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Abstract

Computer modeling aims at transforming the design process of buildings worldwide from the use of 2D to 3D, 4D and 5D design and coordination technologies. To investigate realistic values of bending moment and normal forces, a full three-dimension (3D) analysis is needed in order to obtain correct values, therefore the state of stress within a floor is more complex, in addition to the normal stresses due to bending which is huge and in most cases must be considered if failure is to be avoided. The purpose of this research is to study and compare the effect of bending moment on floors of modeled high rise buildings on elastic ground and firm ground. The research design was exploratory which made use of Complex Program Lira to design and calculate 18-storey residential buildings. The results indicate that for both models the maximum bending stress occurred at the first floors whiles the minimum bending stress occurred at the top floors. The bending stresses from second floor to the top floor are the same for each model. The model with elastic base foundation has high bending stress as compared to the model with firm base foundation by 30% for first floors and 28% for the subsequent floors. It could therefore be concluded that bending moment effect on the floors was greater in the model with elastic base than the model with firm base.

Keywords: Bending moment, Computer-aided design (CAD), Floor, Complex program (CP)

Introduction

To investigate realistic values of bending moment and normal forces, a full three-dimension (3D) analysis is needed in order to obtain correct values (Bonnie, Möller and Vermeer, 2005). Computer modeling aims at transforming the design process of buildings worldwide from the use of 2D to 3D, 4D and 5D design and coordination technologies. The virtual building, where design, construction, environmental performance and operational challenges are visualized, solved and optimized in an integrated computer simulation, is becoming a reality. At the simplest level, working from a 3D model brings significant advantages of increased accuracy, reduced cost and creativity to the design process. When changes are made to the model, the wider impact can be assessed quickly and at low cost. For example, if a column is moved, the ventilation duct has to be rerouted. This is easily spotted and can be easily addressed. Increasingly, structural designers are keen to embrace the creative freedom that 3D building modeling offers. More powerful technology platforms, operating environments and specialized software systems such as SCAD, CP Lira, Robot, and Monomakh for calculation and design of structures do not only create and explore the detailed calculation of the scheme, but also compute the simulation of the life cycle of construction, including stages of construction and operation (Lantukh-Liashenko, 2001). Complex Program (CP) Lira is a modern software package intended for designing and undertaking numerical analysis of structures through computer-aided design (CAD) process.

All elements of upper floor system must be properly sized to support the design loads. The International **Uniform Building Code** requires at a minimum, floors be designed to support the dead load of the floor and the required live load. The major stresses induced due to bending moment are normal stresses of tension or compression. But the state of stress within the floor is more complex, in addition to the normal stresses due to bending which is huge and in most contexts they must be considered if failure is to be avoided. This study therefore seeks to investigate the effect of bending moment on the floors of high rise modeled buildings design on firm ground and elastic ground, and subsequently compare their results.

Calculation models of buildings using CP Lira allows investigation of the stress deformation state of virtually any geometrically complex shapes of buildings, whose designs can be made of different materials. Finite element method implemented in this program is quite universal method for calculating supporting systems of buildings. Along with the many positive reviews for this method, there are some negative aspects such as excessive fragmentation of the elements that can lead to a loss of accuracy of the results, especially for cases of calculating slabs or shell structures. Analysis of any construction begins with an attempt to establish what is essential and what can be ignored. The compliance with the calculation taking into account all the properties of the actual design is possible only with a certain degree of approximation. Computer modeling is a major development of new design solutions that meet the requirements of safety and economy, and contributes to the formation of new architectural forms and directions to the design and analysis of structural works (Herron, 2010).

Design and calculations of multi-storey residential and public buildings is complex. There are numerous difficulties associated with the design of multi-storey buildings, some of which are the choice of appropriate computational models, performance mode analyses and nature of the soil bases (characteristics of the ground). Recent studies have applied the use of firm or rigid soil characteristics in the construction of high-rise buildings. Gorodetsky et al. (2004) described the various effects of the construction of multi-storey buildings with technology aided analysis and design software systems such as CP Lira and structural computer aided design (SCAD). The study applied firm ground characteristics to the base of the structure and analyzed the displacement, bending moment and membrane forces of the floor slabs. Another study conducted by Veryuzhsky (2006) demonstrated the firm ground characteristics of the base of monolithic multi-storey building which relied on the specific numerical modeling method. He also used CP Lira for the modeling of the building and determined the displacement of the floors.

