, 14
8	2	0, 16
9	2	0, 18
10	1	0

NB 0-YEAR IS THE YEAR OF INITIAL OVERLAY CONSTRUCTION FOR EACH STRATEGY.

5.1 OVERLAY DESIGN RESULTS

The results under this section consist of the following:-

(a) Deflection, roughness and condition survey results

(b) Basin matching results

(c) Traffic estimate results

(d) Overlay thickness design results

5.1.1 Deflection, roughness and Condition Survey results

These results are presented in tables 4.1 to 4.6.

The results show that section 6 has the highest mean deflection value while section 3 has the lowest value. Sections 2 and 8 have almost the same value. Also the roughness measurement result indicate that section 1 has the highest value of 51.90 while section 8 has the lowest value of 17.40 followed by section 2 with value of 17.80. The condition survey result show that section 2 is the best with the highest value of 83.6% followed by section 8 with value of 81.6% while section 6 has the least value of 62.5%. These results confirm that the best section is section 2.

TABLE 5.2: DESIGN SECTION MODELS MODULUS OF ELASTICITY (MP_a) FROM BASIN MATCHIN

SECTION	OVERLAY	SURFACE	BASE	SUB-BASE	SUB-GRADE
1	2.76	0.48	0.34	0.24	0.21
2	2.76	1.25	0.34	0.24	0.23
3	2.76	1.39	0.28	0.21	0.20
4	2.76	0.72	0.31	0.25	0.24
5	2.76	0.91	0.34	0.25	0.18
6	2.76	0.94	0.32	0.19	0.14
7	2.76	1.72	0.34	0.21	0.14
8	2.76	1.30	0.31	0.24	0.21
POISSON RATIO					
	0.35	0.35	0.30	0.35	0.40

5.1.2 Basin Matching Results

The basing matching result is presented in table 5.2. This result confirm that section 2 is the strongest with high values of asphalt modulus of elasticity, base modulus of elasticity, sub-base modulus of elasticity and sub-grade modulus of elasticity. While section 6 is the worst section with high value of asphalt modulus of elasticity and low values of base, sub-base and sub-grade modulus of elasticity. The other sections fall in between these two extremes.

5.1.3 Traffic Estimates Results

Traffic estimates in terms of 8200kg Equivalent single Axle load are presented in tables 5.3 to 5.5.

The number of equivalent single axle load applications increase with the design period. A growth rate of 3% is used even though the vehicle growth rate in the country at present is most probably smaller. The growth rate of 3 is used in order not to under design.

LEGEND TO TABLES 5.3 and 5.4

VEHICLE CLASS	VEHICLE CATEGORY
CLASS 1	
CLASS 2	
CLASS 3	
CLASS 4	
CLASS 5	
CLASS 6	
CLASS 7	
CLASS 8	

TABLE 5.3: AVERAGE TRAFFIC EQUIVALENCE FACTOR

$$(FAvg) = \sum_{j=1}^{NA} (1.02\ (L_j/L_s)^{3.8})/N_T$$

DIRECTION OF TRAVEL = KAD - ABUJA

VEHICLE CATEGORY	AVERAGE EQUIVALENCE FACTOR	NUMBER OF TRUCKS	STANDARD DEVIATION	MAXIMUM INDIVIDUAL FACTOR.
CLASS 2	0.00	0.00	0.00	0.00
CLASS 3	0.19	9.0	0.37	1.15
CLASS 4	0.00	0.0	0.00	0.00
CLASS 5	0.00	0.0	0.00	0.00
CLASS 6	6.27	17.0	5.76	15.57
CLASS 7	0.68	2.0	0.31	0.90
CLASS 8	0.00	0.0	0.00	0.00
OTHERS	0.00	0.0	0.00	0.00
OVERALL	3.91	2.8	5.35	15.57

TABLE 5.4 AVERAGE TRAFFIC EQUIVALENCE FACTOR

(FAvg)

$$= \sum_{j=1}^{NA} \left(1.02\ (L_j/L_s)^{3.8}\right)/N_T$$

DIRECTION OF TRAVEL = ABJ - KAD

VEHICLE CATEGORY	AVERAGE EQUIVALENCE FACTOR	NUMBER OF TRUCKS	STANDARD DEVIATION	MAXIMUM INDIVIDUAL FACTOR.
CLASS 2	0.00	0.00	0.00	0.00
CLASS 3	1.30	16.00	1.73	6.36
CLASS 4	0.00	0.00	0.00	0.00
CLASS 5	0.00	0.00	0.00	0.00
CLASS 6	11.38	6.00	15.37	41.15
CLASS 7	0.00	0.00	0.00	0.00
CLASS 8	0.00	0.00	0.00	0.00
OTHERS	0.00	0.00	0.00	0.00
OVERALL	4.11	22.00	8.90	41.15

LEGEND TO TABLE 5.5

A = DESIGN PERIOD n (yrs.)

B = GROWTH RATE i (%).

C = FUTURE GROWTH FACTOR $(1+i)^n$

D = FUTURE TOTAL GROWTH FACTOR $365\left((1+R)^n-1\right)/1_n(R+1)$

E = ACCUMULATED FUTURE TRAFFIC 365 ADT $(1+p)^n$

F = TOTAL NO OF TRUCKS EXPECTED OVER DESIGN PERIOD IN BOTH DIRECTIONS, Q_t = COL 4 x ADT x P_t

G = TOTAL NO OF TRUCKS IN DESIGN LANE, Qd =

Qt x DD x LD

H = DESIGN NO OF 8200kg ESAL APPLICATIONS

$W_{8.2}$ = Qd x F_{AVg}

PAST GROWTH FACTOR $\dfrac{365 \quad (1+i)^n-1}{1_n \ (R+1) \ (1+R)^n}$ = 1377

PAST NO OF ESAL (N_p) = 1377 x ADT x F_{AVG} x DD x LD x P_t

= 1,238105.

TABLE 5.5. TRAFFIC ESTIMATE SUMMARY SHEET

A	B	C	D	E	F	G	H
1	2	3	4	5	6	7	8
2	3	1.061	752	853839	329978	164989	676455
4	3	1.126	1550	905838	680052	340026	1394107
5	3	1.159	1967	933013	863004	431502	1769158
6	3	1.194	2396	961003	1051445	525723	2155462
8	3	1.267	3294	1019528	1445456	722728	2963185
10	3	1.344	4247	1081618	1863462	931731	3820097
12	3	1.426	5257	1147448	2306925	1153463	4729196
14	3	1.513	6330	1217370	2777395	1388698	5693660
15	3	1.558	6890	1253891	3023267	1511634	6197698
16	3	1.605	7467	1291508	3276516	1638258	6716858
18	3	1.702	8674	1370161	3806034	1903017	7802370
20	3	1.806	9954	1453603	4367794	2183897	8953978

DD = Directional Distribution Factor= 1; LD= Lane Distribution Factor = 0.5;
F_{Avg}= Average 8,200kg ESALFactor Per Truck = 4.11 (see TABLE 5.4) ADT = 2205 Vehicles.

5.1.4 Overlay Thickness Design Results

The overlay design thickness results are summarised in table 5.6, while computer layer 5 results are summarised in table 5.7 and the programme presented in appendix E. The results show that the strongest section is section two with highest remaining fatigue life (93.4%). Also most of the strategies for this section give low overlay thickness values (i.e. below the upper boundary or 200mm). The next section that gives reasonable results is section 8 followed by sections 4, 5 and 3 with the remaining fatigue lives of 90%, 87%, 81% and 75% respectively. The results indicate that the worst section is section six with negative remaining fatigue life and as a result it needs total reconstruction. The other sections fall within these two extremes. Infact, sections 1 and 7 may be considered for total reconstruction as the overlay thickness obtained for most of the strategies for these sections are above 200mm. Besides, it is more economical to do total reconstruction than to apply overlay thickness above 200mm. Also it might not be necessary to apply overlay to sections two and eight because of their high values of remaining fatigue lives, condition survey results and low roughness values.

TABLE 5.6: Summary of Overlay Design thickness

SECTION	1	2	3	4	5	6	7	8	WEIGHTED AVERAGE	DP
LENGTH (km)	2.3	5.7	8.1	3.0	8.5	16.9	5.7	3.8	(mm)	
	115	50	85	50	50		88	50	68	2
	145	50	94	56	83		125	50	86	4
	175	55	118	83	100		150	81	107	6
	192	75	137	96	118		167	94	125	8
	202	87	146	106	131		179	100	135	10
	215	94	160	115	140		192	115	147	12
	231	106	169	125	150		206	119	157	14
	240	115	183	133	163		217	133	169	16
	242	125	188	138	171		225	137	176	18
	250	135	200	146	188		239	150	188	20

•DP = DESIGN PERIOD (YR)

TABLE 5.7.SUMMARY OF COMPUTER LAYER 5 RESULTS

SECTION	AVERAGE PAVEMENT THICKNESS ABOVE SUB-GRADE (mm)	VERTICAL STRESS DUE TO WHEEL LOAD (P_a)	FATIGUE REMAINING LIFE %
1	315.47	119.08	43.33
2	474.98	64.47	93.38
3	406.65	86.33	74.99
4	393.45	101.29	86.59
5	406.91	77.02	80.58
6	331.22	100.67	- 9.34
7	432.82	67.71	63.74
8	463.30	66.47	89.64

For the purpose of this study the overlay thicknesses obtained from the design curves (Appendix A) are used directly in obtaining the total costs in order to make a reasonable comparison among the alternatives.

The results indicate that the thicker the pavement structure the lower the vertical stress due to wheel load as expected.

5.2 ECONOMIC APPRAISAL OF THE STRATEGIES

The economic appraisal is based on the sensitivity analysis of some total cost components namely:-

(a) Maintenance cost

(b) Discount rate

(c) Delay costs during period of overlay construction

(d) Labour, Engineering and Administrative costs.

The influence of these components on the total costs versus design period or alternative strategies indicate the same general pattern. Typical results are presented in Figs. 5.2 to 5.6.

TABLE 5.8. TYPICAL SENSITIVITY VALUES USED FOR ANALYSES.

NOTATIONS	% Used for Labour cost (Lc) Administrative cost (Ac) and Engineering costs (Ec) %	Values of P in Maintenance cost ₦-mm/yr	Value of X in Delay cost ₦/km-mm-yr	Discount Rate (R) %	Inflation Rate (i_f) %
1	25	190,000	60	10	5, 10, 20
2	40	376,000	120	20	10, 20, 40
3	60	400,000	200	30	15, 30, 60
4	80	800,000	400	-	-

From the results, the total costs generally decreases with the design period. This clearly indicates that the higher the number of overlays applied the higher the total costs and vice-versa. Alternative 1 which has the highest number of overlays (10 nos) has the highest total costs per km while the reverse is the case for strategy 10 which has the fewest number of repeated overlays during the entire analysis period.

The effect of analysis period on total costs is definitely more pronounced for strategies involving short design periods. For example, the difference between the total costs of alternatives 1 and 2 which have design periods of 2 and 4 years respectively is about 76%, while the difference between the total costs of alternatives 7 and 8 which have design periods of 14 and 16 years is about 7%. This relative difference reduces as one moves from strategy 1 to strategy 10 irrespective of the sensitivity analysis undertaken for the various components of the total costs.

From the graphical presentation of total costs versus design period, as presented in figures 5.2 to 5.6, the total costs for strategies 8, 9 and 10 are almost the same.

The effect of the different components of the total costs are briefly discussed in the subsequent sections. Summaries of the different components of the total costs are given in Tables 5.9 to 5.13, for the various cases considered.

5.2.1 Maintenance costs

Maintenance costs have appreciable effect on the total costs as can be seen in figure 5.2 and tables 5.9A to 5.9D.

Although the effect of maintenance costs on the total costs versus design period gives the same pattern, but decreasing the value of maintenance cost constant, P to ₦190,000-mm/yr reduces the total costs by about 18% while increasing the value to ₦800,000-mm/yr increases the total costs by about 35%. As expected, the higher the amount of maintenance costs the higher the total costs. Another important trend noticeable in the results is that the maintenance costs decreases as the number of overlays applied during the analysis period reduces. This is however reasonable in that fewer overlays imply thicker thickness of initial overlay. The implication then is that the thinner the initial overlay (and of course subsequent ones), the higher the maintenance costs required.

