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A COMPUTATIONAL ALGORITHM FOR CUTTING VOLUMES DETERMINATION WITH APPLICATION IN THE TRACTOR LOGGING NETWORK DESIGN

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Abstract: *The paper presents some aspects regarding the cut and fill volumes determination and it focuses on the development of a computational algorithm with applicability in the studied problem. The current used methodology for embankment works calculation presents some disadvantages regarding the accuracy of determination and the related time management. In this order, the paper identifies the key factors which represent the input data in the computational algorithm and proposes a mathematical resolution for the studied problem.*

Key words: *logging network, transversal profile, algorithm.*

1. Introduction

The tractor logging network from a timber exploitation site is composed from all the tractor roads developed in the felling area and outside its boundaries and it serves in the timber movement as a part of the logging process [4].

The development modalities of the tractor logging tracks on the valley sides are different, and they depend of the terrain slope category, soil disturbance grade, and the valley side stability grade [2-4].

From the predominant slope point of view, there are some distinct situations:

1. Terrains with the predominant slope of the valley sides under 20...25%, where the tractor tracks are oriented on the maximum slope line. These tracks are predominant natural and they are constructed without embankments works.

2. On the terrains with the predominat slope between 20...25 and 40...45%, from both, ecological and technical points of view, the tractor tracks are becoming roads and they are constructed by taking in consideration of the embankments works. The tractor logging network involves construction costs which are correlated with the valley side slope.

3. On the terrains with the predominat slope above 45%, the tractors are becoming inoperable in the skidding process (skidding from uphill), the costs regarding the embankments works are greater and the stability of the valley side could be affected. These terrains are the domain of the skylines.

In the second situation, the tractor roads developed on the valley sides are designed by taking in consideration of some

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different design slopes, and they must provide an optimal traffic for the logging machines (low fuel consumption, increased technical performances) [1], [4]. The opinions regarding the longitudinal design slopes for the tractor roads are multiple. Usually, the longitudinal slopes are between 5 and 15%, sometimes greater (up to 20...30%) [4]. Also, the transversal profile for the tractor road is composed from elements which are designed by taking in consideration of some different slopes. These elements are [1], [4]: the platform width (usually designed with slopes between 6...10% and an orientation for the slope to the cutted part), the slope for the cutting part (slopes between 1.5:1 and 5:1, sometimes unconfigured) and the terrain slope (different values).

As a result, there can be generated a lot of specific situations, and from both, the productivity and the time management points of view, it appears as necessary the development of a computational algorithm regarding the embankment volumes, in order to improve the productivity in the design process.

Until now, in practice, the estimation of the embankment volumes was made by taking in consideration of some graphical methods which involved the design for the transversal profile (section) and the graphical area determination for the cutting surface [1], [4].

2. Elements Regarding the Computational Methodology (input data)

The transversal profile (section) of the tractor road (Figure 1) is composed from the following elements:

- l_p - platform width, completely situated in the cutting part;
- i_{td} - design slope for the cutting embankment;
- i_p - design slope for the road platform;
- i_t - terrain slope;

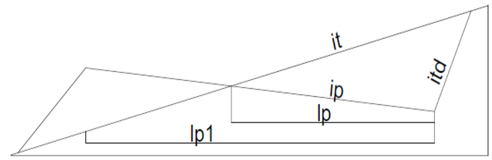

Fig. 1. *Elements for the transversal profile of the tractor road*

- l_{p1} - total width for the road platform.

Because in practice are utilized slopes for the main elements of the profile, there appears as being necessary the determination of the cutting surfaces by taking in consideration of the desired slopes for the profile elements. Also, in practice the slopes are expressed both, in percents (i_t, i_p) and as a rapport (i_{td}).

