CDIAPH: PROGRAM FOR CALCULATING REINFORCED CONCRETE DIAPHRAGM WITH FINITE DIFFERENCE METHOD

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Abstract. *Works in soil requires making of supporting structures to ensure the stability of the field. Reinforced concrete diaphragms allow you to perform the most complex works in a safe manner. The current calculation practice of the effect and movement of diaphragms implied the manual approach to the calculation that requires a serious time commitment of engineers or the use of complex commercial software packages. This paper presents the program automation and acceleration of the process of calculating the effect, movement and rotation of reinforced concrete diaphragms. A software package Cdiaph has been developed, which with the finite difference method calculates and draws diagrams of force impact at the intersection (M and V), movement and rotation of the intersection (x and f) and the recommended depth of foundation (D) of reinforced concrete diaphragms.*

Key words: *Cdiaph, Diaphragms, Finite difference method, Automation of calculations*

1. INTRODUCTION

In the construction of facilities the most complex and difficult works are those carried out in the soil. It may be works on the foundations, construction of underground chambers, shallow tunnel works, works to protect deep excavation or repair of moving earth masses (1). They are particularly demanding in complex engineering - geotechnical conditions (presence of free or ground waters, unstable ground, layers of small capacity) or when it comes to construction in urban areas, limited and confined space influenced by adjacent structures, with minimal disruption of existing traffic and the making of construction site noise (2) (3) (4) (5) (6) (7).

The diaphragm is a thin pliant wall in the ground, built by special technology, in which, depending on the purpose, one can be of reinforced or unreinforced concrete, clay concrete, processed or raw clay. As supporting elements of deep foundations there may be independent (individual) components of deep foundations (diaphragm piles) and independent foundations (wells and containers) formed by the diaphragm.

Performing works in the soil requires the construction of supporting structures to ensure ground stability (8) (9) (10), safety from groundwater and safety of adjacent structures in all phases of construction and service. Previously, there were different kinds of wooden support units, the piling walls or walls from piles. Today we use the diaphragms, which allow us to perform the most complex works in a far safer manner.

The aim of the research is to automatize the process of calculating force impact at the intersection (M and V), as well as movement and rotation of the intersection (x and f) of reinforced concrete diaphragms. Automation is performed by creating a software package Cdiaph, based on the finite difference method. This paper gives an overview of this software package and its presentation on a numerical example. In order to verify the obtained results, the comparative analysis of the operation of the program Cdiaph and the program PLAXIS 8 (11) has been performed.

2. METHODS AND MATERIAL

2.1. Finite difference method

Taken for the analysis in this paper are the basic principles that are applied to the soil as a linear deformable environment characterized by the coefficient of horizontal soil reaction Ch. According to Terzaghi - it defines the relationship between the horizontal displacement of the axis points of the vertical deformable bracket x_z and reactive soil pressure σ_z in the form (12):

$$C_H = \frac{\sigma_z}{x_z} = f_z \qquad (1)$$

where: f_z - distribution function of the coefficient of soil reaction with the depth

To solve the problem of transversely loaded vertical deformable brackets, you usually start with the constant value C_H:

$$C_H = f_z = C_h = const. \qquad (2)$$

or linearly increasing (figure 1)

$$C_H = f_z = C_h \cdot \frac{z}{h_m} \qquad (3)$$

The depth at which we calculate the reference value of the coefficient of vertical soil reaction C_h, according to (13) is:

$$C_h = m \cdot h_m \qquad (4)$$

where in:

$$h_m = 2 \cdot (d + 1) \qquad (5)$$

where by: d – depth of diaphragm wall (m), m – characteristics of the soil (kN/m^4)
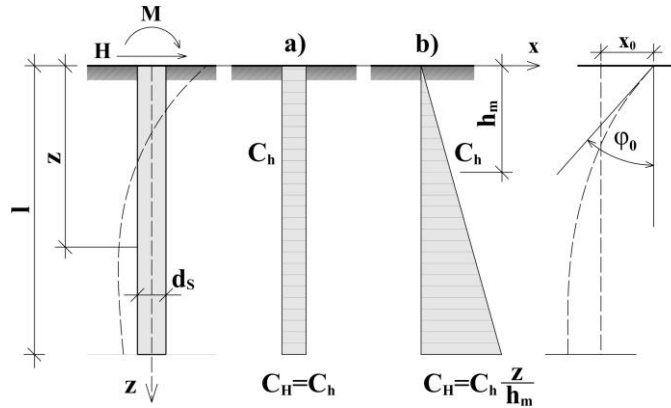
Fig. 1 The distribution of coefficients of horizontal reaction with the depth,
a) a constant distribution of the coefficient of soil reaction,
b) linear distribution of the coefficient of soil reaction

This method is based on differential equation of the elastic line of the bracket and its solution in an analytical form.

