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DYNAMIC COMFORT CONSIDERATIONS IN THE DESIGN OF HIGH-RISE BUILDINGS

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DYNAMIC COMFORT CONSIDERATIONS IN THE DESIGN OF HIGH-RISE BUILDINGS

ABSTRACT
The following paper provides research analysis on the influence of wind on a building, considering the regional and local climate conditions, to improve dynamic stability and reduce wind disruption effects on high-rise reinforced concrete buildings. The main aspect of disturbance in living conditions is caused by wind loads on the building. The data is based on structural analysis, generated by the “Lira CAD 2013” software, for a construction project of a 19-story residential building, completed in Georgia’s capital Tbilisi, 58 Kavtaradze St., in accordance with the given necessary requirements and restrictions by general terms and conditions of the Georgian state law. Computer aided modeling provides the ability to simulate and define parameters caused by the wind disruption on an actual site. Calculation process is based on variables specified by state law for each region of the country. Modified accelerations which have been caused by wind in multi-story, high-rise buildings have significantly greater values on upper floors, and reaching the edges of the minimum living comfort criteria. The given study features the estimation for high-rise buildings under various combinations of loads. High-rise buildings have gone under significant restrictions due to use of conventional rigid frames as structural elements in the construction process. That process tends to develop a series of new research and findings for proper architectural forms, which became possible using the new generation of fast digital computing software and hardware.

Key words: *high-rise building, comfort criteria, wind load, dynamic load, wind distribution, long-term load, wind load acceleration*

1. INTRODUCTION

In recent years, the urban landscape has undergone significant changes with the emergence of high-rise, monolithic apartment buildings, which have become emblematic of economic development. These structures, located in central areas, promise a a comfortable living and solutions to various household issues. The construction of such buildings requires a careful balance between energy conservation, ecological concerns, and other critical factors, with a growing emphasis on ecological safety and integration with service systems [1].

International standards advocate for incorporating natural resources and eco-friendly technologies in high-rise building projects. The global trend includes the construction of high-rise, multifunctional complexes in major cities, addressing land scarcity, population growth, and economic demands. The design criteria have evolved to prioritize resident comfort, safety, reliability, and operational efficiency.

The development of high-rise buildings is particularly prominent in megacities, driven by factors such as rising land prices and population growth. Design considerations have shifted from conventional rigid frames to more flexible structural systems, facilitated by advancements in steel and reinforced concrete technology. The emergence of box-like forms has prompted architects to explore new design trends, leveraging fast digital computers for innovative solutions.

The ideal structure for a high-rise building is characterized by simplicity, regularity, and well-defined load paths in its structural elements. Complexity in configuration and geometry is minimized to streamline building behavior and improve calculability. An analysis of international experience suggests that the construction of buildings with 30-50 floors is economically viable. However, in Georgia, technical solutions for such construction are still evolving, with limited practical experience. Challenges arise in coordinating between high-rise building supervision services, city government structures, and stakeholders such as architects, constructors, and ecologists. Addressing these concerns is crucial for ensuring the successful integration of high-rise complexes in the capital, ultimately benefiting city residents.

2. REGULATION FRAMEWORK

High-rise buildings are more significantly affected by wind loads due to their greater flexibility, which must be taken into account. Among the two main dynamic loads (earthquake and wind) affecting buildings, it is necessary to select the larger one. This selection is defined both by the legislation in force in Georgia and by the international and European standards. The dynamic comfort of the building is not calculated due to its small reproducibility. Wind loads are more frequent and more important for high-rise buildings, especially in the case of aerodynamically complex shapes.

Dynamic comfort criteria are given in the norms of other countries and international standards: (SNiP 2.01.07-85*), ISO 10137, the Canadian National Building Code (NBCC), regulations in Japan according to AIJ, EN 1991-1-4. When calculating buildings using Eurocode, wind acceleration is defined in compliance with Annex B.4. That methodology is closer to the international ISO 10137 standard, since the Eurocode does not provide specific recommendations on the limit accelerations of the wind, and therefore it is necessary to use the international standard [2],[3],[4].

The calculation of buildings in the aerodynamic wind tunnel provides the most accurate results. According to the law in force in Georgia, such a test is not required for high-rise buildings; it is required only for bridges in order to take into account the vibration effect.

The Eurocode and the international ISO 10137 standard provide analytics for buildings up to 200 m in height. For taller buildings, an aerodynamic test becomes necessary, as the standard does not provide wind load data at higher elevations. An aerodynamic test is generally recommended for difficult terrain and complex city development. This test not only provides accurate values of wind load, but also determines the accurate acceleration of the top floor of the building. The norms for conducting the aerodynamic wind tunnel tests for buildings are specified in ISO 4354.

