THE PASS ABILITY OF FOREST NATURAL SOILS AS A FACTOR FOR THE SELECTION OF THE WOOD SKIDDING MEANS

Euaggelos Karagiannis, Ploutarchos Kararizos
Institute of Forest Engineering and Surveying
Aristotle University of Thessaloniki

Metaxia Kalaitzi
School of Forestry and Natural Environment
Aristotle University of Thessaloniki

Abstract

The pass ability of natural soils, which is distinguished in technical and in biological pass ability, affects significantly the planning of forest opening-up and specifically determines firstly the means of detailed forest opening-up and other the means of wood skidding. The factors which affect the technical pass ability of natural soils are soil conditions, the type and the technical data of the circulating vehicles and the number of drives. In this study, the soil conditions under different harvesting equipment have been investigated which prevail in a typical mountainous forest, the type, the technical data of the circulating vehicles for the wood skidding and proposed methods for the calculation and the estimation of the pass ability of forest natural soils.

When the forest natural soils have low moisture they are in compact condition (liquidity index \( I_L < 0 \)), the resistance is good (CBR>3) and the pass ability is satisfactory, without causing damages to the movement of mechanical means. But when the soil moisture increases, soils are in plastic condition (liquidity index \( I_L =0\) -1), the resistance decreases significantly in the area of flysch and the effective rating cone index (ERCI) in cross slope grounds ranges from 83.32 to 131.66, in the area on sedimentary stones the resistance ranges from 2.458 CBR\% to 3.899 CBR\%, and ERCI - from 95.15 to 144.17 whereas in the area of pyrigen stones the soil resistance ranges from 4.389 to 8.602 CBR\% and ERCI in cross slope grounds ranges from 156.73 to 255.60.

During the movement of various types of tractors to the natural ground aiming at round wood skidding, the mobility index (MI) was estimated which is from 32 to 40.70 and the vehicle cone index of natural soil (VCI) ranges from 39.70 to 43.70 for forest tractor Skidder. For Steyer tractor MI is from 25.40 to 31.20 and VCI ranges from 36.50 to 39.30. Respectively, MI for Universal tractor ranges from 27 to 32 and VCI ranges from 37.30 to 39.70. As far as Unimog tractor is concerned MI ranges from 37.70 to 51.10 and VCI ranges from 42.30 to 48.40.

Key words: pass ability of forest natural soils, wood skidding, resistance of forest natural soils

77
INTRODUCTION

The pass ability of natural soils is distinguished into technical and biological (Hirt, 1996). As technical pass ability of natural soils is understood its ability which makes possible vehicle’s movement with the permissible load, without causing unacceptable subsidence to the soil (deep slots).

As biological pass ability is understood soil’s ability which makes possible vehicle’s movement with the permissible load without causing important damages to the standing trees (roots, increase in trees etc.)

The main factors that affect the technical pass ability of natural soils are (Er-das, 1976; Dietz et al., 1984):
- Soils’ type and properties (mainly resistance);
- Machinery type, equipment, weight and axles’ load and the number of drives;
- The climate and season;
- The cross slope and the formation of soil surface.

Many scientists have dealt with the subject of technical pass ability of forest natural soils for the movement of wood skidding means.

Erdas (1976) researched the pass ability of forest natural soils and gave the above connection between pass ability of soil and its resistance (Fig. 1).

![Pass ability map](image)

Fig. 1. Connection between the pass ability of soil and its resistance in CBR%

Löffler (1982) based on the type of soil (classification according to USCS system), refers that the pass ability reduced from the coarse to the finely soils, whereas the depth of the axles’ trace are increased respectively.

Kuonen (1983) gave the relation between the liquidity index and the pass ability of soil. (Fig. 2).

Löffler (1983) also proposed:

The compositions of natural soils pass ability maps, so as to facilitate the selection and the use of the appropriate machinery;
The collaboration of various sectors (soils mechanics, soil physics, soil science, forest technical, machinery and tires of construction factories).

In 1989 Wästerlund proposed the strength components in the forest floor restricting the maximum tolerable machine forces.

In 1991 Wismer has made a study concerning the relation between cone index and depth for various types of soils.

