Comparison of wind load impacts on existing lowrise building, according to TCVN 2737

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ABSTRACT

For nearly three decades, the Vietnamese standard 2737:1995 has been fundamental in predicting the impact of loads on construction projects. Many projects and drafts have been developed to address the existing limitations of this set of standards. Issued by the Ministry of Construction, TCVN 2737:2023 has undergone significant revisions and additions, particularly concerning load impacts on construction structures. This study was conducted to deepen the understanding of the impact of wind load according to this standard. Four actual grade 2 reinforced concrete structures designed according to the old standard TCVN 2737:1995 were simulated to withstand the impact loads according to TCVN 2737:2023. The results showed that the standard static wind load has a higher average value of 0.935 times than TCVN 2737:2023, indicating that the wind load check problem under the new standard is more accessible to meet the related deformation requirements than the old standard. However, for the design according to the first limit state, the wind load according to TCVN 2737:2023 is more robust than 1.5 to 2.3 times due to different confidence factors. The research results will provide a scientific basis for proposing appropriate reinforcement and renovation solutions for each old structure.

Keywords: *Wind load, TCVN 2737:1995, TCVN 277:2023, Design Wind Load, Standard Wind Load*

1. INTRODUCTION

In building design, building loads or, more precisely loads and actions affect building structures in the form of forces (loads) and other non-force effects such as temperature differences imposed strains. These effects must be anticipated and simulated by the design engineer regarding their impact on the structural system of the building, serving as a basis for safe and stable calculation and design of the structure during long-term use as well as taken into account during the construction of the building. The expected load impacts are usually introduced in national standards, in which Vietnamese standard 2737:1995 [1] proposes general load components affecting building structures.

The Vietnamese structural load standard TCVN 2737:1995 has recently drawn research attention from domestic and international academics. The studies have primarily focused on three main areas: The first is benchmarking TCVN 2737:1995 against other global standards to critique the Vietnamese code. Noteworthy examples include John Holmes et al.'s study [2] contrasting wind load computations per 15 Asia-Pacific country standards, including TCVN 2737:1995; N. V. Thong et al. [3] presented the research on the static wind load by comparing RANS turbulence models impact on buildings; and N. L. Thuy et al. [4] compared static wind load calculations between TCVN 2737:1995 and American and European specifications. The second concentrates on dissecting the wind load elements as per TCVN 2737:1995. Seminal works consist of V. T. Luong et al. [5] on calculating static and dynamic wind loads based on the code; D. V. Thuat et al. [6]

focused on identifying the dynamic wind load components; and N. T. Thanh [7] presented the results of the terrain effects on wind loads. And the third involves replicating wind load impacts using simulations to evaluate TCVN 2737:1995's accuracy. Significant examples comprise N. V. Thong et al.'s efforts [8] utilizing CFD simulations to quantify the static wind constituents and contrast with TCVN 2737:1995's outputs.

For the new Vietnam standard TCVN 2737:2023 [9], recent research has focused on TCVN 2737:2023, specifically addressing wind load calculations. T. S. S. Hoach [10] developed automated software for wind loads on specific rooftop structures. L. T. Q. Khai [11, 12] compared frame and shear wall and column responses to the wind in Etabs, finding that shear walls were more affected and noting that centralized wind loads improve stability.

Research on Vietnam's structural load standards, TCVN 2737:1995 and the updated TCVN 2737:2023 has been robust, spotlighting both the strengths and areas needing enhancement. Initial studies on TCVN 2737:1995 critiqued its global standing, dissected wind load components, and used simulations to pinpoint its shortcomings, especially in high-rise load calculations. These insights laid the groundwork for TCVN 2737:2023, which saw further research into wind load computation and structural response, improving software automation and structural stability. While these studies mark significant progress, they also emphasize the ongoing necessity to evolve and refine these standards, ensuring they align with the latest structural safety and design precision.

Therefore, this study raises questions about the impact of the TCVN 2737:2023 wind load on construction structures compared to TCVN 2737:1995. The research will present the impact of the existing building's wind load according to TCVN 2737:2023. By building ETABS models, this study calculated the 02 wind loads according to the 02 TCVN versions, and then compared the results of the 02 wind loads to clarify the level of impact on the actual structure.

2. MATERIALS AND METHOD

This research carries out the analysis of some new contents of TCVN 2737:2023 on wind loads. From there, the calculation is applied to 04 low-rise buildings and compares and evaluates the impact loads compared to the TCVN 2737:1995 standard.

