SAVEZ GRAĐEVINSKIH INŽENJERA SRBIJE
ASSOCIATION OF CIVIL ENGINEERS OF SERBIA

GEOTECHNICAL ASPECTS OF CIVIL ENGINEERING AND EARTHQUAKE ENGINEERING - Vrnjačka Banja, 01-03. novembar 2023.

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TECHNICAL SOLUTION FOR THE FOUNDATION OF THE ELIXIRE GROUP WASTE TO ENERGY TREATMENT IN PRAHOVO

Summary: *The paper presents the technical solution for the foundation of the facilities of the Boiler House for the energy utilization of waste and chimneys. Next to the boiler house, the construction of a Bunker for waste storage is planned, which is founded at a depth of 6.0m below the top of the boiler house's base plate. Based on the conditions of limited settlement, the foundation of the boiler house was envisioned on drilled piles, while a hidden pile wall was designed to protect the foundation pit of the bunker, which has the function of preventing large deformations of the boiler house structure and does not jeopardize its stability. Calculations of the bearing capacity of the piles based on the soil parameters from the geotechnical study are presented, as well as the results of the pile tests with axial vertical pressure force.*
Key words: *piles, pile wall, bearing capacity of piles, static load test of piles*

ТЕХНИЧКО РЕШЕЊЕ ФУНДИРАЊА ОБЈЕКТА ПОСТРОЈЕЊА ЗА ТЕРМИЧКИ ТРЕТМАН ОТПАДА ELIXIR GROUP У ПРАХОВУ

Резиме*:У раду је представљено техничко решење фундирања објеката Котловско постројење за енергетско искоришћење отпада и димњака. Поред котловског постројења предвиђа се изградња Бункера за складиштење отпада који се фундира на дубини од 6.0м испод врха темељне плоче котловског постројења. Из услова ограничених слегања усвојено је фундирање котловског постројења на бушеним шиповима, док је за заштиту темељне јаме бункера испројектована скривена завеса шипова која има функцију да спречи велике деформације конструкције котловског постројења и не доведе у проблем његову стабилност. Приказани су прорачуни носивости шипова на основу параметара тла из геотехничког елабората као и резултати испитивања шипова аксијалном силом притиска.*
Кључне речи: *шипови, завеса шипова, носивост шипова, статичко испитивање шипова*

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1. INTRODUCTION

In recent decades, the rapid growth of population and resource consumption has made waste generation and disposal into the environment a pressing ecological issue for all world economies. The current situation in hazardous waste management in the Republic of Serbia is such that certain types of waste are generated in large quantities without proper treatment, posing a problem for waste producers and operators who face complicated and slow export procedures. Waste-to-Energy (WtE) plays a significant role in the circular economy, as it transforms non-recyclable waste into locally available energy and usable products in an environmentally friendly manner using modern technical and technological solutions. For this reason, Elixir Group is constructing a 30MW Waste-to-Energy (WtE) plant in Prahovo.

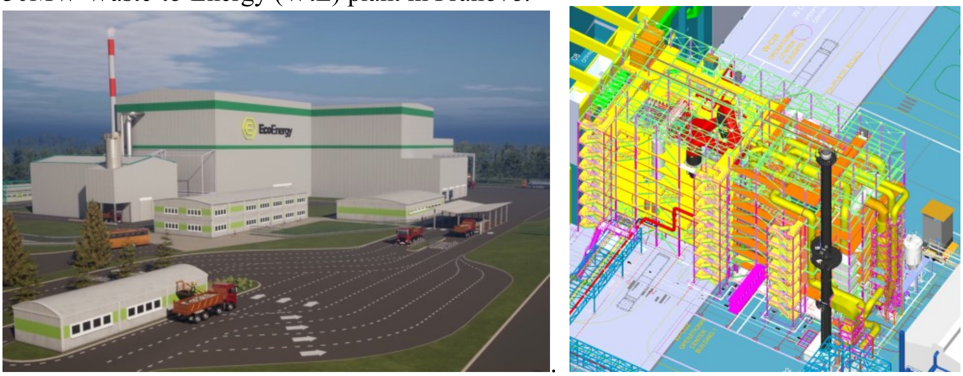

Figure 1. a) Waste to Energy, b) Steel structure of the Waste to Energy

This paper will present the foundation of the Boiler House for thermal waste treatment, where the boiler and accompanying equipment for incinerating hazardous and non-hazardous waste are located. Due to the technological process, only minimal and very uniform settlements of the structure are allowed, which was the criterion based on which the foundation on drilled piles was determined. In addition to the Boiler House facility, the construction of a Waste Storage Bunker is planned, founded 6m below the foundation slab of the Boiler House. To protect the foundation pit, a pile wall has been designed, which represents an integral part of the foundation slab and also serves as a supporting structure.

