UDC 624.131

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OPTIMIZATION OF SLABS REINFORCEMENT DEPENDING ON THE DEGREE OF BASE COMPLIANCE

In the work it was made analysis of stiffness influence of upper basis construction and compliance of basics on stress−strained state of monolithic slabs and capabilities to simplify the design scheme of slabs. Two building options were considered: the one with different design: frame and frameless, the second with homogeneous and heterogeneous bases. It is established that in frame buildings only incomplete modeling of slabs shows adequate quality and does not make significant changes in constructive solution in comparison with the full simulation. For frameless buildings ignoring rigidity of upper basis and constructions compliance structures and foundations not only leads to some excess reinforcement plates, but also to the quality discrepancy reinforcement, particularly in patchy basis.

Keywords: *system building−foundation−base, collaborate, building rigidity, foundation yielding, subsidence, tensely deformed state (TDS).*

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ОПТИМІЗАЦІЯ АРМУВАННЯ ПЛИТ ПЕРЕКРИТТЯ В ЗАЛЕЖНОСТІ ВІД СТУПЕНЯ ПІДДАТЛИВОСТІ ОСНОВИ

Проведено дослідження впливу жорсткості надфундаментної конструкції та піддатливості основи на напружено−деформований стан монолітних плит перекриття і можливості спрощення розрахункової схеми плити. Були розглянуті два варіанти будівель з різним конструктивним рішенням: повнокаркасна і безкаркасна, а також два варіанти основи: однорідна і неоднорідна. Встановлено, що для каркасних будинків неповне моделювання тільки плити перекриття дає адекватну якісну картину та не вносить суттєвих змін до конструктивного рішення у порівнянні з повним моделюванням. Для безкаркасних будинків ігнорування жорсткості надфундаментних конструкцій і піддатливості основи може призвести не тільки до деякого переармування плити, але і до якісної невідповідності армування, зокрема при неоднорідній основі.

Ключові слова: *система будівля−фундамент−основа, сумісна робота, жорсткість будівлі, піддатливість основи, осідання, напружено−деформований стан (НДС).*

Introduction. Elements stresses in buildings and bases deformations are recommended to be determined by calculation of joint foundations, bases and overlying structures work, considering basics depth and plan heterogeneity [1, 2]. These calculation results are achieved in more accurate simulation of the stress−strain state (SSS) of ground base and overlying structures. As building stiffness influence on SSS and the base settling, as the base compliance and nonlinear properties affect the stresses redistribution in foundations and overlying structures. Therefore, relationship among calculation model of building and soil base is important.

In works [3−6] it is noted that the need for joint calculations of the building with the foundation is especially important for the current level of building science development. By the introduction of modern calculation methods and the newest materials, it could be possible to design building structures with minimal strength reserves. In such conditions, slight increase in stresses due to the joint operation of the buildings and bases can lead to the cracks appearance and reduction in the overall reliability of the structures.

But such calculation is associated with considerable time consuming for compiling computational model, and also requires significant computer memory resource. Sometimes, in order to simplify the calculation of monolithic slabs, only the slab itself is modeled with the elements on which it relies, without considering the work of other overlying structures and the compliance of the base.

Research results. Joint calculations are performed using computer technology, usually the finite element method. In many cases, buildings are complex in plan configuration and stiffness distribution, so usually it is quite difficult to assess the impact of various factors (stiffness of different above−ground structure elements and foundations) for calculation results.

For the analysis two primary design scheme of houses are selected:
− frameless with bearing walls of brick;
− frame with monolithic bearing structures.

For both schemes complex joint calculation of above−ground buildings, foundations and soil base are executed in different variants of soil layers:
− location of soil layers close to horizontal;
− there is a pinch of soil layers with different modules deformation.

As basis for the simulation of design schemes basic variants, the design documentation for the frameless residential section of size 25×15 m in the axes was selected. Total height of 9−storey section with basement and technical floors is 30 m. The main walls are from brick, the walls of the ground floor are from concrete block, foundations are monolithic tape up to 3.6 m widths.

In simulation of framework scheme bearing walls above the 0.000 level have been replaced by monolithic columns. Basement and foundations were left unchanged.

As homogeneous base with horizontal placement of the layers were made of random geological conditions of the construction site with the average characteristics of soils. Characteristics of soil area are presented in Table 1. For the simulation of heterogeneous soil base wedging out, soil layer with low deformation modulus of E = 8 MPa was used.

