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THE EFFICIENCY ANALYSIS OF FOUNDATIONS FOR BUILDINGS WITH BEARING WALLS FOR LITHUANIAN SOIL CONDITIONS

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Abstract. The paper deals with selection of foundations for bearing walls of residential buildings depending on the strength of soil and taking into account the economic benefit. Based on in-situ investigation of soil conditions in different Lithuanian regions and construction technologies, it was found that the cost of foundations comprise 2.5–6% of total costs, and takes up 6–10% of construction time. Strip and pile foundations were analysed taking into account dimensions and mode of production. The proposed case study model enables to save up to 30–50% of foundation costs. It has a significant influence on entire life cycle costs of.

Keywords: strip foundation, ground conditions, soil strength, construction costs.

Introduction

Construction sector is one of the biggest and most important sectors of the European economic system. In 2011, it was responsible for 6.3% of the GNP of the EU (European Commission 2013).

The greatest number of projects deals with environmental issues, water treatment facilities and renovation of public buildings. Construction of new objects takes the second place according to the number of projects. Most projects for construction of new houses and residential buildings are concentrated in the capital city and largest towns. In the planning of facilities, it is important to recognize a close relationship between design and construction. These processes can be best viewed as an integrated system. The process of construction involves an understanding of: the nature and characteristics of various materials; the methods to process them and form them into building units and components; structural principles; stability and behaviour under load; building production operations; and building economics. Broadly speaking, design is a process of creating the description of a new facility, usually represented by detailed plans and specifications; construction planning is a process of identifying activities and resources required to make the design a physical reality. Hence, construction is the implementation of a design envisioned by architects and engineers. In both design and construction, numerous operational tasks must be performed with a variety of precedence and other relationships among different tasks. Geotechnical engineers and engineering geologists are responsible for designing and constructing foundations. They explain general principles and practice, and detail current types of foundations, equipment and methods (Tomlinson, Boorman 2001; Tomlinson, Woodward 2007).

Several characteristics are unique to the planning of constructed facilities and should be kept in mind even at a very early stage of the project life cycle. In a growing economy, there is a limit to what we can achieve in terms of environmental sustainability by means of substitution for housing sector growth. As the most common strategy, increasing eco-efficiency of residential buildings mainly refers to densification of urban areas and sustainable building technologies.

Economic situation forces us to construct new buildings in a cost effective manner (Xue 2012; Carter *et al.* 2000; Wang *et al.* 2005). Many specialists in evaluating different alternatives of design – especially in comparing precast and monolithic constructions – have a distrustful attitude toward the cost indices, doubting the existing price-setting principles. This leads to redesign and recalculation of all building parts including foundations. To select proper foundation, the geotechnical investigation and calculations of soil bearing capacity must be done (Dalili Shoaei *et al.* 2012; Dasaka, Sivakumar Babu 2010).

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Strip foundation is normally selected for load-bearing walls and rows of columns which are spaced at a distance so small that pad foundations would nearly touch each other. The width of a foundation depends on the strength of soil and the load on it. Budgetary indicators, such as technical-economic indicators, are valuation tools commonly used in assessing indicative costs in civil engineering. Their applications are used across the professional construction spectrum, from preparation of the investment process to checking implementation of the construction, and in the banking, insurance and property value estimation systems. The catalogues of specific financial indicators may have significant differences between them (Nagy 2012).

Investigations undertaken in the Czech Republic and Slovakia (Chloct, Vyborny 1977) demonstrated that monolithic strip foundations are 35–56% cheaper than assembled foundations. The adjusted expenditures and estimated cost for the construction of the precast strip foundations of brick and block buildings are 40–75% higher than those of monolithic while labour costs (without consideration of the manufacturing and transportation of materials, and intermediate products) are 25–50% higher. The construction of such foundations requires 15–25% more metal and cement with an insignificant decrease of the volume of concrete (by 5–10%). The use of precast strip foundations of standard blocks with up to 30% of hollowness does not substantially reduce the cost and is possible only in dry, unsaturated soils (Valeev, Bogdanov 1975). This type of foundation is not suitable for low bearing capacity soil. In Lithuania, such foundations are 34% cheaper. Seeking to reduce the cost for monolithic strip foundations, monolithic foundations with residual formwork could be used. This solution reduces foundation costs by approx. 10% (Pochman 1978).