In 1994 Çarman has done research concerning the tractor’s velocity and tire load effects on soil compaction.

For the estimation of traffic ability of natural soils a model was developed which gives WES (Waterways Experiment Station), as Rush (1968), Hirt (1996), Grammel (1988) refer aiming to the calculation of soil’s traffic ability index according to the edaphic-technical factors of the area as well as Mobility Index (MI) and Vehicle Cone Index (VCI) of the area.

![Diagram](image)

**Fig. 2.** Liquidity index and soil’s pass ability

The movement of the wood skidding means into the natural grounds causes many problems the extent of which depends on the type and size of machinery and the type and resistance (pass ability) of the soil as well. The minimization of these damages could be achieved by preparing, in an advanced plan which will show the pass ability of the soil in various wood skidding means which are used, aiming at selection of the most suitable machinery which can cause the less damages to forest soils. In case of sensitive and problematic soils, with low pass ability will be chosen aircraft wood skidding means (tower yarder, helicopters ) instead of ground wood skidding means aiming at soils’ protection and protection of the natural environment in general.
According to all mentioned above, in the literature review it is said that for the estimation of the pass ability of forest natural soils and the movement of wood skidding means, various methods have been developed, based on calculation of soil resistance with easy tools such as penetrometer, in relation to the soil moisture and slope of the ground and, on the other hand, on the estimation of the pass ability of natural soils in relation to soil mechanic properties of the research area (resistance, slope) and the technical data of tractors (distribution of the weight to the wheels, pressure to the soil, hp, distribution of the load) used for the round wood skidding.

MATERIALS AND METHOD

Study area

As a research area was chosen the public forest district of Samarina (mountain range North Pindos), Prefecture of Grevena and specifically the clusters 4e, 13h, 25a and 27d (Fig. 3, 4).

Fig. 3. Map of the research area (Source: http://earth.google.com)

Fig. 4. Research area in the public forest district of Samarina
Skidding method

From the elements of forest office in Grevena, the means which are used in the wood’s skidding appeared, as well as the percent of skidding round wood. (Fig. 5).

Fig. 5. Round wood’s skidding means in the research area

Skidding equipment

In Table 1 are given the technical data of wood skidding means, that worked in the research area during the performance of pine (*Pinus nigra*) works in cluster 27d, in summer and autumn of 2008. The total volume of logs measured in the felling site of research area was 155, with a total volume of 53.76 m$^3$.

Table 1

<table>
<thead>
<tr>
<th>Tractors technical data in the wood skidding</th>
<th>Forest tractor (Skidder) Franklin 132 AXL</th>
<th>Agricultural tractor Steyr M 9094a F</th>
<th>Universal 643 DT</th>
<th>Tractor Unimog U 406</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>6.822</td>
<td>6.180</td>
<td>3.010</td>
<td>3.260</td>
</tr>
<tr>
<td>Weight distribution (kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>front:</td>
<td>60%</td>
<td>41%</td>
<td>33%</td>
<td>60%</td>
</tr>
<tr>
<td>rear:</td>
<td>40%</td>
<td>59%</td>
<td>67%</td>
<td>40%</td>
</tr>
<tr>
<td>Tire width b (cm)</td>
<td>46</td>
<td>rear: 48</td>
<td>front: 27</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rear: 57</td>
<td>rear: 47</td>
<td></td>
</tr>
<tr>
<td>Tire diameter d (cm)</td>
<td>142</td>
<td>front: 124</td>
<td>front: 80</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rear: 164</td>
<td>rear: 120</td>
<td></td>
</tr>
<tr>
<td>Tire pressure (bar)</td>
<td>1.7</td>
<td>1.8</td>
<td>2.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Width tractor (cm)</td>
<td>235</td>
<td>228</td>
<td>188</td>
<td>190</td>
</tr>
<tr>
<td>Horsepower (PS/U/min)</td>
<td>80/2500</td>
<td>68/2500</td>
<td>65/2400</td>
<td>65/2550</td>
</tr>
<tr>
<td>Clearance (cm)</td>
<td>46</td>
<td>42.5</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>Load volume (m$^3$)</td>
<td>2.35</td>
<td>1.66</td>
<td>1.26</td>
<td>1.52</td>
</tr>
<tr>
<td>Load weight (kg)</td>
<td>1.293</td>
<td>913</td>
<td>693</td>
<td>836</td>
</tr>
</tbody>
</table>
With the help of district geological and administrative map, the native stones or the geological constructions of the forest clusters were defined. The clusters researched were the following: (Cluster 4e: Pyrigen stones, like Peridotite, Gabbros and Dolerite – Cluster 13h: Flysch - Cluster 25a: Sedimentary stones)