Calculation of 3D computer models is performed using the software package «Lira−CAD» which is a computer system for structural analysis and design. The program was developed by the Scientific Research Institute of Automated Systems in Construction (NIASS), Kyiv, Ukraine. The complex allows to perform spatial calculations of building systems considering the heterogeneity of the base in plan, its depth, influence of neighboring buildings and structures.

For each variant, calculations of monolithic slab are performed both for 3D computer model and simplified slab plate model, taking into account support conditions with the determination of the stress−strain state and the reinforcement design.

Table 1 – Physical and mechanical characteristics of the building site ground

| Soils name | Layer power , m | Specific gravity γ, kN/m³ | Humidity | | | Specific gravity of ground particles γ_s, kN/m³ | Porosity ratio e | Degree of humidity S_r | Plasticity number I_P | The flow rate I_L | Specific adhesion c, kPa | Ext. friction angle φ, degree | Modulus of deformation E, MPa |
			w	w_L	w_p								
Vegetative layer of soil	0,9	16,4	0,13	–	–	–	–	–	–	–	–	–	–
Sandy loam silty	4,8	18	0,17	0,2	0,15	26,8	0,70	0,62	0,05	0,4	11	21	25,8
Soft clay loam	2,7	17,5	0,17	0,21	0,12	26,6	0,78	0,58	0,09	0,55	5	18	22,6
Medium size sand	5,2	20	0,18	–	–	26,5	0,56	0,88	–	–	2	38	39

General view of computer models of frameless and frame construction in the program «Lira−CAD» is shown in Fig. 1, 2.

For the modeling of the soil massif, the connection among the «Lira−CAD» and the sub−program «Grunt» («Soil») was used. To do this, before the simulation began, soil characteristics were introduced into the «Grunt» program and «boreholes» were created setting the layers thickness.

Fig. 3, 4 shows the models of ground base with horizontal placement of seams and with the wedging of seams with different deformation modules.
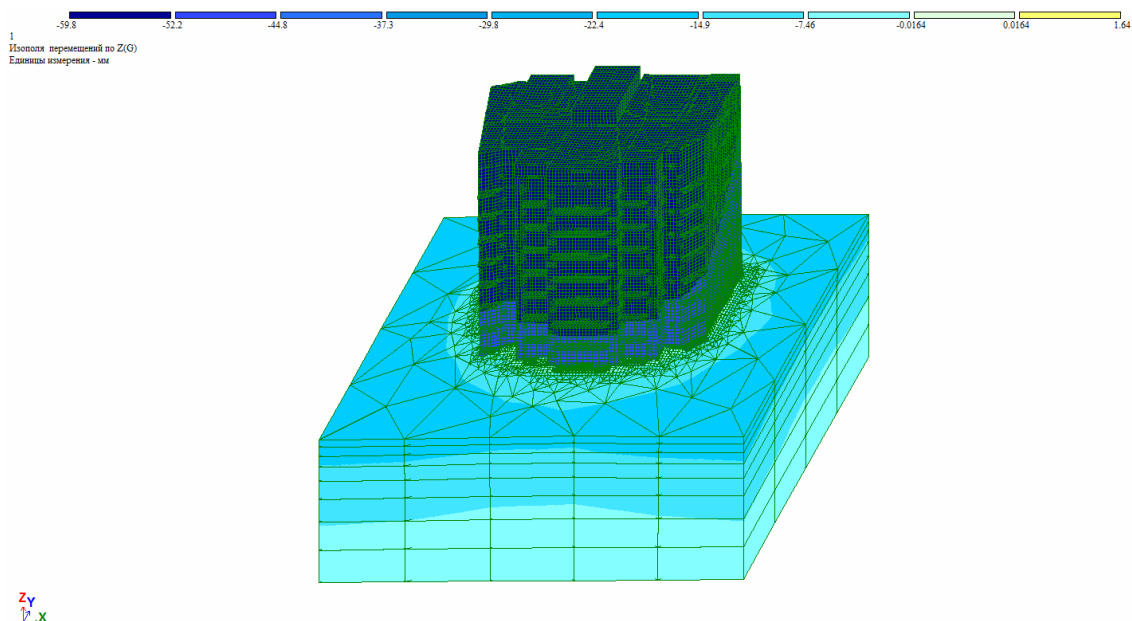

