Ultimate permissible additional hogging of a brick wall during the reconstruction of a historical building

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Abstract. The paper analyzes the possible development of an approach limiting additional deformations of the base of a building during reconstruction. We consider the ultimate permissible value of additional relative hogging in a brickwork wall without reinforcement (f/L)ad,u, which is important for the solution of tasks on the reconstruction of historical buildings. The ultimate values of tensile deformations in a wall can serve as a safety criterion for uneven building settlements. The use of this criterion makes it possible to set more precise values (f/L)ad,u for a brick wall as compared with the values used in Construction Regulations SP 22.13330.

1 Introduction

Assessing ultimate permissible deformations of building bases is a common task for specialists in the field of building structures as well as bases and foundations.

Speaking of the historical development of St. Petersburg, the solution of this task is highly relevant for buildings with a wall structural system made of brickwork without reinforcement since it makes it possible to assess permissible additional impacts on buildings, e.g. when they are adapted for modern use.

2 Literature review

A large number of widely known works study and assess ultimate settlements of buildings, including those made of brickwork without reinforcement [1-14]. Ulitsky & Shashkin [15] proposed criteria of "ultimate additional settlements of buildings" with various structural layouts, and categories of technical condition to be used to solve safety tasks during reconstruction. Later, these criteria were adopted in Construction Regulations SP 22.13330. This approach can be further developed by specifying the limits of ultimate additional settlements of buildings taking into account more detailed characteristics of the structural layout.

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3 Materials and methods

When assessing settlements, two types of the combined deformation of the building and the base can be considered: hogging and sagging. The paper is restricted to the analysis of ultimate hogging deformations of a building.

There are various approaches to regulating the deformations of structures and displacements of foundations that are used in different national standards. Their analysis was performed by Paramonov & Popielski [16]. The current version of Construction Regulations SP 22.13330 for high-rise frameless buildings (greenfield development projects) limits three parameters of base deformation, which were described by pioneers in the field of settlement regulation [8]:

1) ultimate maximum smaxu or average settlement of foundations s`u;
2) ultimate relative difference of settlements (rises) of the base under two foundations (Δs/L)u (L is the distance between the foundations) (slope);
3) ultimate relative hogging or sagging of buildings (f/L)u (f is the hog/sag, L is the length of a definitely deflected part of the structure) (relative deflection).

Thus, the only regulated value of deformation along the building wall is the value of relative hogging or sagging. The ultimate value of this parameter for a frameless building (when considering wall hogging in a greenfield facility) is set equal to 50% of the ultimate relative difference of settlements (Δs/L)u and in the case of a brickwork building without reinforcement it will be as follows:

$$(f/L)u = (\Delta s/L)u \cdot 50\% = 0.002 \cdot 50\% = 0.001.$$

The value of ultimate additional relative hogging (f/L)ad,u during the reconstruction of a historical building is not regulated in Construction Regulations SP 22.13330 but, similarly to the ultimate value of relative hogging for a greenfield facility, it shall be 50% of (Δs/L)ad,u. During the reconstruction of a historical building, (Δs/L)ad,u amounts to 0.0009 for a building of category 2 and 0.0007 for a building of category 3 (the categories are assigned according to the technical condition).

Thus, for a historical building of category 2:

$$(f/L)ad,u = 0.0009 \cdot 50\% = 0.00045.$$

For a building of category 3:

$$(f/L)ad,u = 0.0007 \cdot 50\% = 0.00035.$$

Let us consider an analytical solution of the problem on the determination of the ultimate value of relative hogging in a brick wall.

An analytical model of a brick wall is represented by a beam with height H and length L, where settlement results in hog f and two types of internal forces: transverse force and bending moment.

According to the general rules of materials resistance under bending:

$$\varepsilon tensile,max = (0.5 \cdot H)/R,$$

where εtensile,max is the relative elongation of the bottom longitudinal fiber of the beam wall if the neutral axis is in the middle of the wall height; H is the wall height; 1/R is the curvature of the wall segment under consideration (m-1), where R is the radius of curvature (m). Hence:

$$Rult = 0,5 \cdot H/\varepsilon tensile,u \quad (1)$$

where Ru is the ultimate radius of curvature, at which cracks occur in the wall section; H is the wall height; εtensile,u is the ultimate relative tensile deformation of the brickwork, which, according to different sources, is within 0.03–0.09%.

