Stručni rad/Professional paper
Primljen/Received: 31.10. 2019.
Prihvaćen/Accepted: 16. 12. 2019.

EXAMPLE OF CONSTRUCTION PIT PROTECTION DESIGN

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Abstract: Construction pit is a space where a foundation is constructed. This space must meet the requirements such as safety at work and accessibility for workers and heavy equipment. A construction pit design depends on the type of structure, characteristics of soil and presence of groundwater. In cases of high risks and many unfavourable conditions, a protective structure is built to ensure stability of construction pit walls, and to prevent deformation or possible collapse. The design of a protective structure usually depends on the composition and characteristics of soil, excavation depth, groundwater level or geometry. This paper presents an example of a construction pit protection project where foundation and construction of a residential and business building will be performed. A geotechnical soil model with three geotechnical environments, a model and calculation of the construction pit are defined, which are controlled in geotechnical software.

Key words: construction pit, foundation, protective structure

PRIMJER PROJEKTIRANJA ZAŠTITE GRAĐEVINSKE JAME

Sažetak: Građevinskom jamom se smatra prostor unutar kojeg se izvodi temeljenje. Taj prostor mora zadovoljiti uvjete kao što su sigurnost za rad i dostupnost mašinama i radnicima. Projekt građevinske jame ovisi o vrsti građevine, osobinama terena i prisustvu vode u tlu. U slučajevima kada postoje veliki rizici i mnogo nepovoljnih uvjeta, izvodi se zaštitna konstrukcija koja ima zadatak da osigura stabilnost zidova građevinske jame, te da spriječi deformacije ili eventualno urušavanje. Rješenje zaštitne konstrukcije najčešće ovisi o sastavu tla, karakteristikama tla, dubini iskopa, nivou podzemne vode ili geometriji. U ovom radu se prikazuje primjer projekta zaštite građevinske jame u kojoj će se vršiti temeljenje i izgradnja stambeno-poslovnog objekta. Definiran je geotehnički model tla sa 3 geotehničke sredine, model i proračun temeljne jame koji su kontrolirani u softverima za geotehničke svrhe.

Ključne riječi: građevinska jama, temeljenje, zaštitna konstrukcija

1. Introduction

It is widely known that retaining structures have been used ever since ancient times, and it can be even said that retaining structures emerged at the very beginning of civil engineering as a science. Regardless of what type of retaining structure is involved, each one has the same purpose, which is to protect the outer face of soil. In the case of construction pit protection, rows of piles, various types of diaphragms and embedded walls are most often used.

The subject of this paper is an example of construction pit protection design for a business and residential building in the settlement of Cazin, Bosnia and Herzegovina. The paper consists of several parts, namely: presentation of a geotechnical soil model with three different geotechnical environments, including substratum depth data, then foundation pit modelling and calculation in GEO5 software, pile sizing and control calculation.

2. Construction pit protection

The construction pit protection project is conducted in several stages. It is primarily necessary to define the geotechnical model of the ground and to determine the depth of substratum. Then, foundation pit modelling as well as foundation pit calculation itself are carried out. All design stages are presented in detail below.

2.1. Geotechnical model of the ground

The geotechnical model of the ground was adopted based on the geotechnical parameters adopted in the Study, Earth d.o.o Tuzla, October 2018. The relevant geomechanical parameters given in the Study were determined under laboratory and field test conditions. The ground model with the relevant geomechanical parameters for calculations is shown below.

Geotechnical environment 1: cover consisting of brown clay, medium hard to soft, and fine clayey sand (approximately the same test results were obtained in laboratory)
- bulk density $\gamma = 21.15$ kN/m^3
- compressibility modulus determined on the ground $M_v = 5.5$ MPa
- cohesion $c = 6$ kN/m^2
- internal friction angle $\varphi = 14°$.

Geotechnical environment 2: cover consisting of brown clay, hard and brown clay, sandy, hard (approximately the same test results were obtained in laboratory)
- bulk density $\gamma = 20.75$ kN/m^3
- compressibility modulus determined on the ground $M_v = 10.0$ MPa
- cohesion $c = 10$ kN/m^2
- internal friction angle $\varphi = 24°$.

