

FOREST ENGINEERING AND ENVIRONMENT PROTECTION

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EXTENDED ABSTRACT

The forest ecosystems are dominant ecosystems in our planet and contribute decisively to the protection of the environment. Their protection and their sustainability are carried out by technical and biological interventions. The scientific part which protects the forests, is technically the Forest Engineering which is devoted to designing, controlling and developing technical systems in forestry such as transportation systems and systems to influence natural processes in mountainous regions (erosion, water hazards and landslides). The soil erosion in the forest ecosystems is a phenomenon with severe impacts not only to them but also to the wider environment. More specifically, the erosion for which are liable the non-environment-friendly forest opening-up and forest road construction works, is one of the most severe contemporary problems which the forest engineers are called upon to solve out with direct interventions aiming at their minimization.

In our laboratory, during the recent years, we are working out towards this direction in order to record the causes that create erosion. Such causes are the slopes and the cross-sections of the forest roads which do not help in removing away the precipitations, the entrance of forest works machinery which are incompatible to the topographic relief, and finally the improper design of pavements of the forest roads.

In our paper, conducted in the area of Pertouli University Forest at an altitude of 1000 m and with a fir forest vegetation, are presented the results of a research which includes: a) The best opening-up, the correct layout of a forest transportation network and the rational introduction of transportation means in respect to the cross-cut gradient and the surcharge of soils, following a data processing by the Geländeklassifikation und Abgrenzung der Rückeverfahren Program, β) Stabilization of experimental plots in high slopes of forest roads with a gradient up to 75%. It has been proved that the combination of plant coverage, bitumen emulsion and marble dust provides the best economic and technical results, c) Economic planning for a resistant layer thickness of forest roads, emphasizing on the calculation of the trafficking load so that to avoid the over-consumption of natural resources on one hand and the erosion on the other, d) Development of a vulnerability model for gully and pothole distresses of aggregate surfaced low-volume roads. It was found that the Cambered cross - section grading reduces gully distresses by a factor of about 2 compared with horizontal grading, and canopy protection of roads reduces gully occurrence by a factor 1.4

Key words: Forest ecosystem, forest road, slope stabilization, soil erosion, expression Burlet, vulnerability, gully, pothole.

1. INTRODUCTION

Forest Engineering is the scientific space which deals with the environment protection during the planning and construction of technical projects in the Forest Ecosystems. Because these works hurt the forest on one hand but also have impacts on the broader environment on the other, there should be investigated all factors which are liable for its degradation. One of these factors is the soil erosion which is ought to the opening-up and the construction of forest roads in inclined forest areas. From research, it was shown that this phenomenon may be diminished if we succeed in the best opening-up and the optimum forest road density [1]. Also, the road deterioration due to surface erosion depends on cross-section and layer thickness of road pavement [2], [3]. In our laboratory, was carried out a research and were announced the interventions onto the forest space for the environment protection and the prevention of erosion. Particularly, it was implemented the stabilization of forest roads with industrial by-products such as red mud, marble dust and flyash [4], while vehicle types were recommended -principally four-axial and three-axial- which apply a less load on the soil during the forest works [5]. Also, we estimated the soil distortion and the erosion caused by the use of overloaded vehicles or wheels bearing tires of different width and pressure [6]. Our recent research efforts aiming at limiting the erosion, are directed towards the reduction: (a) of the soil distress in conjunction with the introduction of transportation means compatible to the ground relief and the accomplishment of the forest opening-up by a forest transportation network, (b) of the negative effects of precipitations by the stabilization of the big gradient of slopes and the selection of the appropriate cross-cut of forest roads, (c) of the overuse of raw materials and natural resources by the design and reconstruction of low volume roads with flexible pavements. In this paper the research results of the above directions, are shown.

2. METHODOLOGY

The research was conducted at Pertouli University Forest. The trial was established on flysch at the shoutheast side of the mountain Pindos at an altitude 1000m. Pertouli site was chosen as trial site , where phenomena of soil erosion had been observed because of bad climatic conditions and big depth of embankment. The annual rainfall at the trial site was 1300 mm, the slope of embankment 75% wile the main species of vegetation of the area is Abies

The present investigation aims to develop an analytical road spacing model for steep slope conditions, and to evaluate a model for specific harvesting situations For the soil classification in relation to the cross slopes and the respective selection of the suitable transportation means which will cause the less damages on the soil, it was used the Swiss program Geländeklassifikation und Abgrenzung der Rückeverfahren PC prog. In the map of the research area various ground points are placed depending on their position on the road, and their horizontal and vertical distance as well as the cross-cut gradient are measured. Working out all the above data in the computer, the inclined length of the slope, the average cross-cut gradient, the ground accessibility gradient, the optimum opening-up and the road density are assessed and it is proposed if wood removal can be done by skidding, tractor, truck or by cable-crane.

