Reducing uneven deformations of the base through the use of strip self-adjusting foundations

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Abstract. The article considers the reduction of uneven deformations of the base of the foundations of a five-story building, caused by local subsidence of the soil, through the use of strip self-adjusting foundations. The dependences of settlement, subsidence and stiffness coefficient of the self-adjusting foundation base on the load acting on it were obtained. Using the obtained dependences, numerical studies of the interaction of a building with a non-uniformly deformed subsidence base were performed. The results obtained showed the effectiveness of the use of self-adjusting foundations to reduce uneven deformations of the base and ensure the operational suitability of frameless buildings on subsiding soils. The uneven deformation of the base under the given conditions was reduced by about two times due to an increase in the penetration of the foundation into the ground. At the same time, the maximum shear stresses in the walls of the building decreased by about 30%.

1 Introduction

The problem of construction on weak structurally unstable soils is relevant not only in the Russian Federation, but also for the world practice of foundation construction [1-5].

Additional forces and stresses arise in the buildings and structures built on structurally unstable soils, as a rule, due to uneven deformations of the foundation base. This leads to an increase in the cost of design solutions due to additional protective measures or damage to the building structures during operation and, accordingly, the cost of their restoration.

Ensuring the operational suitability of buildings on structurally unstable soils can be carried out in the following main areas:

– full or partial elimination of uneven deformations of the base caused by the special properties of structurally unstable soils, by improving the characteristics of the base soils [6-13] or the use of deep foundations [14, 15]. In this case, the operating conditions of buildings are practically no different from ordinary engineering and geological conditions;

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– strengthening the supporting structures of the building based on the joint calculation of the "building - foundation - deformable base" system, which allows to effectively use the strength and rigidity of the supporting structures to absorb additional forces caused by uneven deformations of the base [16-21]. However, there are complex engineering and geological conditions that do not allow rational design of the building, applying only constructive protection measures;
– correction of excess uneven deformations of the base during operation by raising the more settled part of the building [22] or lowering the less settled part of the building by drilling out the soil or using foundations with adjustable height [23]. The disadvantage of such measures is the need to perform them during operation, often with a stop of the technological process in the building;
– the use of non-traditional forms of foundation structures, which make it possible to reduce the non-uniformity of base deformations due to the transformation of the contact stress diagram [16, 18] and increase their immersion into the ground during the redistribution of loads caused by non-uniform deformations bases [17]. Some types of such foundations automatically change the parameters of their interaction with a deforming base, adapting to uneven deformations and partially compensating them. This allows us to consider such foundations as self-regulating.

This paper considers the use of tape self-adjusting foundations with a base in the form of longitudinal ribs of a trapezoidal shape, united on top by a slab part. The cavities between the longitudinal ribs are filled with soil as the foundation settles, thus changing the area of the contact surface. Similar "waffle slab" slab foundations have a positive experience of use on swelling soils, but there is no experience of their use in other types of structurally unstable soils and a methodology for their calculation in regulatory documents.

2 Materials and methods

The effectiveness of the use of self-adjusting foundations to ensure the usability of buildings on structurally unstable soils is considered on the example of a frameless five-story rectangular building with overall dimensions of 34.8 × 10.8 m.

Engineering-geological conditions at the explored depth are represented by three engineering-geological elements (Table 1).

Table 1. Characteristics of the soil base.

No. of soil layer	Thickness, m	γ, kN/m^3	e	C_{II}, kPa	φ_{II}, degrees	E, MPa
1	2.8-3	18.05	0.65	4	30	18
2	5.8-6.2	17.1	0.81	23	21	14
3		18.39	0.65	31	24	22

The groundwater level is located at a depth of 12 m from the surface.

Engineering-geological element No. 2 is hard subsidence loam with subsidence characteristics given in Table 2.

The subsidence from the own weight of the soil is ≈ 6 cm. In accordance with the norms of the Russian Federation, the site belongs to type II of soil conditions in terms of subsidence.

The average load on the edge of the strip foundation along the "A" axis is ≈270 kN/m.

The characteristics of the subsiding soil in its natural state allow us to accept the width of the base of the foundation as 1 m. In this case, the settlement will be ≈2.5 cm, which does

not exceed the permissible value. However, when soaking, the total subsidence value will be 14.85 cm.

Table 2. Subsidence characteristics of EGE-2.

P_{sl}, kPa		Relative subsidence capacity ε_{sl} at pressure P					
		50	100	150	200	250	300
at superface of stratum	90	0.006	0.011	0.015	0.0185	0.022	0.0245
at the subface of stratum	100	0.005	0.01	0.015	0.02	0.025	0.03

An increase in the width of the base of the foundation to 3 m allows reducing the settlement to 1.8 cm, and the subsidence to 8 cm. The total value of settlement and subsidence in this case does not exceed the allowable value of 10 cm. However, the uneven deformation of the foundation base during subsiding soil significantly exceeds the allowable value for this constructive solution of the building. A further increase in the width of the sole practically does not affect the unevenness of deformations, since the possible subsidence from the own weight of the soil does not depend on the size of the foundation.

