LOW-VOLUME FOREST ROADS. PAVEMENT THICKNESS COMPUTATION FOR ENVIRONMENTAL PROTECTION

P.Eskioglou, A. Stergiadou
Aristotle University of Thessaloniki, Dept. of, of Forestry and Natural Environment
Laboratory of Mechanical Sciences and Topography, 54124 , Thessaloniki , Greece
E-mail: pxeskio@ for.auth.gr;nanty@for.auth.gr

ABSTRACT

Forest road construction is an important aspect of forest management and the design of pavement thickness of forest roads has been associated with environmental protection, since the smaller thickness leads to erosion whereas a bigger than the normal signals over-consumption of raw material and energy In this paper a new method is proposed for the estimation of pavement thickness in forest roads .This method is based not only on bearing capacity (CBR) but on the circulation load associated with transported wood volume. Other variables include tire pressure, aggregate thickness, load and number of repetitions. A companion computer program, known as the surfacing –thickness-program is also included to assist in the structural design of aggregate-surfaced roads.

1.INTRODUCTION

The calculation of the layer thickness of pavement, besides being a technical is also an environmental problem, since the smaller thickness leads to erosion and losses of soil mass whereas a bigger than the normal signals over-consumption of raw material and energy[6].In the forest roads, a precise design of pavement is required in order to avoid the above negative impacts.

On the other hand, although all flexible–pavement design methods must consider the factors of subgrade and pavement layer strength and composition, load and traffic characteristics, environmental conditions and economics of design and construction, design philosophies between highway and low-volume forest road differ. Principal among these differences is the design number of stress repetitions, type of vehicles and the composition of the traffic.The forest road may only carry less than 100 vehicles a day, the greatest percentage of these vehicles (80%-100%) are heavy trucks, which affect the pavement life appreciably[4,5].

As a calculation basis is taken the design set out by the AASHO method[1]. Some researchers, beginning from the acceptance of this method, have modified and adapted it to the conditions prevailing in their research fields [4]. Burlet, after research, has given an equation by which he calculated the structural number SN (an index number that may be converted to thickness of various flexible pavement layers) for low-volume roads in respect to the soil resistance, the traffic load W and the local factor taking the prices R=1, 1.5 and 2, when the road is at elevations up to 400m, 400-80m and over 800m, respectively[3].

In 1988, the U.S Forest Service rewiewed the current direction regarding the design of aggregate and asphalt road surfacings and produced a "Surfacing Design Evaluation report" for internal use and discussion [8]. Two key recommendations resulted from that report and they were: Adopt the revised 1986 AASHTO Design Guide and develop a Surfacing Design Guide for aggregate and unsurfaced roads using existing technology[2].

Concurrently, USDA developed the STP method by which, via a simple program in BASIC, gives the required layer thickness of pavement for aggregate roads and earth roads while at the same time it also defines the thickness of layers required for the maintenance of these roads when they have suffered a specific damage and rut depth from the truck wheels [9]. The problem arising form the above dominant methods is the difficulty for calculating the traffic load, the type of trucks and the composition of traffic in the forest roads.

For this reason, in the present paper, a new method for calculating the traffic load of forest roads is developed using as criteria some factors which can be easily determined for any time length. By this method, the dominant regulator of the load is the type of trucks, the needs for which the trucks are used (needs for forestry or recreation of people) and finally the transported amount of timber.
By this manner, the above two methods (Burlet and STP) acquire a new tool that makes easy the process of calculating the layer thickness of pavement and finally a new computer program is compiled that makes easier and faster the solution of the problem.

2. MATERIALS AND METHODS

2.1 Research area

For the purpose of this research work we have selected the eastern forest complex of Drama ,with an area of 76000Ha, wood stock volume at 5.000.000 m^3 and an annual increment(timber cut) at 180.000 -200.000m^3 ·The forest road studied is the road Kentrika- Paranesti, which is crossing the central area of Eastern Rodopi and has a geological support of calcareous sandstone and estimate sub-grade resistance CBR =6.This road, receives the wood transportation of 59.000m^3 annually or 25MMBF.For the examination of the impact of wood transport with vehicles we have studied the composition of circulation, vehicles types, the number and the weight of axle load under the present circulation conditions on the basis of transportation and technical specifications of manufacturing companies.

2.2. Materials

The methodological priorities of this paper are focused on: a. the estimation of circulative equivalent axle load, b. the estimation of a number **n** which implies how many equivalent standard axles (E.S.A.L.) carry 1m^3 of wood, c. the creation of mathematic relation that would then express the circulatory pressure concerning the transported quantity of timber, d. the estimation of structural number (SN) and e. the application all above in the program STP,so that is calculated essential.

