TOPIC 4. FOUNDATIONS ON SWELLING SOILS

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SWELLING AND SHRINKAGE PROPERTIES OF CLAY SOILS

- Swelling is the property of some soils, when moistened, to increase in volume (swell) both due to the thickening of the water shells around colloidal particles, and also due to chemical processes that entail a change in the composition and volume of the particles themselves. A characteristic feature of swelling soils is the increased density and high content (65–85%) of clay particles less than 0.005 mm in size. Clayey sands and sandy loams either do not show swelling at all, or swell insignificantly. The swelling of loams and clays increases with an increase in the content of clay and especially colloidal particles.

- Swelling soils are widespread across the globe, and are confined to zones of dry steppes and semi-deserts. The areas of development of swelling soils are characterised by a slight amount of precipitation, a general deficit of air humidity, and prolonged dry periods in the summer. Such soils are widespread in Egypt, Ethiopia, Sudan, South Africa, the USA, Canada, Iraq, Syria, Mauritius (Dark Magnesium Clay), and in India more than 30% of the territory is occupied by so-called cotton soils. In the CIS (Commonwealth of Independent States) countries, such soils are found in Kazakhstan, Georgia, Azerbaijan, Moldova, Russia (Volga region, North Caucasus and other areas). In Ukraine, they are found in the areas of Kupyansk, Kharkiv, Poltava and Crimea.

SWELLING SOILS



SWELLING SOIL WITH INTACT STRUCTURE



HYPOTHESES EXPLAINING THE PHENOMENON OF SWELLING OF CLAY SOILS

- There are several hypotheses that explain the phenomenon of swelling of clay soils, from which two main ones can be distinguished: physic-mechanical and physic-chemical.
- *The physic-mechanical hypothesis* is the Terzagi – Gersevanov capillary theory, according to which water penetration between soil particles becomes possible after concave menisci disappear at the water-air interface in the capillaries, i.e. after capillary pressure removal. The surface tension forces acting between the capillary walls and the water form concave menisci of water, which press the soil particles against each other and bend them with concavity towards the capillaries, and negative capillary pressure develops in the liquid itself. The movement of water inside the capillaries occurs under this pressure until the hydrostatic pressure of the liquid column balances that of capillary pressure.
- The second hypothesis derives from *the physic-chemical* nature of the interaction of clay particles with water. According to this hypothesis, the swelling of the soil during wetting is considered as the ability of the surface of clay particles to adsorb water due to osmotic pressures caused by the influence of aging of the crystal lattices, the exchange complex in pore and soaking solutions.

FACTORS AFFECTING SWELLING

- The swelling properties of clay soils to a large extent depend on their mineralogical composition and dispersion. Minerals of the montmorillonite group possess a high swelling ability, and minerals of the kaolinite group to a much lesser extent. These minerals (kaolinite, halloysite) have a strong fixed lattice in which the distance between the packets does not change when moistened.
- swelling process revealed the dependence of the latter on a number of physical properties of soils.
- The dependence of swelling on the particle size distribution of the soil, and more precisely on the content of clay fractions in it, is noted. This relationship is linear. But this pattern takes place within the specific regional genetic origin of rocks.
- The amount of swelling also depends on the initial moisture of the soil; the more moisture it contains, the less, other things being equal, its swelling. Inversely proportional relationship between relative swelling and pressure on the one hand and moisture capacity on the other.

■ **“Initial swelling density”,** at which swelling does not develop.

■ The dependence of swelling on density is determined by porosity. It is clear that this dependence is inversely proportional. Other things being equal in the soil mass, a soil with low porosity value is most susceptible to swelling. As the density of clay samples increases, the degree of their swelling and the pressure of swelling usually increase. .

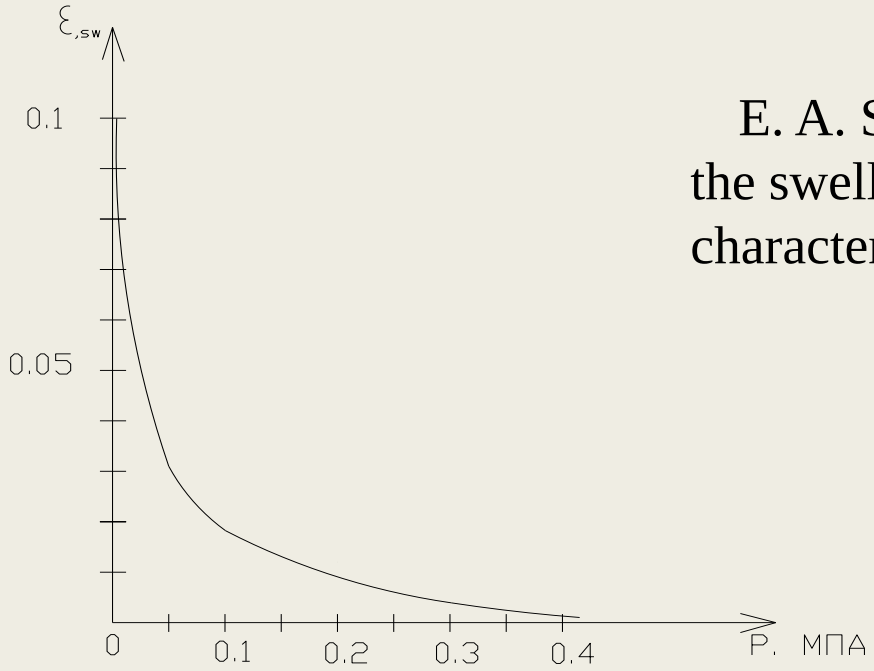
■ Layered clay soils are characterised by a pronounced **anisotropy in the manifestation of swelling**. It develops more intensively in the direction perpendicular to the bedding of the rocks than in the direction parallel to it.

■ Soil swelling, especially when studying them in an array, is affected by their fracture. Cracks are the paths of water penetration into the soil, they increase the contact surface of the soil with water and thereby intensify the swelling process.

