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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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CALCULATION OF ROAD PROJECTS EARTHWORK: A COMPARISON OF METHODS

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Abstract

Two of the most prevalent calculation methods of road projects' earthworks in terms of robustness and computational easiness are the methods of the average end-area and applicable lengths. The present study, focuses on the second method and specifically, compares the classical calculation approach to a simplified approach. The classical calculation approach of the applicable lengths computes the earthworks of a cross section (n) by multiplying its surface area with the respective applicable lengths, which is the sum product of 1/4 or 1/2 of the distance with the prior cross section (n-1) and 1/4 or 1/2 of the distance with the following cross section (n+1), depending on whether the prior/following cross section is of the same type (cut or fil) with the section (n). The proposed simplified approach computes the earthworks of a section, by considering that the applicable lengths is always equal to the mean value of the distances with the prior and the following cross section, without checking the type of the prior/following cross section. To validate the performance of the simplified approach the earthworks' volumes of a number of projects was computed with the classical and simplified approach and the results were compared with the exported results from a road design software where volume measurements were taken every one meter. As a first step towards the validation of the approach, nine projects with different territories were investigated. Then, projects with different slope and standard deviations of the height differences between the road profile and the terrain profile were further investigated. Finally, in 45 road projects with the same horizontal alignment but different longitudinal profile, the earthworks' volumes were calculated for three different typical cross sections. The results that arouse from each step of the analysis, indicate that both approaches produce very similar results, regardless of the changing parameters.

Keywords: road project, earthwork volumes, applicable lengths method, mass table

1 Introduction

The calculation of the earthwork volumes in a road project is a very important part of the project, as it greatly affects its budget. The current existing methods used to calculate the mass table can produce reliable results, however there is still place for further improvements. This improvement is achieved in this study through the introduction of a new simplified calculation approach of the "applicable lengths" method. The selection of the specific method is due to the complex task of checking the prior/next cross section to determine the applicable length that should be considered within the calculation process.

The adoption of a simplified approach, requires in depth analysis in order to determine the accuracy level that is achieved as well as to disclose the trade-offs within the planning process of a road project. For this reason, within this study answers are given associated to the following research questions; to what extent a simplified approach of the method affects the results in the mass table of a road project and how accurate are the produced results as compared with the results of the classical approach?
The study which is organized in five chapters. Chapter 2 explains in detail the calculation process of earthwork volumes by focusing in the last chapter on the two approaches of the applicable length method. In Chapters 3 and 4 the methodological approach and the analysis of the results are presented. Lastly, Chapter 5 presents the conclusions that can be retrieved by the analysis.

2 Calculation of earthwork volumes

The most widely used methods for the calculation of earthwork volumes in literature are the methods of Cross section, Grid and Triangular prisms [1]. To compute volumes according to the Cross section method the surface of two consecutive areas (sections) and their distance need to be known. To calculate the area of a cross section, three are the methods that are used in the field of Surveying, namely the planimeter, the graphical and the co-ordinate method [2]. The above methods follow two main rules: the rule of Trapezoidal and the rule of Simpson's, see Table 1.

Table 1 Calculation methods of earthwork volumes between two cross sections

Rules	Formula	Explanation
Trapezoidal	$V = L * \frac{(A_1 + A_2)}{2}$	A = area of adjacent cross sections L = distance between cross section
Simpsons	$V = \frac{L}{6}(A_1 + 4A_m + A_2)$	A_1, A_2 = areas of adjacent cross sections Am = area of midway cross section L = distance between cross section

2.1 The cross section method

For the calculation of the earthwork volumes in the Cross section method there are two basic computational methods; the "average end-area" and the "applicable lengths". Table 2 shows the volumes' computational formula for n cross sections, either in excavation or in embankment. The area of each cross section is designated with the letter "A" while the distance between two cross sections with "L".