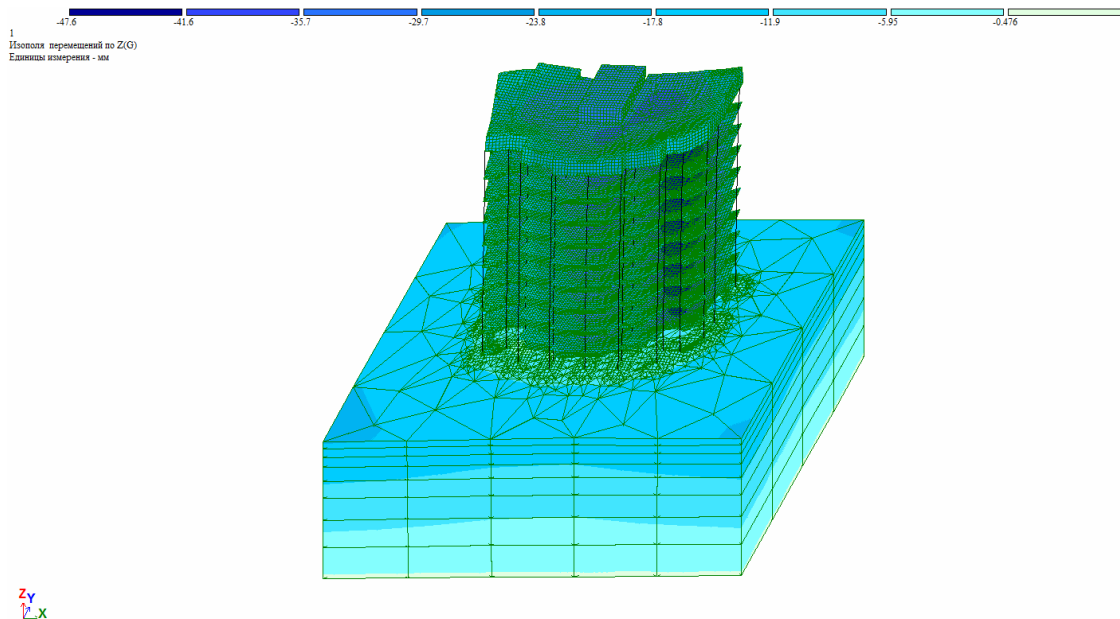**Figure 1 – General view of the computer model of a frameless building**

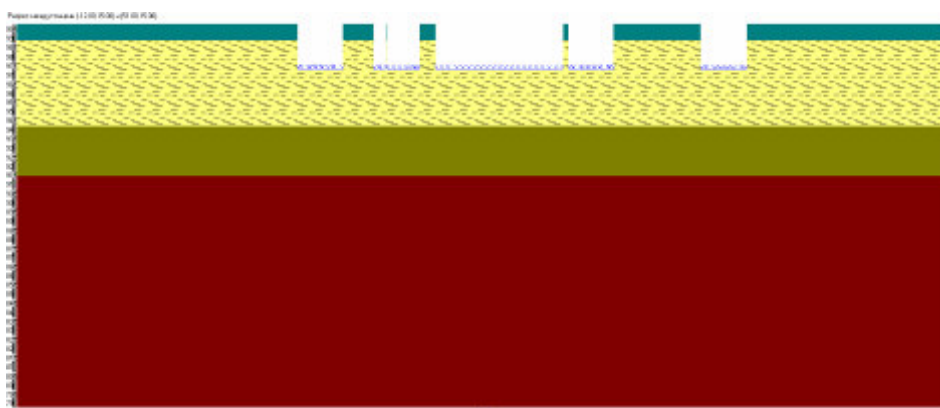**Figure 2 – General view of the computer model of building with full frame**

Figure 3 – Model of soil base with horizontal arrangement of seams
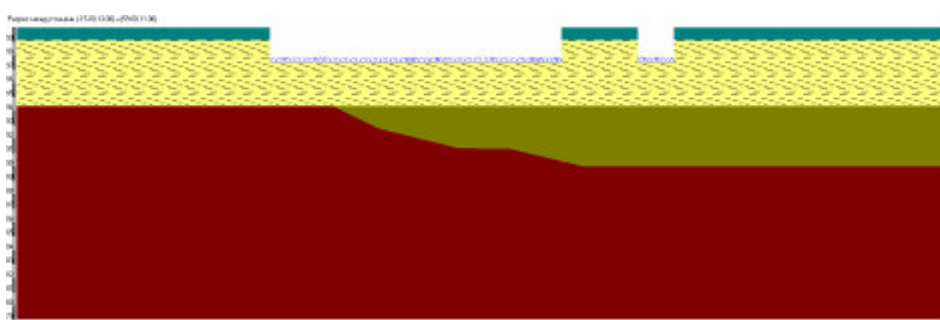