■ Clay soil swelling also depends on the presence of **salts in the solutions circulating in the soil**, their concentration and the pH of the solutions. The chemical composition of water largely determines the composition of exchange cations, and, consequently, the magnitude of the swelling of soils. In addition, in the presence of the same salts in natural water, the amount of soil swelling will vary depending on their concentration**..**

■ Swelling also depends on the structural connectivity of soils. All other things being equal, soils of an undisturbed structure usually swell less than soils of a disturbed structure.

■ Pressure dependence of swelling



E. A. Sorochan notes that the dependence of the swelling on pressure has a curvilinear character :

$$\varepsilon_{sw} = m(1 - \frac{P_i}{P_{sw}})\Delta W$$

P_{sw} -where m is a coefficient depending on the physical characteristics of the soil and determined by the formulas or experimentally;

P_i is the pressure in the direction of swelling;

P_{sw} is the swelling pressure;

Δw is the change in humidity.

Swelling soils are characterized by

swelling pressure p_{sw},

swelling moisture w_{sw},

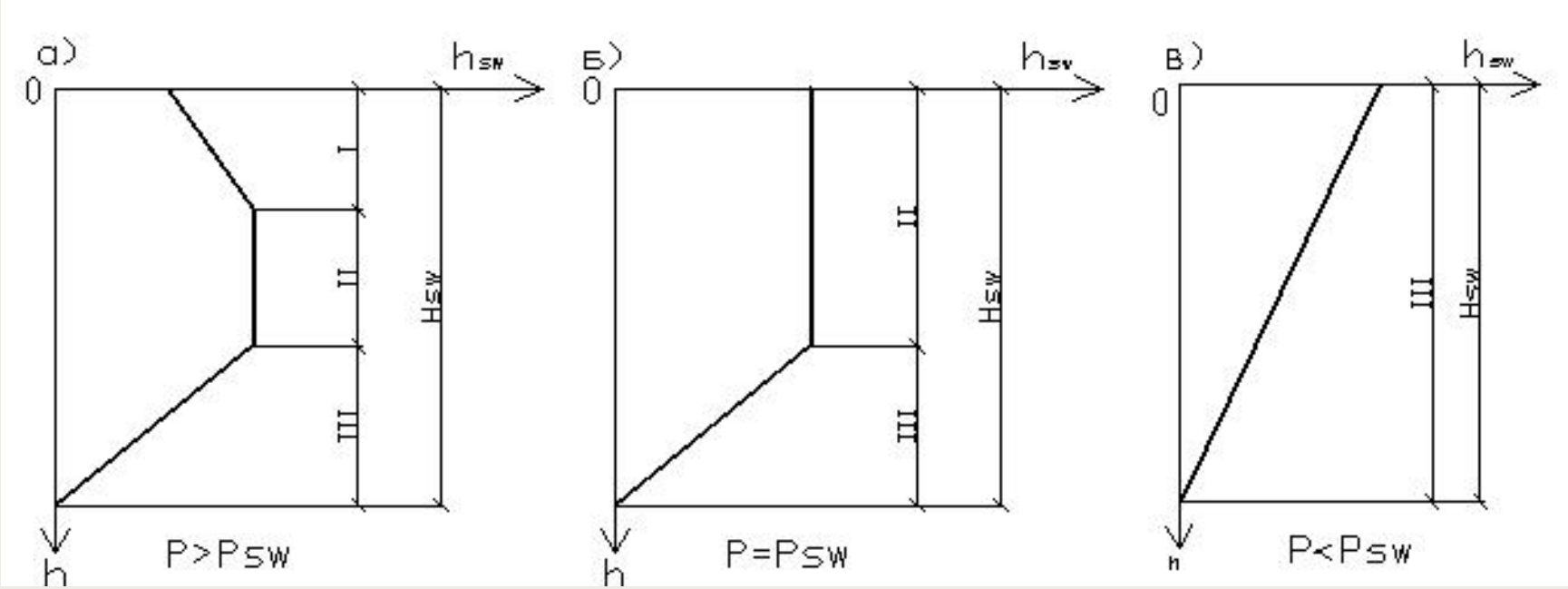
relative swelling at a given pressure ε_{sw}

relative shrinkage upon drying ε_{sh}

Varieties of dusty clay soils by the relative swelling ε_{sw}

Non-swelling	$\varepsilon_{sw} < 0{,}04$
Slightly swelling	$0{,}04 \le \varepsilon_{sw} \le 0{,}08$
Moderately swelling	$0{,}08 \le \varepsilon_{sw} \le 0{,}12$
Highly swelling	$\varepsilon_{sw} > 0{,}12$

DEFORMATION ZONES IN THE MASSIF DURING SWELLING OF THE SOIL



The part of the massif where layer-by-layer movements occur – layer rises caused by soil swelling during soaking are called “swelling zones”

CLAY SHRINKAGE

Shrinkage of the soil is called a decrease in its volume as a result of water removal during drying or during the manifestation of physicochemical processes (syneresis, osmosis).



Shrinkage of swelling soils during drying

DETERMINATION OF SWELLING AND SHRINKAGE OF SOILS

The characteristics of swelling and shrinkage of the soil should be determined by the relative deformation:

- swelling – in conditions that exclude the possibility of lateral expansion when the soil is saturated with water or a chemical solution;
- shrinkage – under conditions of free triaxial deformation during drying of the soil.

Determination of swelling is carried out until complete water saturation, and shrinkage – until complete loss of moisture.

