A NOVEL APPROACH FOR THE PRELIMINARY DETERMINATION OF THE DYNAMIC WIND IN THE DESIGN PROBLEM

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Abstract - In the design problem, the determination and selection of preliminarily geometrical dimensions for all structures in buildings normally shows big differences in comparison with real results. Simultaneously, it consumes a lot of time. Specifically, for high-rise buildings with the impact of the dynamic wind on the results of preliminary verification, the assessment and design is considerable. Therefore, the search for a solution that can surmount and reduce the aforementioned drawbacks is very necessary. This paper is about the description of a novel approach based upon a factor which is defined via a ratio between the dynamic wind and the static wind in order to precisely and effectively evaluate the preliminary design. During the formulation of this factor, it is based on TCVN 2737:1995 [1] and TCXD 229:1999 [2] concerning the computation of the dynamic and static components of the wind load. Fortunately, the results of the proposed method have been validated with the results via the use of the SAP2000® software, simultaneously in comparison with the ratio of bottom shear forces (BSF). Furthermore, this approach also investigates the effect of structural stiffness with respect to the values of the dynamic component of the wind load. All the comparative results have demonstrated that the proposed approach is reliable and effective.

Key words - wind load; dynamic wind; static wind; gust loading factors.

1. Introduction

The behavior of high rise buildings under the action of the wind load is very complicated. Many international and national standards have been introduced, and proposed the guidelines and procedures for the assessment of the effect of wind loads on high rise buildings [3]. The majority of worldwide standards use the gust loading factor (GLF) to evaluate the action of wind load on buildings along the wind flow. The GLF concept is first introduced by Davenport, and foremost its application in civil engineering area was in 1967 [4]. There Davenport proposed to transfer the problem of the dynamic wind using the statistic method to solvethe equivalent problem of the static wind by taking into account the effects of dynamics and the gust of wind loads as well as the interaction between wind load and structures. Afterwards, many countries in the world, i.e., United State America, Europe, India, China, etc., have exerted GLF into their standard of wind load based upon some of their improvements and changes for conformity with each specific country.

The core of Vietnamese standard TCVN 2737:1995 is based upon the Russian standard SNiP 2.01.07-85 [5] but it has been regulated for conformity with wind zone of Vietnam. According to TCVN 2737:1995 and TCXD 229:1999, the wind load is divided into two parts: the dynamic component and the static component, in which the dynamic wind load is only computed for the buildings with a reference height higher than 40 (m). The computation of the dynamic wind according to this standard is very complicated and encounters many difficulties in practice. Meanwhile, the computation of the wind load according to the American standard ASCE/SEI 7-05 [6], the Australian standard AS/NZS 1170.2:2002 [7], the Japanese Standard AIJ-2004 [8], the consideration of the dynamic component of the wind load is simpler. It is calculated through a dynamic coefficient.

Recently, Hung et al. have had a few researches which mention a simple procedure of computation with respect to the dynamic component of the wind load [9]. He uses the structural software ETASB® to analyze the dynamic wind according to TCVN 2737:1995. Another study of his is an analysis of the parameters which impacts on the dynamic component of the wind load through numerical examples; after that the analyzed results are compared to the static component [10]. Simultaneously, he proposes a factor which can be used in practical design. However this study can only be applied to a few simple buildings.

This paper develops a procedure to compute the dynamic component through the static component of the wind load by using a coefficient which has taken into account the influence of many factors such as the shape and stiffness of building, the characterization of geographic/ meteorological conditions, etc. We can claim that this is a novel approach because it helps us to solve the design problem rapidly, simply and reliably.

2. Theoretical modeling

2.1. Wind loads

Wind loads on structures are characterized by the dynamics of gusts and structures. In reality, the magnitude of wind loads vary according to time, and it causes the buffeting action of structures. Hence, in order to analyze the effects of wind precisely, the wind action distributed over structures will be separated into static and dynamic components.

The static component is the mean pressure of wind computed according to its time action on building.

The dynamic component under investigation is an instant pressure of wind loads which takes into account the inertia force of structures when the building oscillates due to the impulse of wind gusts.

2.1.1. Static component

The normative pressure of the static wind load impacts on an area at a reference height, which is computed according to the following formulae:

$$W_j^{tc} = W_0 k(z_j) c_j [daN/m^2] \quad (1)$$

Where,

W_0: normative wind pressure that depends on division of wind zones, in each wind zone it has the constant normative wind pressure W_0.

$k(z_j)$ and c_j are the coefficients which takes into account the variation of wind pressure with reference height z and aerodynamics respectively.

