TCXD **CONSTRUCTION STANDARD**

**20 TCXD 229:1999**

# GUIDELINES ON CALCULATING DYNAMICS OF WIND LOAD CAPACITY UNDER TCVN 2737:1995

**(This translation is for reference only)**

**Construction Publishing House**
**HANOI - 1999**

## Foreword

20 TCXD 229:1999 was prepared on the basis of regulations on determination of dynamic component of wind load given in TCVN 2737:1995.

20 TCXD 229: 1999 was prepared by the Institute of Construction Technology Sciences – Ministry of Construction, proposed by Department of Construction Technology Sciences, issued by Ministry of Construction.

# Guidelines on calculating dynamics of wind load capacity under TCVN 2737:1995

## 1. Scope

**1.1.** This guidance is used for determining dynamic component of wind load acting on structures, foundations, houses and buildings according to load and action standard TCVN 2737:1995 [1].

**1.2.** The dynamic component of wind load shall be taken into account when determining works such as tower, column, chimney, electric pole, columnar equipments, conveyor corridor, open frames…buildings with height more than 40 meters, transverse frame of one storey, one span industrial work having the height more than 36 meters and the ratio between height and span greater than 1,5.

**1.3.** For high buildings and soft structures (chimney, column, tower…), it must carry out dynamic stability loss check. The check can be referred to Annex C of this guidance.

**1.4.** For specified works under sector: transports, irrigation, electric power, post….it needs to take into account the particular calculations suitable for characteristics of each work.

## 2. Principles

**2.1.** Wind load consists of two components: static component and dynamic component. Values and calculation directions of the static component shall be defined according to clauses given in standard on load and action TCVN 2737:1995 [1].

**2.2.** The dynamic component of wind load shall be determined according to the direction corresponding to calculation directions of static component.

**2.3.** Dynamic component of wind load acting on buildings is the force caused by pulse of wind speed and inertia force of buildings. This force value shall be determined on the basis of static component of wind load multiplied with coefficients that are taken into account the impact of wind speed impulse and building inertia force.

**2.4.** The calculation of works under dynamic action of wind load consists of: the determination of dynamic component of wind load and the reaction of works caused by dynamic component respective to each vibration.

**2.5.** Number of formulae, clauses, sections, tables and figures are explained or stipulated for use in content of clauses, sections and annexes; if associated documents are not mentioned, it means that this is formula, clause, section, table or figure of this guidance.

## 3. Procedures for determination of dynamic component of wind load

**3.1.** Check if work belongs or not to scope of dynamic component determination and dynamic stabilization loss according to Clause 1.2 and 1.3 above.

**3.2.** Set up dynamic force calculation scheme.

**3.2.1.** Selected calculation scheme shall be a console system with limited volume concentration points, see Annex A, figure A.1.

**3.2.2.** Divide the work into n parts so that each part has a hardness and wind pressure of work surface regarded as constant

**3.2.3.** The position of the volume concentration points shall be laid corresponding to the center altitude of transverse load structure of work (floor, transverse brace layout plan, working floor), or the center of the structures, the fixed equipments, regularly stored materials (water on stage of water tower ...).

**3.2.4.** Value of the concentration volume at different level in the calculation scheme shall be equal to the total value of volumes of load-bearing structure, cladding and decorative structure, fixed equipments (working machine, motor, storage tank, pipelines…), stored materials (liquids, bulk materials…) and other volumes. The determination and combination of these concentration volumes shall meet requirements given in TCVN 2737:1995 and relevant standards. For determination of dynamic force of wind load, it must enter the volume reduction coefficient when taking into account the volume of provisional objects on the work.

**Table 1 – Reduction coefficient for several types of weights provisionally piled on the work**

<table>
<tr><th colspan="2">Volume type</th><th>Volume reduction coefficient</th></tr>
<tr><td colspan="2">Dust heaped on the roof</td><td>0.5</td></tr>
<tr><td colspan="2">Materials stored in the warehouse, silo, bunker, tank</td><td>1.0</td></tr>
<tr><td rowspan="2">People, objects on the floor evenly distributed</td><td>Libraries, warehouses for goods and documents</td><td>0.8</td></tr>
<tr><td>Other civil works</td><td>0.5</td></tr>
<tr><td rowspan="2">Crane and hanging crane for heavy objects</td><td>With hard hook</td><td>0.3</td></tr>
<tr><td>With soft hook</td><td>0.0</td></tr>
</table>

**3.2.5.** The hardness of console bar shall be equal to the equivalent hardness of work. The equivalent hardness can be determined so that the movements at the actual work peak and at the console bar peak are similar when acting to work peak and console peak by a same transversal force.

**3.3.** Determination of the standard value of static components of wind pressure acting on work parts

**3.3.1.** Determine the standard wind pressure according to clause 4.11.

**3.3.2.** Determine the height coefficient k(zj) for each $j^{th}$ part of the work according to table 7, where standard elevation for height calculation is determined according to Annex A, section A.2.3.

**3.3.3.** Determine the aerodynamic coefficient c for each part of the work in accordance with table 6 of TCVN 2737:1995.

**3.3.4.** Determine the standard value of static component of wind pressure acting on work parts according to Clause 4.10.

**3.4** Determine the standard value of dynamic component of wind load acting on calculated work parts when taking into account only the impact of wind speed impulse.

**3.4.1.** Determine the dynamic pressure coefficient and the space correlation coefficient for calculated work parts according to table 3, table 4 and table 5.

**3.4.2.** Determine the standard value of dynamic component of wind load acting on designed work parts when taking into account only the impact of wind speed impulse in accordance with clause 4.2.

**3.5.** Determination of standard value and designed value of dynamic component of wind load acting on designed parts of work.

**3.5.1.** Determination of frequency and vibration types

**3.5.1.1.** Determine the first vibration frequency $f_l$ (Hz) of work. It may be apply formulae given in Annex B, from clauses B.1 to B.3.

**3.5.1.2.** Compare the frequency $f_l$ with limit frequency $f_L$ in the table 2. If $f_l > f_L$, the standard value of dynamic component shall be determined according to clause 4.2. If $f_l < f_L$, the standard value of dynamic component shall be determined according to clauses from 4.3 to 4.8.

**3.5.2.** Determine the designed value of dynamic component of wind load acting on designed work parts according to clause 4.9.

**3.6.** Combine the internal force and displacement of work caused by static and dynamic components of wind load according to clause 4.12.

## 4. Determination of dynamic component of wind load in accordance with TCVN 2737:1995

**4.1.** Depending on the work sensibility toward the dynamic impact of wind load, the dynamic component of wind load shall take into account only impact of wind speed impulse or also the inertia force of work.

The sensibility shall be monitored through the correlation between values of specific private vibration frequencies of work, particularly the first private vibration frequency, and the limit frequency $f_L$ given in table 2. Values given in this table are referenced to TCVN 2737:1995.

**Table 2 - Limit values of the private vibration frequency $f_L$**

| Wind pressure area | $f_L$ (Hz) | |
|---|---|---|
| | $\delta = 0.3$ | $\delta = 0.15$ |
| I | 1.1 | 3.4 |
| II | 1.3 | 4.1 |
| III | 1.6 | 5.0 |
| IV | 1.7 | 5.6 |
| V | 1.9 | 5.9 |

***Note:*** *$\delta$ - the vibration logarithmic reduction of structure, depending on structural types and main materials of work. For TCVN 2737:1995, values $\delta$ given in table 2 are corresponding to types of work given in the note of figure 2.*

**4.2.** For works and structural components having basic vibration frequency $f_l$ (Hz) greater than the critical value of natural vibration frequency $f_L$ given in clause 4.1, the dynamic components of wind load shall take into account only the action of wind speed impulse. Since the standard value of dynamic component $W_{pj}$ acting on $j^{th}$ part of work shall be defined by the formula:

$$W_{pj} = W_j \zeta_j \nu \qquad (4.1)$$

Where:

$W_{pj}$ – pressure, calculated in daN/m$^2$ or kN/m$^2$ according to unit of $W_j$;

$W_j$ – Standard value of static component of wind pressure acting on $j^{th}$ part of work, defined in accordance with clause 4.10;

$\zeta_j$ – The dynamic pressure coefficient of wind load, at the height respective to $j^{th}$ part of work, non-dimensional. Values of $\zeta_j$ shall be in accordance with TCVN 2737:1995 and given in table 3.

$\nu$ - Space correlation coefficient of dynamic pressure of wind load respective to different vibration types of work, non-dimensional. In the formula (4.1), $\nu$ shall be equal to $\nu_1$. If the luff side of work having rectangular shape oriented parallel to base axles in figure 1, value of $\nu_1$ shall be taken from table 4, where $\rho$ and $\chi$ parameters shall be defined according to table 5, value of $\nu$ respective to the second and third vibration type $\nu_2 = \nu_3 = 1$. Values given in table 4 and table 5 shall be taken from TCVN 2737:1995.

**Table 3 – The dynamic pressure coefficient $\zeta$**

| Height z (m) | The dynamic pressure coefficient $\zeta$ for relief types | | |
|---|---|---|---|
| | A | B | C |
| ≤ 5 | 0.318 | 0.517 | 0.754 |
| 10 | 0.303 | 0.486 | 0.684 |
| 20 | 0.289 | 0.457 | 0.621 |
| 40 | 0.275 | 0.429 | 0.563 |
| 60 | 0.267 | 0.414 | 0.532 |
| 80 | 0.262 | 0.403 | 0.511 |
| 100 | 0.258 | 0.395 | 0.496 |
| 150 | 0.251 | 0.381 | 0.468 |
| 200 | 0.246 | 0.371 | 0.450 |
| 250 | 0.242 | 0.364 | 0.436 |
| 300 | 0.239 | 0.358 | 0.425 |
| 350 | 0.236 | 0.353 | 0.416 |
| ≥ 480 | 0.231 | 0.343 | 0.398 |

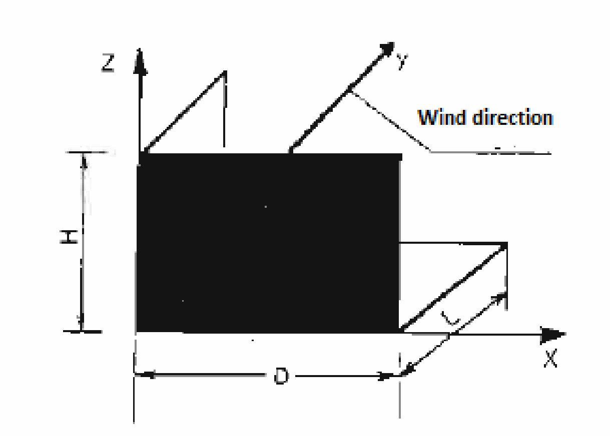



**Figure 1: Coordinate system determining the space correlation coefficient $\nu$**

**Table 4: Space correlation coefficient $\nu_1$ when considering the correlation between wind speed impulses by height and luff width, depending on $\rho$ and $\chi$**

| $\rho$(m) | Coefficient $\nu_1$ when $\chi$ is equal to (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 40 | 80 | 160 | 350 |
| 0,1 | 0,95 | 0,92 | 0,88 | 0,83 | 0,76 | 0,67 | 0,56 |
| 5 | 0,89 | 0,87 | 0,84 | 0,80 | 0,73 | 0,65 | 0,54 |
| 10 | 0,85 | 0,84 | 0,81 | 0,77 | 0,71 | 0,64 | 0,53 |
| 20 | 0,80 | 0,78 | 0,76 | 0,73 | 0,68 | 0,61 | 0,51 |
| 40 | 0,72 | 0,72 | 0,70 | 0,67 | 0,63 | 0,57 | 0,48 |
| 80 | 0,63 | 0,63 | 0,61 | 0,59 | 0,56 | 0,51 | 0,44 |
| 160 | 0,53 | 0,53 | 0,52 | 0,50 | 0,47 | 0,44 | 0,38 |

**Table 5: Parameters $\rho$ and $\chi$**

| **Basic coordinate plan parallel to designed surface** | $\rho$ | $\chi$ |
|---|---|---|
| zox | D | H |
| zoy | 0.4L | H |
| xoy | D | L |

***Note**: For work with non-rectangular luff surface, H shall be taken equally to work height, D and L shall be of corresponding dimension at the projection center of luff surface on vertical surfaces, perpendicular to wind current direction.*

**4.3.** For works and structural components having basic vibration frequency $f_1$ (Hz) smaller than the critical value of natural vibration frequency $f_L$ stipulated in clause 4.1, the dynamic component of wind load shall take into account action of both wind speed impulse and work inertia force. Therefore, number of vibration types to be determined and standard values of dynamic component of wind load $W_{p(ji)}$ acting on $j^{th}$ part respective to $i^{th}$ vibration type shall be defined in accordance with clauses from 4.4. to 4.8.

**4.4.** Works or structural components having a $s^{th}$ free basic vibration frequency that meets the following inequality:

$$f_s < f_L < f_{s+1} \qquad (4.2)$$

need to be determined for dynamic component with s of first vibration type.

4.5. Standard value of dynamic components of wind load acting on the $j^{th}$ part respective to $i^{th}$ vibration type shall be defined by the formula:

$$W_{p(ji)} = M_j \xi_i \psi_i y_{ji} \qquad (4.3)$$

Where:

$W_{p(ji)}$ – force, unit is usually in daN or kN depending ton unit of $W_{Fj}$ in the formula for coefficient $\psi_i$;

$M_j$ – weight concentration of the $j^{th}$ part of work, in (t);

$\xi_i$ – Dynamic coefficient respective to the i[th] vibration type, non-dimensional, depending on the parameter $\varepsilon_I$ and the logarithmic reduction of vibration:

$$\varepsilon_i = \frac{\sqrt{\gamma W_o}}{940 f_i} \tag{4.4}$$

Where:

$\gamma$ - reliability coefficient of wind load, taken equally to 1.2;

$W_o$ – value of wind pressure, in N/m$^2$;

$F_i$ – the i[th] natural vibration frequency (Hz).