Swelling of the soil – defined indicators:

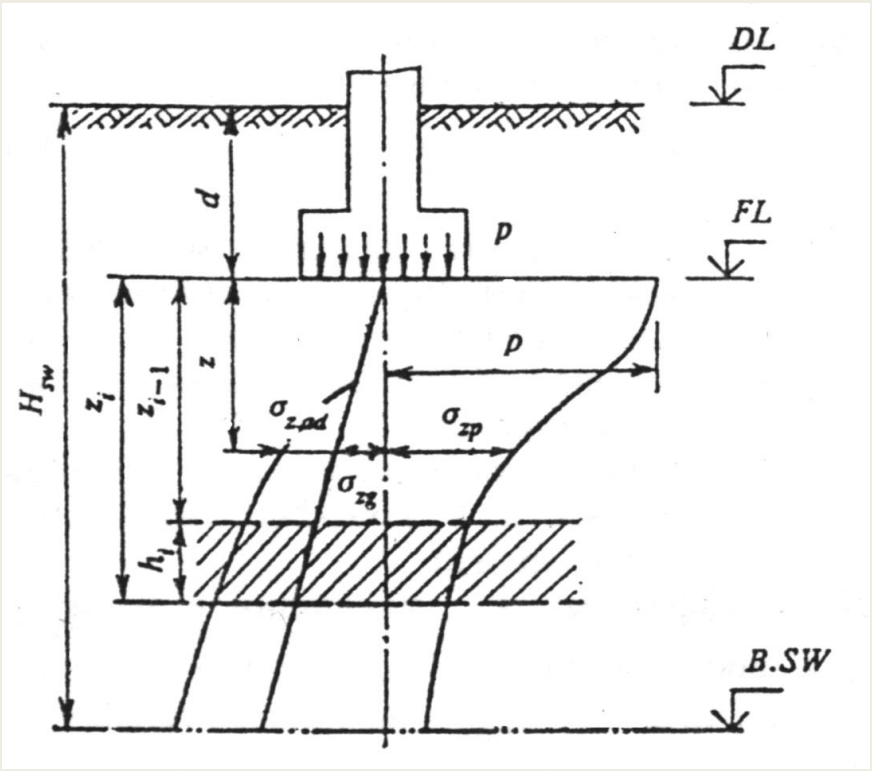
- free swelling,
- swelling under load,
- swelling pressure,
- soil moisture after swelling;

Soil shrinkage – defined indicators:

- shrinkage of the soil in height ε_h, diameter ε_d and volume ε_v,
- soil moisture at the shrinkage limit W_y.
- linear shrinkage limit.



DETERMINING THE DEFORMATION OF THE BASE ON SWELLING SOILS



Rise of the foundation when the soil swells h_{sw} :

$$h_{sw} = \sum_{i=1}^{n} \varepsilon_{sw,i} h_i k_{sw,i}$$

Relative soil swelling ε_{sw} :
during infiltration of moisture

$$\varepsilon_{sw} = (h_{sat} - h_n)/h_n$$

$\varepsilon_{sw,i}$ - relative swelling of the soil of the i-th layer;

h_i - thickness of the ith soil layer;

$k_{sw,i}$ - coefficient, which is determined according to DBN;

n - the number of layers into which the swelling zone of the soil is divided.

Total vertical stress $\sigma_{z,tot}$ at depth z from the foundation sole :

$$\sigma_{z,tot} = \sigma_{zp} + \sigma_{zg} + \sigma_{z,ad}$$

$\sigma_{zp,}$ σ_{zg} - vertical stresses, respectively, from the load of the foundation and from the soil's own weight;

$\sigma_{z,ad}$ - additional vertical pressure caused by the influence of the weight of the non-moistened part of the soil massif outside the soaking area, which is determined by the formula

$$\sigma_{z,ad} = k_g \gamma (d + z)$$

k_g - the coefficient taken according to the table

$(d + z) / B_w$	The coefficient kg in the ratio of length to width of the soaked area Lw / Bw,				
	1	2	3	4	5
0,5	0	0	0	0	0
1	0,58	0,50	0,43	0,36	0,29
2	0,81	0,70	0,61	0,50	0,40
3	0,94	0,82	0,71	0,59	0,47
4	1,02	0,89	0,77	0,64	0,53
5	1,07	0,94	0,82	0,69	0,77

TAKING INTO ACCOUNT THE INFLUENCE OF THE SWLING ON THE STRESS-DEFORMED STATE OF THE "BASE - FOUNDATION - BUILDING" SYSTEM IN CONDITIONS OF PLANE DEFORMATION

For a flat problem, 9 variants of the combination of voltages can be distinguished.

1. $\sigma_z > 0$ i $\sigma_x > 0$

$$E_{np} = \frac{E}{1-\mu^2} \qquad \mu_{np} = \frac{\mu}{1-\mu}$$

E – soil deformation module; μ – Poisson's ratio.

2. $\sigma_z <- P_{sw}$ i $- P_{sw} < \sigma_x < 0$.

let $$\frac{P_{sw}}{P_{sw} + Ekm\Delta w} = \alpha$$, then

$$E_x^{np} = \frac{1}{\frac{1-\mu^2\alpha}{E} + \frac{km\Delta w}{P_{sw}}} \qquad \mu_{xz}^{np} = \frac{\mu + \alpha\mu^2}{1-\mu^2\alpha + E\frac{km\Delta w}{P_{sw}}}$$

$$E_z^{np} = \frac{E}{1-\mu^2\alpha} \qquad \mu_{zx}^{np} = \frac{\mu + \mu^2\alpha}{1-\mu^2\alpha}$$

P_{sw} – swelling pressure;
m is a coefficient determined experimentally;
Δw - change in soil moisture.

3. σ_x <- P_{sw} i - P_{sw} < σ_z < 0.

$$E_z^{np} = \frac{1}{\frac{1-\mu^2\alpha}{E} + \frac{km\Delta w}{P_{sw}}} \qquad \mu_{zx}^{np} = \frac{\mu + \alpha\mu^2}{1-\mu^2\alpha + E\frac{km\Delta w}{P_{sw}}}$$

$$E_x^{np} = \frac{E}{1-\mu^2\alpha} \qquad \mu_{xz}^{np} = \frac{\mu + \mu^2\alpha}{1-\mu^2\alpha}$$

4. - P_{sw} < σ_z < 0, - P_{sw} <σ_x < 0.