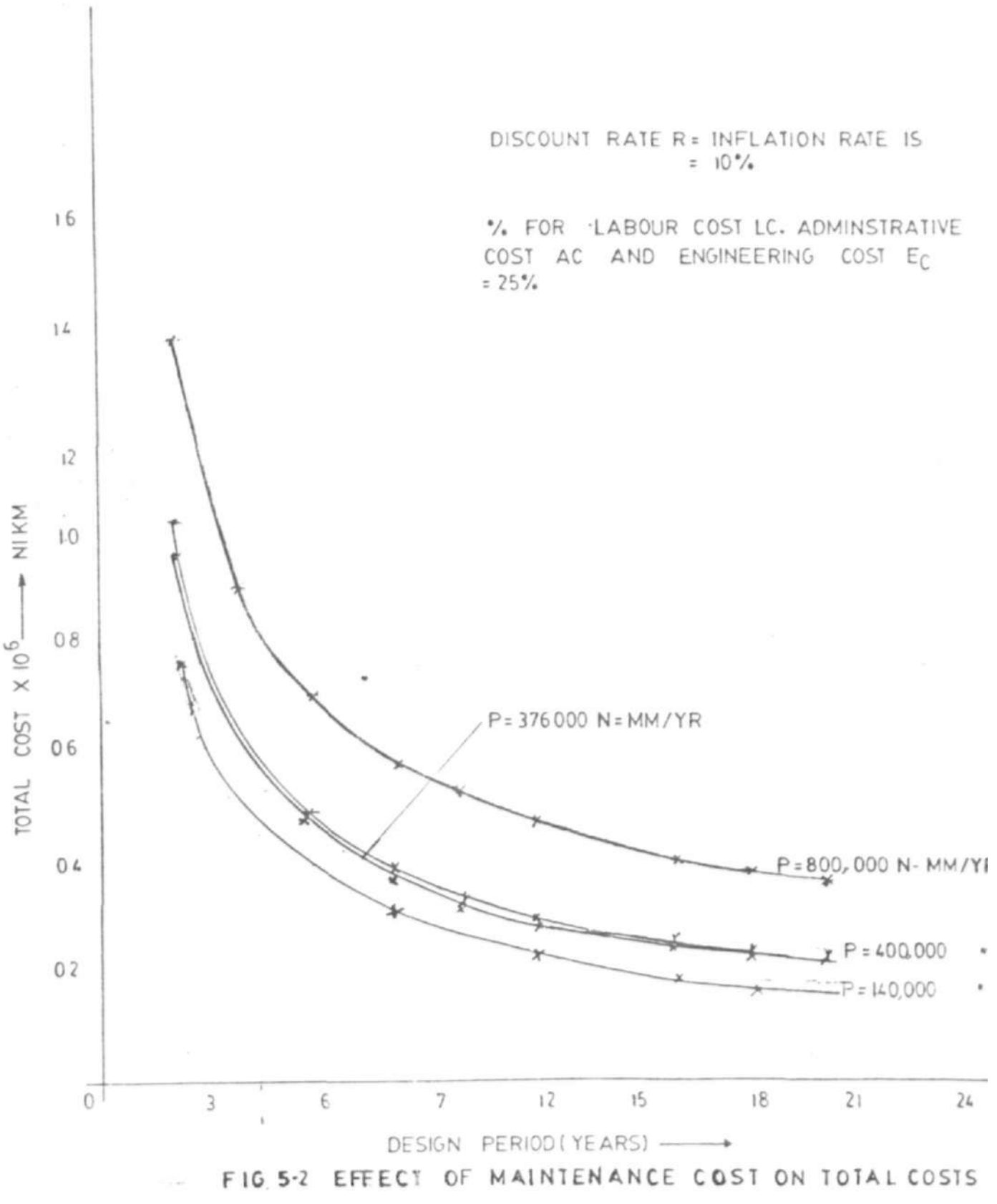


FIG 5-2 EFFECT OF MAINTENANCE COST ON TOTAL COSTS

TABLE 5.9A SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	63,416.96	570,752.64	160,033.30	9,637.80	-	803,840.70
	RELATIVE %	7.89	71.13	19.90	1.19	-	100.00
2	ACTUAL COST	72,290.44	28,9161.76	126,537.70	5,415.76	-	493,405.66
	RELATIVE %	14.65	58.61	25.65	1.20	-	100.00
3	ACTUAL COST	82,642.91	247,928.73	101,703.25	6,066.41	55095.55	383,245.75
	RELATIVE %	21.56	64.69	26.54	1.58	14.38	100.00
4	ACTUAL COST	91,516.50	183,033.06	87,058.03	4,724.41	45758.25	320573.72
	RELATIVE %	28.55	57.10	27.16	1.47	14.27	100.00
5	ACTUAL COST	96,446.26	96,446.26	80,609.44	2,125.98	-	275,627.94
	RELATIVE %	34.99	34.99	29.25	0.77	-	100.00
6	ACTUAL COST	102,361.92	102,361.92	74029.11	2,777.95	34,115.22	247 410.61
	RELATIVE %	41.37	41.37	29.92	1.12	13.79	100.00
7	ACTUAL COST	107,258.86	107,258.86	69313.65	3461.43	61,290.78	226002.02
	RELATIVE %	47.46	47.46	30.67	1.53	27.12	100.00
8	ACTUAL COST	113,207.42	113,207.42	64392.02	4258.27	84,905.54	210159.55
	RELATIVE %	53.87	53.87	30.64	2.03	40.4	100.00
9	ACTUAL COST	116,658.22	116,658.22	62862.20	4,988.98	103694.18	197471.44
	RELATIVE %	59.09	58.08	31.83	2.53	52.51	100.00
10	ACTUAL COST	122,573.96	-	57884.43	-	-	180458.39
	RELATIVE %	67.92	-	32.08	-	-	100.00

P = N190,000 X = N60 R = 10% % FOR Ac, Ec, Lc = 25% $i_{f=10\%}$

TABLE 5.9B SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	63,416.96	570,752.64	316697.06	9637.80	-	1023,921.44
	RELATIVE %	6.19	55.74	30.93	0.94	-	100.00
2	ACTUAL COST	72,290.44	28,9161.76	250411.52	5,415.76	-	617279.50
	RELATIVE %	11.71	46.84	40.57	0.88	-	100.00
3	ACTUAL COST	82,642.91	247,928.73	201265.56	6,066.41	55095.55	482808.06
	RELATIVE %	17.12	51.35	41.69	1.26	11.41	100.00
4	ACTUAL COST	91,516.50	183,033.06	172283.27	4724.41	45758.25	405798.94
	RELATIVE %	22.55	45.10	42.46	1.16	11.28	100.00
5	ACTUAL COST	96,446.26	96,446.26	159521.81	2,125.98	-	354540.31
	RELATIVE %	27.20	27.20	44.99	0.60	-	100.00
6	ACTUAL COST	102,361.92	102,361.92	146499.15	2,777.96	34,115.22	319880.69
	RELATIVE %	32.00	32.0	45.80	0.87	10.66	100.00
7	ACTUAL COST	107,258.86	107,258.86	137167.94	3461.43	61,290.78	293862.31
	RELATIVE %	36.50	36.50	46.68	1.18	20.86	100.00
8	ACTUAL COST	113,207.42	113,207.42	127478.34	4258.27	84,905.54	273195.81
	RELATIVE %	41.44	41.44	46.66	1.56	31.08	100.00
9	ACTUAL COST	116,658.22	116,658.22	120360.06	4,988.98	103694.18	256969.30
	RELATIVE %	45.40	45.40	46.84	1.94	40.35	100.00
10	ACTUAL COST	122,573.96	-	114550.06	-	-	237124.03
	RELATIVE %	51.69	-	48.30	-	-	100.00

P = N376,000 Y = N60 R = 10% % FOR Ac, Ec, Lc = 25% i=10%

TABLE 5.9C SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	63416.96	570752.64	336911.72	9637.80	-	1044136.13
	RELATIVE %	6.07	54.66	32.27	0.92		100.00
2	ACTUAL COST	72290.44	289161.76	266395.28	5415.76	-	633263.25
	RELATIVE %	11.42	45.66	42.07	0.86	-	100.00
3	ACTUAL COST	82642.91	247928.73	214112.34	6066.41	55095.55	495654.84
	RELATIVE %	16.67	50.02	43.20	1.22	11.12	100.00
4	ACTUAL COST	91515.50	183033.06	183280.08	4724.41	45758.25	416795.79
	RELATIVE %	21.96	43.91	43.94	1.13	10.98	100.00
5	ACTUAL COST	96446.26	96446.26	169703.59	2125.98	-	364727.09
	RELATIVE %	26.44	26.44	46.53	0.58	-	100.00
6	ACTUAL COST	102361.92	102361.92	155850.45	2777.96	34115.22	329232.00
	RELATIVE %	31.09	31.09	47.34	0.84	10.36	100.00
7	ACTUAL COST	107258.86	107258.86	145923.58	3461.43	61290.78	302611.94
	RELATIVE %	35.44	35.44	48.22	1.14	20.25	100.00
8	ACTUAL COST	113207.42	113207.42	135561.95	4258.27	84905.54	281329.50
	RELATIVE %	40.24	40.24	48.19	1.51	30.18	100.00
9	ACTUAL COST	116658.22	116658.22	130170.66	4,988.98	103694.18	264779.91
	RELATIVE %	44.06	44.06	49.16	1.88	39.16	100.00
10	ACTUAL COST	122573.96	-	121861.76	-	-	244435.73
	RELATIVE %	50.15		49.85			100.00

P = N400,000 [illegible]

TABLE 5.9D SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	63416.96	570752.64	673824.00	9637.80	-	1318043.30
	RELATIVE %	4.59	41.33	48.79	0.70	-	100.00
2	ACTUAL COST	72290.44	289161.76	532791.13	5415.76	-	899659.17
	RELATIVE %	8.04	32.14	59.22	0.60		100.00
3	ACTUAL COST	82642.91	247928.73	428224.69	6066.41	55095.55	709767.19
	RELATIVE %	11.64	34.93	60.33	0.85	7.76	100.00
4	ACTUAL COST	91516.50	183033.06	366560.16	4724.41	45758.25	600075.88
	RELATIVE %	15.25	30.50	61.08	0.79	7.63	100.00
5	ACTUAL COST	96446.26	96446.26	339407.75	2125.98	-	534426.25
	RELATIVE %	18.05	18.05	63.5	0.40	-	100.00
6	ACTUAL COST	102361.92	102361.92	311700.97	2777.96	34115.22	485092.47
	RELATIVE %	21.10	21.10	64.26	0.57	7.03	100.00
7	ACTUAL COST	107258.86	107258.86	291847.16	3461.43	61290.78	448535.53
	RELATIVE %	23.91	23.91	65.07	0.77	13.66	100.00
8	ACTUAL COST	113207.42	113207.42	271123.93	4258.21	84905.54	416891.44
	RELATIVE %	27.16	27.16	65.03	1.02	20.37	100.00
9	ACTUAL COST	116658.22	116658.22	260340.75	4988.98	103694.18	394950.00
	RELATIVE %	29.54	29.54	65.92	1.26	26.26	100.00
10	ACTUAL COST	122573.96	-	243723.52	-	-	366297.50
	RELATIVE %	33.46	-	66.34	-	-	100.00

P = N800,000 X = N60 R = 10% % FOR Ac, Ec, Lc = 25% i_f = 10%

5.2.2 Discount Rate

Discount rate is used for discounting future expenditures to present day value. The effect of discount rate on total costs is highlighted in Fig. 5.3. The higher the discount rate the lower the total costs. For example decreasing the discount rate from 20% to 10% will increase the total costs by about 75% while increasing the value to 30% will decrease the total costs by about 28%. Tables 5.10A to 5.10C shows the effect of the discount rate on total costs.

5,2.3 Delay costs during overlay

The effect of delay costs on total costs is illustrated in fig. 5.4. The computations for this effect are shown in tables 5.11A to 5.11D.

From the results, the delay costs have rather minimal effects on the total costs. For example, increasing the value of the constant x in delay cost equation 3.4 from ₦60/mm-yr to ₦400/mm-yr increases the total costs by just about 3%. Indications from the results presented seem to confirm that delay cost increases with the frequency of overlays as well as the thickness of overlay involved in each construction.

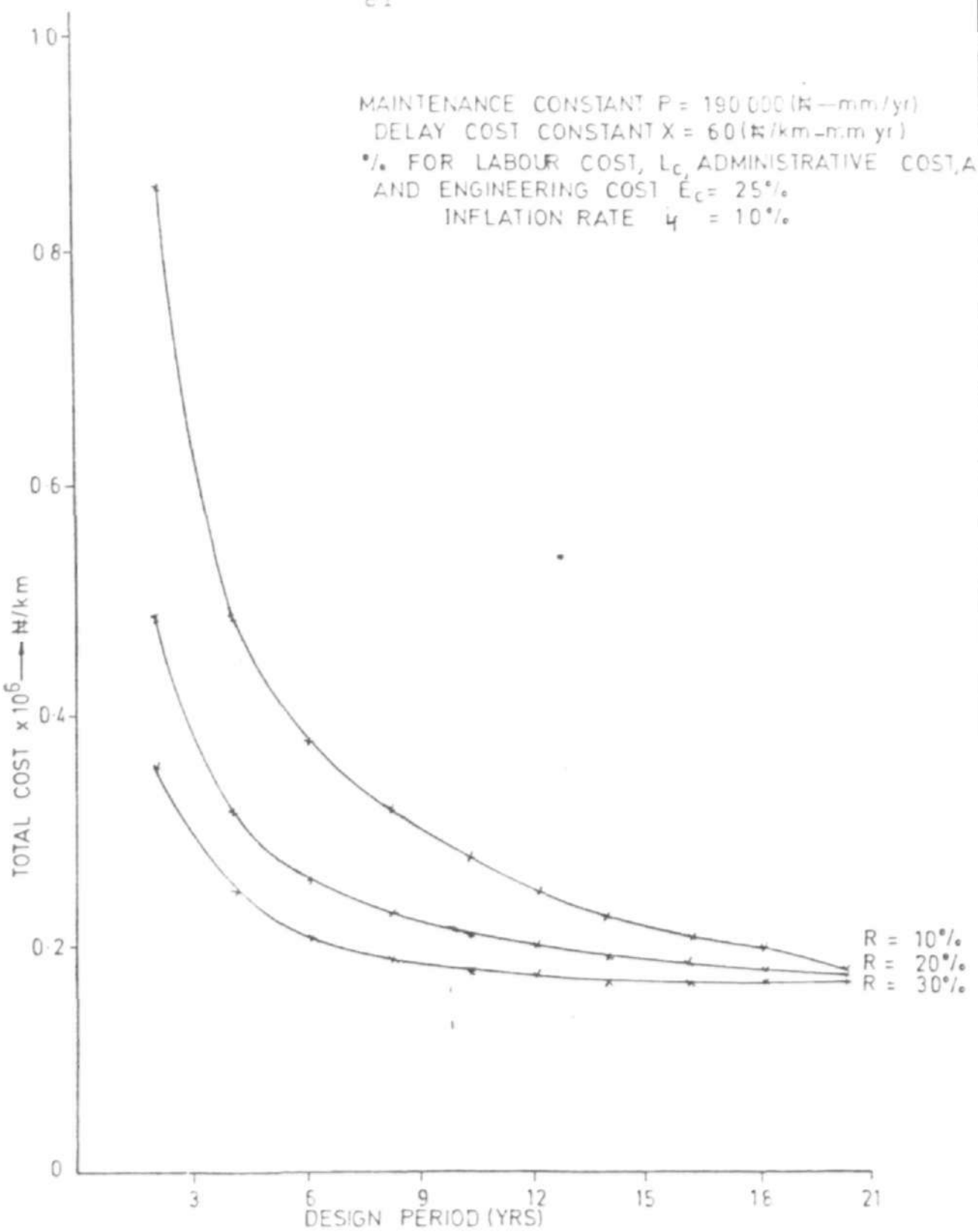


FIG. 5.3 EFFECT OF DISCOUNT RATE ON TOTAL COSTS.

