Determination of the soil reaction coefficient value – software solution

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Abstract: In numerical modeling of structures, it is necessary to model the soil on which the structures rest. This soil simulation is performed through the Winkler springs model. In the simplest case of shallow foundations, this is done through the coefficient of soil reaction. Since a large number of authors have dealt with this topic, for the needs of a more reliable modeling, the SE_Calc software solution has been developed. The subgrade reaction is calculated on the templates of several authors in order to graphically display their relationships.

Key words: numerical modeling, subgrade reaction, software solution

Određivanje vrijednosti koeficijenta reakcije tla – programsko rješenje

Sažetak: Pri numeričkom modeliranju konstruktivnih sustava potrebno je simulirati i tlo na koje se taj sustav oslanja. Obično se simulacija tla izvodi putem modela Winklerovih opruga. U najjednostavnijem slučaju plitkih temelja krutost opruga se zadaje preko koeficijenta reakcije tla. S obzirom kako se veliki broj autora bavio ovom tematikom za potrebe pouzdanijeg proračuna razvilo se programsko rješenje SE_Calc. U suštini obuhvaćen je proračun po predlošcima više autora kako bi se na kraju grafički mogli prikazati njihovi odnosi i odabrati odgovarajuća vrijednost.

Ključne riječi: numeričko modeliranje, koeficijent reakcije tla, programsko rješenje

1. INTRODUCTION

The Winkler spring model is usually used for soil modeling for the purposes of calculating structural systems. This implies that it is necessary to determine the coefficient of subgrade reaction, which is essentially a relationship between stress and settlement. Numerous authors have dealt with this topic, beginning from Terzaghi, Burmister, Teng etc.

Considering that quite often there is a doubt which author to choose and what reaction coefficient value to adopt, we decided to develop a software solution for square footings that would automatically give a parallel view of subgrade reaction coefficients according to different authors' approaches. Since it is necessary to verify the accuracy of software solution results and compare them with those from the literature, the presentation is limited to granular soil only.

2. APPROACHES OF DIFFERENT AUTHORS

Before going into the subject of defining the coefficient of subgrade reaction, in order to be familiar with its reference values for particular soil types, empirical values of this modulus are listed in the following table, taken over from paper [1].

Table 1. Empirical values of modulus of subgrade reaction according to Wölfer

Soil type	k_s (MN/m^3)
loose peat and organic soils (similar to humus)	5-10
heavy, compacted peat and organic soils	10-15
fine, loose sand (e.g. in riverbeds)	10-15
humus, sand and gravel fills	10-20
water-saturated clayey soil	20-30
wet clayey soil	40-50
dry clayey soil	60-80
dry and hard clayey soil (hard clays)	100
consolidated humus with fine sand and small content of rock	80-100
consolidated humus with fine sand and significant content of rock	100-120
fine gravel with high content of sand	80-100
medium-sized gravel mixed with fine sand	100-120
medium-sized gravel mixed with coarse sand	120-150
rough gravel mixed with rough sand	150-200
rough gravel with small content of sand	150-200
highly consolidated rough gravel with small content of sand	200-250

2.1 Coefficient of subgrade reaction according to Vesić

One of the frequently used approaches when determining the coefficient of subgrade reaction in our region is calculation according to Vesić. The coefficient of subgrade reaction for a square footing of width B, knowing the elastic modulus of soil E_s of an undisturbed sample obtained in laboratory, is obtained from the expression

$$k_s = \frac{0.65 \cdot E_s}{B \cdot (1-\nu^2)} \cdot \sqrt[12]{\frac{E_s \cdot B^4}{E_b \cdot I}} \qquad (1)$$

where

E_b – is the modulus of elasticity of the footing, and

I – is the moment of inertia of the footing.

