The building’s structural elements stress-strain state assessment taking into account soil consolidation (uniaxial task)

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Abstract. This article discusses a comparative analysis of the building design results when calculating the final draft and taking into account the soil consolidation over time. The bases uneven effect deformations assessment was made on the elements’ stress state of the frame buildings erected under difficult ground conditions, which causes a rational stiffness diaphragms arrangement and the expansion joints in order to evenly distribute the efforts when choosing a space-planning solution.

Introduction
In connection with the development of the territory, most of the construction sites belong to a complex or a particularly complex category. The current regulatory documents recommend to evaluate the strata heterogeneity in terms of the base compressibility variability.

A preliminary estimate of the overall base compressibility within the construction area can be represented as the result of the strain modules analysis and comparison or the layers relative compressibility coefficient along the base strike and depth. This assessment should be made in relation to the relief, the projected building, taking into account the process of precipitation over time, its dependence on the size and shape of the base, type of foundation, loading conditions, pressure, etc. It is necessary to take into account that the compressibility characteristics are determined on compacted soils, which correspond to a given level of the stressed state, and do not allow us to estimate the attenuation of precipitation over time. For example, if sand lies beneath one part of a building, and clayey soil lies below another, and their deformation moduli are approximately equal, such a foundation cannot be considered to be uniformly compressible. Sand precipitation will end at 80–90% during construction, and clayey soils may continue after the building has been commissioned for tens or even hundreds of years, and as a result, the difference in sediment over time may be unacceptable [1-4].

From the practice of designing, building and operating buildings and structures, it is known that basement precipitation develops over time, including the period after the construction completion. The design does not pay enough attention to the sediment base rate prediction in time. As a rule, they stop at calculations of stabilized sediments, which is possible only with the complete consolidation of the
soil foundation. This is due, on the one hand, to the absence in the regulatory documents of the requirements for predicting the base foundations SSS, on the other, to the lack of research on the sediment of bases in time and the lack of relatively simple methods for calculating them. It seems that the soils in the norms are considered as a one-component medium, like concrete or steel. Only in the section of the bases design from organic-mineral soils of regulatory documents it is stated that sediment should be calculated according to the theory of filtration consolidations, while no guidance is given on the method of calculating precipitation in time [5,6].

Next, we consider the finite width foundations bases deformed state quantitative assessment problem, depending on the change in speed and the amount of precipitation with time. For comparison, there are two options for calculating a 6-story building erected on a covered ravine. In the first case, backfilling was made with sandy soil, in the second - with clay. The foundation is structurally implemented in the form of a plate 60 cm thick. Two thirds of the designed building are located on bedrock, and one third is erected on a covered ravine, the thickness of the filling soils reaches 8 meters.

![Figure 1. Combined graph of changes in sediment over time for the bedrock and sandy rocks of the ravine backfill.](Figure 1)

![Figure 2. Combined graph of the sediment change over time for the bedrock and clayey rocks of the ravine backfill.](Figure 2)

Tables 1, 2 present the foundation sediment values over time for 16 years, as well as the differences in the sediment for indigenous and bulk sandy / clay soils.
The structure is 28% higher than the design value of the difference in sediment for which the building foundation is 4.738 cm, which is 28% higher than the design value of the difference in sediment for which the building structure is calculated.

