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Comparative Analysis of Kazakhstani and European Approaches for the Design of Shallow Foundations

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Abstract: The design of shallow foundations is performed in accordance with different building regulations depending on geotechnical and geological conditions. This paper involves the design calculations applying Kazakhstani and European approaches. The design of shallow foundations in Nur-Sultan city in Kazakhstan was implemented by the calculation of bearing capacity and elastic settlement in accordance with the design procedures provided in SP RK 5.01-102-2013: Foundations of buildings and structures, and Eurocode 7: Geotechnical design. The calculated results of bearing capacity and elastic settlement for two types of shallow foundations, such as pad foundation and strip foundation, adhering to Kazakhstani and European approaches are relatively comparable. However, the European approach provided higher values of bearing capacity and elastic settlement for the designed shallow foundation compared to the Kazakhstani approach. The difference in the results is explained by the application of different values of partial factors of safety for the determination of bearing capacity and different methods for the calculation of the elastic settlement of shallow foundations (i.e., elasticity theory and layer summation method).

Keywords: comparative analysis; shallow foundation design; bearing capacity; elastic settlement; Eurocode 7; SP RK; SNiP

1. Introduction

In recent years, Kazakhstan has been experiencing a rapid urbanization supported by solid economic growth and strong political engagement in modernization programs [1]. The stable economic progress of Kazakhstan over the years of independence has contributed to the continuous development of the construction industry in the country, making the construction sector one of the driving forces in the country's economy. The government pays particular attention to the realization of large-scale, high-priced projects, therefore encouraging foreign investors to implement international projects in Kazakhstan [2]. The construction of buildings and structures based on international codes of practice (e.g., Eurocode and American Association of State Highway Transportation Officials (AASHTO)) experiences some difficulties associated with the adaptation of project documentation to the local regulation system due to the differences in the applied design methods.

Since the time of the Soviet Union, shallow foundations have been designed by the methods provided in Kazakhstani building regulations (i.e., SP RK 5.01-102-2013: Foundations of buildings and structures (SP RK) [3]), developed based on the Russian SNiP code [4]. However, the regulations have not been modified for decades and do not conform to modern scientific technologies and solutions for the realization of international construction projects in Kazakhstan. The use of the traditional Soviet approach results in difficulties regarding the introduction of innovations and the development of the construction industry in Kazakhstan. Therefore, starting from 2010, the harmonization of national building regulations with the Eurocode has been initiated for (1) the design of infrastructure and (2) the application of construction materials. The Eurocode is the European technical standard used for the design of construction works for civil purposes, developed by the European Committee for Standardization [5]. The Eurocode represents a complex and innovative code of practice applied in more than 45 countries around the world. Compared to SP RK, the Eurocode represents a set of technical regulations that are well recognized all over the world, and it can be applied in many nations. For example, Eurocode 7: Geotechnical design (EC 7) [6] represents a building regulation covering the geotechnical design of structural elements interacting with the ground (e.g., foundations, retaining structures, and bridges) [7]. The design of buildings and structures is governed by National Annexes (NA) developed for each country of the European Union (EU). The NA to EC 7 consider additional requirements for technical parameters and design specifications for each country, determined in accordance with their climatic, geotechnical, and seismic features in order to ensure a high safety level.

In 2015, SP RK EN (the set of national building regulations identical to the Eurocode), was introduced for application alongside the existing design code (i.e., SP RK). In order to implement EC 7 in Kazakhstan, the NA has been developed by considering several factors (e.g., seasonal temperature changes, wind and snow loads, and seismic conditions) that differ from the conditions in EU countries. The adaptation of the Eurocode in Kazakhstan accommodates (1) the integration of the Kazakhstani construction industry into the European system; (2) the application of innovative technologies and materials in the construction field; and (3) an increase in the competitiveness of local specialists on the international market of construction services. However, the introduction of the Eurocode into the national regulatory system represents a gradual process which requires local specialists to refocus on the performance of their construction services, with higher requirements for the quality and safety of designed structures.

Even after the introduction of SP RK EN and even with an understanding of the advantages of applying the European approach, the national SNiP-based regulations are still widely applied for the design of buildings and structures in Kazakhstan. Moreover, the regulations developed in accordance with the Soviet approach are widely used for geotechnical design in the territory of the Commonwealth of Independent States (CIS). Nowadays, the CIS countries, including the Republic of Belarus, the Republic of Kazakhstan, the Russian Federation, and Ukraine, are at various stages of incorporating the Eurocode into their own technical regulations (Figure 1).

