v. 3, n. 40, 2023

Journal of
Engineering
Research

COMPARATIVE STUDY OF COMPUTATIONAL TOOLS FOR REINFORCED CONCRETE WALL SIZING

Márcio Corrêa da Silva Filho
Postgraduate in Geotechnical Engineering at: ``Faculdade Futura``, Votuporanga – São Paulo and a degree in Civil Engineering at: Faculdade Única de Ipatinga, BRAZIL
http://lattes.cnpq.br/4749309230452673

Abdon José Corrêa Filho
Graduated in Civil Engineering at: Faculdade Única de Ipatinga, BRAZIL
http://lattes.cnpq.br/9563267137550656

Marcelo de Lima Beloni
Master in Geotechnics and Civil Engineer from: Universidade Federal de Viçosa, BRAZIL
http://lattes.cnpq.br/3068426463897189

 DOI 10.22533/at.ed.31734023231110

Abstract: The present work aims to compare the manual calculation method with the Cypecad software method (2014) for the design of reinforced concrete walls. Furthermore, contrast with the software GEO5 Empuxo de Terra (2016) and Ftool version 3.01, with regard to the calculation of active efforts. For this, the same application example was used for the manual and digital solution, with the aim of mainly evaluating the results obtained for the consumption of steel and concrete, but also the shear forces and bending moments that require containment. The results demonstrated that there was no major discrepancy between requesting efforts calculated by the analyzed methods, however, in relation to Cypecad, when adopting some international criteria, there was a variation in the amount of steel and concrete used.
Keywords: Comparison. Software. Sizing. Soliciting efforts.

INTRODUCTION

According to FREITAS et al. (2014), technological developments obtained by humanity have directly influenced Structural Engineering, especially with regard to the implementation of structural projects. For Colla (2013), the evolution of information technologies has made it possible to create mechanisms that enable data manipulation by computerized systems, which are called software.

The use of computer programs to aid in the calculation of structures has become indispensable due to the benefits arising from these tools, among which the agility and precision of mathematical calculations stand out. Therefore, the manipulation of these tools by a trained professional is essential, as it guarantees the correct entry of information, the analysis of the requested efforts, the calculation results and detailing of the structure.

In this sense, this study sought to evaluate commercial software by comparing the results obtained through manual calculations. The programs used in the calculations were Cypecad (2014), GEO5 Empuxo de Terra (2016) and Ftool version 3.01.

The comparison of the results achieved between software and manual calculation sought to evaluate the advantages and disadvantages of each method, the difference in material consumption and the resources that the software provides. Therefore, this study provides support to those interested in the use of possible software for the design of reinforced concrete retaining walls.

METHODOLOGY

Initially, an example situation was determined in which some information about the soil was applied. Furthermore, an analysis was made of the materials to be used in the wall. For the soil, the slope slope of 4m was considered, the apparent specific weight was 19 kN/m^3, the angle of internal friction was 30°, in addition to not including cohesion and water. It was also established that the allowable stress of the foundation soil would be equivalent to 185 kPa. As for the materials, concrete with a characteristic compressive strength of 20 MPa and CA-50 steel, which has a characteristic yield strength of 500 MPa, were used. Finally, a linear load distributed on the embankment of 5 KPa and 8m was adopted for the length of the wall in plan.

Due to the settlement of the adopted foundation (running footing), the retaining wall was extended by 25 cm, so that the total length of the wall became 4.25 m.

Based on the initial considerations, the determination of the forces acting on the wall was carried out using three methods. In relation to the software methods, Cype made available the thrusts, shear force and bending moment diagrams, details of the structure and quantity of steel and concrete. With GEO5 Earth Thrust, only the pressure diagram corresponding to the contained soil and the overload on the embankment was obtained, therefore it was necessary to use the two-dimensional analysis software Ftool version 3.01 to construct the shear and moment diagrams.

MANUAL METHOD

The first method to be implemented was the manual, based on the recommendations of Pinheiro (1999) and Domingues (1997). In this procedure, Rankine's theory was used to calculate thrust.

A pre-dimensioning of the containment was carried out with the purpose of suggesting the dimensions of both the wall and the foundation footing. Once the dimensions were fixed, the vertical forces and horizontal forces were calculated, which cause, respectively, the stabilizing moments and the overturning moments. Next, checks were made regarding tipping, sliding and pressure in the foundation soil. The safety factors, both for tipping and sliding, must be greater than or equal to 1.5 for the verification to be met.

According to Pinheiro (1999), to minimize slippage, one of the possible solutions to be adopted is the use of a vertical plate or anchor tooth. Therefore, it was considered an anchor tooth in the shoe. Figure 1 illustrates the geometry of the wall, obtained by manual calculation.