Table 2 Volume calculation formulas

Methods	Formula
Average end-area	$V = \frac{A_1 + A_2}{2} * L_1 + \frac{A_2 + A_3}{2} * L_2 + \cdots + \frac{A_{n-1} + A_n}{2} * L_n$
Applicable lengths	$V = A_1 * \frac{L_1}{2} + A_2 * \frac{L_1 + L_2}{2} + \cdots + A_n * \frac{L_{n-1} + L_n}{2}$

2.2 The method of applicable lengths

The classical calculation approach of the applicable lengths method computes the earthworks of a cross section (n) by multiplying its surface area with the respective applicable lengths, which is the sum product of 1/4 or 1/2 of the distance with the prior cross section (n-1) and 1/4 or 1/2 of the distance with the following cross section (n+1), depending on whether the prior/following cross section is of the same type (cut or fill) with the section (n).
The simplified approach which differentiates from the classical approach proposes that the applicable lengths should be always equal to the mean value of the distances with the prior and the following cross section, without checking the type of the prior/following cross section. This lowers the computational effort, thus it speeds up the calculation process, while it is proved that it produces more accurate results.

3 Methodology

The analysis in the present study is a synthesis of three diploma thesis, which were carried out by three graduate students of the Department of Civil Engineering, University of Thessaly, under the supervision of Professor Nikolaos Eliou; Karakikes [3], Gizas [4] and Gkoutzini [5]. The purpose of the three theses was to compare the classical and the aforementioned simplified approach of the method of "applicable lengths" under several changing parameters to test its accuracy. These parameters were the average slope, length of the road, deviation of the elevation differences between the longitudinal road profile and terrain line, and the type of the typical cross section used. The reference measurements to be compared with the results of the two approaches were generated in Anadelta Tessera software [6], which is a multifunctional, highly configurable highway design and construction software. The measurements in Anadelta Tessera software were taken every one meter in order to be as close as possible to the real volumes. The analysis performed by each diploma thesis is described in subchapters 3.1 – 3.3.

3.1 First analysis

Within the first thesis, the volumes of nine real road projects of different territories in Greece, provided by the Laboratory of Highway Engineering [7], were measured in Anadelta Tessera software. For the computation of the volumes, a typical cross section for small settlements and forest roads was used. The selection of this particular cross section was made as this is the simplest in terms of dimension and structural details. The volumes then were recalculated according to the classical and simplified approach in excel sheets taking measurements of the surface of the cross sections every 20 meters to lower the computational effort. As a final step, a sensitivity test was performed to disclose results' pattern associated to the criteria of average slope and road length of each and every project.

3.2 Second analysis

In the second thesis, the volumes of another twenty-four delivered road projects were calculated as previously. The difference this time was that the results were now tested under the criteria of the deviation of the elevation differences between the longitudinal road profile and terrain line and the average slope.

3.3 Third analysis

In the frame of the third thesis, the earthwork volumes of a single project were calculated 45 times in Anadelta Tessera software, keeping the same horizontal alignment but with different longitudinal profiles. In addition, the earthwork volumes were calculated by the usage of three different types of typical cross sections. These tree typical cross sections used two lanes per direction with different lane width and are proposed mainly for roads that connect provinces and/or counties. Their names from the widest to the narrowest are b2, c2 and z2, while their lane width was equal to 3.75 m, 3.50 m and 2.75 m, respectively.

4 Results & Analysis

The deviations of the volumes calculated by the two approaches from the real volumes which were calculated in Anadelta Tessera software per analysis step can be found in Figures 1-4. Analytically, Figures 1 and 2 illustrate the volumes' deviations of the nine road projects analyzed in the first thesis and 24 projects analyzed in the second thesis, respectively, separately for excavations and embankments. Figures 4 and 5, similarly, depict the deviations' calculated within the third thesis for the three types of typical cross sections, namely b2, c2 and z2.
The results of the performed analysis in a sample of 168 (9+24+(3*45)) road projects indicate that the simplified approach performs better in 156 (93 %) and 108 (64 %) projects, for the calculation of the excavation and embankment volumes, respectively. Table 3 summarizes the aggregated results per thesis. It is clear, based on the results, that the simplified approach produces more accurate results in all three analyses except for the calculation of the embankment volumes in the third thesis in which the classical approach seems to perform slightly better. A very interesting observation is that in the most extensive analysis (thesis 3), the simplified method calculates more accurately the excavation volumes in all projects as compared to the classical approach, no matter what the type of the typical cross section is.