The harmonization of EC 7 and SP RK in Kazakhstan still requires careful study and further consideration of their design applications. As the transition from SP RK to EC 7 has already been initiated, it is important to understand the differences between the two codes of practice for the design of shallow foundations. Several previous studies on the comparison of EC 7 and SNiP-based regulations have revealed the differences between the methods applied for the geotechnical design of shallow foundations [8–14]. For example, Vardanega et al. [13] showed that a SNiP-based approach provides significantly fewer conservative results compared to the European approach for geotechnical design. Trofimenkov and Mikheev [12] stated that EC 7 applies higher safety factors compared to SNiP for the design of shallow foundations. With reference to Kremniov and Lobacheva [10] and Lobacheva and Kremnev [11], the traditional Soviet and European approaches were compared based on the calculation results of the elastic settlement of shallow foundations, indicating higher values for EC 7. However, the previous studies did not consider both the ultimate and serviceability limit states in the comparison of EC 7 and SNiP-based regulations for the complete design of shallow foundations. The objective of this article is to compare SP RK and EC 7 in terms of the conservativeness of their shallow foundation design by performing calculations for both bearing capacity and elastic settlement.

The comparative analysis of the design codes is performed by the determination of bearing capacity and elastic settlement for two design cases in Nur-Sultan city.

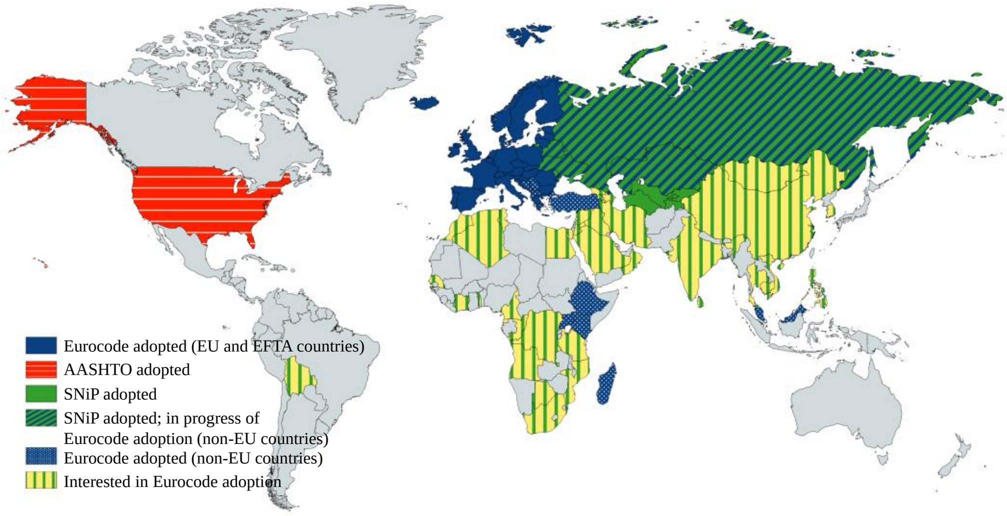

Figure 1. Distribution of building regulations around the world.

2. Review of the Design Codes

2.1. Bearing Capacity

When adhering to SP RK 5.01-102-2013: 'Foundations of buildings and structures', the bearing capacity of soil under the foundation base is determined in accordance with the following equation:

$$R = \frac{\gamma_{c1}\gamma_{c2}}{k}\left[M_{\gamma}k_z b\gamma_{II} + M_q d_I \gamma'_{II} + \left(M_q - 1\right)d_b\gamma'_{II} + M_c c_{II}\right], \tag{1}$$

where $\gamma_{c1} = 1.25$, $\gamma_{c2} = 1.0$, $k = 1.0$, $M_{\gamma} = 0.61$, $M_q = 3.44$, $M_c = 6.04$, $k_z = 1.0$, $b = 1.5$ m for pad foundation or 2.0 m for strip foundation, $\gamma_{II} = \gamma'_{II} = 19.42$ kN/m^3, $c_{II} = 15$ kPa, $d_I = 1.0$ m, and $d_b = 0$.