The abovementioned studies used firm ground as the base of the structures modeled. However, firm ground is not the only type of ground used for construction of buildings. Multi-storey buildings could be constructed on other grounds. Thus, there is the need to conduct studies on the application of other ground types in the design and construction of buildings with CP Lira. The elastic soil (lose ground, made-up ground and clay ground) has unique characteristics such as low bearing capacity and unstable nature which require special attention during the design process of structures. Research on the use of elastic soil ground for constructing high rise building is limited. This study therefore focuses on the application of elastic soil ground for the construction of high rise building as against firm ground.

Experimental work carried out by Potts and Fourie (1986) clearly indicated that under the same operating conditions, stiffer walls attract larger bending moment than more flexible walls. They, therefore, suggested a compromise between reduced bending moment and increased movements as the flexibility of the wall increases. Thus, there is the need also to study and compare the effect of bending moment on floors of modeled high rise buildings on elastic ground and firm ground

Materials and Methods

Research Design

This sub‑study of a larger study used exploratory design for modeling which relied on the use of CP Lira that generated and provided results for the structural analysis. The study designed and analyzed two 18-storey buildings, which are modeled with elastic base foundation and firm or rigid base foundation, each with basement.

Design Details of Buildings

The buildings (in plan) have dimensions 52 m x 20 m, height 55.8 m. Each building includes a basement of 2.3 m height, and super-structure of 2.8 m high for each floor of 18-storey. The stiffness thicknesses of the buildings are as follows: Internal basement walls of reinforced concrete is 400 mm; External basement walls reinforced concrete is 600 mm; Internal reinforced concrete walls is 180 mm; External reinforced concrete walls is 300 mm; Foundation slab is 1000 mm; Floor slabs is 200 mm.

Description of Computational Models

The design and calculations used version 9.6 of CP Lira. The Finite Elements (FE) was produced by refinement of the grid in places of conjugation of the wall slabs. The type of FE and section characteristics adopted by the modulus of elasticity for each group of elements of the computational model is presented in Table 1, according to the values of Evzerov (1990) and Gorodetsky et al. (1975). Modulus of elasticity of elements and the coefficient of deformation of concrete at loading period was determined by the use of Russian Building Regulation Standard (SP 52-101-2003). The models produced along a given direction for the planes are as follows: for vertical planes - along the Z-axis, a common coordinate system, horizontal planes - along the X-axis. Boundary conditions are defined as follows: the two diametrically opposite sides of the foundation slab links: X and Y to the first node, and only Y for the second. Such binding can be roughly compared to fixing a simple beam running in the horizontal plane, one of the columns of which is hinged and the second on track rollers. The entire foundation slab for the model with elastic base was given a single bed coefficient $C_1 = 1241.72$ t/m^2. The application of this coefficient at the base of the foundation slab of the structure as incorporated in the CP Lira makes it possible for the foundation slab to assume the characteristics of an elastic base.

Table 1: Characteristics of the Elements for Computational Model

Name of element	**Type of finite element**	**Thickness, mm**	**Modulus of elasticity, t/m ^{2}**
External walls	41 (rectangular shell FE)	300	3.31e+006 (concrete C30)
Internal walls	41 (rectangular FE shell)	180	3.31e+006 (concrete C30)
Roof slab	41, 42 (rectangular and triangular shell FE)	200	3.31e+006 (concrete C30)
Foundation slab	42, 44 (triangular and quadrilateral shell FE)	1000	3,67e+006 (Conditional hardness)
Floor slab	41, 42 (rectangular and triangular shell FE)	200	3.31e+006 (concrete C30)
Internal basement walls	41 (rectangular FE shell)	250	3.31e+006 (concrete C30)
External basement walls	41 (rectangular FE shell)	600	3.31e+006 (concrete C30)
Foundation restraint stiffness	51 (single-node communications FE elastic foundation)	-	-