2.2.1. Estimation of equivalent standard axle load (ESAL)

Most of the methods of pavement design use as a design input value the equivalent 80KN single axle load (ESAL) repetitions as the indicator of load and traffic intensity. This load with a tire pressure of 80psi has been selected as the standard axle type. The axial loads are converted in to equivalent axles, from relations and the equivalent damage effects of all other vehicle types in terms of ESALs can then be determined [9].Table 1 summarize the equivalency factors for various axle loads and configurations, for 80 and 100psi tire pressure

TABLE 1. Equivalency factors for tire pressures of 80 and (100) psi

Weight of axle	Equivalency factor for different type of axle		
KN	Single axle single wheel	Single axle dual wheels	Tandem axle dual wheels
44.5	0.45 (0.76)	0.33 (0.55)	0.13 (0.21)
53	0.64 (1.00)	0.48 (0.80)	0.18 (0.30)
62.3	0.86 (1.44)	0.62 (1.10)	0.24 (0.40)
80	1.4 (2.32)	1.00 (1.70)	0.38 (0.64)
106.8	2.4 (4.00)	1.75 (3.00)	0.66 (1.10)
124.5	3.2 (5.36)	2.30 (4.00)	0.89 (1.50)
133.5	3.7 (6.11)	2.65 (4.40)	1.01 (1.70)
178	6.3 (10.6)	4.50 (7.60)	1.75 (2.90)
195.7		5.20 (9.00)	2.10 (3.50)
204.5		5.85 (10.0)	2.30 (3.80)
213		6.70 (11.0)	2.47 (4.10)

2.2.2 Estimation of a factor n

Having calculate the equivalency factor for different type of axle, we can create Table 2 which presents the vehicles which circulated in the forest road with their technical and transportation specifications. In column 1 we can see the type of vehicles and the traffic percentage while in the second column the distribution of the vehicles axle load. In the third column is shown the equivalent standard axle load of vehicles and in column 4 the total equivalent load for each vehicle. Finally in column 5 we see the quantity of wood transported (for each vehicle) and in the last column the coefficient **n** which expresses the number of equivalent standard axle load of vehicles which transport $1m^3$ of wood. This is derived from the division of the total ESAL through the quantity of wood volume transported and is one and only for every vehicle

TABLE 2: Technical and transportation specification of vehicles 2, 3 and 4-axles (axl) under normal conditions for tire pressures of 80 psi

Vehicles Type (Traffic percentage %)	Axle load distribution KN	Equivalent Axle load Distribution (ESAL)	Total ESAL	Quantity of Wood Transported m^3	Coefficient of E.S.A.L load which transport 1 m^3 n
Mercedes 2axl. (8)	60 / 130	0.84 / 2.60	3.44	14	0.240
VOLVO 3axl (40)	60/ 200	0.84 / 2.2	3.04	22	0.138
Mercedes 3axl (37)	70 / 200	1.2 / 2.2	3.4	24	0.141
DAF 4axl (7)	50/60/ 220	0.62/0.6/ 2.65	3.87	28	0.138
Merc./ MAN (8)	55/ 55/ 270	0.68/0.5 /3.2	4.4	36	0.122

Because there are various truck types with different prices of coefficient **η,** its final price is calculated by quota. If there are α% vehicles with coefficient η_1, β% with coefficient η_2 and γ% with η_3, the coefficient will be equal to $\boldsymbol{\eta} = \alpha\% \cdot \eta_1 + \beta\% \cdot \eta_2 + \gamma\% \cdot \eta_3 ..$ (1)

2.2.3. Estimation the circulatory pressure concerning the transported quantity of timber

The traffic load of a forest road -after modifications- for a time span of **v** years will be given by the following formula[didk]: $W = Q \cdot v \cdot n\,(1+z)$ (2)

where **η** = the factor which implies how many (E.S.A.L.) carry 1m3 of wood and is equal to $\alpha\% \cdot \eta_1 + \beta\% \cdot \eta_2 + \gamma\% \cdot \eta_3 + \ldots \mu\% \cdot \eta_\mu$ .This factor ranges between 0.12 -0.24

α,β,γ…= the percentage of traffic with the respectively price of factor $\eta_1, \eta_2, \eta_3 \ldots$

Q = the annual transported amount of wood.

z = the additional rate of trucks traveling with no wood load. This percentage extends to 25% and refers to recreation and social necessity [7].