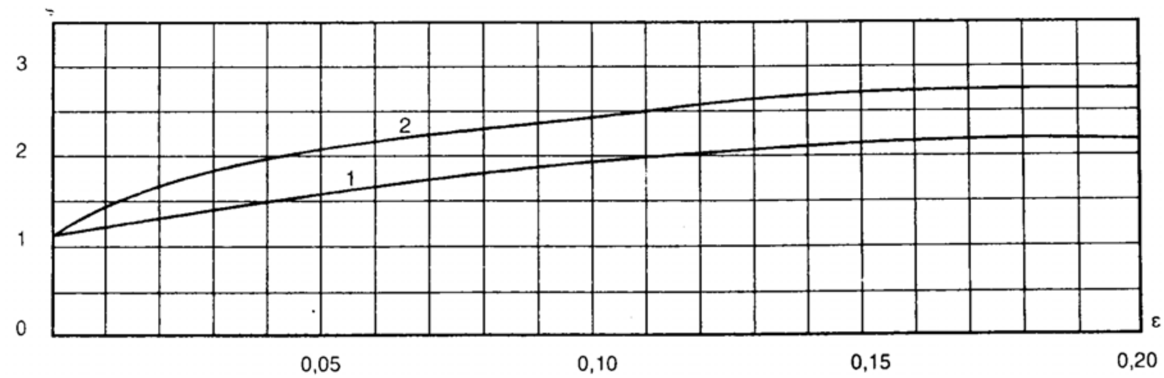



**Figure 2: Graph for determination of the dynamic coefficient ξ**

***Note:***

*1) The curve 1: used for concrete reinforced and brick, stone works including work of steel frame with cladding structure ($\delta$ = 0.3).*

*2) The curve 2: used for tower, steel pillar, chimney, columnar equipment having concrete reinforced base ($\delta$ = 0.15).*

$y_{ji}$ – the relative transversal movement of the center of gravity of the j[th] work part, respective to the i[th] natural vibration type, non-dimensional;

$\psi_i$ - Coefficient that is determined by dividing the work into n parts, in the range of each component of wind load regarded as constant:

$$\Psi_i = \frac{\sum_{j=1}^{n} y_{ji} W_{Fj}}{\sum_{j=1}^{n} y_{ji}^2 M_j} \tag{4.5}$$

Where:

$W_{Fj}$ – standard value of dynamic component of wind load acting on the j[th] part of work, corresponding to different vibration types while taking into account only the wind speed impulse, dimensional force, shall be defined by the formula:

$$W_{Fj} = W_j \zeta_i S_j \nu \tag{4.6}$$

Where:

$W_j$, $\zeta_I$ – meanings as given in formula (4.1)

ν - meaning as given in formula (4.1). When calculating the first vibration type, ν shall be equal to $\nu_1$, but for the rest vibration types, ν is equal to 1. Values of $\nu_1$ shall be determined by Clause 4.2;

$S_j$ – the luff area of the j[th] part of work ($m^2$);

***Note:*** *The formula (4.6) is similar to formula 8 in TCVN 2737:1995 but it was multiplied further with $S_j$ to transform calculation result from pressure into force.*

**4.6.** Symmetrical plan house, with $f_l < f_L$, the effect of the first vibration type on value of dynamic component is essential. Since it may define the standard value of dynamic component by the formula:

$$W_{P(jl)} = M_j \xi_l \Psi_l y_{jl} \tag{4.7}$$

Where:

$W_{p(jl)}$ – force, calculation unit is suitable to unit of $W_{Fj}$ when defining coefficient $\psi_1$;

$M_j$, $\xi_l$, $\psi_l$ – meanings similar to those mentioned in formula (4.3) but with I = *l*;

$y_{jl}$ – relative transversal movement of j[th] part center corresponding to the first natural vibration type. Allow taking $y_{jl}$ equal to displacement caused by the evenly distributed transverse load that was statically laid.

**4.7.** For multi-storey building with symmetrical plane, the stiffness, weight and luff width remaining constant by height, with $f_l < f_L$, allow determining the standard value of dynamic component at the height z by the following formula:

$$W_{fz} = 1{,}4 \frac{z}{H} \xi W_{pH} \tag{4.8}$$

Where:

$W_{Fz}$ – pressure, with calculation unit suitable to unit of $W_{pH}$;

ξ - Dynamic coefficient respective to the basic vibration of work;

$W_{pH}$ – standard value of dynamic component of wind load at the height H of work peak, determined according to formula (4.1).

**4.8.** For work or structural parts whose calculation diagram has one degree of freedom and $f_l < f_L$, the standard value of dynamic component of wind load shall be determined by the formula:

$$W_p = W\zeta\xi\nu \qquad (4.9)$$

Where:

$W_p$, W – standard value of dynamic component and static component of wind load corresponding to the designed height, dimensionality is  force per area;

ζ - dynamic pressure coefficient of wind load, non-dimensional;

ξ, ν - dynamic coefficient and correlative space coefficient of dynamic pressure corresponding to the basic vibration, non-dimensional.

**4.9.** Designed value of dynamic component of wind load or pressure shall be determined by the formula:

$$W^{tt} = W\gamma\beta \qquad (4.10)$$

Where:

$W^{tt}$ – designed value of wind load or pressure;

W – standard value of wind load or pressure, determined by formulae (4.1), (4.3), (4.7), (4.8), (4.9);

γ - reliability coefficient of wind load, γ is equal to 1.2;

β - Correction coefficient of wind load according to assumed using time of work, defined in Table 6. Values given in this table are taken from TCVN 2737:1995.

**Table 6 – Coefficient β**

| Assumed using time | 5 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|
| Correction coefficient of wind load β | 0.61 | 0.72 | 0.83 | 0.91 | 0.96 | 1.00 |

**4.10.** The standard value of static component of wind pressure $W_j$ at the point j respective to height $z_j$ in comparison with standard level shall be defined by the formula:

$$W_j = W_o k(z_j)c \qquad (4.11)$$

Where:

$W_j$ – a dimensionality is force per area, depending on calculation unit of $W_o$;

$W_o$ – standard value of wind pressure according to classification of wind pressure region in TCVN 2737:1995;

c – aerodynamic coefficient taken from table 6 in TCVN 2737:1995, non-dimensional;

$k(z_j)$ – factor, non-dimensional, taking into account the wind pressure change: $k(z_j)$ depends on the height $z_j$, standard level for calculating height and designed relief type. Values of $k(z_j)$ according to TCVN 2737:1995 are given in Table 7. See annex A, section A.2.3. for method of determination of standard level to calculate the height.

**Table 7: Coefficient $k(z_j)$ taking into account wind pressure change by height and relief type.**

| Height z (m) \ Relief type | A | B | C |
|---|---|---|---|
| 3 | 1.00 | 0.80 | 0.47 |
| 5 | 1.07 | 0.88 | 0.54 |
| 10 | 1.18 | 1.00 | 0.66 |
| 15 | 1.24 | 1.08 | 0.74 |
| 20 | 1.29 | 1.13 | 0.80 |
| 30 | 1.37 | 1.22 | 0.89 |
| 40 | 1.43 | 1.28 | 0.97 |
| 50 | 1.47 | 1.34 | 1.03 |
| 60 | 1.51 | 1.38 | 1.08 |
| 80 | 1.57 | 1.45 | 1.18 |
| 100 | 1.62 | 1.51 | 1.25 |
| 150 | 1.72 | 1.63 | 1.40 |
| 200 | 1.79 | 1.71 | 1.52 |
| 250 | 1.84 | 1.78 | 1.62 |
| 300 | 1.84 | 1.84 | 1.70 |
| 350 | 1.84 | 1.84 | 1.78 |
| ≥ 400 | 1.84 | 1.84 | 1.84 |

***Note:***

*1) For the intermediate height, allow determining value of $k(z_j)$ by the linear interpolation according to table 7.*

*2) When determining wind load for a work, for different wind directions, it may have different types of relief.*

**4.11.** Value of wind pressure $W_o$ shall be determined from wind speed $v_o$ that was handled on the basis of monitoring data on wind speed at the height of 10m in comparison with standard level (the mean speed within 3 seconds, is exceeded by average once every 20 years), corresponding to B type relief, (surface roughness $z_o$= 0.005). The standard value of wind pressure $W_o$ according to the map classifying wind pressure region in TCVN 2737:1995, is given in table 8.

For region where storm effect is considered weak, value of wind pressure $W_o$ shall be reduced by 10 daN/m$^2$ for region I-A, by 12 daN/m$^2$ for region II-A and 15 daN/m$^2$ for region III-A.

**Table 8 – Standard values of wind pressure $W_o$**

| Wind pressure region | I | II | III | IV | V |
|---|---|---|---|---|---|
| $W_o$ (daN/$m^2$) | 65 | 95 | 125 | 155 | 185 |

For region I, the value of wind pressure $W_o$ in accordance with table 8 is applied to design houses and buildings in the mountain region, plain region and valley region.

For complicated relief (defile, between two parallel mountains, mountain pass gates….), value $W_o$ shall be taken from data of National Department on Hydro- Meteorological services or survey results on site that were handled taking into account the experiences on use of work. Thus, the value of wind pressure $W_o$ shall be determined by the formula:

$$W_o = 0{,}0613 v_o^2 \tag{4.12}$$

***Note:*** *In the formula (4.12), $v_o$ shall be in m/s, $W_o$ shall be in daN/$m^2$.*

For houses and works built in mountain and island region with the same height, same relief type and next to hydro-meteorological stations given in annex F of TCVN 2737:1995, the designed value of wind pressure with the different assumed life time shall be taken according to independent number of these stations (see Table $F_1$ and $F_2$, annex F in TCVN 2737:1995).

**4.12.** Internal force and displacement caused by static and dynamic component of wind load shall be defined as follows:

$$X = X^t + \sqrt{\sum_{i=1}^{s} (X_i^d)^2} \tag{4.13}$$

Where:

X – bending (twisting) moment, shear force, longitudinal force or displacement;

$X^t$ – bending (twisting) moment, shear force, longitudinal force or displacement caused by static component of wind load;

$X_i^d$ - bending (twisting) moment, shear force, longitudinal force or displacement caused by dynamic component of wind load with the $i^{th}$ vibration type;

s - number of designed vibration types.

## Annex A

## (Reference)

## Construction of formula calculating dynamic component of wind load

**A.1. Reaction of work and dynamic component of wind load:**

General differential equation describes the vibration of console bar with limited degree of freedom when ignoring the bar weight:

$$[M]\ddot{U} + [C]\dot{U} + [K]U = W^{'}(\tau) \qquad \text{(A.1)}$$

Where:

[M], [C], [K] – weight matrix, resistance matrix, stiffness matrix of system

$\ddot{U}, \dot{U}, U$ - vectors of acceleration, velocity and displacement of coordinates determining degree of freedom of system.

W'(τ) – vector of activation force placed at respective coordinates.

Using the transformation:

$$u = [\phi]p \qquad \text{(A.2)}$$

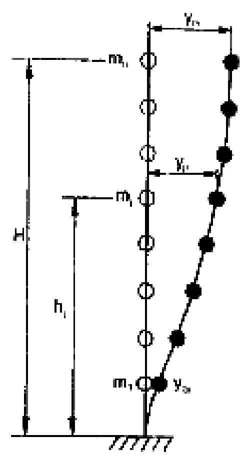



**Figure A.1 : Calculation diagram of dynamic force of wind load acting on work**

The formula (A.1), with conditions such as: [M] is the diagonal matrix; [C] and [K] are symmetric matrixes that are positive, it may result in an independent differential equation system:

$$\ddot{p}i + 2\gamma_i \omega_i \dot{p}_i + \omega_i^2 p_i = W'_i \qquad \text{(A.3)}$$

With $\gamma_i$ that is resistance ratio of structure respective to the $i^{th}$ type of vibration:

$$\gamma_i = \frac{C_i}{2M_i\omega_i} = \frac{\delta_i}{2\pi}$$

Where:

δ - the logarithmic reduction of the i$^{th}$ vibration.

For the random stopping process and linear dynamic system constant by time, from formula (A.3), corresponding to each equation, we have:

$$\overline{P_i}^2 = \frac{1}{2\pi}\int_{-\infty}^{+\infty} |H(i\omega)|^2 \Phi_{ww}(\omega).d\omega \tag{A.4}$$

$$|H(i\omega)|^2 = \frac{1}{\omega^4 - 2(1-2\gamma_i^2)\omega^2\omega_i^2 + \omega_i^4} \tag{A.5}$$

$\overline{P_i}$ - the quadratic mean value, understood as the probability of the reaction $P_i$;

$\Phi_{ww}(\omega)$ – a spectral density of the correlative load function. According to $|6|$, $\Phi_{ww}(\omega)$ shall be determined by the formula:

$$\Phi_{ww}(\omega) = \sum_{k=1}^{n}\sum_{j=1}^{n} \Phi_{ki}\Phi_{ji}W_kW_j\zeta_k\zeta_j S_{v'}(\omega) \tag{A.6}$$

Where:

$\Phi_{ki}$, $\Phi_{ji}$ – relative transversal movement corresponding to the i$^{th}$ standard vibration type at point k and j;

$W_k$ , $W_j$ – standard value of static component of wind load placed at point k and j;

$\zeta_k$, $\zeta_j$ – dynamic pressure coefficient of wind speed, corresponding to level of point k and j;

$S_{v'}$ – Interactive spectral density of longitudinal impulse of wind speed at point k and j, determined by the Davenport's formula:

$$S_{v'}(\omega) = \frac{1200\varepsilon^{5/3}}{3v_o(1+\varepsilon^2)^{4/3}} \exp\left[\left(-\frac{|z_k - z_j|}{150\varepsilon}\right) - \left(\frac{|x_k - x_j|}{60\varepsilon}\right)\right] \tag{A.7}$$

From formula (A.5), it can deduce:

$$|H(i\omega)|^2 = \frac{\varepsilon^4}{\omega_i^4(\varepsilon^3 - 2(1-2\gamma_i^2)\varepsilon^2\varepsilon_i^2 + \varepsilon_i^4)} \tag{A.8}$$

Where:

$$\varepsilon = \frac{v_o}{1200\omega};\ \varepsilon_i = \frac{v_o}{1200\omega_i}$$

From (A.4), (A.6), (A.7) formulae, we have:

$$\overline{P}_i^2 = \frac{1}{3\pi\omega_i^4} \sum_{k=1}^{n} \sum_{j=1}^{n} \Phi_{ki}\Phi_{ji} W_k W_j \zeta_k \zeta_j \int_o^{+\infty} \frac{e^{11/3}\exp\left(-\frac{|z_k - z_j|}{150\varepsilon} - \frac{|x_k - x_j|}{60\varepsilon}\right)}{(1+\varepsilon^2)^{4/3}\left[\varepsilon^4 - 2(1-2\gamma_i^2)\varepsilon^2\varepsilon_i^2 + \varepsilon_i^4\right]} d\varepsilon \tag{A.10}$$

When ignoring the correlation between point k and point j, we have:

$$\exp\left(-\frac{|z_k - z_j|}{150\varepsilon} - \frac{|x_k - x_j|}{60\varepsilon}\right) = 1$$

Thus, we shall have:

$$\overline{P}_{io}^2 = \frac{1}{\omega_i^4}\left(\sum_{j=1}^{n}\Phi_{ji} W_j \zeta_j\right)^2 \frac{1}{3\pi}\int_o^{+\infty} \frac{\varepsilon^{11/3} d\varepsilon}{(1+\varepsilon^2)^{4/3}\left[\varepsilon^4 - 2(1-2\gamma_i^2)\varepsilon^2\varepsilon_i^2 + \varepsilon_i^4\right]} \tag{A.11}$$

Establish that:

$$\xi_i^2 = \frac{1}{3\pi}\int_o^{+\infty} \frac{\varepsilon^{11/3} d\varepsilon}{(1+\varepsilon^2)^{4/3}\left[\varepsilon^4 - 2(1-2\gamma_i^2)\varepsilon^2\varepsilon_i^2 + \varepsilon_i^4\right]} \tag{A.12}$$

$\xi_i$ – depending on $\varepsilon_I$, e.g. depending on natural vibration frequency of works and resistance of structure, called as dynamic system. Basing on (A.12), we can set diagram determining the dynamic coefficient $\xi$ in TCVN 2737:1995.