When $C_H = C_h = const.$, the differential equation of the elastic line of the bracket has the form:

$$EI\frac{d^4x}{dz^4} + z \cdot C_h = 0 \tag{6}$$

with the solution:

$$x_z = \frac{2\lambda}{C_h \cdot 1.0} \cdot e^{-\lambda z} \cdot \left[H_0 \cos \lambda z + M_0 \lambda (\cos \lambda z - \sin \lambda z) \right]$$

$$\varphi_z = \frac{2H_0\lambda^2}{C_h \cdot 1.0} \cdot e^{-\lambda z} (\cos \lambda z + \sin \lambda z) + \frac{4M_0\lambda^3}{C_h \cdot 1.0} \cdot e^{-\lambda z} \cos \lambda z \tag{7}$$

$$M_z = \frac{H_0}{\lambda} e^{-\lambda z} \sin \lambda z - M_0 \lambda e^{-\lambda z} (\cos \lambda z + \sin \lambda z)$$

$$V_z = H_0 e^{-\lambda z} (\cos \lambda z - \sin \lambda z) - 2M_0 \lambda e^{-\lambda z} \sin \lambda z$$

whereby:

H_0, M_0 – transversal load for $z=0$ (known initial parameters)

$\lambda = \sqrt[4]{\dfrac{C_h \cdot 1.0}{4EI}}$ (m^{-1}) – linear characteristics of the beam

For linearly increasing coefficient of soil reaction, differential equation of the elastic line of a beam has a form (13):

$$EI\frac{d^4x}{dz^4} + x_z \cdot C_h \frac{z}{h_m} = 0 \tag{8}$$

with a known solution:

$$x_z = x_0 A_1 + \frac{\varphi_0}{\alpha} B_1 + \frac{M_0}{\alpha^2 EI} C_1 + \frac{H_0}{\alpha^3 EI} D_1$$

$$\frac{\varphi_z}{\alpha} = x_0 A_2 + \frac{\varphi_0}{\alpha} B_2 + \frac{M_0}{\alpha^2 EI} C_2 + \frac{H_0}{\alpha^3 EI} D_2$$

$$\frac{M_z}{\alpha^2 EI} = x_0 A_3 + \frac{\varphi_0}{\alpha} B_3 + \frac{M_0}{\alpha^2 EI} C_3 + \frac{H_0}{\alpha^3 EI} D_3$$ (9)

$$\frac{V_z}{\alpha^3 EI} = x_0 A_4 + \frac{\varphi_0}{\alpha} B_4 + \frac{M_0}{\alpha^2 EI} C_4 + \frac{H_0}{\alpha^2 EI} D_4$$

where:

H_0, M_0 – transversal load for $z = 0$ (known initial parameters)

x_0, φ_0 – horizontal movement and rotation angle of intersection for $z=0$ (unknown initial parameters)

α – indicator of stiffness

A_1, B_1, ... C_4, D_4 – effect functions of the (13)

Vertical deformable structures, transversely loaded at certain depth are trapped into the ground. At this depth, there is no horizontal movement and all static effects are of very small value.

2.2. Automation of the finite difference method

The entire calculation and process of drawing diagrams of force impact at the intersection (M and V), as well as movement and rotation of the intersection (x and f) of reinforced concrete diaphragms are automated with the program Cdiaph. Based on the input data (γ c, φ, m, d, Ec and h) the recommended depth of the foundations D is determined. By further calculation according to the formulas given in section 2.1, values are obtained which are used for drawing of effect diagrams.

The calculation of the effect of reinforced concrete diaphragms with finite difference method involves reading the coefficients of the effect from the table of V.S. Kirilov (13), obtained by using the differential equations of the fourth degree. These equations are incorporated within the software package Cdiaph, so the effect coefficients are calculated. This offsets the effect of human factors and potential errors in reading tables, within which the authors of this study found numerical errors.