Although the most common method of combating the problem of slope stabilization is the use of vegetation, we investigated the possibility of using a combination of plant cover, bitumen emulsion and marble dust. The seeding mixture contains: Lolium regidum (15%) ,Festuca aruddinacea and ovina (28%) , Cinodon Dactylon (15%) , as well a mixture of Trifolium, Lotus, Fachelia and Thymus (27%). Additionally, fertilisers, adhesive, and tyrph

were used for better adhesion of the above mentioned seeding mixture. Two types of bitumen emulsion were used, an anionic slow setting, BAE (SS -1, according to ASTM) and a cationic slow setting, BCE (CSS-1, according to ASTM). The emulsions had the following properties (Table 1)

Table 1. Properties of mulching bitumen emulsions

| Characteristics | BAE | BCE |
|---|----------|----------|
| a. Tests on emulsion | | |
| Viscosity , Saybolt Furol at 25° C,sec | 32 | 28 |
| Storage stability test , 24 h,% | <1 | <1 |
| Cement mixing sieve test, % | <2 | <2 |
| Sieve test | <0.1 | <0.1 |
| Residue by distillation, % | 59 | 61 |
| Particle charge test | negative | positive |
| b. Tests on residue from distillation test , % | | |
| Penetration,25°C,100g,5sec,0.1 mm | 112 | 107 |
| Ductility, 25°C, 5cm/min,cm | >40 | >40 |
| Solubility in trichloroethylene, % | 99 | 98.5 |

The use of bitumen emulsions in mulching is very old. Their energy consumption is very low, they are applied under normal conditions, they are cheap and environment friendly. (Also the emulsion which is sprayed directly onto seeded area, cover holds the seeds and prevents their loss by the eroding forces of wind and water, absorbs and holds solar heat during the germination period and tends to hold moisture in the soil, thereby promoting faster plant growth). Marble treatment waste consists of marble dust (80%) and water (20%) approximately. Marble dust is pure CaCO₃ (98%). There are factories for treating marble in the territory, producing annually more than 2.000 MT of waste. So, marble treatment waste use can minimize their deposits which cause huge environmental problems. Three areas of research were monitored , with a surface of 100m² each of them , where the treatment was done as follows: in the first, only with hydroseeding with the specific seeding mixture, in the second, with hydroseeding with the specific seeding mixture and the use of (BAE) Emulsion and Marble treatment waste (MTW) in dry form , and in the last with hydroseeding with the specific seeding mixture and the use of (BCE) and Marble treatment waste (MTW) in dry form. The applied quantities of the materials are 50 gr/m² for hydroseeding mixture and 150 gr/m² for BAE, BCE and marble waste. The time of application by mulching and use of bitumen emulsion and marble treatment waste was March 2001. A modified piece of equipment by a Greek company (Aktis S.A) was used for the application of the materials.

To assess the surface erosion and the probability of distress occurrence there have been studied 8 combinations of 3 factors 'cross-section grading pattern', 'canopy protection ' and 'precipitation', and two types of distresses were investigated , erosion gullies and potholes. Wherever there was canopy protection and horizontal cross-section pattern we put 0 in the binary notation, while for cambered and no canopy we put 1, for the formation of the vulnerability model .

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 regional 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

$$SN = \frac{2,67(W.R)^{0,1068}}{10^{0,1647-\log CBR-0,655}} \quad [1]$$

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 in a formula related to the transported wood volume Q and a coefficient η . The coefficient η – which is one and only for every vehicle - expresses the number of equivalent standard axle load of vehicles which carry 1m^3 of wood. This is derived from the division of the total ESAL course divided by the quantity Q of transported wood volume. Because there are various truck types with different prices of coefficient η , its final price is calculated by quota. If there are $\alpha\%$ vehicles with coefficient η_1 , $\beta\%$ with coefficient η_2 and $\gamma\%$ with η_3 , the coefficient will be equal to $\eta = \alpha\% \cdot \eta_1 + \beta\% \cdot \eta_2 + \gamma\% \cdot \eta_3$.