Upon approximation of settlements in a building base with an arc having the radius of curvature Rult:

$$fu = Ru - (Ru2 - (0.5 \cdot L)2 \quad (2)$$

where fu is the ultimate wall hogging, at which cracks occur in the most tensile fiber of its section.

The ultimate relative hogging is equal to the following:

$$(f/L)u = fu/L \quad (3)$$

According to Burland, for a brick building without reinforcement, at the deformation capacity of walls L/H > 2, crack formation caused by brickwork tension due to bending deformations will be a factor determining the ultimate values of the relative building hogging. With more rigid walls, at L/H < 2, shear will be the determining factor for a brick building.

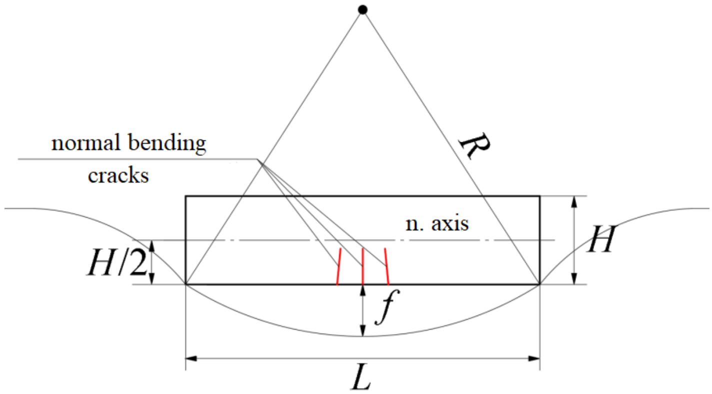

Fig. 1. Analytical model of a brick wall on a base under consideration.

During reconstruction, cracks are usually reinforced with mortar injection. In this case:

$$\varepsilon tensile,ad,u = \varepsilon bt2,$$

where εtensile,ad,ult is the ultimate additional relative tensile deformation of brickwork after injection; εbt2 = 0.027–0.036% is the ultimate relative deformation of concrete at continuous loading pursuant to Construction Regulations SP 63.13330.

Thus, taking into account Eqs. (1), (2), and (3), εtensile,ad,u determines the ultimate value of additional hogging fad,u and the ultimate additional relative hogging (f/L)ad,u based on the condition of crack formation in the areas of existing injected cracks.

Let us consider the results of fu and (f/L)u calculation for a brick wall without reinforcement at different L/H dimensions using Eqs. (1)–(3) at εtensile,u = 0.027% and εtensile,u = 0.05%, as well as the equations proposed in various literature sources.

The analysis will be restricted to the ultimate values of relative hogging, and tensile deformations at a normal section due to wall deflection will serve as acceptance criteria, i.e. we will consider walls at L/H > 2.

4 Results

Figure 2 shows curves (f/L)u – L/H.

The diagram also has points representing the data on field measurements (f/L)u – L/H for a number of buildings according to the results of “classic” works [5, 8].

