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Designing Foundations on Natural Soil for Specified (Uniform) Settlement

Merancang Pondasi di Atas Tanah Alami untuk Pemukiman Tertentu (Seragam)

Tulakov Elmurad Salomovich, mzebinisso@gmail.com, (0)
Samarkand State Architecture and Construction University, Samarkand, Uzbekistan

Mamatkulova Zebinisso Shavkatovna, mzebinisso@gmail.com, (1)
Samarkand State Architecture and Construction University, Samarkand, Uzbekistan

(1) Corresponding author

Abstract

This study addresses the critical issue of differential settlement and long-term fracture prevention in building foundations. Mistakes in designing strip and column foundations on natural soil often lead to cracks due to uneven settlements, as traditional methods prioritize matching foundation base pressure to soil bearing resistance, often neglecting settlement calculations. This research highlights the importance of incorporating settlement analysis into foundation design. A comparative review of existing methods and field data reveals significant disparities between standard design approaches and those considering settlement. Findings show that foundations designed with consistent settlement criteria exhibit better structural strength and reduced crack formation. The study underscores the need for a fundamental shift in foundation design procedures to include settlement analysis, ensuring the long-term durability and safety of buildings.

Highlights:

- Traditional foundation design often neglects settlement calculations, leading to structural issues.
- Incorporating settlement analysis results in stronger, more durable foundations.
- Comparative review highlights the need for updated design procedures to prevent cracks.

Keywords: Foundation Design, Settlement Analysis, Structural Strength, Differential Settlement, Crack Prevention

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Introduction

One of the main reasons for the appearance and development of cracks in building structures with strip and column foundations on natural ground, which occur during the operational period of the structures, is errors in design[1]. Designers, guided by modern building codes, typically design foundations on natural ground based on the condition of limiting the average pressure (p_{avg}) under the foundation's base with the design resistance (R) of the ground (p_{avg} ≤R) [2]. For low-compressible soils, building codes allow not determining settlements during such calculations, since their absolute values (S) will certainly be less than the ultimate values (S_u), i.e., the condition for calculating foundations by deformations ($S \leq S_u$) is met [2].

Using the condition p_{avg} ≤R as the primary calculation criterion for foundations allows designers not to determine the absolute and, moreover, the relative settlements for the designed structures. However, the settlements of foundations designed in this way will typically be uneven, and the resulting relative differential settlements in many cases may exceed the allowable values, creating conditions for the formation of cracks in the above-ground structures[3]. It should be emphasized that designing foundations based on the condition p_{avg} ≤R allows designers in many cases to underload the foundations by 20-30% or more relative to R, assuming this creates a "reserve" of foundation strength. However, such design results create conditions for even greater unevenness in settlements, provoking the development of cracks in the building's load-bearing structures[4].

Methods

It is believed that the calculation of foundations (strip, columnar) on natural ground should be carried out based on the condition of these structures having equal settlements [5]. This design method allows determining the dimensions of the foundations based on a certain (acceptable) settlement value [6]. By setting an equal settlement value, foundations of different sizes are obtained as a result of the calculation, but with practically minimal (less than permissible) uneven settlement, which helps avoid the conditions that cause cracks in the above-ground load-bearing structures[7].

As an example, let us consider the building of a sewing factory located in Samarkand on Navoi Street.

The technical survey of the building revealed the following[8].

The building is a 4-story industrial structure with an incomplete reinforced concrete frame, the construction of which was completed in 1984. There is a basement under the entire building with a height of 1.7-1.8 m, part of which is occupied by a civil defense shelter[9], [10].

The columns of the building's reinforced concrete frame rest on prefabricated column foundations with a plan size of 3.2 x 2.4 m and a foundation depth of 3.05 m from the ± 0.00 mark or 0.93 m from the basement floor level[11].

The building has three built-in staircases, whose prefabricated flights rest on transverse brick walls (380 mm thick), prefabricated foundation blocks FS-4, and foundation cushions with a foundation width of 1.6 m[12].

The longitudinal external walls of the building rest on strip foundations made of prefabricated blocks with a wall thickness of 0.5 m and prefabricated cushions with a foundation width of 2.0 to 2.4 m [13].

The basement floor consists of fill soils with a foundation mark of -2.05 m[14].

The ground conditions for this area are represented by the following layers:

1. a fill layer up to 2.0 m thick;

2. silty, plastic loam up to 7.0 m thick with γ=20.4 kN/m^3; φ=30°; C=23 kPa; E=18 MPa;

3. silty, fluid plastic loam up to 4.0 m thick with γ=19 kN/m^3; φ=15°; C=20 kPa; E=5 MPa;

4. silty loam with gravel and pebbles, soft plastic, underlain by denser soil layers with γ=20.9 kN/m^3; φ=20°; C=18 kPa; E=18 MPa.

The survey revealed the presence of through vertical cracks between the transverse load-bearing walls of the staircases and the longitudinal external wall of the courtyard façade[15]. The width of the cracks is 2 to 5 mm. Cracks are also observed between the prefabricated reinforced concrete staircase flights and the adjoining longitudinal load-bearing wall[16], [17]. The largest deformations (crack openings) are noted for the staircase in axes 4-5. Based on the survey, verification calculations were carried out for the existing foundations under the longitudinal external wall and the transverse load-bearing walls of the building's staircases[18], [19].