2.2 Coefficient of subgrade reaction according to Biot

In its final expression, the approach according to Biot uses the same terms as the previous expression according to Vesić. Finally, this approach gives the expression for coefficient of subgrade reaction in the form

$$k_s = \frac{0.95 \cdot E_s}{B \cdot (1-\nu^2)} \cdot \left[\frac{E_s \cdot B^4}{(1-\nu^2) \cdot E_b \cdot I} \right]^{0.108} \quad (2)$$

2.3 Coefficient of subgrade reaction according to Meyerhof & Baike

The expression for reaction coefficient of these two authors is slightly simpler than the previous ones. Namely, when determining the required coefficient, only footing width B and soil characteristics are taken into account, and not characteristics of the foundation (material, moment of inertia ...). The expression is given in the form

$$k_s = \frac{E_s}{B \cdot (1-\nu_s{}^2)} \quad (3)$$

2.4 Coefficient of subgrade reaction according to Kloppe & Glock

Like with previous authors, the expression for coefficient of subgrade reaction is slightly simpler and looks like

$$k_s = \frac{2 \cdot E_s}{B \cdot (1+\nu_s)} \quad (4)$$

2.5 Coefficient of subgrade reaction according to Selvadurai

The final expression according to Selvadurai that is implemented in the software solution is given below. In this expression too, when determining the required coefficient, only footing width B and soil characteristics are taken into account, in the form

$$k_s = \frac{0.65 \cdot E_s}{B \cdot (1-\nu_s{}^2)} \quad (5)$$

3. SOFTWARE SOLUTION

The software solution for determining the value of coefficient of subgrade reaction was implemented in the object-oriented programming language C#, within the Microsoft Visual Studio 2015 software package. The software module kComp was developed for the Windows platform, allowing the user to easily specify the parameters for footing width and soil characteristics, as well as to select the soil type in a separate drop-down menu. After specifying the parameters, it is possible for the user to compare the values of coefficient of subgrade reaction according to several different authors in separate windows/tabs, and in tabular and graphical form. In addition to the standard option of printing the comparison results, it is possible at any time to export/save the graphically presented values of subgrade reaction coefficients to special image files (.png files) on the local hard disk and/or a flash disk, as well as to export a snapshot of the entire module, all in order to more completely document a particular calculation.

The software solution implemented as the kComp module within the SE_Calc program is shown in Figure 1.

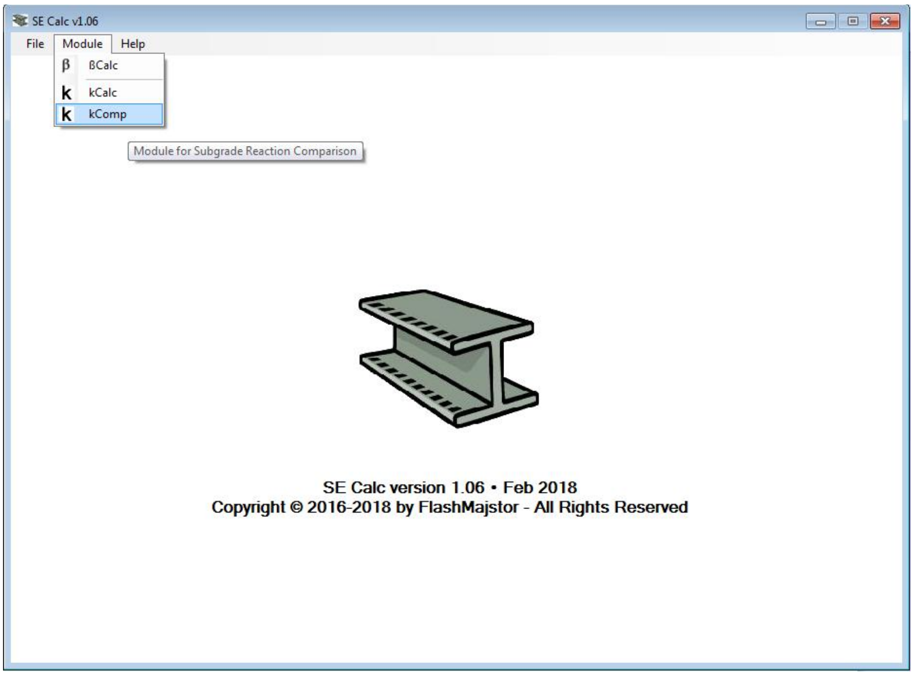

Figure 1. Software solution interface

The parameters that are specified are footing width B and soil characteristics. Soil characteristics can be defined by the user or by using the values that are taken over from the literature (Figure 2).