TABLE 5.10A SUMMARYU OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
	ACTUAL COST	63416.96	570752.64	160033.30	9337.80	-	803540.70
1	RELATIVE %	7.89	71.00	19.91	1.20		100.00
	ACTUAL COST	72,290.44	289161.76	12[illegible]37.70	5415.76	-	403405.66
2	RELATIVE %	14.65	58.60	[illegible]5.65	01.10	-	100.00
	ACTUAL COST	82642.91	247928.73	101703.25	6066.41	55095.55	383245.75
3	RELATIVE %	21.56	64.69	26.54	01.58	14.37	100.00
	ACTUAL COST	91516.50	183,033.06	87058.03	4724.41	45758.25	320573.72
4	RELATIVE %	28.55	57.10	27.16	01.47	14.28	100.00
	ACTUAL COST	96446.25	96446.25	80669.44	2125.98	-	275627.94
5	RELATIVE %	34.99	34.99	29.25	00.77	-	100.00
	ACTUAL COST	102361.92	102361.92	74029.11	2777.96	34115.22	247410.61
6	RELATIVE %	41.37	41.37	29.92	01.12	13.79	100.00
	ACTUAL COST	107258.86	107258.86	69313.65	3461.43	61290.78	226002.02
7	RELATIVE %	47.46	47.46	30.67	01.53	27.12	100.00
	ACTUAL COST	113207.42	113207.42	64382.02	4258.27	84905.54	210159.55
8	RELATIVE %	53.87	53.87	30.64	02.02	40.40	100.00
	ACTUAL COST	116658.22	116658.22	62862.20	4988.08	103694.18	197471.44
9	RELATIVE %	59.08	59.08	31.83	02.53	52.52	100.00
	ACTUAL COST	122573.96	-	57884.43	-	-	180458.39
10	RELATIVE %	67.92	-	32.08	-	-	100.00

P = N190,000 X = N60 R = 10% % FOR Ac, Ec, Lc = 25% $i_{f=10\%}$

TABLE 5.10B SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	63,416.96	277,198.54	146697.17	3463.42	-	490776.09
	RELATIVE %	12.92	56.48	29.89	00.71	-	100.00
2	ACTUAL COST	72,290.44	130,492.93	115,092.88	2033.25	-	320809.50
	RELATIVE %	22.53	40.68	36.16	00.63	-	100.00
3	ACTUAL COST	82,642.91	95,380.13	93227.98	1945.00	9668.05	263527.97
	RELATIVE %	31.36	36.19	35.38	00.74	03.67	100.00
4	ACTUAL COST	91,516.50	68,368.59	79303.20	1567.87	8029.68	233226.48
	RELATIVE %	39.24	29.31	34.22	00.67	03.44	100.00
5	ACTUAL COST	96,446.26	40,401.73	73,391.99	390.58	-	211630.56
	RELATIVE %	44.57	19.09	34.92	00.42	-	100.00
6	ACTUAL COST	102,361.92	36030.96	67,860.02	977.82	5987.45	201243.27
	RELATIVE %	50.86	17.90	33.73	00.49	02.98	100.00
7	ACTUAL COST	107,258.86	31724.39	63,537.52	1023.79	10755.33	192789.23
	RELATIVE %	55.64	16.46	32.96	00.52	05.58	100.00
8	ACTUAL COST	113,207.42	28435.71	59,026.01	1058.32	14899.27	186828.19
	RELATIVE %	60.59	15.22	31.59	00.57	07.97	
9	ACTUAL COST	116,658.22	24,362.47	57,623.68	1042.07	18196.47	181489.59
	RELATIVE %	64.28	13.42	31.75	00.57	10.02	100.00
10	ACTUAL COST	122,573.96	-	53,060.73	-	-	175634.69
	RELATIVE %	69.79	-	30.21	-	-	100.00

P = N190,000 X = N60 R = 20% % FOR Ac, Ec, Lc = 25% $i_{f=10\%}$

TABLE 5.10C SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	63416.06	155095.19	135[illegible]12.78	1566.66	-	[illegible]1.59
	RELATIVE %	17.84	43.63	38.09	00.44	-	100.00
2	ACTUAL COST	72290.44	70784.16	107,[illegible]70.36	930.98	-	[illegible]75.94
	RELATIVE %	28.79	28.19	42.65	00.37	-	100.00
3	ACTUAL COST	82642.91	45550.62	86,[illegible]56.59	793.41	1950.28	[illegible]3093.25
	RELATIVE %	38.78	21.38	40.38	00.37	00.91	100.00
4	ACTUAL COST	91516.50	30368.43	73664.48	631.32	1619.78	194560.95
	RELATIVE %	47.04	15.61	37.86	00.32	00.83	100.00
5	ACTUAL COST	96446.26	18,145.91	68,207.98	399.99	-	183200.14
	RELATIVE %	52.65	09.90	37.23	00.22	-	100.00
6	ACTUAL COST	102361.92	13788.94	6[illegible]640.01	374.21	1207.81	177957.27
	RELATIVE %	57.52	07.75	35.20	00.21	00.68	100.00
7	ACTUAL COST	107258.86	10344.85	5[illegible]650.01	333.84	2169.61	174417.95
	RELATIVE %	61.50	05.93	33.62	00.19	01.24	100.00
8	ACTUAL COST	113207.42	7817.44	54485.54	294.05	3005.54	172798.91
	RELATIVE %	65.51	04.53	31.53	00.17	01.74	100.00
9	ACTUAL COST	116658.22	5767.67	53191.09	246.66	3670.67	172192.97
	RELATIVE %	67.75	03.35	30.89	00.14	02.13	100.00
10	ACTUAL COST	122573.96	-	48979.13	-	-	171553.11
	RELATIVE %	71.45	-	28.55	-	-	100.00

P = N190.000 X = N60 R = 30% % FOR Ac, Ec, Lc = 25% $i_{f=10\%}$

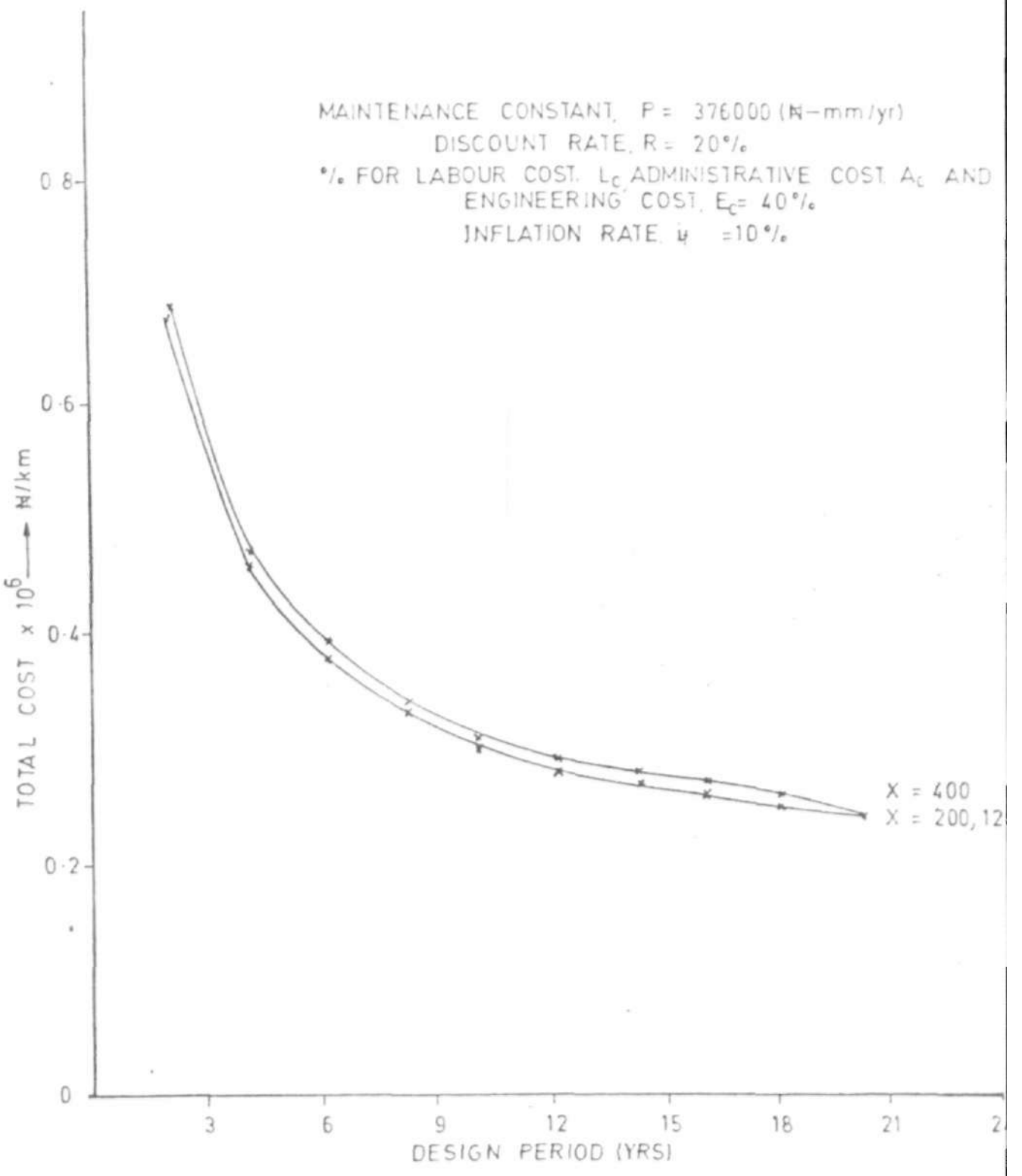


FIG. 5.4 EFFECT OF DELAY COST ON TOTAL COSTS.

TABLE 5.11A SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	71027.00	310462.35	290305.66	3463.42	-	675258.44
	RELATIVE %	10.52	45.96	42.99	0.51	-	100.00
2	ACTUAL COST	80965.29	146152.14	229543.91	2033.25	-	458694.59
	RELATIVE %	17.65	31.86	50.04	0.44	-	100.00
3	ACTUAL COST	92560.06	106825.70	184493.44	1945.00	10828.21	374996.00
	RELATIVE %	24.68	28.49	42.20	0.52	2.89	100.00
4	ACTUAL COST	102498.48	76572.28	157926.31	1567.87	8993.24	329572.22
	RELATIVE %	31.10	23.23	47.92	0.48	2.73	100.00
5	ACTUAL COST	108019.80	45249.94	146928.31	890.58	-	300388.63
	RELATIVE %	35.96	15.06	48.68	0.30	-	100.00
6	ACTUAL COST	114645.34	40354.67	134790.92	977.82	6705.94	283562.81
	RELATIVE %	40.43	14.23	47.36	0.35	2.37	100.00
7	ACTUAL COST	120129.92	35531.32	125737.27	1023.79	12045.97	270376.34
	RELATIVE %	44.43	13.14	46.51	0.38	4.46	100.00
8	ACTUAL COST	126792.31	31512.01	116309.30	1058.32	16687.18	259484.75
	RELATIVE %	48.86	11.66	43.20	0.39	6.17	100.00
9	ACTUAL COST	130657.20	27285.77	112163.40	1041.88	20380.05	250768.20
	RELATIVE %	52.10	10.88	44.73	0.42	8.13	100.00
10	ACTUAL COST	137282.84	-	105004.21	-	-	242287.05
	RELATIVE %	56.66	-	43.34	-	-	100.00

P = N376000 X = N60 R = 20% % FOR Ac, Ec, Lc = 40% i_c=10%

TABLE 5.11B SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
	ACTUAL COST	71027.00	310462.35	290305.66	6926.80	-	678721.81
1	RELATIVE %	10.47	45.74	42.77	1.02	-	100.00
	ACTUAL COST	80965.29	146152.14	229543.91	4066.88	-	460728.22
2	RELATIVE %	17.57	31.72	49.82	0.88	-	100.00
	ACTUAL COST	92569.06	106825.70	184493.44	3890.01	10828.21	376941.00
3	RELATIVE %	24.56	28.34	48.95	1.03	2.87	100.00
	ACTUAL COST	102498.43	76572.28	157925.31	3136.26	8993.24	331140.09
4	RELATIVE %	30.95	23.12	47.69	0.95	2.72	100.00
	ACTUAL COST	108019.80	45249.94	146228.31	1781.17	-	301279.22
5	RELATIVE %	35.85	15.02	48.54	0.59	-	100.00
	ACTUAL COST	114645.34	40354.67	134290.92	1955.67	6705.94	284540.66
6	RELATIVE %	40.29	14.18	47.20	0.69	2.36	100.00
	ACTUAL COST	120129.92	35531.32	125737.27	2047.59	12045.97	271400.13
7	RELATIVE %	44.26	13.09	46.33	0.76	4.44	100.00
	ACTUAL COST	126792.31	31512.01	116809.30	2116.62	16687.18	260543.06
8	RELATIVE %	48.67	12.10	44.83	0.81	6.41	100.00
	ACTUAL COST	130657.20	27285.77	112163.40	2083.76	20380.05	251810.08
9	RELATIVE %	51.89	10.84	44.54	0.83	8.09	100.00
	ACTUAL COST	137282.84	-	105004.21	-	-	242287.05
10	RELATIVE %	56.66	-	43.34	-	-	100.00

P = N376000 X = N120 R = 20% % FOR Ac, Ec, Lc = 40% i_f=10%

TABLE 5.11C SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	71027.00	310462.35	290305.66	11544.68	-	683339.69
	RELATIVE %	10.39	45.43	42.48	01.69	-	100.00
2	ACTUAL COST	80965.29	146152.14	229543.91	6777.88	-	463439.22
	RELATIVE %	17.47	31.54	49.53	01.46	-	100.00
3	ACTUAL COST	92560.06	106825.70	184493.44	6483.35	10828.21	379534.34
	RELATIVE %	24.39	28.15	48.61	01.71	02.85	100.00
4	ACTUAL COST	102498.48	76572.28	157926.31	5226.76	8993.24	333230.59
	RELATIVE %	30.76	22.98	47.39	01.57	02.7	100.00
5	ACTUAL COST	108019.80	45249.94	146228.31	2968.61	-	302466.66
	RELATIVE %	35.71	14.96	48.35	00.98	-	100.00
6	ACTUAL COST	114645.34	40354.67	134290.92	3259.45	6705.94	285844.44
	RELATIVE %	40.11	14.12	46.98	01.14	02.35	100.00
7	ACTUAL COST	120129.92	35531.32	126737.27	2412.68	12045.97	272765.22
	RELATIVE %	44.04	13.03	46.46	00.88	04.41	100.00
8	ACTUAL COST	126792.31	31512.01	116809.30	3527.72	16687.18	261954.16
	RELATIVE %	48.40	12.03	44.59	01.35	06.37	100.00
9	ACTUAL COST	130657.20	27285.77	112163.40	3472.93	20380.05	253199.25
	RELATIVE %	51.60	10.78	44.30	01.37	08.05	100.00
10	ACTUAL COST	137282.85	-	105004.20	-	-	242287.05
	RELATIVE %	56.66	-	43.34	-	-	100.00

P = N376000 X = N200 R = 20% % FOR Ac, Ec, Lc = 40% i_f=10%

TABLE 5.11D SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
	ACTUAL COST	71027.00	310462.35	290305.66	23389.43	-	694384.44
1	RELATIVE %	10.22	44.68	41.78	3.32	-	100.00
	ACTUAL COST	80965.29	146152.14	229543.91	14628.35	-	471289.69
2	RELATIVE %	17.18	31.01	48.71	3.10	-	100.00
	ACTUAL COST	92560.06	106825.70	184493.44	12966.70	10828.21	386017.69
3	RELATIVE %	23.98	27.67	47.79	3.36	2.81	100.00
	ACTUAL COST	102498.48	79572.28	157926.31	10452.98	8993.24	336456.81
4	RELATIVE %	30.28	22.62	46.66	3.09	2.66	100.00
	ACTUAL COST	108019.80	45249.94	146228.31	5937.23	-	305435.28
5	RELATIVE %	35.37	14.82	47.89	1.94	-	100.00
	ACTUAL COST	114645.34	40354.67	134290.92	6518.65	6705.94	289103.84
6	RELATIVE %	39.66	13.96	46.45	2.25	2.32	100.00
	ACTUAL COST	120129.92	35531.32	125737.27	6825.50	12045.97	276177.84
7	RELATIVE %	43.50	12.87	45.52	2.47	4.36	100.00
	ACTUAL COST	126792.31	31512.01	116309.30	7055.47	16687.18	265481.91
8	RELATIVE %	47.76	11.87	43.50	2.66	6.29	100.00
	ACTUAL COST	130657.20	27285.77	112163.40	6945.87	20380.05	256672.19
9	RELATIVE %	50.90	10.63	43.70	2.71	7.94	100.00
	ACTUAL COST	137282.84	-	105004.21	-	-	242287.05
10	RELATIVE %	56.66	-	43.34	-	-	100.00

P = N376000 X = N400 R = 20% % FOR Ac, Ec, Lc = 40% i_f=10%

5.2.4 Initial Overlay Construction Costs

The effect of initial construction costs are indicated in tables 5.9 to 5.13.