Through the proper sample and with the help of the portable penetrometer FARNELL, the resistance of the natural soil in the searching clusters was measured, in depth of 17 cm and 34 cm. This was repeated in different periods, such as spring, summer and autumn 2008.

For the estimation of traffic ability of natural soils a model was used (Fig. 7, Table 2) which gives the WES, refer having as an aim the calculation of soil’s traffic ability index according to edaphic-technical factors of the area as well as MI and VCI of the area.
Soil properties

- Terrain formation
- Obstacles
  - Soil abnormalities
  - Slope
- Soil mechanic properties
  - Soil classes
  - Edaphic place
  - Seasonal factor
  - Slipperiness
  - Clamminess
  - Homogeneity

Number of drives

- SI

Vehicles’ properties

- Weight
- Clearance
- Engine horsepower
- Tires or Caterpillars
- Load

Traffic ability

Where:
- CI: Cone Index
- RI: Remolding Index
- RCI: Rating Cone Index RI = CI x RI
- SI: Slope Index
- ERCI: Effective Rating Cone Index ERCI = RCI – Si
- MI: Mobility Index
- VCI50: Vehicle Cone Index

Fig. 7. Estimation model of natural soil’s traffic ability according to the WES (Rush, 1968)
Table 2
Calculation of MI for wheeled vehicles (WES, 1968)

(1) Contact pressure factor =
\[
\frac{2,2045 \times \text{gross vehicle weight (kg)}}{\text{tire width (cm)} \times \text{outside diam. of tire (cm)} \times \frac{2,54}{2 \times 2,54} \times \text{No. of tires}} = 2,8445 \times \text{gross vehicle factor (t)}
\]

(2) Weight factor: \( X = \frac{2,2045 \times \text{gross vehicle weight (kg)}}{1000 \times \text{No. of axles}} = \frac{2,2045 \times \text{gross vehicle weight (t)}}{\text{No. of axles}} \)

The weight factor for vehicles comes to equations:

\[
<2.0 t = 0.553 X
2.0-13.5 t = 0.033 X+1,05
13.5-20.0 t =0142 X-0.420
over 20.0 t = 0.278 X-3.1155
\]

(3) Tire factor = \( \frac{10 + \text{tire width (cm)}}{254} \)

(4) Grouser factor with chains = 1.05
Grouser factor without chains = 1.00

(5) Wheel load factor = \( \frac{\text{gross weight (kg)} \times 2,2045}{1000 \times \text{No. of wheels}} = \frac{2,2045 \times \text{gross weight (t)}}{\text{No. of wheels}} \)

(double wheels are considered as one)

(6) Clearance factor = \( \frac{\text{clearance}}{2.54 \times 10} = \frac{\text{clearance}}{25.4} \)

(6) Engine factor = \( \frac{\text{No. DINkW}}{\text{gross weight (t)}} \)

for vehicles until 7.4 kW/t = factor 1.05
over 7.4 kW/t = factor 1.00

(8) Transmission factor =

hydraulic = factor 1.00
mechanical = factor 1.05

**Mobility Index (MI)** = \( \left[ \frac{1}{(1) \times (2)} + (5) - (6) \right] \times (7) \times (8) \)
RESULTS AND DISCUSSION

Resistance of the soils

By the help of the portable penetrometer, the resistance of the natural soil in the searching clusters was measured, in depth of 17 cm and 34 cm (Table 3).