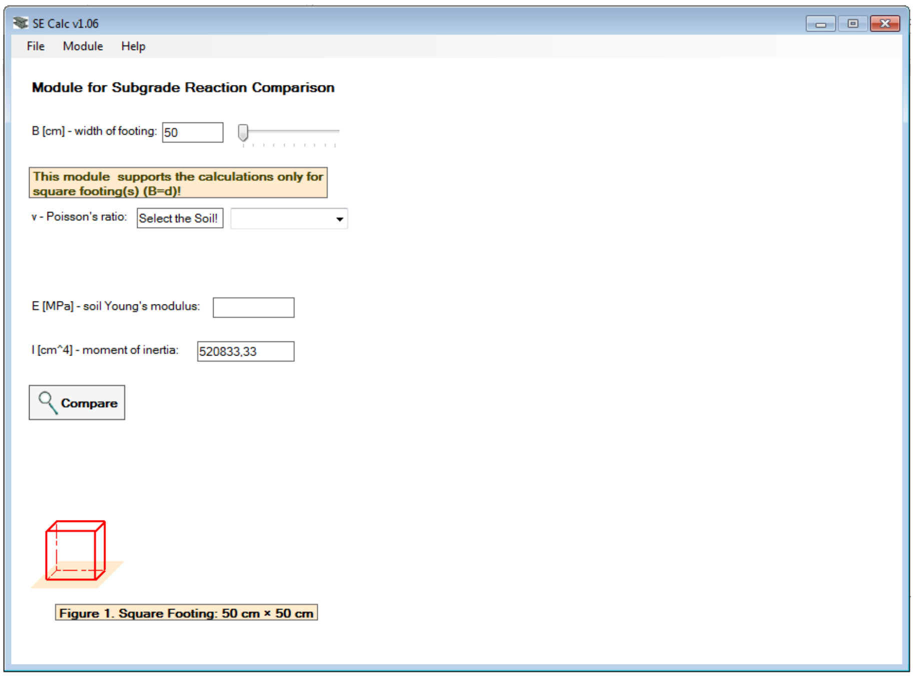

Figure 2. Setting input data

Three footings with dimensions below are taken for the purpose of verifying the reliability of the software solution:

a) 300 cm x 300 cm x 120 cm,
b) 250 cm x 250 cm x 120 cm, and
c) 150 cm x 150 cm x 120 cm.