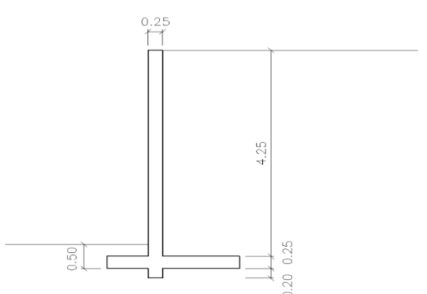

Figure 1. Wall geometry obtained by manual method.

Source: author (2017).

Once the checks were met, the values of shear forces and bending moments acting on the containment wall were obtained using Equation 1 and Equation 2, respectively.

$$Q = \frac{(q0 * ly^2)}{2} + q1 * ly \quad (1)$$

$$M = \left(\frac{q1 * ly^2}{2}\right) + \left(\frac{q0 * ly^2}{6}\right) \quad (2)$$

Where:

Q = cutting force (kN/m)

q0= pressure corresponding to the contained soil (kN/m²)

ly = depth or height of the wall (m)

q1 = pressure corresponding to overload on the embankment (kN/m²)

M = bending moment (kN*m/m)

After calculating the active efforts, the reinforced concrete was designed using the methodology of Pinheiro (2007) and following the criteria of ABNT NBR 6118:2014.

SOFTWARE CYPE

In the second method, using the Cype software, the necessary data was inserted according to the initial considerations. Data on soil, containment and materials are gradually entered by the user, with the possibility of editing after launching the wall geometry.

First, the running shoe is chosen as an option for the foundation, then the height of the containment wall, the environmental aggressiveness class, maximum size of the coarse aggregate, the characteristic resistance of the concrete to compression, the type of steel (CA -50-A), allowable tension of the foundation soil, length of the containment in plan and the coefficient of soil-concrete friction.

The software makes it possible to enter the water table level and the percentage of relief due to drainage. Furthermore, you can choose the depth for mobilizing the passive thrust; in addition to allowing the evaluation of the effect of earthquakes (earthquakes) on containment and the verification of the global stability of the structure using the strip or slice method (Bishop's simplified method).

As in the manual method, here the minimum value of 1.5 was chosen for the tipping and sliding safety factor. For the weighting coefficient, adopted for both Cype and the manual method, 1.4 was defined for the efforts. For the characteristic compressive strength of concrete and the characteristic yield strength of steel, unfavorable coefficients of 1.4 and 1.15, respectively, were applied.

Cype's complete configuration followed the same parameters as the manual method, so that an assessment of the same example situation was possible. Once the conFiguretion was carried out, the software dimensioned the geometry and reinforcement of the structure. Figure 2 shows the geometry given by the program.

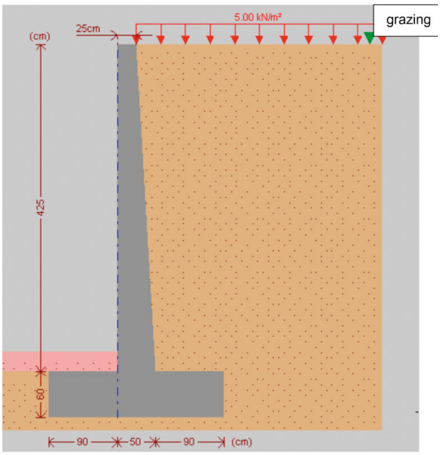

Figure 2. Wall geometry obtained by the Cype program.

Source: author (2017).

SOFTWARE GEO5 EARTH THURST + FTOOL

The introduction of the initial data was similar to that of Cype, however, GEO5 Earth Thrust calculated only the horizontal components that act on containment.

In the same way as the other methods, 4.25 m of retaining wall was considered here. As well as the soil with the same characteristics and the same variable load on the embankment. A differentiator of this program is the shaping of the soil profile on the embankment, making it possible to accurately simulate a real work situation in which the embankment is quite irregular.

The program allows the introduction of hydrostatic buoyancy action, both in front and behind the wall. Additionally, it performs an analysis of the earthquake effect on the structure.

As the program only evaluates the thrust acting on the containment wall, the Ftool program was used to determine the shear and moment. The shear force and bending moment diagrams are presented in Figure 3 and Figure 4, respectively.

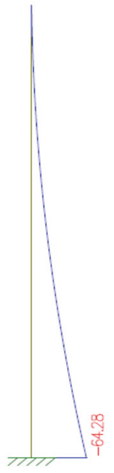

Figure 3. Shear force diagram (kN)

Source: author (2017).