As the tractors traffic is realized at least in a first phase only on the cutting portions of the road platform (the filled portions are not compressed, and, consequently, they are unstable) [4], there can be determined the known elements regarding the cutting surface calculation. These elements are:

- l_p - sized, usually, at 3.0-3.5 meters and which cad be modified in the curves by taking in consideration of some supplementary width in accordance with the gauge dimensions for certain logging machines;
- i_{td} - can be sized at different dimensions in rapport with the certain terrain conditions;
- i_p - adapted as size in order to maintain the moved timber on the road platform and it presents, also, importance in water collection;
- i_t - presents different values for the slope (collected from the design plan or from the field);
- $M_1(x_1,y_1)$ - the point of intersection generated by the M_1M_2 and M_1M_3 segments (Figure 2), is considered an initial point and it can be taken in the system origin, or at some arbitrary coordinates.

From all the known data, in the computational algorithm is taken as input data only the first four variables because the last one (the arbitrary point) does not influence the area determination (presents only a support role).

In curves, the cutting area determination is realized in the same way like the determination of the cutting area from the alignment portions of the road, the main problem being represented by the cutting volumes determination. The platform width in the curves is dependent by the increment for the platform width generated by the curve. Both, the width increment and the minimum radius (for a certain curve) are obtained by using some more complex calculations (depending by the dimensions of the moved charges and the logging machine type).

Regarding the cutting volumes calculation, after the determination of the cutting surface for a certain (homogeneous) part of the road, the volume is calculated by using the real length for the considered road portion [1-4]. The total afferent volumes for a tractor logging network can be calculated as a sum for the individual volumes (volumes calculated for the homogeneous parts of the road).

In the computational algorithm, a homogeneous road portion represents a road portion designed with a certain longitudinal slope, in similar or identical terrain conditions (slopes, terrain nature: rock, soil etc.) and with the same slope values for the transversal profile (section).

3. Elements Regarding the Mathematical Operations (input data computing)

In order to obtain an improved time management in the design process of the tractor logging networks there appears as necessary the elaboration of a computational algorithm which must incorporate all the computational steps from the input data to the final results. The establishing of the computational steps is complex because the known data is expressed as slopes (all the sides of the triangle $M_1M_2M_3$). There is also known the length of the l_p variable as an input data. Sometimes the point $M_1(x_1,y_1)$ can be taken in consideration.

In a certain algorithm, the order of the steps linkage is defined as so called the algorithm control structure. The most unsophisticated control structure is the sequential structure and it is composed from linked steps which are computed in the same order they appear in the structure.

Also, an algorithm can define the way of resolution for a certain problem, but any problem can appear as a sub problem of a more complex problem. The algorithm of resolution for the first problem becomes a sub algorithm for the second, more complex, problem. This is the case of the surface computation which presents a specific algorithm, being in the same time a sub problem for the volume computation, and, in the same time, the surface computation algorithm represents a sub algorithm for the volume computation algorithm.

Thus, if the Figure 2 is considered, there can be observed the following notations:

- $M_1(x_1,y_1)$ - the arbitrary point with known coordinates (x_1,y_1);
- $M_2(x_2,y_2)$ - dependent point with unknown coordinates (x_2,y_2);
- $M_3(x_3,y_3)$ - dependent point with unknown coordinates (x_3,y_3);
- known slopes: i_t, i_p and i_{td};

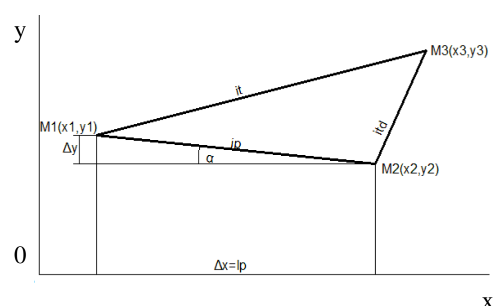

Fig. 2. *Mathematical (computational) elements regarding the transversal section of a tractor road*

- l_p - the width of the road platform situated in the cutting area, known as input data in the algorithm;
- Δx - the difference from the points M_1 and M_2 expressed on the X axis and equal with the value of l_p;
- Δy - the difference from the points M_1 and M_2 expressed on the Y axis, unknown.