3. PRELIMINARY CALCULATIONS

High-rise buildings have structural and technological specifications. Typically, they can be categorized as sections of frame, structure and core. Safe and reliable operation of these structures sometimes requires special engineering solutions. The design of high-rise buildings is a complex process, considering the list of forces and loads that result in diverse planning solutions.

The following research provides solutions for dynamic comfort criteria in high-rise buildings under the influence of wind. Usually, dynamic comfort criteria of a building are not calculated when their occurrence is not frequent. Wind loads are important for high-rise buildings, especially for a geometry of surface with a difficult or complex aerodynamic shape.

Dynamic comfort criteria for high-rise buildings lack universal standards and vary by country. Norms and standards, such as SNiP 2.01.07-85*, ISO 10137, the National Building Code of Canada (NBCC), AIJ guidelines in Japan, and EN 1991-1-4, outline specific mandatory requirements.

Research data provided by specialized institutions properly describe various types of psychophysical changes by individuals residing in high-rise buildings. Air currents above nine floors induce oscillations with a frequency of 3-4 Hz due to structural loads, potentially causing resonance with the human body's vibration and disrupting physiological activity.

According to the Eurocode, wind acceleration follows the methodology outlined in Annex B4, similar to other international standards. However, the Eurocode lacks specific recommendations on maximum wind accelerations and refers to the international standard ISO 10137 for guidance.

The following solution is given as an example of a 19-story building, with a 2-story garage in the basement (Figure 1).

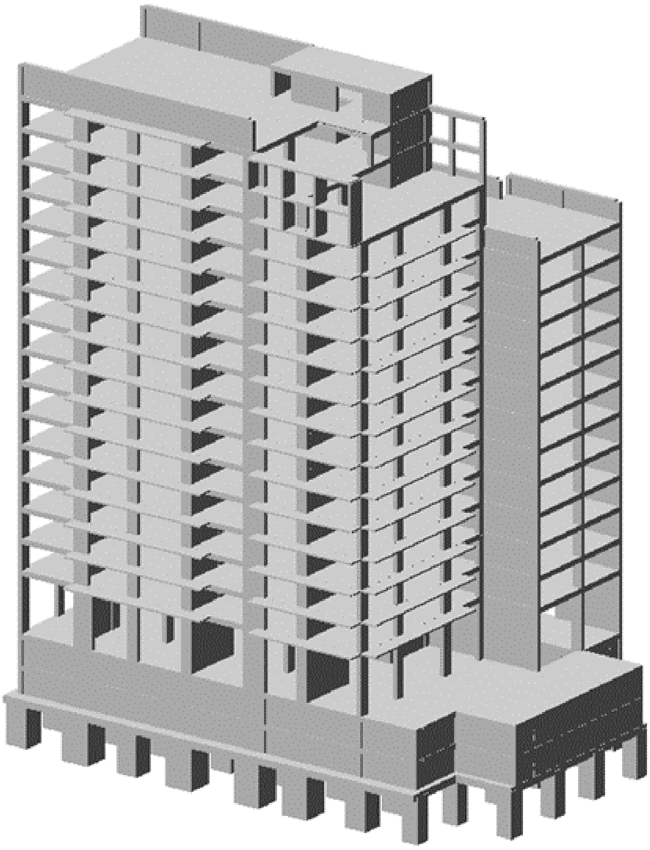

Figure 1. 3D Model of Building (Image Generated by "Lira SAPR 2013" Software)

According to the ground floor plan, the building has maximum dimensions of 44.9X28.1m. The vertical supporting elements are reinforced concrete columns and shells stand as structural members. The roofing structure consists of monolithic slabs and rails. Calculations are based on finite element methods with the "Lira SAPR 2013" software. All variables used in structural calculation are derived from the general terms and conditions defined by the Georgian state law in force.

Seismic load analysis is given for the 2nd ground category, with an acceleration of 0.17g. The initial seismic impact data follows the guidelines from PN 01.01-09 technical document, in accordance with the general terms and conditions of Georgian state law. Specific correlation coefficients are applied for the analysis of static loads. The detailed data is provided in the table below (Table 1) [5].

Table 1. *Wind Direction (W and W/O Safety Coefficient) According to the Terms and Conditions of Georgian State Law for Different Levels of Structure*

Wind Loads				
Building Height	Frontal Side		Vent Side	
	Normative	Accountable	Normative	Accountable
	t/m²	t/m²	t/m²	t/m²
0	0.034	0.048	-0.026	-0.036
6.64	0.037	0.052	-0.028	-0.039
9.96	0.044	0.062	-0.033	-0.046
19.92	0.058	0.081	-0.043	-0.061
39.84	0.075	0.105	-0.056	-0.078
49.8	0.082	0.114	-0.061	-0.085
59.76	0.088	0.124	-0.066	-0.093

The given set of loads is distributed on the columns evenly, corresponding to the area of the exterior surface. It is important to note that, based on research data from specialized institutions, individuals in high-rise buildings experience psychophysical changes due to wind disruption. To be more specific, air currents at higher levels, induced as structural loads above the 9th floor, generate oscillations with a frequency of 3-4 Hz (Table 2).