$$E_z^{np} = \frac{1}{\frac{1-\mu^2\alpha}{E} + \frac{km\Delta w}{P_{sw}}} \qquad \mu_{zx}^{np} = \frac{\mu + \alpha\mu^2}{1-\mu^2\alpha + E\frac{km\Delta w}{P_{sw}}}$$

$$E_x^{np} = \frac{1}{\frac{1-\mu^2\alpha}{E} + \frac{km\Delta w}{P_{sw}}} \qquad \mu_{xz}^{np} = \frac{\mu + \alpha\mu^2}{1-\mu^2\alpha + E\frac{km\Delta w}{P_{sw}}}$$

5. σ_x >0, - P_{sw} < σ_z < 0.

$$E_z^{np} = \frac{1}{\frac{1-\mu^2\alpha}{E} + \frac{km\Delta w}{P_{sw}}} \qquad \mu_{zx}^{np} = \frac{\mu - \mu^2\alpha}{E\left(\frac{1-\mu^2\alpha}{E} + \frac{km\Delta w}{P_{sw}}\right)}$$

$$E_x^{np} = \frac{E}{1-\mu^2\alpha} \qquad \mu_{xz}^{np} = \frac{\mu + \mu^2\alpha}{1-\mu^2\alpha}$$

6. $-P_{sw} < \sigma_x < 0,\ \sigma_z > 0.$

$$E_x^{np} = \frac{1}{\frac{1-\mu^2\alpha}{E} + \frac{km\Delta w}{P_{sw}}} \qquad \mu_{xz}^{np} = \frac{\mu - \mu^2\alpha}{E\left(\frac{1-\mu^2\alpha}{E} + \frac{km\Delta w}{P_{sw}}\right)}$$

$$E_z^{np} = \frac{E}{1-\mu^2\alpha} \qquad \mu_{zx}^{np} = \frac{\mu + \mu^2\alpha}{1-\mu^2\alpha}$$

7. $\sigma_x < -P_{sw},\ \sigma_z > 0.$

$$E_x^{np} = \frac{E}{1-\mu^2} \qquad \mu_{xz} = \frac{\mu - \mu^2}{1-\mu^2}$$

$$E_z^{np} = \frac{E}{1-\mu^2} \qquad \mu_{zx} = \frac{\mu + \mu^2}{1-\mu^2}$$

8. $\sigma_x > 0,\ \sigma_z <- P_{sw}$.

$$E_x^{np} = \frac{E}{1-\mu^2} \qquad \mu_{xz} = \frac{\mu+\mu^2}{1-\mu^2}$$

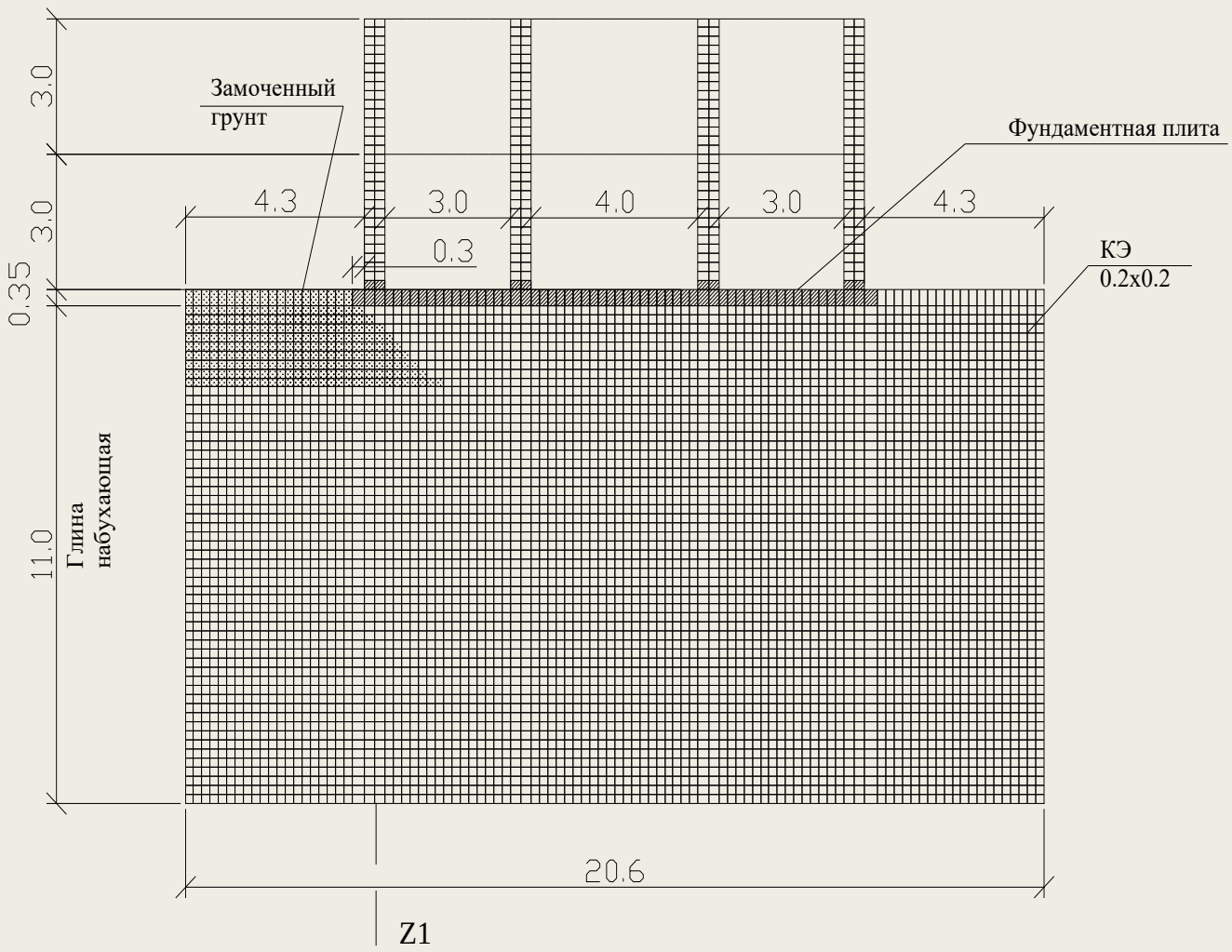
$$E_z^{np} = \frac{E}{1-\mu^2} \qquad \mu_{zx} = \frac{\mu-\mu^2}{1-\mu^2}$$

9. $\sigma_x <- P_{sw}\ ,\ \sigma_z <- P_{sw}$.