Design pressure/specified pressure:

$$W_j^{tt} = W_j^{tc}\gamma\beta[daN/m^2] \quad (2)$$

Here γ and β are the coefficient about reliability (it normally select by 1.2) and coefficient which is adjusted according to time for using of building.

2.1.2. Dynamic component

Fora building, its structures possess a basic frequency $f_1(Hz)$ larger than its natural (vibration) frequency $f_l(Hz)(f_1 > f_l)$ then.

Normative pressure:

$$W_{pj}^{tc} = W_j^{tc}\varsigma_j\nu[daN/m^2] \quad (3)$$

Where,

W_j^{tc} is calculated as expression (1).

ς_j is dynamic coefficient of wind load, it depends upon geographic/meteorological conditions and reference heightz_j.

ν is coefficient of spatial correlation of building, it can be determined by looking up in the table with the parameter conditions $\rho = B$ and $\chi = H$.

Design pressure/specified pressure:

$$W_{pj}^{tt} = W_{pj}^{tc}\gamma\beta[daN/m^2] \quad (4)$$

For a building that its plane is symmetric and $f_1 < f_l$. Further for every building that has to satisfy the condition $f_1 < f_l < f_2$, in which f_2 is second natural (vibration) frequency of building.

$$W_{p(ij)} = M_j\xi_i\psi_i y_{ij} \quad (5)$$

Where,

M_j is mass of j^{th}floor, it is summation of all distributed and concentrated loads over thej^{th}floor.

y_{ij} is displacement of j^{th} floor corresponding with the i^{th} mode shape.

ξ_i is dynamic coefficient corresponding with the i^{th} mode shape. It is determined by using graph and based on the factor $\varepsilon_i = \sqrt{\gamma W_0}/940f_i$, here f_i is natural frequency of i^{th} mode shape.

$\psi_i$is computed according to the following expression:

$$\psi_i = \frac{\sum_{j=1}^{n} y_{ji}W_{Fj}}{\sum_{j=1}^{n} y_{ji}^2 M_j} \quad (6)$$

In the expression (6), W_{Fj} is computed as formulae (7):

$$W_{Fj} = W_j^{tc}\zeta_j S_j\nu \quad (7)$$

And ν is proportionate to the first mode shape.

2.2. Formulizing to compute wind loads from W_t

The investigation of a loaded structure consists of the frame and diaphragm so that the oncoming wind with respect to the width of the building is constant over the vertical building, the model is employed to analyze/compute the dynamics of the building, which is a cantilever beam clamped into the ground. The mass is assumed as the concentration of each floor. Consider the wind pressure at a reference height, $z_j = \text{const}$.

Set $n = (W_t + W_đ)/W_t$ (∗), based upon the expressions (1)-(4) that are used to compute static and dynamic winds, we can obtain:

Static wind concentrated on the reference height z_j,

$$W_t = W_0 k(z_j)c_j B_j h_j = const\ [daN] \quad (8)$$

Where B_j the width and height of the oncoming wind area correspond with the reference height z_j.

Dynamic wind at reference height z_j,

$$W_đ = M_j\xi_i\psi_i y_{ij}[daN] \quad (9)$$

Which ξ_i depends on $\varepsilon_i$what is calculated as in the following equation,

$$\varepsilon_i = \frac{\sqrt{\gamma W_0}}{940f_i} \rightarrow \xi_i = f(f_i) \quad (10)$$

$$\psi_i = \frac{\sum_{j=1}^{n} y_{ji}W_{Fj}}{\sum_{j=1}^{n} y_{ji}^2 M_j} = F(y_{ji}, W_{Fj}) \quad (11)$$

Here W_{Fj} is determined as expression (7), $\nu = f(H)$ and $\zeta_j = f(z_j) = \text{const}$, from (11), it can infer $\psi_i = f(H, y_{ij}, M_j)$. Therefore, from (8)-(11), we can conclude that it n is a function which depends on many parameters such as $n = f(H, f_i, y_{ij}, M_j)$. In the next section, a mathematical analysis is used to formulize the correlation between itselfn and its variables (H, f_i, y_{ij}, M_j).

2.3. Application of the regression method [11] to formulize for n

For convenience in mathematical manipulation, in this section we set$y = n$; $x_1 = H$; $x_2 = f_i, x_3 = y_{ij}, x_4 = M_j$. According to (∗) and (8)-(11)n or y is expressed by relationship $y = f(x_1, x_2, x_3, x_4)$. To simplify this, this approach uses the regression method in multiple linear correlation as shown in the equation (12).

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \quad (12)$$

Where b_0, b_1, b_2, b_3 and b_4 are linear coefficients of equation (12).