Table 2. *Frequency Ranges, Intersection to Critical values (Table Generated by "Lira SAPR 2013" Software)*

No.	EIGEN VALUES	FREQUENCIES		PERIODS
1	0.246055	4.06	0.65	1.5452
2	0.201205	4.97	0.79	1.2636
3	0.152244	6.57	1.05	0.9561
4	0.065316	15.31	2.44	0.4102
5	0.059593	16.78	2.67	0.3742
6	0.044384	22.53	3.59	0.2787
7	0.032391	30.87	4.92	0.2034
8	0.029436	33.97	5.41	0.1849
9	0.028755	34.78	5.54	0.1806
10	0.026685	37.47	5.97	0.1676
11	0.025604	39.06	6.22	0.1608
12	0.024253	41.23	6.57	0.1523
13	0.023123	43.25	6.89	0.1452
14	0.022458	44.53	7.09	0.1410
15	0.022316	44.81	7.14	0.1401
16	0.021491	46.53	7.41	0.1350
17	0.019732	50.68	8.07	0.1239
18	0.019334	51.72	8.24	0.1214
19	0.018779	53.25	8.48	0.1179
20	0.018730	53.39	8.50	0.1176
21	0.018329	54.56	8.69	0.1151
22	0.017803	56.17	8.94	0.1118
23	0.017364	57.59	9.17	0.1090
24	0.017049	58.65	9.34	0.1071
25	0.016863	59.30	9.44	0.1059
26	0.016584	60.30	9.60	0.1041
27	0.016524	60.52	9.64	0.1038

If this frequency coincides with the human body's vibration, resonance occurs, inhibiting physiological activity. In such cases, it is necessary to include specialized instructions and practical solutions. Therefore, architects and constructors are actively involved to solve a comfortable living condition.

The impact of loading, including forces from internal loads and structural displacement, must be considered by applying a proper coefficient of reliability. In the given example, the coefficients of reliability above the ground level of the building are provided in the following diagrams (Figure 2, Figure 3).

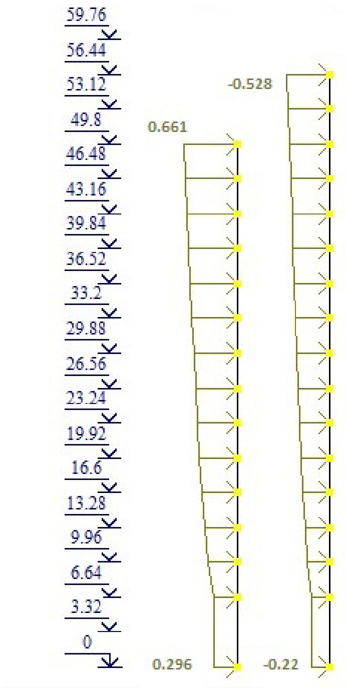

Figure 2. Wind Load for X Direction (Image Generated by "Lira SAPR 2013" Software)

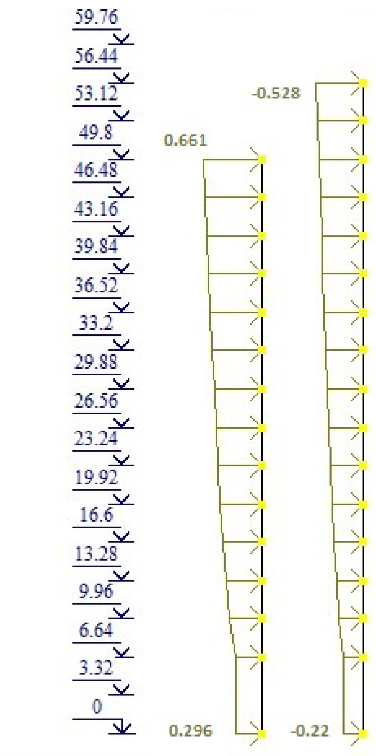

Figure 3. Wind Load for Y Direction (Image Generated by "Lira SAPR 2013" Software)

Depending on building's height and geometry, the wind coefficient has to be estimated using the following data with the finite element method analysis software - Lira SAPR 2013 (Figure 4):