To ensure the usability of the building when the subsiding soil is soaked, it is necessary either to eliminate its subsiding properties or to change the constructive solution of the foundations.

To reduce uneven vertical deformations of the base, we accept a strip self-adjusting foundation with a width of the supporting surface varying from 1 to 3 m. The height of the longitudinal ribs is taken to be 10 cm from the condition of ensuring sufficient compensation for possible subsidence deformations (Fig. 1).

When redistributing loads on foundations as a result of uneven deformations of the base, the effective bearing area of the foundation can change as necessary by 3 times.

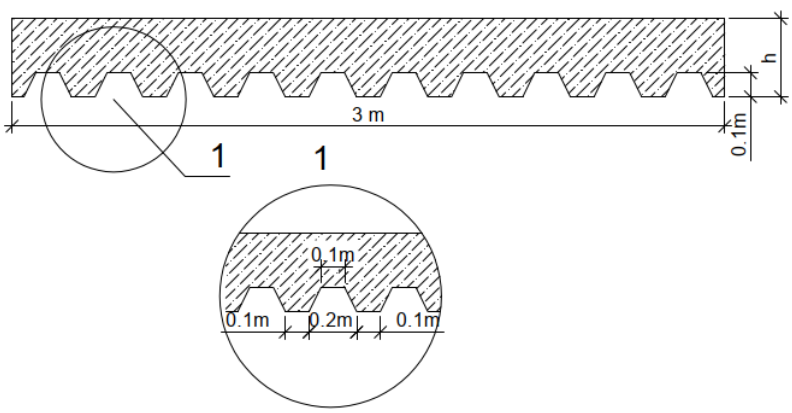

Fig. 1. Geometric parameters of the base of the strip self-adjusting foundation.

Determination of the stress-strain state of the walls of the building was carried out by a joint calculation of the system “Building - Foundation – Base” by the finite element method using the Lira-SAPR software package. The base in this case was modeled by a variable coefficient of base stiffness according to S.N. Klepikov [24]. The variable stiffness coefficient of the base of the self-adjusting foundation was determined depending on the current load acting on the considered section of the foundation. For this, the dependences of settlement, subsidence and the stiffness coefficient of the base on the load on the foundation

were previously calculated in accordance with the methodology proposed by V.V. Yarkin in his monograph Modeling of the "Base - Foundation – Structure" System in Complex Engineering and Geological Conditions (https://profspo.ru/books/93864).

Dependencies were built by step-by-step loading of a self-adjusting strip foundation. At the same time, at each loading step, depending on the amount of settlement at the previous step, the parameters of interaction between the foundation and the base were corrected (contact surface area, pressure, etc.). At the same time, since the pressure along the bottom of the longitudinal ribs under certain loads exceeded the design resistance of the base, the settlement was determined taking into account shear deformations [25].

Since the groundwater level was located much lower than the subsiding soil layer, soaking was taken from above from surface sources.

Subsidence from the own weight of the soil were modeled by forced displacements of the foundation.

3 Results

The obtained dependences of settlement, subsidence and base stiffness coefficient on the load on the foundation are shown in Figs. 2-4.

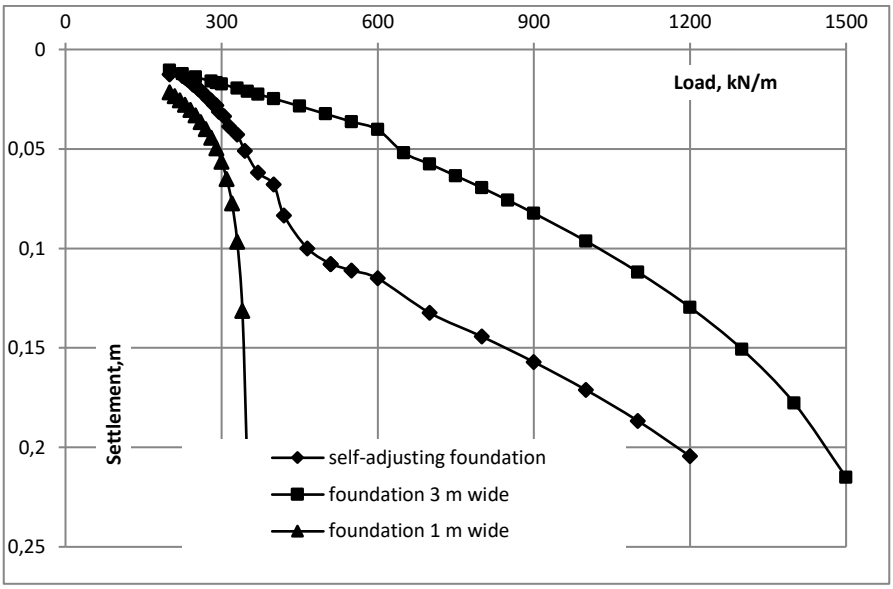

Fig. 2. Dependence of settlement on the load on the foundation.