Geotechnical environment 3: marls, grey, hard (substratum)
- bulk density $\gamma = 24.10$ kN/m^3
- compressibility modulus determined on the ground $M_v = 17.0$ MPa
- cohesion $c = 26$ kN/m^2
- internal friction angle $\varphi = 26°$.

The depth of substratum was not determined by exploratory boreholes B-1 and B-2 because the boreholes ended in cover materials. For this reason, a new exploratory borehole NB-1 was drilled. The borehole is located close to 503. Slavne Brdske Brigade Street. The drilled core of the borehole is shown in the following figure:

Figure 1. Drilled cores from the borehole NB-1

By engineering-geological mapping of the drilled core, it can be concluded that the depth of the substratum at this location is 10.0m. A new borehole NB-2 was also drilled near Kulina bana Street. A substratum depth of up to 7.5m was established in this borehole.

2.2. Modelling of the foundation pit

The foundation pit model is shown in figures:

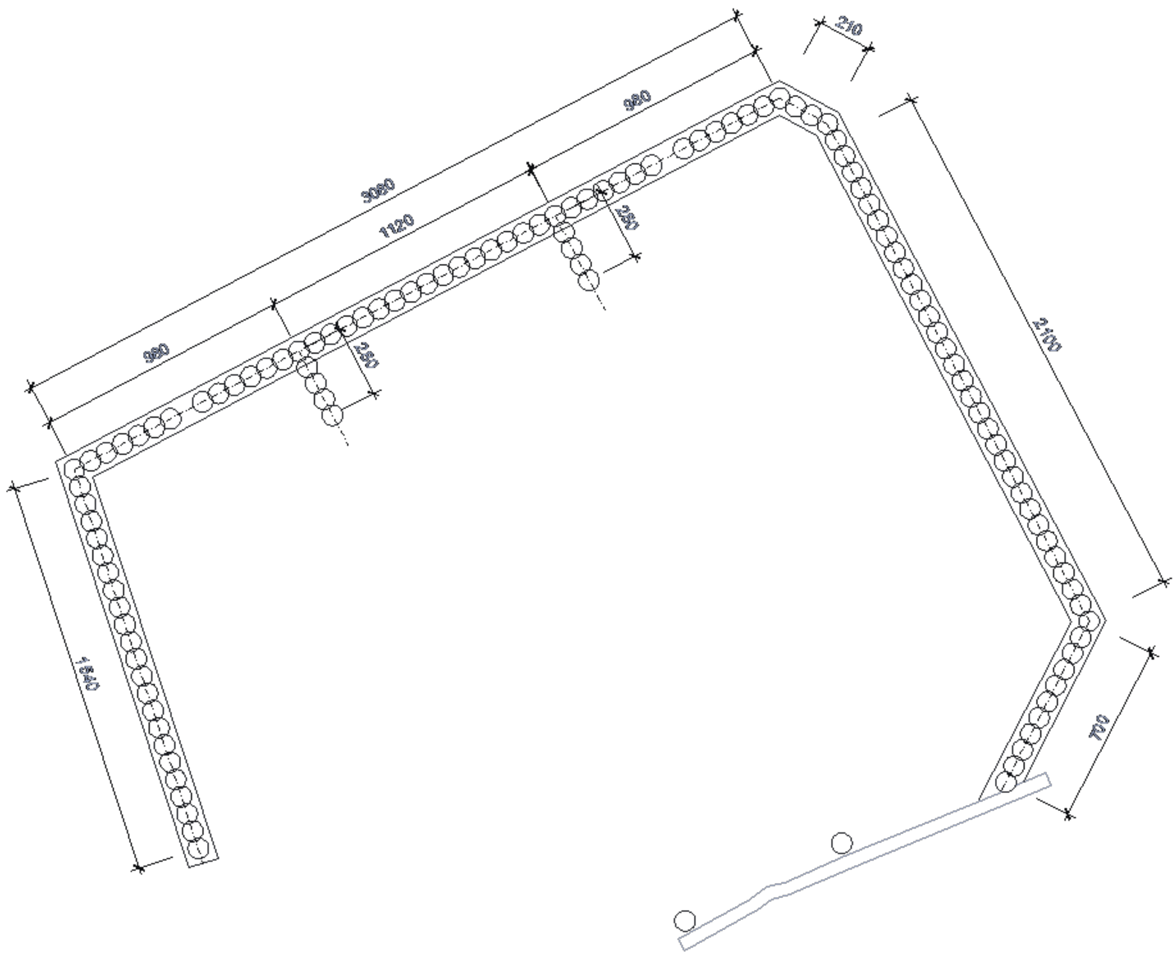


Figure 2. Base of the structure

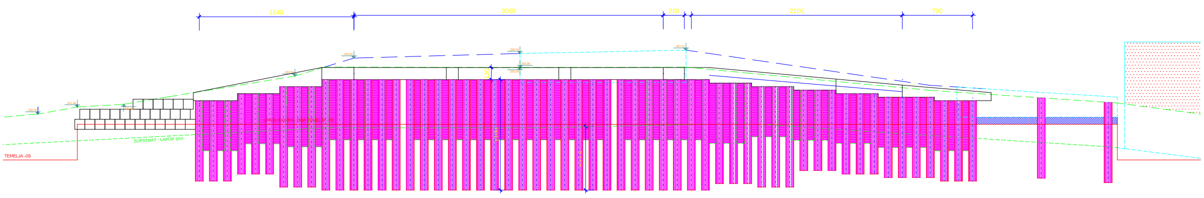


Figure 3. Developed longitudinal section of the structure

2.3. Calculation of the foundation pit

In the calculation model and construction, the series of unreinforced piles is ignored and is considered a structural lining series between the supporting pile series. The underground water pressure behind the series of piles below the existing ground level is also ignored, because the project specifies leaking through openings. During excavation of the foundation pit at the foundation level of the structure, groundwater is expected to occur in the foundation pit. It will be removed by pumps during foundation works. Pressures of vehicular and machinery loads on existing roads near the foundation pit were also taken into account at distances of 1.0m and 2.4m (sides A and B). Calculation of the construction pit was performed in software packages GEO5 and Tower7, in which the results were compared.