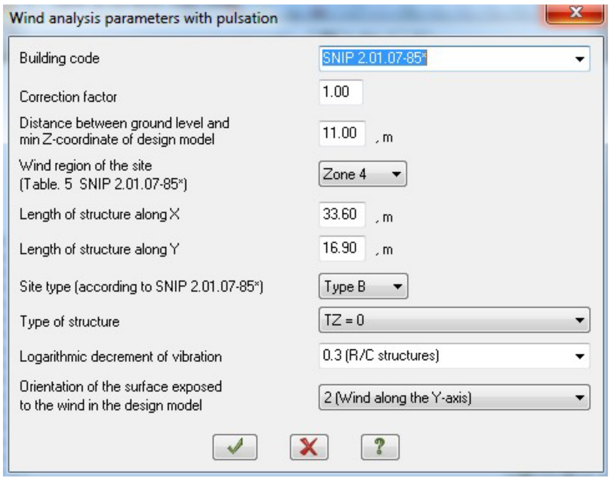

Figure 4. Wind Analysis Parameters for a Specific Zone (Image Generated by "Lira SAPR 2013" Software)

According to the valid standard used for design of structural construction under the Georgian state law (SNiP 2.01.07-85), buildings higher than 40 meters must be analyzed with the wind pulsation coefficient to properly maintain dynamic comfort criteria. This standard also defines the maximum acceleration obtained under wind load for the upper floors - 0.08 m/s².

Dynamic load analysis also could be solved with the finite element method using the Lira or Scad software. This allows the wind to be accelerated at the knots for a variety of geometric shapes. The direction of the load is critical to properly determine the vibration values. For the given example, the load caused by the wind condition is estimated with the following equation (1):

$$Wc = 0.5Wp \tag{1}$$

Where: Wp is the design value of the pulsation coefficient.

4. CONCLUSION

The research results show that accelerations caused by wind in multi-story high-rise buildings, especially on the upper floors, are significantly higher, and it is necessary that their values do not exceed the values of minimal comfort criteria. Therefore, it is necessary to consider the given results in the design process.

Aerodynamic testing is highly recommended in the design process of complex geometrical shapes and in the urban environmental development. This also provides accurate values of wind load on the upper levels of the building. Based on the analysis of the given example, it is necessary to determine the comfort living criteria of a high-rise building and refer to the relevant structural engineering guidelines, to avoid deviation from the necessary values for the use of the building.

5. ACKNOWLEDGMENT

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Vladimer Kikadze

Vladimir Kikadze was born on 03.12.1995. In 2018, he graduated from the Faculty of Construction (Bachelor's Degree) of the Technical University of Georgia with the specialty "Builder-Engineer". In 2020, he graduated from the Faculty of Construction of the Technical University of Georgia (master's degree) with a Master of Engineering in construction, specializing in civil and industrial construction. In 2021, he passed and is studying at the Faculty of Construction of the Technical University of Georgia as a doctoral student. Vladimir Kikadze has been working as an engineer-constructor at "Georgian Technical Group" LLC since 2018.

ДИНАМИЧКА УДОБНОСТ У ПРОЈЕКТОВАЊУ ВИСОКИХ ЗГРАДА

Сажетак: Сљедећи рад даје истраживачке анализе о утицају вјетра на зграду, с обзиром на регионалне и локалне климатске услове, ради побољшања динамичке стабилности и смањења утицаја вјетра на високе армирано-бетонске зграде. Главни аспект нарушавања животних услова је узрокован оптерећењем вјетра на зграду. Подаци су засновани на структурним анализама, генерисаним софтвером „Lira CAD 2013", за пројекат изградње стамбене зграде од 19 спратова, завршен у главном граду Грузије, Тбилисију, улица Кавтарадзе 58, у складу са датим неопходним захтјевима и ограничењима општих одредби и услова државног законодавства Грузије. Компјутерски потпомогнуто моделирање пружа могућност симулације и дефинисања параметара узрокованих сметњама вјетра на стварној локацији. Процес израчунавања је заснован на варијаблама одређеним законодавством за сваки регион земље. Модификована убрзања која су изазвана вјетром у вишеспратницама имају знатно веће вриједности на спратовима, а достижу границе критеријума минималне удобности становања. У датој студији је дата процјена за вишеспратнице под различитим комбинацијама оптерећења. Високе зграде су претрпјеле значајна ограничења због употребе конвенционалних крутих оквира као структурних елемената у процесу изградње. Тај процес тежи да развије серију нових истраживања и открића за одговарајуће архитектонске форме, што је постало могуће коришћењем нове генерације брзог дигиталног рачунарског софтвера и хардвера.

Кључне ријечи: висока зграда, критеријум удобности, оптерећење вјетром, динамичко оптерећење, дистрибуција, дуготрајно оптерећење, убрзање оптерећења вјетром