In the forest roads, where trucks constitute the main volume of this load, a percentage 70-90% - in proportion of the road function - refers exclusively to wood transportation. This means that pavement thickness depending on the quantity of wood transported and on the number **n.**

2.2.4 Calculation of Structural Number (SN)

Finally for the calculation of the case-depending structural number SN of resistant pavement, there was initially used the Burlet's equation [7] in which the standard variables are the traffic load equivalent axle load (80KN) =W, the local factor R which is related to the altitude of the area and the bearing capacity ratio of subgrade CBR for terminal service ability (pt) = 1,5

$$SN = \frac{2{,}67(W.R)^{0{,}1068}}{10^{0{,}1647 - \log CBR - 0{,}655}} \qquad (3)$$

In this formula, we replaced the local factor R by the price 2, since the forest roads of the under research area are found in altitude over 800 m, and the vehicle load W from prices of equivalent axles (ESAL), by the formula (3) related to the transported wood volume Q and coefficient **η**.

After this replacement , the Burlet equation diverts into

$$SN = -2.54 + 10^{\,0.52416 - 0.16471\log CBR + 0.10681\log[(Q \cdot v \cdot n)(1+z)]} \qquad (4)$$

The solution of the above equation results in a design SN. Based on the above equation we can design nomographs for SN calculation, for various transported amounts of wood, prices of **n**, for soils with various resistance CBR and in a time span of 20 years. Such nomographs can be constructed for each research area.

2.2.5. Calculation of ESAL from the program STP

Having calculate the rate of factor **n** we can work on STP program by introducing the data on traffic information table and ESALs are automatically calculated Secondary we put the materials information and finally we get the calculate results (Figure 1).

It follows a comparison between the ESAL number, estimated by the STP method and the ESAL number estimated by the equation 2

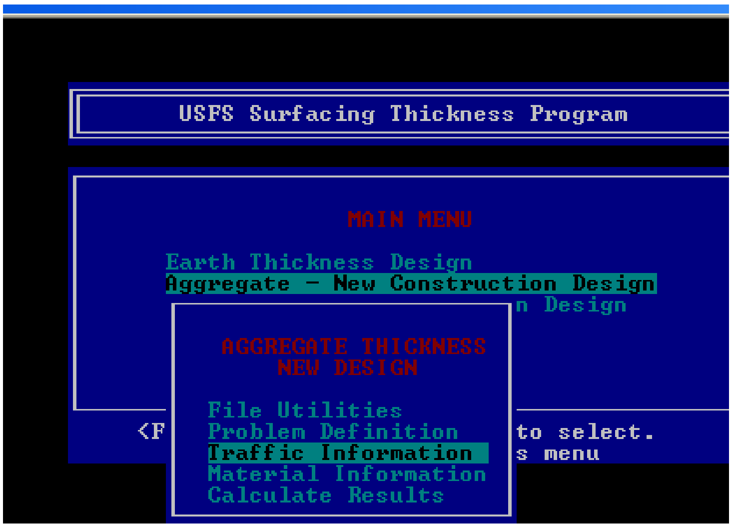

Figure 1. The main menu of the ST Program for aggregate Thickness new design

3.RESULTS

3.1.Results based on the STP program

After the insert of data in the field of traffic information, we can calculate the timber volume ESAL and the total ESALS. In addition, the computer program has defaults present to assist the designer. The defaults used are summarized below : Reliability factor =1, Timber Conversion factor to 1 standard log truck =9322BF (when 1BF =2,36.10^{-3}m^3 and 1 Standard heavy Vehicle = 9322 BF = 22 m^3). Figure 2 shows that timber volume ESAL= 10627 and the total ESALS= 10996.

Secondary we insert in the program the material information(Subgrade and surface CBR for different season) and Figure 3 shows the above information .

Finally Figure 4 shows the Calculate Results.Here the defaults used are : Allowable rut depth =2 in., layer of aggregate strength coefficient=0,13 ,aggregate loss (typically 1inch for 10MMBF) .In the research area the final calculated results are: Structural Thickness =11 inches and Total Aggregate Thickness =12 inches or 28cm and 30,5cm respectively. Also, the damage ratios 0,77 and 0,21 for the first and second season respectively, was calculated .