The ultimate limit state analysis (ULS) of a shallow foundation requires the average pressure under the foundation base (p) not to exceed the bearing capacity of soil (R):

$$p \leq R, \tag{2}$$

The average pressure under the foundation base is determined using the following equation:

$$p = \frac{N + G_f + G_g}{b}, \tag{3}$$

where N is the average pressure per 1 m of foundation under the foundation base, kN/m, G_f is the foundation weight per 1 m, kN/m and G_g is the weight of soil on the foundation slab per 1 m of foundation, kN/m.

The analytical method for the calculation of bearing capacity is provided in Annex D of EC 7. In drained conditions, the design bearing capacity for a shallow foundation is determined using the following equation:

$$R/A' = c'N_c b_c s_c i_c + q'N_q b_q s_q i_q + \frac{1}{2}\gamma' B' N_{\gamma} b_{\gamma} s_{\gamma} i_{\gamma}, \tag{4}$$

where $A' = 3.0$ m^2 for a pad foundation or 20.0 m^2 for a strip foundation, $\gamma' = 19.42$ kN/m^3, $N_q = 7.82$ (DA1-1 and DA2) and 5.06 (DA1-2 and DA3), $N_c = 16.88$ (DA1-1 and DA2) and 12.79 (DA1-2 and DA3), $N_{\gamma} = 5.51$ (DA1-1 and DA2) and 2.57 (DA1-2 and DA3), $b_q = b_c = b_{\gamma} = 1.0$, $s_q = 1.28$ (DA1-1 and DA2) and 1.23 (DA1-2 and DA3) for a pad foundation or 1.07 (DA1-1 and DA2) and 1.06 (DA1-2 and DA3) for a strip foundation, s_c = 1.32 (DA1-1 and DA2) and 1.28 (DA1-2 and DA3) for a pad foundation or 1.09 (DA1-1 and DA2) and 1.08 (DA1-2 and DA3) for a strip foundation, s_γ = 0.78 for a pad foundation or 0.94 for a strip foundation, $i_c = i_q = i_\gamma = 1.0$.

Due to the design procedure of limit state analysis with the combination of partial factors according to EC 7, the designer should ensure that the design value of bearing capacity (R_d) is larger than/equal to the design value of the vertical load acting on the foundation base (V_d) as follows:

$$V_d \leq R_d, \tag{5}$$

EC 7 involves three design approaches (DA1, DA2, and DA3), which require the application of different values of partial factors. For the design of shallow foundations, partial factors are used for the calculation of actions (A), material properties (M), and resistances (R). The combinations of partial factors corresponding to different design approaches are presented in Table 1. There are two combinations of DA1 which involve the application of partial factors on actions only and variable actions and soil parameters for DA1-1 and DA1-2, respectively. For DA2, the partial factors are applied on actions and resistances, rather than soil properties, whereas, for DA3, the partial factors are applied on actions and soil parameters simultaneously. The material strength design (MSD) method is used by DA1 and DA3 so that the partial factors are applied on actions and material strength parameters. As the partial factors for DA2 are applied on actions and resistance simultaneously, this approach is based on the load and resistance factor design (LRFD) method.

Table 1. Design approaches and combinations.

Design Approach (DA)	Combination
DA1-1	A1 "+" M1 "+" R1
DA1-2	A2 "+" M2 "+" R1
DA2	A1 "+" M1 "+" R2
DA3	(A1 or A2) "+" M2 "+" R3

The distribution of the design approaches applied in EU countries for the design of shallow foundations is provided in Figure 2. The application of different design approaches in EU countries is associated with the difference in the safety levels of buildings and structures, which are set by each country by considering different regulatory systems, design traditions, and environmental conditions [5]. The recommended values of partial factors for all design approaches are presented in Table 2.

Table 2. Partial factors for GEO ultimate limit states.

Design Approach	γ_G		γ_Q		$\gamma_{C'}$	$\gamma_{\varphi'}$	$y_{R;v}$
	Unfav.	**Fav.**	**Unfav.**	**Fav.**			
DA1-1	1.35	1.0	1.5	0	1.0	1.0	1.0
DA1-2	1.0	1.0	1.3	0	1.25	1.25	1.0
DA2	1.35	1.0	1.5	0	1.0	1.0	1.4
DA3	1.0	1.0	1.3	0	1.25	1.25	1.0

Note: GEO = Failure or excessive deformation of the ground, in which the strength of soil or rock is significant in providing resistance.

The design vertical load acting on the foundation base is determined using the following equation:

$$V_d = \gamma_G * (W_{Gk} + G_k) + \gamma_Q * Q_k, \tag{6}$$

where G_k is the characteristic permanent load, kN; W_{Gk} is the foundation self-weight, kN, Q_k is the characteristic variable load, kN, γ_G is the partial factor on permanent load, taken in accordance with Table 2 and γ_Q is the partial factor on variable load, taken in accordance with Table 2.