The article proposes the model for the selection of economic type of foundations for bearing walls of residential buildings depending on soil strength.

1. Determination of soil bearing capacity

A geotechnical site investigation is the process of collecting information and evaluating the conditions of the site for the purpose of designing and constructing the foundation for a structure. Good planning for and management of a geotechnical site investigation is the key to obtaining sufficient and correct site information for designing a structure in a timely manner and with minimum cost for the effort needed. Every construction design starts from collecting information about soil structure and resistance. There are two types of procedure for determination of soil parameters: 1) laboratory tests; 2) onsite tests (Pantelidis 2008; Cai *et al.* 2010; Look 2007). This research adopted static cone penetration test (Shrivastava, Levacher 2005; Eslami, Fellenius 2004). The research is based on in situ investigation. Geotechnical site investigation (drilled test holes and sampling) and laboratory testing for soil characteristics was done. More than 1200 tests have been done. The beginner of tests in Lithuania was engineer Furmonavicius (ITI Kauno filialas 1978). The soil strength was defined in various depths with intervals of 0.5 m down to 3.0 m in depth, 1.0 m to 5.0 m in depth and 2.0 m to 11.0 m in depth. The tests were done in Vilnius, Kaunas, Klaipėda, Panevėžys and some other urban residential areas.

Soil could be classified according to the strength of different layers and depths. Proposed soil classification is shown in Table 1.

The soil of the upper part of Vilnius district Justiniškės mostly consists of medium dense sand with low water level. At 1.5 m in depth of the district Justiniškės I and Justiniškės 2B, the soil has more than 200 kPa strength with 96–97% probability. At 5 m depth, the strength is more than 500 kPa with the probability of 60–70%. In the districts Justiniškės A and Justiniškės III, the upper layer of the soil consists of porous sand. At the depth of 1.5 m, 15–35% of soil strength is less than 200 kPa. At 5 m depth, the strength is more than 500 kPa with the probability 85–90%. This soil belongs to type 2. The district Santariškės also has 2 type 2 soil. The difference is only that the soil consists of almost 50% of clay.

The upper layer of the soil in Kaunas districts Eiguliai and Šilainiai almost consists of loam with the strength more than 200 kPa. According to the soil structure, Eiguliai belongs to type 1 and Šilainiai – to type 3 soil.

The residential district in Klaipėda between Šilutė road and Taikos street belongs to type 4 soil. At 1.5 m depth, the soil has less than 200 kPa strength with 35% probability. But at 3.0 m depth, the soil has more than 200 kPa strength. At 9 m depth, the strength is more than 500 kPa with the probability of 70%.

The soil of Šiauliai district Dainiai belongs to type 2 soil (ITI Kauno filialas 1978). Almost all residential districts of Panevėžys belong to type 1 soil.

2. The methodology of economical evaluation

The selection of foundations is based on economy and profit. The relative costs of foundation, labour force and materials requirements are used as evaluation parameters. The relative fundament cost is the ratio between the cost of a fundament and the soil strength. To evaluate relative costs, various types of foundations were designed according to the soil strength. The soil strength was defined as $R = 0.1q_c$ for clay soil and $R = 0.05q_c$ for sandy soil (Van Wambeke 1975). All characteristics were calculated for the foundation, which is 1 meter in length. The length of foundations according to axes was summarized to calculate the total relative cost of a foundation.

The following types of foundations were analysed:

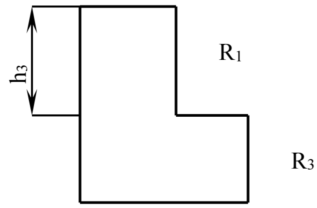
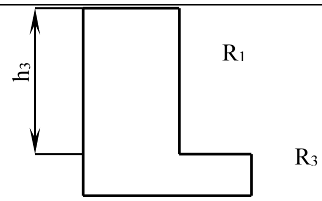
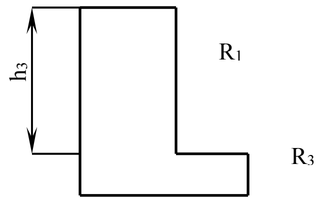
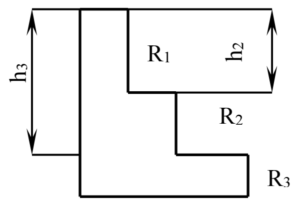
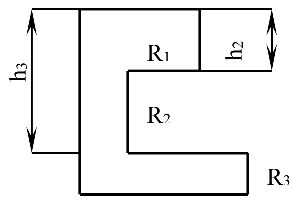
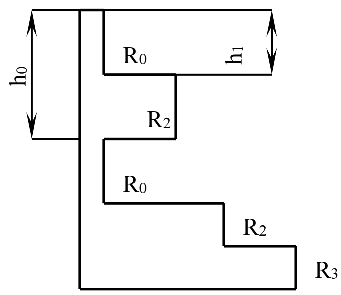
1) Strip foundation (typical (Fig. 1a) and enlarged assembled (Fig. 1b));

2) Strip monolithic (Fig. 1c), monolithic with residual formwork (Fig. 1d), monolithic cast in trench (Fig. 1e);

3) Pile foundation (Fig. 1f) (prismatic 300×300 sections with monolithic cap, prismatic with assembled cap, prismatic without cap, pyramidal).

Ground work was divided into "valuable" and "inutile". Valuable work includes removing soil for foundations and cellar or other engineering equipment. Inutile work includes removing soil for the ease of assembling the basement, which is later filled with soil.

Table 1. Soil classification

Classification of ground					
Soil type	Characteristics	Scheme	Parameters	Distri-bution, %	Place
1.	Medium resistance with a high resistance layer near the surface		$R_1 < R_3$ $h_3 \le 3$ m	19.7	Panevėžys, Kėdainiai, Mažeikiai, Kaunas, Vilnius
2.	Medium resistance with a high resistance layer near the surface		$R_1 < R_3$ $h_3 \le 5-6$ m	51.0	Vilnius, Šiauliai, Kaunas
3.	Medium resistance and homogeneous with a deep high resistance layer		$R_1 < R_3$ $h_3 \ge 7-8$ m	16.7	Kaunas, Klaipėda
4.	Twin layer with low resistance surface layer and a deep high resistance layer		$R_2 = (1.5-2.0)R_1$ $R_2 < R_3$ $h_2 = 2.5-5.0$ m $h_3 \ge 8.0$ m	5.6	Klaipėda
5.	Twin layer with medium resistance surface layer and a deep high resistance layer		$R_1 = (1.5-3.0)R_2$ $R_3 >> R_2$ $h_2 = 2.5-5.0$ m $h_3 \ge 8.0$ m	4.9	Marijampolė, Tauragė
6.	Ground has one or more weak layers		$R_0 \le 100$ kN/m^2 $h_0 \ge 2-3$ m $h_1 > 2-3$ m	2.1	Klaipėda