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Results and Discussion

A. Results

The results of the conducted calculations show that the existing foundations with a footing width of 2.0 m are actually underloaded by a factor of 4 (Pmax is 25% of R). As a result, the foundations and the entire structure of the external wall in these soil conditions experience a settlement of 1.55 cm (calculated according to the second limit state), having an unjustifiably high safety factor of 16.29 (calculated according to the first limit state) [20].Similar calculations for strip foundations under the internal load-bearing wall of the staircase yield the following information [21].

1. Calculation of the foundation footing width according to two limit states for the external wall of the building.

a. Soil layer data:

Layer No	Thickness (m)	Specific Weight (kN/m³)		Strength Characteristics				Deformational Characteristics			Coefficients		
		γ_1 kN/m³	γ_2 kN/m³	φ_1, deg.	φ_2 deg .	C_1 kPa	C_2, kPa	E_o, kPa	η	soil density	γ_{C1}	γ_{C2}	K
1	1,45	17	18	15	18	0	0	5000	0,3	Low	1	1	1,1
2	7	9,8	10,2	29	30	23	25	18000	0,3	Average	1,2	1	1
3	4	9,9	10,3	9	11	8	12	5000	0,3	Low	1,1	1	1
4	10	20,4	20,6	15	17	8	12	18000	0,3	Average	1.1	1	1

Figure 1. *Soil layer data*

b. Foundation Data:

Foundation Location	External Walls
Foundation Type	Strip
Wall Type	External
Foundation Height	2.65 m
Foundation Depth	1.45 m
Distance from Planning Level to Basement Floor	0.45 m
Basement Floor Construction Thickness	0.2 m
Calculated Specific Weight of the Structure	17 kN/m
Reduced Foundation Depth	1.00 m

Table 1. *Foundation data*

c. Loads:

N, kN	QB, kN	MB, kN . m	QL, kN	ML, kN . m

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155	0	0	0	0
Horizontal Load from Lateral Pressure			0.95 kN	
Moment from Lateral Soil Pressure			0.27 kN . m	

Table 2. *Loads*

d. Calculation Results:

Accepted Footing Width, B, m	Calculated Resistance, R, kPa	Average Pressure under Footing, Pavg, kPa	Maximum Pressure under Footing, Pmax, kPa	Ultimate Resistance, Pult, kPa	Obtained Settlement, S, cm	Safety Factor, Ks
For existing foundation						
2,0	410,63	102,15	102,55	1848,78	1,55	16,29
For recommended foundation						
0,6	392,43	282,98	287,42	1456,77	2,35	4,63

Table 3. *Calculation Results*

2. Calculation of the foundation footing width according to two limit states for the internal wall of the building

a. Foundation Data:

Foundation Location	Internal Walls
Foundation Type	Strip
Wall Type	Internal
Foundation Height	1.03 m
Foundation Depth	1 m

Table 4. ***Foundation data***

b. Loads:

N, kN	QB, kN	MB, kN . m	QL, kN	ML, kN . m
311	0	0	0	0

Table 5. *Loads*

c. Calculation Results:

Accepted Footing Width, B, m	Calculated Resistance, R, kPa	Average Pressure under Footing, Pavg, kPa	Maximum Pressure under Footing, Pmax, kPa	Ultimate Resistance, Pult, kPa	Obtained Settlement, S, cm	Safety Factor, Ks
For existing foundation						
1,60	364,13	214,38	214,38	1828,97	2,91	7,68
For recommended foundation						
2,5	375,83	144,4	144,4	1910,96	2,45	11,9

Table 6. ***Calculation Results***

B. Discussion

The results of this calculation show that the existing foundations with a base width of 1.6 meters are also underloaded (P_{max} is 58% of R). As a result, in these soil conditions, the foundations and the entire internal wall structure settle by 2.91 cm (calculated at the second limit state), with an unjustifiably high safety factor of 7.68 (calculated at the first limit state) [22], [23].

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It is evident that there is a settlement difference between the calculated foundations: S= S_1 - S_2 1.36 cm. Since these foundations are adjacent to each other, the relative settlement difference (according to Construction Rules and Regulations) between these structures exceeds the allowable values for this type of construction, leading to conditions where cracks form, as observed in the above-ground structures of the surveyed building [24].

The calculation results for the recommended foundation allow for an analysis of design parameters for foundations with a 0.6 meter base width for the external wall and 2.5 meters for the internal wall of the stairwell. According to the calculations, the foundation with a 0.6 meter base width (external wall) will settle by 2.35 cm, while the foundation with a 2.5 meter base width (internal wall) will settle by 2.45 cm. The relative settlement difference between these foundations will be S= S_1 - S_2 = 2.45 - 2.35 = 0.1 cm, indicating that the foundations will experience nearly identical settlement [25].

Conclusion

This study emphasises the crucial significance of constructing foundations to achieve consistent settlements, therefore guaranteeing minimum variation in settlement and greatly decreasing the likelihood of cracks forming in above-ground structures over extended periods of use. By implementing a technique that utilises a consistent settlement value, the dimensions of the foundation can be optimised to reduce differential settlement, especially in structures with diverse load-bearing components. This strategy successfully mitigates structural deterioration, hence improving the overall longevity and safety of the structure. The findings of this study indicate that there should be a fundamental change in the way foundation design is approached, with settlement analysis being recommended as a routine technique. Future research should prioritise the development of sophisticated modelling approaches and field validation studies to enhance and authenticate this strategy, guaranteeing its wider applicability in various soil types and construction settings.

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