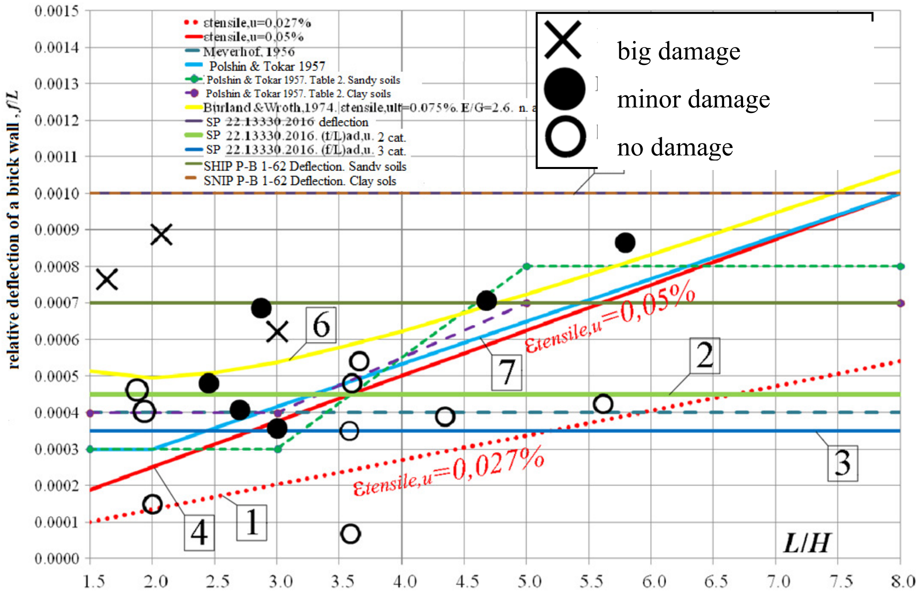

Fig. 2. Diagrams (f/L)u – L/H.

For the case of reconstruction, it is interesting to compare curve 1 constructed based on Eqs. (1)–(3) at εtensile,u = 0.027% with the values (f/L)ad,u proposed in the current regulations for historical buildings of categories 2 and 3 (curves 2 and 3).

As it can be seen, the values (f/L)u, obtained by Eqs. (1)–(3) (curves 4 and 1), as well as by using more complex functions ([4] — curve 6; [8] — curve 7) increase with an increase in L/H. The current version of the regulations uses a more simplified approach and the rigidity of a brick wall is not accounted for — (f/L)u (curve 5) and (f/L)ad,u (curves 2 and 3) are parallel to the X axis.

According to curves 1, 2, 3, the values (f/L)ad,u are less than (f/L)u (curves 4, 5, 6, 7), which is obvious. It can be seen that the use of the regulatory values (f/L)ad,u, at L/B < 5 according to curve 3 and at L/B < 6.5 according to curve 2 will result in the estimated values εtensile,max > 0.027%. This means that repeated cracks may occur in the areas of brickwork injection.

Figure 3 shows curves fad,u – L2/H constructed based on Eqs. (1)–(3) at εtensile,u = 0.05% and εtensile,u = 0.027%. The diagram has points fad,u (pursuant to Construction Regulations SP 22.13330) for a wall of L = 30 m of categories 2 and 3.

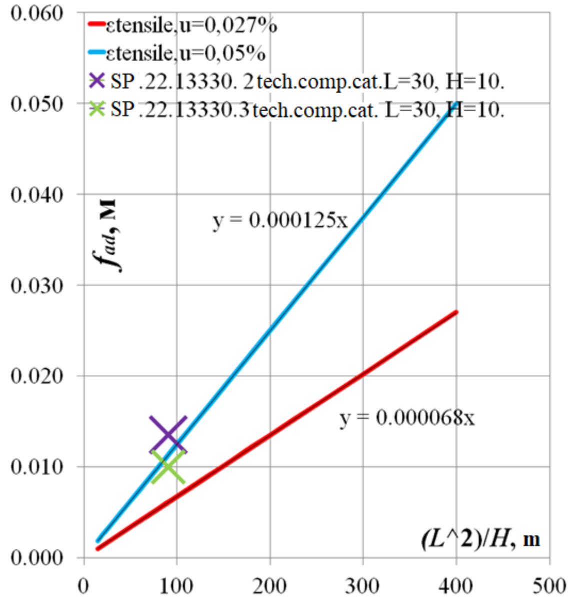

Fig. 3. Diagrams fad,u – L2/H according to Eqs. (1)–(3) at εtensile,u = 0.05% and εtensile,u = 0.027%.

Figure 4 shows curves fad,u – L pursuant to Construction Regulations SP 22.13330 for buildings of categories 2 and 3. The values fad,u cannot exceed the values of maximum additional settlements smaxad,u for buildings of respective categories, which correspond to the horizontal sections of the curves in Figure 4. Figure 4 also has points fad,u plotted for a wall of L = 30 m, H = 10 m at εtensile,u = 0.027% and εtensile,u = 0.05% according to Eqs. (1)–(3).