We have:

$$\overline{P}_{io}^2 = \frac{1}{\omega_i^4}\left(\sum_{j=1}^{n}\Phi_{ji} W_j \zeta_j\right)^2 \xi_i^2 \tag{A.13}$$

Deduce that:

$$\overline{P}_i^2 = \overline{P}_{io}^2 \frac{\overline{P}_i^2}{\overline{P}_{io}^2} = \overline{P}_{io}^2 \nu_i^2$$

$$\overline{P}_i^2 = \frac{1}{\omega_i^4}\left(\sum_{j=1}^{n}\Phi_{ji} W_j \zeta_j\right)^2 \xi_i^2 \nu_i^2$$

Or
$$\overline{P}_i = \frac{1}{\omega_i^2}\left(\sum_{j=1}^{n} \Phi_{ji} W_j \zeta_j\right) \xi_i \nu_i \qquad (A.14)$$

Where:

$$\nu_i^2 = \frac{\overline{P_i}^2}{\overline{P_{io}}^2} \qquad (A.15)$$

$\nu_i$ – the relative space coefficient of longitudinal impulse of wind speed.

The formula (A.15) is a base setting formula for determination of the relative space coefficient of TCVN 2737:1995 in the luff plane.

From (A.2), we have a displacement at the point j:

$$u_j = \sum_{i=1}^{n} \phi_{ji} P_i \qquad (A.16)$$

Where:

$$\phi_{ji} = \frac{y_{ji}}{\sqrt{\sum_{j=1}^{n} M_j y_{ji}^2}} \qquad (A.17)$$

With $M_j$ – Weight at point j;

$y_{ji}$ - relative transversal movement at the point j in the i$^{th}$ vibration type;

From (A.14), (A.16), (A.17) formulas, we have a displacement of work at the point j caused by the dynamic component of wind load, which is:

$$u_j = \sum_{i=1}^{n} \frac{1}{\omega_i^2} \xi_i \psi_i y_{ji} \qquad (A.18)$$

Or:

$$u_j = \sum_{i=1}^{n} u_{ji}$$

Where:

$u_{ji}$ – Displacement at the point j caused by dynamic component of wind load in the i$^{th}$ vibration:

$$u_{ji} = \frac{1}{\omega_i^2} \xi_i \psi_i y_{ji} \qquad (A.19)$$

$$\psi_i = \frac{\sum_{j=1}^{n} y_{ji} W_j \zeta_j \nu_i}{\sum_{j=1}^{n} M_j y_{ji}^2} \quad \text{(A.20)}$$

According to Newton's law II, the inertia force acting on mass concentration point $M_j$ corresponding to the $i^{th}$ vibration shall be:

$$W_{ji} = M, u_{ji} = M_j u_{ji} \omega_i^2$$

Deducing that:

$$W_{ji} = M_j \xi_i \psi_I, y_{ji} \quad \text{(A.21)}$$

Formula (A.21) shall be used for determination of dynamic component of wind load due to dynamic action of wind respective to each type of vibration.

**A.2. Height coefficient k**

**A.2.1.** Coefficient taking into account the wind pressure change by height shall be defined basing on describing variable of wind speed by height, which is exponential:

$$V_t(z) = V_t^g \left(\frac{z}{z_t^g}\right)^{m_t} \quad \text{(A.22)}$$

Where:

$z_t^g$ – Height of relief of type t where wind speed shall not be affected by the lining surface, called also gradient height;

$V_t(z)$, $V_t^g$ – wind speed at the height z and gradient height of relief type t;

$m_t$ – an exponent corresponding to relief type t.

Values of $z_t^g$, $m_t$, respective to t = A, B, C according to TCVN 2737:1995 are given in table A.1.

**Table A.1. The gradient height and factor $m_t$**

| Type of relief | $z_t^g$ (m) | $m_t$ |
|---|---|---|
| A | 250 | 0.070 |
| B | 300 | 0.090 |
| C | 400 | 0.140 |

From (A.22) formula and experimental values given in table A.1, formula determining the height coefficient respective to relief type t shall be set:

$$k_t(z) = 1.844\left(\frac{z}{z_t^g}\right)^{2m_1} \qquad \text{(A.23)}$$

From formula (A.23), we have the table on values of coefficient of wind pressure change by height in TCVN 2737:1995.

**A.2.2. Types of relief**

According to TCVN 2737:1995, there are three types of relief as follows:

- Relief type A is a spacious region, absent or poor in obstructing objects over 1.5m of height (open beach, river surface, big lake, salt field, field without high trees…).
- Relief type B is a relatively spacious region with presence of sparse obstructing objects under 10m of height (urban area poor in houses, small town, village, light forest or young forest, sparse tree cultivation…).
- Relief type C is a strongly blocked view, with different obstructing objects over 10m of height (in town, thick forest…)

Work is classified into such relief type if characteristics of this relief remain constant within a range of 30H when H ≤ 60m and of 2 km when H > 60m calculated from the luff side of work. H is the work height.

**A.2.3.** When determining coefficient k in table 7, if the ground around building is not even and flat, the standard level for calculating the height z shall be defined as follows:

a) Where ground has a small slope in comparison with horizontal direction: i ≤ 0.3; the height z shall be calculated from the ground surface of work to the point in consideration.

b) Where ground has a slope 0.3 < i < 2, the height z shall be calculated from the conventional high level $z_o$ that is lower than actual ground surface to the point in consideration.

Surface of conventional high level $z_o$ shall be defined according to Figure A.2

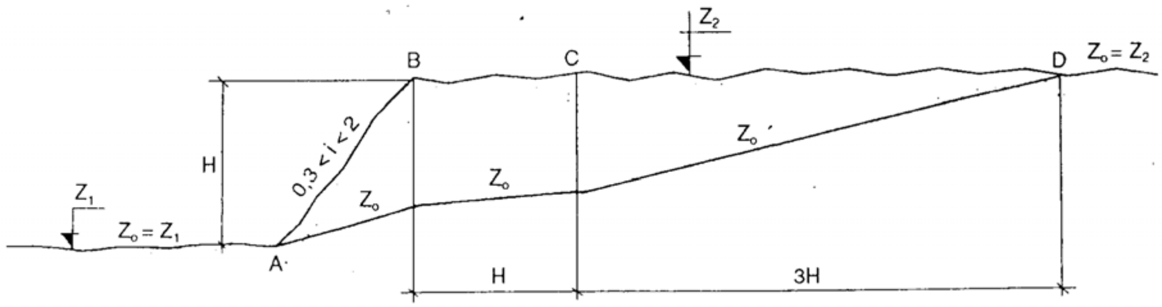



**Figure A.2. High level $z_o$ when 0.3 < i < 2**

Left of point A: $z_o = z_1$

On the section BC: $z_o = H(2-i)/1.7$

Right of point D: $z_o = z_2$

On the sections AB and CD: determine $z_o$ by the linear interpolation method.

c) Where ground has a slope $i \geq 2$, the surface of conventional high level $z_o$ to define the height z that is lower than the actual ground shall be determined by the Figure A.3.

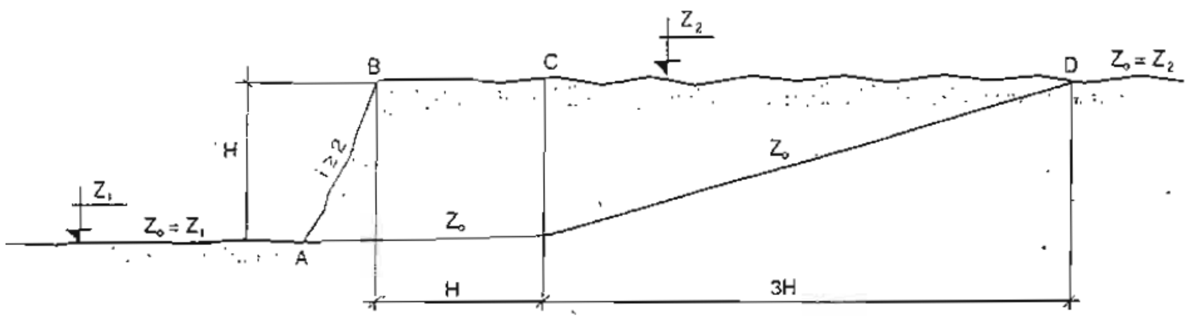



**Figure A.3: High level $z_o$ when $i \geq 2$**

Left of point C: $z_o = z_1$

Right of point D: $z_o = z_2$

On the section CD: determine $z_o$ by the linear interpolation method.

### A.3. Dynamic pressure coefficient of wind load

Wind pressure acting on work at the height z shall be:

$$W(z, \tau) = W(z) + W'(z, \tau) \qquad \text{(A.24)}$$

Where:

W(z, τ) – wind pressure acting on work up to the action direction of wind;

W(z) – pressure due to average component of wind speed, determined by the formula:

$W(z) = 0.0613v^2(z)$

W'(z, τ) – pressure caused by impulse component of wind speed at the height z, determined by the formula:

$$W'(z,\tau) = 2W(z)\frac{V'(z,\tau)}{V(z)} \tag{A.25}$$

Where:

V(z) – the average component of wind speed at the height z;

V'(z, τ) – the impulse component of wind speed at the height z.

The impact of impulse component of wind speed on work is characterized by the tangle intensity of wind current γ*(z). For the determined relief type, it shall be:

$$\gamma^*(z) = \frac{\delta v'(z)}{v(z)} \tag{A.26}$$

Where:

γ*(z) – the tangle intensity of wind current;

$\delta_{v'(z)}$ - quadratic mean of longitudinal impulse of wind speed at the height z;

v(z) – value of average component of wind speed at the height z.

Formula (A.26) was set based on assumption that:

- Impulse component of wind speed, assumed to be equal to composition of a random time function and space coordinate function (coordinate z)

$$V'(z,\tau) = \delta_{v'(z)}\varphi(\tau) \tag{A.27}$$

- Quadratic mean of function φ(τ) by unit:

$$\delta_{\varphi(\tau)} = 1 \tag{A.28}$$

From formula (A.25), (A.26) and (A.27), we have:

$$W'(z,\tau) = 2W(z)\gamma_t^*(z)\varphi(\tau) \tag{A.29}$$

According to formula of Davenport [6], the tangle intensity of wind current shall be determined by the formula:

$$\gamma_t^2(z) = 2.45(r_t)^{1/2}\left(\frac{z}{10}\right)^{-m_t} \quad \text{(A.30)}$$

Where:

t = A, B, C – types of relief, defined in clause A.2.2;

$r_t$ – the roughness of lining surface of relief type t;

z – a designed height;

$m_t$ – an exponent corresponding to relief type t.

According to Davenport [6], the dynamic pressure coefficient of wind load shall be defined by the formula:

$$\zeta_t(z) = 2\alpha_c\gamma_t^*(z) \quad \text{(A.31)}$$

Where: $\alpha_c$ is a coefficient.

In TCVN 2737:1995, corresponding to the mean time of wind speed of 3 seconds, dynamic pressure coefficient shall be determined by the formula:

$$\zeta_A(z) = 0.303(\frac{z}{10})^{-0.07} \quad \text{(A.32)}$$

$$\zeta_B(z) = 0.486(\frac{z}{10})^{-0.09}$$

$$\zeta_C(z) = 0.684(\frac{z}{10})^{-0.14}$$

Where:

$\alpha = 1.395$

$r_A = 0.002$; $r_B = 0.005$; $r_C = 0.01$

From formula (A.32) we can built up a table for dynamic pressure coefficient mentioned in TCVN 2737:1995.

**A.4. Correlative space coefficient ν**

From (A.10), deducing $\overline{P_i}$ that shall be defined by the formula:

$$\overline{P_i}^2 = \frac{1}{3\pi\omega_i^4}\int_0^{-\infty}\frac{\varepsilon^{11/3}J(\varepsilon)d\varepsilon}{(1+\varepsilon)^{4/3}\left[\varepsilon^4 - 2(1-2\gamma^2)\varepsilon^2\varepsilon_i^2 + \varepsilon^4\right]} \quad \text{(A.33)}$$

Where:

$$J(\varepsilon) = \sum_{k=1}^{n} \sum_{j=1}^{n} \Phi_{ki} \Phi_{ji} W_k W_j \zeta_k \zeta_j \exp\left(-\frac{|z_k - z_j|}{150\,\varepsilon} - \frac{|x_k - x_j|}{60\,\varepsilon}\right) \quad (A.34)$$

Consider work with mass evenly distributed and stiffness constant by height. Standard type of the 1st vibration type shall be:

$$\phi(z) = (\frac{z}{H})$$

From (A.23), deduce that:

$$W(z) = 1{,}844\, W_o \left(\frac{H}{z_t^g}\right)^{2m_t} \left(\frac{z}{H}\right)^{2m_t}$$

$$W(z) = W_o\, k_t\, (H) \left(\frac{z}{H}\right)^{2m_t}$$

$$W(z) = W(H) \left(\frac{z}{H}\right)^{2m_t} \quad (A.35)$$

From (A.30) and (A.31), we have:

$$\zeta_t(z) = 2\alpha_c \gamma_t^*(z) = 2 \times 2{,}45\, \alpha_c (r_t)^{1/2} \left(\frac{z}{10}\right)^{-m_t}$$

$$\zeta_1(z) = 2 \times 2{,}45\, \alpha_c (r_t)^{1/2} \left(\frac{H}{10}\right)^{-m_t} \left(\frac{z}{H}\right)^{-m_t}$$

$$\zeta_1(z) = \zeta_1(H) \left(\frac{z}{H}\right)^{m_t} \quad (A.36)$$

Where:

W(z), W(H) – standard pressure caused by average component of wind speed at the height z and H;

$\zeta_t(z)$, $\zeta(H)$ – dynamic pressure coefficient of relief type t at the height z and H;

$m_t$ – an exponent respective to relief type t, taken from section A.2.1.

Replace (A.35) and (A.36) to (A.34), we have:

$$J(\varepsilon) \left[W_{(H)} \zeta_t (H)\, DH\right]^2 \int_0^1 \int_0^1 \int_0^1 \int_0^1 \beta^{m_t+1} \beta_1^{m_t+1} \exp\left(-\frac{\rho}{\varepsilon}|\beta - \beta_1| - \frac{\chi}{\varepsilon}|\lambda - \lambda_1|\right) d\beta\, d\beta_1,\, d\lambda\, d\lambda_1 \quad (A.37)$$

Where:

$$\beta = \frac{z}{H};\ \rho = \frac{H}{150};\ \lambda = \frac{x}{D};\ \chi = \frac{D}{60} \tag{A.38}$$

H – height of work (m);

D – Width of luff side of work (m).