To compare the considered codes of practice in terms of design conservativeness for pad and strip foundations, the values of over-design factor (ODF) must be obtained. ODF, representing the degree of safety of the structural system, can be calculated by using the following equation [15]:

$$\mathrm{ODF} = \frac{R_d}{E_d}, \quad (7)$$

where R_d is the design resistance, kN, and E_d is the design effect of actions, kN. The GEO ultimate limit state is satisfied when ODF is larger than/equal to unity.

By assuming the ODF for SP RK to be equal to unity and applying the above-mentioned equations, the actual vertical load acting on the designed shallow foundation can be obtained. By considering the design of a standard structure ($LL = 0.25DL$), the values of permanent and variable loads acting on the foundation can be calculated. The obtained values of permanent and variable loads allow the calculations for the determination of ODF, as well as the elastic settlement, to be calculated, both adhering to the European approach.

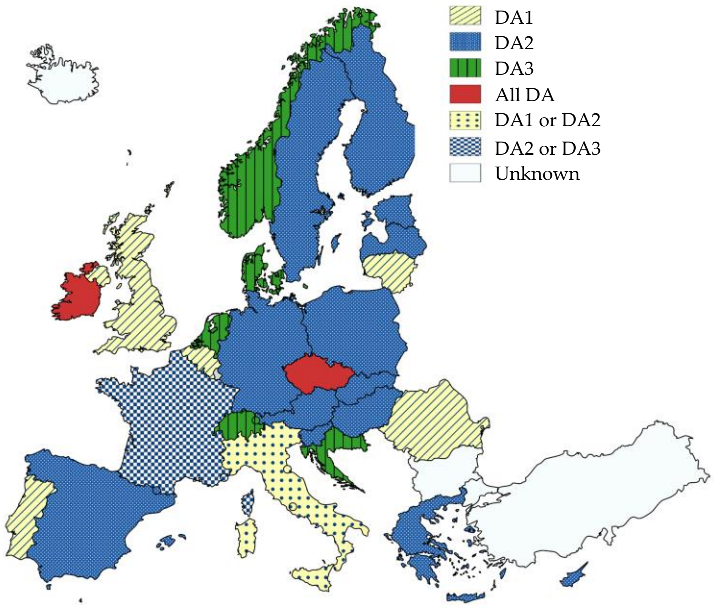

Figure 2. Design Approaches in the European member states for the design of shallow foundations.

2.2. Elastic settlement

SP RK applies the method of layer summation for the determination of the elastic settlement of shallow foundations:

$$s = \beta \sum_{i=1}^{n} \frac{\sigma_{zp,i} \cdot h_i}{E_i}, \quad (8)$$

where β = 0.8, h_i = 0.6 m for pad foundations or 0.8 m for strip foundations, E_i = 7.0 MPa.

Adhering to EC 7, the settlement and rotation of shallow foundations should be considered for the serviceability limit state (SLS) design. The elastic settlement of shallow foundations on cohesive and non-cohesive soil is determined by means of the adjusted elasticity theory provided in Annex F of EC 7:

$$s = pBf/E_m, \quad (9)$$

where B = 1.5 m for pad foundations or 2.0 m for strip foundations and E_m = 7.0 MPa. The SLS partial factors for actions and material properties are equal to unity for the determination of the settlement of shallow foundations. The settlement coefficient is determined using the following equation [15]:

$$f = \left(1 - v^2\right) I_p, \tag{10}$$

where v is the Poisson's ratio of soil and I_p is the influence factor for settlement. The Poisson's ratio for the Nur-Sultan city soil profile is assumed to be equal to 0.325 for a long-term design situation [16].

3. Application of the Design Codes in Kazakhstan

With reference to the site investigation data obtained from Alibekova and Zhussupbekov [16], the soil profiles and soil properties for Nur-Sultan were studied. Based on the analysis of soil properties performed at the construction sites, the whole city territory was divided into uniform zones using "Geographic information database" software. The soil profile of Nur-Sultan mainly consists of three layers, including loam, sandy gravel, and clay, with the depth varying depending on the soil profile type (Figure 3). The zoning of three different types of Nur-Sultan soil profiles is provided on the map (Figure 4). Table 3 summarizes the soil properties for Nur-Sultan city used in this study.