Table 3
Resistance of the forest natural soil in the searching clusters (Liquidity index IL=0-1)

<table>
<thead>
<tr>
<th>Depth cm</th>
<th>Cluster</th>
<th>Native stones</th>
<th>Average resistance of soil CBR%</th>
<th>Standard deviation of soil CBR%</th>
<th>Values of average</th>
<th>Standard error of the average $s_{\bar{x}}= \frac{s}{\sqrt{N}}$</th>
<th>Confidence limits of average for $95%$ $\bar{x} \pm t \cdot s_{\bar{x}}$</th>
<th>Tolerable error $a_{CBR}(%)$</th>
<th>Necessary sample size $N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>13h</td>
<td>Flysch</td>
<td>2,386</td>
<td>0.950</td>
<td>1.99</td>
<td>0.099</td>
<td>2.582</td>
<td>0.25</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>4e</td>
<td>Pyrogen</td>
<td>4,713</td>
<td>1.476</td>
<td>1.99</td>
<td>0.163</td>
<td>4.389</td>
<td>0.40</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>25a</td>
<td>Sedimentary</td>
<td>2,691</td>
<td>1.156</td>
<td>1.99</td>
<td>0.117</td>
<td>2.924</td>
<td>0.25</td>
<td>82</td>
</tr>
<tr>
<td>34</td>
<td>13h</td>
<td>Flysch</td>
<td>3,411</td>
<td>1.152</td>
<td>1.99</td>
<td>0.118</td>
<td>2.982</td>
<td>0.25</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>4e</td>
<td>Pyrogen</td>
<td>8,117</td>
<td>2.212</td>
<td>1.99</td>
<td>0.244</td>
<td>6.02</td>
<td>0.30</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>25a</td>
<td>Sedimentary</td>
<td>3,637</td>
<td>1.079</td>
<td>1.99</td>
<td>0.111</td>
<td>3.417</td>
<td>0.25</td>
<td>74</td>
</tr>
</tbody>
</table>

Traffic ability of forest natural soils

From the elements of Table 3 it is appeared the resistance of natural soils in CBR%, from which comes out soil’s Cone Index (Fig. 8) that if it is multiplied with Remolding Index (RI) of soils (0.8) it emergers the Rating Cone Index (RCI). From the mean slope of soil (21%) comes out the soil Slope Index (SI) (Fig. 9) that if it is subtracted from the Rating Cone Index (RCI) it will finally comes out the Effective Rating Cone Index (ERCI) (Table 4).

Table 4
Calculation of the traffic ability for the research area (Liquidity index IL= 0-1)

<table>
<thead>
<tr>
<th>Resistance of soil CBR%</th>
<th>Cone Index CI</th>
<th>Remolding Index RI (0,7-1,2)</th>
<th>Rating Cone Index RCI=CIXRI</th>
<th>Slope Index SI</th>
<th>Effective Rating Cone Index ERCI=RCI-SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>0.8</td>
<td>64</td>
<td>17</td>
<td>47</td>
</tr>
<tr>
<td>2</td>
<td>115</td>
<td>0.8</td>
<td>92</td>
<td>17</td>
<td>75</td>
</tr>
<tr>
<td>3</td>
<td>170</td>
<td>0.8</td>
<td>136</td>
<td>17</td>
<td>119</td>
</tr>
<tr>
<td>4</td>
<td>205</td>
<td>0.8</td>
<td>164</td>
<td>17</td>
<td>147</td>
</tr>
<tr>
<td>5</td>
<td>236</td>
<td>0.8</td>
<td>189</td>
<td>17</td>
<td>172</td>
</tr>
<tr>
<td>6</td>
<td>262</td>
<td>0.8</td>
<td>210</td>
<td>17</td>
<td>193</td>
</tr>
<tr>
<td>7</td>
<td>287</td>
<td>0.8</td>
<td>230</td>
<td>17</td>
<td>213</td>
</tr>
</tbody>
</table>
When the soils are in plastic condition (Liquidity index IL = 0-1) and in 17 cm depth, in the area of flysch, the soils’ resistance ranges from 2.189 to 2.583 CBR% and ERCI ranges from 83.32 to 100.65, in the area of sedimentary stones the resistance of natural soil ranges from 2.458 to 2.924 CBR% and in cross slope grounds - from 95.15 to 115.66, whereas in the area of pyrigen stones the soil resistance ranges from 4.389 to 5.037 CBR% and ERCI - from 156.73 to 172.78. For the same values of Liquidity index (IL = 0-1) and in 34 cm depth, in the area of flysch the resistance of soil ranges from 2.982 to 3.452 CBR% and ERCI in cross slope grounds - from 118.21 to 131.66, in the area of sedimentary stones the resistance of natural soil ranges from 3.418 to 3.899 CBR% and in cross slope grounds ERCI ranges from 130.68 to 144.17, whereas in the area of pyrigen stones the soil resistance ranges from 7.630 to 8.602 CBR% and in cross slope grounds ERCI ranges from 225.60 to 241.68.