3. DESCRIPTION OF THE CDIAPH PROGRAM

Cdiaph is a software package for calculating the force impact at the intersection (M and V), movement and rotation of the intersection (x and f) and the recommended depth of foundation (D) of reinforced concrete diaphragms with finite difference method. Calculation and diagram presentation are for the dug in part of reinforced concrete diaphragm. The program is written in Java, using the Eclipse and the Standard Widget Toolkit. The main screen of the program is shown in Figure 2.
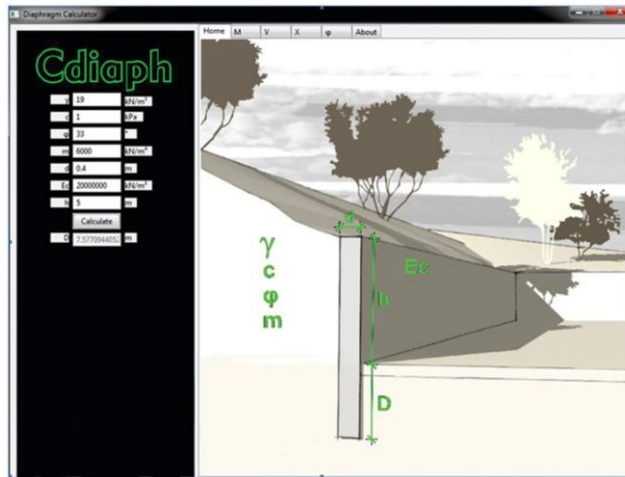
Fig. 2 The welcome screen of Cdiaph program

The interface for data entry is simplified to the maximum. On the left side of the main screen there is the interface for input of variables with a graphic explanation on the right.

3.1. Input and output data

The entire process of calculations in Cdiaph refers to one soil type ground. The input data required for the calculation are the characteristics of the soil: g, c, f, m, reinforced concrete diaphragm dimensions: d, h and characteristics of concrete: Ec.

Where: g – volume weight, c - cohesion, f - angle of internal friction, m - soil characteristics, d - thickness of the diaphragm, h - clear height of the ground and Ec - Young's modulus of elasticity of concrete. Using the finite difference method, the program gives the recommended depth of the foundation D, diagrams: the moment (M) (Figure 3), transversal force (V) (Figure 4), movement (x) (Figure 5) and rotation (f) (Figure 6), with automatic reading of maximum and minimum values.
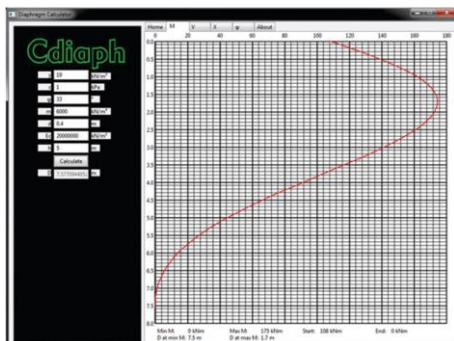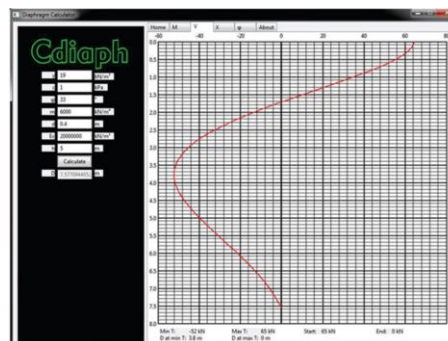

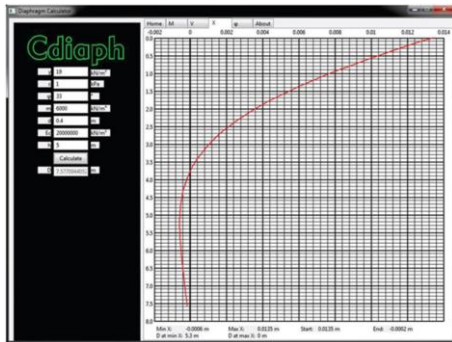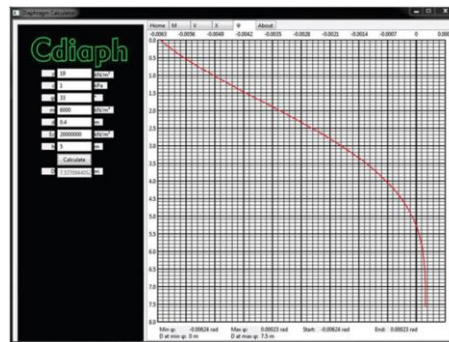**Fig. 3** M - diagram

Fig. 4 V - diagram

Fig. 5 x - diagram   **Fig. 6** f - diagram

3.1. Accessibility of the program

Program and future updates can be downloaded from the website http://petarpejic.wix.com/ djordje-lazarevic. Questions, comments, and any irregularities in the program operation can be sent to the authors to petar.pejic@gaf.ni.ac.rs.

4. VALIDATE THE SOFTWARE SOLUTION

In order to verify the functionality of the Cdiaph program, a comparative analysis of the results obtained in this program with the results obtained in Plaxis 8 (11) was performed. The main difference of these two programs is reflected in the method of calculation, Plaxis uses finite element method (FEM) and Cdiaph uses finite difference method.