From (A.37), deduce that:

$$J(\varepsilon) = \left[\frac{2W_{(H)}\zeta_1(H)\,DH\varepsilon\,\mathrm{sh}\left(\frac{\chi}{2\varepsilon}\right)}{\chi}\right]^2 \int_0^1\int_0^1 \beta^{(m_t+1)}\ \beta_1^{(m_t+1)} \exp\left(-\frac{\rho}{\varepsilon}|\beta-\beta_1|\right) d\beta\, d\beta_1 \tag{A.39}$$

While ignoring the mutual effect between point k and j, we have:

$$J_o = \left[\frac{2W_{(H)}\zeta_{1(H)}DH\varepsilon}{\chi}\right]^2 \int_0^1\int_0^1 \beta^{(m_t+1)}\beta_1^{(m_t+1)} d\beta\, d\beta_1$$

$$J_o = \left[\frac{2W_{(H)}\zeta_{1(H)}DH\varepsilon\,\mathrm{sh}\frac{\chi}{2\varepsilon}}{\chi}\right]^2 \frac{1}{(m_1+2)^2} \tag{A.40}$$

From (A.11), we have:

$$\overline{P_{io}}^2 = \frac{1}{3\pi.\omega_i^4}\int_0^{+\infty}\frac{\varepsilon^{11/3}J_o d\varepsilon}{(1+\varepsilon^2)^{4/3}\left[\varepsilon^4 - 2(1-2\gamma_i^2)\varepsilon^2\varepsilon_i^2 + \varepsilon_i^4\right]} \tag{A.41}$$

Or:

$$\overline{P_{io}}^2 = \frac{1}{\omega_i^4}\xi_i J_o \tag{A.42}$$

From (A.15), (A.33), (A.39), (A.40) and (A.42), we have:

$$\nu_1^2 = \frac{\overline{P}_1^2}{\overline{P}_{10}^2} = \frac{1}{3\pi\xi_1(m_1+2)^2}\int_0^\infty \left\{\int_0^1\int_0^1 \beta^{(m_t+1)}\beta_1{}^{(m_t+1)} \exp\left(-\frac{\rho}{\varepsilon}|\beta-\beta_1|\right) d\beta\, d\beta_1\right\} \times$$
$$\times\ \mathrm{sh}^2\left(\frac{\chi}{2\varepsilon}\right)\frac{\varepsilon^{17/3}d\varepsilon}{(1+\varepsilon)^{4/3}\left[\varepsilon^4 - 2(1-2\gamma_1^2)\varepsilon^2\varepsilon_1^2 + \varepsilon_1^4\right]} \tag{A.43}$$

If ignoring effect of parameters $\varepsilon_1$, $m_t$, $\xi_1$ and the resistance ratio $\gamma_1$ of structure in the formula (A.43), the correlative space coefficient $\nu_1$ will depend only on parameters $\rho$, $\chi$ that are characteristic dimensions of work surfaces where the correlative space of dynamic pressure of wind load is taken. From the formula (A.43), we determine table of values of system $\nu_1$ in TCVN 2737:1995.

**A.5. Dynamic coefficient ξ**

The formula (A.12) consists of base for establishing diagram for determination of dynamic coefficient $\xi_i$ in TCVN 2737:1995, where ξi depends on parameter $\varepsilon_I$ and resistance of structure, e.g. depending on frequency $f_i$ and logarithmic reduction of vibration δ.

# ANNEX B

## (Reference)

## Determination of dynamic characteristics

**B.1. Determination of frequency and type of vibration of structural system made from console bars having limited weight concentration:**

Consider a system consisting of a console bar, n point of weight concentration, figure B.1. The general differential equation describes system vibration while ignoring weight of bar having shape (A.1).

Frequency and natural vibration type shall be defined from homogeneous differential equation without resistance:

$$M\ddot{U} + KU = 0 \tag{B.1}$$

$$U = y \sin(\omega\tau - \alpha) \tag{B.2}$$

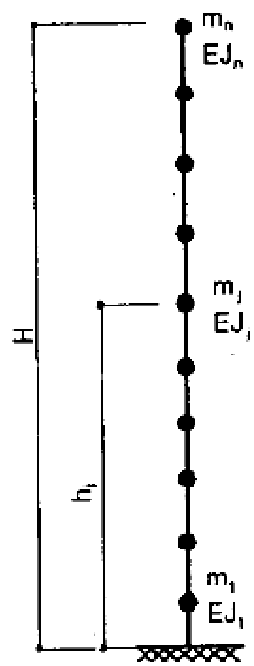



**Figure B.1. Diagram for determination of system of console bars with limited weight concentration**

From (B.1) and (B.2), we have:

$$[K - \omega^2 M]y = 0 \tag{B.3}$$

Where:

$$M = \begin{vmatrix} M_1 & & & & \\ & M_2 & & & \\ & & \cdot & & \\ & & & \cdot & \\ & & & & \cdot \\ & & & & & M_n \end{vmatrix}$$

$$K = \begin{bmatrix} k_{11} & k_{12} & \dots & k_{1n} \\ k_{21} & k_{22} & \dots & k_{2n} \\ \dots & \dots & \dots & \dots \\ k_{n1} & k_{n2} & \dots & k_{nn} \end{bmatrix} \qquad \text{(B.3)}$$

With $K_{ji} = \dfrac{1}{\delta_{ji}}$

Condition for vibration presence: $y \neq 0$, so:

$$K - \omega^2 M = 0 \qquad \text{(B.4)}$$

Or:

$$D(\omega_i^2) = \begin{vmatrix} \delta_{11} M_1 \omega_i^2 - 1 & \delta_{12} M_2 \omega_i^2 & \dots & \delta_{1n} M_n \omega_i^2 \\ \delta_{21} M_1 \omega_i^2 & \delta_{22} M_2 \omega_i^2 - 1 & \dots & \delta_{2n} M_n \omega_i^2 \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \delta_{n1} M_1 \omega_i^2 & \delta_{n2} M_2 \omega_i^2 & \dots & \delta_{nn} M_n \omega_i^2 - 1 \end{vmatrix} = 0 \qquad \text{(B.5)}$$

Where:

$M_j$ – Weight concentration at the $j^{th}$ point;

$\delta_{ji}$ – displacement at the point j caused by unit force placed at the point i;

$\omega_i$ – circle frequency of natural vibration (Rad/s).

Equation (B.5) is called as characteristic equation. From (B.5), it may determine n positive and actual values of $\omega_i$. Replace found values of $\omega_i$ to equation (B.3), types of natural vibration shall be determined. When number of weight concentration point n >4, equation (b.5) can find only an approximate root and it needs to use multiple and complicated calculations. Therefore, frequency and natural vibration type shall be handled by computer with specialized program or by approximate formulas or experimental formulas.

Some formulas determining frequency and type of vibration are mentioned as follows:

**B.1.1.** Work having calculation diagram of console bar with one weight concentration

- Characteristic equation shall be:

$$\delta_{11} M_1 \omega^2 - 1 = 0 \tag{B.6}$$

- Natural vibration frequency shall be defined by the formula:

$$\omega = \sqrt{\frac{1}{M_1 \delta_{11}}} \tag{B.7}$$

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{1}{M_1 \delta_{11}}} \tag{B.8}$$

Dimensionality of ω is Rad/s, dimensionality of f is 1/s or Hz.

If work having stiffness EJ constant and clamping link at foundation:

$$\delta_{11} = \frac{H^3}{3EJ} \tag{B.9}$$

With H is height of work (m).

Replace (B.9) to (B.8), we have a natural vibration frequency:

$$f = \frac{1}{2\pi}\sqrt{\frac{3EJ}{M_1 H^3}} \tag{B.10}$$

**B.1.2.** Work having calculation diagram of console bar with two weight concentrations

- Characteristic equation shall be:

$$\begin{vmatrix} \delta_{11} M_1 \omega_i^2 - 1 & \delta_{12} M_2 \omega_i^2 \\ \delta_{21} M_1 \omega_i^2 & \delta_{22} M_2 \omega_i^2 - 1 \end{vmatrix} = 0 \tag{B.11}$$

Or

$$\frac{1}{\omega_i^4} - (M_1 \delta_{11} + M_2 \delta_{22}) \frac{1}{\omega_i^2} + M_1 M_2 (\delta_{11} \delta_{22} - \delta_{12}^2) = 0 \tag{B.12}$$

- Natural vibration frequency shall be defined by the formula:

$$\omega_{1.2}^2 = \frac{A \mp \sqrt{A^2 - 4B}}{2B} \tag{B.13}$$

$$f_{1.2}^2 = \frac{A \mp \sqrt{A^2 - 4B}}{8\pi^2 B} \quad \text{(B.14)}$$

Where:

$$A = M_1\delta_{11} + M_2\delta_{22}$$

$$B = M_1M_2(\delta_{11}\delta_{22} - \delta^2_{12}) \quad \text{(B.15)}$$

- Types of natural vibration shall be defined by the equation:

$$(\delta_{11}M_1\omega_i^2 - 1)y_{i1} + \delta_{12}M_2\omega_i^2 y_{i2} \quad \text{(B.16)}$$

Where:

$\omega_i$ – taken from formula (B.13)

$y_{i1}$ – previously chosen equal to some value, normally $y_{i1}$ = 1.

**B.1.3.** Work having calculation diagram of console bar with three weight concentrations

- Characteristic equation shall be:

$$\begin{vmatrix} \delta_{11} M_1 \omega_i^2 - 1 & \delta_{12} M_2 \omega_i^2 & \delta_{13} M_3 \omega_i^2 \\ \delta_{21} M_1 \omega_i^2 & \delta_{22} M_2 \omega_i^2 - 1 & \delta_{23} M_3 \omega_i^2 \\ \delta_{31} M_1 \omega_i^2 & \delta_{32} M_2 \omega_i^2 & \delta_{33} M_3 \omega_i^2 - 1 \end{vmatrix} = 0$$

(B.17)

Or:

$$\frac{1}{\omega_i^6} + \frac{C}{\omega_i^4} + \frac{D}{\omega_i^2} + E = 0 \quad \text{(B.18)}$$

Where:

$$C = -(M_1\delta_{11} + M_2\delta_{22} + M_3\delta_{33})$$
$$D = M_1M_2(\delta_{11}\delta_{22} - \delta_{12}^2) + M_1M_3(\delta_{11}\delta_{33} - \delta_{13}^2) + M_2M_3(\delta_{22}\delta_{33} - \delta_{23}^2)$$
$$E = M_1M_2M_3(\delta_{11}\delta_{23}^2 + \delta_{22}\delta_{13}^2 + \delta_{33}\delta_{12}^2 - \delta_{11}\delta_{22}\delta_{33} - 2\delta_{12}\delta_{13}\delta_{23})$$

From equation (B.18), determine three actual and positive roots respective to 3 natural vibration types.

- Types of natural vibration shall be determined by the system of equations:

$$\begin{cases} (\delta_{11} M_1 \omega_i^2 - 1) + \delta_{12} M_2 \omega_i^2 \dfrac{y_{i2}}{y_{i1}} + \delta_{13} M_3 \omega_i^2 \dfrac{y_{i3}}{y_{i1}} = 0 \\ \delta_{12} M_1 \omega_j^2 + (\delta_{22} M_2 \omega_i^2 - 1) \dfrac{y_{i2}}{y_{i1}} + \delta_{13} M_3 \omega_i^2 \dfrac{y_{i3}}{y_{i1}} = 0 \end{cases} \quad \text{(B.19)}$$

Where: $y_{i1}$ previously chosen equal to some value, normally $y_{i1} = 1$.

**B.1.4.** Work having calculation diagram of console bar with n weight concentrations

- When n > 4, it may determine the natural vibration frequency from double inequation:

$$\frac{1}{\sqrt{B_{12}}} < \omega_i^2 < \frac{2}{B_{i1}\left(1 + \sqrt{2\dfrac{B_{i2}}{B_{i1}^2} - 1}\right)} \quad \text{(B.20)}$$

When determining the first natural vibration frequency (i=1), values of $B_{11}$, $B_{12}$ shall be equal to:

$$B_{11} = \sum_{j=1}^{n} M_j \delta_{jj} \quad \text{(B.21)}$$

$$B_{12} = \sum_{j=1}^{n} M_j^2 \delta_{jj}^2 + \sum_{k=1}^{n} M_j M_k \delta_{jk}^2$$

When determining the second natural vibration frequency (i=2), values of $B_{21}$, $B_{22}$ shall be:

$$B_{21} = B_{11} - \frac{1}{\omega_i^2}$$

$$B_{22} = B_{12} - \frac{1}{\omega_i^4} \quad \text{(B.22)}$$

- Natural vibration types shall be determined by system of equations:

$$\begin{cases} (\delta_{11} M_1 \omega_i^2 - 1) + \delta_{12} M_2 \omega_i^2 \dfrac{y_{i2}}{y_{i1}} + \ldots + \delta_{1n} M_n \omega_i^2 \dfrac{y_{in}}{y_{i1}} = 0 \\ \delta_{21} M_1 \omega_j^2 + (\delta_{22} M_2 \omega_i^2 - 1) \dfrac{y_{i2}}{y_{i1}} + \ldots + \delta_{2n} M_n \omega_i^2 \dfrac{y_{in}}{y_{i1}} = 0 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \delta_{1.n-1} M_1 \omega_i^2 + \ldots + (\delta_{n-1.n-1} M_{n-1} \omega_i^2 - 1) \dfrac{y_{1.n-1}}{y_{i1}} + \delta_{n.n-1} M_n \omega_i^2 \dfrac{y_{in}}{y_{i1}} = 0 \end{cases} \quad \text{(B23)}$$

Where: $y_{i1}$ is normally equal to unit.

**B.2. Work having calculation diagram of console bar with weight evenly distributed.**

**B.2.1.** For works having weight evenly distributed (m), the stiffness EJ constant and clamping link at foundation, the natural vibration frequency shall be determined by the formula [3.6].

$$f_i = \frac{\alpha_i^2}{2\pi H^2}\sqrt{\frac{EJg}{q}} \quad \text{(B.24)}$$

Ordinales of three first natural vibration types are given in table B.1 or shall be defined according to formula [3.6].

$$y_{ji} = \sin\alpha_i\xi_j^* - sh\alpha_i\xi_j^* - B_i(\cos\alpha_i\xi_j^* - ch\alpha_i\xi_j^*) \quad \text{B.25)}$$

In formulas (B.24), (B.25), factors $\alpha_i$ and $B_i$ are respective to 3 first vibrations and shall be:

$\alpha_1 = 1.875$ $B_1 = 1.635$

$\alpha_2 = 4.694$ $B_2 = 0.980$

$\alpha_3 = 7.860$ $B_3 = 1.000$

$$\xi_j^* = \frac{h_j}{H} \quad \text{(B.26)}$$

Where:

$f_i$ – the $i^{th}$ natural vibration frequency (Hz);

q – Weight of length unit by work height (kN/m);

EJ – bending resistant stiffness of work ($kN.m^2$);

g – acceleration of gravity ($m/s^2$);

hj – height of the $j^{th}$ weight point (m);

H – Height of whole work (m).