![Fig. 8. Cone index in connection to the resistance of soil (CBR %)](image1)

![Fig. 9. Slope index in connection to the cross slope (%)](image2)

![Fig. 10. Vehicle cone index (VCI) in connection to Mobility index (MI)](image3)

The means used in the wood skidding are shown in Fig. 5. According to Table 2, the tractors technical data, which are used in the wood skidding and the mean load, it is estimated the tractor’s Mobility Index (MI), with or without load (Table 5). In accordance with the results of MI from Table 5 and simultaneously with Fig. 10, is finally estimated the Vehicle Cone Index for tractors movement, with or without load (Table 5).
During the movement without load of the mechanical wood skidding means (tractors) to the natural ground was estimated MI which was 32 and VCI of natural soil was 39.70 for the forest tractor (Skidder). For Steyer tractor the mobility index was 25.40 and VCI was 36.50. Respectively, MI for the Universal tractor was 27 and VCI was 37.30. As far as Unimog tractor is concerned MI was 37.70 and VCI was 42.30. During the movement with load was estimated MI which was 40.70 and VCI of natural soil was 43.70 for the forest tractor Skidder. For Steyer tractor MI was 31.20 and VCI was 39.30. Respectively MI for Universal tractor was 32 and VCI was 39.70. As far as Unimog tractor is concerned MI was 51.10 and VCI was 48.40.

## CONCLUSIONS AND PROPOSALS

According to the results of the research, the following conclusions were reached:

When the soils are in plastic situation (Liquidity index IL= 0-1) the resistance of soil, in the district of pyrigen petrification is satisfactory (CBR% > 3), however depth 17 and 34 cm, but in the districts of Flysch and sedimentary petrifications it is satisfactory (CBR% > 3) for depth 34 cm and it is low (CBR %< 3) for depth 17 cm.

The resistance of soil decreases during winter and spring and it is satisfactory during autumn and summer. The resistance of soil rises in accordance with the depth. In 1994 Çarman Kazim has done a research concerning the soil compaction in relation with the depth and reached the same conclusion.

The Mobility Index for forest and agricultural tractors, with or without load and for the tractor Unimog without load, is lower than the Vehicle Cone Index.

The Mobility Index for the tractor Unimog with load is bigger than the Vehicle Cone Index.

According to the conclusions of the research, the following proposals were reached:

<table>
<thead>
<tr>
<th>Forest tractor (Skidder) Franklin 132 AXL</th>
<th>Agricultural tractor</th>
<th>Tractor Unimog U 406</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility Index (MI) (Vehicle Cone Index VCI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without load:</td>
<td>32 (39.70)</td>
<td>25.40 (36.50)</td>
</tr>
<tr>
<td>With load:</td>
<td>40.70 (43.70)</td>
<td>31.20 (39.30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32 (39.70)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>37.70 (42.30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51.10 (48.40)</td>
</tr>
</tbody>
</table>

## Table 5
Calculation of Mobility Index and Vehicle Cone Index for the wood skidding tractors
Tractor’s movement in Flysch and sedimentary petrifications area’s soils must not be permitted, when the moisture of the soil surpasses (Liquidity index IL= 0-1) in order to avoid the damages to the soil.

Tractor Unimog and Skidder FRANKLIN, during the wood’s skidding works, especially in soils of low resistance, must be reinforced with broad tires in order to reduce the soil pressure.

The damages caused by the wood’s skidding means to the remaining stand can be reduced and stay within limits. This can be obtained by better organization of the work, education of the tractors’ operators and selection of the right machines in each case.

REFERENCES


88