From the results, the higher the overlay thickness the higher the initial construction costs and consequently the higher the total costs.

5.2.5 Engineering, Labour and Administrative Costs

These costs exhibit about the same pattern as the other components as regards effect of design period on total costs. The general pattern is illustrated in fig. 5.5. Indication from the figure is that the higher the percentage of construction cost used for engineering, labour and administrative costs, the higher the total costs. These costs decrease with the analysis period. The effect is more pronounced at the early stage of analysis period than towards the end of the analysis period. The computation of effects are shown in tables 5.12A to 5.12D.

5.2.6 Inflation Rates

The effect of inflation rates is illustrated in figure 5.6 while the relevance computations are shown in tables 5.13A to 5.13D. A general trend is that the higher the inflation rate the higher

MAINTENANCE CONSTANT P = 190 000 (₦–mm/yr)
DISCOUNT RATE R = 20%
DELAY COST CONSTANT X = 60 (₦/km–mm-yr)
INFLATION RATE ϕ = 10%

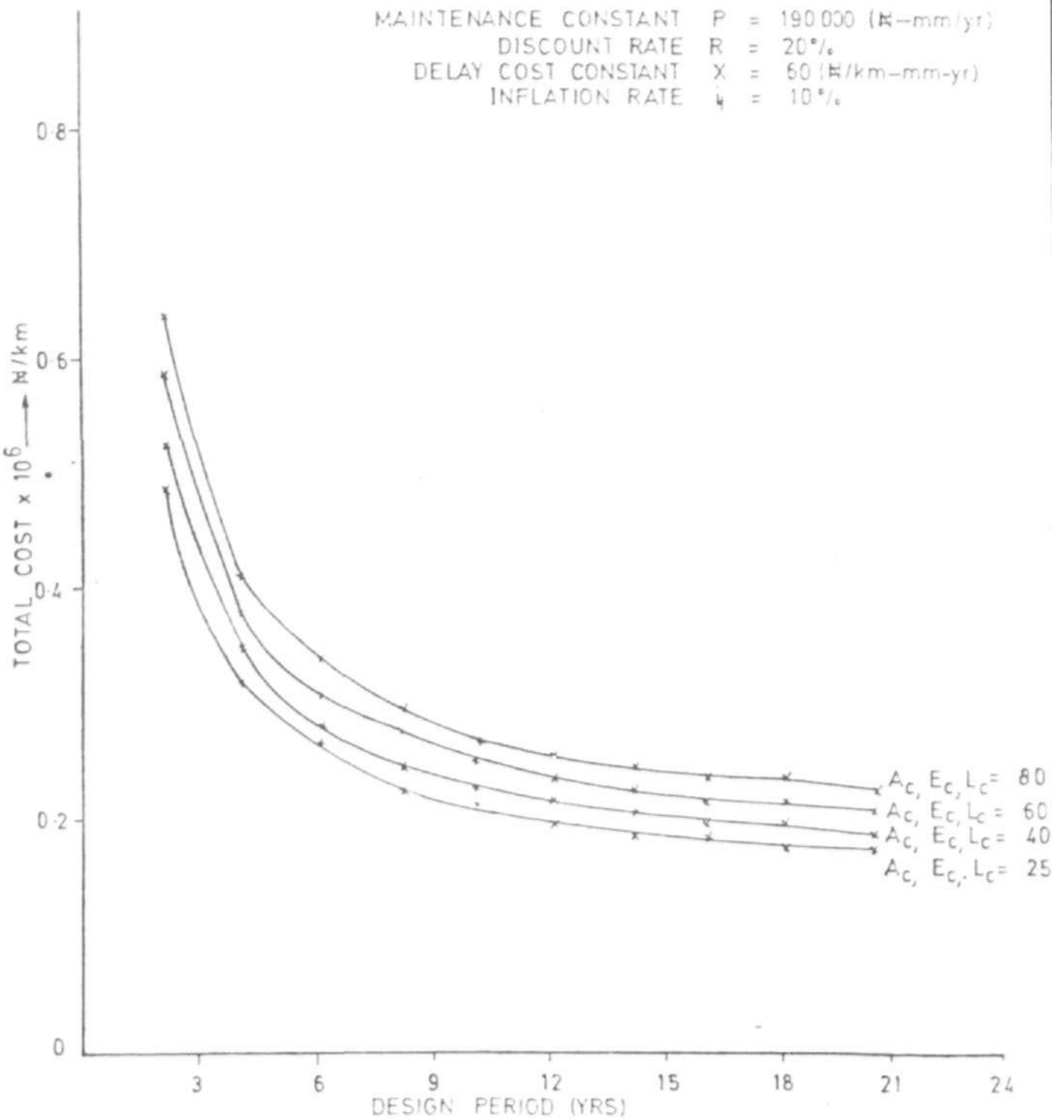


FIG 5.5 EFFECT OF L_c, A_c, E_c ON TOTAL COST

TABLE 5.12A SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	63,416.96	277,198.54	146697.17	3463.42	-	490776.09
	RELATIVE %	12.92	56.48	29.89	00.71	-	100.00
2	ACTUAL COST	72,290.44	130,492.93	115,992.83	2033.25	-	320809.50
	RELATIVE %	22.53	40.68	36.16	00.63	-	100.00
3	ACTUAL COST	82,642.91	95,380.13	93227.98	1945.00	9668.05	265527.97
	RELATIVE %	31.36	36.19	35.38	00.74	03.67	100.00
4	ACTUAL COST	91,516.50	68,368.59	79303.20	1567.87	8029.68	233226.48
	RELATIVE %	39.24	29.31	34.22	00.67	03.44	100.00
5	ACTUAL COST	96,446.26	40401.73	73,891.99	890.58	-	211630.56
	RELATIVE %	45.57	19.09	34.92	00.42	-	100.00
6	ACTUAL COST	102,361.92	36030.96	67,860.02	977.82	5987.45	201243.27
	RELATIVE %	50.86	17.90	33.73	00.49	02.98	100.00
7	ACTUAL COST	107258.86	31724.39	63557.52	1023.79	10755.33	192789.23
	RELATIVE %	55.64	16.46	32.96	00.52	05.58	100.00
8	ACTUAL COST	113,207.42	28435.71	59,026.01	1058.32	14899.27	186828.19
	RELATIVE %	60.59	15.22	31.59	00.57	07.97	100.00
9	ACTUAL COST	116,658.22	24,362.47	57,623.68	1042.07	18196.47	181489.59
	RELATIVE %	64.28	13.42	31.75	00.57	10.02	100.00
10	ACTUAL COST	122,573.96	-	53,060.73	-	-	175634.69
	RELATIVE %	69.79	-	30.21	-	-	100.00

P = N190000 X = N60 R = 20% % FOR Ac, Ec, Lc = 25% i_f=10%

TABLE 5.12B SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	71027.00	310462.35	146,607.17	3453.42	-	531649.94
	RELATIVE %	13.36	58.40	27.59	00.65	-	100.00
2	ACTUAL COST	80965.29	146152.14	115,992.88	2033.25	-	345,143.56
	RELATIVE %	23.46	42.35	33.61	00.58	-	100.00
3	ACTUAL COST	92560.06	106825.70	93227.98	1945.00	10828.21	283730.53
	RELATIVE %	32.62	37.65	32.86	00.69	03.82	100.00
4	ACTUAL COST	102498.48	76572.28	79803.20	1557.87	8993.24	251449.11
	RELATIVE %	40.76	30.46	31.74	00.62	03.58	100.00
5	ACTUAL COST	108019.80	45249.94	73891.99	890.58	-	228,052.31
	RELATIVE %	47.37	19.84	32.40	00.39	-	100.00
6	ACTUAL COST	114645.34	40354.67	67860.02	977.82	6705.94	217131.91
	RELATIVE %	52.80	18.59	31.25	00.45	03.09	100.00
7	ACTUAL COST	120129.92	35531.32	63537.52	1023.79	12045.97	208176.58
	RELATIVE %	57.71	17.07	30.52	00.49	05.79	100.00
8	ACTUAL COST	126792.31	31512.01	59026.01	1058.32	16687.18	201701.47
	RELATIVE %	62.86	15.62	29.26	00.52	08.27	100.00
9	ACTUAL COST	130657.20	27285.77	57623.68	1041.68	20380.05	196228.48
	RELATIVE %	66.58	13.91	29.37	00.53	10.39	100.00
10	ACTUAL COST	137282.84	-	53060.72	-	-	190343.56
	RELATIVE %	72.12	-	27.88	-	-	100.00

P = N190,000 X = N60 R = 20% % FOR Ac, Ec, Lc = 40% i_f=10%

TABLE 5.12C SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	81,173.71	354,814.08	146,697.17	3463.42	-	586,148.38
	RELATIVE %	13.85	60.53	25.03	00.59	-	100.00
2	ACTUAL COST	92,531.76	167,031.08	115,992.88	2033.25	-	377,588.97
	RELATIVE %	24.51	44.24	30.72	00.54	-	100.00
3	ACTUAL COST	105,782.93	122,086.64	93,227.98	1945.00	12375.21	310667.34
	RELATIVE %	34.05	39.30	30.00	00.63	03.98	100.00
4	ACTUAL COST	117,141.12	87,511.77	79,803.20	1567.87	10277.99	275745.97
	RELATIVE %	42.48	31.74	28.94	00.57	03.73	100.00
5	ACTUAL COST	123,451.20	51,714.21	73,891.99	890.58	-	249,947.98
	RELATIVE %	49.39	20.69	29.56	00.36	-	100.00
6	ACTUAL COST	131,023.25	46,119.64	67860.02	977.82	7663.93	238,316.80
	RELATIVE %	54.98	19.35	28.47	00.41	03.21	100.00
7	ACTUAL COST	137,291.36	40,507.21	63537.52	1023.79	13766.83	228693.05
	RELATIVE %	60.03	17.76	27.78	00.45	06.02	100.00
8	ACTUAL COST	144,905.49	36,013.72	59036.01	1058.32	19071.06	221932.48
	RELATIVE %	65.29	16.23	26.60	00.48	08.59	100.00
9	ACTUAL COST	149,322.51	31,183.75	57623.68	1041.88	23291.49	215880.33
	RELATIVE %	69.18	14.44	26.69	00.48	10.79	100.00
10	ACTUAL COST	156,894.67	-	53060.72	-	-	209955.39
	RELATIVE %	74.73	-	25.27	-	-	100.00

P = N190000 X = N60 R = 20% % FOR Ac, Ec, Lc = 60% i_f=10%

TABLE 5.12D SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
	ACTUAL COST	91320.42	399165.87	146697.17	3463.42	-	640646.88
1	RELATIVE %	14.25	62.31	22.90	00.54	-	100.00
	ACTUAL COST	104098.23	187909.98	115992.88	2033.25	-	410034.34
2	RELATIVE %	25.38	45.83	28.29	00.50	-	100.00
	ACTUAL COST	119005.80	137347.34	93227.98	1945.00	13921.99	337604.13
3	RELATIVE %	35.25	40.68	27.61	00.58	04.12	100.00
	ACTUAL COST	131783.76	98450.75	79803.20	1567.87	11562.74	300042.84
4	RELATIVE %	43.92	32.81	26.60	00.52	03.85	100.00
	ACTUAL COST	138882.60	58178.49	73891.99	890.58	-	271343.66
5	RELATIVE %	51.09	21.40	27.18	00.33	-	100.00
	ACTUAL COST	147401.16	51884.58	67860.02	977.82	8621.92	259501.66
6	RELATIVE %	56.80	19.99	26.15	00.38	03.32	100.00
	ACTUAL COST	154452.75	45683.14	63537.52	1023.79	15487.68	249209.52
7	RELATIVE %	61.98	18.33	25.50	00.41	06.22	100.00
	ACTUAL COST	163018.68	40515.44	59026.01	1058.32	21454.95	242163.50
8	RELATIVE %	67.34	16.72	24.36	00.44	08.86	100.00
	ACTUAL COST	167987.83	35081.72	57623.68	1041.88	26202.92	235532.19
9	RELATIVE %	71.32	14.89	24.47	00.44	11.12	100.00
	ACTUAL COST	176506.50	-	53060.73	-	-	229567.23
10	RELATIVE %	76.89	-	23.11	-	-	100.00

P = N190,000 X = N60 R = 20% % FOR Ac, Ec, Lc = 80% i_f = 10%

MAINTENANCE CONSTANT P = 190000 (₦-mm/yr)
DISCOUNT RATE R = 10%
DELAY COST CONSTANT X = 60 (N/km-mm/yr)
% FOR LABOUR COST, L_c, ADMISTRATIVE COST,
AND ENGINEERING COST, E_c = 25%