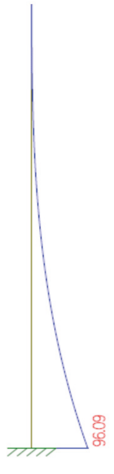

Figure 4. Bending moment diagram (kN*m)

Source: author (2017).

RESULTS AND DISCUSSIONS

The results presented in Table 1 indicate that the thrusts calculated by the analyzed methods were practically the same, with the highest values attributed to the Cype software. For this analysis, passive buoyancy was considered as "relief" from a depth of 4 m into the containment wall.

Profundidade	Método manual	Cype	GEO5 + Ftool
(m)	(kPa)	(kPa)	(kPa)
0,00	1,67	1,78	1,67
1,00	8,00	8,51	8,00
2,00	14,32	15,27	14,33
3,00	20,65	22,03	20,67
4,00	26,98	28,80	27,00
4,25	15,98	16,62	15,92

Table 1 – Thrusts for each method.

Source: author (2017).

Thus, the small difference demonstrated between the manual method and GEO5 is possibly due to the rounding used in the first method, which worked with precision of two decimal places. While GEO5 Empuxo de Terra is a computational program, it can work with more decimal places easily.

The thrusts were calculated in Cype using the Coulomb theory, while the Rankine theory was used in the other two methods. The variation obtained between Cype's efforts in relation to other methods is mainly due to the difference in the containment geometry presented by the program.

The active thrust coefficient according to Coulomb theory is given in Equation 3, taken from Marchetti (2007).

$$Ka = \frac{sen^2(\alpha + \varphi)}{sen^2\alpha * sen(\alpha - \delta) * \left(1 + \sqrt{\frac{sen(\varphi+\delta)*sen(\varphi-\beta)}{sen(\alpha+\delta)*sen(\alpha+\beta)}}\right)^2} \quad (3)$$

Where:

Ka = active thrust coefficient

α = angle of containment with the horizontal (°)

φ = angle of internal friction of the ground (°)

δ = soil-containment friction (°)

β = terrain slope angle (°)

As shown, the inclination of the wall, that is, the geometry of the wall, directly influences the buoyancy coefficient, which is why there was this difference in efforts.

Figure 5 and Figure 6 show the distribution of shears and moments, respectively, along the depth of the wall. At a depth of 4.25 m, the shears reach their maximum value with 66.79 kN for Cype, 62.47 kN for the manual method and 62.50 kN for the shears determined in Ftool through the thrusts calculated in GEO5.

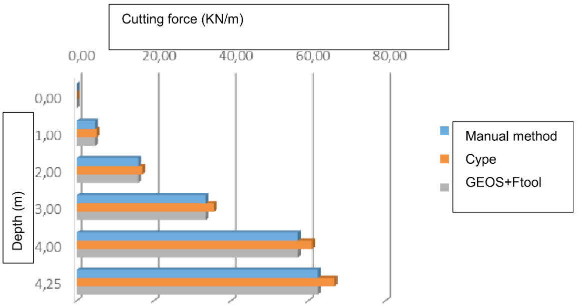

Figure 5. Shear force along the depth

Source: author (2017).

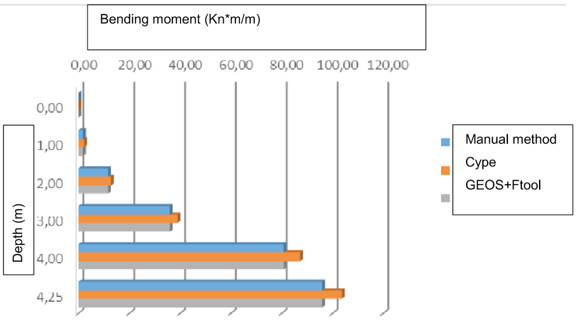

Figure 6. Bending moment along depth

Source: author (2017).

The quantity of concrete showed a significant difference (Figure 7), in which the volume of concrete calculated by Cype was greater in relation to that dimensioned using the manual method. The reason for this discrepancy is some criteria adopted by the program that ABNT NBR 6118:2014 does not take into consideration, such as articles 42.3.2 and 42.3.5 of the ``Instrucción Española del Hormigón Structural`` (EHE) standard.

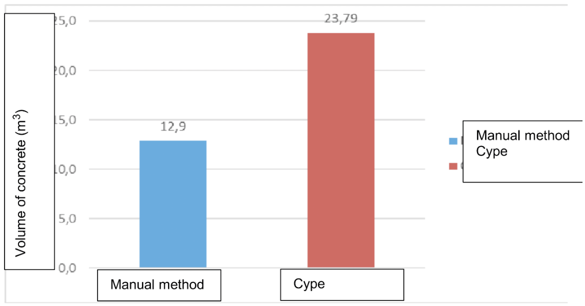

Figure 7. Concrete volume.

