COMPARATIVE STUDY OF DESIGN CHARTS FOR FLEXIBLE PAVEMENT

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ABSTRACT: Various methods for development of design charts have been discussed. In Group Index Method the total thickness of pavement (surfacing, base and sub base) is determined. Also the thickness of sub-base is determined. The CBR method is probably the most widely used method for the design of flexible pavement. The CBR method is based on strength parameter of the material and is, therefore, more rational than the Group Index Method. North Dakota Method is similar to the CBR method. Pavement thickness is found from the design curve which is between pavement thickness and cone bearing ratio. The Burmister's Design Method is based on the concept of two-layer system, consisting of road surfacing, base course and the sub-base as top layer of thickness h, and the sub-grade as bottom layer of infinite extent. In this method, the thickness corresponding to deflection of 5 mm has been recommended by Burmister as the required thickness of pavement. U.S. Navy Plate Bearing Test Method is also based on Burmister's two-layer theory. This method uses modulus of elasticity of base course and sub-grade. California Resistance Value Method uses California Resistance value, called R-value. In McLeod Method curves are plotted between depth of construction and CBR for traffic conditions. Maharaj and Gill have performed axisymmetric finite element analysis by varying different parameters to develop design charts. The parameters varied are thickness of pavement, pressure and elastic modulus of subgrade. Based on finite element analysis varying above parameters four types of design charts have been developed. Each of the design charts has three parameters. For two known parameters, the third parameters can be obtained.

Keywords: Design Chart, Finite Element Analysis, CBR, Group Index Method, Thickness.

INTRODUCTION

The flexible pavements consist of wearing surface built over a base course and they rest on compacted subgrade. The design of a flexible pavement is based on the principle that a surface load is dissipated by carrying it deep into the ground through successive layer of granular materials. Flexible pavements with asphalt concrete surface courses are used all around the world.

LITERATURE REVIEW

Khan (1998) describes the Group Index Method and California Bearing Ratio Method for design of flexible pavements. In Group Index Method the thickness is obtained by first determining the Group Index of soil. The curves are plotted between Group Index of subgrade and thickness for various traffic conditions. In

California Bearing Ratio Method, the curves are plotted between California Bearing Ratio Percent and depth of construction.

Arora (2003) have reported various methods for design of flexible pavements. These various methods are Group Index Method, CBR Method, California Resistance Value Method and McLeod Method. In the Group Index Method, the thickness of base and surfacing is related to the volume of traffic. In CBR Method the curves are plotted between CBR and pavement thickness for light, medium and heavy traffic. California Resistance Value Method uses California Resistance value, called R-value. In Mcleod Method curves are plotted between depth of construction and CBR for traffic conditions

Punmia et. al (2005) have reported stresses in homogeneous mass; elastic deformation under circular load and Burmister analysis for flexible pavement. Charts for vertical deflections have been developed. The design curves by Group Index Method and California Bearing Ratio Method have been developed. In Group Index Method, the curves are plotted between Group Index and thickness. In California Bearing Ratio Method curves are plotted between thickness of construction and California Bearing Ratio.

Subagio et.al (2005) discusses a case study for multi layer pavement structural analysis using methods of equivalent thickness. An approximate method has been developed to calculate stresses and strains in multilayer pavement systems by transforming this structure into an equivalent one-layer system with equivalent thicknesses of one elastic modulus. This concept is known as the method of equivalent thickness which assumes that the stresses and strains below a layer depend on the stiffness of that layer.

Das (2008) discusses the reliability issues in bituminous pavement design, based on mechanistic-empirical-approach. Variabilities of pavement design input parameters are considered and reliability, for various proposed failure definitions, of a given pavement is estimated by simulation as well as by analytical method. A methodology has been suggested for designing bituminous pavements for a given level of overall reliability by mechanistic empirical pavement design approach.