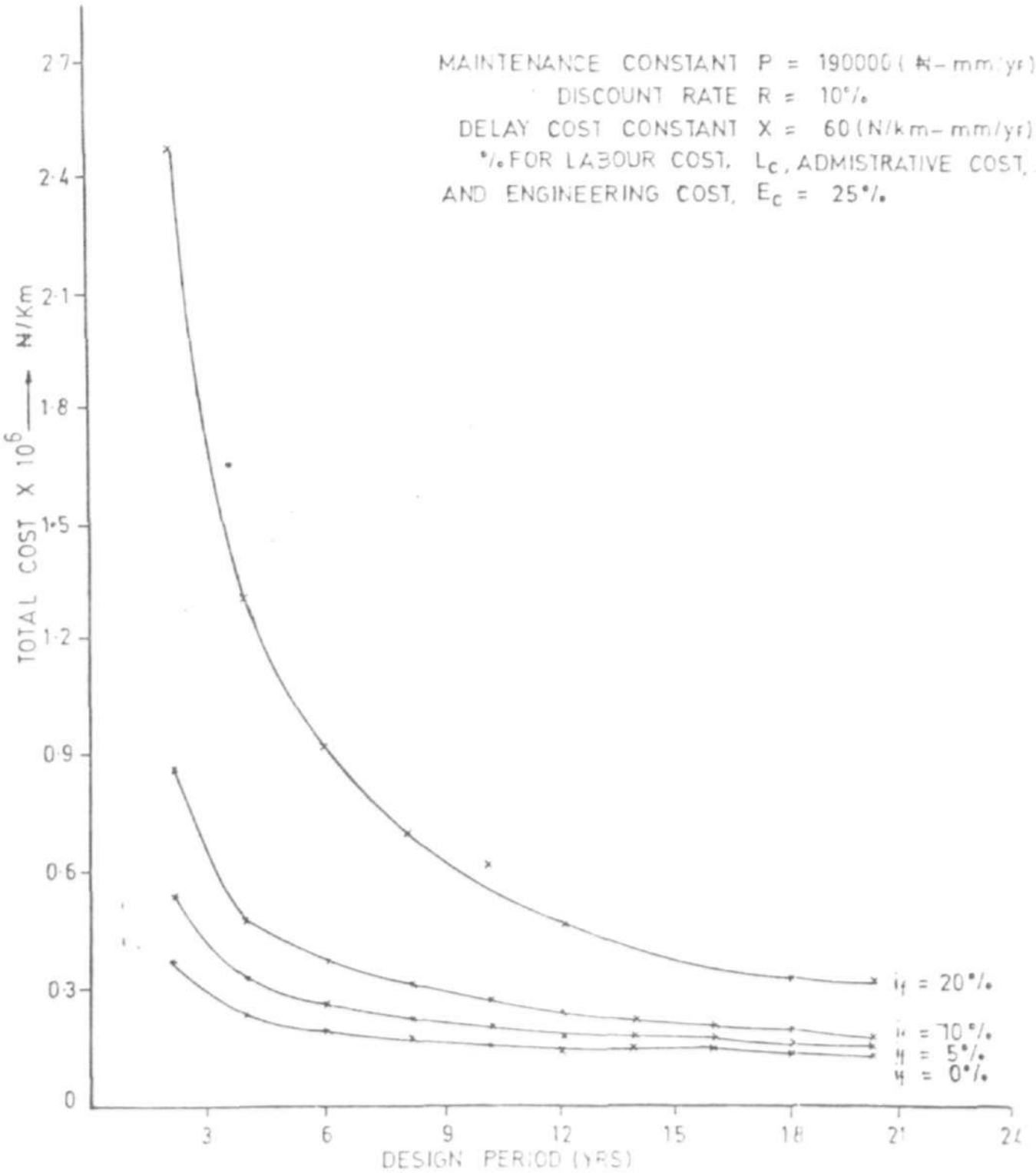


FIG. 5.6 EFFECT OF INFLATION RATES ON TOTAL COST

TABLE 5.13A SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
	ACTUAL COST	63416.96	247670.71	50802.18	14574.78	-	376464.63
1	RELATIVE %	16.85	65.79	13.49	03.87	-	100.00
	ACTUAL COST	72290.44	121865.83	40169.09	1364.52	-	235189.88
2	RELATIVE %	30.61	51.60	17.00	00.79	-	100.00
	ACTUAL COST	82642.91	87846.34	32285.46	1760.49	8189.48	196345.72
3	RELATIVE %	42.09	44.74	16.44	00.90	04.17	100.00
	ACTUAL COST	91516.50	62609.78	27636.37	1420.10	6801.67	176381.08
4	RELATIVE %	51.89	35.50	15.67	00.80	03.86	100.00
	ACTUAL COST	96446.26	37104.21	25589.27	899.64	-	160039.38
5	RELATIVE %	60.27	23.18	15.99	00.56	-	100.00
	ACTUAL COST	102631.92	32615.66	23500.36	885.16	5071.77	154291.33
6	RELATIVE %	66.34	21.14	15.24	00.57	03.29	100.00
	ACTUAL COST	107258.86	28244.61	22003.45	911.50	9110.48	149307.94
7	RELATIVE %	71.84	18.92	14.74	00.60	06.10	100.00
	ACTUAL COST	113207.42	24637.23	20441.09	926.71	12620.67	146591.78
8	RELATIVE %	77.23	16.81	13.94	00.63	08.61	100.00
	ACTUAL COST	116658.22	20981.99	19955.46	897.31	15413.76	143079.22
9	RELATIVE %	81.53	14.66	13.95	00.63	10.77	100.00
	ACTUAL COST	122573.96	-	18375.27	-	-	140949.23
10	RELATIVE %	86.96	-	13.04	-	-	100.23

P = N190000 X = N60 R = 10% % FOR Ac, Ec, Lc = 25% i_f=0%

TABLE 5.13B SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
	ACTUAL COST	63416.96	396318.92	88196.62	5465.06	-	553391.56
1	RELATIVE %	11.46	71.62	15.94	00.99	-	100.00
	ACTUAL COST	72290.44	185549.66	69731.00	3155.90	-	330727.00
2	RELATIVE %	21.86	56.10	21.08	00.95	-	100.00
	ACTUAL COST	82642.91	145576.53	56046.30	3234.70	21729.13	265771.31
3	RELATIVE %	31.10	54.78	21.09	01.21	08.18	100.00
	ACTUAL COST	91516.50	106552.73	47975.66	2581.66	18046.86	230579.69
4	RELATIVE %	39.69	46.21	20.81	01.12	07.83	100.00
	ACTUAL COST	96446.26	60569.08	44421.99	1335.14	-	202772.47
5	RELATIVE %	47.56	29.87	21.91	00.66	-	100.00
	ACTUAL COST	102361.92	58573.00	40796.73	1589.59	13456.90	189863.34
6	RELATIVE %	53.91	30.85	21.49	00.84	07.09	100.00
	ACTUAL COST	107258.86	55922.38	38197.15	1804.71	24172.83	179010.27
7	RELATIVE %	59.92	31.24	21.34	01.01	13.50	100.00
	ACTUAL COST	113207.42	53779.97	35484.95	2022.92	33486.40	171008.86
8	RELATIVE %	66.20	31.45	20.75	01.18	19.58	100.00
	ACTUAL COST	116658.22	50491.59	34641.90	2159.49	40893.25	163057.95
9	RELATIVE %	71.54	30.97	21.25	01.32	25.08	100.00
	ACTUAL COST	122573.96	-	31898.76	-	-	154472.73
10	RELATIVE %	79.35	-	20.65	-	-	100.00

P = N190000 X = N60 R = 10% % FOR Ac, Ec, Lc = 25% i_F=5%

TABLE 5.13C SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	63416.96	570752.64	160033.30	9637.80	-	803840.70
	RELATIVE %	07.89	71.00	19.91	01.20	-	100.00
2	ACTUAL COST	72290.44	289161.76	126537.70	5415.76	-	493405.66
	RELATIVE %	14.65	58.60	25.65	01.10	-	100.00
3	ACTUAL COST	82642.91	247928.73	101703.25	6066.41	55095.55	383245.75
	RELATIVE %	21.56	64.69	26.54	01.58	14.37	100.00
4	ACTUAL COST	91516.50	183033.06	87058.03	4724.41	45758.25	320573.72
	RELATIVE %	28.55	57.10	27.16	01.47	14.28	100.00
5	ACTUAL COST	96446.25	96446.25	80609.44	2125.98	-	275627.94
	RELATIVE %	34.99	34.99	29.25	00.77	-	100.00
6	ACTUAL COST	102361.92	102361.92	74029.11	2777.95	34115.22	247810.61
	RELATIVE %	41.37	41.37	29.92	01.12	13.78	100.00
7	ACTUAL COST	107258.86	107258.86	69313.65	3461.43	61290.78	226002.02
	RELATIVE %	47.46	47.46	30.67	01.53	27.12	100.00
8	ACTUAL COST	113207.42	113207.42	64392.03	4258.27	84905.54	210159.55
	RELATIVE %	53.87	53.87	30.64	02.02	40.40	100.00
9	ACTUAL COST	116658.22	116658.22	62862.20	4988.98	103694.18	197471.44
	RELATIVE %	59.08	59.08	31.83	02.52	52.51	100.00
10	ACTUAL COST	122573.96	-	57884.43	-	-	180458.39
	RELATIVE %	67.92	-	32.08	-	-	100.00

P = N190000 X = N60 R = 10% % FOR Ac, Ec, Lc = 25% i_f=10%

TABLE 5.13D SUMMARY OF VARIOUS COST COMPONENTS (PRESENT VALUE)

	DESIGN STRATEGY	INITIAL CONSTR. COSTS (₦/km)	SUB-SEQUENT OVERLAYS CONSTR. COSTS (₦/km)	MAINTENANCE COSTS (₦/km)	EXTRA COSTS OF TIME DELAY DURING CONSTR. (₦/km)	SALVAGE RETURN (₦/km)	TOTAL COSTS (₦/km)
1	ACTUAL COST	63416.96	1807850.12	569049.56	31063.61	-	2471380.25
	RELATIVE %	02.57	73.15	23.02	01.26	-	100.00
2	ACTUAL COST	72290.44	743627.29	449945.81	16276.56	-	1282140.13
	RELATIVE %	05.64	58.00	35.09	01.27	-	100.00
3	ACTUAL COST	82642.91	769805.50	361638.44	21573.52	313964.99	922095.38
	RELATIVE %	08.96	83.48	39.22	02.38	34.04	100.00
4	ACTUAL COST	91516.50	551800.27	309562.69	15831.71	260759.79	707951.38
	RELATIVE %	12.93	77.94	43.72	02.24	36.83	100.00
5	ACTUAL COST	96446.26	230234.78	286632.66	5075.11	-	618388.81
	RELATIVE %	15.60	37.23	46.35	00.82	-	100.00
6	ACTUAL COST	102361.92	290804.49	263234.19	7892.01	194439.30	469853.31
	RELATIVE %	21.79	61.89	56.02	01.68	41.38	100.00
7	ACTUAL COST	107258.86	362637.78	246466.36	11702.91	349274.07	378792.34
	RELATIVE %	28.31	95.74	65.07	03.09	92.21	100.00
8	ACTUAL COST	113207.42	455503.56	228966.42	17133.65	483846.24	330964.91
	RELATIVE %	34.20	137.63	69.18	05.18	146.19	100.00
9	ACTUAL COST	116658.22	558605.13	223526.66	23889.42	590921.37	331758.06
	RELATIVE %	35.16	168.38	67.38	07.20	178.12	100.00
10	ACTUAL COST	122573.96	-	205826.59	-	-	328400.56
	RELATIVE %	37.32	-	62.68	-	-	100.00

P = N190,000 X = N60 R = 10% % FOR Ac, Ec, Lc = 25 i_f=20%

the total costs. Also as inflation rates increase, longer periods generally are more attractive. The effect of inflation rates on total costs is more pronounced at higher inflation rates. For example decreasing inflation rates from 10% to 0% will decrease the total costs by about 58% while increasing it to 20% will increase the total costs by about 185%. This is quite a wide gap. This shows that the effect of inflation rates on total costs is very great.

5.3 Selection of Optimum Alternative Strategy.

Figures 5.2 to 5.6 show graphically the relationship between the total costs and design periods. On the basis of discounted total costs, strategies 8, 9, and 10 are almost the same, whereas strategy 1 is the most expensive alternative, consequently, either of these three alternatives (i.e. alternatives 8, 9 and 10) might be chosen. But because alternative 10 has a high average performance throughout the analysis period couple with its minimum total costs, it should have lower costs and this alternative might be the preferable alternative.

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CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

From the analysed results, graphical presentations, field measurement and Laboratory observations, the following conclusions and recommendations can be made.

6.1 CONCLUSIONS

(1) Based on the economic appraisal carried out in this work, the least cost design shifts its position several times. Alternative 1 is optimal when only initial construction cost is considered, while alternative 9 becomes optimal when only salvage return cost is considered. When considering only maintenance or extra costs of time delay alternative 10 becomes optimal.

(2) It is more economical to design overlay that will last for the whole analysis period than applying overlays during the analysis period.

(3) Maintenance cost has a great effect on total costs. The effect is more pronounced on thinner overlays.

(4) Delay cost during construction has minimal effect on the total costs and this cost increases with the year of application of overlay.

(5) Increase in both discount and inflation rates have appreciable effect on the total costs. The higher the discount rate the lower the total costs while the reverse is the case for inflation rate.

(6) The salvage return cost has an appreciable effect on the total costs. The effect is more pronounced on thicker overlays.

(7) It is advisable economically not to design for overlay design period below 9 years.

(8) The design method adopted in this work incorporates field measurement results, laboratory measurement results and traffic estimates. Thus, through the use of this method, a more economical total cost may result than with other traditional approaches to overlay design.

(9) On the basis of field measurement results, Laboratory results, Basin matching results and overlay thickness design results, the best section is section 2 (ks 2.3-8.0) while the worst section is section 6 (kms 27.6-44.5). Also, section 6 needs total reconstruction while sections 1 and 7 might be considered for reconstruction too.

(10) The vertical stress due to wheel load decreases as the pavement structure thickness increases.

(11) Judging from the performance of each alternative throughout the analysis period and effect of each cost component on total costs, it can be concluded that the 10th alternative is the best strategy.

(12) An economic evaluation of the type done in this work provides a basis for making a management decision to select the best strategy, which in this case is alternative 10. However, other factors in addition to economic such as past experience with a particular alternative, preference of one material type to another, expected availability of initial capital funds, and so on, may be used to make comprehensive judgement.

RECOMMENDATIONS

From this study, it is recommended that:

(1) The monitoring of road pavement performance in the country be carried out at least once in every two years, in order to obtain a concrete decision as regards cost, performance and serviceability measures for future planning.

(2) Economically, designers should design overlays for a period of 14 or more years. At a design period of 9 years or less the total costs of overlay are higher.

(3) Designers should consider the effect of total cost components on overlay thickness while designing.

(4) The model developed in this work can be used for the estimation of total costs prior to the time of carrying out pavement overlay projects.

(5) Further work in this area can also be done using the application of linear programming.