TCVN 2737 Standard on Loads and Actions was first introduced in 1995. It played a crucial role in Vietnam's Technical Standards system and underwent two assessments in 2006 and 2009. Over 25 years, the 1995 version served the design and construction of structures during a period of rapid development in the Vietnamese construction industry. However, due to a lack of updates and reviews over this extended period, it still retained specific issues, including excessive loads for garages, a lack of helicopter and fire truck support systems, outdated reliability coefficients, load combinations, and wind load data.

To address these challenges, the TCVN 2737:2023 Standard on Loads and Actions was issued by the Ministry of Science and Technology through Decision No. 1341/QĐ-BKHCN [13] and came into effect on June 29, 2023. This standard holds significant importance in shaping the design of structural elements in Vietnam. TCVN 2737:2023 has been updated to classify loads and address issues related to seismic loads. It adheres to international standards and represents the inheritance and development of the Vietnamese construction industry. During the conference on load actions according to TCVN 2737:2023, various adjustments and additions were discussed, including references, terminology, definitions, symbols, general requirements, and load classifications.

Notably, it has improved determining loads from equipment, materials, and products in storage areas. TCVN 2737:2023 also adjusted the method for determining uniformly distributed loads, added new information, and removed long-term component values. The Conference on TCVN 2737:2023 [14] introduced additional information on uniformly distributed loads and concentrated loads in automotive garages, as well as loads from helicopters and collision loads from forklifts.

Concerning wind loads, as shown in Figure 1, Table 1 - 2, TCVN 2737:2023 modified the calculation method and adjusted the formulas. It also introduced aerodynamic coefficients for specific types of structures, based on international standards and added provisions for wind tunnel testing, especially by utilizing the Reliability Factor γ_n, Gust Wind Loading Factor G_f, and Wind Loading Coefficient K_{ze} (following ASCE 7-16) Aerodynamic Coefficients c (following EN 1991-1-4 and SP 20.1330.2016), and the Wind Pressure Wo (following ASCE 7-05). Additionally, TCVN 2737:2023 incorporated supplementary content related to sway and deflection.

Table 1: The wind pressure W_o

TCVN 2737:1995	TCVN 2737:2023
IA (55 daN/m^2)	I (65 daN/m^2)
IB (65 daN/m^2)	
IIA (83 daN/m^2)	II (95 daN/m^2)
IIB (95 daN/m^2)	
IIIA (110 daN/m^2)	III (125 daN/m^2)
IIIB (125 daN/m^2)	
IV (155 daN/m^2)	IV (155 daN/m^2)
V (185 daN/m^2)	V (185 daN/m^2)

Table 2: The Aerodynamic Coefficients c for vertical walls

h/d	TCVN 2737:1995		Zone TCVN 2737:2023				
	Push	Pull	A	B	C	D	E
5	+0.8	-0.6	-1.2	-0.8	-0.5	+0.8	-0.7
1	+0.8	-0.6	-1.2	-0.8	-0.5	+0.8	-0.5
≤0.25	+0.8	-0.6	-1.2	-0.8	-0.5	+0.7	-0.3