Tarefder et. al (2010) present that reliability is an important factor in flexible pavement design to consider the variability associated with the design inputs. In this paper, subgrade strength variability and flexible pavement designs are evaluated for reliability. Parameters such as mean, maximum likelihood, median, coefficient of variation, and density distribution, function of subgrade strength are determined. Design outputs are compared in terms of reliability and thickness using these design procedures. It is shown that the AASHTO provides higher reliability values compared to the probabilistic procedure. Finally, the reliability of the flexible pavement design is evaluated by varying hot mix asphalt properties. Alternative designs are recommended for the existing pavement thickness by modifying material and subgrade properties to mitigate different distresses.

According to Rahman et. al (2011), design of flexible pavement is largely based on empirical methods using layered elastic and two-dimensional finite element analysis. Currently a shift underway towards more mechanistic design techniques to minimize the limitations in determining stress, strain and displacement in pavement analysis. In this study, flexible pavement modeling is done using ABAQUS software in which model dimensions, element types and meshing strategies are taken by successive trial and error to achieve desired accuracy and convergence of the study.

Ameri et. al (2012) have used finite element method to analyse and design pavements. Finite element method is able to analyse stability, time dependent problems and problems with material nonlinearity. In this paper, a great number of the prevalent pavements have been analyzed by means of two techniques: Finite element method and theory of multilayer system. Eventually, from statistical viewpoint, the results of analysis on these two techniques have been compared by significance parameter and correlation coefficient. The results of this study indicate that results of analysis on finite elements are most appropriately compiled with results came from theory of multilayer system and there is no significant difference among the mean values in both techniques.

Jain et. al (2013) discuss about the design methods that traditionally being followed and examine the "Design of rigid and flexible pavements by various methods and their cost analysis by each method". Flexible pavements are preferred over cement concrete roads as they have a great advantage that these can be strengthened and improved in stages with the growth of traffic and also their surfaces can be milled and recycled for rehabilitation. The flexible pavement is less expansive also with regard to initial investment and maintaince. Although rigid pavement is expansive but less maintenance and have good design period. It is observed that flexible pavements are more economical for lesser volume of traffic. The life of flexible pavement is near about 15 years whose initial cost is less needs a periodic maintenance after a certain period and maintenance costs very high. The life of rigid pavement is much more than the flexible pavement of about 40 years, approximately 2.5 times life of flexible pavement whose initial cost is much more than flexible pavement but maintenance cost is very less.

Dilip et.al (2013) discuss the uncertainty in material properties and traffic characterization in the design of flexible pavements. This has led to significant efforts in recent years to incorporate reliability methods and probabilistic design procedures for the design, rehabilitation, and maintenance of pavements. This study carries out the reliability analysis for a flexible pavement section based on the first-order reliability method and second-order reliability method techniques and the crude Monte Carlo Simulation. The study also advocates the use of narrow bounds to the probability of failure, which provides a better estimate of the probability of failure, as validated from the results obtained from Monte Carlo Simulation.

Maharaj and Gill (2014) performed axisymmetric finite element analysis by varying different parameters to develop design charts. The parameters varied are thickness of pavement, pressure and elastic modulus of subgrade. The pavement and base course has been idealized as linear elastic material while the subgrade has been idealized as nonlinear material by Drucker-Prager yield criterion. The pavement, base course and soil have been discretized by four noded isoparametric finite elements. Four types of design charts have been developed. Each of the design charts has three parameters. For two known parameters, the third parameters can be obtained.

Based on literature review it is found that very few literatures are available on design chart of flexible pavements. Important design charts have been discussed in the following section.

IMPORTANT METHODS FOR DEVELOPMENT OF DESIGN CHARTS FOR FLEXIBLE PAVEMENT

Group Index Method

The group index method was suggested by the Highway Research Board for making an approximate estimation of thickness of the pavement. The strength of the subgrade is determined by the group index method. The higher the group index of subgrade, the lower its strength and the greater the thickness of sub base required. Fig.1 gives the designed charts. The description of the various curves in the design charts are as follows:
Curve A: Thickness of sub-base required.
Curve B: Total thickness of surface, base and sub-base for light traffic.
Curve C: Total thickness of surface, base and sub-base for medium traffic.
Curve D: Total thickness of surface, base and sub-base for heavy traffic.
Curve E: Thickness as additional base which may be substituted for sub-base of curve A
Light traffic=<50 commercial vehicles/day
Medium traffic=50-300 commercial vehicles/day
Heavy traffic =>300 commercial vehicles/day.