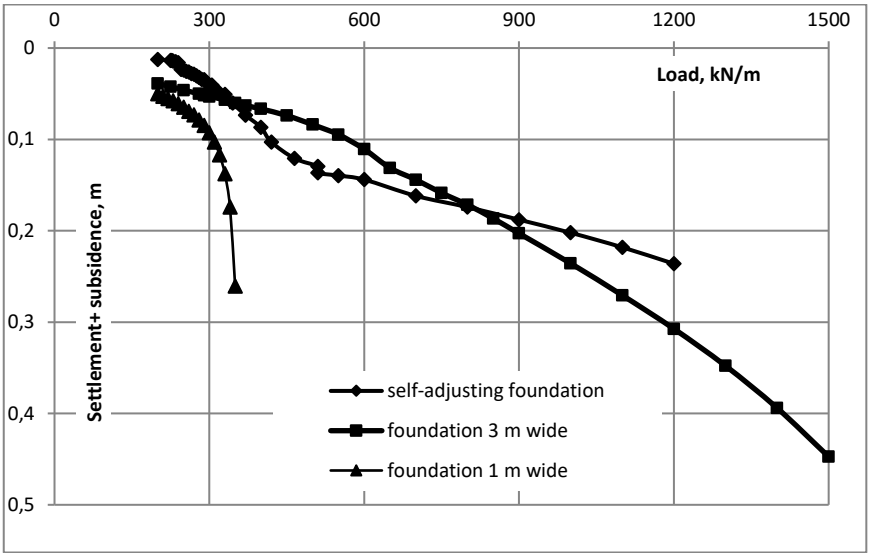

Fig 3. Dependence of the total vertical deformations (settlement and subsidence) on the load on the foundation.

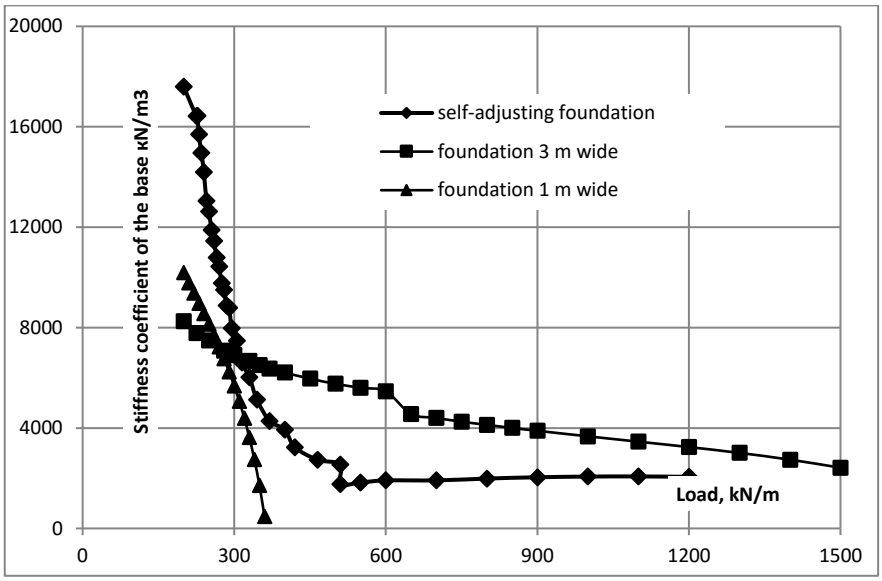

Fig. 4. Dependence of the stiffness coefficient of the base on the load on the foundation.

The stress-strain state of the building wall along the "A" axis with the location of the soaking source 9 m wide in the center of the building is shown in Figs. 5-6.

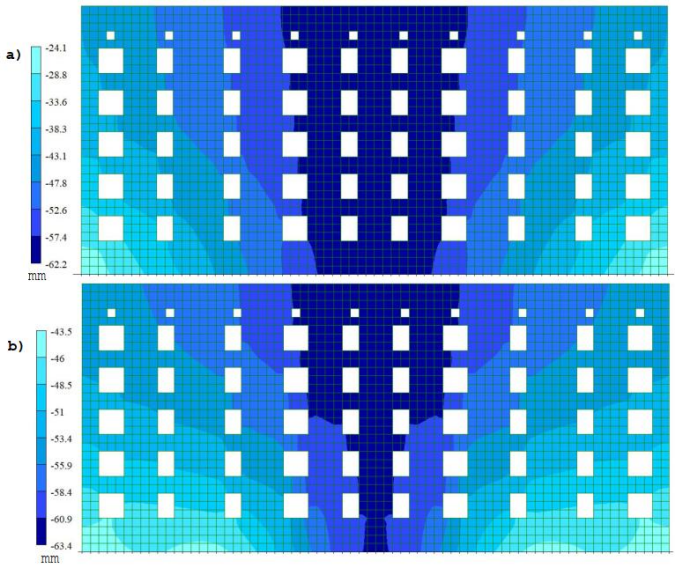

Fig. 5. Vertical movements: a) for a strip foundation 3 m wide; b) for a strip self-regulating foundation.