Figure 4 – Model of ground base with wedging out layers

Analysis of the calculations results showed:

– for a frameless building, the rigidity of the skeleton and the compliance of the base, substantial leveling of the displacements in the slab are cosidered;

– for a frame building such influence is very insignificant;

– taking into account the rigidity of overlying structures and the compliance of the base leads to a lower concentration of forces in the slabs;

– taking into account the heterogeneity of the bedding of the base has little effect on the required amount of reinforcement, but leads to some qualitative inconsistency of the reinforcement.

– in the case of homogeneous basis, the calculation of overlapping slabs can be performed without consideration the rigidity of the overlying structures and the compliance of the base with the assurance of reliable operation.

To analyze the economic aspects of the results joint foundations, bases and overlying structures work, considering basic depth and plan heterogeneity and simplified modeling, the working reinforcement of the slabs in all the variants considered was compared.

Calculation of the reinforcement is carried out in the program «Lira–Arm». The result of the program is colour diagrams of reinforcement with scale where such features are indicated: from above – the pitch of the rods of a certain diameter, from below – the area in cm^2, which should be located on 1 m of the length of the plate. Diagrams are obtained for two directions of reinforcement of the lower and upper zone of the plate.

For example, in Fig. 5–7 the coloured diagrams of the reinforcement of frameless building slab lower zone are shown. It can be seen from the figures that in the calculation of a plate without consideration the influence of the skeleton rigidity and the compliance of the base, excessive reinforcement takes place.

It has to be considered that heterogeneity of the base bedding has little effect on the required amount of reinforcement, but leads to some qualitative inconsistency of the reinforcement.

The reinforcement is accepted by mesh in upper and lower zone, with additional mesh in the stress concentration zones, as well as with additional mounting frames and transverse reinforcement.

After processing the results of calculations in the «Lira–Arm» program for the ultimate limit state, the slab reinforcement for all simulation schemes is presented in Table 2.
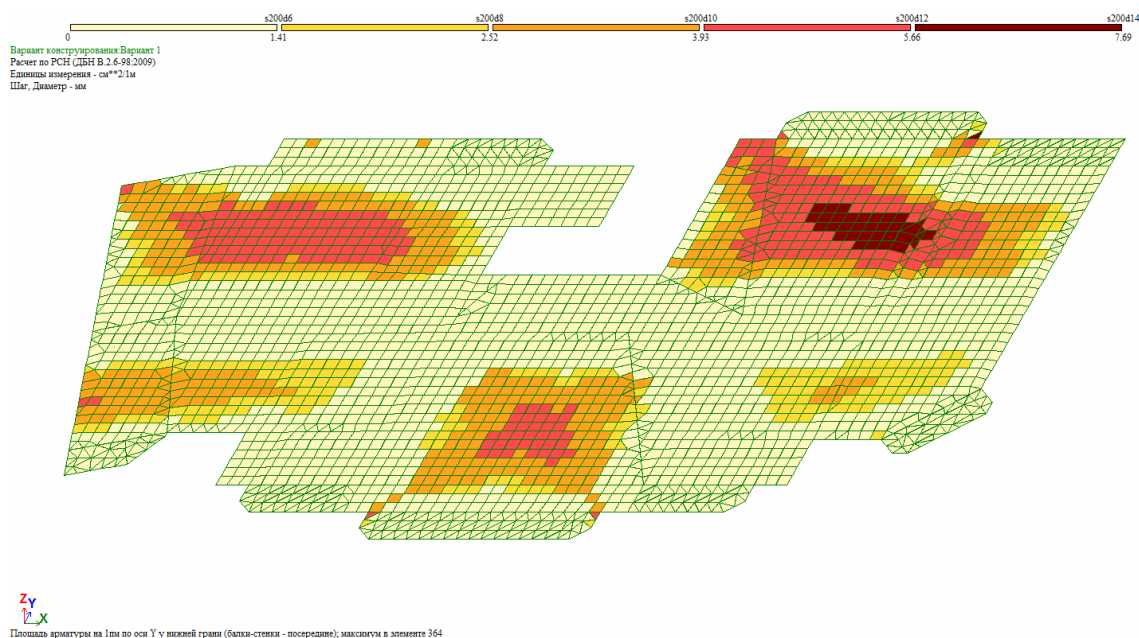