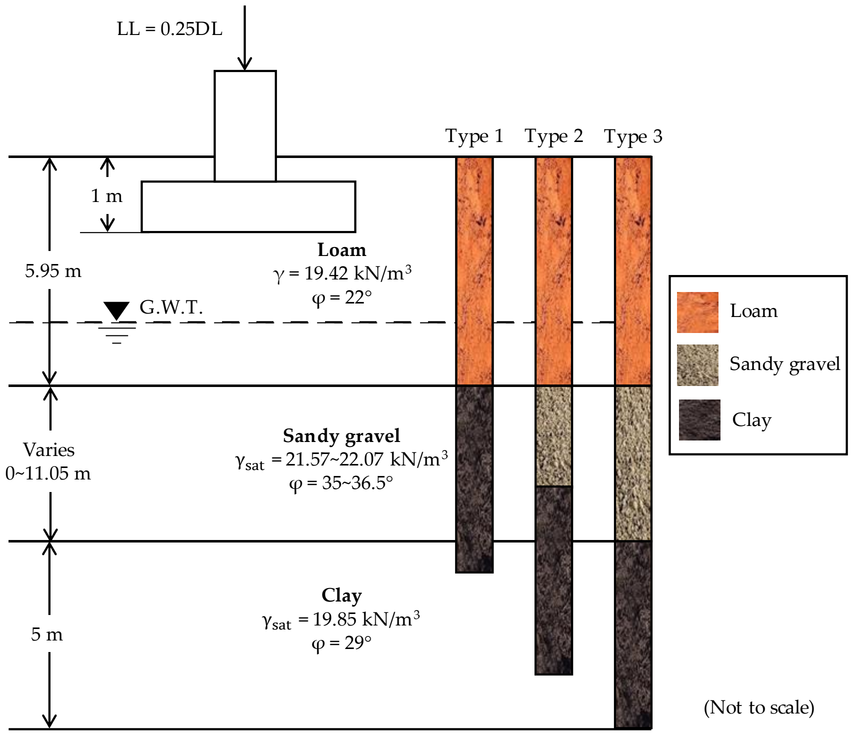

Figure 3. Design problem and types of soil profiles in Nur-Sultan city.

Table 3. Soil engineering properties in Nur-Sultan city.

Soil Type	φ (°)	E (MPa)	LI	γ (kN/m^3)	γ_{sat} (kN/m^3)	c (kPa)
Loam	22.00	7.00	0.09	19.42	20.10	15.00
Sandy gravel	35.00	17.00	-	18.83	21.57	2.00
	36.50	20.00	-	19.35	22.07	1.50
Clay	29.00	10.00	< 0	19.61	19.85	27.00

Note: friction angle (φ), modulus of deformation (E), liquidity index (LI), unit weight (γ), saturated unit weight (γ_{sat}), cohesion (c).

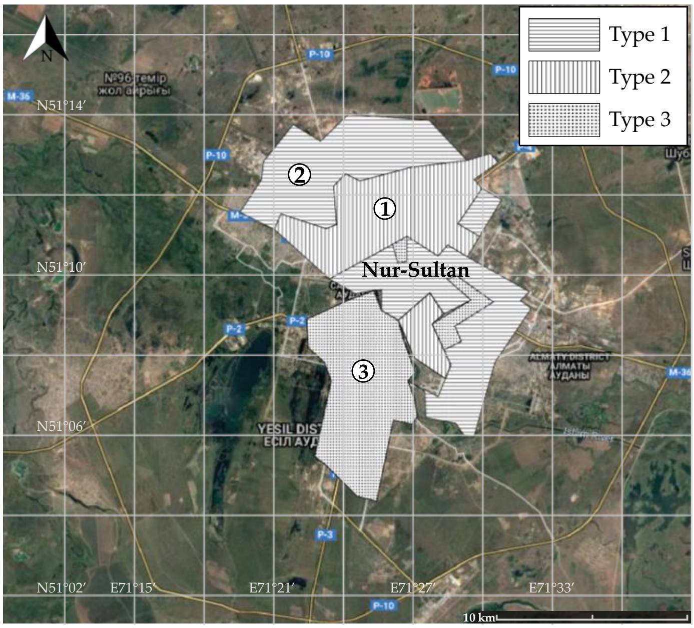

Figure 4. Zoning of the territory of Nur-Sultan city in accordance with the types of soil profiles.