The data is standardized before performing covariance. To standardize the Y and X data, we first subtract the mean from each observation then divide by the standard deviation, i.e., we compute,

$$y_i^0 = \frac{y_i - \bar{y}}{S_y};\ \ x_{ji}^0 = \frac{x_{ji} - \bar{x}_j}{S_{xj}}; i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, 4 \quad (13)$$

Where $\bar{y}$and$\bar{x}_j$ are mean value, and we are calculate,

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n};\ \bar{x}_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \quad (14)$$

S_y and S_{xj} are standard deviation of Y and X, they are given as follows:

$$s_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \overline{y})^2}{n-1}};\ s_{xj} = \sqrt{\frac{\sum_{i=1}^{n}(x_{ji} - \overline{x}_j)^2}{n-1}} \quad (15)$$

The covariance between the standardized X and Y data is known as the correlation coefficient between Y and X and is given by:

$$r_{yx_j} = \frac{1}{n-1}\sum_{i=1}^{n} y_i^0 x_{ji}^0 \quad (16)$$

$$r_{x_l x_m} = \frac{1}{n-1}\sum_{i=1}^{n} x_{l_i}^0 x_{m_i}^0 \quad l, m = 1,2,3,4; l > m \quad (17)$$

Combining the expression (12), (16) and (17), we establish the following equation system,

$$\begin{aligned} a_1 + a_2 r_{x_1x_2} + a_3 r_{x_1x_3} + a_4 r_{x_1x_4} &= r_{yx_1} \\ a_1 r_{x_2x_1} + a_2 + a_3 r_{x_2x_3} + a_4 r_{x_2x_4} &= r_{yx_2} \\ a_1 r_{x_3x_1} + a_2 r_{x_3x_2} + a_3 + a_4 r_{x_3x_4} &= r_{yx_3} \\ a_1 r_{x_4x_1} + a_2 r_{x_4x_2} + a_3 r_{x_4x_3} + a_4 &= r_{yx_4} \end{aligned} \quad (18)$$

Transforming the equation (18) into natural form as expression,

$$b_j = a_j.\frac{s_y}{s_{xj}} \quad (19)$$

$$b_0 = \overline{y} - \sum_{j=1}^{k} b_j \overline{x}_j \quad (20)$$

To maintain the relation between the dependent variable y and these independent variables x_j, we calculate the coefficient of multiple correlation R, with $R = \sqrt{R^2}$ and $(-1 < R < 1)$.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - b_0 - b_1.x_{1i} - b_2.x_{2i} - b_3.x_{3i} - b_4.x_{4i})^2}{\sum_{i=1}^{n}\left[(y_i - b_0 - b_1.x_{1i} - b_2.x_{2i} - b_3.x_{3i})^2 + (y_i - \overline{y})^2\right]} \quad (21)$$

2.4. Validation with the results using SAP2000®

Through the analysis of the computational model of the building that has the plane as shown in Figure. **2**. the height of this building changes from 17 floors to 21 floors, the applied loads of this building consist of the dead load, the live load and the wind load.

The geometrical properties of this building are given as,

The height of each floor: $h = 3.3\ (m)$

The cross section of the beam $b \times h = 35cm \times 75cm$; the thickness of the concrete diaphragm $30cm$; the thickness of the floor $13cm$.

The preliminary assignment for the column cross section as shown in Table 1.

Table 1. *Preliminary assignment for column cross section of building*

Building				
17 Stories (cm^2)	**18 Stories (cm^2)**	**19 Stories (cm^2)**	**20 Stories (cm^2)**	**21 Stories (cm^2)**
80×80	90×90	100×100	110×110	120×120

- concrete durability $B25$: $R_b = 14.5MPa, E_b = 3 \times 10^4 MPa$.
- Determination of wind loads:
  - Aerodynamic coefficient $c = 1.4$.
  - The building is located in the wind zone II.B (Da Nang city, Vietnam), so $W_0 = 95\ daN/m^2$.
- The investigation of the dynamic and static wind at a reference height $z_j = 42.9m$ (corresponding with the 13rd floor) for all cases with the assumption that the Y direction is the weakest direction of building with respect to wind pressure. And the analyzed results are given in Table 2.

The linear regression equation has the form (22).

$$\begin{aligned} y = n = 1,844 - 3,655E^{-04}.x_1 - 0,599.x_2 \\ +1223,453.x_3 - 0,002.x_4 \end{aligned} \quad (22)$$

And the coefficient of multiple correlation $R = 0,99996$, easily determine the wind load as,

$$W = W_t.n = 27324,132.n\ (daN) \quad (23)$$

From expression (22) and (23), we do the calculations, and the assessment results are presented in Table 3.