Source: author (2017).

However, a large part of the effort involved in containment is absorbed by the concrete structure, resulting in less use of steel by the computer program, as shown in Figure 8.

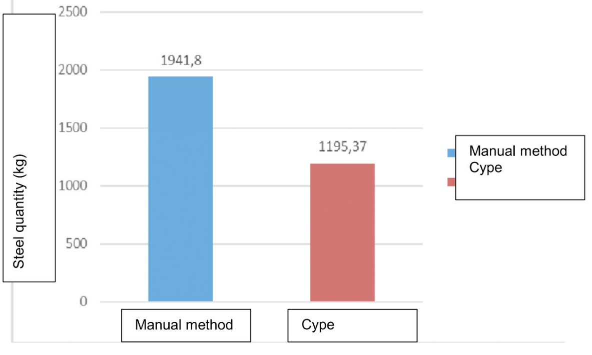

Figure 8. Quantity of steel.

Source: Author (2017)

Regarding the time taken to obtain results, Table 2 presents the approximate time in hours required to carry out each method. For the time estimate, it was considered that each method would carry out checks for tipping, sliding and pressure in the foundation soil. In addition, the calculation and dimensioning of the structure followed ABNT NBR 6118:2014.

Methods	Time (h)
Manual Method	2,5
Cypecad	0,3
GEO5 + Ftool	1,5

Table 2 – Approximate time to obtain results.

Source: Author (2017).

From the results, it was found that the Cypecad software presented greater agility compared to the other methods analyzed. It must be noted that the GEO5 Earth Thrust software and Ftool only provided the calculation of thrust and the diagrams of shear forces and bending moments. Therefore, they only performed part of the procedure, with the need to resort to the manual method to carry out the remaining tasks.

CONCLUSIONS

There are several factors that affect the design of reinforced concrete walls, such as the height and inclination of the slope, the presence or absence of hydrostatic buoyancy, soil characteristics, among others. Through the results obtained in this work, it was noticed that of the methods analyzed, there were no significant differences in the calculations of the active efforts. Regarding the quantity of materials, it was found that the Cype program, by adopting some international criteria, designed a more robust geometry, using more concrete compared to the manual method. On the other hand, the savings in the amount of steel were interesting.

Regarding the execution time of the analyzed methods, Cype presented the shortest time, with approximately 18 minutes, from data entry to results. GEO5 and Ftool demonstrated some agility compared to the manual method, therefore, they are interesting tools for saving time when designing reinforced concrete retaining walls.

Without a doubt, the Cype program demonstrated complete results, with work reports and material quantities. Therefore, it was found that the computational solution has advantages that make the manual method practically unfeasible.

REFERENCES

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 6118**: Projeto de estruturas de concreto - Procedimento. 3 ed. Rio de Janeiro: ABNT, 2014. 238 p.

DOMINGUES, Paulo Cesar. **Indicações para projeto de muros de arrimo em concreto armado.** 1997. 97 p. Dissertação (Mestrado) - Curso de Engenharia Civil, Universidade de São Paulo, São Carlos, 1997.

COLLA, André Luis. **Desenvolvimento de sistema de controle de estoque e produção para madeireiras.** 2013. 65 p. TCC (Graduação) - Curso de Tecnólogo, Universidade Tecnológica Federal do Paraná, Pato Branco, 2013. Disponível em: <http://repositorio.roca.utfpr.edu.br/jspui/handle/1/1465>. Acesso em: 16 set. 2017.

FREITAS, A, H, C., et al., **Cálculos Estruturais em Concreto Armado: Comparativo entre o cálculo manual e com auxílio de software**, Revista Pensar Engenharia, Belo Horizonte, v. 2, n. 2, p. 1 – 19, 2014.

MARCHETTI, O., **Muros de Arrimo**. São Paulo: Blucher, 2007. 141p.

PINHEIRO, L. M., **Muros de Arrimo.** Julho de 1999. Notas de Aulas. Departamento de Engenharia de Estruturas – Universidade de São Paulo, Escola de Engenharia de São Carlos.

PINHEIRO, L. M.; MUZARDO, C. D.; SANTOS, S. P., **Fundamentos do concreto e projeto de edifícios**. Maio de 2007. Notas de aula. Departamento de Engenharia de Estruturas – Universidade de São Paulo, Escola de Engenharia de São Carlos.