The given example is presented to compare two independently developed codes of practice in terms of their conservativeness for the design of shallow foundations. The design problem shown in Figure 3 requires the identification of the bearing capacity and the elastic settlement of shallow foundations designed in Nur-Sultan in Kazakhstan, adhering to EC 7 and SP RK for a long-term design situation.

The bearing capacity and the elastic settlement were determined for two types of shallow foundations (i.e., strip foundations with B = 2 m and L = 10 m and pad foundations with B = 1.5 m and L = 2 m). The foundation depth is considered to be 1 m below the ground surface for both design cases. The ground water level is assumed to be located 2 m below the existing ground surface [16]. The given load condition requires the variable load to be 0.25 times that of the permanent load ($LL = 0.25DL$). The simplified analysis does not consider tilt or rotation over the foundation base.

4. Results and Discussion

The calculated values of permanent and variable loads required for the comparative analysis of the design codes (particularly for the determination of bearing capacity and the elastic settlement of pad and strip foundations) are provided in Table 4. Figures 5 and 6 provide the calculated values of bearing capacity and elastic settlement of shallow foundations for each type of soil profile, respectively. The results show that the bearing capacity and the elastic settlement for pad and strip foundations are relatively comparable for the considered codes of practice. However, EC 7 overestimates the bearing capacity and the elastic settlement compared to SP RK. The obtained EC 7 results of bearing capacity are between 1.6 and 2.7 and are 1.4 to 2.4 times higher than SP RK values for pad and strip foundations, respectively. As both design codes apply to the ULS analysis for determining bearing capacity for shallow foundation design, the lower values of bearing capacity are provided due to the application of the lower values of partial factors adhering to the Kazakhstani approach.

Table 4. Loads applied on shallow foundations.

Applied Loads	Pad Foundation	Strip Foundation
Permanent load (kN)	493	3580
Variable load (kN)	123	895

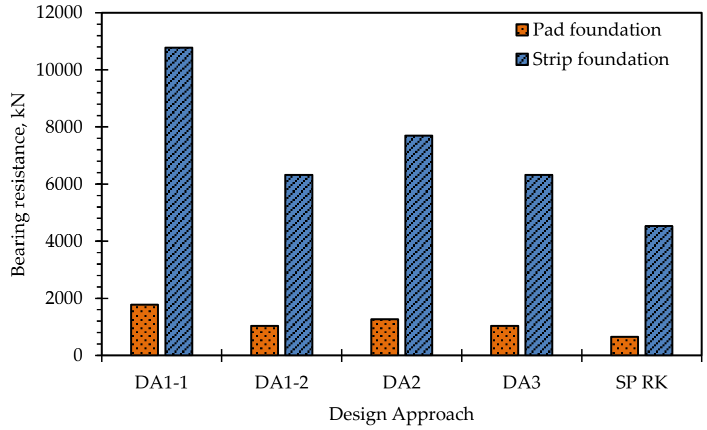

Figure 5. Comparison of the values of bearing capacity for pad and strip foundations adhering to Kazakhstani and European approaches.

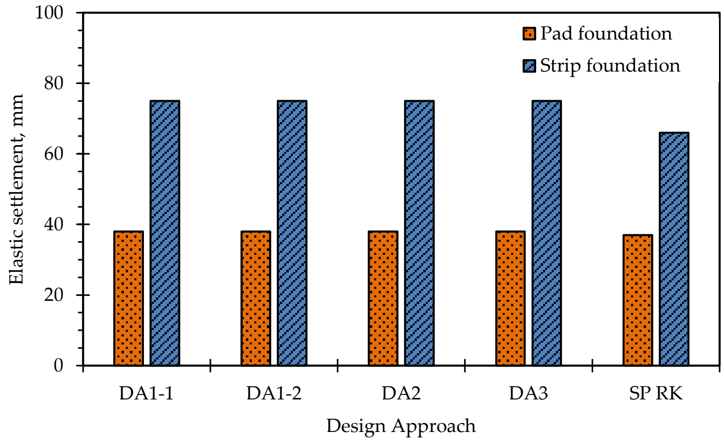

Figure 6. Comparison of the values of elastic settlement for pad and strip foundations adhering to Kazakhstani and European approaches.