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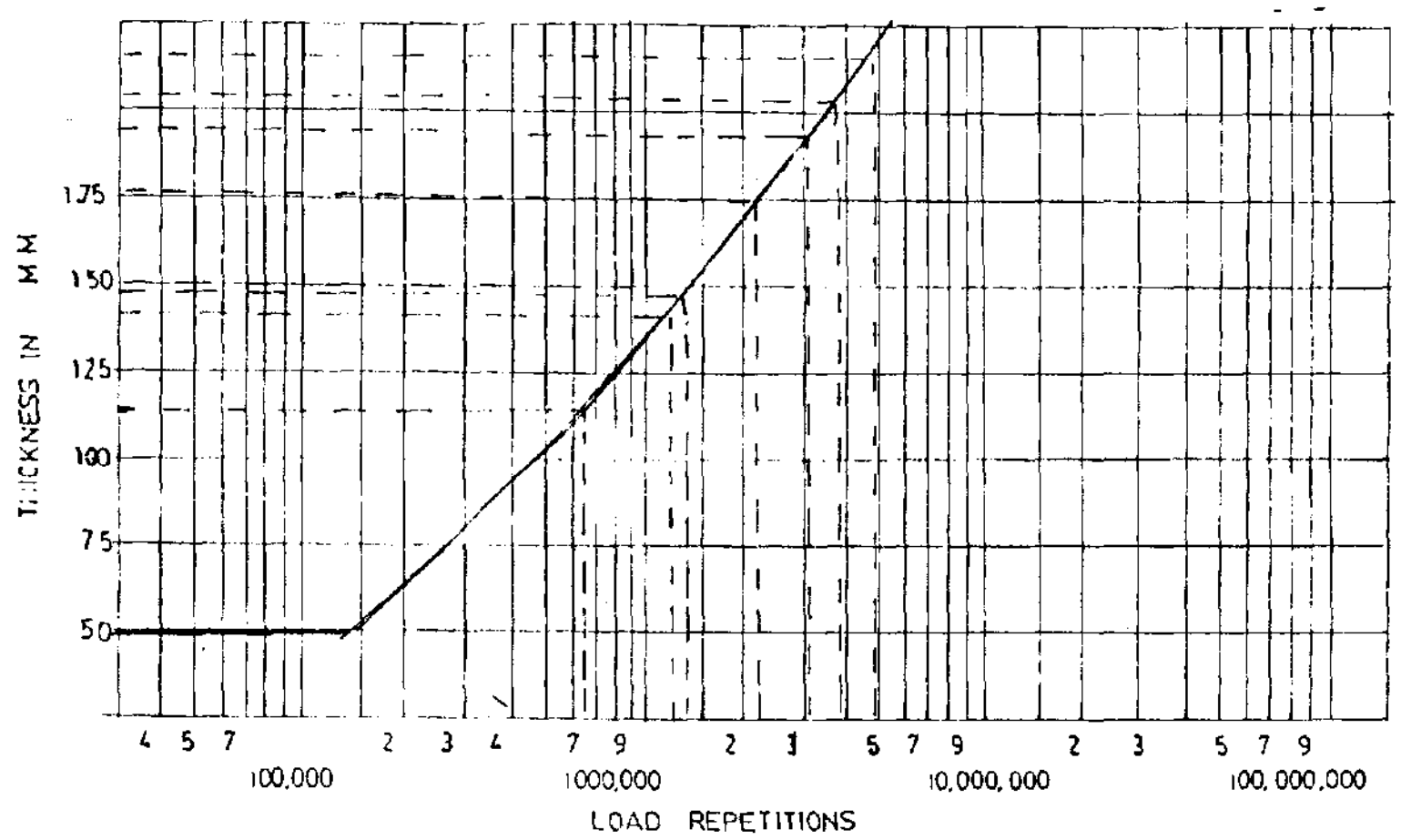
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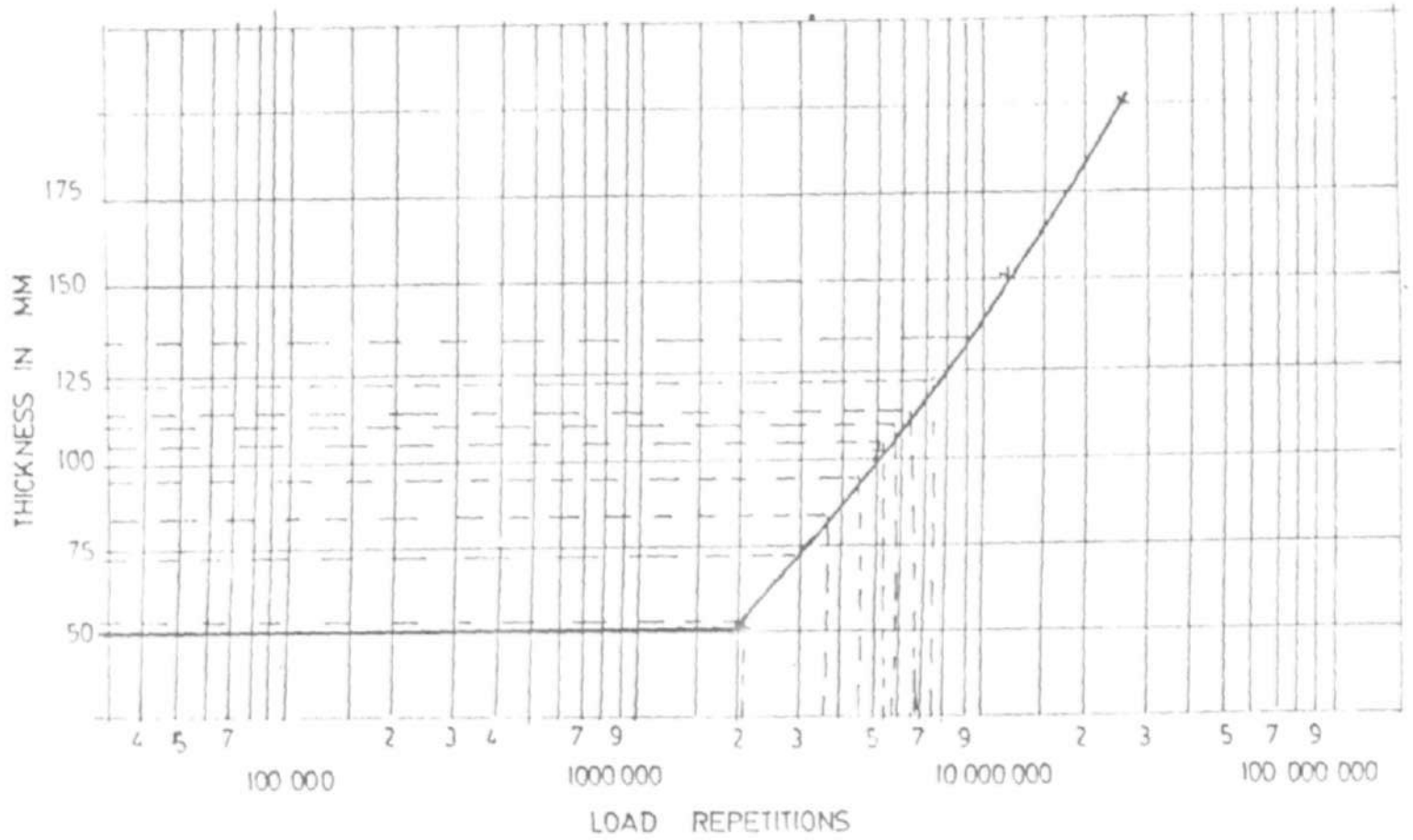
APPENDIX A