Simulation in Cdiaph was performed for the one soil type ground with features:

$$\gamma = 19 \, kN/m^3,$$
$$c = 1 \, kPa,$$
$$\varphi = 30^o,$$
$$m = 2000 \, kN/m^4,$$

and reinforced concrete diaphragm with features:

$$D = 0,4 \, m,$$
$$h = 3,0 \, m,$$
$$E_C = 31000000 \, kN/m^2$$

The recommended depth of the foundation D = 5.53 is obtained and effects of the buried part of the reinforced concrete diaphragm:
- the maximum bending moment (Figure 7) $M_{max} = 55.5$ kNm,
- maximum transversal force (Figure 8) $V_{max} = 25$ kN,
- maximum movement (Figure 9) $X_{max} = 10.4$ mm
- maximum rotation (Figure 10) $f_{max} = 0.00314$.

Fig 7. M - diagram
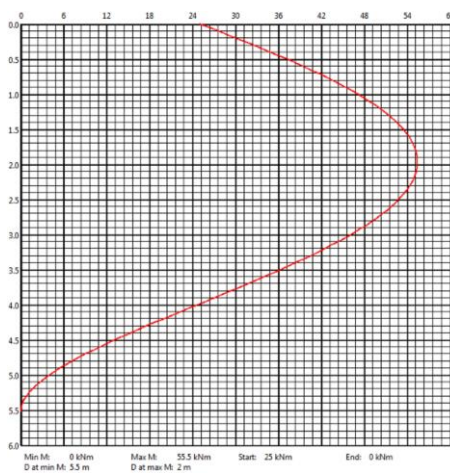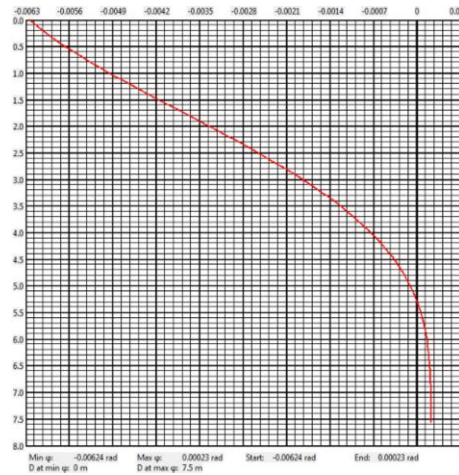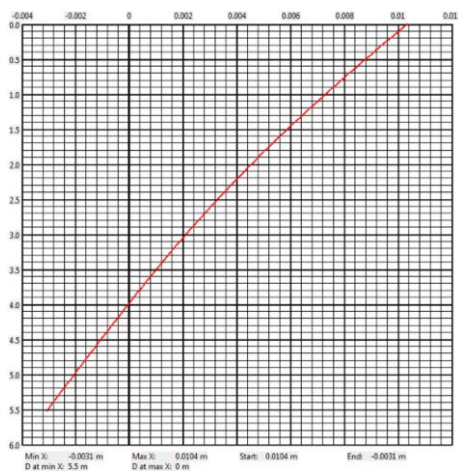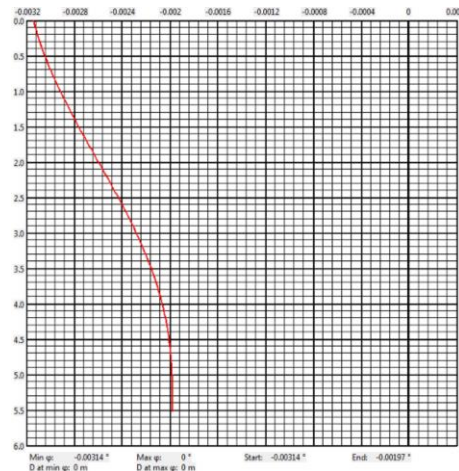

Fig 8. V - diagram

Fig 9. x – diagram

Fig. 10 f – diagram

Simulation in Plaxis was performed for the one soil type ground with features:

$\gamma = 19\,kN/m^3,$

$E_{soil} = 15000\,kN/m^2$

$c = 1\,kPa,$

$\varphi = 30^o,$

and reinforced concrete diaphragm with features:

$D = 0,4\ m,$

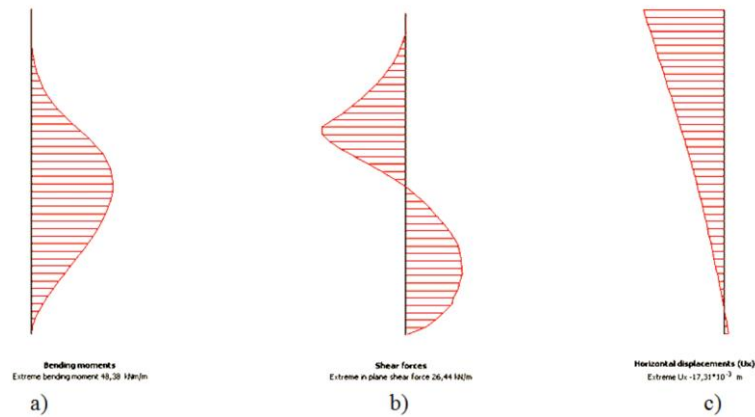$h = 3,0\,m,$

$E_C = 31000000\,kN/m^2$

Fig. 11 Effects and strains: a) bending moment, b) transversal force c) movement.

The taken depth foundation is D = 5.50 m, and the resulting effects of the buried reinforced concrete diaphragms are:

- The maximum bending moment (Figure 11a) M_{max} = 48.38 kNm,
- The maximum transversal force (Figure 11b) V_{max} = 26.44 kN
- The maximum horizontal movement (Figure 11c) x_{max} = 10.4 mm

5. DISCUSSION

The result of the research is a software package Cdiaph that automates calculation process of effects and strains of reinforced concrete diaphragms with finite difference method.

When manually calculating the effect diagrams of AB diaphragms by finite difference method, regardless of the skill and experience of the designer, it is necessary to consume a certain amount of time. The effect diagrams are obtained by connecting certain points in foundation depth D, and for each point different calculation is performed. This means that the time of the calculation directly depends on the desired accuracy of the final effect diagrams. This method of drawing the effect diagrams requires much more time than Cdiaph program.

Based on the obtained maximum values for effects and strains by using Plaxis and Cdiaph programs, the table 1 has been created to present the deviation of the results in percentages.

Table 1 Comparative presentation of results.

	M (kNm)	V(kN)	x(mm)
Cdiaph	55.50	25.0	10.40
PLAXIS	48.38	26.44	9.64
Deviation %	12.82	5.76	7.80

A comparative analysis of the results with conventional software package Plaxis shows that the obtained values for M, V and x deviate in average 8.79%.

5. CONCLUSION

Cdiaph, being software package based on the finite difference method calculates and draws the effect and deformation diagrams of reinforced concrete diaphragms. Obtained discrepancies in the results of the given example when using the software package PLAXIS and software package Cdiaph are the result of different calculation methods for these two programs. Partial coefficient for the constant load according to Eurocode 2 (14) is 1.35 (EN 1992-1-1 2004). The increase of the effect of reinforced concrete diaphragm in further calculation of 35% ensures that the obtained average deviation of 8.79% does not significantly affect the stability of the structure.

Using this program the human factor is reduced which accelerates the calculation and avoids potential errors. The calculation of the effect of reinforced concrete diaphragms by using Cdiaph program, does not require knowledge of the calculation process or prior knowledge of geometric modeling. The entire process is intuitive and adapted for the use of engineers which makes this software package easier to use than other methods and software of the same type.

Future research will be based on improving the Cdiaph program in terms of calculating reinforced concrete diaphragms for cases of multi-type soil and adding modules for dimensioning the diaphragm. Hereby it tends to further development of the software for calculation of effects and dimensioning of reinforced concrete diaphragms with a greater level of automation and minimized human factor on the calculation.

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CDIAPH: PROGRAM ZA PRORAČUN ARMIRANO BETONSKIH DIJAFRAGMI METODOM KONAČNIH RAZLIKA

Izvođenje radova u tlu zahteva izradu potpornih konstrukcija kojima se osigurava stabilnost terena. Armirano betonske dijafragme omogućavaju izvođenje najsloženijih radova na bezbedan način. Dosadašnja praksa proračuna uticaja i pomeranja dijafragmi podrazumevala je manuelni pristup proračuna koji zahteva veliko vremensko angažovanje inženjera ili korišćenje složenih komercijalnih softverskih paketa. Ovaj rad ima za cilj prezentovanje programa za automatizaciju i ubrzanje procesa proračuna uticaja, pomeranja i obrtanja u armirano betonskim dijafragmama. Razvijen je softverski paket Cdiaph, koji metodom konačnih razlika proračunava i iscrtava dijagrame uticaja sila u preseku (M i V), pomeranja i obrtanja preseka (x i φ) i preporučene dubine fundiranja (D) armirano betonskih dijafragmi.

Ključne reči: *Cdiaph, dijafragme, metoda konačnih razlika, program, automatizacija*