Because the point M_1 is known there can be determined the coordinates for the unknown points M_2 and M_3, starting from the known elements. In this order, there can be written the following relations:

$$x_2 = x_1 + \Delta x = x_1 + l_p, \tag{1}$$

and in $x_1 = 0$ hypothesis, $x_2 = l_p$;

$$y_2 = y_1 - \Delta y, \tag{2}$$

and in $y_1 = 0$ hypothesis, $y_2 = -\Delta y$;
Δy - unknown;

$$\Delta y = \Delta x \operatorname{tg}\alpha, \tag{3}$$

and

$$\operatorname{tg}\alpha = i_p/100. \tag{4}$$

$$\Delta y = \Delta x i_p/100. \tag{5}$$

(i_p is expressed in percents).

After the M_2 point coordinates determination there can be calculated the coordinates for the point M_3. The determination of the x_3 and y_3 coordinates is more complex, and it takes in consideration the resolution of the equations system composed from the equations for the M_3M_1 and M_3M_2 segments.

The mentioned system of equations is composed from the following relations:

$$\begin{aligned} &(M_1M_3)\text{: } y_3 - y_1 = i_t\,(x_3 - x_1), \\ &(M_2M_3)\text{: } y_3 - y_2 = i_{td}\,(x_3 - x_2), \end{aligned} \tag{6}$$

with the known variables: x_1, y_1, x_2, y_2, i_t and i_{td}.

By substitution there can be obtained the relations (7) and (8):

$$x_3 = \frac{i_t x_1 - i_{td} x_2 - y_1 + y_2}{i_t - i_{td}}, \tag{7}$$

and

$$y_3 = i_{td}\left(\frac{i_t x_1 - i_{td} x_2 - y_1 + y_2}{i_t - i_{td}} - x_2\right) + y_2. \tag{8}$$

After the determination of all the coordinates, the next mathematical step is represented by the surface calculation. In order to obtain the surface from points with known coordinates, there can be applied the relation (9):

$$Sd = \left(\frac{x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2)}{2}\right), \tag{9}$$

where Sd - cutting surface.

For the input variables (slopes values) can be made a conversion, in the computational algorithm, from percents in tangent, by calculating the rapport slope/100. This conversion is necessary for all the slope variables excepting i_{td}. In the i_{td} case is sufficient the calculation of the input rapport.

The cutting volumes are estimated with some specific relations. As a final result, the total cutting volume is obtained by calculating the sum of the cutting volumes for homogeneous conditions. The computational relation for the total cutting volumes (for a tractor logging network) can be written as follows (relation 10):

$$Vs = \sum_{i=1}^{n} Sd_i Lt_i, \tag{10}$$

where:

- Vs - total (estimated) cutting volume expressed in m^3;
- Sd_i - the cutting area for the homogeneous road portion i;
- Lt_i - the real length of the homogeneous portion of the road i (obtained by hypotenuse determination when there are known the slope of the hyponeuse (i_{pr}) and the bigger cathetus (L_{tio}));
- i_{pr} - longitudinal design slope;
- L_{tio} - horizontal projection for the real length of the homogeneous road part i.

Because in practice the longitudinal design slopes for tractor roads are expressed in percents, they can be converted as tangent in order to be used in the relation written above. The conversion relations (according to the Figure 3) are the following:

$$\mathrm{tg}\alpha = i_{pr}/100, \quad (11)$$

and

$$\alpha = \mathrm{arctg}\ i_{pr}/100. \quad (12)$$

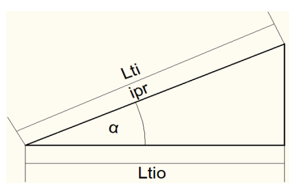

Fig. 3. *Elements regarding the real length of the homogeneous portions of the tractor roads*

4. The Algorithm Description

An algorithm is a finite text (a finite sequence of sentences belonging to a language), where each sentence of the language describes a certain computational rule. An algorithm is written in order to resolve a problem, but for the resolution of a certain problem there can be more than one algorithm. Any problem starts from the initial data (input data) and ends with the final data (results).