OVERLAY DESIGN CURVES



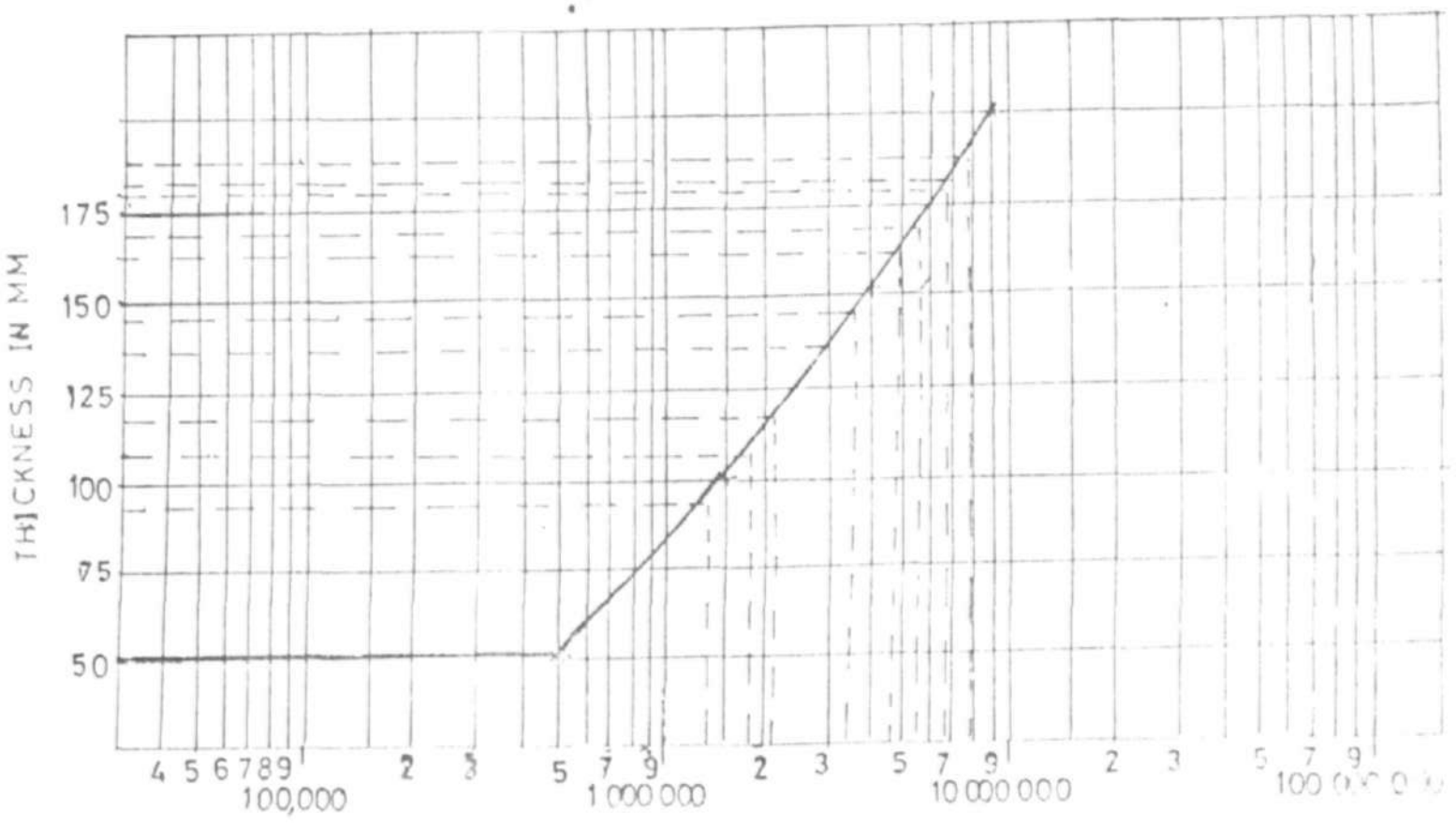
OVERLAY DESIGN CURVE FOR SECTION 1

APPENDIX A_2



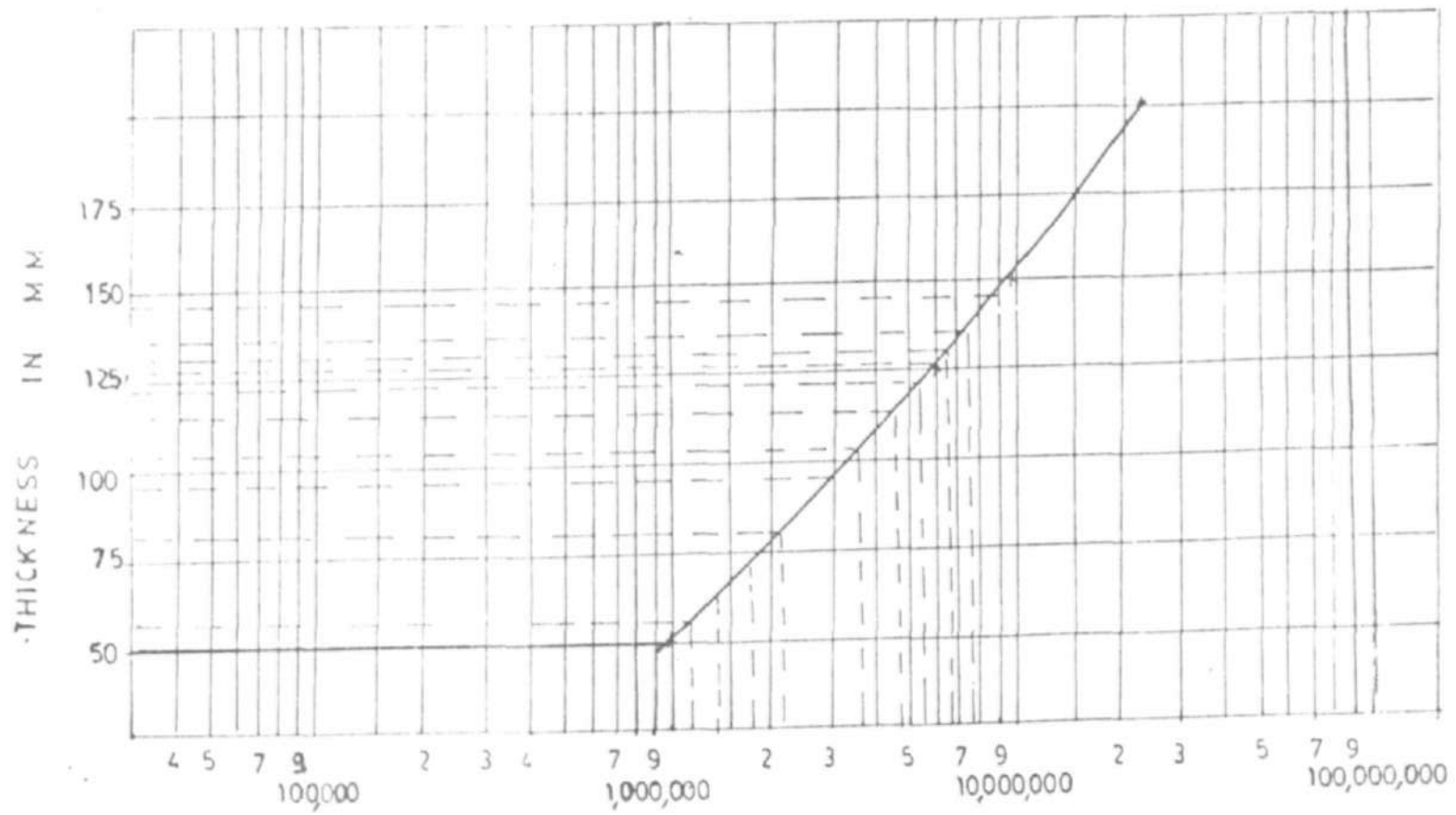
OVERLAY DESIGN CURVE FOR SECTION 2

APPENDIX A_3



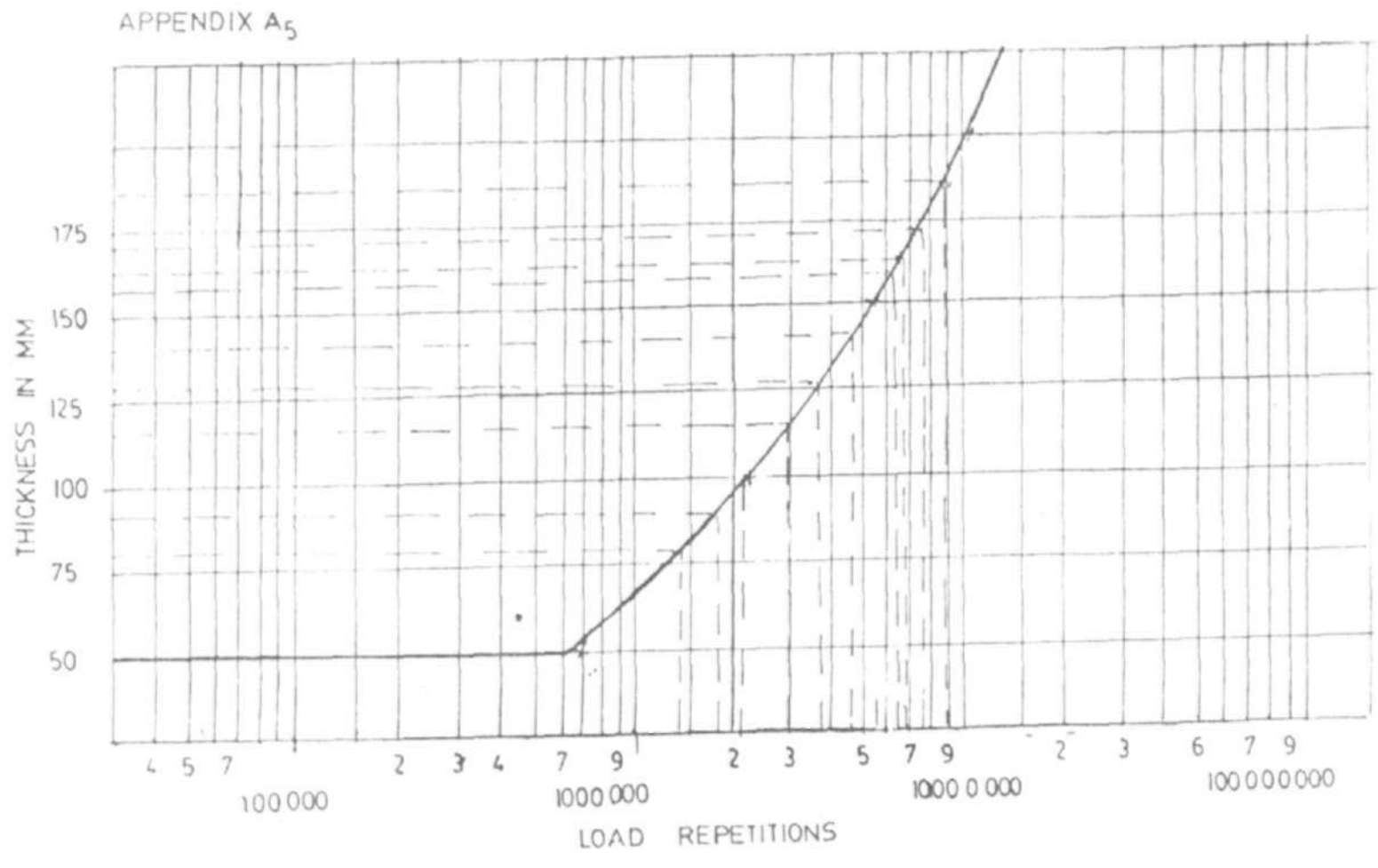
OVERLAY DESIGN CURVE FOR SECTION 3

APPENDIX A_4



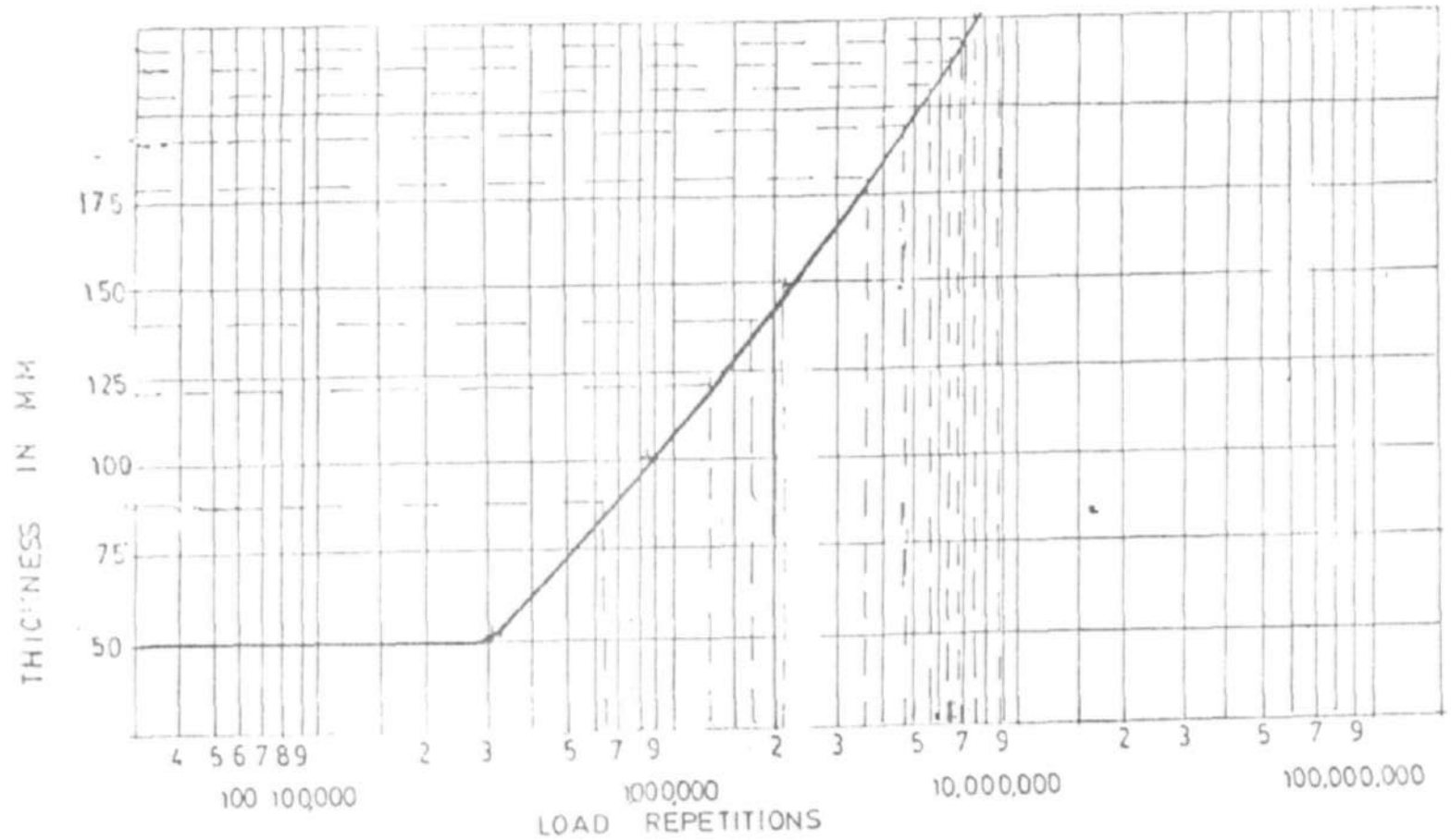
OVERLAY DESIGN CURVE FOR SECTION 4

APPENDIX A_5



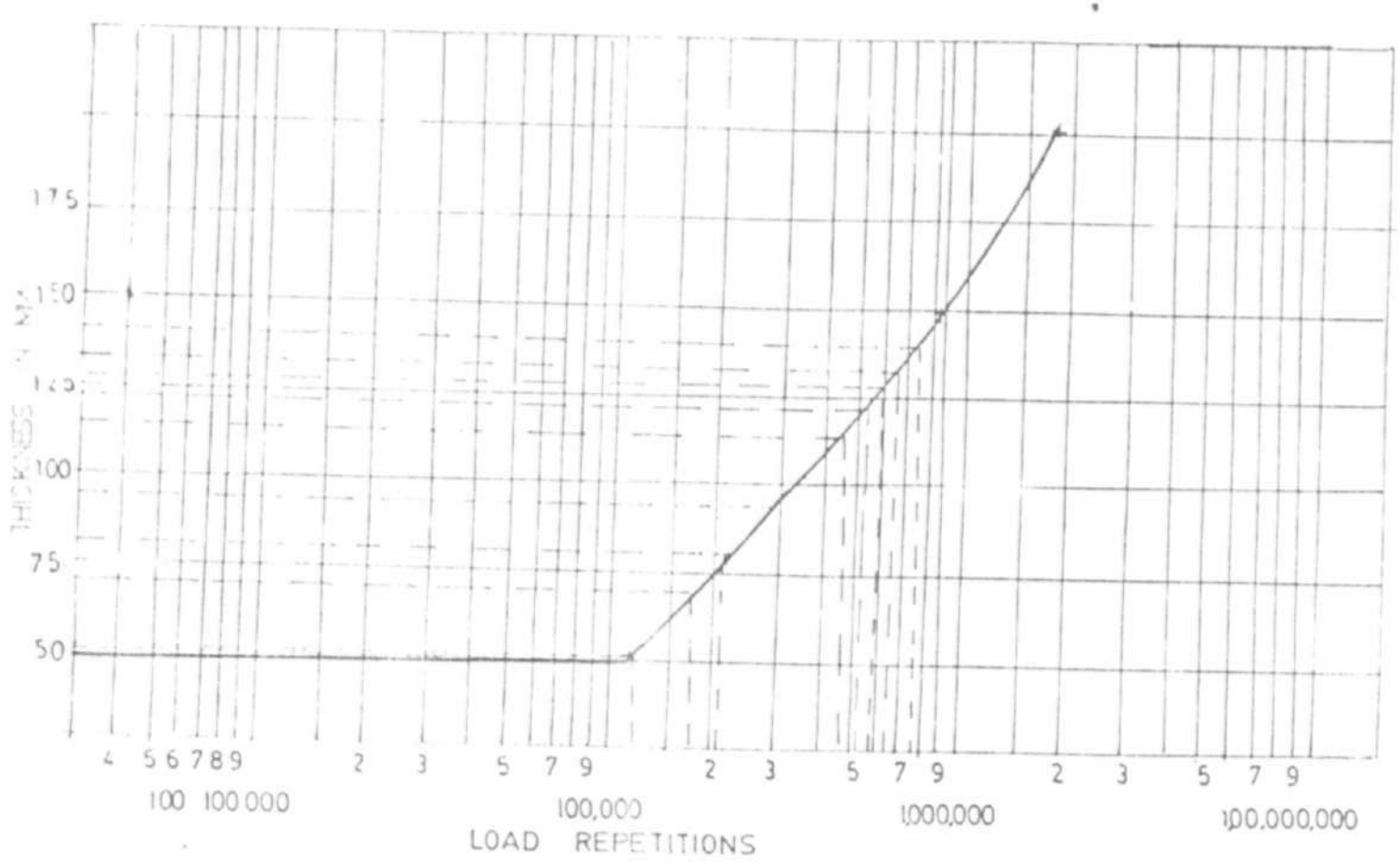
OVERLAY DESIGN CURVE FOR SECTION 5

APPENDIX A_6



OVERLAY DESIGN CURVE FOR SECTION 7

APPENDIX A7



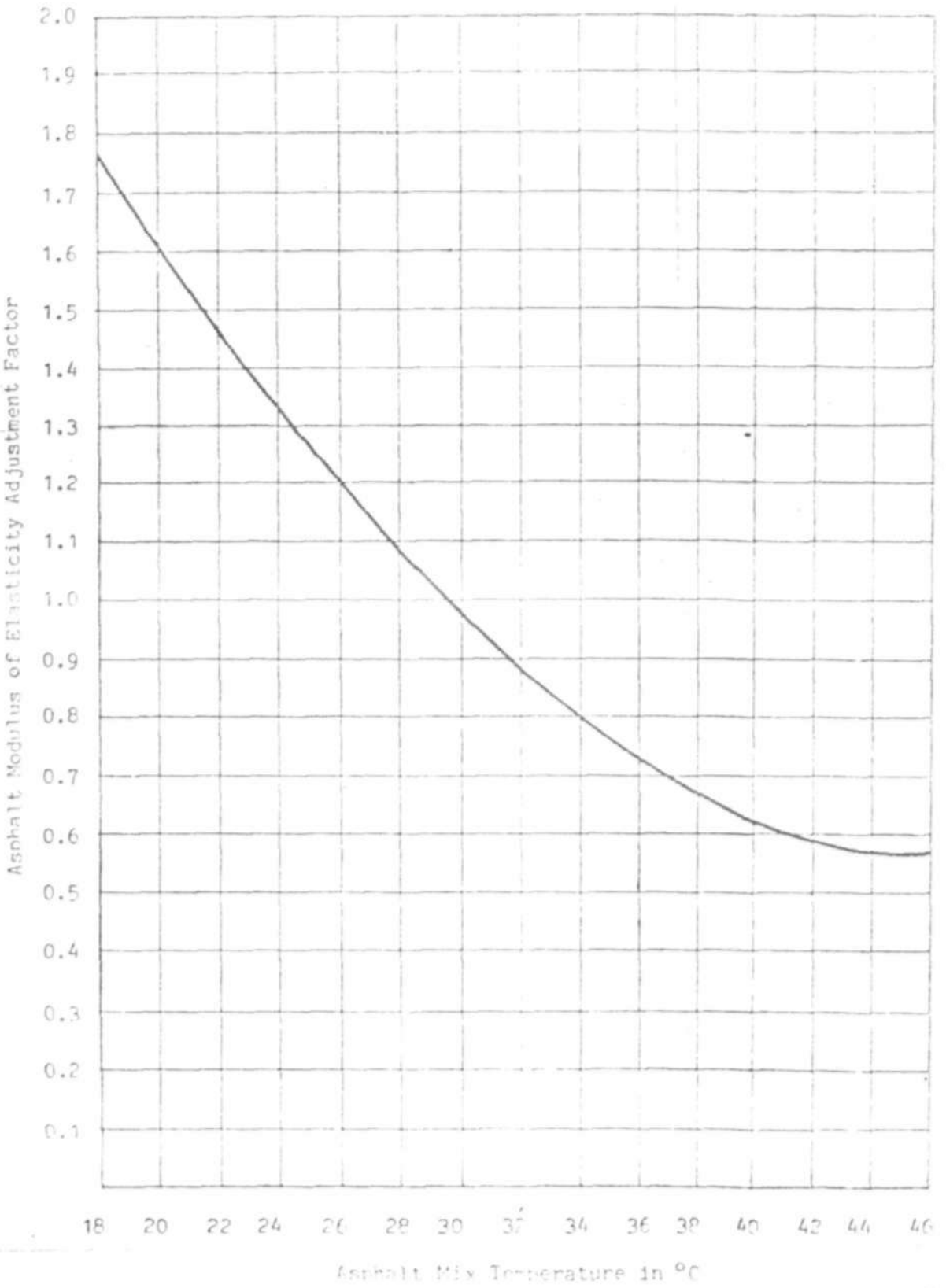
OVERLAY DESIGN CURVE FOR SECTIONS 8

APPENDIX B

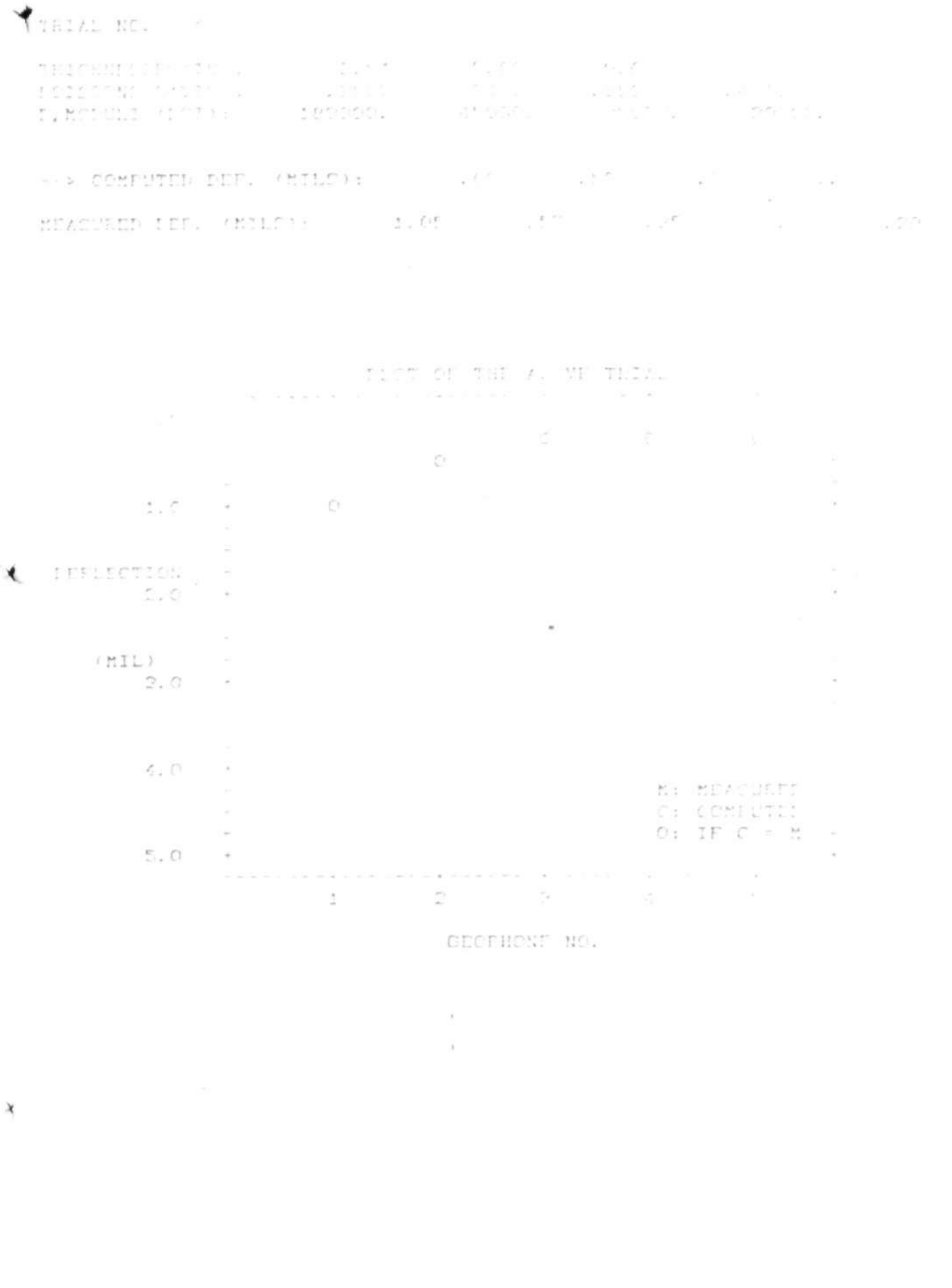
APPENDIX B-TYPICAL POISSON RATIO VALUES

Material	General Range	Remarks	Typical Value
Portland Cement Concrete	0.10 - 0.45		
Asphalt Concrete/ Asphalt Treated Bases	0.15 - 0.45	Highly dependent upon temperature; use low value (0.15) for cold temperatures (less than 30°F) and high value (0.45) for warm pavement (120°F plus).	0.35
Cement Stabilized Bases	0.15 - 0.30	Degree of cracking in stabilized layer tends to increase value towards 0.30 from sound (crack free) value of 0.15	0.20
Granular Base/ Subbase	0.30 - 0.40	Use lower value for crushed material and high value for unprocessed rounded gravels/ sands	0.35
Subgrades	0.30 - 0.50	Value dependent upon type of subgrade soil. For cohesionless soils, use value near 0.30. A value of 0.50 is approached for very plastic clays (cohesive soils).	0.40

APPENDIX C TEMPERATURE ADJUSTMENT FACTOR FOR [illegible] LABORATORY ASPHALT CONCRETE MIXTURE [illegible] IN FIELD AT TIME OF DEFLECTION TESTING.



APPENDIX D


TRIAL NO.
--> COMPUTED DEF. (MILS):
MEASURED DEF. (MILS):
PLOT OF THE A. VS TRIAL
DEFLECTION
(MIL)
2.0
4.0
5.0
M: MEASURED
C: COMPUTED
O: IF C = M
1
GEOPHONE NO.

TRIAL NO. 3

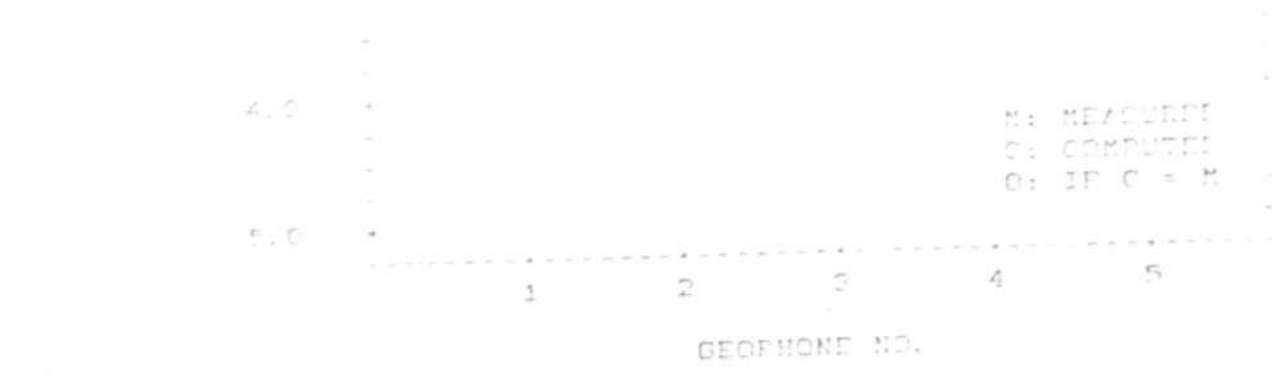
THICKNESS(IN): 2.04 5.80 9.00
POISSONS RATIO: .3500 .3000 .2500
E,MODULI (PSI): 1000000. 1000000. 1000000.

--- COMPUTED DEF. (MILS) : .05 .01 .01 .0

MEASURED DEF. (MILS) : 1.67 .07 .04 .02

PLOT OF THE ABOVE TRIAL

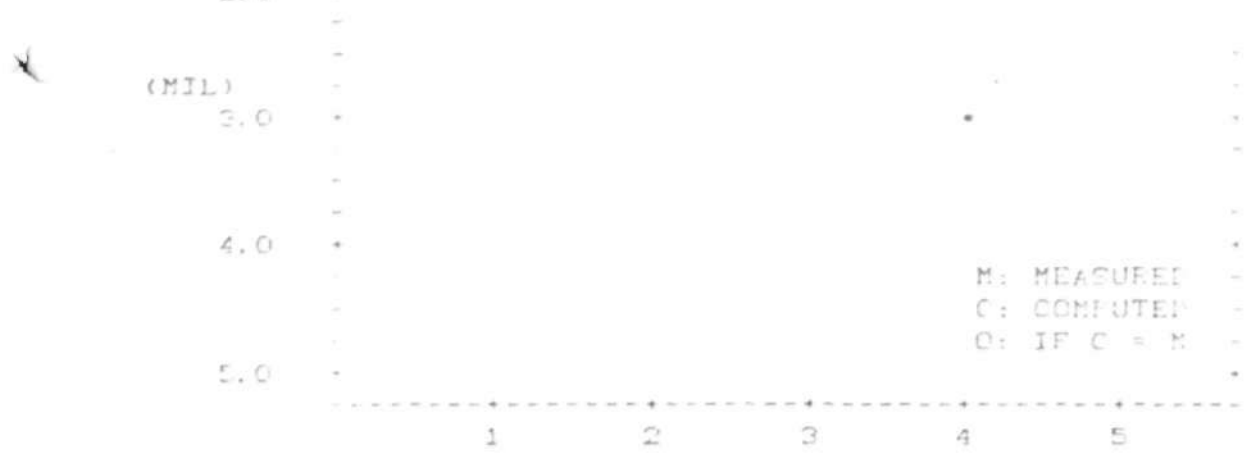



(MIL)
3.0
4.0
5.0
1
2
3
4
5
M: MEASURED
C: COMPUTED
O: IF C = M
GEOPHONE NO.

TRIAL NO. 1

THICKNESSES(IN):	2.04	5.00	5.00		
POISSONS RATIOS:	.3500	.3000	.3500	.4[illegible]	
E,MODULI (PSI):	1000000.	50000.	35000.	[illegible]	
--> COMPUTED DEF. (MILS):	.87	.59	.38	.27	
MEASURED DEF. (MILS):	1.05	.57	.35	.24	.20

PLOT OF THE ABOVE TRIAL



```
      PROGRAM LAYERS
      DIMENSION HL(5),H(5),V(5),E(5),SH(5)
      REAL NFA,NF3,NFC,NF,LU,NP
      REAL*8 NF2
      REAL*8 NR
      DATA C,P,NP/0.18,75,1238105/
      OPEN (4,FILE='LAYERS.DAT',STATUS='OLD')
      DO 40 K=1,8
      DO 5 I =1,5
      READ (4,*) HL(I),H(I),V(I),E(I)
    5 CONTINUE
      DO 40 J= 1,5
      H(1)=HL(J)
      DO 30 I=1,4