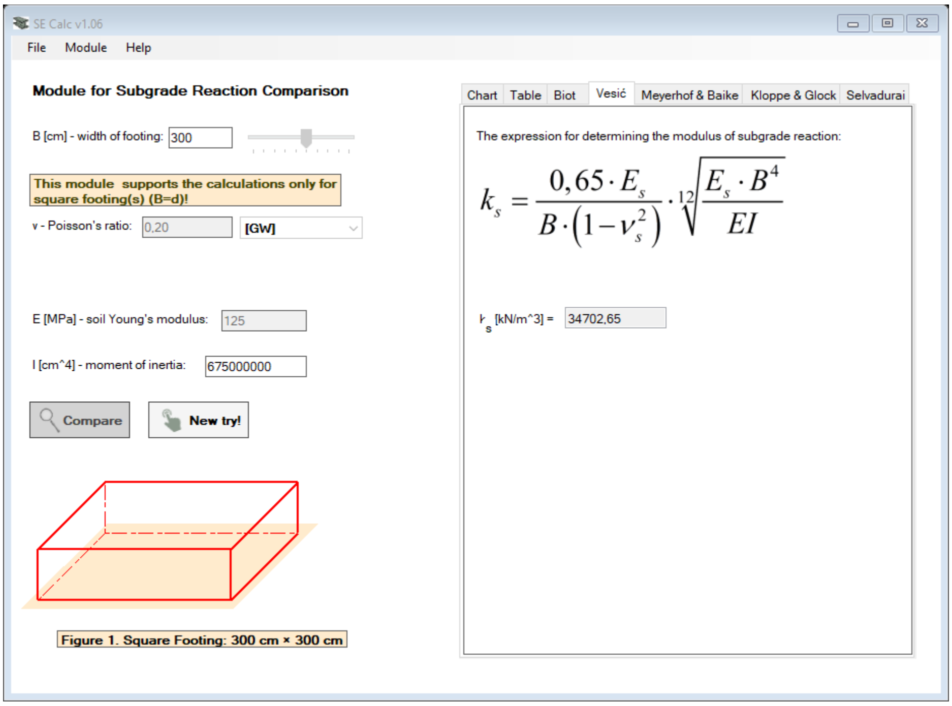

Figure 3. View of the calculation according to Vesić for footing 300 cm x 300 cm x 120 cm

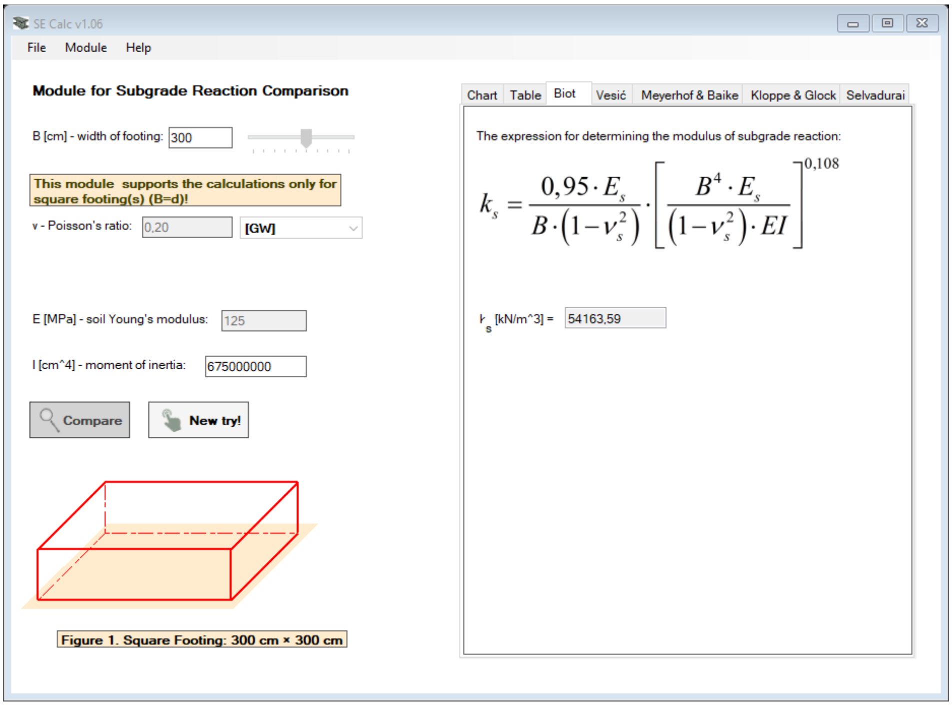

Figure 4. View of the calculation according to Biot for footing 250 cm x 250 cm x 120 cm