Figure 5 – The diagram of the slabs lower zone reinforcement for a frameless building, determined without consideration base compliance and frame rigidity
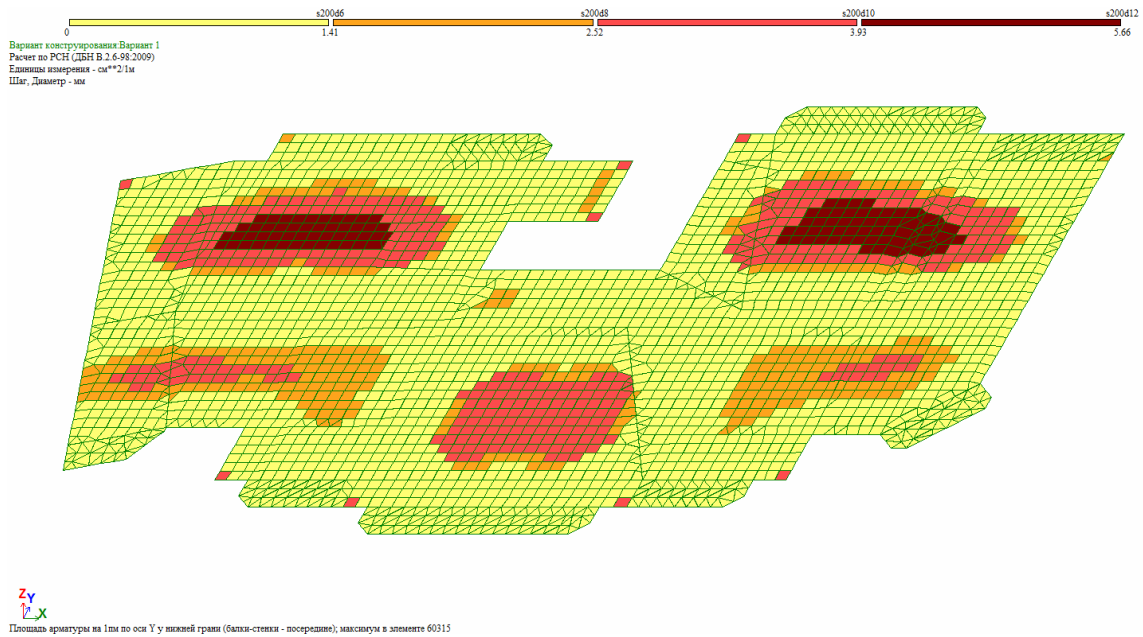
Figure 6 – The diagram of the slabs lower zone reinforcement for the frameless building, defined considering the homogeneous base compliance and the frame rigidity
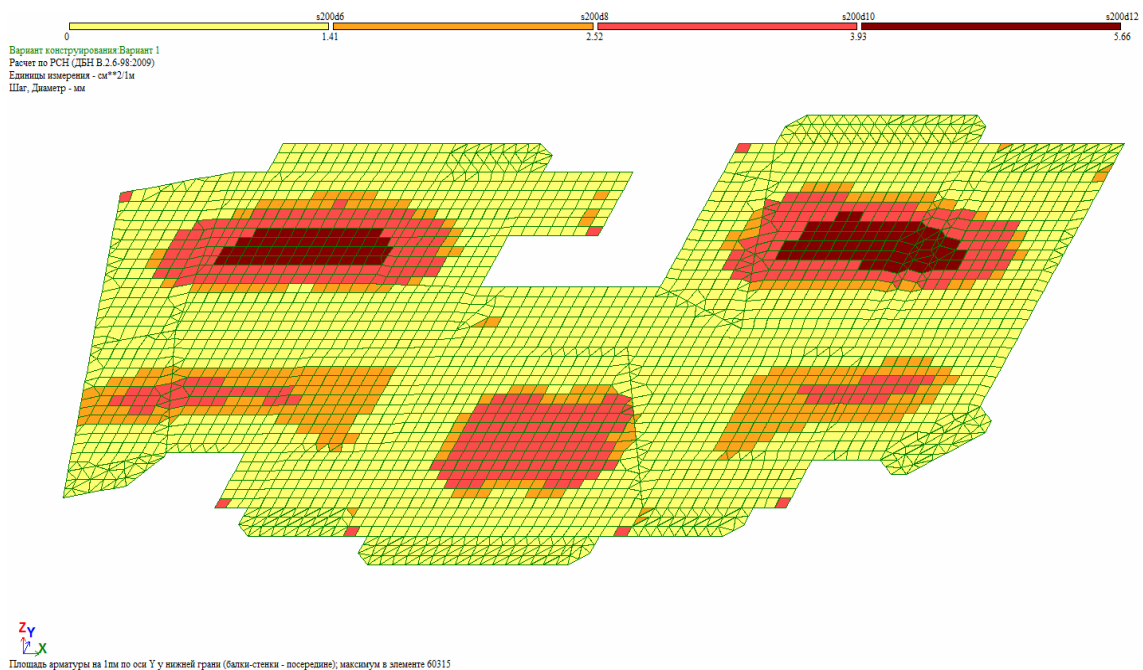