      SH(I)=((E(I)*((1-(V(5)**2))/E(5))*(1-(V(I)**2)))**.333)*H(I)
   30 CONTINUE
      AH=(SH(1)+SH(2)+SH(3)+SH(4))
      PRINT*,'AH =',AH
C     COMPUTE VERTICAL STRESS
      DZ1=1/((1+((C/AH)**2))**1.5)
      DZ=P*(1-DZ1)

C     COMPUTE VERTICAL STRAIN

      ZA=1+((AH/C)**2)
      EZA=(P*(1+V(5)))/E(5)
      EZB=(AH/C)/(ZA**1.5)
      EZC1=((AH/C)/(ZA**0.5))-1
      EZC2=EZC1*(1-2*V(5))
      EZ=EZA*(EZB-EZC2)

C     COMPUTE TENSILE STRAIN

      ERA=(DZ-(E(5)*EZ))
      ERB=(1-V(5))/(2*V(5))
      ERC=(ERA*ERB)-(V(5)*DZ)
      ER=(ERC/E(5))*-1
      WRITE(6,*)'OVERLAY THICKNESS=',HL(J)
      WRITE(6,*)'VERTICAL STRESS',DZ
      WRITE(6,*)'VERTICAL COMPRESSIVE STRAIN
     - AT THE TOP OF THE SUBGRADE',EZ
      WRITE(6,*)'TENSILE STRAIN AT THE BOTTOM
     - OF THE EXISTING ASPHALT PAVEMENT',ER

      IF(HL(J).EQ.0)THEN
C     COMPUTE NUMBER OF ALLOWABLE 8200KG ESAL APPLICATIONS
      NFC =3.291*(LOG10(ER*1000000.0))
      NFA =0.854*(LOG10(E(2)/1000))
      NF3=15.988-(NFA+NFC)
      NF=(10**(NF3))
      PRINT*,'NF',NF
      LU=(NP/NF)
      RL=(1-(LU))
      WRITE(6,*)'THE VALUE OF RL AT H=0',RL
      ELSE
C     COMPUTE ALLOWABLE 8200KG ESAL (TRAFFIC)APPLICATION
      ND=(ER*1000000)**3.291
      NC=(E(2)*0.001)**0.854
      NA=ND*NC
      POW1=100000
```

```
      POW2=100000
      POW3=100000
      POWER=POW1*POW2*POW3
      N8=(9.727*POWER)/(NA*24.5)
      NF2=(N8)*RL
      NR=((1.36*0.000001)*((1/EZ)**4.7036))
      WRITE(6,*)'NUMBER OF ALLOWABLE DESIGN 8200KG.ESAL APPLICATIONS
     - FOR FATIGUE CRACKING CRITERIA',NF2
      WRITE(6,*)'NUMBER OF ALLOWABLE DESIGN 8200KG. ESAL APPLICATIONS
     - FOR RUTTING CRITERIA',NR
      WRITE(6,*)'OVERLAY THICKNESS=',HL(J)
      END IF
      PRINT*,' '
      PRINT*,' '
      CONTINUE
      STOP
      END
```

APPENDIX F_2 DEFLECTION MEAN AND STANDARD DEVIATION FOR SENSORS.

DESIGN SECTIONS	SENSORS MEAN DEFLECTION SENSOR'S NO					SENSOR STANDARD DEVIATION DEFLECTION SENSOR'S NO				
	1	2	3	4	5	1	2	3	4	5
1	.93	.54	.24	.16	.12	.26	.15	.08	.07	.06
2	.82	.41	.19	.13	.09	.15	.08	.05	.04	.04
3	.88	.48	.24	.16	.12	.23	.12	.07	.05	.04
4	.74	.39	.20	.12	.09	.13	.10	.06	.05	.04
5	.86	.50	.28	.18	.13	.21	.13	.09	.06	.05
6	1.00	.58	.34	.22	.17	.24	.14	.11	.09	.08
7	.90	.52	.32	.22	.18	.19	.12	.10	.08	.08
8	.82	.47	.27	.17	.13	.14	.06	.05	.04	.04

APPENDIX F_3 -

STANDARD NORMAL DEVIATE VALUES CORRESPONDING

TO SELECTED LEVELS OF RELIABILITY.

RELIABILITY %	STANDARD NORMAL DEVIATE	
50	0.000	
60	0.253	
70	0.524	
75	0.674	
80	0.841	
85	1.037	
90	1.282	
91	1.340	
92	1.405	
93	1.476	
94	1.555	
95	1.645	* USED
96	1.751	
97	1.881	
98	2.054	
99	2.327	
99.9	3.090	

APPENDIX G. MATERIAL CHARACTERISATION RESULTS.

PIT NO	LAYER	IN-SITU CBR %	MODULUS (MP_a)	REMARK
	BASE	-	-	
1	SUB-BASE	53	0.37	SOIL CEMENT
	SUB-GRADE	43	0.13	"
	BASE	-	-	"
2	SUB-BASE	36	0.21	
	SUB-GRADE	30	0.18	
	BASE	-	-	"