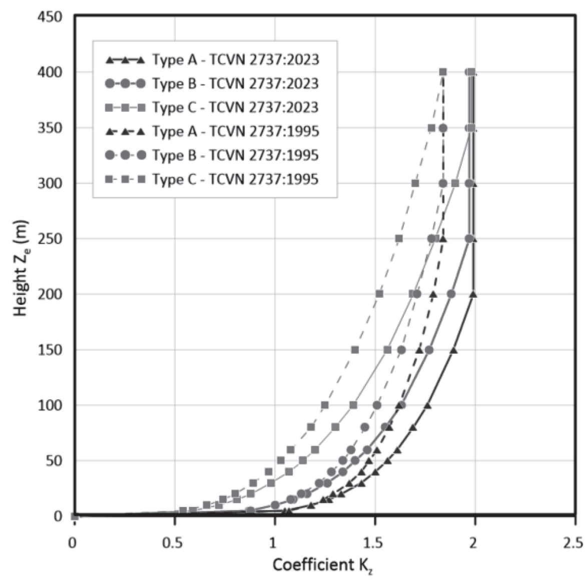


***Figure** 1. Coefficient K_z*

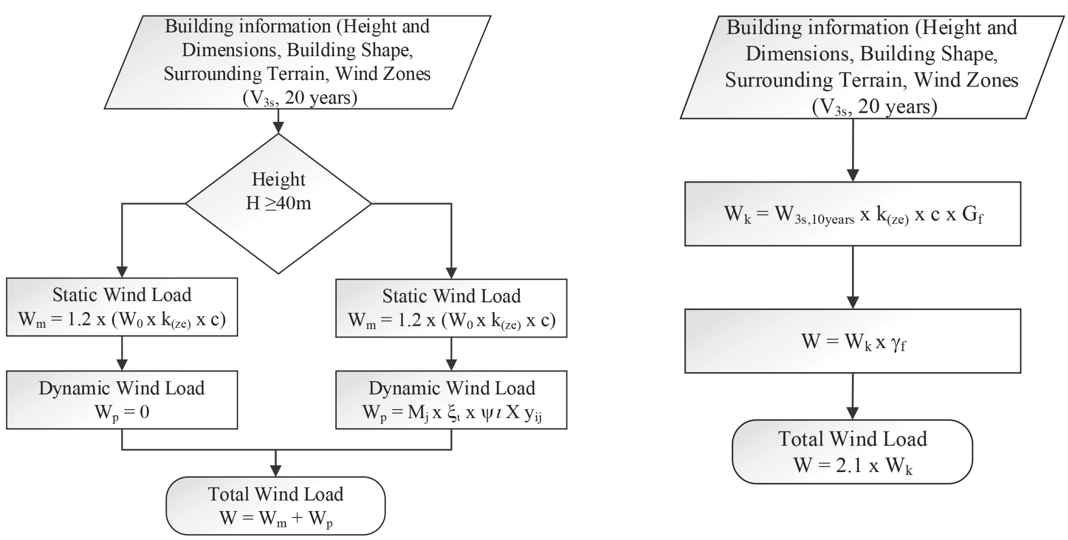


***Figure** 2. Comparison of the calculation process for wind loads*

Where:

W_m - Static wind load for calculation, daN/m^2.

W_p, - Dynamic wind load, daN/m^2.

W_o hay $W_{3s,\ 20\ years}$ - 3-second gust wind pressure with a 20-year return period, daN/m^2.

$W_{3s,\ 10\ years}$ - 3-second gust wind pressure with a 10-year return period, daN/m^2.

$k_{(ze)}$ Coefficient considering height and terrain.

c - Aerodynamic Coefficient

M_j - the mass of j[th] story

ξ_i The coefficient of motive power

ψ_i the Coefficient in i[th] modes

G_f - The gust effect factor

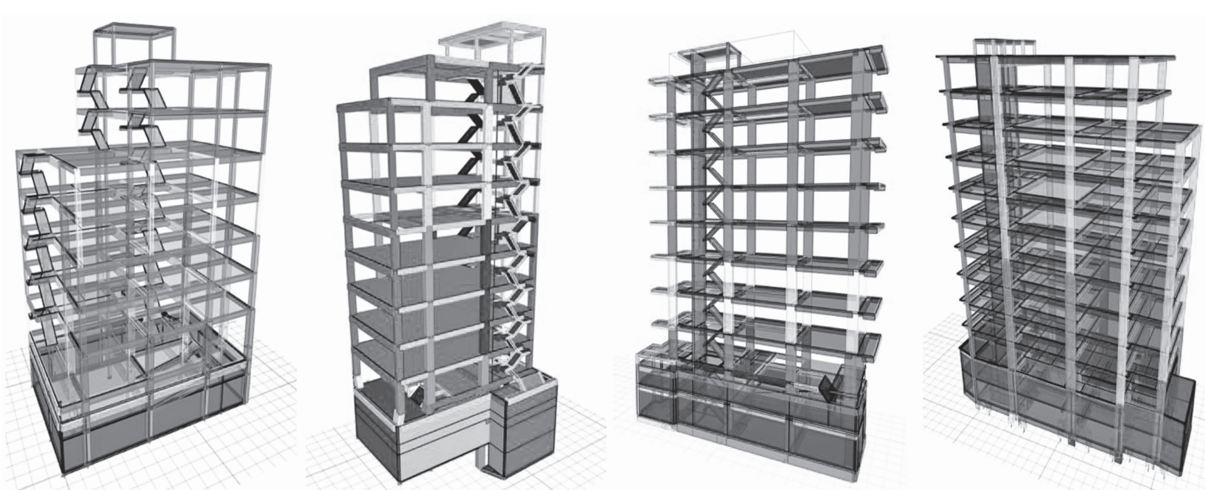
γ_f - Wind load reliability factor

z_e - Equivalent height,, m.