California Bearing Ratio (CBR) Method

The method combines a load penetration test performed in the laboratory or in-situ with the empirical design charts to determine the thickness of pavement and of its constituent layers. This is probably the most widely used method for the design of flexible pavement. The thickness of the different elements comprising a pavement is determined by CBR values. The California bearing ratio, abbreviated as CBR is defined as the ratio of the test load to the standard load, expressed as percentage, for a given penetration of the plunger.

CBR = (Test load/standard load) x 100
Generally CBR values of both soaked as well as unsoaked samples are determined. The CBR values are usually calculated for penetration 2.5 mm and 5 mm. Generally the CBR values at 2.5 mm penetration will be greater than that at 5mm penetration and in such case the former is to be taken as the CBR value for design purposes. If the CBR value corresponding to a penetration of 5mm exceeds that for 2.5 mm, the test is repeated. If identical results follow, the bearing ratio corresponding to 5 mm penetration is taken for design. Fig.2 gives the design charts for determining the appropriate thickness of construction required above a material with a given CBR, for different wheel loads and traffic conditions. These design charts for roads have been proposed by the Road Research Laboratory, England, and are also followed in India.

North Dakota Method

This method, similar to the CBR method has been developed by the North Dakota State Highway Department. The method consists in finding out the in-situ bearing power of the subgrade by means of a cone penetrometer, of the North Dakota Cone apparatus. The thickness is then found from the design chart (Fig.3). The North Dakota cone apparatus consists essentially of a shaft with a sharp cone attached to lower end. The movement of the shaft into the soil measured with the help of a vernier. The load carried by the shaft, during penetration into the soil, divided by the area of the cone at the surface level is termed as the cone bearing value, q_c. Knowing the bearing value, the thickness of pavement is determined from Fig.3. A minimum thickness of 24 cm is provided for bearing values of 28 kg/cm^2 or more.

Burmister's Design Method

Burmister's design method is based on the concept of a two-layer system, consisting of the road surfacing, base course and the sub-base as the top layer of thickness h, and the subgrade as the bottom layer of infinite extent. The displacement of such a system, under a loaded area of radius a with load intensity p is given by

$\Delta=1.5\ (pa/E_2)F$
Where E_2=modulus of elasticity of the subgrade
F=deflection factor, determined from Fig.4.
The method consists in selecting various values of thickness h of the top layer and finding the value of the deflection corresponding to each value of h from above equation, the value of factor F being taken in each case from Fig.4. The thickness h corresponding to an arbitrary deflection of 5 mm has been recommended by Burmister as the required thickness of pavement. Tentative design curves for flexible runway pavement, using 5 mm as limiting deformation have been drawn assuming approximate value of modulus of elasticity for various types of sub-grades.

U.S Navy Plate Bearing Test Method

This method is also based on Burmister's two layer theory. It has the following steps:
Step1. The thickness h of the base course is calculated on the basis of the two-layer theory. From two plate bearing tests the values of modulus of elasticity E_1 and E_2 for the base course and sub-grade are determined. It is necessary first of determining the value of E_2 by the plate bearing tests on the sub-grade. A 30 inch diameter plate is recommended for this test. The load P corresponding to a deflection of 0.2 inch is determined from the test, and the modulus of elasticity E_2 is calculated from following equation by taking the plate to be rigid.
$\Delta=1.18\ (pa/E_2)F$
Where F is the deflection factor depending upon E_2/E_1 ratio. p is pressure and a is radius.
From above equation
$F= (\Delta.E_2)/(1.18pa)$
After having known E_2 and E_2/E_1, the value of F corresponding to a given wheel load intensity p is computed from equation
$\Delta=1.5\ (pa/E_2)F$, by taking $\Delta=0.2$ inch
$\Delta= 0.2$ inch $=1.5\ (pa/E_2)F$
In this equation Δ, E_2, p and a are known. Knowing F and E_2/E_1 ratio, the thickness h of the base course is determined from Fig.4.