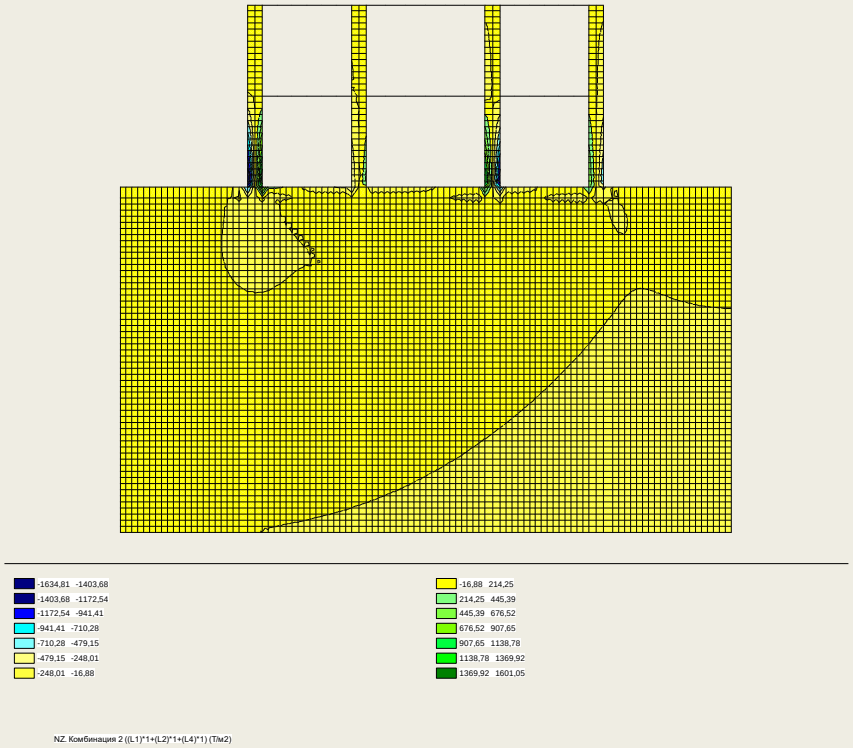
$$E_x^{np} = \frac{E}{1-\mu^2} \qquad \mu_{xz} = \frac{\mu-\mu^2}{1-\mu^2}$$

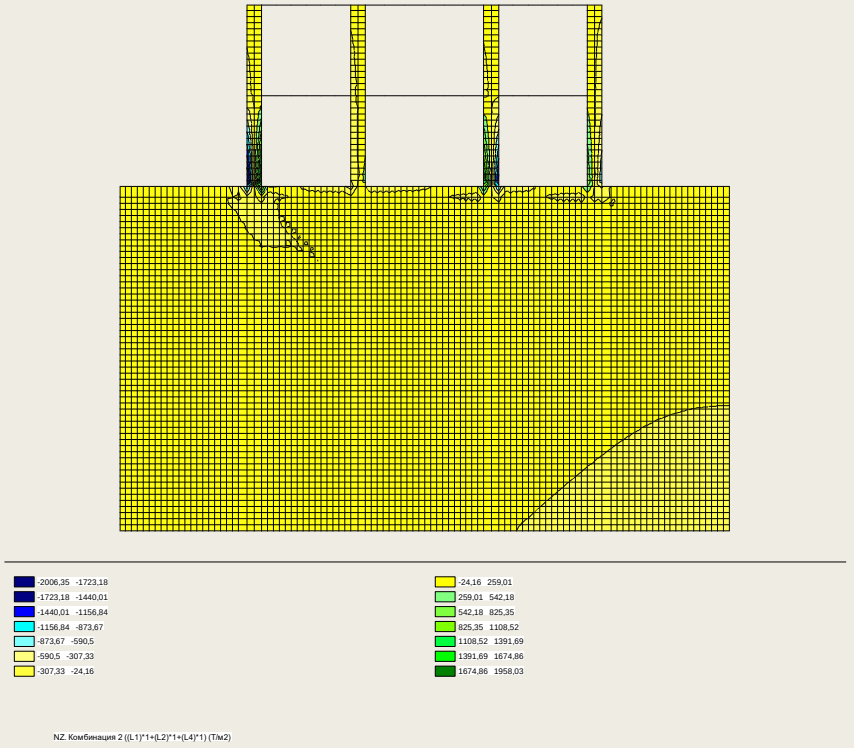
$$E_z^{np} = \frac{E}{1-\mu^2} \qquad \mu_{zx} = \frac{\mu-\mu^2}{1-\mu^2}$$