3. RESULTS

3.1. Opening-up ,layout of forest transportation network and means

By processing the map data of the under research area, the soils were classified in relation to their cross-cut gradient. It was found that the maximum gradient of truck road is 12%, while for second order transportation is 20% for skidder and 60% for yarder-based extraction. The respective use of such machinery minimizes the soil erosion. Also, it was planned an idealized three-dimensional model of road network layout on steep slopes for the optimist design of opening-up and road density (see Figure 1). The model takes into account two classes of transportation lines: a. truck roads, b. skid roads and cable roads respectively The theoretically optimum density is achieved in the fir functional class at 18 m/ha and the economically optimum one at 24m/ha. Also, we can see that Road spacing on slopes depends on the underlying off-road transportation technology.

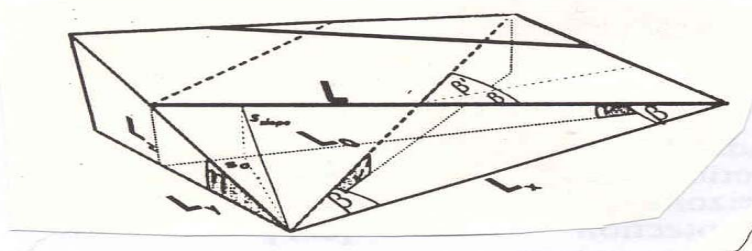


Figure 1. Three- dimensional model of a transportation network. L, length of road segment ; s, road spacing; n, slope grade; v, maximum grade of transportation line

3.2. Slope stabilization

The results of slopes stabilization are shown in photo 1. Left. Intense erosion before stabilization. Right. After two years of application (March 2001 –March 2003), we have noticed the following results: Great soil erosion has occurred in area I , because only hydroseeding was applied. No soil erosion has occurred in areas II, III because of the positive combination of hydroseeding ,bitumen emulsion and marble treatment waste. Compared to the plant coverage, 60-70% with BCE was measured, since the corresponding amount of coverage with BAE was 50 –60%. The result is because BCE

and MTW have different electric charge and, due to this reaction, a stronger net was created keeping the seeds more steadily in the ground.



Photo 1, 2. Erosion phenomena in the research area. Results from the stabilization

3.3. Vulnerability model for gully and pothole distresses

Equation (2) gives the model fitted for erosion gullies and equation (4) for potholes. Logistic regression analysis results in relationship (2). To get the probability, the logit-transformed response variable has to be re-transformed using equation (2)

$$\text{Logit (gully)} = - 5.39 + 2.28 \cdot G - 0.3 \cdot \text{CSP} - 2.25 \cdot \text{CP} + 0.49 \cdot G \cdot \text{CSP} + 1.46 \cdot G \cdot \text{CP} \quad [2]$$

where G = Road gradient (%)

CSP = Cross-section grading pattern. 0 for horizontal and 1 for cambered

CP = Canopy protection. 0 for existing and 1 for no canopy

$$P = \frac{e^{\text{logit}}}{1 + e^{\text{logit}}} \quad [3]$$

Where p = probability of gully occurrence [0...1]

Logit = value calculated by equations 1 and 3

$$\text{Logit (potholes)} = - 2.31 - 0.34 \cdot G + 1.5 \cdot \text{PR} + 0.36 \cdot \text{CP} + 0.26 \cdot \text{PR} - 0.1 \cdot G \cdot \text{PR} + 1.5 \cdot \text{CP} \quad [4]$$

where G = Road gradient (%)

PR = Precipitation . 0 for 1400 –1600mm/a , 1 for 1600-2000mm

CP = Canopy protection. 0 for existing and 1 for no canopy

The results of the study will have several management implications for forest roads. Figure 2 visualizes equations [2] and [3] and also summarizes the results by adding gully and pothole erosion probabilities for extreme variable values resulting in lower and upper erosion distress limits. To minimize the overall erosion risk, road gradients for aggregate – surfaced forest roads should be between 2% and 4%. If a cambered cross-section pattern is built and maintained, road gradients between 0% and 8% are within an acceptable range, and even gradients of 12% increase the erosion risk only by a factor of two. Horizontal cross-section patterns should be avoided. For the investigated area it doubles the erosion risk of the pavement structure compared with horizontal grading. Increasing road gradient from 2% to 12% multiplies the probability of surface erosion by a factor of six compared to a factor of 3 for the cambered cross-section.