**Table B.1. Values of relative transversal movement corresponding to 3 first types of vibration of system having weight evenly distributed and stiffness constant**

| $\xi^*$ / i | **0** | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** | **1** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0.017 | 0.064 | 0.136 | 0.230 | 0.340 | 0.462 | 0.558 | 0.725 | 0.863 | 1 |
| 2 | 0 | 0.093 | 0.301 | 0.526 | 0.685 | 0.715 | 0.589 | 0.317 | 0.007 | -0.523 | -1 |
| 3 | 0 | 0.224 | 0.605 | 0.957 | 0.526 | 0.020 | -0.474 | -0.658 | -0.395 | 0.228 | 1 |

**B.2.2.** Besides of weights evenly distributed, if work has also weight concentration, it should use formula (B.24) for determining frequencies of natural vibration but q shall be equal to converted evenly distributed weight [3,6]:

$$q = q' + \frac{\lambda_i}{H_j}\sum_{j=1}^{n} P_j y_{ji}^2 \qquad \text{(B.27)}$$

Where

q' – evenly distributed weight (kN/m);

$P_j$ – The $j^{th}$ weight concentration (kN);

$y_{ji}$ – determined according to formula (B.25), non-dimensional;

n – number of weight concentration

$\lambda$ - factor depending on the natural vibration type;

H – Height of work (m)

For three first types of vibration, values of $\lambda_i$ shall respectively be:

$\lambda_1 = 0.54$; $\lambda_2 = 1.04$; $\lambda_3 = 1$

B.2.3. For work with section changed by height, the first vibration frequency can be defined by the formula[6]

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{g y_H}{\sum_{j=1}^{n} P_j y_j^2}} \qquad \text{(B.28)}$$

Where:

$y_H$, $y_j$ – displacement at the top and center of the j$^{th}$ portion of work, caused by force P = 1kN placed at work top (m);

$P_j$ – weight of the j$^{th}$ portion of work (kN);

n – Number of portion;

g – acceleration of gravity (m/s$^2$).

B.2.4. For chimney type work or similar works with annular cross section, natural vibration frequency taking into account deformation effect of foundation, shall be defined by the formula [3.4.6]

$$f_i = \frac{\lambda_i r_o}{2\pi H^2}\sqrt{\frac{Eg}{q}} \qquad \text{(B.29)}$$

Where:

$f_i$ – the i$^{th}$ natural vibration frequency (Hz);

E – elasticity modulus of materials making chimney body (kN/m$^2$);

H – height of chimney, measured from peak to foundation (m);

g – acceleration of gravity (m/s$^2$);

q – volumetric weight of chimney body (kN/m$^3$);

$r_o$ – inertia radius of bottom section of chimney (m).

$$r_o = \sqrt{\frac{j_o}{F_o}} \qquad \text{(B.30)}$$

$J_o$, $F_o$ – inertia moment and area of bottom section of chimney (m$^4$, m$^2$)

$\lambda_i$ – factor respective to the i$^{th}$ vibration type. With three first types of vibration, $\lambda_I$ shall be defined by the diagram in figure B.2.

Lining layer of chimney should increase only the weight but does not affect chimney stiffness, the value of q is then approximate according to formula:

$$q = q_{th} + q_L \frac{F_L}{F_{th}} \qquad \text{(B.31)}$$

Where:

$q_{th}$ and $q_L$ – volumetric weights of materials making chimney body and lining layer (kN/m$^3$);

$F_{th}$ and $F_L$ - area of cross section of body part and lining part corresponding to mean level of chimney (m$^2$).

Types of natural vibration of chimney shall be defined by the formula [3, 4, 6].

$$y_{ji} = \frac{1}{1 + k\frac{h_j}{H}}\left[\sin\frac{\pi h_j}{2H} + A_i \sin\frac{3\pi h_j}{2H} + B_i \sin\frac{5\pi h_j}{2H}\right] \quad (B.32)$$

Where:

$$k = 0.75\left(\frac{J_H}{J_o} - 1\right)$$

$A_i$, $B_i$ – coefficients respective to natural vibration types, defined by figure B.3;

Coefficients $\lambda_i$, $A_i$, $B_i$ for each vibration type depend on parameters:

$$\frac{J_H}{J_o}, \frac{H}{r_o}, \alpha = \frac{2EJ_o}{C_z F_m H^3}$$

Where:

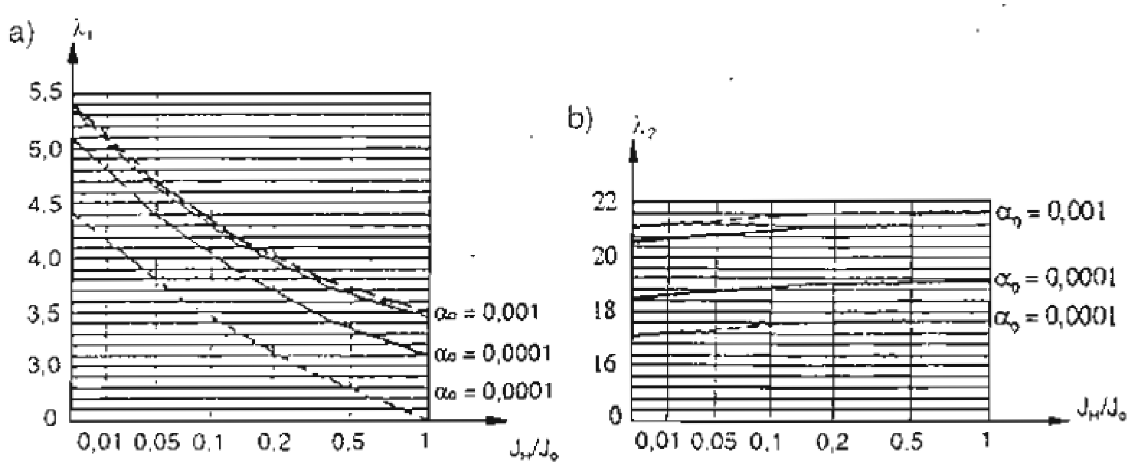
$J_H$, $J_o$ – inertia moments of section of chimney top and bottom ($m^4$);

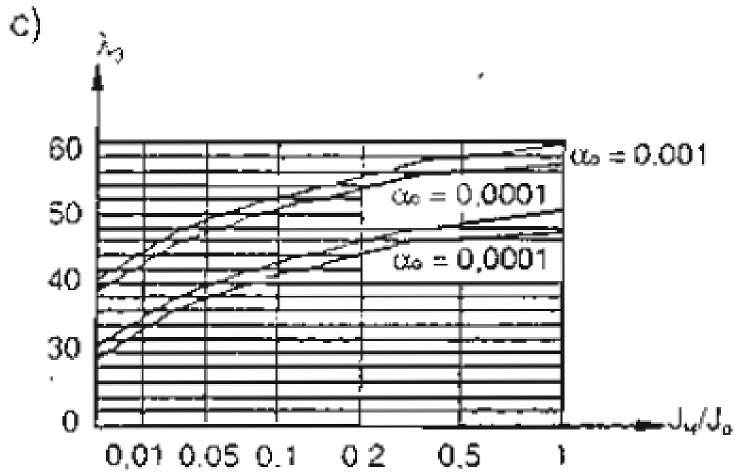
E – elasticity moment of materials making chimney body ($kN/m^2$0;

$h_j$ – height measured from chimney bottom to the point in consideration (m);

$F_m$ – area of chimney foundation base ($m^2$0;

$C_z$ – bedding compliance factor of ground ($kN/m^2$)






a) For the first type of vibration

b) For the second type of vibration

c) For the third type of vibration

For $\frac{H}{r_o} = 40$

For $\frac{H}{r_o} = 80$

**Figure B.2 : Diagram for determination of factor $\lambda_i$**

**B.3. Experimental formulas [3.6]**

Basic natural vibration cycle of buildings can be determined by experimental formula:

Formula 1: $$T = \alpha\, n \qquad \text{(B.33)}$$

Where:

n – number of storey ;

α - coefficient depending on work structure and foundation types. For an average deformation foundation:

+ Large panel building α = 0.047;

+ buildings with load bearing wall of bricks and big blocks α = 0.056;

+ School and other public works with load bearing wall of bricks and big blocks α = 0.065;

+ Monolithic concrete reinforced frame, wall made of brick or light concrete α = 0.064;

+ Steel frame filled with brick or light concrete α = 0.08.

Formula 2:

$$T = \mu \frac{H}{\sqrt{D}} \tag{B.34}$$

Where:

H – Height of building, in meter (m);

D – Width of luff side, in meter (m);

μ - Coefficient depending on structural types:

+ Building having wind screen system made from concrete reinforced frame, μ = 0.09;

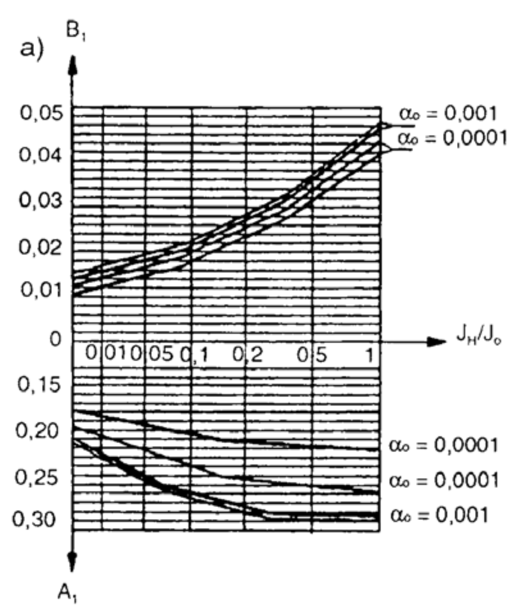
+ Building having wind screen system made from steel frame, μ = 0.10;

+ Building having wind screen system made from brick or concrete walls,

$$\mu = 0.06\sqrt{\frac{H}{2D+H}}$$

+ Building having wind screen system made from concrete reinforced panel

$$\mu = 0.08\sqrt{\frac{H}{D+H}}$$



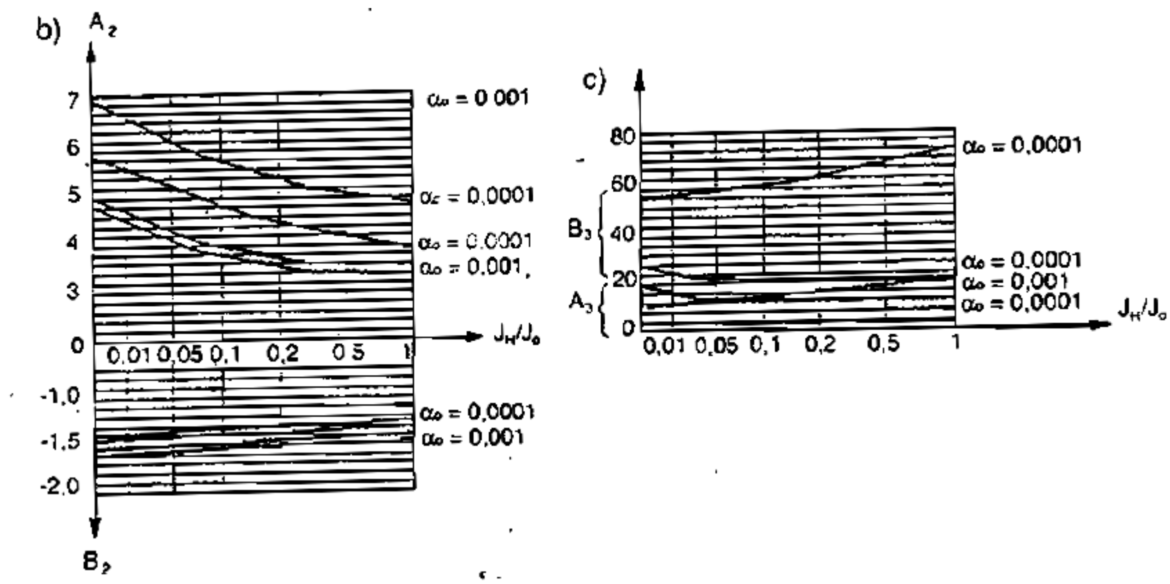



**Figure B3: Diagram for determination of coefficient $A_i$, $B_i$**

a) For the first type of vibration

b) For the second type of vibration

c) For the third type of vibration

# ANNEX C

## (Reference)

## Control of aerodynamic stability loss for high raised buildings and soft structures

### C.1. Query

The clause 6.12 of TCVN 2737:1995 stipules that: for high raised buildings and soft structures (chimney, tower, column…), it must check for aerodynamic stability loss by specific instructions.

It represents herein-after the aerodynamic stability loss and methods of calculation and control for cylindrical and prism works corresponding to two phenomena:

- aerodynamic stability loss due to cyclone activation for cylindrical works and structures
- aerodynamic stability loss of galloping type for prism works and structures.

### C.2. Stability loss due to cyclone activation for cylindrical works and structures

**C.2.1.** Cyclone separation and dynamic force

Wind creates an air current behind work. Properties of this air current depend on its viscosity whose characteristic is Reynolds number $R_c$:

$$R_c = 6900\ vD \qquad (C.1)$$

Where:

v – wind speed (m/s);

D – Width of luff side (m);

$R_c$ – Reynolds number, non-dimensional.

Study results [7, 8, 9, 10] shown that for a cylindrical works, when:

- $3.10^2 \le R_c < 3.10^5$, air current behind the work creating cyclones with rules, which are separated by definite cycles (Figure C.1a) shall be called as near-critical range;
- $3.10^5 < R_c < 3.5 \times 10^6$ , air current behind the work creating cyclones without any rules, (Figure C.1b) shall be called as range within limitation;
- $R_c > 3.5x10^6$ cyclones gradually coming back with rules and separated by definite cycle (Figure C.1c) shall be called over limit range.

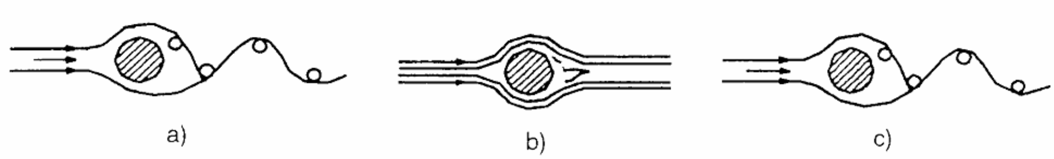


**Figure C.1: The cyclone separation of air current behind the cylindrical work.**

Cyclone separated behind the work creates also a cross force making work vibration by direction normal to wind current. Depending on cyclone separation with or without definite cycle, transverse vibration and cross force acting on work shall be preordained or random.

- For near – critical range and over limit range, cross force will be preordained and circulated:

$$P_L(z,\tau) = 0.5\rho(z)v^2(z)D(z)\mu_L(z)\sin\omega_s\tau \tag{C.2}$$

- Range within limitation, cross force has a random property:

$$P_L(z,\tau) = 0.5\rho(z)v^2(z)D(z)\mu_L(z)f(\tau) \tag{C.3}$$

Where:

$P_L(z, \tau)$ – force horizontal to wind direction acting on work at the height z in time $\tau$;

$\rho(z)$ - the air density at the height z;

D(z) – width of luff area at the height z;

$\mu_L(z)$ – coefficient of force horizontal to wind direction at the height z, determined by experiment, $\mu_L(z)$ depends on $R_c$. For cylindrical work, relation between $\mu_L(z)$ and $R_c$ is given in Figure C.2;

$f(\tau)$ – random time function;

$\omega_s$ – frequency of cyclone separation behind the work, $\omega_s$ shall be defined by the formula:

$$S_h = \frac{f_s D}{v} = \frac{D(z)}{vT_s} \qquad \text{C.4)}$$

$$\omega_s = 2\pi f_s \tag{C.5}$$

Where:

$S_h$ – Strouhal number, non-dimensional, determined by experiment, given in table C.1;

$f_s$ – frequency of cyclone separation (Hz);

D(z) – width of luff side (m), at the height z;

v – wind speed (m/s);

$T_s$ – cycles of separation of cyclone behind the work (s).