DESIGN DIAGRAM OF A TWO-STORY BRICK BUILDING WITH A SLAB FOUNDATION ON A SINGLE-LAYER BASE



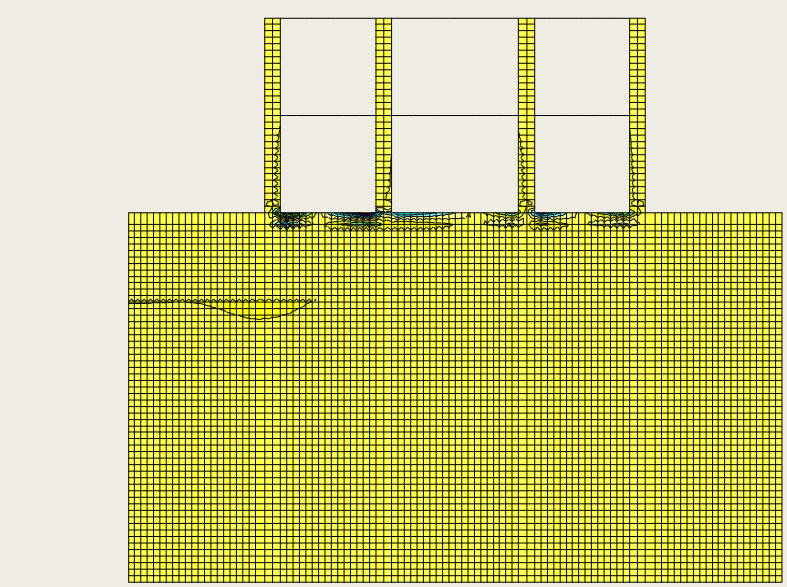
Epures of tension Nz

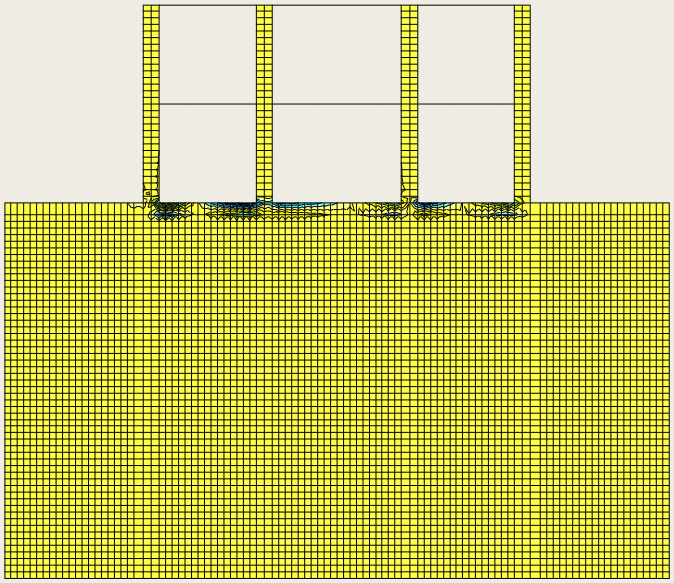




a) without taking into account swelling and shrinkage b) taking into account swelling and shrinkage

Epures of tension Nx





-1861,7 -1592,89
-1592,89 -1324,08
-1324,08 -1055,26
-1055,26 -786,45
-786,45 -517,64
-517,64 -248,83
-248,83 19,99

19,99 288,8
288,8 557,61
557,61 826,42
826,42 1095,24
1095,24 1364,05
1364,05 1632,86
1632,86 1901,68

NX. Комбинация 2 ((L1)*1+(L2)*1+(L4)*1) (T/м2)

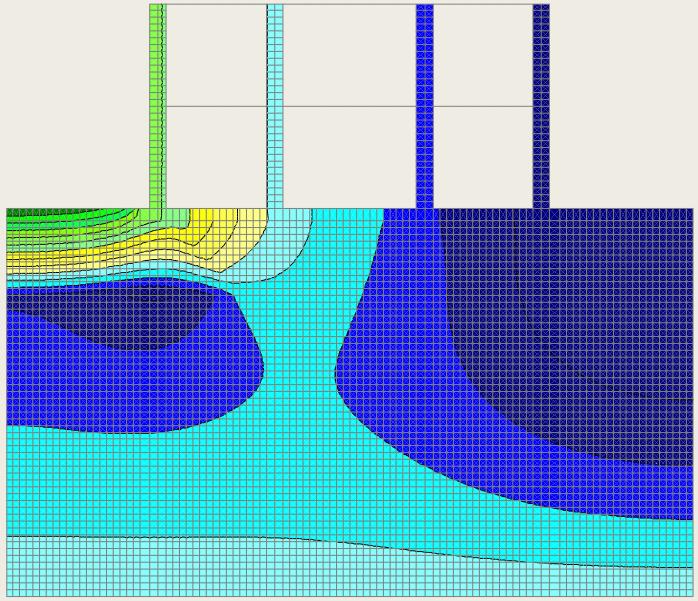
-1808,96 -1536,77
-1536,77 -1264,58
-1264,58 -992,38
-992,38 -720,19
-720,19 -448,0
-448,0 -175,81
-175,81 96,39

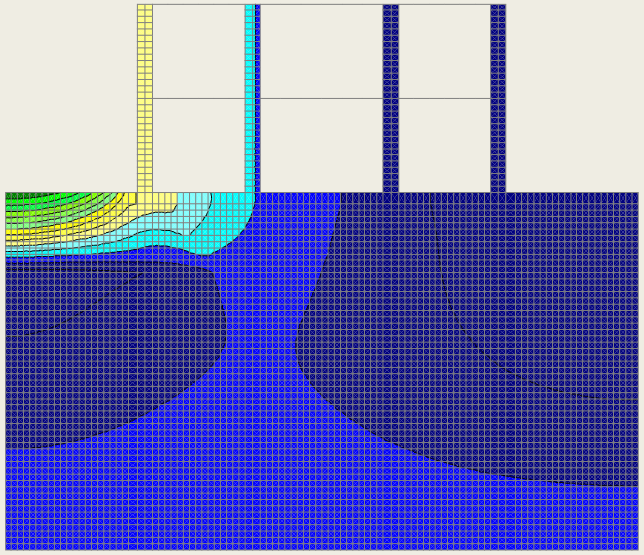
96,39 368,58
368,58 640,77
640,77 912,97
912,97 1185,16
1185,16 1457,35
1457,35 1729,55
1729,55 2001,74

NX. Комбинация 2 ((L1)*1+(L2)*1+(L4)*1) (T/м2)

a) without taking into account swelling and shrinkage b) taking into account swelling and shrinkage