Occurrence of potholes is opposing to that one of erosion gullies. The probability of potholes is maximal at a road gradient of 0%, and decreases considerably down to zero at a road gradient of 5%. This finding quantifies what practitioners know from their

experience . It was assumed that cross – section grading patterns would also influence the building of potholes. The analysis did not support this hypothesis. The main reason is probably structure of data. The study area is located in mountainous conditions where steep road gradients dominate.

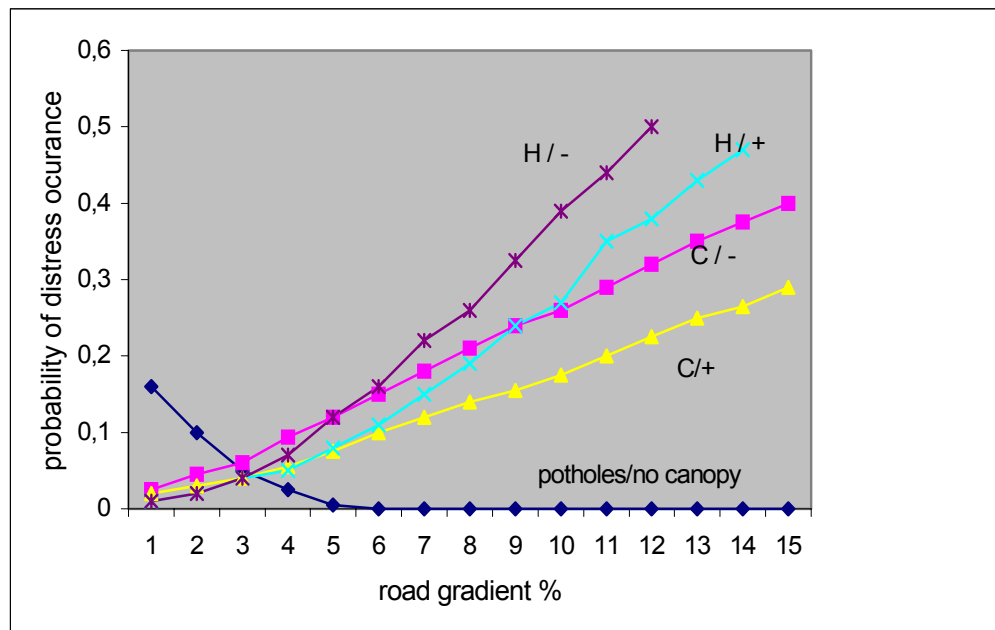


Figure 2. Vulnerability model for gully and pothole distresses of aggregate-surfaced low-volume roads (H =horizontal, C= cambered cross-section , + = with canopy).

The cells of the study layout containing pothole distresses contained only few data records, which limited the meaningfulness of results at lower road gradients. An interesting finding is the influence on annual precipitation on pothole building. While the concentrated flow of surface water is the cause of erosion in gullies, potholes are built by ponding water . Therefore the total amount of water falling on a certain area is an indicator for pothole occurrence. Canopy protection reduces the pothole risk due to interception of precipitation. Canopy protection of roads reduces gully occurrence by a factor of 1.3 to 1.5

3.4. Design of pavements

The traffic load of a forest road -after modifications- for a time span of v years will be given by the following formula:

$$W = Q \cdot v \cdot n (1+z) \tag{5}$$

While the structural number SN of resistant pavement by the formula:

$$SN= -2.54+10 \cdot 0.52416-0.16471 \log CBR+0.10681 \log [(Q \cdot v \cdot n) (1+\zeta)] \tag{6}$$

where ζ = the additional rate of trucks travelling with no wood load.
 CBR = The bearing capacity of the subgrade (California Bearing Ratio)
 η = the factor which implies how many (E.S.A.L.) carry 1m³ of wood and is equal to $\alpha\% \cdot \eta_1 + \beta\% \cdot \eta_2 + \gamma\% \cdot \eta_3 + \dots + v\% \cdot \eta_v$. This factor ranges between 0.12 -0.3

Q = the annual transported amount of wood.