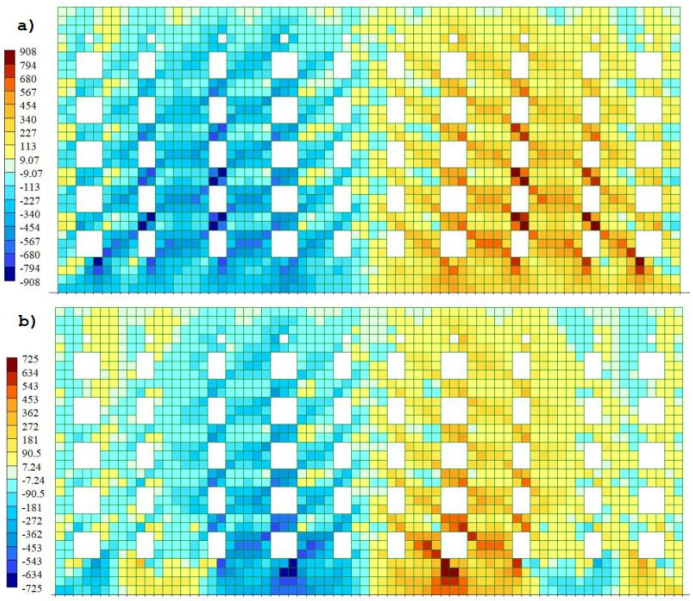

Fig. 6. Tangential stresses, kPa: a) for a strip foundation 3 m wide; b) for a strip self-regulating foundation.

4 Discussion

The analysis of the obtained results shows that:

– strip self-adjusting foundations under the considered conditions make it possible to reduce the non-uniformity of base deformations by about 2 times;

– maximum tangential stresses when using a conventional strip foundation with a width of 3 m are concentrated mainly on the sections of the walls in the sections, weakened by window openings, and located at the boundaries of the subsidence funnel. As a result of this, oblique cracks may appear, ascending to the center of the subsidence funnel (Fig. 7);

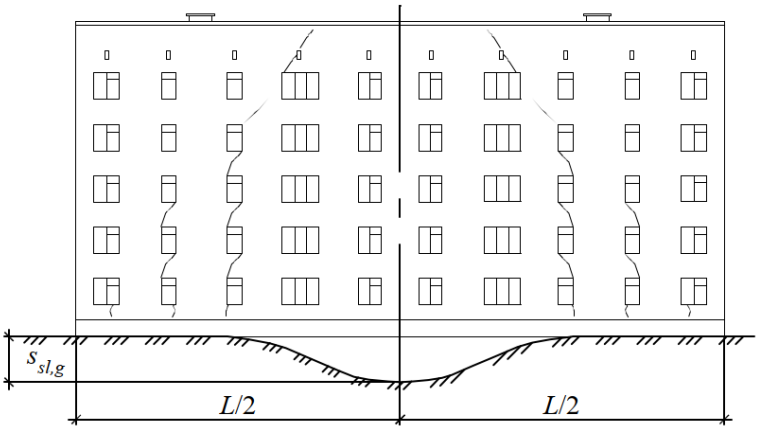

Fig. 7. Scheme of damage to the wall along the "A" axis with the location of the subsidence funnel in the centre of the building.

– strip self-adjusting foundations can reduce the stiffness of the base and significantly reduce additional forces in the building structures from uneven deformations of the base. The maximum shear stresses decreased by about 30% and shifted towards the foundation, and since the strength of the foundation material is higher than that of brick walls, the possible damage will be significantly less.

5 Conclusions

1. Self-adjusting strip foundations are an effective constructive measure to protect buildings from uneven deformations of the base in the event of local subsidence. The greatest effect from their use is observed with base deformations that do not depend on the external load on the base.
2. Longitudinal ribs of a self-adjusting strip foundation are stress concentrators in the base, increase the penetration of the foundation into the ground and thus make it possible to reduce the stiffness of the base by 2-3 times, while maintaining its bearing capacity.
3. Under the conditions considered, the use of a self-adjusting strip foundation made it possible to reduce the maximum shear stresses in brick walls by about 30%.

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