Movement along the axis of z





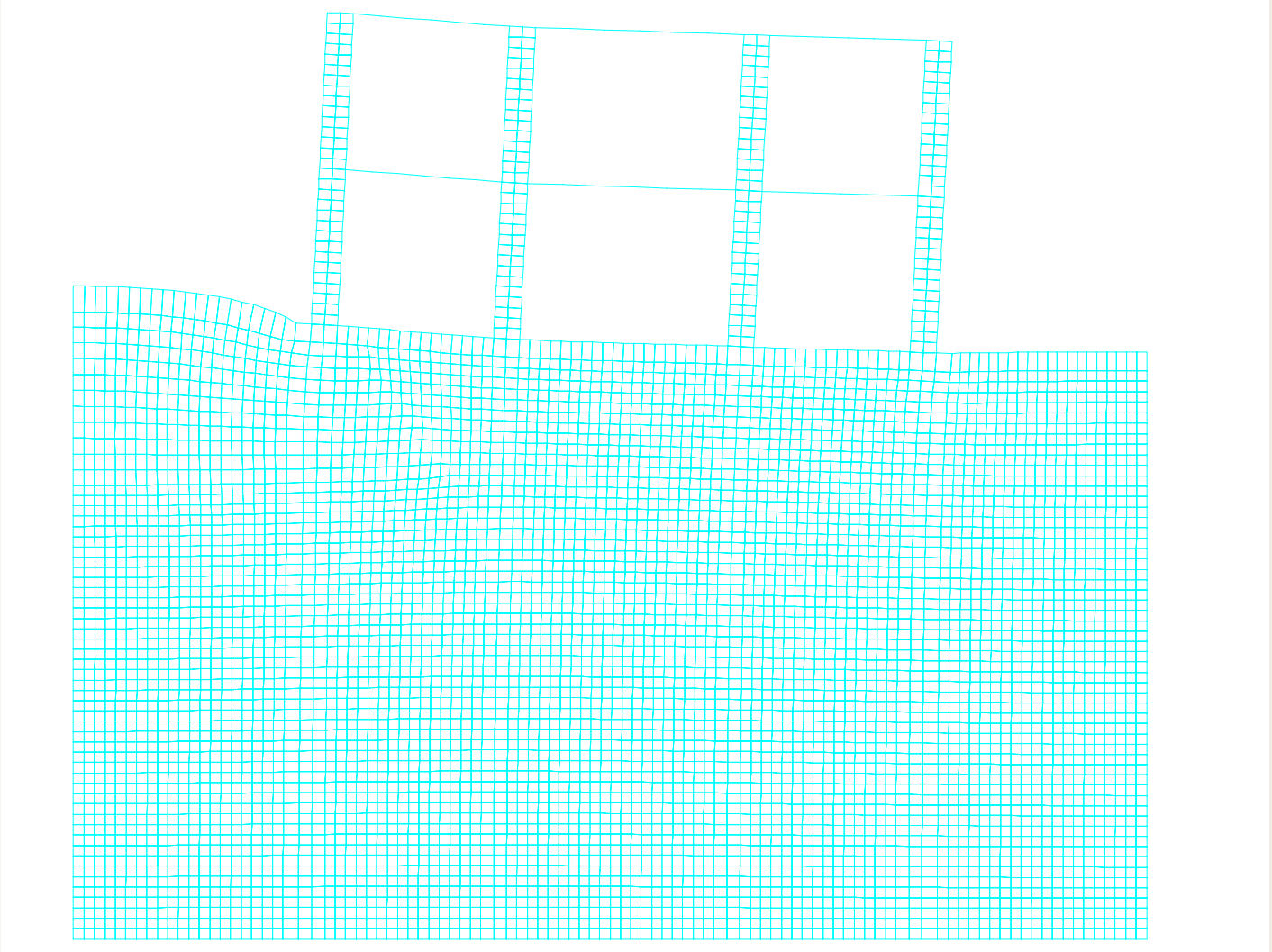
-30,93 -24,27
-24,27 -17,61
-17,61 -10,96
-10,96 -4,3
-4,3 2,36
2,36 9,01
9,01 15,67
15,67 22,33
22,33 28,99
28,99 35,64
35,64 42,3
42,3 48,96
48,96 55,62
55,62 62,27

Перемещения Z (мм). Комбинация 2 ((L1)*1+(L2)*1+(L4)*1)

-31,55 -20,65
-20,65 -9,74
-9,74 1,16
1,16 12,07
12,07 22,98
22,98 33,88
33,88 44,79
44,79 55,7
55,7 66,6
66,6 77,51
77,51 88,41
88,41 99,32
99,32 110,23
110,23 121,13

Перемещения Z (мм). Комбинация 2 ((L1)*1+(L2)*1+(L4)*1)

a) without taking into account swelling and shrinkage b) taking into account swelling and shrinkage



Swelling deformations





So, in 2012 in Karaganda, in a five-story building of the Besoba residential complex (Fig. 4.6.10), erected on swelling soils, a crack from 10 to 15 cm wide went from the foundation to the roof, the building first tilted, and then collapsed. On the eve of the emergency, 138 people were evacuated.





bulging of the basement floor as a result of the swelling of the clay soils of the base

cracks in the foundation blocks as a result of the swelling of the clay soils of the base

A two-story building of a preschool educational institution with a semi-basement in the Balakliya district of the Kharkiv region

CONSTRUCTION ON SWELLING SOILS

Water protection measures:

• provide dry area around buildings with a width of 2–3 m;

• apply waterproof screens under the entire structure of polymer materials, or of asphalt;

• enclose water and sewer pipes in reinforced concrete trays, etc.

Improving the properties of the bases.

For small thicknesses of swelling soils, preliminary soaking is used and then construction is carried out as on water-saturated non-swelling soils. However, the implementation of this measure is complicated by the slow progress of this process.