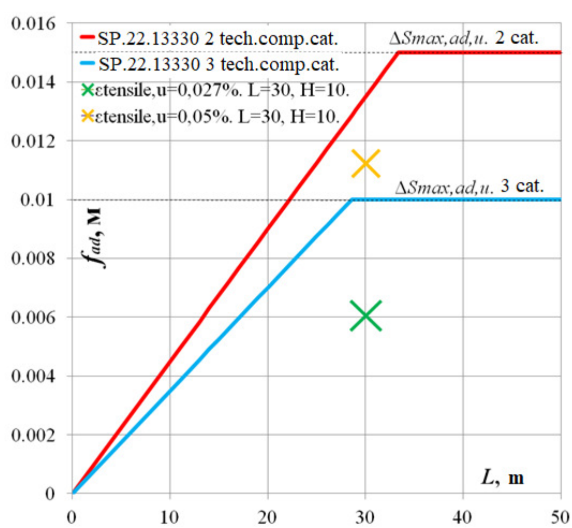

Fig. 4. Diagrams fad,u – L pursuant to Construction Regulations SP 22.13330 for buildings of categories 2 and 3.

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The diagrams show that pursuant to Construction Regulations SP 22.13330 for a building of category 3, fad,u = 0.010 m, and for a building of category 2, fad,u = 0.0135 m. The value fad,u, obtained by Eqs. (1)–(3) at εtensile,u = 0.027%, equals 0.006 m.

The analysis of these diagrams shows that the limitations for fad,u and smaxad,u used in the regulations will not make it possible to reliably guarantee the absence of cracks in the wall structure in the case of the building under consideration.

5 Discussion

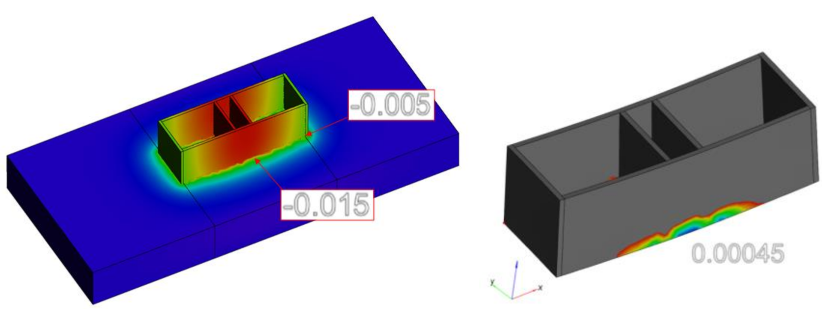
In the case of rather strict limitations regarding the value of additional settlement of a building during reconstruction smaxad,u, the regulatory values of the ultimate additional relative hogging (f/L)ad,u and the ultimate value of additional hogging fad,u will not always result in "safety margin" of the reconstructed building.

Let us consider the numerical calculation of a reconstructed building with a wall of L = 30 m, H = 10 m.

Figure 5 shows the results of calculating the values of additional settlement, which do not exceed the regulated values for a building of category 2:

$$smaxad = smaxad,u = 0.015\ m;$$
$$fad = 0.01\ m;$$
$$(f/L)ad = (0.015 - 0.005) / 30 = 3 \cdot 10\text{-}4 \leq (f/L)ad,u = 4.5 \cdot 10\text{-}4.$$

The reverse calculation by Eqs. (1)–(3) will result in εtensile,max = 0.044%. This value is close to the result of the numerical calculation: 0.045% (Fig. 5b) and exceeds εbt2, thus the existing cracks of the injected brickwork may open.



a) b)

Fig. 5. Building analysis with FEM-models: a) vertical displacements, m; b) normal deformations εx. The area where εx ≥ εbt2 is marked.

Figure 6 shows the results of calculating the values of additional settlement, which do not exceed smaxad,u for a reconstructed historical building: smaxad = 0.022 m.

This results in the following:

$$fad = 0.01\ m.$$
$$(f/L)ad = (0.022 - 0.016) / 30 = 2 \cdot 10\text{-}4.$$

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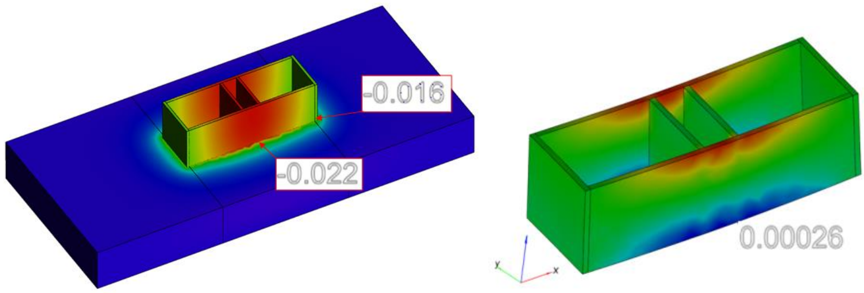
According to Eqs. (1)–(3) at such values of L, H, and f: εtensile,max = 0.027%. This value is close to the result of the numerical calculation: 0.026% (Fig. 6b) and does not exceed εbt2, thus, no cracks shall occur in the injected brickwork and such additional settlements can be considered safe.



a) b)

Fig. 6. Building analysis with FEM-models: a) vertical displacements, m; b) normal deformations εx.

6 Conclusion

In geotechnical analysis during the reconstruction of brick historical buildings, the permissible values of additional settlements shall be established based on the detailed analysis of the stress-strain state of the building. In a number of cases, the use of the ultimate values proposed in Construction Regulations SP 22.13330 may not guarantee the absence of cracks in brickwork. In such an event, ultimate tensile deformations of brickwork can serve as a criterion of safe settlements. The use of this criterion makes it possible to set more precise values (f/L)ad,u depending on the actual structure of the walls according to the results of analytical and numerical calculations.

References

1. L. Bjerrum, *Allowable settlement of structures. Proceedings of the European Conference on Soil Mechanics and Foundation Engineering Wiesbaden,* Deutsche Gesellschaft für Erd und Grundbau (1963).
2. S.J. Boone, J. of Geotech. and Environm. Eng. **122(11),** 886-896 (1996).
3. M.D. Boscardin, E.J. Cording, J. of Geotech. Eng. **115(1),** 1-21 (1989).
4. J.B. Burland, C.P. Wroth, *Settlement of buildings and associated damage. SOA review,* Conference on settlement of structures (Cambridge, 1974).
5. J.B. Burland, B.B. Broms, V.F.B. De Mello, *Behaviour of Foundations and Structures*. Ninth International Conference on Soil Mechanics and Foundation Engineering, Tokyo, Japan, pp. 495-546 (1977).
6. R. Grant, J.T. Christian, E.H. Vanmarcke, J. of Geotech. Eng. Division **100(GT 9),** 973-991 (1974).
7. G.G. Meyerhof, 1953. *Some recent foundation research and its application to design.* The structural Engineer 31(June), pp. 151-167 (1953).
8. D.E. Polshin, R.A. Tokar, *Maximum allowable non-uniform settlement of structures.* Proceedings 4th Int. Conference On Soil Mechanics and Foundation Engineering. London, UK, vol.1, Butterworth's scientific (1957).

9. W.J. Rankin, 1988. Eng. Geology Special publication, Geological Society **5,** 79-92 (1988).
10. A.G. Shashkin, et al., *Analysis of causes of deformations in historic buildings on weak clay soils*, Geotechnics Fundamentals and Applications in Construction: New Materials, Structures, Technologies and Calculations. Proceedings of the International Conference on Geotechnics Fundamentals and Applications in Construction: New Materials, Structures, Technologies and Calculations «GFAC 2019». Saint-Petersburg. Vol. 2. pp. 329-334, (2019).
11. A.W. Skempton, D.H. McDonald, Proceedings Institution of Civil Engineers part III **5(50),** 727-768 (1956).
12. V.M. Ulitsky, et al., *Soil-structure interaction effects. In: Geotechnical Engineering for Infrastructure and Development,* Proceedings of the XVI European Conference on Soil Mechanics and Geotechnical Engineering, ECSMGE 2015 16, Geotechnical Engineering for Infrastructure and Development, pp. 4191-4196. (2015)
13. V.A. Vasenin, Soil Mechanics and Foundation Eng. **4,** 2–7 (2013).
14. H.E. Wahls, ASCE, J. of Geotechnical Eng. Division **107(GT 11),** 1489-1505 (1981).
15. V.M. Ulitsky, A.G. Shashkin, Geotechnical support for urban reconstruction (M.: Ed. ACB, 1999).
16. P. Popielski, A. Dombska, V.N. Paramonov, Urban development and geotechnical construction. **14,** 215-226 (2012).