The divergence between the elastic settlement values is achieved by the application of different design methods and the determination of the vertical pressure acting on the foundation base. In particular, EC 7 estimates the settlement of shallow foundations using the adjusted elasticity theory, whereas Kazakhstani regulations use the method of layer summation. In addition, the obtained results of bearing capacity and elastic settlement for strip foundations indicate higher values than for pad foundations. The performed calculations for all types of soil profiles of Nur-Sultan city resulted in similar values for both the bearing capacity and elastic settlement of shallow foundations. However, the elastic settlement for strip foundations varied in the range of 66–69 mm when adhering to the Kazakhstani approach.

Figure 7 represents the comparison of ODF values obtained for pad and strip foundations based on different design approaches. The European approach provides a higher ODF than the Kazakhstani approach, thus resulting in more conservative shallow foundation designs. As the ODF for the SP RK design was assumed to be equal to unity, the calculations of EC 7 ODF produced 1.32 to 1.85 and 1.12 to 1.57 times higher results for pad and strip foundations, respectively.

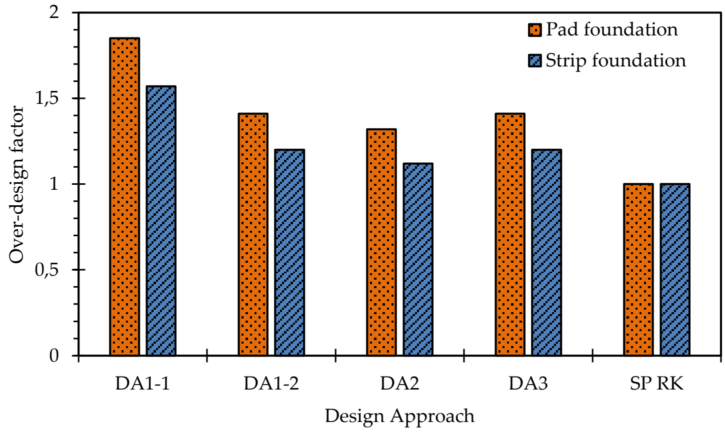

Figure 7. Comparison of the values of over-design factor for pad and strip foundations adhering to Kazakhstani and European approaches.

5. Summary and Conclusions

This paper provides the procedure for the determination of the bearing capacity and the elastic settlement of shallow foundations adhering to SP RK and EC 7. The comparison of the considered design codes is performed based on the explanation of the computational methods for the design of shallow foundations in Nur-Sultan city in Kazakhstan. The results of the comparative analysis of Kazakhstani and European design approaches showed that differences do exist in the implementation of shallow foundation designs. The provided design procedures for the determination of the bearing capacity and elastic settlement of shallow foundations reveal differences in the design methods adhering to SP RK and EC 7.

The performed calculations allowed comparable results to be obtained for bearing capacity and elastic settlement for pad and strip foundations, as well as for over-design factors (ODF). The bearing capacity, elastic settlement, and ODF determined by the application of the European approach resulted in higher values for all design cases than those calculated using the Kazakhstani approach. Therefore, it can be concluded that EC 7 provides more conservative results for the design of shallow foundations compared to SP RK.

As this comparative study of the considered design codes was performed on a limited number of design cases, further analysis is required. Thus, the transition from SP RK to Eurocode 7 requires additional consideration to enhance these conclusions.

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Nomenclature

For SP RK parameters	
γ_{c1}, γ_{c2}	Partial factors on operational conditions
k, M_γ, M_q, M_c, k_z, β	Dimensionless coefficients
b	Width of the foundation base (m)
γ_{II} and γ'_{II}	Average design values of the specific weight of soil layers under and above the foundation base, respectively (kN/m^3)
c_{II}	Design value of the specific cohesion of soil below the foundation base (kPa)
d_I	Depth of the foundation (m)
d_b	Depth of the basement (m)

n	Number of layers in the compressible soil profile
$\sigma_{zp,i}$	Average value of the additional vertical pressure from external load in the middle of the *i*-th soil layer (kPa)
h_i	Thickness of the *i*-th soil layer taken as not more than 0.4 of the foundation width (m)
E_i	Deformation modulus of the *i*-th layer of soil (MPa)
For EC 7 parameters	
$\gamma_G, \gamma_Q, \gamma_{c'}, \gamma_{\varphi'}, \gamma_{R;v}$	Partial factors on permanent action, variable action, effective cohesion, angle of shearing resistance, and bearing resistance, respectively
B'	Effective width of the foundation (m)
L'	Effective length of the foundation (m)
A'	Design effective area of the foundation (m^2)
c'_d	Design effective cohesion (kPa)
φ_d	Design angle of shearing resistance (°)
q'	Design effective overburden pressure at the level of the foundation base (kN/m^2)
γ'	Design effective weight density of soil below the foundation level (kN/m^3)
N_q, N_c, N_γ	Bearing resistance factors
b_q, b_c, b_γ	Inclination factors
s_q, s_c, s_γ	Shape factors
i_c, i_q, i_γ	Inclination factors of the load caused by horizontal load H
α	Inclination of the foundation base to the horizontal
p	Net bearing pressure linearly distributed on the foundation base (kPa)
E_m	Design elasticity modulus of soil (MPa)
f	Settlement coefficient