The construction pit consists of reinforced concrete piles 8, 10 and 11m in length at equal distances of 140cm. The spacing between piles is filled with concrete 5m and 6m long piles, which form niches between reinforced concrete piles, partly penetrating into the substratum. The diameter of the piles is Ø80, and reinforced concrete piles and concrete piles overlap (enter one another) 10 cm on both sides. The minimum required embedment of load-bearing reinforced concrete piles in the substratum of 3d, or 240 cm, is also satisfied. Concrete piles are not treated through the calculation, and thereby we are on the safety side.

The head beam (tie beam) is designed with variable height on the sides A, C and D, where it is connected with the structure of the most loaded and most demanding side B in a stepped manner on the sloping ground. Dimensions of the head (tie) beam are 120x120cm.

The calculation was performed in GEO5 for the relevant part of the structure side B, and a comparative calculation was made on the 3D model to obtain the overall effects on the whole structure. Side F was not treated in this calculation due to the proximity of the structure, and the planned excavation up to 3m near the structure will be performed and the foundation depth of the structure will be observed during the works. Based on the data obtained from the excavated state, it will be decided whether protection is required for side F.

The layout plan, formwork plans and bending schedules are given in the graphical part of the design. Placement of piles, excavation for construction pit and foundation work were analysed in the first phase. The head beam (tie beam) displacement results showed that the displacements exceeded the allowable ones on the critical side B, and so the pit was reinforced providing an additional transverse series of piles simulating buttresses. This solution reduced the displacement on top of the structure and brought it within the allowable limits. Structural RC stiffeners are planned at the corners.

After the foundation slab is built, it is planned to demolish the remaining part of the transverse stiffening. It is also recommended to take into account the excavation and replacement of soil in parts where the foundation plate of the structure does not enter the substratum. The calculation shows and proves that the planned solution satisfies all the conditions for execution of the construction pit.