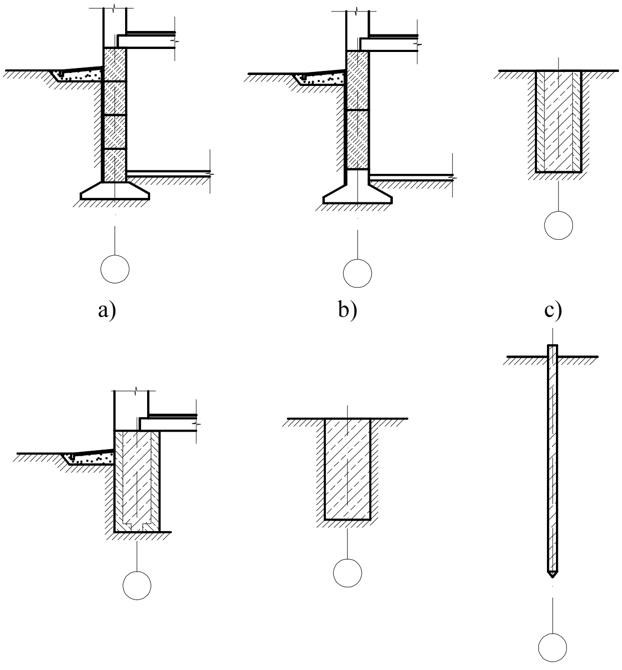


Fig. 1. Foundation types

3. Results

Calculation of the relative ground work cost is shown in Figure 2. Series "0" shows dependence of the valuable work cost upon the width of a foundation. Other series indicate foundation depth under the basements level. The difference between upper and "0" series is the cost of inutile work. Inutile work has the most of influence on the profit. The foundation depth has a considerable influence on the foundation cost and has to be minimized. In case of a 1.5 m deep foundation, all ground works under the level of the basement cost approx. 3.5 times more than valuable works. Relative costs of strip foundations are shown in Figure 3.

A similar situation is with strip foundation from enlarged banquettes. The value of the amount of used man work is shown in Figure 4. Relative costs of strip foundations from enlarged bedplate are shown in Figure 5.

The cumulative costs of various strip foundations are shown in Figure 6.

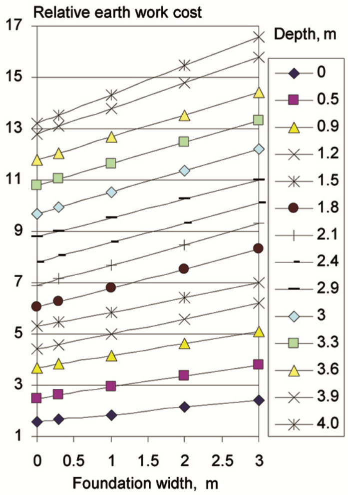


Fig. 2. The cost of ground works for a strip foundation (typical assembled)

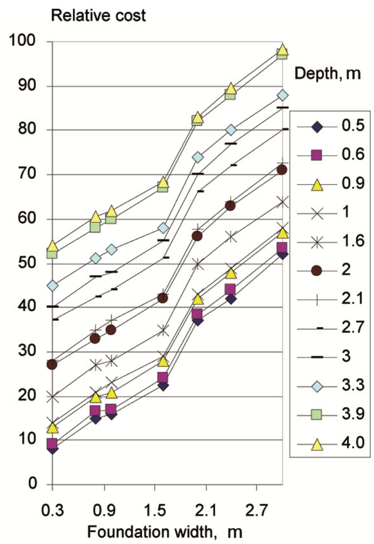


Fig. 3. The relative cost of a strip foundation (typical assembled)

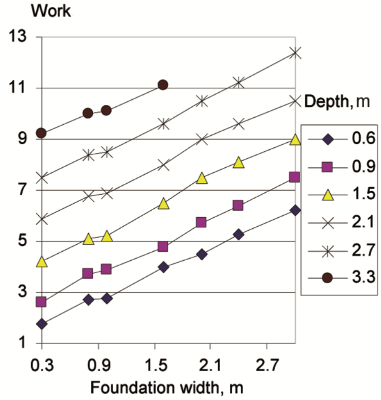


Fig. 4. Strip foundation work force (enlarged assembled)

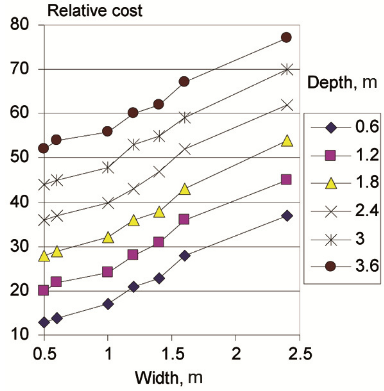


Fig. 5. Strip foundation relative cost (enlarged assembled)

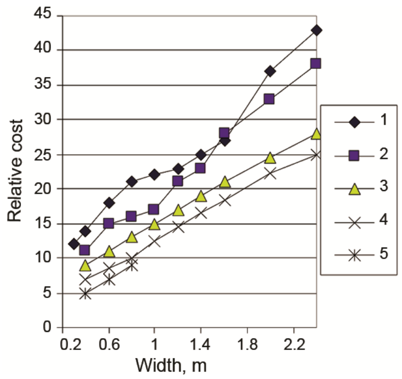


Fig. 6. The cumulative costs of various strip foundations: 1 – typical assembled; 2 – enlarged assembled; 3 – monolithic with RC residual formwork; 4 – monolithic; 5 – monolithic cast in trenches