### Table 1. Baseline sediments in time (backfill - sandy soil)

| Ground foundation                  | Time, year | Bedrock sludge, cm | Sand Sediment, cm | Time difference, cm | The difference in sediment design, cm | Percent discrepancy, (*100%) |
|-----------------------------------|------------|--------------------|-------------------|---------------------|---------------------------------------|-----------------------------|
| Bedrock and sandy ground filling  | 0.10       | 0.919              | 1.992             | 1.073               | -0.685                                |                             |
| the ravine                        | 0.25       | 1.281              | 3.071             | 1.790               | -0.475                                |                             |
|                                   | 0.50       | 1.766              | 4.339             | 2.573               | -0.245                                |                             |
|                                   | 0.75       | 2.157              | 5.302             | 3.145               | -0.078                                |                             |
|                                   | 1.00       | 2.490              | 6.084             | 3.594               | 0.051                                 |                             |
|                                   | 1.50       | 3.048              | 7.258             | 4.210               | 0.190                                 |                             |
|                                   | 2.00       | 3.512              | 8.061             | 4.549               | 0.250                                 |                             |
|                                   | 2.50       | 3.907              | 8.610             | 4.703               | 0.275                                 |                             |
|                                   | 3.00       | 4.247              | 8.985             | 4.738               | 0.280                                 |                             |
|                                   | 4.00       | 4.793              | 9.416             | 4.623               | 0.262                                 |                             |
|                                   | 5.00       | 5.199              | 9.618             | 4.419               | 0.228                                 |                             |
|                                   | 6.00       | 5.502              | 9.712             | 4.210               | 0.190                                 |                             |
|                                   | 8.00       | 5.895              | 9.777             | 3.882               | 0.122                                 |                             |
|                                   | 10.0       | 6.113              | 9.791             | 3.678               | 0.073                                 |                             |
|                                   | 12.0       | 6.235              | 9.794             | 3.559               | 0.042                                 |                             |
|                                   | 14.0       | 6.302              | 9.795             | 3.493               | 0.024                                 |                             |
|                                   | 16.0       | 6.385              | 9.795             | 3.410               | 0.000                                 |                             |

Thus, the maximum difference in sediment for the option of filling a ravine with sandy soils is 4.738 cm, which is 28% higher than the design value of the difference in sediment for which the building structure is calculated.

### Table 2. Baseline sediments in time (backfill - clay soil)

| Ground foundation                  | Time, year | Bedrock sludge, cm | Clay Sediment, cm | Time difference, cm | The difference in sediment design, cm | Percent discrepancy, (*100%) |
|-----------------------------------|------------|--------------------|-------------------|---------------------|---------------------------------------|-----------------------------|
| Rocks and clay soil backfill      | 0.10       | 0.919              | 1.172             | 0.253               | -0.693                                |                             |
|                                   | 0.25       | 1.281              | 1.718             | 0.437               | -0.470                                |                             |
|                                   | 0.50       | 1.766              | 2.407             | 0.641               | -0.223                                |                             |
|                                   | 0.75       | 2.157              | 2.947             | 0.79                | -0.042                                |                             |
|                                   | 1.00       | 2.490              | 3.401             | 0.911               | 0.094                                 |                             |
|                                   | 1.50       | 3.048              | 4.149             | 1.101               | 0.251                                 |                             |
|                                   | 2.00       | 3.512              | 4.745             | 1.233               | 0.331                                 |                             |
|                                   | 2.50       | 3.907              | 5.223             | 1.316               | 0.373                                 |                             |
|                                   | 3.00       | 4.247              | 5.609             | 1.362               | 0.394                                 |                             |
|                                   | 4.00       | 4.793              | 6.17              | 1.377               | 0.401                                 |                             |
|                                   | 5.00       | 5.199              | 6.535             | 1.336               | 0.382                                 |                             |
|                                   | 6.00       | 5.502              | 6.771             | 1.269               | 0.350                                 |                             |
|                                   | 8.00       | 5.895              | 7.025             | 1.13                | 0.270                                 |                             |
|                                   | 10.0       | 6.113              | 7.132             | 1.019               | 0.190                                 |                             |
|                                   | 12.0       | 6.235              | 7.177             | 0.942               | 0.124                                 |                             |
|                                   | 14.0       | 6.302              | 7.196             | 0.894               | 0.077                                 |                             |
|                                   | 16.0       | 6.385              | 7.21              | 0.825               | 0.000                                 |                             |
Thus, the maximum difference in sediment for the option of filling the ravine with clay soils is 1.377 cm, which is 40.1% higher than the design value of the difference in sediment, for which the building structure is calculated.

Figures 3, 4 show the time intervals with the difference of the sediment exceedances, as well as the sediments difference maximum value for the bedrock and sandy / clay bulk rocks of the soil.

![Graph of changes in precipitation for indigenous and sandy rocks of the ravine backfill.](image1)

**Figure 3.** Graph of changes in precipitation for indigenous and sandy rocks of the ravine backfill.

![Graph of changes in precipitation for indigenous and clay rocks of the ravine ground filling.](image2)

**Figure 4.** Graph of changes in precipitation for indigenous and clay rocks of the ravine ground filling.

Taking into account the obtained excess in difference between the sediment on two variants of soil bases, the design schemes were modeled. The soil base was defined by stiffness coefficients characteristic of the time period when the difference between the sediments of the bedrock and the gully soil was the greatest, namely 3 and 4 years of operation for filling the gully with sandy and clay soils, respectively.