Concrete structures: EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1: standard
Steel structures: EN 1993-1-1 (EC3)
Partial factor on steel cross-section bearing capacity: $\gamma_{M0} = 1.00$
Timber structure: EN 1995-1-1 (EC5)
Partial factor for wooden areas: $\gamma_M = 1.30$
Modif. factor of load duration and moisture content: $k_{mod} = 0.50$
Coef. of participating width for shears: $k_{cr} = 0.67$

Calculation of active pressure: Coulomb
Calculation of passive pressure of soil: Caquot-Kerisel
Analytical method: dependent pressures
Analysis for earthquake: Mononobe-Okabe
Modulus of reaction of foundation soil: standard
Consider reducing the modulus of reaction of foundation soil.
Verification methodology: in accordance with EN 1997
Design approach: 3 - decreasing activities (GEO, STR) and parameters of soil
Verification methodology: Limit states (LSD)

Figure 4. Input parameters for calculation, GEO5

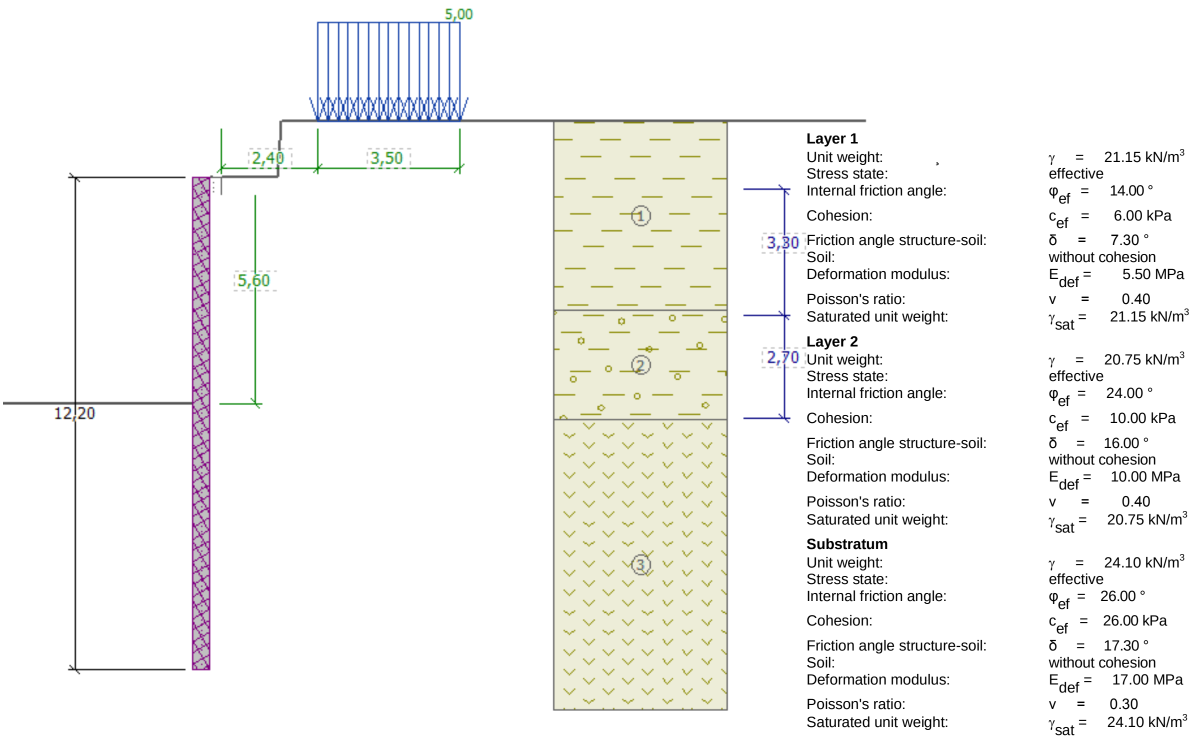


Figure 5. 2D model of soil and loads. GEO5

The calculation and presentation of results were performed in three phases:

- Phase 1: pile driving + excavation for foundation + external loads
- Phase 2: stiffener in two places at an average distance of 30.8 m/3 + Phase 1
- Phase 3: load of the newly constructed foundation slab + Phase 2

Phase 1 results: it is proved that the displacements at the top are greater than the allowable ones, and that a reinforcement system must be selected. Reinforcement in the form of a transverse series of piles that simulates buttresses is used (which is modelled as a support, to reduce displacements at the pile top).

Phase 2 results: it is proved that a transverse series of piles is required. Deformations of the structure at the top are lower than the allowable displacements defined in the operating state for cantilevers. Values up to 25.5mm were obtained.