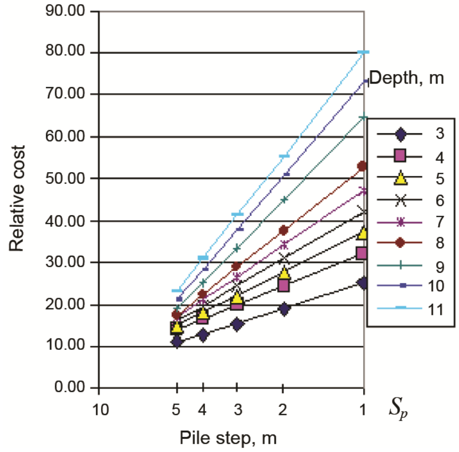


Fig. 7. Piles (with pile caps cast at place)

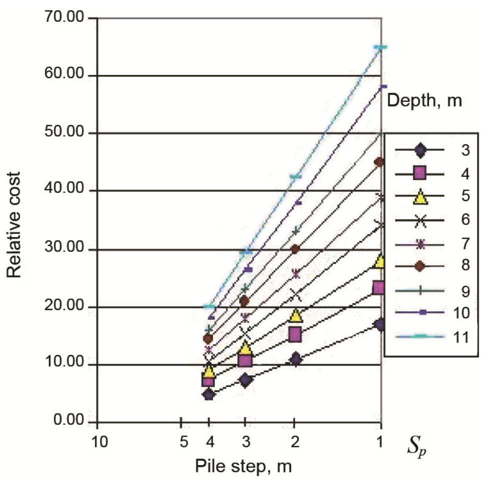


Fig. 8. Piles (with pre-fabricated caps)

In pile foundation case, the pile dimensions depend on soil bearing capacity and the cumulative cost depends on dimensions and pile step. The Figures 7 and 8 show cumulative costs dependence on pile depth and step. On first piles with monolithic grate, the second piles with pre-fabricated heads.

The comparison of different foundations is shown in Figure 9. Figure enables to select foundation type. If the load is 900 kN/m pile foundation and monolithic foundation relative cost is equal if monolithic foundation width is 3.0 m and pile length is 6.0 m. If soil bearing capacity is less than 300 kPa pile foundation will be economically better if pile length will not exceed 6.0 m.

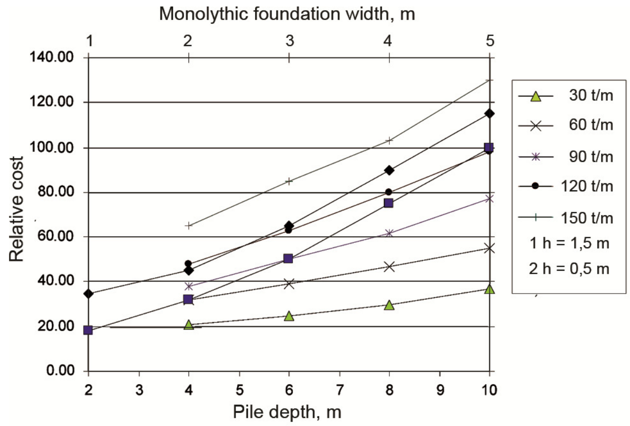


Fig. 9. Relative cost of monolithic (Fig. 1) and pile (300×300) foundations

Conclusions

The research aims to investigate rationality problem of foundations for 5–9 storey buildings. Soil strength and structure analysis in residential areas of various Lithuanian cities and economic analysis of various foundation types suggest the following conclusions:

1. Most rational type of foundation for bearing walls of 5 and 9 floor buildings is strip foundation. Strip foundation comprises 91–96% of all foundations.
2. About 60% of the total number of 5 floor residential buildings in Lithuania could have monolithic shallow foundations, which are constructed in trenches.
3. Pile foundations are economically useful for 4–8.5% of all residential building cases.
4. In case of higher buildings, pile foundations become more useful. For 12 floor buildings, it could be economically used in 45% of cases.

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