Similarly, this is applied for the building that contains 21 floors, this building has geometric properties as mentioned above. But its plane is given in Figure. **1**.

Table 2. *The analyzed results of dynamic wind, static wind and n factor-case 1.*

Building	H(m)	fi(Hz)	yji(m)	Mj(T)	Wt (daN)	Wd(daN)	Wg(daN)	n
17 Stories	56,1	0,6994	3,01E-04	111,11	27324,13	13564,65	40888.78	1,4964
18 Stories	59,4	0,6623	2,69E-04	114,23	27324,13	12857,96	40182.09	1,4706
19 Stories	62,7	0,6269	2,42E-04	117,72	27324,13	12255,13	39579.25	1,4485
20 Stories	66,0	0,5934	2,18E-04	121,57	27324,13	11702,41	39026.54	1,4283
21 Stories	69,3	0,5620	1,96E-04	125,80	27324,13	11179,21	38503.33	1,4091

Table 3. Evaluation of results-case 1.

Building	H(m)	fi(Hz)	yji(m)	Mj(T)	Wt (daN)	n	Wg(daN)	Δ%
17 Stories	56,1	0,6994	3,01E-04	111,11	27324,13	1.4964	40886.49	0,0056%
18 Stories	59,4	0,6623	2,69E-04	114,23	27324,13	1.4704	40178.23	0,0096%
19 Stories	62,7	0,6269	2,42E-04	117,72	27324,13	1.4488	39586.00	0,017%
20 Stories	66,0	0,5934	2,18E-04	121,57	27324,13	1.4286	39035.90	0,024%
21 Stories	69,3	0,5620	1,96E-04	125,80	27324,13	1.4088	38493.36	0,026%

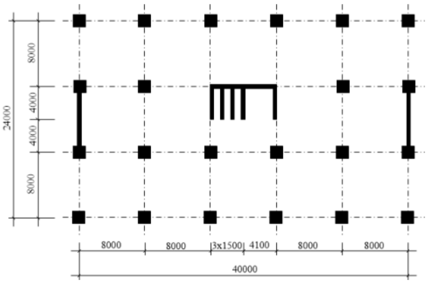

Figure. 1. *A typical plane of building-case 2*

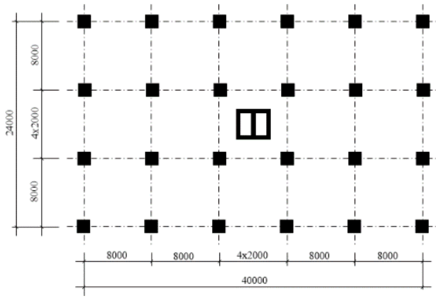

Figure. 2. *A typical plane of building-case 1*

The results obtained at 13rd floor and 15th floor are described in Table 4.

Table 4. *The analyzed results of dynamic wind, static wind and n factor-case 2.*

Floor	**13**	**15**
W_t(daN)	27324,13	28166.82
H(m)	69,3	69,3
f_i(Hz)	0,5827	0,5827
y_{ji}(m)	1,99E-04	2,39E-04
M_j(T)	123,253	123,253
W_d(daN)	11127.85	13364.61
$W_{gió}$(daN)	38453,23	41531,43
n	1,407	1,474

Similar to the above case, from expressions (22) and (23), and in comparison with the wind load in Table 4. we do the calculations, and the assessment results are presented in Table 5.

Table 5. *Evaluation of results-case 2*

Floor	**13**	**15**
W_t(daN)	27324,13	28166.82
H(m)	69,3	69,3
f_i(Hz)	0,5827	0,5827
y_{ji}(m)	1,99E-04	2,39E-04
M_j(T)	123,253	123,253
n	1,405	1,454
$W_{gió}$(daN)	38389,126	40960,10
Δ%	0,16%	1,37%

2.5. Comparison of the bottom shear forces

In an investigation into 6 buildings with the number of floors varies from 17 floors to 22 floors, the relationship between the BSF with respect to dynamic and static components of the wind load is described in Figure. **2.3** and Figure. **2.4**.