Step2. In the next step, trial sections are constructed of thickness h, (2/3)h and (3/2)h. Each trial section of a given thickness is constructed for three different soil conditions. Thus, in all, nine trial sections are built.

Step3. Plate –bearing tests are performed on these trial sections. The data then are used to determine the required pavement thickness which will result in the assumed deflection of 0.2 inch.

Maharaj and Gill Method

Axisymmetric finite element analysis has been done by varying different parameters to develop design charts. The parameters varied are thickness of pavement, pressure and elastic modulus of subgrade. The pavement and base course has been idealized as linear elastic material while the subgrade has been idealized as nonlinear material by Drucker-Prager yield criterion. The pavement, base course and soil have been discretized by four noded isoparametric finite elements. First type of design chart has been plotted between thickness of pavement and nodal deflections for various pressures for a particular elastic modulus of soil. Second type of design chart has been plotted between thickness of pavement and element stress for various pressures for a particular elastic modulus of soil.
The third type of design chart has been plotted between thickness of pavement and nodal deflections for various elastic moduli of subgrade for a particular pressure. Fourth type of design chart has been plotted between thickness of pavement and element stress for various elastic moduli of subgrade for a particular pressure. Each of the design charts has three parameters. For two known parameters, the third parameters can be obtained. From the design charts developed, the effect of thickness, elastic modulus of soil and pressure on nodal deflection and element stress has been studied. Typical design charts for pavement thickness and element stress for various pressures for a particular elastic modulus of subgrade have been shown below:

Fig.5 shows the design chart which has been plotted between thickness of pavement and element stress for various pressures for a particular elastic modulus of soil. The thickness of pavement (asphalt concrete) varies from 100 mm to 400 mm; the pressure varies from 100 kN/m^2 to 3000 kN/m^2 and the elastic modulus of soil is 5000 kN/m^2. It can be seen that for a particular pressure the element stress reduces with increase in pavement thickness. This reduction of element stress increases with increase in pressure and is predominant at highest pressure. The design chart has three parameters. For any two parameters known, the third parameter can be obtained from the design chart. Fig.6, Fig.7 and Fig.8 are similar design charts as for Fig.5. In these design charts, the reduction of element stress with increase in thickness is predominant at higher elastic modulus of subgrade.

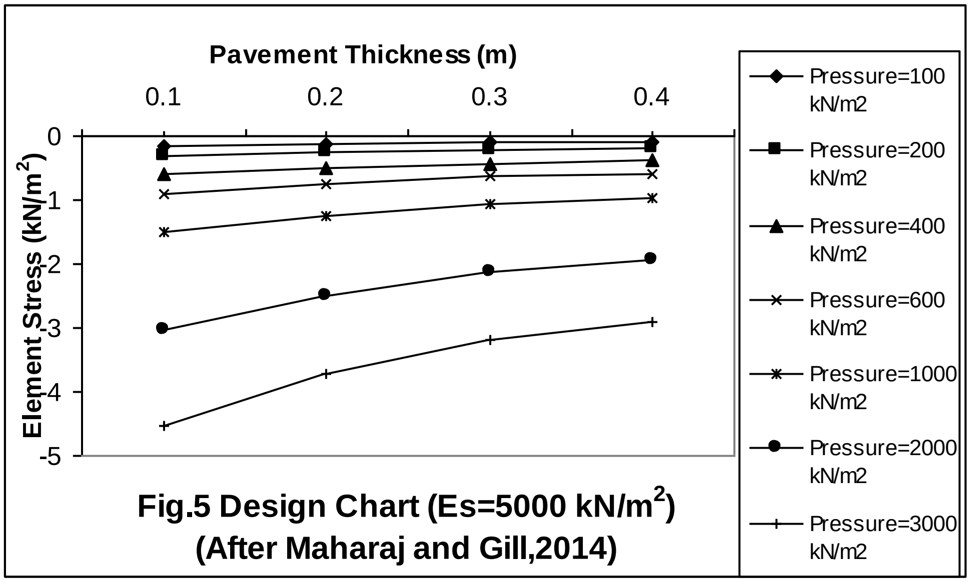

Fig.5 Design Chart (Es=5000 kN/m^2)
(After Maharaj and Gill,2014)