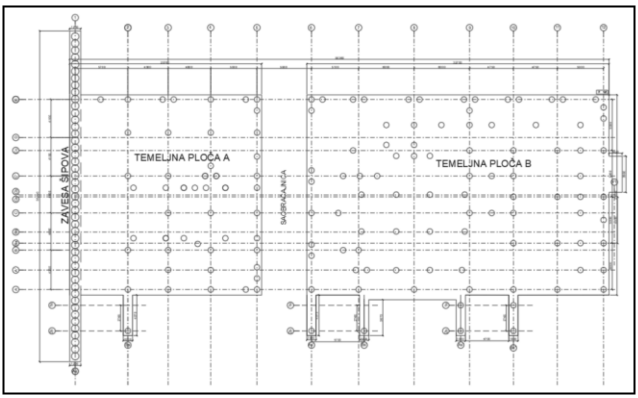

Figure 2. Disposition of base plates with piles

The foundation slab is divided into two parts: slab A, supporting the boiler, and slab B, supporting the filter. The spacing between the slabs is provided to allow a clear passage for trucks through the facility. The building has a total of P+8 floors, with a height of 37.5m. The dimensions of the building are 21.6m x 58.3m. Foundation slab A is supported by 48 CFA piles of Ø600mm, while the pile curtain consists of 24 main piles of Ø800mm and 23 secant CFA piles of Ø800mm (a hidden pile beam is formed inside the foundation slab, connecting the piles in the curtain). The length of the main curtain piles is L=13.0m, and the length of the secant piles is L=7.0m. Foundation slab B is supported by 89 CFA piles of Ø600mm, with a length of L=9.0m for the Ø600mm piles.

Figure 3. a) Head plate A, b) Head plate B

1.1. The geotechnical model of the terrain

For geostatic calculations of allowable loading and consolidation settlements of the waste-to-energy plant complex, a unified geotechnical terrain model with four geotechnical units has been adopted. These units are provided in tabular form below.

	GTS-1	GTS-2	GTS-3	GTS-4
ZAPREMINSKA TEŽINA	γ =19.12 kN/m^3	γ =18.80kN/m^3	γ =19.60kN/m^3	γ =20.00kN/m^3
KOHEZIJA	C= 15.6 kPa	C= 0 kPa	C= 0 kPa	C= 40 kPa
UGAO UN. TRENJA	φ= 24°	φ= 31°	φ= 35°	φ= 23°
MODUL STIŠLJIVOSTI	$Mv_{(1-2)}$=7950 kPa $Mv_{(2-4)}$=11200 kPa	Mv =21800 kPa	Mv =38400 kPa	$Mv_{(1-2)}$=23500 kPa $Mv_{(2-4)}$=51600 kPa
CKD	CKD=3.6MPa	CKD=9.4 MPa	CKD=35 MPa	
DEBLJINA SLOJA	h_{sr}=5.80m	h_{sr}~1.60m	h_{sr}~11.40m	h_{sr}>10.0m

GTS-1- dusty clay;

GTS-2-sand;

GTS-3- sand and gravel;

GTS-4- marl-clay complex.

Table 1. Terrain model

The underground water level is 14.5m below the ground.

2. CALCULATION OF SUPPORT STRUCTURE MADE OF Ø800MM PILES

The hidden pile beam of the support structure made of piles is an integral part of the foundation slab. The connection of the hidden beam to the foundation slab is provided with reinforcement Ø20/20cm in the upper and lower zones, anchored in the slab in a length of 2.0m. The purpose of this reinforcement is to withstand tensile forces due to the action of active pressure on the support structure, resulting from the excavation of the foundation pit for the adjacent structure.