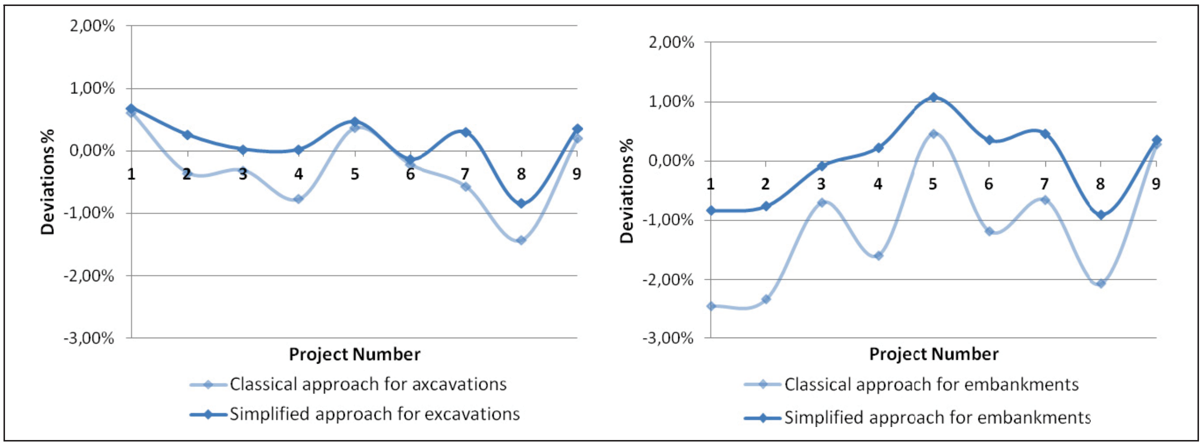

Figure 1 First analysis volumes' deviations (Left: Excavations, Right: Embankments)

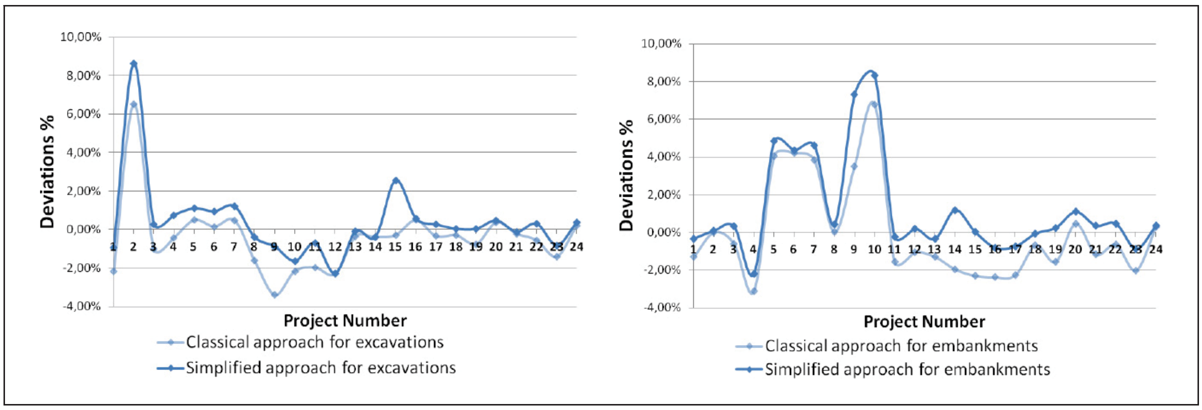

Figure 2 Second analysis volumes' deviations (Left: Excavations, Right: Embankments)