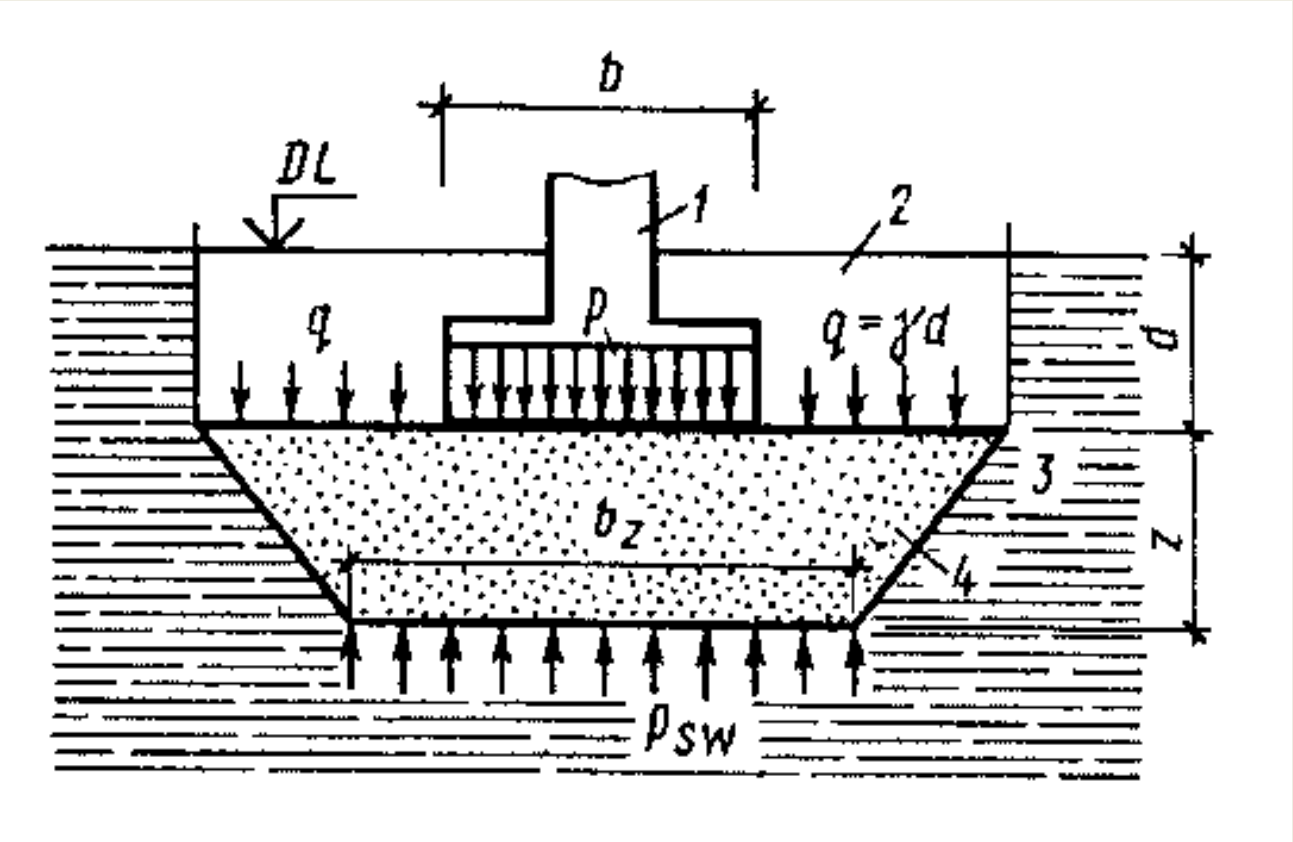
It is possible to eliminate the influence of adverse effects from swelling or shrinkage by completely or partially replacing the layer of swelling soil with a non-swelling soil.

Compensating cushions are used to reduce the unevenness of the lifting of foundations.

The principle of operation of the *compensating pillow* is as follows: since the width of the sand cushion exceeds the width of the foundation, when the soil swells, sand bulges out between the foundation and the wall of the trench. Therefore, when raising the bottom of such a trench, the sand rises around the foundation, and the foundation itself remains almost motionless.

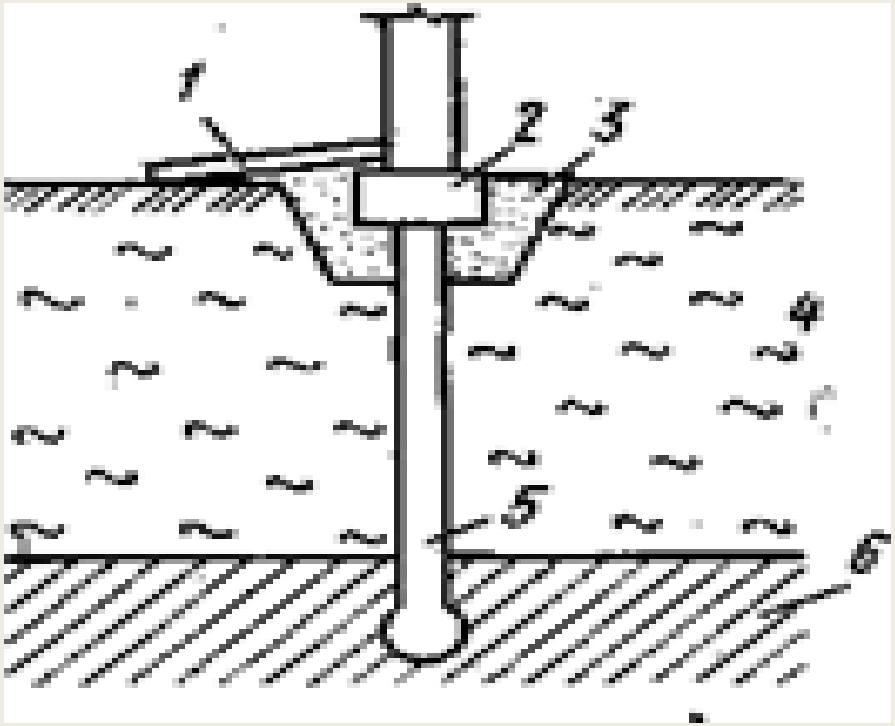
Constructive measures

Constructive measures include increasing the rigidity of the building by breaking them into separate compartments, cutting large-panel buildings with sedimentary seams into compartments less than 30 m long, reinforcing belts arranged at several levels in height



Scheme of the forces acting on the compensating cushion: 1 - foundation; 2 - backfill; 3 - swelling soil; 4 - sand compensating cushion

CUTTING SWELLING SOILS



Foundation of bored piles with a widened heel in the conditions of swelling and shrinking soils: 1 – waterproof blind area; 2 – grillage; 3 – sand; 4 – swelling or shrinking soil; 5 – pile with broadening; 6 – non swelling soil