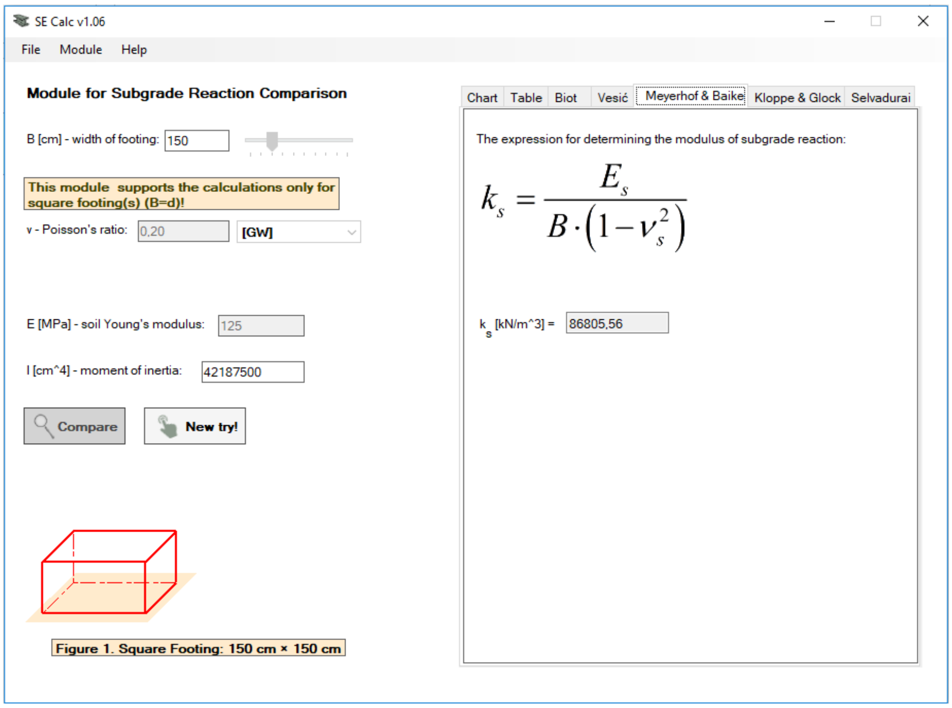

Figure 5. View of the calculation according to Meyerhof & Baike for footing 150 cm x 150 cm x 120 cm

The results obtained for these foundations for all these authors were compared with those listed in the literature [2]. Their values specified in the figure below are identical to those given in the literature [2].

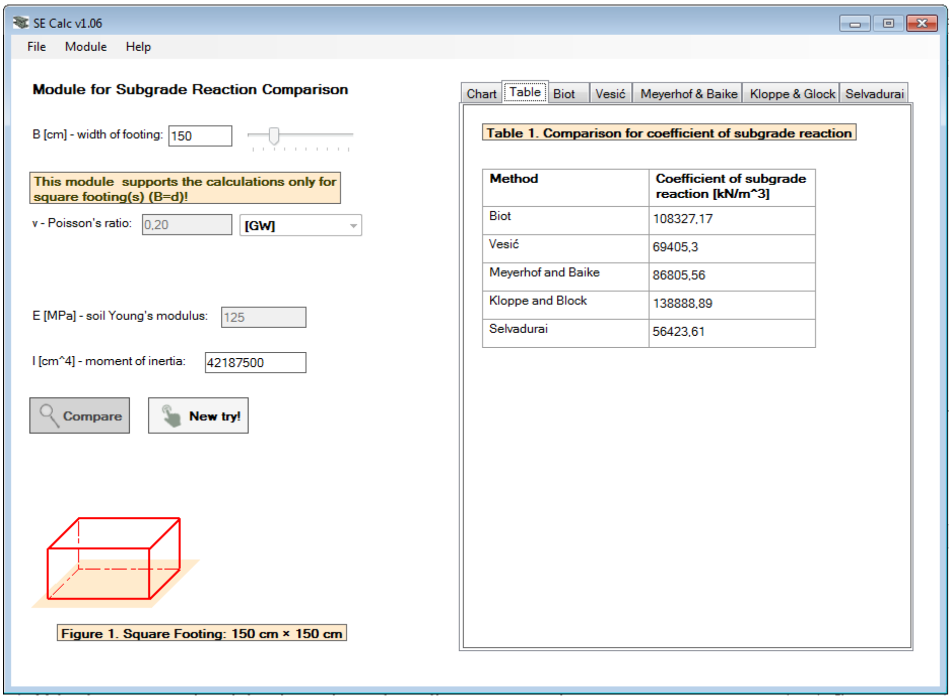

Figure 6. Tabulation of values according to all authors for footing 150 cm x 150 cm x 120 cm