Study results [2] shown that: when wind speed increases, frequency of cyclone separation $f_s$ will increase also. Until $f_s$ reaches $f_i$ that is the natural vibration frequency of work, resonance will occur causing the possibility of dynamic stability loss of work.

**C.2.2.** Limited wind speed and effect scope of the aerodynamic force when losing stability due to cyclone activation.

The interval of wind speed making frequency of cyclone separation $f_s$ coincide with the natural vibration frequency $f_i$ of work shall be called as limited speed interval. By the height of work, wind speed will change so $R_c$ shall be changed. Therefore, a work can have in maximum three near-critical range, range within limitation and over limit range (figure C.2). The limited speed interval causing stability loss of cyclone activation type may be in near-critical range or over-limit range. In the over limit range, wind speed is normally great so in some cases, force horizontal to wind load acting on work will be very large, which causes the dynamic stability loss.

The smallest limited wind speed will correspond to the case where frequency of cyclone separation $f_s$ coincides with the 1st natural vibration frequency of work, and shall be called as critical wind speed.

From relation (C.4), we have the formula determining the critical wind speed:

$$v^* = \frac{f_1 D(z)}{S_h} \qquad (C.6)$$

Where:

$v^*$ - critical wind speed causing stability loss by cyclone activation

$D(z)$, $S_h$ – as given in formula (C.4);

$f_1$ - the 1st natural vibration frequency of work (Hz). Relation between $f_1$ and $\omega_1$ shall be determined by the formula (C.5) with s = 1.

The experimental study results [2] shown that the range where dynamic stability loss happens due to cyclone activation shall be within wind speed interval as:

$$v^* \leq v \leq 1.3v^* \qquad (C.7)$$

Wind speed by height will change by rule:

$$V_t(z) = V_t^g \left(\frac{z}{z_t^g}\right)^{m_t} \qquad (C.8)$$

Where:

$z_t^g$ – height of relief type t where wind speed shall not be affected by lining surface, called also as gradient height;

$V_t(z)$, $V_t^g$ – wind speed at the height z and gradient height of relief type t;

$M_t$ – exponent respective to relief type t, determined by experiment.

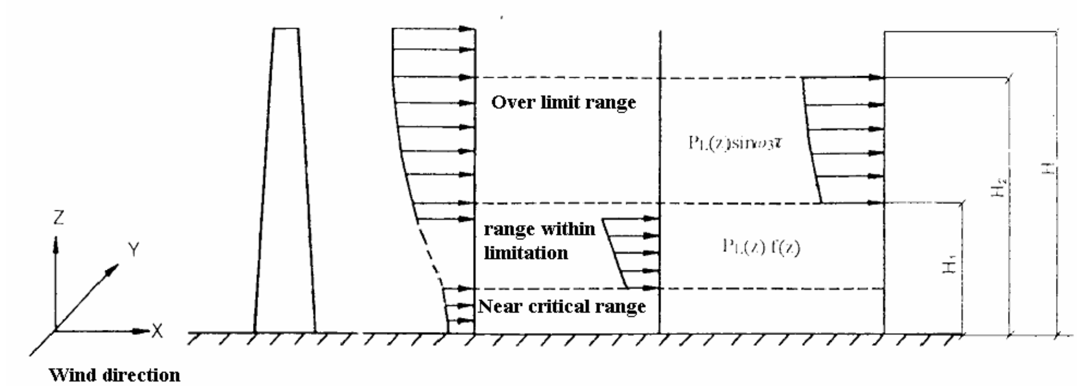



**Figure C.2. Ranges of action of forces horizontal to wind direction on work**

From (C.7) and (C.8), we have the initial level $H_1$ and final level $H_2$ of the resonance area determined by the formula:

$$H_1 = 10\left(\frac{v^*}{v_o}\right)^{\frac{1}{m_t}} \qquad (C.9)$$

$$H_2 = 10\left(\frac{1.3v^*}{v_o}\right)^{\frac{1}{m_t}}$$

Where:

$v^*$ - critical wind speed (m/s);

$v_o$ – basic wind speed at the height of 10m (m/s);

$m_t$ – exponent respective to relief type t;

1.3 – experimental factor.

If $H_2 > H$ (H is the work height), take $H_2 = H$.

**C.2.3.** Displacement and load acting on works by stability loss due to cyclone activation

If wind direction is toward direction y, we have a vibration equation of system:

$$[M]\ddot{X} + [C]\dot{X} + [K]X = F(\tau) \qquad (C.10)$$

Where:

[M], [C], [K] are respectively mass matrix, resistance matrix and stiffness matrix of system by direction normal to wind current;

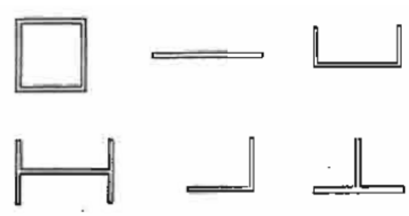
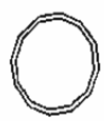
$\ddot{X}, \dot{X}, X$ - are acceleration vector, speed and displacement by direction normal to wind current of coordinates determining weight concentration of system;

F(τ) – vector of force horizontal to wind direction placed at respective coordinates.

Use the transformation: X = [φ]q (C.11)

Where [φ] is the transformation matrix having orthogonal property with [M], [C], [K].

**Table C.1. Strouhal number for some sections**

| **Wind direction** | **Sectional type** | **$S_h$ value** |
|---|---|---|
| → |  | 0.15 |
| → |  $3.102 < R_c < 3.10^5$<br>$3.10^5 \leqslant R_c < 3.5.10^6$<br>$R_c \geqslant 3,5\ 10^6$ | 0.2<br>0.2 ÷ 0.3<br>0.3 |

Replace (C.11) into (C.10), after reduced, we have a system of linear differential equations:

$$\ddot{q}_i + 2\gamma_i\omega_i\dot{q}_i + \omega_i^2 q_i = \frac{1}{\sum_{j=1}^{n} M_i\varphi_{ji}^2}\sum_{k=1}^{n}\varphi_{ki}F_k(\tau) \quad (C.12)$$

Where:

$F_k$ (τ) – force horizontal to wind direction acting on point k.

If taking into account only effects of resonance force, we have:

$$\ddot{q}_i + 2\gamma_i\omega_i\dot{q}_i + \omega_i^2 q_i = \frac{1}{\sum_{j=1}^{n} M_i\varphi_{ji}^2}\sum_{k=l_1}^{l_2}\varphi_{ki}F_k(\tau) \quad (C.13)$$

Where:

$$F_k(\tau) = 0.5\rho v_k^2 D_k \mu_{Lk} \sin\omega_s\tau \quad (C.14)$$

$l_1$, $l_2$ – the lowest and highest point within resonance area from $H_1$ to $H_2$;

$\omega_s$ – frequency of cyclone separation behind work in the resonance area.

Replace (C.14) into (C.13), we have:

$$\ddot{q}_j + 2\gamma_i \omega_i \dot{q}_i + \omega_i^2 q_i = \sum_{k=l_1}^{l_2} C_{ki} \sin \omega_s \tau \tag{C.15}$$

With :

$$C_{ki} = \frac{1}{2}\rho \frac{1}{\sum_{j=1}^{n} M_j \varphi_{ji}^2} \varphi_{ki} v_{ki}^2 D_k \mu_{Lk} \tag{C.16}$$

Solution of (C.15) shall be:

$$q_i = \frac{1}{\sum_{j=1}^{n} M_j \varphi_{ji}^2} \sum_{k=l_1}^{l_2} \frac{\frac{1}{2}\rho v_k^2 D_k \mu_{L.k} \varphi_{ki} \sin(\omega_s \tau + \theta)}{\omega_i^2 \sqrt{\left(1 - \frac{\omega_s^2}{\omega_i^2}\right)^2 + 4\gamma_i^2 \frac{\omega_s^2}{\omega_i^2}}} \tag{C.17}$$

Where:

$$tg\theta = \frac{2\gamma_i \omega_s}{\omega_i^2 - \omega_s^2} \tag{C.18}$$

Where resonance $\omega_i = \omega_s$ and $v_k = v_k'$, we have:

$$q_i = \frac{1}{\sum_{j=1}^{n} M_j \varphi_{ji}^2} \sum_{k=l_1}^{l_2} \frac{\frac{1}{2}\rho v_k^{*2} D_k \mu_{L.k} \varphi_{ki} \sin(\omega_i \tau + \frac{\pi}{2})}{2\gamma_i \omega_i^2} \tag{C.19}$$

Deduce that:

$$q_{i\max} = \frac{\frac{1}{2}\rho \sum_{k=l_1}^{l_2} V_k^{*2} D_k \mu_{L.k} \varphi_{ki}}{2\gamma_i \omega_i^2 \sum_{j=1}^{n} M_j \varphi_{ji}^2} \tag{C.20}$$

$v_k^*$ - the critical wind speed respective to high level of point k.

From (C.11), we have:

$$X_j = \sum_{i=1}^{n} q_i \varphi_{ji} = \sum_{i=1}^{n} X_{ji} \tag{C.21}$$

Where:

$$X_{ji} = q_i \varphi_{ji} \tag{C.22}$$

$$X_{ji} = \frac{\varphi_{ji}}{2\gamma_i \omega_i^2 \sum_{j=1}^{n} M_j \varphi_{ji}^2} \sum_{k=l_1}^{l_2} \frac{1}{2} \rho v_k^{*2} D_k \mu_{Lji} \varphi_{ki} \sin(\omega_i \tau + \frac{\pi}{2}) \tag{C.23}$$

From (C.23), we have the biggest displacement at the point j respective to the $i^{th}$ vibration type, which shall be:

$$X_{ji\max} = \frac{1}{\omega_i^2} \eta_{Lji} \xi_{Li} \tag{C.24}$$

Load acting on the $j^{th}$ part of work respective to the $i^{th}$ vibration type when stability loss by cyclone activation occurs shall be:

$$Q_{ji} = M_j \ddot{X}_{ji\max} = M_j X_{ji\max} \omega_i^2$$

Deduce that:

$$Q_{ji} = M_j \eta_{Lji} \xi_{Li} \tag{C.25}$$

Where:

$M_j$ – weight concentration at the point j

$$\xi_{Li} = \frac{1}{2\gamma_i} \tag{C.26}$$

For steel structure, $\gamma_i = 0.02$; for concrete reinforced structure, $\gamma_i = 0.05$

$$\eta_{Lji} = \frac{\frac{1}{2} \rho \varphi_{ji} \sum_{k=l_1}^{l_2} v_k^{*2} D_k \mu_{I.k} \varphi_{ki}}{\sum_{j=1}^{n} M_j \varphi_{ji}^2} \tag{C.27}$$

With:

$\rho$ – Air density ($kN.s^2/m^4$);

$v^*_k$ – critical wind speed at the level respective to point k (m/s);

$D_k$ – width of luff side of work at the level respective to point k (m);

$\varphi_{ji}$, $\varphi_{ki}$ – relative transversal displacements of point j and point k respective to the $i^{th}$ vibration type.

$\mu_{Lk}$ – Force factor horizontal to wind direction at the level of point k, taken from experiment, depending on Reynolds number $R_c$ (Figure C.3)

$\mu_L$

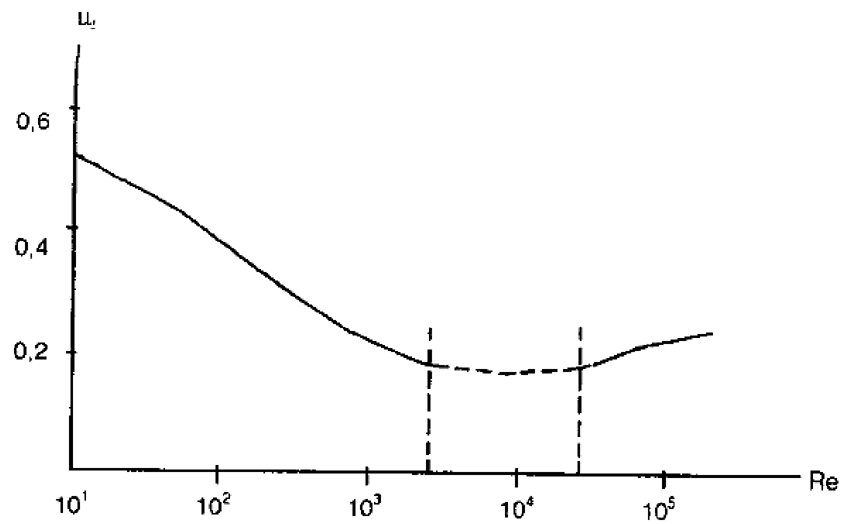



**Figure C.3: Experimental relation between $R_c$ and $\mu_L$ of cylindrical structure**

Based on formula (C.25), (C.26), we have some remarks: the resistance of structure is ever smaller, load caused by resonance is ever greater. If ignoring effect of structure resistance, load due to resonance is equal to infinite.

## C.3. Aerodynamic stability loss of galloping type for prism structures and works

### **C.3.1.** Phenomena

Work reacts under wind load action. Normally, this reaction is controlled due to structure resistance, vibration will be stable, but in some cases, activation part can generate dynamic resistant component. If the wind speed reached a certain number where value of dynamic resistant component is greater than value of structure resistance, generated dynamic vibration will progressively increase to maximum and cause damage due to aerodynamic stability loss, which shall be called as galloping phenomena. Therefore, it is imperative to design work protected from stability loss status.

### **C.3.2.** Reaction of work and critical wind speed

Take into account the cross section of prism object having constant stiffness and section under wind load (Figure C.4).

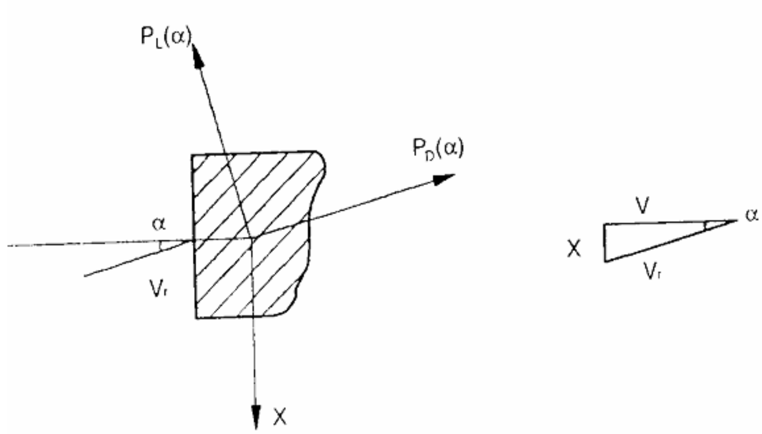



**Figure C.4: Wind force acting on prism object**

Equation for vibration horizontal to wind direction:

$$m\ddot{x} + c\dot{x} + kx = P_o(\alpha) \tag{C.28}$$

Where:

m – distributed weight;

c – resistance coefficient of structure by direction horizontal to wind current;

k – stiffness of system by direction horizontal to wind current.