In this research, the author's team used the Etabs 2018 software to analyze 04 Reinforcement Concrete (RC) Low-rise buildings, which are 2 Grade according to Appendix II of Circular 06/2021/TT-BXD [15], as introduced in Table 3. These structures were constructed in Ho Chi Minh City, Vietnam, before 2023. To predict the gust effect factor G_f, the vibration of the structure needs to be determined, where for "stiff" structures (T1 ≤ 1 s), a simple formula can be used, while for "flexible" structures (T1 > 1 s), a dynamic analysis method needs to be employed. This study used Etbas software to model low-rise buildings and analyze modal by Modal – Eigen method using mass source according to TCXD 229:1999 [16] The Etabs models are presented in Figure 3, in which T_x and T_y are the Period of the 1[st] mode shapes in X and Y direction, respectively.

Table 3: The building information

Symbol	Location	Function	Construction Area (m²)	Number of Floors		Height
				Basement	Above Ground	H (m)
No.1	Pasteur Street, Ward Nguyen Thai Binh, District 1, Ho Chi Minh City	Office	202,3	2	9	27,0
No.2	Nguyen Trai Street, Ward Nguyen Cu Trinh, District 1, Ho Chi Minh City	Office	138,31	2	10	33,7
No.3	Van Don Wharf, Ward 9, District 4, Ho Chi Minh City Office	Office	146,3	2	10	27,0
No.4	Pho Quang Street, Ward 2, Tan Binh District, Ho Chi Minh City	Office	318.4	2	10	33,8



a) No1, Tx = 1.37s, Ty = 1.23s   b) No2, Tx = 1.43s, Ty = 0.90s   c) No3, Tx = 1.17s, Ty = 1.48s   d) No4, Tx = 1.59 (s), Ty = 2.19(s)

***Figure** 3. Etabs models of low-rise buildings*

The general observation shows that applying the TCVN 2737:2023 standard on wind loads for construction projects in Vietnam will result in more detailed and accurate calculation results than applying the old TCVN 2737:1995 standard. This is because the new standard provides and adds more content that is more suitable for the characteristics of the structures, which the old version was limited to.

This is because the new standard is based on the latest updated meteorological wind data, accurately reflecting Vietnam's actual wind characteristics. Additionally, the new standard supplements more detailed calculation coefficients for different types of structures and their individual components and updates the calculation formulas to be in line with modern aerodynamic principles.

However, as each structure has unique characteristics in terms of location, structure, architecture, and the wind conditions at the construction site, when applying the new standard, it is necessary to study each case to assess the differences accurately. This issue will be further researched and discussed in the next steps of this study.

3. RESULTS AND DISCUSSION

Reinforced concrete structural design is primarily based on the ultimate limit state (ULS) approach following the TCVN 5574:2018 standard. The ULS design ensures that the structure does not suffer from brittle or ductile failure, loss of stability in shape or position, fatigue failure, or failure due to the combined effects of loads and environmental factors. ULS calculations are typically performed using design loads to verify that the allowable stress limits are not exceeded.

Additionally, reinforced concrete structural design also considers the serviceability limit state (SLS), which aims to ensure the normal working conditions of the structure. As per the TCVN 5574:2018 standard, the SLS approach focuses on controlling the deformations and cracking of the structure to ensure that the building remains safe and maintains its aesthetics and functionality during its operational life. The key factors to be controlled include deflections, lateral displacements, and the formation and propagation of cracks. Adherence to these standards is necessary to ensure that construction projects achieve safety, sustainability, and economic efficiency. The SLS design typically uses characteristic (service) loads to ensure that the allowable stress limits are not exceeded.

Therefore, the research results will focus on evaluating the standard wind loads and the calculated wind loads or design wind loads according to TCVN 2737.

3.1. Wind Pressures

Based on the procedure in Figure 2, the Wind Pressure effects on 04 low-rise buildings are presented in Figure 4. Where SD is the symbol for the Standard value, DE is the symbol for the Design value, X and Y are the symbols for the direction of wind load action.