Calculating the coefficients of the elastic foundation bed

In LIRA, foundation model of elastic characteristics is designed by two coefficients of bed which are C_1 (t/m^3) and C_2 (t/m) that describe the vertical deformation of the foundation. The parameter C_2 takes into account the work of the soil outside the foundation. The following formulas are used to calculate the coefficients for one layer of ground of the elastic foundation bed:

Slab foundation for single layer of ground

$$C_1 = \frac{E_1}{h_1 \cdot \left(1 - 2\nu_1^2\right)} \tag{1}$$

$$C_2 = \frac{E_1 \cdot h_1}{6 \cdot \left(1 + \nu_1\right)} \tag{2}$$

Where:

E_1 - modulus of soil deformation

V_1 - Poisson's ratio

h_1 - thickness of compressible ground layer

Loads Application

Load and impact on the building are defined by Russian Building Regulation Standard (SNIP 2.01.07-85). The computational complex LIRA full design loads are applied. The combination of load cases takes into account the coefficient system for the calculation, as well as calculations on seismic effects and progressive collapse. Values taken for loads and coefficient are presented in Table 2. The wind load was calculated by the use of vest table in Table 3.

Table 2: Loads Application

Load Type	**Pn**	γ_f	**P**	**Kdlit**	**$К_1$**	**$К_2$**	**$К_3$**
Permanent							
Bearing design	LIRA *	1,1	LIRA *	-	1	0,91	0,91
Enclosing structures	600 kg/m	1,3	780 kg/m	-	1	0,77	0,77
Floors	180	1,3	234	-	1	0,77	0,77
Temporary: short-term							
Live	200	1,2	240	0,35	0,9	0,29	0,29
Snow	126	1,4	180	0,5	0,9	0,35	0,35
Wind	Vest	1,4	Table 3	0	±0,9	±0,71	0
Fluctuating component of wind	LIRA *	1,4	LIRA *	0	±0,9	±0,71	0

LIRA *: the load is determined by the software system automatically. Pn: standard value of load, kg / m^2 (except specified); γf: factor of safety for load; P: calculated value of the load, kg/m^2 (except specified); Kdlit: conversion factor from the total value of short-term load to low values of live load of long-acting (the proportion of duration); K_1: coefficients for the combination of # 1, determine the estimated value of load reduction factors based combinations, including permanent and at least two loads of time (for the settlement of Group I PS); K_2: coefficients for the combination of # 2, defining the normative values of the permanent and long-term loads as well as the action of wind (for the calculation of the group II PS); K_3: coefficients for the combination of # 3, defining the normative values of permanent and long-term loads (for payments for special effects). These same factors apply in the transition from static loads to the masses.

Table 3: Wind Loads

Height Z, m	Windward surface, t/m	Leeward surface, t/m
0,0	0,046	-0,036
2,3	0,046	-0,036
5,1	0,046	-0,036
7,9	0,047	-0,036
10,7	0,049	-0,043
13,5	0,051	-0,050
16,3	0,054	-0,054
19,1	0,056	-0,058
21,9	0,058	-0,061
24,7	0,062	-0,065
27,5	0,069	-0,068
30,3	0,079	-0,072
33,1	0,085	-0,076
35,9	0,094	-0,079
38,7	0,097	-0,083
41,5	0,101	-0,083
44,3	0,104	-0,086
47,1	0,108	-0,090
49,9	0,112	-0,094
52,7	0,115	-0,094
55,8	0,119	-0,097

Results and Discussions

Design Models

The 3D designed state of both models is presented in FE form in Figures 1 and 2. In the course of the calculation of structural elements by CP Lira, the finite elements were divided into triangular and rectangular slabs of 58,014 units, interconnected at the nodal point of 53,559. Calculation of the bearing system of the building was completed within 135 minutes which solved the system equations of 285,445 for Model 1, as compared to 56,251 units of elements, 52,704 nodal points and 262,537 equations carried out within 116 minutes for Model 2. From the results of the numerical design for both models, it can be concluded that the fragmentation of finite elements leads to an increase in computation time and is associated with a request to use more memory for data storage and processing. This is because Model 1 used more time for the analysis than Model 2, which is due to the fact that the FE in Model 1 is more than that of Model 2.