**Results obtained in studies**

The obtained results were compared with the results of models designed for final precipitation for structural elements: floor plate P1, base plate Pf1, diaphragm D1, columns K1. The results of the calculations are shown in tables 3, 4 [7].
Table 3. The results of calculations for to PP1, Pf1, D1 (filling with sandy soil)

| Load model | Structural elements       | Calculated parameters |
|------------|---------------------------|-----------------------|
|            |                           | N_x, N_y, M_x, M_y, M_xy, Q_x, Q_y, z |
|            |                           | N_x, N_y, M_x, M_y, M_xy, Q_x, Q_y, z |
|            |                           | N_x, N_y, M_x, M_y, M_xy, Q_x, Q_y, z |
|            |                           | N_x, N_y, M_x, M_y, M_xy, Q_x, Q_y, z |
| 2          | Floor slab Fs1            | -3.04, -2.02, -6.57, -7.32, 1.41, -17, -15.6, -87.7 |
|            | Base plate Bp1            | -39.7, -42.8, -46.1, -54, 15.7, -130, -177, -82.9 |
|            | Stiffness diaphragm D1    | -121, -24, 0.199, -0.01, -0.08, 0.8, -0.99, -97.5 |
| 2a         | Floor slab Fs1            | -3, -1.82, -6.67, -7.93, 1.39, -18.2, -16.8, -67.7 |
|            | Base plate Bp1            | -71.2, -50.9, -42.9, -53.1, 16, -129, -185, -63 |
|            | Stiffness diaphragm D1    | -121, -23.9, 0.327, -0.015, -0.128, 1.32, -1.64, -81.2 |

Table 4. The results of calculations for PP1, Pf1, D1 (filling with clay soil)

| Load model | Structural elements       | Calculated parameters |
|------------|---------------------------|-----------------------|
|            |                           | N_x, N_y, M_x, M_y, M_xy, Q_x, Q_y, z |
|            |                           | N_x, N_y, M_x, M_y, M_xy, Q_x, Q_y, z |
|            |                           | N_x, N_y, M_x, M_y, M_xy, Q_x, Q_y, z |
|            |                           | N_x, N_y, M_x, M_y, M_xy, Q_x, Q_y, z |
| 3          | Floor slab Fs1            | -3.18, -2.34, -6.66, -6.54, 1.46, -15.7, -14, -77.3 |
|            | Base plate Bp1            | -15, -29.9, -48.3, -52, 13, -127, -164, -72.5 |
|            | Stiffness diaphragm D1    | -122, -24.1, 0.04, -0.001, -0.013, 0.143, -0.18, -78.5 |
| 3a         | Floor slab Fs1            | -3.18, -2.08, -6.82, -6.87, 1.45, -16.6, -14.9, -62.3 |
|            | Base plate Bp1            | -19.9, -29.9, -46.6, -50.7, 13.4, -124, -164, -57.5 |
|            | Stiffness diaphragm D1    | -122, -24, 0.086, -0.0028, -0.03, 0.334, -0.017, -65 |

Percentage charts of correlation of forces in structural elements for design models.

Figure 5. The forces and displacements correlation percentages in Fs1, Bp1, D1 for design models 2 and 2a.
Summary
As mentioned earlier, the bulk soils composed grounds should be designed taking into account their features: heterogeneity in composition, uneven compressibility and self-consolidation, etc. When analyzing the development of sediment over time, it was found that the difference value in sediment over the design value is for sandy soils, 28%; for clay soils, the ravine backfills - 40%. Such differences in sediments during the operation period must be taken into account when designing foundations, above-ground structures and especially pipelines of engineering communications, which must have certain gradients and integrity.

For residential and industrial buildings, uneven sediment (relative difference in sediment) of more than 2 mm / m is felt as an obstacle to operation, and with a value of 50 mm / m, normal operation of the structure is impossible due to skewed floor and walls, the elevator equipment technical maintenance impossibility, the cracks in the walls, damage to communications [8-11].

When comparing the calculated models with regard to stabilized sediment and taking into account the temporary consolidation of soils for the considered structural elements (F1, B1, D1 and K1), the overwhelming majority of efforts turned out to be 15–20% more for the second variant.

References
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