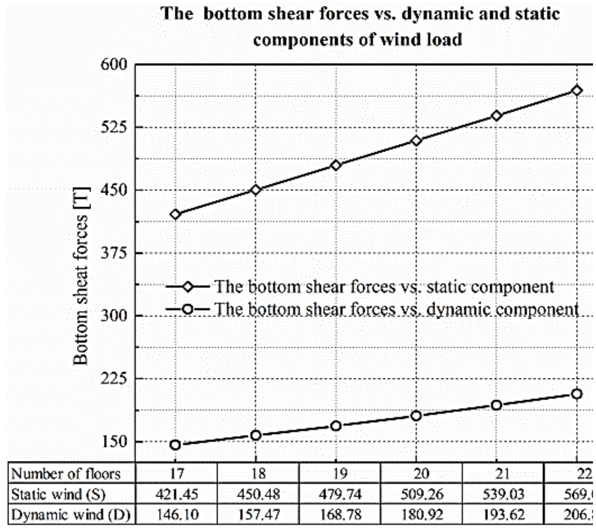

Figure. 2.3. *Relation of the BSF vs. dynamic and static components of wind load*

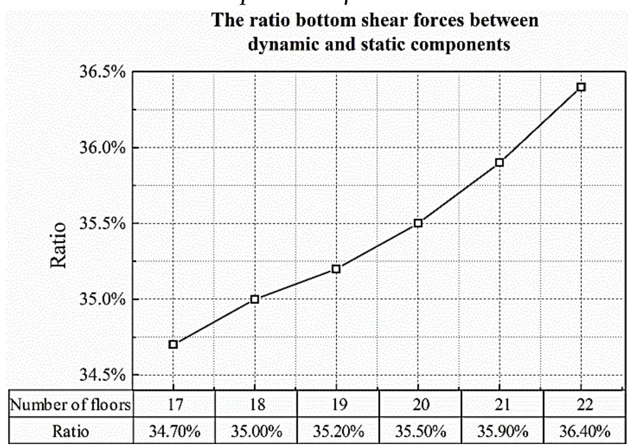

Figure. 2.4. *Relation between ratio of the BSF vs. ratio of dynamic and static components of wind load.*

The relationship between the stiffness of the building and the BSF is presented in Figure. **2.5**.

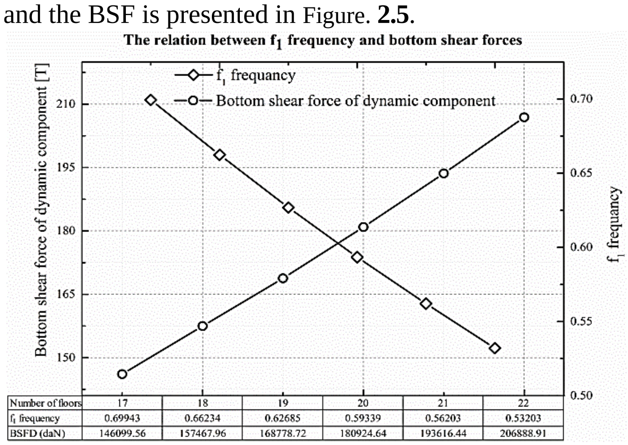

Figure. 2.5. *Relation of the BSF vs. the stiffness of building.*

3. Evaluations

The coefficient of the multiple correlation of all the aforementioned cases has $R > 0.9$, this maintains that the relation between the BSF with dynamic and static components of the wind load, the relation of the BSF with the stiffness of building are reliable.

The maximum errors between the results computed by the proposed method and the results are shown by formulations in TCVN 2737:1995 is 0.026%. This demonstrates that the proposed method meets with TCVN 2737:1995. Therefore our method can be applied to the preliminary verification, assessment and design.

After the application of 21 floors of the building model into computing the wind load at 13th floor and 15th floor, the results presented in Table 4 and Table 5 are sufficiently small. This additionally strengthens the reliability of the proposed method.

Through Figure. **2.3** and Figure. **2.4**, it enables us to evaluate the total BSF of the dynamic component of the wind load. It is about $(34-37)\%$ of the total BSF of the static component of the wind load.

Figure. **2.5** shows that if the building reduces its stiffness then the BSF of the dynamic component of the wind load increases sufficiently. This leads to the conclusion that the building has small stiffness then it is easily influenced by the dynamic wind. This judgment is very important for design problems because if we are looking for the reduction of dynamic wind effect, then the building must increase its stiffness.

4. Conclusions

We can use the proposed expression to compute the total wind load which acts on the building in conditions namely the same oncoming wind of the area, geographic/meteorological conditions, the reference height according to the static component of the wind load. And the total wind load is computed with the following formula:

$$W=n.W_t \tag{4.1}$$

When we design a high rise building, specifically in the preliminary design stage or the verification of the structural/building stability under the wind load, to reduce the time consuming and computation, we can calculate the total BSF of the dynamic component of the wind load by $(34-37)\%$ of the total BSF of the static component of the wind load.

To reduce the action of the dynamic wind on the high rise building, the building's stiffness needs to increase in the design process.

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