Project forces on direction x, we have:

$$P_o(\alpha) = -P_D(\alpha)\sin\omega - P_L\cos\alpha \tag{C.29}$$

Where:

$P_o(\alpha)$ – force acting on object by direction horizontal to wind current corresponding to incident angle α of the wind;

$P_D(\alpha)$, $P_L(\alpha)$ – wind force acting on object corresponding to incident angle α by directions longitudinal and normal to wind current:

$$P_D(\alpha) = 0.5\rho v_r^2 D\mu_D(\alpha)\sin\alpha$$

$$P_L(\alpha) = 0.5\rho v_r^2 D\mu_L(\alpha)\cos\alpha \tag{C.30}$$

$\mu_D(\alpha)$, $\mu_L(\alpha)$ – Coefficient of forces longitudinal and normal to wind current respective to incident angle α.

Replace (C.30) into (C.29), we have:

$$P_o(\alpha) = 0.5\rho v_r^2 D[-\mu_D(\alpha)\sin\alpha - \mu_L(\alpha)\cos\alpha]$$

Because:

$$v_r = \frac{v}{\cos\alpha}$$

So: $$P_o(\alpha) = \frac{1}{2}\rho v^2 D\left[-\mu_D(\alpha)\frac{\sin\alpha}{\cos^2\alpha} - \mu_L(\alpha)\frac{1}{\cos\alpha}\right]$$

Or: $$P_o(\alpha) = \frac{1}{2}\rho v^2 D\mu_{DL}(\alpha) \qquad (C.31)$$

Where:

$$\mu_{DL}(\alpha) = -\left[\mu_D(\alpha)\frac{\sin\alpha}{\cos^2\alpha} + \mu_L(\alpha)\frac{1}{\cos\alpha}\right] \qquad (C.32)$$

With α is small, we can develop $\mu_{DL}(\alpha)$ according to Taylor series at α = 0 and taken approximately to two first terms of series.

$$\mu_{DL}(\alpha) = \mu_{DL}(0) + \mu'_{DL}(0)\alpha$$

With α = 0, deduce that $\alpha = \frac{\dot{x}}{v'}$, so we have:

$$\mu_{DL}(\alpha) = \mu_{DL}(0) + \mu'_{DL}(0)\frac{\dot{x}}{v'} \qquad (C.33)$$

Replace $\mu_{DL}(\alpha)$ from (C.33) into (C.31) and replace $P_o(\alpha)$ in (C.28), after reducing, we have:

$$\ddot{x} + 2\gamma\omega\dot{x} + \omega^2 x = \frac{1}{2m}\rho v^2 D\mu_{DL}(0) \qquad (C.34)$$

Where:

$$\gamma = \frac{1}{2}\left[c - \frac{1}{2}\rho v^2 D\mu'_{DL}(0)\right] \qquad (C.35)$$

$$\omega^2 = \frac{k}{m} \qquad (C.36)$$

Solution of (C.34) shall be:

$$x = x_o + \beta e^{-\gamma\omega t}\cos(\sqrt{1-\gamma^2}\,\omega t + \theta) \qquad (C.37)$$

Where:

x – Displacement horizontal to wind current of survey section;

$x_o$ – particular solution of equation (C.34);

β, θ – integration constants.

From (C.37), it shown that:

- when $\gamma > 0$, vibration amplitude will gradually decrease, work is in stable status.
- When $\gamma < 0$, vibration amplitude will increase to infinite by t, work in instable status.
- When $\gamma = 0$, work is in critical status. Therefore, from (C.35) we have a galloping dynamic stability loss condition as follows:

$$v \geq v^* = \frac{2c}{\rho D \mu_{DL}(0)} \tag{C.38}$$

Where:

v – wind speed acting on work (m/s);

$v^*$ - critical wind speed (m/s);

ρ – air density ($kN.s^2/m^4$);

D – width of luff side at the considered level

c – Resistance coefficient of structure by direction horizontal to wind current.

From (C.28) and (C.34), we have:

$$c = 2\gamma\omega m \tag{C.39}$$

Where:

ω - Determined by the formula (C.36);

m – distributed weight of work (T/m);

γ - resistance ratio of structure by direction horizontal to wind current;

$$\gamma = \frac{\delta}{2\Pi} \tag{C.40}$$

δ - logarithmic reduction of vibration;

$\mu'_{DL}(0)$ – determined by experiment. Respective to different sections, $\mu'_{DL}(0)$ is given in table C.2.

Formula (C.38) shall be used for checking possibility of galloping dynamic stability loss for works.

Generally, resistance coefficient of structure c> 0, necessary condition for $\gamma < 0$ shall be $\mu'_{DL}(0) > 0$. From (C.32), we have:

$$\mu'_{DL}(0) = -[\mu_{DL}(0) + \mu_L(0)]$$

So the necessary condition for the presence of galloping aerodynamic stability loss shall be:

$$\mu_D(0) + \mu'_L(0) < 0 \quad \text{(C.41)}$$

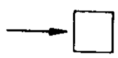
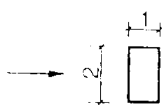
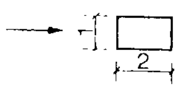
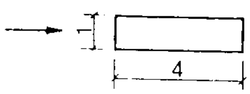
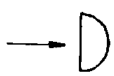
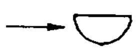
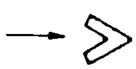
For cylindrical section structure and work, we have:

$$\frac{d\mu_L(\alpha)}{d\alpha} = 0$$

In the other hand, $\mu_D(\alpha) > 0$

So according to formula (C.41), the galloping aerodynamic stability loss shall not happen to cylindrical section structure and work.

**Table C.2. : Values of $\mu'_{DL}(0)$**

| **Section** | **$R_c$** | **$\mu'_{DL}(0)$** |
|---|---|---|
|  | 66000 | +2.7 |
|  | 66000 | 0 |
|  | 33000 | +3.0 |
|  | 2000 ~ 20,000 | +10.0 |
|  | 63,000 | 0 |
|  | 51,000 | -0.5 |
|  | 7,500 | +0.66 |

**C.4. Conclusion**

- For high raised buildings and soft structures, it should check for the aerodynamic stability loss.

- Stability loss due to cyclone activation happens normally to cylindrical section works and structures with wind speed within definite limit interval. In this case, the aerodynamic force acts essentially on a range of work height, which is ever higher, aerodynamic force is ever greater.

- Galloping stability loss happens normally for prism high raised buildings and soft structures, works having round cross section but harsh luff outside surface, when wind speed is greater than critical wind speed.

- It may design so that work can bear aerodynamic force once stability loss due to cyclone activation happens. For galloping stability loss, it must change design solution for protecting work from this stability loss status.

**C.5. Example 1**

Find out the displacement at peak and aerodynamic force for steel cylindrical tower, with height of 90m and calculation diagram as given in Figure C.5. Diameter of work D = 5.3m; Strouhal $S_h$ = 0.22; vibration frequency $f_1$=0.75 (Hz); force coefficient $\mu_L$ = const = 0.2; resistance ratio $\gamma$ =0.02; factor $m_t$ = 0.14; wind speed at the height 10 m $v_{10}$ = 15 m/s.

Critical wind speed shall be:

$$v^* = \frac{5.30 \times 0.75}{0.22} = 18.07 m/s$$

Action range of cyclone activation shall be:

$$H_1 = 10 \times \left(\frac{18.07}{15}\right)^{\frac{1}{0.14}} = 37.81 m$$

We have $H_1$ = 37.81m, smaller than H = 90m, so it will generate resonance phenomena due to cyclone activation for work:

$$H_2 = 10 \times \left(\frac{1.3 \times 18.07}{15}\right)^{\frac{1}{0.14}} = 246.32 m$$

Take $H_2$ =H = 90m

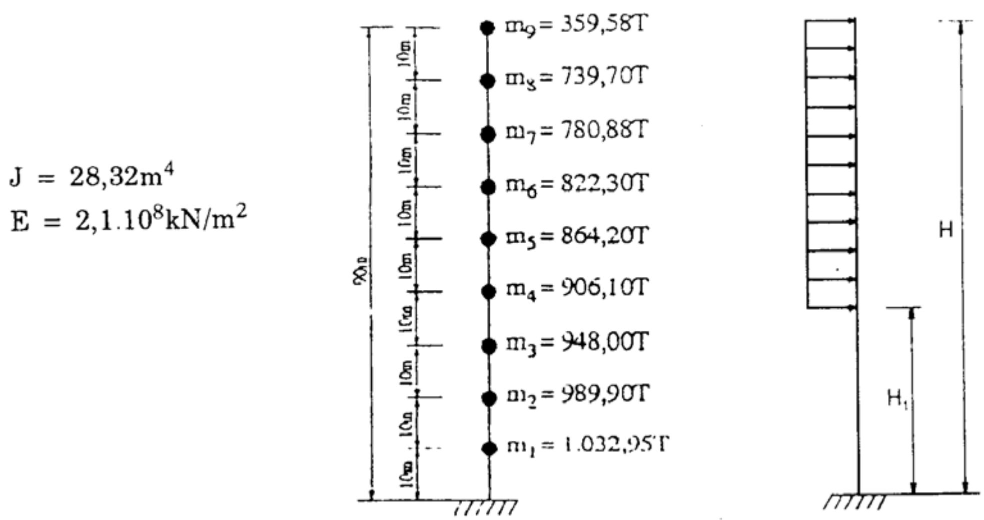



**Figure C.5 – Diagram for determination of dynamic force**

The largest displacement and the biggest load acting on work shall be defined by the formula:

$$X_{ji\max} = \frac{1}{\omega_i^2}\eta_{Lji}\xi_{Li}$$

$$Q_{ji} = M_j\eta_{Lji}\xi_{Li}$$

Where:

$$\xi_{Li} = \frac{1}{2\gamma_i} = \frac{1}{2\times 0.02} = 25$$

$\omega_i$ – the natural vibration frequency of work corresponding to the $i^{th}$ type of vibration. For simplification, take into account only the first type of vibration with $\omega_1 = 2\Pi f_1 = 4.71$ Rad/s.

$$\eta_{Lji} = \frac{\frac{1}{2}\rho\varphi_{ji}\sum_{k=l_1}^{l_2} V_k^{*2} D_k \mu_{Lk}\varphi_{ki}}{\sum_{j=1}^{n} M_j\varphi_{ji}^2}$$

With:

$V^*_k = V_{10}$ k (k is the factor taking into account wind pressure change by the height and relief type corresponding to weight concentration points within interval from $H_1$ to H (see table 7);

$D_k$ – width of luff side of work, $D_k$ = D = 5.3m;

$\mu_{Lk}$ = const = 0.2;

$\varphi_{ki}$ – relative transversal movement by direction horizontal to wind current at the point k respective to the $i^{th}$ type of vibration;

Because $H_1$ = 37.81m; $H_2$ = 90m, take $l_1$ at the point 4 with height $z_4$ = 40m and $l_2$ at the point 9 with height $z_9$ = 90m;

$M_j$ – weight concentration of work placed at the $j^{th}$ point;

Results of largest displacement and load acting on work at the $j^{th}$ point corresponding to the first vibration type shall be given in table C.3.

**Table C.3. Values of $X_{ljmax}$ and $Q_{lj}$ of work**

| Point j | Height z (m) | Weight $m_j$ (kg) | $\varphi_{1j}$ | $\eta_{Lli}$ | $X_{ljmax}$(m) | $Q_{lj}$ (kN) |
|---|---|---|---|---|---|---|
| 1 | 10 | 1,032,950 | $4{,}95.10^{-4}$ | $14{,}85.10^{-7}$ | 0.0163 | 0.12783 |
| 2 | 20 | 989,900 | $1{,}87.10^{-3}$ | $5{,}61.10^{-6}$ | 0.0617 | 1.38833 |
| 3 | 30 | 948,000 | $3{,}97.10^{-3}$ | $11{,}91.10^{-6}$ | 0.1010 | 2.82267 |
| 4 | 40 | 906,100 | $6{,}22.10^{-3}$ | $19{,}86.10^{-6}$ | 0.2185 | 4.49879 |
| 5 | 50 | 864,200 | $9{,}70.10^{-3}$ | $29{,}10.10^{-6}$ | 0.3201 | 6.28706 |
| 6 | 60 | 822,300 | $1{,}31.10^{-2}$ | $3{,}93.10^{-5}$ | 0.4323 | 8.07909 |
| 7 | 70 | 780,880 | $1{,}66.10^{-2}$ | $4{,}98.10^{-5}$ | 0.5478 | 9.72196 |
| 8 | 80 | 739,700 | $2{,}02.10^{-2}$ | $6{,}06.10^{-5}$ | 0.6666 | 11.20646 |
| 9 | 90 | 359,580 | $2{,}38.10^{-2}$ | $7{,}14.10^{-5}$ | 0.7854 | 6.41850 |

So the largest displacement at the work top is 0.7854m.

**C.6. Example 2**

Check for the aerodynamic stability loss of a square steel beam with thin wall, dimension of cross section is given in figure C.6. Span L = 12m, designed wind speed v= 44,5m/s; resistance ratio of structure $\gamma = 0.01$.

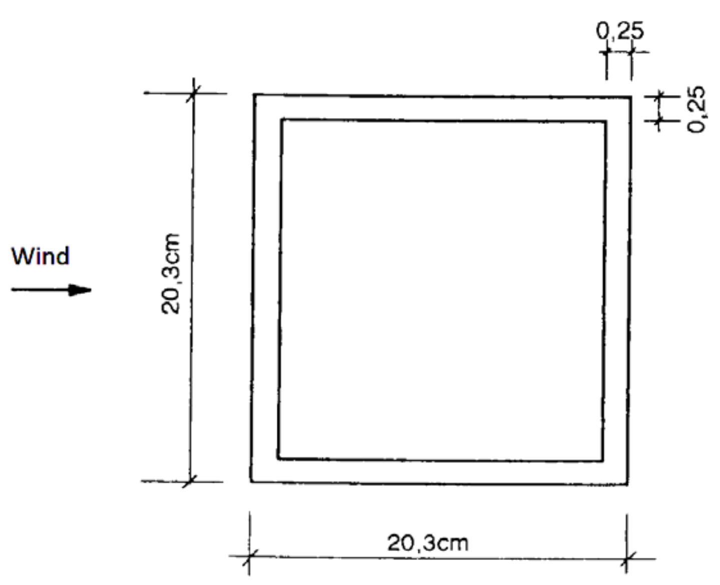



**Figure C.6. Cross section of steel beam**

Elasticity modulus: $E = 2.10^4$ kN/cm$^2$

Inertia moment resistant to bending of section J = 1420 cm$^4$

Section area A = 20.5cm$^2$

Distributed weight: m = 1.678 x $10^6$ kN.$s^2$/$cm^2$.

Air density: ρ = 0.125 x $10^{-10}$ kN.$s^2$/$cm^4$.

Vibration frequency $f_1$

$$f_1 = \frac{\pi}{2L^2}\sqrt{\frac{EJ}{m}}$$

$f_1$ = 4.49Hz

From table C.2, we have:

$\mu'_{DL}(0) = +2.7$

Resistance coefficient: C = 2γωm

C = 4πγ$f_1$m

C = 0.9468.$10^6$.