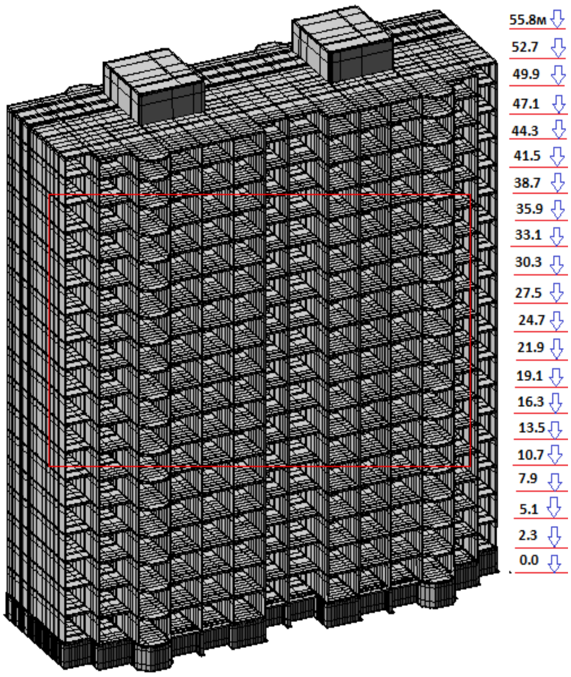

Figure 1: 3D Model**1**-with elastic base foundation

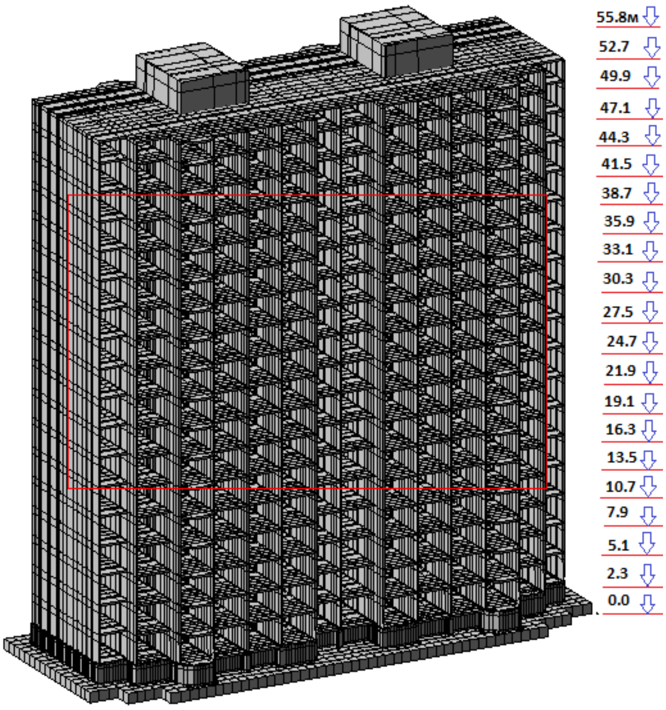

Figure 2: 3D Model 2-with rigid base foundation

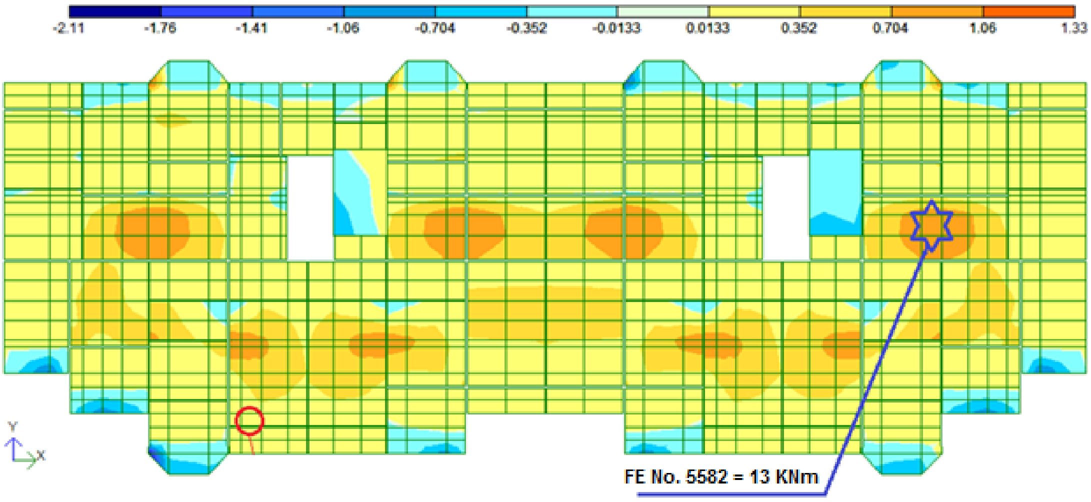

Figure 3: Contour Plots of Bending Stress (Moment)

Bending moment

Table 4 shows the bending moment values for both models. The contour plots of stress, bending moment of the first floor for the model with elastic base is shown in Figure 3. The design models were found to have different moment. For both models the results indicated that the maximum values occurred at the first floors whiles the minimum values occurred at the top floors. The values from second floor to the top floor are the same for each model; it is only the first floor values that are different. The values for the model with elastic base were more than the model with firm base. This means that the model with elastic base foundation has high bending stress as compared to the model with firm base foundation by 30% for first floors and 28% for the subsequent floors. This implies that the bending moment effect was greater in the model with elastic base than the model with firm base. Additionally, for both models the bending moment effect was greater in the first floor than that of the subsequent (second to last) floors. Last but not the least, the bending moment effect from second floor to the top floors was the same for each model.

Table 4: Bending Moment Values

Model	Max. Value, **kNm** (Second- Last Floors)	Percentage	Min. Value, **kNm** (Second- Last Floors)	Percentage
With elastic base	13	130	9.6	128
With firm base	10	100	7.5	100
Difference	3	30	2.1	28

Conclusion

This study focused on the application of elastic ground as against firm ground for the construction of high rise buildings for which CP Lira was used to model two buildings for the purpose of comparison. The study compared the bending moment effect on the floors of both models. Based on the results, it can