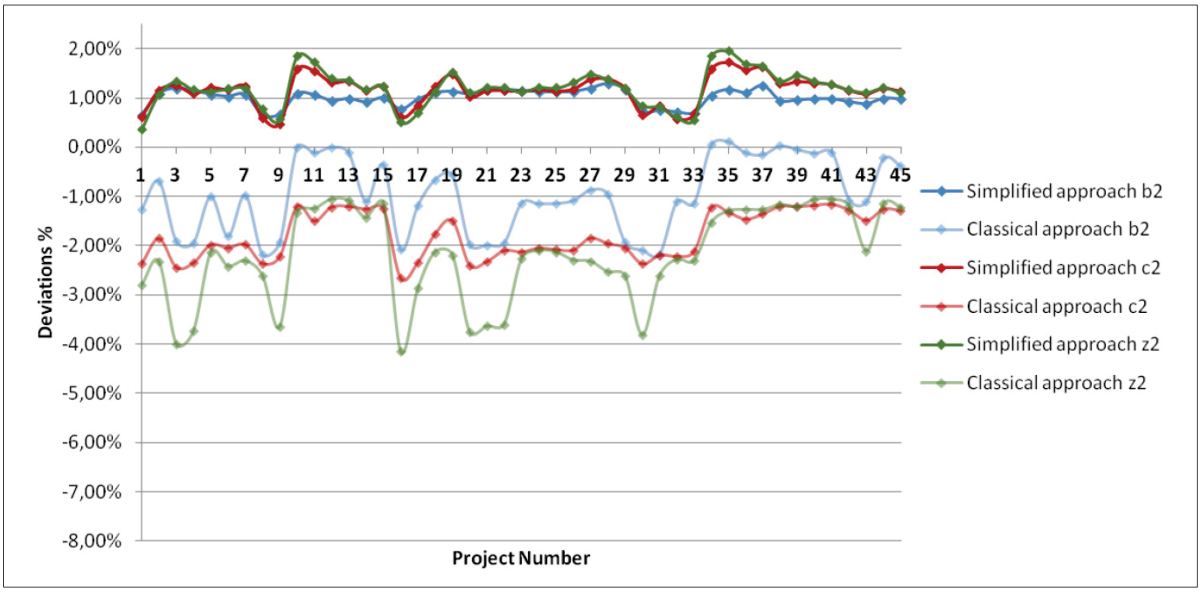

Figure 3 Third analysis volumes' deviations – Excavations

Figure 4 Third analysis volumes' deviations – Embankments

Table 3 Accuracy percentage of the simplified and classical approach per analysis

Analysis/ Methods	Thesis 1	Thesis 2	Thesis 3 Type: b2	Thesis 3 Type: c2	Thesis 3 Type: z2
Excavations					
Simplified	66.7 %	62.5 %	100.0 %	100.0 %	100.0 %
Classical	33.3 %	37.5 %	0.0 %	0.0 %	0.0 %
Embankments					
Simplified	88.9 %	62.5 %	47.0 %	73.0 %	69.0 %
Classical	11.1 %	37.5 %	53.0 %	27.0 %	31.0 %

5 Conclusions

The method of applicable lengths constitutes one of the most concrete and robust methods for the calculation of earthwork volume in road projects. In this study a simplified approach of the applicable lengths method that requires lower computational effort is investigated so as to examine its level of accuracy. In addition, a sensitivity test is carried out to determine the parameters or attributes of a road project that set this approach more reliable from the classical one. Analytically, the conclusions that can be safely retrieved are the following:

- Road projects specific parameters as the average slope, type of typical cross section, deviation of the elevation differences between the longitudinal road profile and terrain line, and road length do not emerge any identifiable pattern or tendency for the uptake of one approach over the other.
- Both approaches are quite reliable and in some cases they calculate with very high accuracy the earthwork volumes.
- The results of the two approaches do not differentiate greatly, while in some cases they produce the same results.
- No approach presents high deviations from the real volumes. In fact, only in two projects the deviations of both approaches exceed more than 6 %.
- An approach can calculate more accurately the total earthwork volumes of a road project, but the other one can produce more accurate results in a specific section of this particular project.
- According to Figures 4 and 5, it appears that the simplified method calculates the volumes in a similar way for the three types of typical cross sections, as there is a uniformity in the results. This makes this approach more reliable as compared to the classical approach, as this approach lacks of any pattern in the results.
- In some cases, the measurements that were taken every 20 meters as compared to the measurements taken every ten meters are closer to the measurements taken every one meter in Anadelta Tessera Software.

All in all, it can be concluded that the simplified approach of the applicable lengths method is producing more reliable results than the classical approach. The authors based on the performed analysis suggest that the classical approach should be replaced by the simplified, especially in calculating software, as the computational process is simplified.

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