Phase 3 results: the influence of the newly constructed underground floor is additionally observed before backfilling around the structure, that is, the foundation pit itself. It is proved that the effects of the underground floor structure on the type of structure are negligible before demolition of the transverse stiffeners and backfilling.

Analysis of global stability in GEO5:

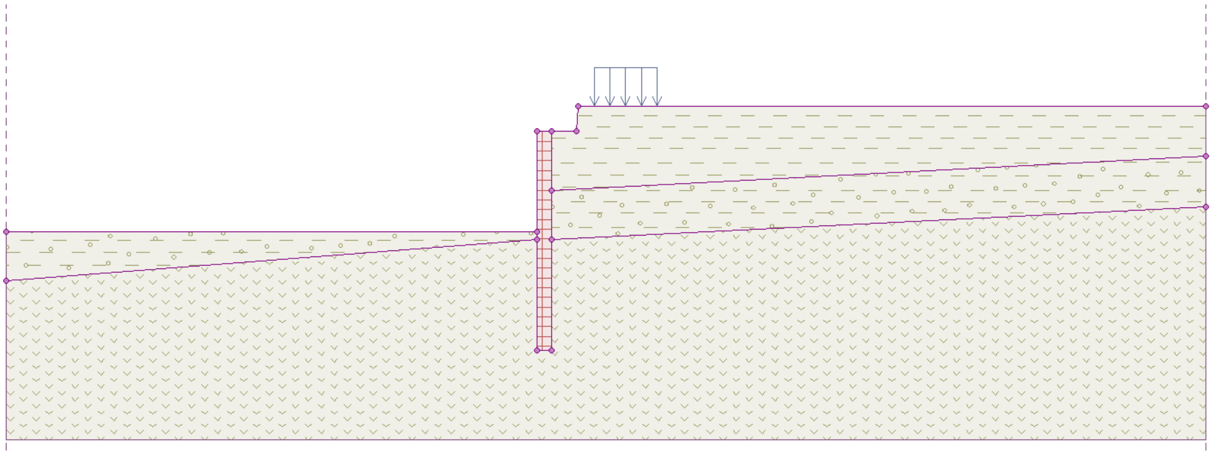


Figure 6. Analysis of global stability - model, GEO5:

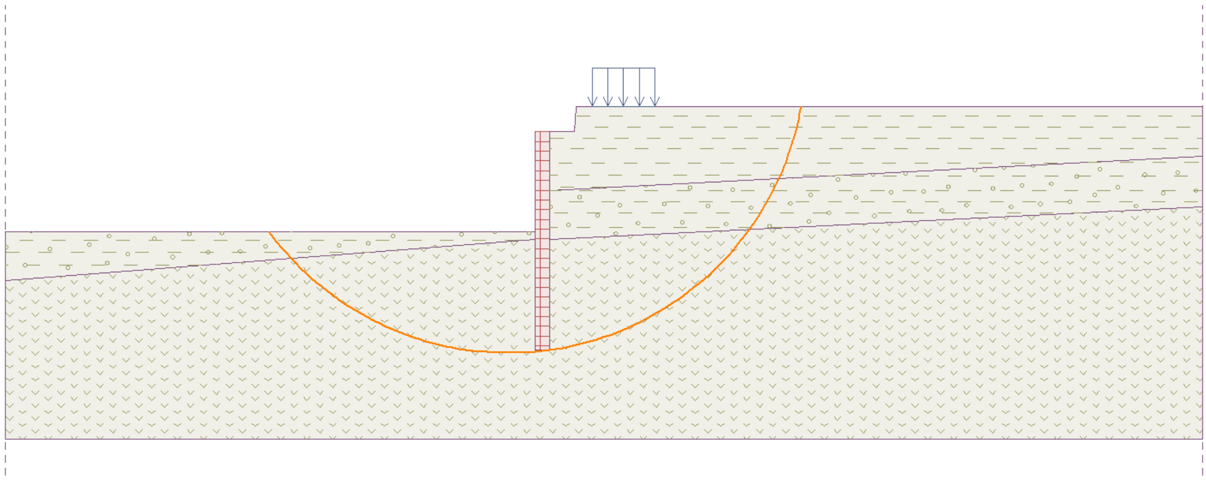


Figure 7. Analysis of global stability - model, GEO5:

The following values were obtained using Bishop's method:

Slope stability control (Bishop)

Sum of active forces: F_a = 1024.37 kN/m

Sum of passive forces: F_p = 2816.60 kN/m

Moment of movement: M_a = 17065.97 kNm/m

Moment of resistance: M_p= 46924.51 kNm/m

Usage: 36.4 %

Slope stability ACCEPTABLE

Figure 8. Bishop's method, GEO5

Pile dimensioning:

The material and characteristics of piles: concrete C 25/30, reinforcement B500, pile diameter Ø80

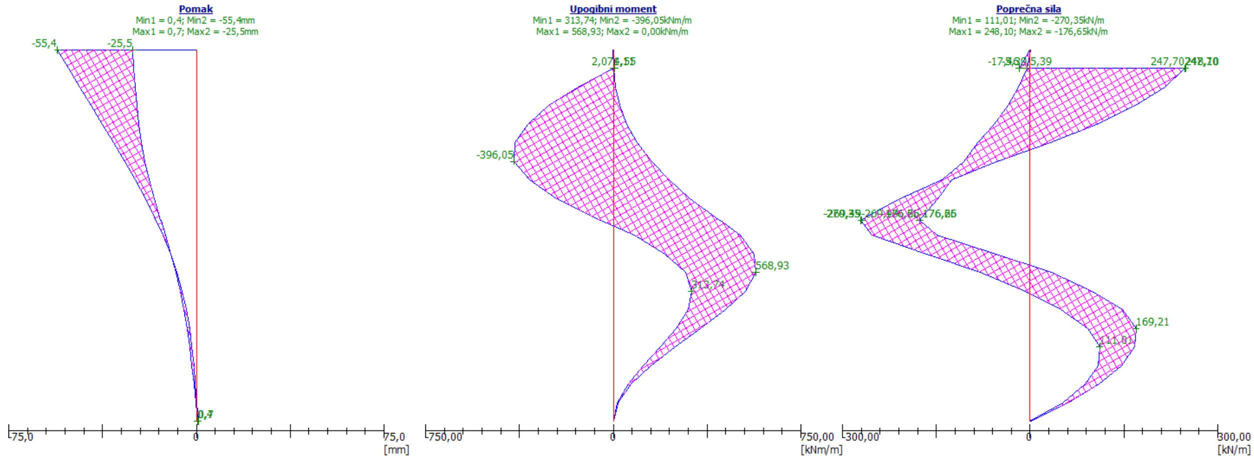


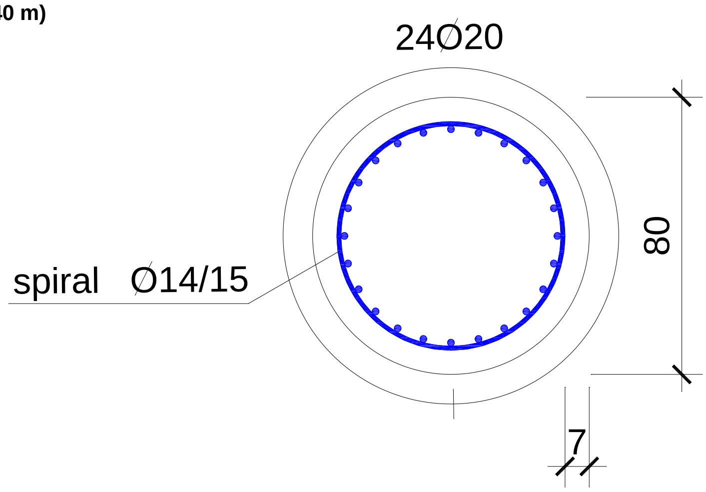
Figure 8. Pile dimensioning, GEO5

Check of RC cross section (Pile curtain d = 0.80 m; a = 1.40 m)
All phases of construction are taken into analysis.
Reduced coef. of bearing capacity = 1.00

Cross section bending control:
Reinforcement - 24 pc bars 20.0 mm; covered 60.0 mm
Type of structure (coefficient of reinforcement): beam
Reinforcement ratio $\rho = 0.750\ \% > 0.135\ \% = \rho_{min}$
Load: $M_{Ed} = 796.50$ kNm
Bearing capacity: $M_{Rd} = 927.30$ kNm
Designed pile reinforcement SATISFACTORY

Cross section shear control:
Shear of reinf. - profile 14.0 mm; spacing 150.0 mm
Final shear force: $V_{Rd} = 944.12\ \text{kN} > 378.49\ \text{kN} = V_{ed}$
Cross section SATISFACTORY.