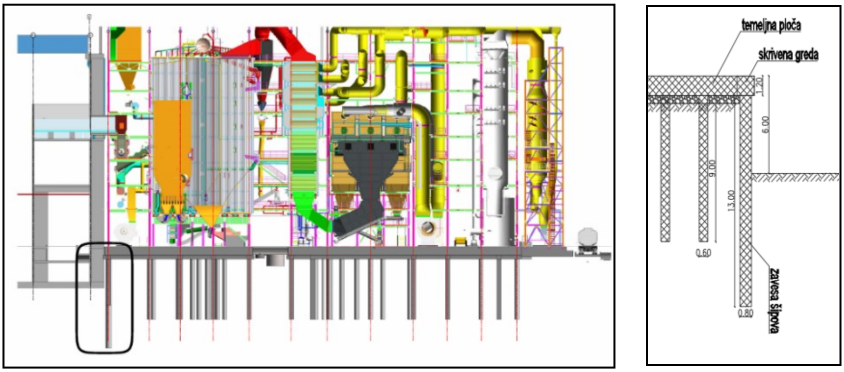

Figure 4. a) Cross-section of the Bunker Building and Waste Thermal Treatment Facility b) Cross-section of the foundation structure of the Waste Thermal Treatment Facility

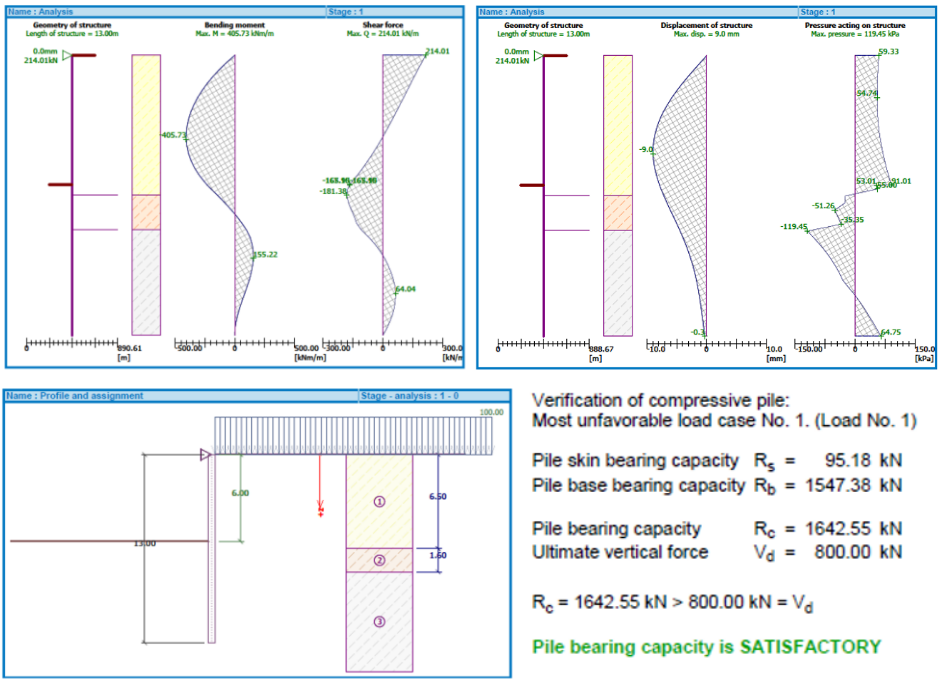

Figure 5. Static influences in the curtain of piles and bearing capacity of piles

In addition to providing adequate safety and bearing capacity against horizontal pressures, the pile-supported structure needs to accommodate vertical loads from the boiler house. When calculating the axial bearing capacity of the piles, the shaft bearing capacity up to the depth of excavation for the foundation pit of the Bunker is neglected. The calculated embedment depth of the piles is 7m. The total axial bearing capacity of the piles is 1642kN, with the dominant base bearing capacity being 1547kN, which is sufficient to handle the vertical load from the facade structure of the boiler house.