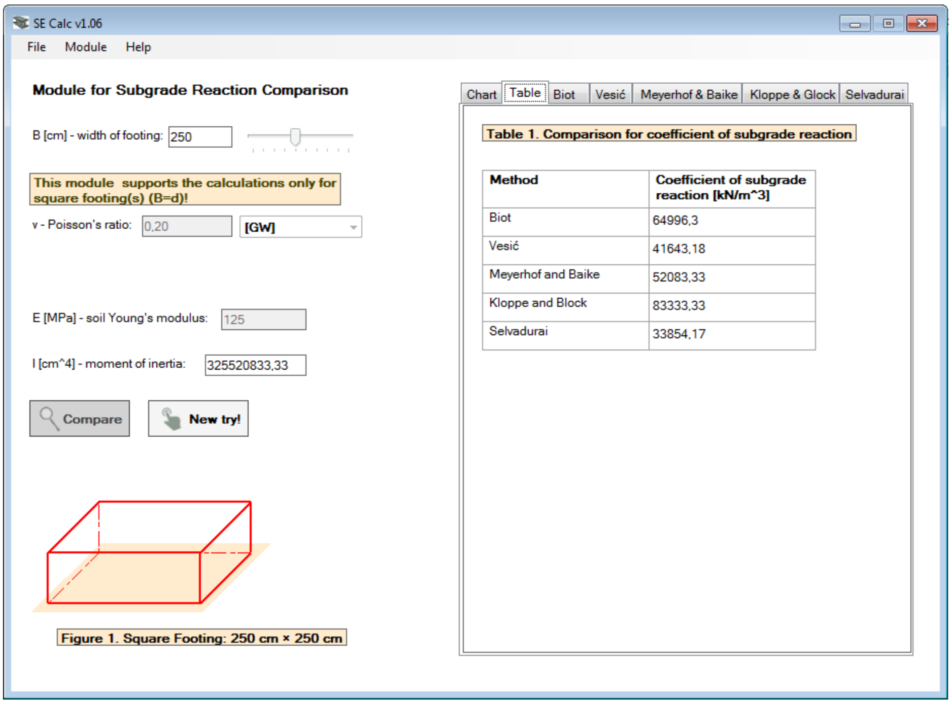

Figure 7. Tabulation of values according to all authors for footing 250 cm x 250 cm x 120 cm