Total control: Cross section SATISFACTORY



Reinforcement							Results		
No. of bars:	24.00	[pcs]	Shear reinforcement				**STRENGTH:**	SATISFACTORY	(40.1%)
Cover:	60.0	[mm]	Profile:	14.0	[mm]		**BENDING:**	SATISFACTORY	(85.9%)
Profile:	20.0	[mm]	Spacing:	150.0	[mm]		**DESIGN PRINCIPLES:**	SATISFACTORY	(18.0%)

Figure 9. Pile dimensioning, GEO5

3. Control calculation

The necessary dimensions were obtained by calculation in software GEO5: 24Ø20 for piles, and spiral Ø16/15. The results obtained in the calculation on the 3D model in Tower 7 were slightly lower than the result from GEO5. The pile tie beam is structurally reinforced.

ADOPTED:

C 25/30
B 500
a = 7cm for piles
a = 5cm for pile head beams (tie beams)

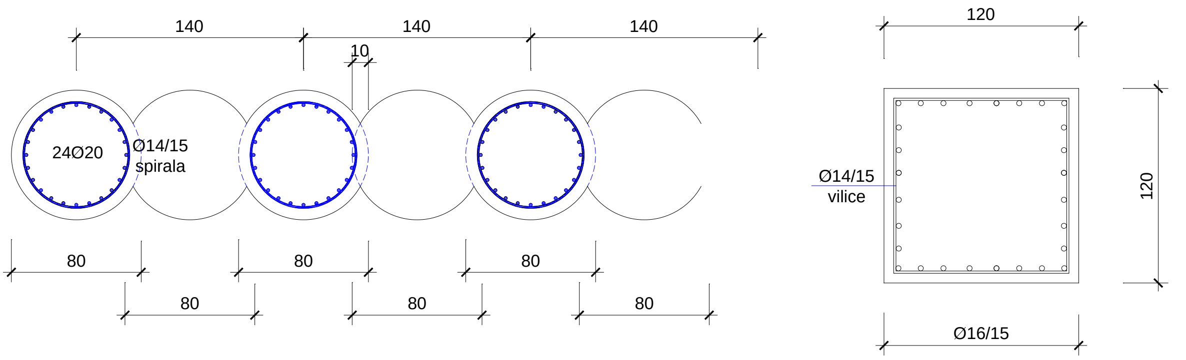


Figure 10. Dimensions of piles and head beam (tie beam)

4. Conclusion

An example of construction pit protection design is presented through the GEO5 and Tower software (for control calculation) using RC piles as a load-bearing part of the structure, concrete piles between the RC piles as lining of the load-bearing piles (considered as structural) and transverse piles. During the calculation, the software registered displacements of the head beam (tie beam) on one critical side, and an example of solving the given problem by using transverse piles, which are an efficient and cost-effective solution, is presented.

This helped to avoid anchoring with prestressed bars (which makes construction more expensive), protecting the pit with IPE braces (which would slow down construction work of the foundations of the structure), and constructing a new internal structure for braces (which complicates the situation for construction on the spot).

“Soil Mechanics arrived at the borderline between science and art. I use the term “art” to indicate mental processes leading to satisfactory results without the assistance of step-for-step logical reasoning. To acquire competence in the field of earthwork engineering one must live with the soil. One must love it and observe its performance not only in the laboratory, but also in the field, to become familiar with those of its manifold properties...”

(Karl Von Terzaghi, 4th International Congress on Soil Mechanics, England, 1957.)

5. References

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2. BAS EN 1997-2: 2008 *Eurocode 7 – Geotechnical design – Part 2: Ground investigation and testing* (EN 1997-2:2007 IDT).
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The software packages (programmes) used:

1. GEO 5
2. Tower 7