be concluded that the model with elastic base foundation has high bending moment effect on the floors as compared to the model with firm base foundation. This implies that the deformation is high in the floors of the model with elastic base foundation; therefore the necessary precautions should be taken by the users of CP Lira and structural designers in general when designing structures to be constructed on ground with elastic base characteristics in order to avoid structural failure.

References

[1] Bonnie, P.G. Möller, S.C. and Vermeer, P.A., 2005, "Bending Moment and Normal Forces in Tunnel Linning".

[2] Evzerov, I.D., 1990, "The Finite Element Methods to Calculate Long-Term Effect of Load: Strength of Materials and Theory of Structures", Budivelnik Publishers, Kiev.

[3] Gorodetsky, A.S., Zdorenko, V.S. Elsukov K.P. and Slivker, V.I., 1975, "Application of Finite Element Methods to the Calculation of Structure", Budivelnik Publishers, Kiev.

[4] Gorodetsky, A.S. Labirer, L.G. Gorodetsky, D.A. Laznyuk, M. and Yusypenko, V.S., 2004, "Calculation and Design of Structures of High-Rise Buildings made of reinforced Concrete", Fact Publishers, Kiev.

[5] Herron, J., 2010 "3D Model-Based Design: Setting the Definitions Straight", Available at: www.mcadcafe.com

[6] Lantukh-Liashenko, A.I., 2001, "LIRA Software Package for Analysis and Design of Structures", Fact Publishers, Kiev.

[7] Potts, D.M. and Fourie, A.B., 1986, "A Numerical Study of the Effects of Walls Deformation on Earth Pressures", *International Journal of Numerical and Analysis Methods.* Geom, 10(1) 383-405.

[8] SP 52-101-2003. Concrete and Reinforced Concrete Structures without Pre-stress Reinforcement. Official Publication, Moscow, 2003.

[9] SNIP 2.01.07-85. Pressures and Forces. USSR State Committee for Construction. Moscow, 1986.

[10] Veryuzhsky, U.V, Kolchunov, V.I. Barabash, M.S. and Genzerski, V., 2006, "Computer Design Technology for Reinforced Concrete Construction", Fact Publishers, Kieve.