The calculation of the embedment depth of the piles is very important because insufficiently estimated depth could cause significant deformations in the supporting structure, causing a problem with the stability of the objects. Conversely, an excessively determined embedment depth could result in an irrational and expensive structure. The embedment depth is primarily determined by the equilibrium of moments due to active and passive pressure acting on the supporting structure. It is then necessary to limit the horizontal movement of the support to 1cm. The embedment depth of 7m is determined based on these two conditions.

Calculation check of maximum displacements and dimensioning of the piles was conducted using the software package Tower 8. Lateral soil stiffness values were determined:

$$K_{si} = \frac{0{,}65}{D} \sqrt[12]{\frac{E_{si} \times D^4}{EI}} \times \frac{E_{si}}{1 - \nu_{si}^2}$$

Layers	**Mv [kN/m2]**	**E [kN/m2]**	**v**	**H [m]**	**Ks [kN/m3]**
GS1	7950,0	5300	0,3	4,50	3199
GS2	21800,0	14533,33333	0,3	1,60	9540
GS3	38400,0	25600	0,3	2,90	23990

Table 2. Lateral stiffness of the spring

where Es is the soil modulus of elasticity determined as 2/3 of the modulus of compressibility Mv, Ep is the modulus of elasticity of the material from which the pile is made, v is the Poisson's ratio of the soil, Ip is the moment of inertia of the cross-section of the pile.

In the computational model, the soil is replaced by springs with calculated axial stiffness. The pile is loaded by active soil pressure and by a load from the structure amounting to 100 kN/m^2. The reaction of the spring, determined by the calculation, should be less than the force of passive resistance. As long as this condition is not satisfied, the calculation is iteratively repeated, and the springs in which the stress is exceeded are replaced by the force of passive resistance in their place.

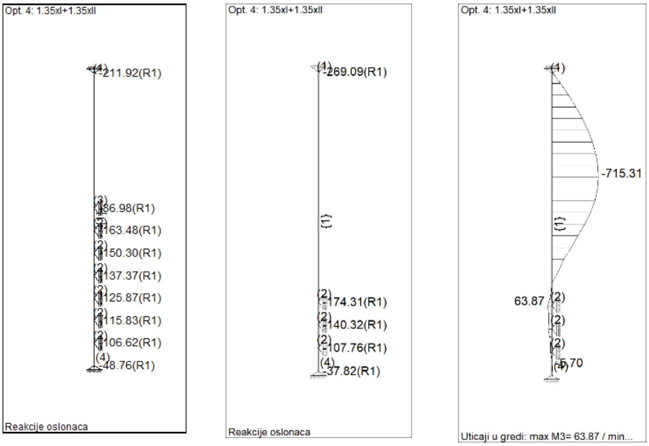

Figure 6. Representation of influence in a pile with alternating springs

3. PILE CALCULATIONS Ø600MM

The allowable bearing capacity of the piles for the foundation of the Boiler House was conducted based on the results of laboratory soil tests using the Mayerchof method, as well as the results of field soil testing using the static penetration method. The bearing capacity calculation was also cross-verified using the GEO5 software package. The calculation results are presented in Table 3.

CPT	Qcpt= 2040 kN
Mayerhof	Q_{BH}=1003 kN
Geo5	Qgeo5= 1155 kN

Table 3. Bearing capacities of piles Ø600mm

The calculated permissible force in the pile Q=1200 kN is adopted.

4. CHIMNEY FOUNDATION SLAB

The chimney structure is 55.7m tall with a diameter of 2.0m. The dominant load is caused by wind and vortex shedding. As a result of these loads, there are tensile forces in the piles that are reactively resisted only by the weight of the structure. Increasing the weight of the foundation structure is irrational in this case, so the chimney is founded on piles. An analysis needs to be conducted to reach a compromise regarding the appropriate distance between the piles and their length. Increasing the distance between the piles increases the bending moment and reduces the tensile force, while also increasing the dimensions of the foundation slab. A smaller moment arm results in larger forces in the piles, potentially leading to irrational pile lengths.

The chosen foundation slab is 2.0m thick, with a base dimension of 6.2m x 6.2m. The foundation slab is deeply founded using 8 Ø600mm piles with a length of 9m.