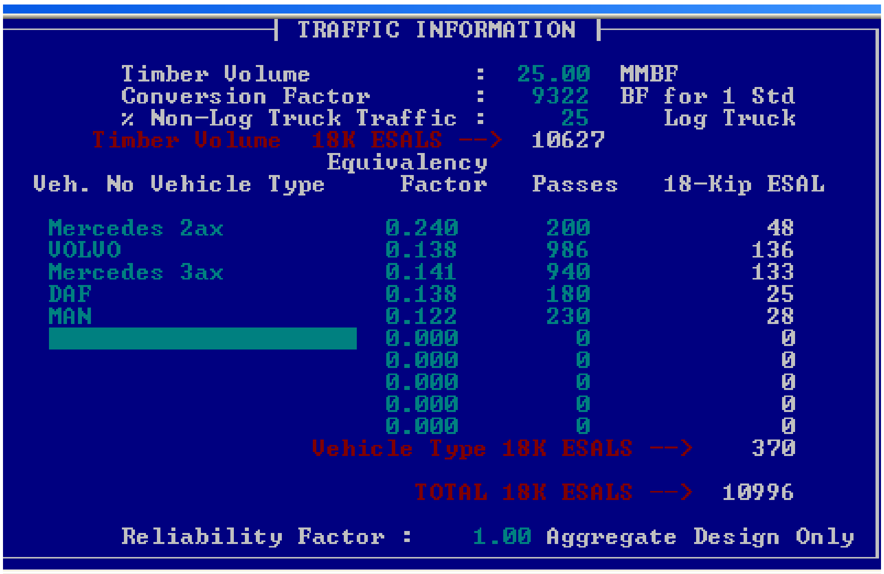

Figure 2. Calculation of ESAL in the research area by STP program

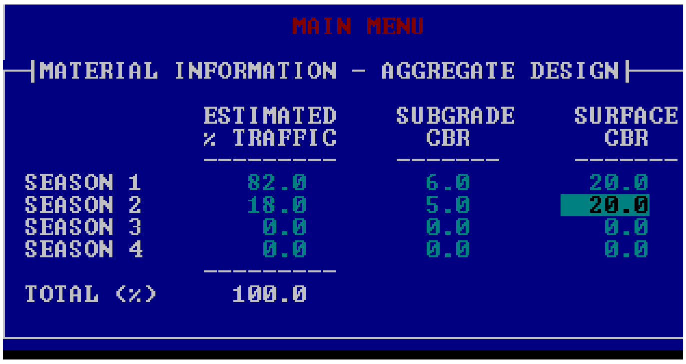

Figure 3. Material information for aggregate design

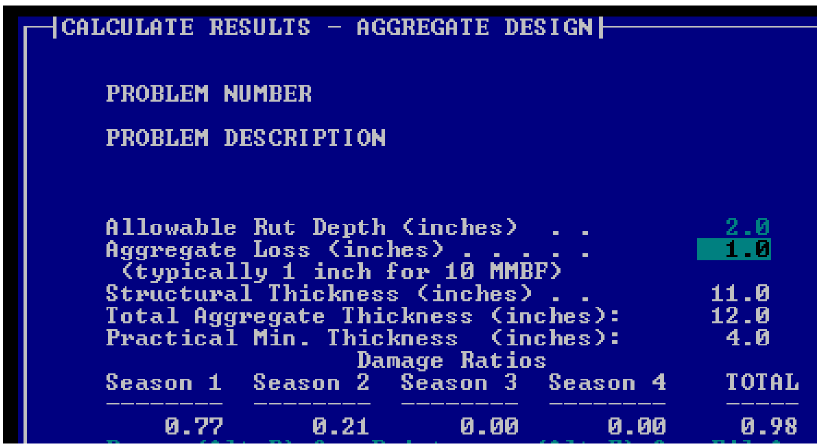

Figure 4.Calculate Results (Rut depth,structural and aggregate thickness) by STP method

3.2.Results based on the new method eskio-surfacing thickness

The value of the factor **n** is calculated as below :

n = 0,08.0,24+0,4.0,138+0,37.0,141+0,07.0,138+0,08.0,122=0,147

when (0,08),(0,4), (0,37) and (0,07) are the frequencies of the vehicle traffic - on the research area - as we can see in the first column in Table 2.

If we wish to calculate the total ESALS with the new method, we need to replace in the equation the factor **n** by the price 0,147 , the annual transported amount of wood Q by the price 59000m^3, and the percentage non-log truck factor z by the price 25% .Then the total ESALS for a span of 1 year is calculated

W =Q.n.(1+z) = 59000 m^3.0,147.1,25 = 10841ESAL. If we compare the results of these two methods we will find that they are approximately the same.