Figure 7 – The diagram of slabs lower zone reinforcement for a frameless building, defined considering the heterogeneous base compliance and the frame stiffness

The outlays based on the obtained results were compiled in the program «AVK 5.3» for each variant, graphs of the amount of reinforcement, cost and labor intensity depending on the modeling method were plotted (Fig. 8 – 9).

As can be seen for the frameless building, for the case of full simulation all the indicators are much better than only from simplified slab modeling.

For a frame building with full simulation, all the indicators are also better than only from simplified slab modeling , but the difference is smaller than in the previous case.

Table 2 – Results of slab versions reinforcement

| Direction of rods location	Main reinforcement		Additional reinforcement		Total weight, t
	Along the lower edge	Along the upper edge	Along the lower edge	Along the upper edge	
A building with a full frame, simulation without considering the base compliance and frame rigidity					
Along the Y axis	Ø10 A400C	Ø14 A400C	Ø10 A400C Ø16 A400C	Ø12 A400C Ø32 A400C	13.28
Along the X axis	Ø10 A400C	Ø14 A400C	Ø8 A400C Ø18 A400C Ø22 A400C	Ø16 A400C Ø32 A400C	
The building with a full frame, a simulation considering the homogeneous base compliance and the frame rigidity					
Along the Y axis	Ø12 A400C	Ø14 A400C	Ø12 A400C Ø18 A400C	Ø16 A400C Ø32 A400C	12.93
Along the X axis	Ø12 A400C	Ø14 A400C	Ø10 A400C Ø18 A400C	Ø12 A400C Ø22 A400C Ø32 A400C	
Frameless building, a simulation without considering the base compliance and frame rigidity					
Along the Y axis	Ø8 A400C	Ø10 A400C	Ø10 A400C Ø12 A400C	Ø14 A400C Ø20 A400C	7.09