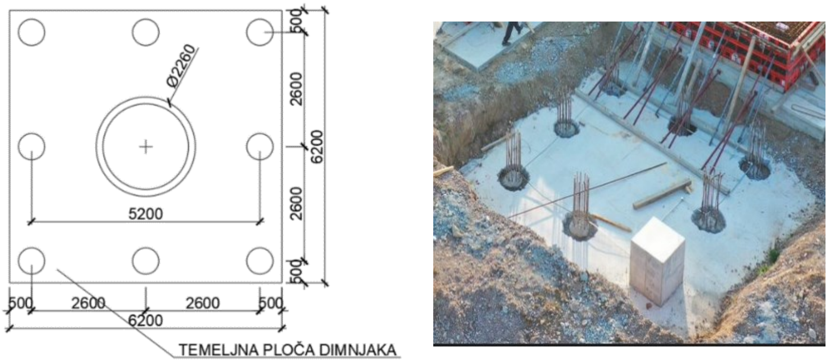

Figure 6. Chimney foundation piles

5. TESTING OF PILES WITH VERTICAL PRESSURE FORCE

The Institute IMS a.d., Center for Roads and Geotechnics, from Belgrade, conducted testing on two CFA piles with a diameter of Ø600 mm using a static load test with vertical pressure force for the Waste Thermal Treatment Plant facility. The tested pile had a length of L=12m and a circular cross-section of Ø600 mm.

Figure 6. a) Derived piles that have been prepared for testing b) Static load test

The working load of the pile corresponding to the calculated force was Q=1200 kN, and the maximum applied force on the pile was 150%Q, Q_max = 1800 kN.

In the first test at the maximum force Q_max = 1800 kN, the settlement was s = 4mm.

In the second test at the maximum force Q_max = 1800 kN, the settlement was s = 6mm.

The settlement calculation for the pile group through an equivalent slab was performed for Q = 1200 kN and settlement s = 1.05 cm.

It is noticed that in application, settlements obtained from these calculations are actually realized to be less than 30%. Therefore, the structure founded on reinforced concrete piles on soil with this level of consolidation and high compressibility modulus will be completely safe in terms of consolidation settlement.

6. CONCLUSION

This paper presented the foundation solution for the Boiler House in the Waste Thermal Treatment Industrial Complex of Elixir Group in Prahovo. The foundation solution on piles was elaborated with a specific focus on the pile calculation with a dual function of transferring vertical loads from the structure to deeper layers and simultaneously protecting the foundation pit of the adjacent structure, which is constructed at a depth of 6m relative to the Boiler House.

In industrial construction, a common practice is to design for serviceability limit state conditions when limiting structural settlements due to complex technological processes that occur in the machinery installations. Excessive settlements could lead to a collapse in the technological process and hence significant production and financial loss. This is the reason for designing a technical foundation solution with piles, which may not be cost-competitive but is in fact the only solution that meets the project criteria.

In the end, static load tests on the piles were conducted as the most relevant test for determining settlements and comparing them with anticipated settlement calculations. The piles met the project criteria, and the achieved settlements were 30% of the anticipated settlements. Predictive settlement models for piles provide conservative solutions, primarily focusing on safety. Therefore, the best project approach would be to perform calculations for piles with different geometric characteristics first, followed by field tests for several designed variants, which is a rare case in practice.

Acknowledgments

This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Reg. No. 451-03-47/2023-02 /200012.

7. REFERENCES

[1] Slobodan Ćorić, Dragoslav Rakić, Stanko Ćorić, Irena Basarić,: Lateral bearing capacity and displacements of vertical piles loaded with horizontal forces Projektno-tehnička, 2018.
[2] Marija Krstić, Nikola Božović, Marko Prica, Kristina Božić-Tomić: Fundamentals of testing piles by horizontal force with examples from practice.
[3] Nikola Božović, Marija Krstić, Kristina Božić-Tomić,: Analysis of the bearing capacity of piles based on the results of geomechanical research and the results of static testing of piles by axial pressure force.
[4] Elixir group documentation.
[5] Documentation, Archives of the IMS Institute
[6] Milan Maksimović, Soil Mechanics, Belgrade 2008.
[7] Slobodan Ćorić, Geostatic calculations, Belgrade 2006.