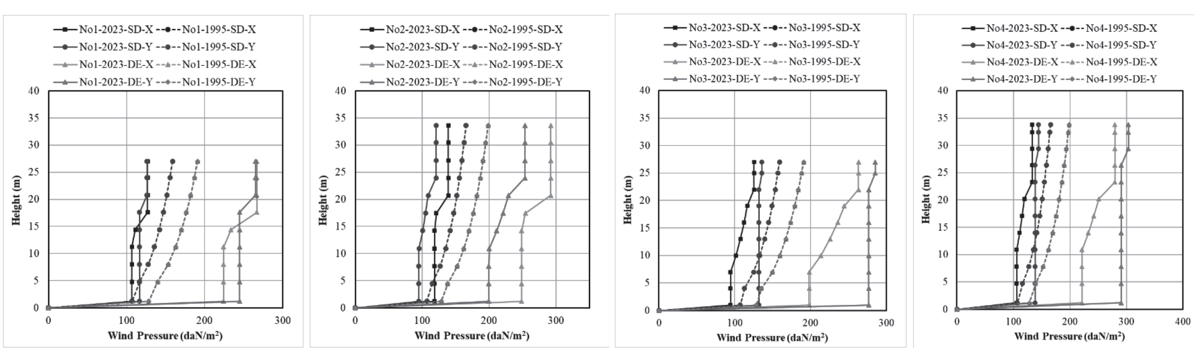


***Figure** 4. The Wind Pressure*

3.1.1. Standard Wind Pressure

The vibration behavior of the structural models and the calculation results can be discussed, and the standard wind loads calculated according to TCVN 2737:2023 are generally lower than those calculated using

TCVN 2737:1995. The wind loads, according to TCVN 2737:2023, are reduced by 0.76 to 1.11 times compared to TCVN 2737:1995, depending on the floor level and wind direction. In some cases, the wind loads may slightly increase or decrease insignificantly, especially on the lower floors. This reduction is due to several factors in the formula and the calculation process for the standard wind load values:

- Although the height and terrain factor Ke(z) values in TCVN 2737:2023 are evaluated to be higher than the old version (Figure 3), they do not have a significant impact.

- The conversion factor of 0.853 to convert the wind pressure from a 20-year return period to a 10-year return period, taken as 0.852, significantly reduces the wind pressure value Wo.

- The gust effect factor Gf < 1 for all this research models, which considered the structural vibration, also significantly reduces the standard wind load value. In contrast, according to TCVN 2737:1995, structures below 40m did not consider the effect of vibration, while structures above 40m had to consider the dynamic wind load (Wp). This dynamic wind load is added to the total wind load, increasing the standard wind load by an average of about 30% (W = Wm + Wp, Figure 2). However, all the research structures had a height lower than 40m, and the dynamic wind load was not considered, following TCVN2737:1995.

3.1.2. Design Wind Pressure

According to TCVN 2737:2023, the wind load calculations show a general increasing trend with the structure's height. At the lower floors (below 10m), the calculated wind loads range from 1.5 to 1.9 kN/m2. At the middle floors (10-20m), the calculated wind loads increase to the range of 1.6 to 1.7 kN/m2. For the higher floors (above 20m), the calculated wind loads continue to rise, reaching values between 1.8 and 2.3 kN/m2. At the roof level and ground floor, the calculated wind loads are lower than the intermediate floors, which are 0 kN/m2 and around 1.5 kN/m2, respectively. Overall, according to TCVN 2737:2023, the wind load calculations exhibit an increasing trend with the height of the building, accurately reflecting the characteristics of wind loads. These conclusions will provide engineers and designers with a comprehensive understanding of the level of wind loads that must be considered to ensure safety and efficiency in structural design.

For the Design wind loads used in Ultimate Limit State design (ULS), the results calculated according to TCVN 2737:1995 using a partial safety factor γw = 1.2 yields lower calculated wind loads compared to the wind loads calculated using TCVN 2737:2023, as the latter proposes using a partial safety factor of γw = 2.1. The Design wind loads according to TCVN 2737:2023 are reduced by 1.23 to 2.26 times compared to TCVN 2737:1995, depending on the floor level and wind direction.