Along the X axis	Ø8 A400C	Ø10 A400C	Ø10 A400C	Ø10 A400C Ø18 A400C	
Frameless building, a a simulation considering the base compliance and frame rigidity					
Along the Y axis	Ø8 A400C	Ø8 A400C	Ø10 A400C	Ø10 A400C Ø14 A400C	6.20
Along the X axis	Ø8 A400C	Ø8 A400C	Ø10 A400C	Ø10 A400C Ø12 A400C	
Frameless building, a simulation considering the heterogeneous base compliance and the frame					
Along the Y axis	Ø8 A400C	Ø8 A400C	Ø10A400C	Ø10 A400C Ø14 A400C	5.62
Along the X axis	Ø8 A400C	Ø8 A400C	Ø6 A400C	Ø10 A400C Ø12 A400C	
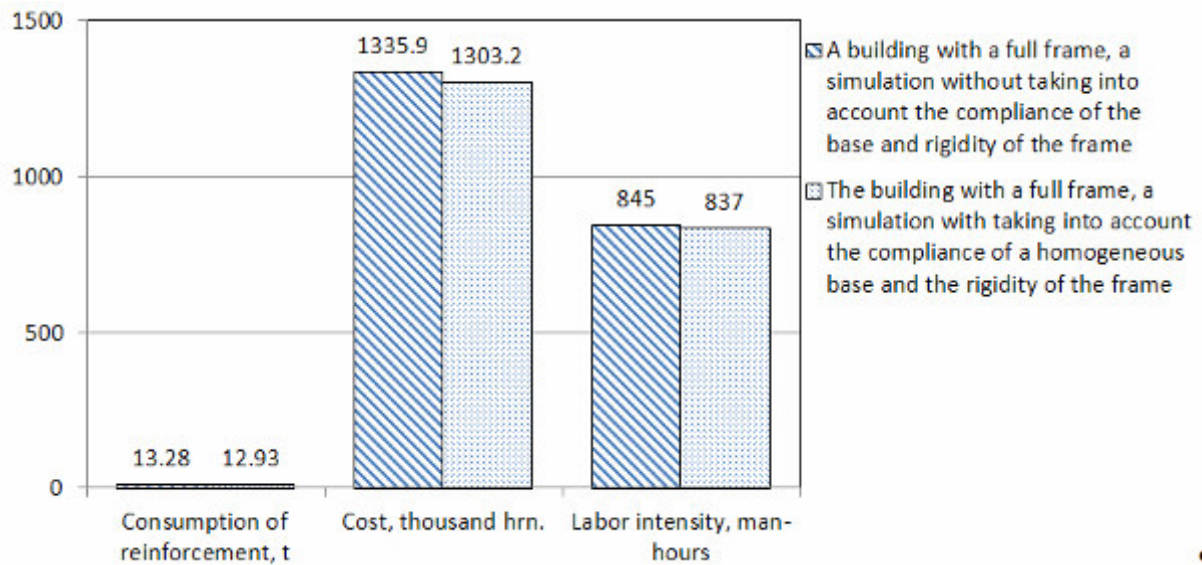
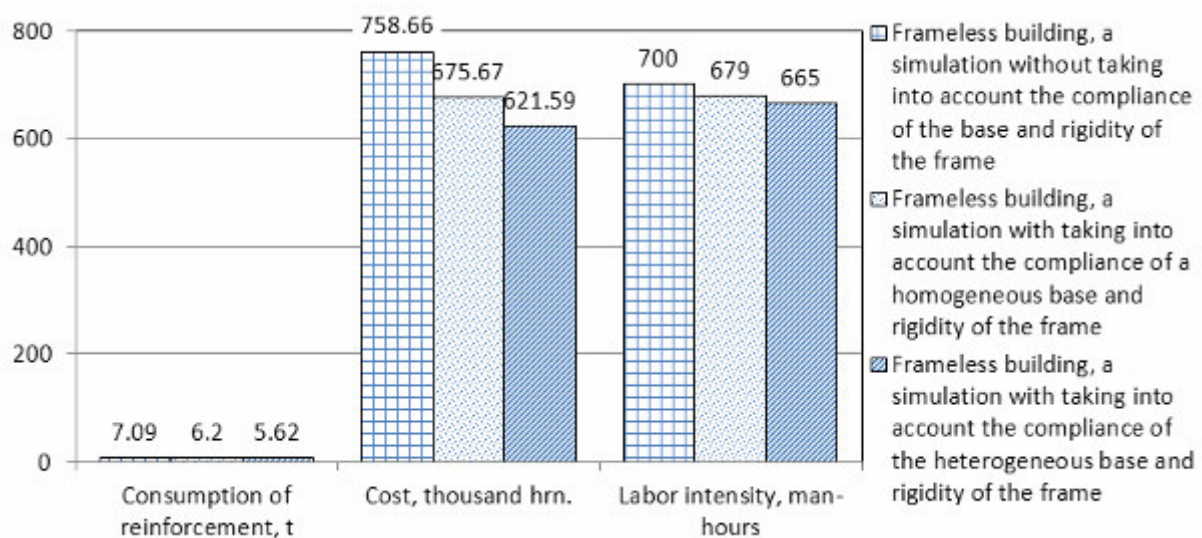**Figure 8 – A building with a full frame**

Figure 9 – Frameless building

Conclusions. In overlying structures it has to be considered rigity and the compliance of the base affects on the forces distribution and slabs reinforcement nature.

For frameless buildings, ignoring the rigidity of overlying structures and the base compliance leads not only to a little excrescent in slab reinforcement, but also to qualitative inconsistency of reinforcement, in particular, on heterogeneous basis.

For framed buildings, the simplified slab modeling does not make significant changes in the design solution with full simulation comparison.

In the case of homogeneous basis, the calculation of overlapping slabs can be performed without consideration the rigidity of overlying structures and the compliance of the base with the assurance of reliable operation.

The application of spatial building modeling on compliant basis compared with the simplified slab simulation allows obtaining reinforcement savings in the slab up to 2.5% for frame and up to 14% for frameless buildings.

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