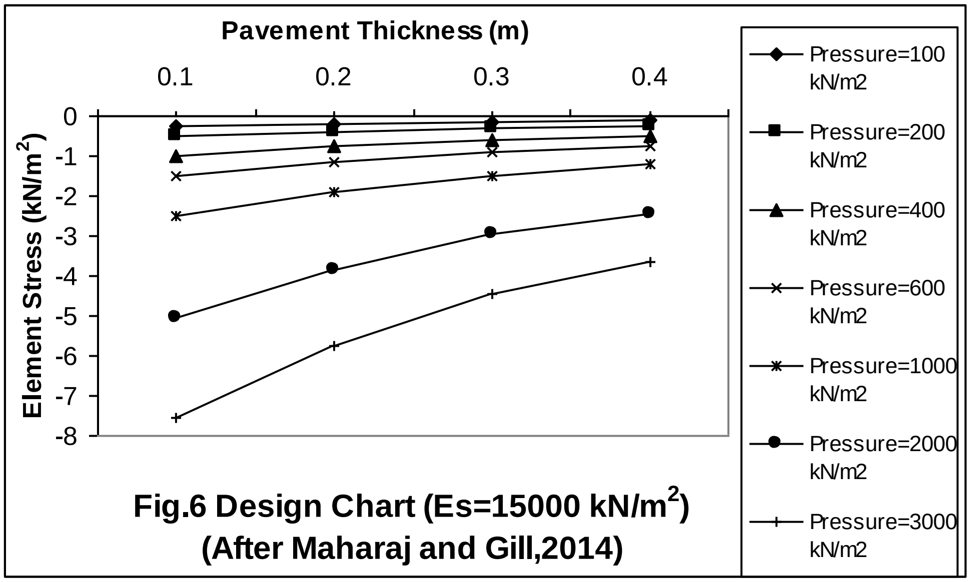

Fig.6 Design Chart (Es=15000 kN/m^2)
(After Maharaj and Gill,2014)

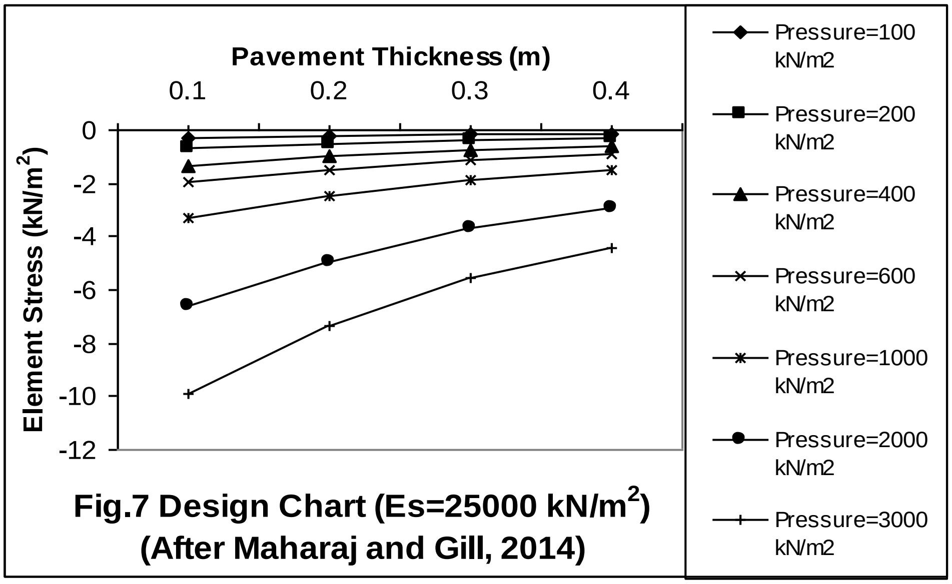

Fig.7 Design Chart (Es=25000 kN/m^2) (After Maharaj and Gill, 2014)