The solution of the above equation results in a design SN. Based on the above equation we can design nomographs for SN calculation. In Figure 3, for the research area with price $\eta = 0.2$ is shown the index of thickness SN for soils with resistance CBR =2-7 and for various transported amounts of wood in a time span of 20 years. Such nomographs can be constructed for each research area.

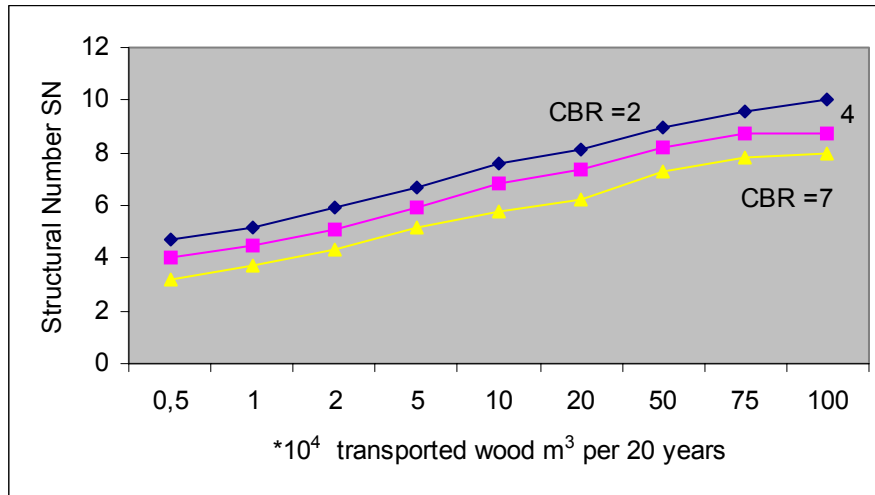


Figure 3. Calculation of index thickness SN for soils with resistance CBR =2-7 and for various transported amounts of wood in a time span of 20 years ($\eta=0.2$).

4. CONCLUSION

The purpose of this paper is to present some environment-friendly interferences in the construction of forest roads with the objective to limitate the soil erosion. The research was conducted on the forest roads of the Forest Offices of Pertuli. By the above analysis and discussion of the research outcomes the following conclusions are drawn up:

- ◆ The classification of the forest areas based on their cross-cut gradients is a step for constructing an optimum road network and for introducing transportation means compatible to the relief, which is a factor that influences substantially any interference in the environment. By this way, interferences that may lead to erosion phenomena can be avoided. One major decision in road network planning is to determine under what terrain conditions ground – or cable based extraction systems should be applied. Using computer programs it was found that the maximum gradient of truck road is 12%, while for second order transportation is 20% for skidder and 60% for yarder–based extraction. We presented an idealized model of road network layout on step slopes for the optimist design of opening – up and road density. The theoretically optimum density is achieved in the fir functional class at 18 m/ha and the economically optimum one at 24m/ha.
- ◆ The stabilization of slopes leads to the safe removal of precipitations, preventing from erosion occurrence. The use of hydroseeding in combination with bitumen emulsion (especially with cationic one) and marble treatment waste gave very satisfactory results, increasing road safety and environment protection. The use of marble treatment waste by the kind of soil stabilization method can help to decrease the environmental problem of its huge deposits, which annually are thousands of tones in the area of our country. On the other hand we found that road gradient is the main

effect of road surface erosion processes, followed by cross–section grading patterns. Using a camber significantly reduces the occurrence of erosion gullies. The relevant effects grow with increasing road gradient. Canopy closure also has a significant influence. Gully erosion is the decisive deterioration process on inclined roads while potholes dominate on horizontal road sections. The probability of pothole occurrence is at maximum at zero per cent gradient disappearing at 5% gradient. Cambered cross–section grading reduces gully distresses by a factor of about two compared with horizontal grading. Canopy protection of roads reduces gully occurrence by a factor of 1.3 to 1.5

- ◆ Finally, a precise planning for a resistant pavement leads to the non-overuse of raw materials, natural resources, and energy. Knowing the resistance of subsoil and the local factor, and in order to achieve our goal, we need to carefully assess the traffic load. This can be accomplished by knowing the synthesis and the types of vehicles as well as the price of the factor η which implies how many (E.S.A.L.) carry 1m³ of wood.

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