The wind exposure factor Ce, according to TCVN 2737:1995 for a square surface, was $Ce = C_{windward} + C_{leeward} = 0.8 + 0.6 = 1.4$. However, according to TCVN 2737:2023, this wind exposure factor varies in the X and Y directions, with the windward factor Cwindward = 0.8 (as in TCVN 2737:1995), but the leeward factor Cleeward is no longer a constant 0.6 as in TCVN 2737:1995. Therefore, the calculated wind load values according to TCVN 2737:1995 are the same in both directions, while TCVN 2737:2023 has a variable wind exposure factor Ce in the X and Y directions, resulting in different values.

The wind load values at the ground floor are considered from the natural ground level and half of the first floor, while the wind load values at the roof level are considered from the height of half a roof floor. Therefore, the wind loads on these two floors do not follow the same pattern of variation.

3.2. Wind loads are converted to concentrated loads.

To solve the design problem, the analysis of internal forces considering the influence of wind loads is commonly done using the Etabs model in Vietnam, which allows the equivalent wind loads to be simulated as concentrated forces at the center of rigidity of each floor. Therefore, it is necessary to convert the wind loads from wind pressure to concentrated loads. Moreover, the calculation results help evaluate the influence of the windward width on the wind load values. Accordingly, the calculated wind loads for each structure, converted to concentrated loads (kN), are summarized in Figure 5. In this figure, SD is the symbol for the Standard value, DE is the symbol for the Design value, X and Y are the symbols for the direction of wind load action.

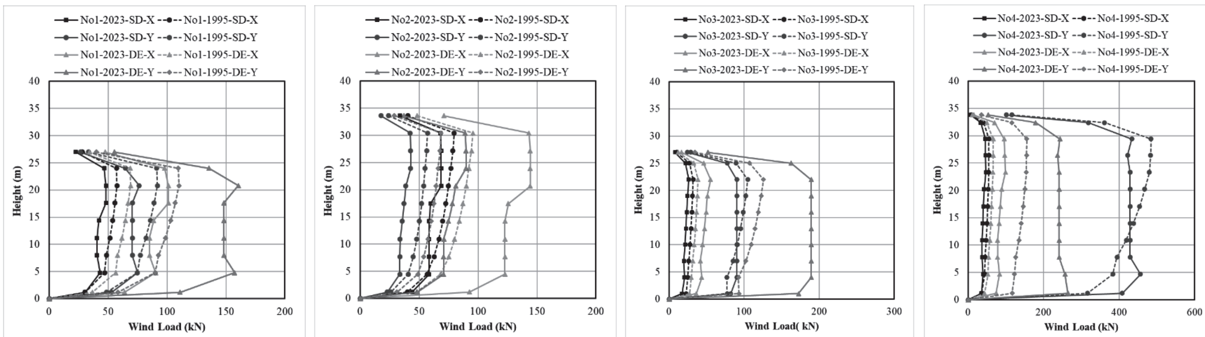


***Figure** 5*. Wind loads converted to concentrated loads

The windward width also influences the value of the wind loads when converting the wind loads into concentrated loads (kN) to model the loads in the Etabs software. When calculated using both standards, the changing width of the floors also alters the distribution of the wind load values. The calculation results show that depending on the floor plan, the concentrated wind load results will vary for each structure. In some cases, a few lower floors may have higher load values compared to the upper floors due to a larger floor plan design.

3.3. Comparison of the impact of wind loads

The results presented in Figure 6 compare the wind load values according to the two standards, TCVN 2737:2023 and TCVN 2737:1995, expressed through the ratio of the wind loads. For the standard wind loads in the serviceability limit state (SLS) check, the averages ratio was 0.935 times, indicating that the wind load check problem under the new standard is more accessible to meet the related deformation requirements than the old standard. However, when considering the reliability factor for the ultimate limit state (ULS) design, the ratio is calculated from 1.23 to 2.26 times, showing that the new standard ensures greater safety and requires higher design standards than the old standard.