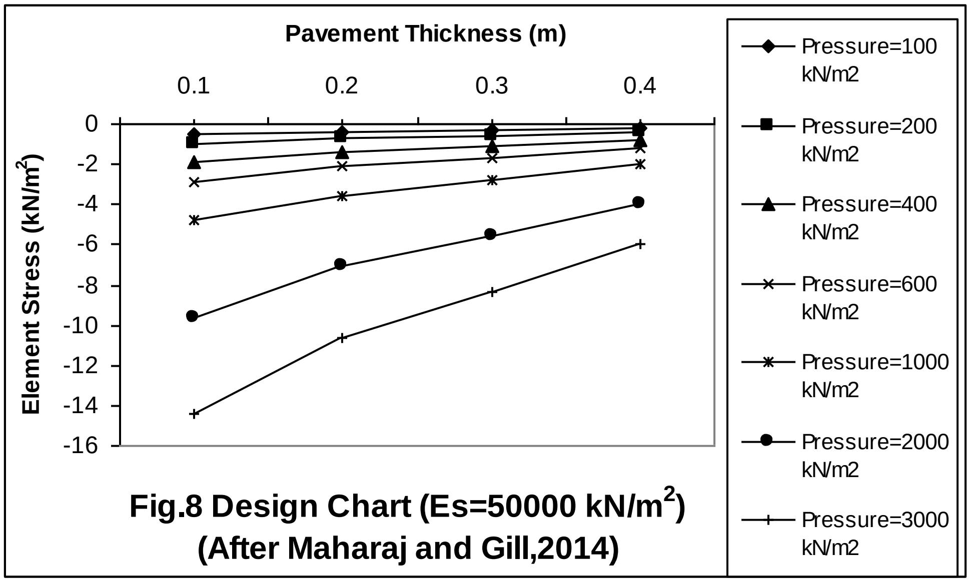

Fig.8 Design Chart (Es=50000 kN/m^2) (After Maharaj and Gill,2014)

CONCLUSIONS

The advantages of Group Index Method are that the total thickness of pavement (Surfacing, base and sub base) is determined. Also the thickness of sub base is determined.

Higher the group index, poor is the sub-grade and lower the group index, stronger is the subgrade. The CBR method is probably the most widely used method for the design of flexible pavement. The CBR method is based on strength parameter of the material and is, therefore, more rational than the Group Index Method. The shortcoming of the method is that it gives the same total thickness above a material irrespective of the quality of the overlying layers. North Dakota Method is similar to the CBR method. Pavement thickness is found from the design curve which is between pavement thickness and cone bearing ratio. The Burmister's Design Method is based on the concept of two-layer system, consisting of road surfacing, base course and the sub-base as top layer of thickness h, and the sub-grade as bottom layer of infinite extent. In this method, the thickness corresponding to deflection of 5 mm has been recommended by Burmister as the required thickness of pavement. U.S. Navy Plate Bearing Test Method is also based on Burmister's two-layer theory. This method also uses modulus of elasticity of base course and sub-grade. California Resistance Value Method uses California Resistance value, called R-value. In McLeod Method curves are plotted between depth of construction and CBR for traffic conditions. Maharaj and Gill have performed axisymmetric finite element analysis by varying different parameters to develop design charts. The parameters varied are thickness of pavement, pressure and elastic modulus of subgrade. The finite element method is a versatile tool for solving complex problems like various layers of pavement. Four types of design charts have been developed. First type of design chart has been plotted between thickness of pavement and nodal deflections for various pressures for a particular elastic modulus of soil. Second type of design chart has been plotted between thickness of pavement and element stress for various pressures for a particular elastic modulus of soil. The third type of design chart has been plotted between thickness of pavement and nodal deflections for various elastic moduli of subgrade for a particular pressure. Fourth type of design chart has been plotted between thickness of pavement and element stress for various elastic moduli of subgrade for a particular pressure. Each of the design charts has three parameters. For two known parameters, the third parameters can be obtained

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