References

1. Makhmutova, E.V. Central Asia in Search for Its Own Way of Integration. *Mgimo Rev. Int. Relat.* **2018**, 78–91. [CrossRef]
2. Lambla, V. Construction sector in Kazakhstan 2019. In *Market Analysis and Development Forecasts for 2019–2024*; PMR Market Insight: Krakow, Poland, 2019.
3. *SP RK 5.01-102-2013—Foundations of Buildings and Structures*; KAZGOR: Almaty, Kazakhstan, 2013. (In Russian)
4. *SNiP 2.02.01-83—Foundations of Buildings and Structures*; Federal Registry of National Building Codes and Standards of Russia: Moscow, Russia, 1985. (In Russian)
5. Orr, T. Implementing Eurocode 7 to achieve reliable geotechnical designs. In *Modern Geotechnical Design Codes of Practic*; IOS Press: Amsterdam, The Netherlands, 2013; pp. 72–86.
6. Eurocode 7: Geotechnical Design–Part 1: General Rules. In *British Standards*; The European Union: Brussels, Belgium, 1997.
7. Frank, R. Basic principles of Eurocode 7 on Geotechnical design. In Proceedings of the 18th EYGEC, Ancona, Italy, 17–20 June 2007.
8. Askarova, N.A.; Musabayev, T.T. Comparative analysis of design and calculation of pile foundations between Eurocode 7 and national building norms of the Republic of Kazakhstan. *Eur. Res. Innov. Sci. Educ. Technol.* **2018**, 14–18. (In Russian) [CrossRef]
9. Dzheget, K.A.; Menshenina, K.V. Comparison of the design of shallow foundations adhering to Russian Norms and Eurocode 7. In Proceedings of the LX Международная научно-практическая конференция"Научное сообщество студентовXXI столети, Novosibirsk, Russia, 21–25 December 2017; pp. 53–59. (In Russian).
10. Kremniov, A.P.; Lobacheva, N.G. Comparative analysis of design settlement foundations methods according to data of Cone Penetration Test on National and European standards. In ЗбірникНауковихПраць[Полтавського національного технічного університету ім. Ю. Кондратюка]; Серія: Галузеве машинобудування, будівництво ; Poltava National Technical Yuri Kondratyuk University: Poltava, Ukraine, 2017; pp. 212–225.
11. Lobacheva, N.G.; Kremnev, A.P. Some aspects of shallow foundation settlement calculations in accordance with National and European standards. In Proceedings of the Международная научно-техническая конференция, Minsk, Belarus, 16–17 November 2019; pp. 321–328.

12. Trofimenkov, Y.G.; Mikheev, V.V. Calculations on shallow foundations from various standards. *Soil Mech. Found. Eng.* **1999**, *36*, 62–66. [CrossRef]
13. Vardanega, P.J.; Kolody, E.; Pennington, S.H.; Morrison, P.R.; Simpson, B. Bored pile design in stiff clay I: Codes of practice. *Proc. Inst.Civil Eng. Geotech. Eng.* **2012**, *165*, 213–232. [CrossRef]
14. Zhakulin, A.S.; Zhakulina, A.; Akhmetov, Y.; Zhakulin, A. Foundation Bearing Capacity at the Critical Limit State. In Proceedings of the Geo-China 2016: In Situ and Laboratory Test Methods for Site Characterization, Design, and Quality Control—GSP 265, Shandong, China, 25–27 July 2016; pp. 271–277.
15. Smith, I. *Smith's Elements of Soil Mechanics*; John Wiley & Sons: Hoboken, NJ, USA, 2014.
16. Alibekova, N.T.; Zhussupbekov, A.Z. *GIS Technology for Engineering and Geological Surveys*; LAP LAMBERT Academic Publishing: Saarbrücken, Germany, 2018. (In Russian)