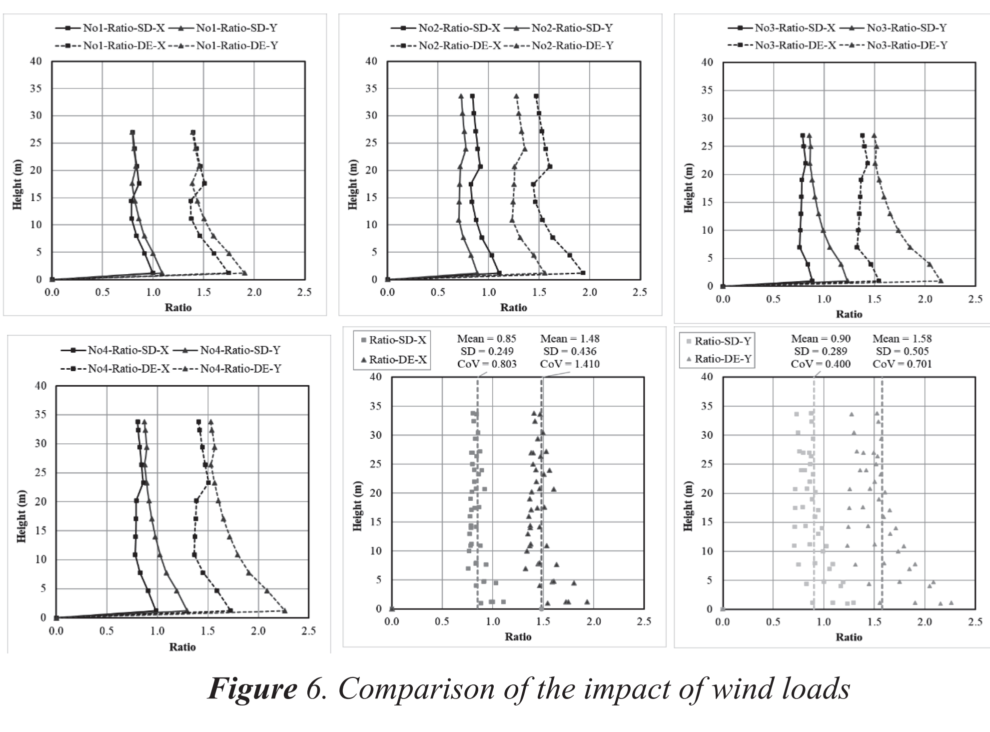


***Figure** 6. Comparison of the impact of wind loads*

The average values in the X and Y directions confirm a more specific assessment of the wind loads in TCVN 2737:2023, as reflected by the wind exposure factor Ce. On some lower floors, the ratio is higher than on the upper floors, as indicated by the standard deviation factor, which varies from 0.249 to 0.505. This is because TCVN 2737:2023 determines the reference height ze based on the building dimensions, resulting in a higher k(ze) factor compared to the old standard. The CoV (Coefficient of variation) analysis shows that the wind load ratio increases with building height in the case study, confirming that the new standard provides a more specific assessment of wind loads, especially at lower floors and for low-rise buildings.

4. CONCLUSION

This study is one of the first to compare the impact of wind loads according to the old TCVN 2737:1995 standard and the new TCVN 2737:2023 standard on existing civil engineering structures. This is a new point compared to previous studies, which usually focused on only one standard or compared to theoretical models. The research results will provide a scientific basis for proposing appropriate reinforcement and renovation solutions for each existing structure. The following conclusions can be conducted for this study:

- The standard wind load values according to TCVN 2737:2023 are generally lower than those calculated using TCVN 2737:1995, reduced by 0the average of 0.935 times, depending on the floor level and wind direction. This reduction is mainly due to the influence of factors such as the gust effect factor Gf and The conversion factor of 0.853 to convert the wind pressure from a 20-year return period to a 10-year return period.

- The Design wind load, according to TCVN 2737:2023, shows a general increasing trend with the structure's height, reaching values from 1.5 to 2.3 imtes at the upper floors. For the ultimate limit state (ULS) design, the calculated wind loads according to TCVN 2737:2023 are higher than those according to TCVN 2737:1995, due to the use of a partial safety factor of γ_w = 2.1 compared to γ_w = 1.2. The ratio of the calculated wind loads according to TCVN 2737:2023 to TCVN 2737:1995 ranges from 1.23 to 2.26 times, depending on the floor and wind direction.

- The windward width influences the value of the wind loads when converting them to concentrated loads (kN) for modeling in software. When calculated using both standards, the changing width of the floors also alters the distribution of the wind load values. The calculation results for each specific structure will vary depending on the floor plan, and some lower floors may have higher load values compared to the upper floors due to a larger floor plan design.

- Due to the different nature of the structural systems of the buildings, the study only focuses on the results of the distribution of wind loads without assessing the impact on the building's structural system. However, this is a very large research volume that needs to be evaluated on representative structures.

The study only focuses on researching grade 2 buildings with a height of less than 40m, without comparing the impact of dynamic wind loads according to TCVN 2737:1995 with wind loads according to TCVN 2737:2023.

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