In the description of the algorithms are utilized a lot of describing languages, the most frequent one being the pseudo code language. The pseudo code language was invented for the algorithms designing and it is formed by sentences with structures inspired from the common language. The pseudo code language contains also some explicative sentences called comments, which, in order to be distinguished by the rest of the code, are introduced in accolades.

The sequential structure of the pseudo code language is realized by the simple or composed sentences concatenation, which will be computed in the order of apparition in text. The alternative structure is realized in the pseudo code language by introducing of the sentence "IF", and in the case of the repetitive structures there is used the sentence "AS LONG".

The sentence "DATA" is used in order to identify the initial data (input data) and it has the following syntax: "DATA *list*", where *list* contains the names of the input variables with known values. The results are mentioned by the following sentence: "RESULTS *list*" where *list* contains the results required by the problem.

Thus, for a random homogeneous portion of a tractor road, the specific algorithm can be as follows:

```
        CVE ALGORITHM
{Cutting Volumes Evaluation}

                       START

{Input data introduction and reading}

READ it, ip, itd, lp, ipr, Ltio

{Input data conversion: it, ip, itd}

        it:= it/100;
        ip:=ip/100;

{itd conversion from text to number,
because the program will "see" the rapport
x:y as text at input}

        itd:=CONVERSION TEXT TO DECIMAL;
{Initialization for M1 point (x1, y1)}

          x1:=0;
          y1:=0;

{Coordinate calculation for point M2(x2, y2)}
```

```
x2:= x1+lp;
y2:= y1-lp ip;
{Coordinate calculation for M3 point (x3, y3)}
x3:=(it x1 - itd x2 - y1 + y2)/(it - itd);
y3:=itd(((it x1-itd x2-y1+y2)/(it-itd))-x2)+y2;
{Area calculation for the cutting surface}
Sd:=(x1(y2-y3)+x2(y3-y1)+x3(y1-y2))/2;
{ipr conversion in tangent}
ipr:= ipr/100;
{The calculation of the real length}
Lti:=SQRT(Ltio^2+(Ltio*ipr)^2);
{The calculation of the cutting volume}
Vd:=(Sd Lti)
END
```

5. Conclusions and Practice Recommendations

By keeping in mind that the tractor tracks developed on the valley sides with slopes between 20...25 and 40...45% are realized by cutting and filling volumes (embankment works), there can be taken in consideration, as being important, the following aspects:

- The possibility of the calculus automation regarding the cutting volumes estimation, because the current methodology (graphical methodology) presents an inefficient time management and a low accuracy. For example, in order to determine the cutting area for a certain transversal section (profile), the minimum necessary time required by the drawing and calculation activities is about five minutes. By using the proposed algorithm as an implementation in a program (for example as a procedural code in Visual Basic for Applications) and when the input data is known, all the afferent calculations for a certain logging network can be solved in less than 5 minutes. Also, there can be mentionated that the proposed algorithm will improve along with the time management, the accuracy of the necessary determinations;
- The usage of the above described algorithm can be concluded in some simulations regarding the optimal geometrical characteristics for the tractor roads designing;
- The described algorithm could be implemented, both, at forecasting level (estimations regarding the costs of the logging network in different variants) and in the field operations (estimations regarding a certain technological solution which involves a certain tractor logging network);
- In some certain situations, in practice could be designed roads for the animal logging. In these cases and by taking in consideration of the adequate input data, the cutting volumes can be estimated as an implementation of the same computing algorithm.

With title of recommendation may interest the following aspects:

- The geometrical characteristics of the transversal profile will be designed by taking in consideration of the real terrain situations;
- Before the final solution of the design process it is recommendable to realize some simulations in order to obtain some low-cost design solutions.

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