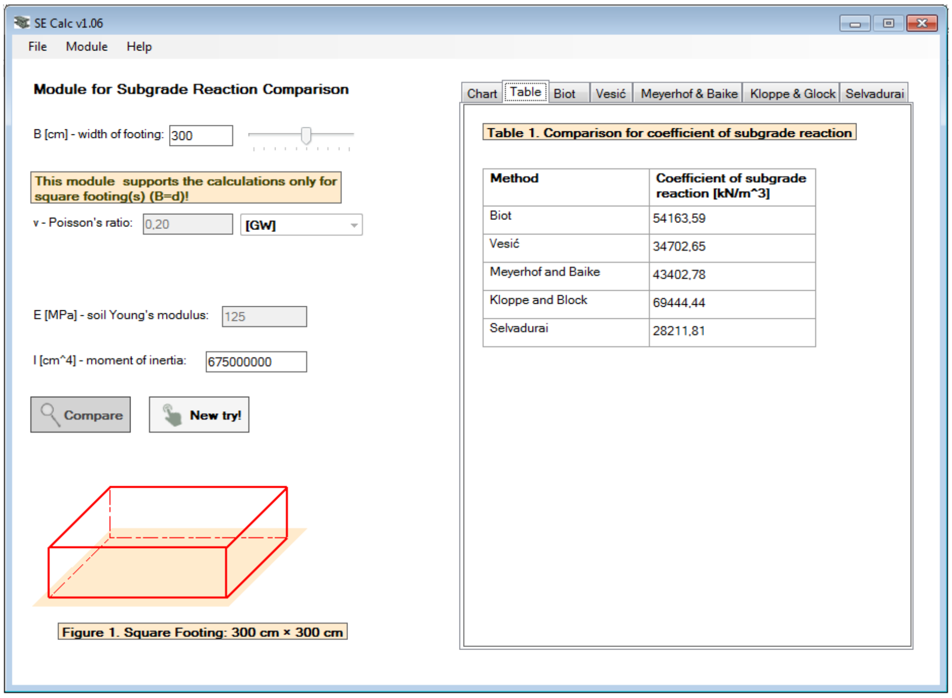

Figure 8. Tabulation of values according to all authors for footing 300 cm x 300 cm x 120 cm

Certainly, the results can also be presented through a chart that shows the values of subgrade reaction coefficients depending on footing width B, and obtained by individual authors. Because of space limitations, only the chart for footing sized 300 cm x 300 cm x 120 cm will be presented below.

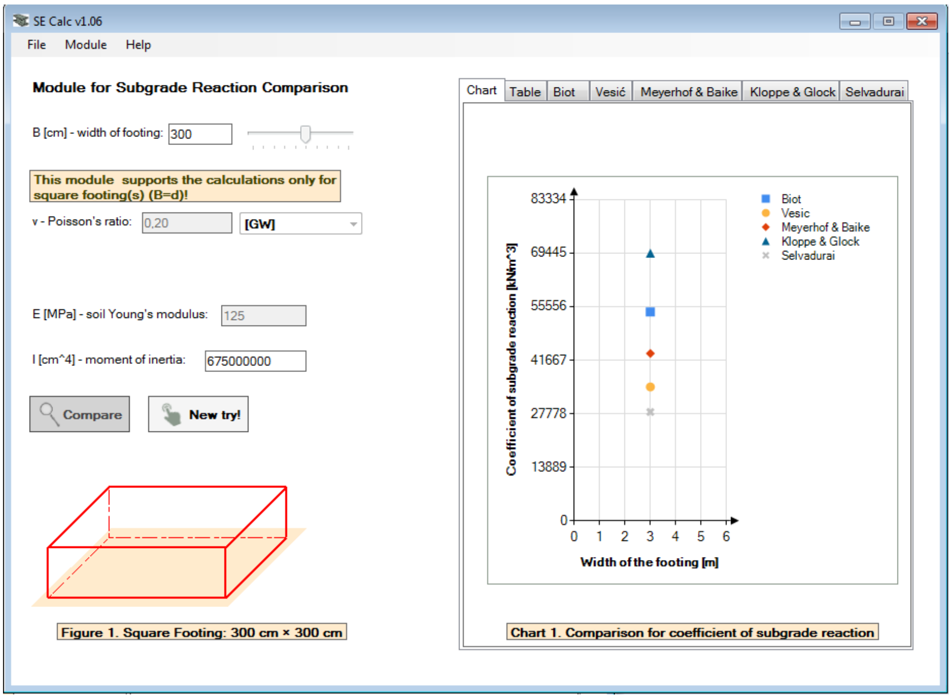

Figure 9. Graphical presentation of coefficient values calculated according to all authors for footing 300 cm x 300 cm x 120 cm

4. CONCLUSION

Numerical modeling of structural systems implies knowing characteristics of soil in order to be able to simulate it, usually using the Winkler springs model. The paper treats simplest cases of square shallow footings when soil stiffness below the footing is set through coefficient of subgrade reaction. Since this problem was dealt with by different authors, the software solution that gives the values of this coefficient according to all these authors has been developed. A chart that graphically presents these values and thereby helps the designer decide which value to adopt is obtained after calculation. In further development of the software solution, it remains to determine the average value of this coefficient, taking into account the values obtained by different calculations.

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