If we wish to calculate the structural Number (SN) with the new method, we need to replace in the equation $SN= -2.54+10^{0.52416-0.16471logCBR+0.10681log [(Q . v . n) (1+z)]}$ the CBR by the price 6, the factor [(Q.ν.η)(1+z)] by the price 10841ESAL and the SN is calculated equal to 4,1.

From the relation "SN = D*ai " (5)

when D= thickness of aggregate pavement layer

(a_i) = 0,13 =strength layer coefficient

was calculated the thickness D= 31cm or 12,2inches .So the results of the two methods are approximately the same.

Finally the following computer program, known as eskio- surfacing –thickness-program is also developed to assist in the structural design of aggregate-surfaced roads.

```
 100   CLS
 200   INPUT "Q";Q
 300   INPUT  "ν";ν
 400   INPUT  "n";n
 500   INPUT   "K";K
 600   INPUT  "CBR";CBR
 700   LET  W= 100*Q*ν*η
 800   LET  D =W/K
 900   F  =  log10(D)
1000   LET  a= CBR
1100   U= log10(a)
1200   Y = 0.52416-0.1647*U+0.1068*F
1300   SN = 10^Y-2.54
1400   PRINT     ‘‘ Y   =’’ ; Y ;
1500   PRINT     ‘‘ SN =’’ ; SN ;
```

4. CONCLUSIONS

Based on the above results, the following conclusions can be drawn:

1. The main factor which affects the design of pavements thickness is the traffic flow of road, with particular interest to the type and the loading of vehicles. In the forest roads, where trucks constitute the main volume of this load, a percentage 60-90% - in proportion of the road function - refers exclusively to wood transportation. This means that pavement

thickness depending on the quantity of wood transported and on a number **n** which is one and only for every vehicle .

2. For this reason, it was created 2 Tables. The first summarizes the equivalency factors for various axle loads and configurations, for 80 and 100psi tire pressure. The second shows the quantity of wood transported (for each vehicle) and the coefficient **n** which expresses the number of equivalent standard axle load (E.S.A.L.) of vehicles which carry $1m^3$ of wood and is derived from the division of the total ESAL through the quantity of wood volume transported .
3. After the calculation of the rate of **n** factor, it was developed the equation W= Q.n.ν.(1+z).This equation estimating the traffic load , if it is known the annual transported amount Q of wood and the percentage z of non-log truck traffic.
4. In the formula of Buret, we replaced the local factor R by the price 2, and the vehicle load W from prices of equivalent axles (ESAL), by the above equation related to the transported wood volume Q and coefficient **η**, and after this replacement , the Burlet equation diverts into $SN= -2.54+10^{0.52416-0.16471 \log CBR+0.10681 \log [(Q \cdot v \cdot n) (1+z)]}$ The solution of the above equation results in a design SN.
5. A computer program, known as eskio- surfacing –thickness-program is also developed to assist in the structural design of aggregate-surfaced roads.
6. Finally the results of the new method was compared with the results from the STP method. Comparing the two methods, we can conclude that the results are approximately the same.

REFERENCES

1. AASHO.(1972)'**AASHO Interim Guide for Design of Pavement Structures',**Washington, D.C.
2. AASHTO (1986) '**Guide for Design of Pavement Structures',** American Association of State Highway and Transportation officials.
3. Burlet E.(1980) 'Design and reconstruction of low volume roads with flexible pavements', **PhD-Thesis No 6711**. Swiss Federal Institute of Technology ETH.
4. Eskioglou P.(1991) 'Durables and economics pavements on the mountainous forests'**, PhD-Thesis.** Dept. of Forestry.Aristotle University of Thessaloniki.
5. Eskioglou P. and P. Efthymiou (1995) 'The impact of wood transportation with overloaded vehicles on the dimensions and the duration of road pavements'**.** Proc. Int. Conf. **Harvesting Early Thinnings cost Effectivelly** (eds. L.Buvarel and P.Kofman), Limoge, France,1995.
6. Eskioglou P. (2001) 'The reduction of the destructive elements of forest road construction projects', Proc. Int. Conf. **Ecological protection of the Planet earth I,** (eds.V.A.Tsihrintzis and Ph. G.Tsalides) Xanthi, Greece, 2001.
7. Stergiadou A. (2002) "Flow environment at road transportations in mountainous areas', Proc. Nat.Conf. **Greek Business Research Union XV,** (eds.EEE)Tripoly,Greece,2002.
8. USDA Forest Service(1988) '**Surfacing Design Evaluation Report',** Technical Report ,USDA Experiment Station, Washington .
9. Whitcomb W., M. Yapp and M. Myers (1990) ' **Aggregate Surfacing Design Guide'**,USDA Forest Service