Critical wind speed:

$$v^* = \frac{2\times 0.9468\times 10^6}{0.125\times 10^{-10}\times 20.3\times 2.7} = 2764 cm/s = 27.64 m/s$$

Because v > $v^*$, beam lost its stability. It needs to expand dimension of beam.

# ANNEX D
## (Reference)
## Examples of calculation

**D.1. Example 1:**

Determine the dynamic component of wind load acting on building of 21 stories in Hanoi. Building height H = + 77.7m; plan dimension D x L = 24m  x 24m. Working life is 50 years.

For the layout plan of wall structure, hard core and frame of house, see Figure D.1

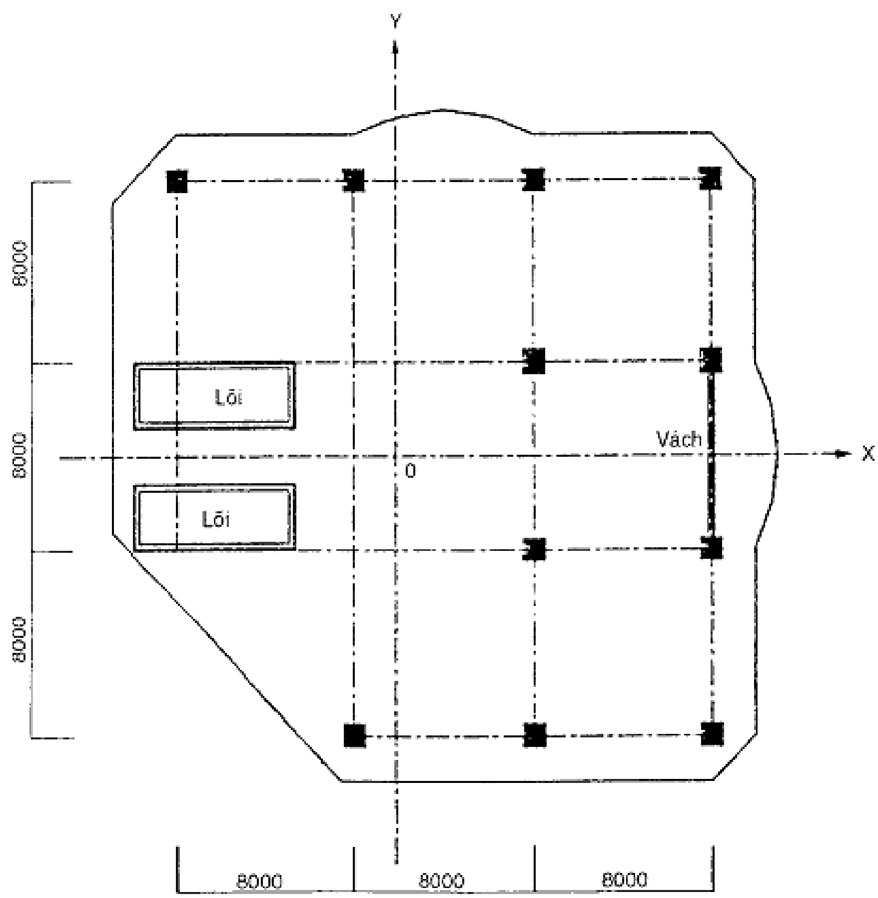



**Figure D.1: Building layout**

Because the building height H =77.7m, greater than 40 m so it must take into account the dynamic component of wind load.

**D.1.1.** Layout of dynamic calculation

The stiffness by unfavorable direction of the building $EJ_y$ = 922529.515 kN.m$^2$; 21 points of mass concentration corresponding to floor levels. Dynamic calculation layout of building shall be taken as a console clamped to ground, see Figure D.2.

**D.1.2.** Determination of dynamic characteristics

D.1.2.1. Determination of natural vibration frequency

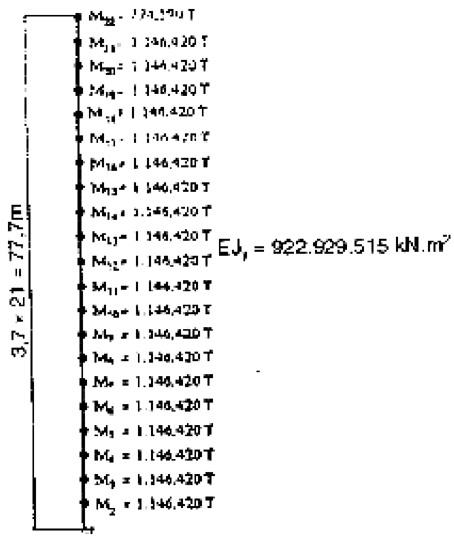



**Figure D.2. Layout of dynamic calculation**

For building having section and stiffness constant by the height, the natural vibration frequency shall be defined by the formula B.24, annex B:

$$f_i = \frac{\alpha_i^2}{2\pi H^2}\sqrt{\frac{EJg}{q}} = \frac{\alpha_i^2}{2\pi H^2}\sqrt{\frac{EJh}{m}}$$

Where:

$\alpha_i$ – coefficient respective to natural vibration frequency of work, with three first types, we have:

$$\alpha_1 = 1.875;\ \alpha_2 = 4.694;\ \alpha_3 = 7.86$$

H – Height of work, H = 77.7m;

m – Work mass per a unit of length by work height (T/m$^3$);

Hence:

$$f_1 = \frac{1{,}875^2}{2 \times 3{,}14 \times 77{,}7^2} \sqrt{\frac{922529515 \times 3{,}7}{1146{,}42}} = 0{,}16\text{Hz}$$

$$f_2 = \left(\frac{\alpha_2}{\alpha_1}\right)^2 f_1 = \left(\frac{4{,}694}{1{,}875}\right)^2 \times 0{,}16 = 1{,}002\text{Hz}$$

$$f_3 = \left(\frac{\alpha_3}{\alpha_2}\right)^2 f_1 = \left(\frac{7{,}86}{1{,}875}\right)^2 \times 0{,}16 = 2{,}819\text{Hz}$$

Because $f_2 < f_L < f_3$ (with $v_L$ is the critical value of natural vibration frequency, according to Table 2 $f_L = 1.3$), the determination of dynamic component of wind load shall take into account only the effect of the two first oscillation types.

D.1.2.2. Determination of natural vibration types

The ith natural vibration amplitude at the point j shall be defined by the formula:

$$y_{ji} = \sin \alpha_i \xi_j^* - \text{sh}\, \alpha_i \xi_j^* - B(\cos \alpha_i \xi_j^* - \text{ch}\, \alpha_i \xi_j^*)$$

With three first types, we have:

$$\alpha_1 = 1.875; \ \alpha_2 = 4.694; \ \alpha_3 = 7.86$$

$$B_1 = 1.365; B_2 = 0.980; B_3 = 1.00$$

$$\xi_j^* = \frac{h_j}{H}$$

With $h_j$ is the distance from the point where located the jth mass to foundation surface of work.

Calculation result of values $y_{ji}$ of the two first types of oscillation given in table D.1.

**Table D.1. Amplitude of the two first oscillation types**

| Storey | High level z (m) | $\xi_j^*$ | $y_{j1}$ | $y_{j2}$ |
|---|---|---|---|---|
| 2 | 3,7 | 0,048 | 0,0108 | 0,0459 |
| 3 | 7,4 | 0,095 | 0,0414 | 0,1653 |
| 4 | 11,1 | 0,143 | 0.0917 | 0,3410 |
| 5 | 14.8 | 0,190 | 0,1583 | 0,5442 |
| 6 | 18,5 | 0,238 | 0,2423 | 0,7628 |
| 7 | 22.2 | 0,286 | 0,3413 | 0,9725 |
| 8 | 25,9 | 0,333 | 0,4512 | 1,1521 |
| 9 | 29,6 | 0,381 | 0,5756 | 1,2938 |
| 10 | 33,3 | 0,429 | 0,7107 | 1,3808 |
| 11 | 37,0 | 0,476 | 0,8521 | 1,4040 |
| 12 | 40,7 | 0,524 | 1,0046 | 1,3587 |
| 13 | 44,4 | 0,571 | 1,1600 | 1,2447 |
| 14 | 48,1 | 0,620 | 1,3257 | 1,0535 |
| 15 | 51,8 | 0,667 | 1,4955 | 0,8049 |
| 16 | 55.5 | 0,714 | 1,6655 | 0,4993 |
| 17 | 59,2 | 0,762 | 1,8418 | 0,1371 |
| 18 | 62,9 | 0,810 | 2,0201 | -0,2656 |
| 19 | 66,6 | 0,857 | 2,1959 | -0,6888 |
| 20 | 70.3 | 0,905 | 2,3763 | -1,1405 |
| 21 | 74.0 | 0,952 | 2,5533 | -1,5951 |
| 22 | 77,7 | 1,000 | 2,7343 | -2,0656 |

**D.1.3.** Determination of standard value for static component of wind load acting on designed parts of work

The standard value for static component of wind load $W_j$ at the height $z_j$ compared with standard level shall be defined by the formula (4.11)

$$W_j = W_o k(z_j)c$$

Where:

$W_o$ – Standard value of wind pressure. Work built in Hanoi is classified in region II-B, so $W_o$ = 95daN/m$^2$ = 0.95 kN/m$^2$;

$k(z_j)$ – Factor taking into account the wind pressure change by height, given in table 7;

c – Aerodynamic coefficient. The luff side $c_d$ = 0.8; the draft side $c_h$ = 0.6

$$c = 0.8 + 0.6 = 1.4$$

Calculation results of Wj values are given in Table D.2

**Table D.2. Values $W_j$ respective to designed parts of work**

| **Storey** | **High level z (m)** | **k** | **$W_j$(kN/m$^2$)** |
|---|---|---|---|
| **1** | **2** | **3** | **4** |
| 2 | 3.7 | 0.828 | 1.10124 |
| 3 | 7.4 | 0.938 | 1.24754 |
| 4 | 11.1 | 1.018 | 1.35394 |
| 5 | 14.8 | 1.077 | 1.43241 |
| 6 | 18.5 | 1.115 | 1.48295 |
| 7 | 22.2 | 1.150 | 1.52950 |
| 8 | 25.9 | 1.183 | 1.57339 |
| 9 | 29.6 | 1.216 | 1.61728 |
| 10 | 33.3 | 1.240 | 1.64920 |
| 11 | 37.0 | 1.262 | 1.67846 |
| 12 | 40.7 | 1.284 | 1.70772 |
| 13 | 44.4 | 1.306 | 1.73698 |
| 14 | 48.1 | 1.329 | 1.76757 |
| 15 | 51.8 | 1.347 | 1.79151 |
| 16 | 55.5 | 1.362 | 1.87746 |
| 17 | 59.2 | 1.377 | 1.83141 |
| 18 | 62.9 | 1.390 | 1.84870 |
| 19 | 66.6 | 1.403 | 1.86599 |
| 20 | 70.3 | 1.416 | 1.88328 |
| 21 | 74.0 | 1.429 | 1.90057 |
| 22 | 77.7 | 1.442 | 1.91786 |

**D.1.4.** Determination of dynamic component of wind load acting on works

Standard value of dynamic component of wind load acting on the jth part (with the height z) corresponding to the ith natural vibration shall be defined by the formula (4.3).

$$W_{p(ji)} = M_j \xi_i \psi_i y_{ji}$$

Where:

$M_j$ – weight concentration of the jth part of work;

$\xi_i$ – Dynamic coefficient respective to the $i^{th}$ oscillation;

$y_{ij}$ – Relative transversal displacement of the center of the jth part corresponding to the ith oscillation;

$\psi_i$ – Factor defined by dividing work into n parts so that within each part, wind load can be regarded as constant.

a) Determination of $\psi_i$ factor

The factor $\psi_i$ shall be defined by formula (4.5)

$$\Psi_i = \frac{\sum_{j=1}^{n} y_{ji} W_{Fj}}{\sum_{j=1}^{n} y_{ji}^2 M_j}$$

For $V_{Fj}$: Standard value of dynamic component of wind load acting on the jth part of work, respective to different oscillations types taking into account only the effects of wind speed impulse, shall be defined as follows:

$$V_{Fj} = W_j \zeta_j \nu D_j h_j$$

Where:

$D_j$, $h_j$ – the width and height of luff side respective to the jth part;

$\zeta_j$ – Dynamic pressure coefficient of wind load at the height z corresponding to the jth part of work, see Table 3;

$\nu$ – the correlative space coefficient of dynamic pressure of wind load, defined depending on parameters $\rho$, $\chi$ and types of oscillation. For basic coordinate plane parallel to the designed surface zOx, we have:

$\rho = D = 24m$; $\chi = H = 77.7m$

With table 4 and table 5, we have:

- for the first oscillation, $\nu_1 = 0.673$;
- for the second oscillation, $\nu_2$ shall be taken from Table 1.

Calculation results of $W_{Fj}$ are given in the Table D.3

**Table D.3: Values of $W_{Fj}$**

| Storey | High level z (m) | $W_j$ ($kN/m^2$) | $\zeta_j$ | $W_{Fj}$ (kN) | |
|---|---|---|---|---|---|
| | | | | 1st type | 2nd type |
| 2 | 3.7 | 1.10124 | 0.517 | 34.02519 | 50.55749 |
| 3 | 7.4 | 1.24754 | 0.504 | 37.57622 | 55.83390 |
| 4 | 11.1 | 1.35394 | 0.483 | 39.08180 | 58.07103 |
| 5 | 14.8 | 1.43241 | 0.472 | 40.40521 | 60.03746 |
| 6 | 18.5 | 1.48295 | 0.461 | 40.85596 | 60.70723 |
| 7 | 22.2 | 1.52950 | 0.454 | 41.49859 | 61.66210 |
| 8 | 25.9 | 1.57339 | 0.449 | 42.21927 | 62.73295 |
| 9 | 29.6 | 1.61728 | 0.444 | 42.52712 | 63.76482 |
| 10 | 33.3 | 1.64920 | 0.438 | 43.16934 | 64.14464 |
| 11 | 37.0 | 1.67846 | 0.433 | 43.43371 | 64.53796 |
| 12 | 40.7 | 1.70772 | 0.428 | 43.68059 | 64.90429 |
| 13 | 44.4 | 1.73698 | 0.426 | 44.22140 | 65.70787 |
| 14 | 48.1 | 1.76757 | 0.423 | 44.68328 | 66.39417 |
| 15 | 51.8 | 1.79151 | 0.420 | 44.96727 | 66.81616 |
| 16 | 55.5 | 1.81146 | 0.417 | 45.14325 | 67.07767 |
| 17 | 59.2 | 1.83141 | 0.414 | 45.31208 | 67.32849 |
| 18 | 62.9 | 1.84780 | 0.412 | 45.49673 | 67.63580 |
| 19 | 66.6 | 1.86599 | 0.410 | 45.72158 | 67.93696 |
| 20 | 70.3 | 1.88328 | 0.408 | 45.92018 | 68.23199 |
| 21 | 74.0 | 1.90057 | 0.406 | 46.11455 | 68.52087 |
| 22 | 77.7 | 1.91786 | 0.404 | 46.30483 | 68.80361 |

From values of $M_j$, $y_{ji}$ and $W_{Fj}$, we can define the factor $\psi_i$ respective to the two first oscillation types:

$$\psi_1 = 0.0229; \psi_2 = 0.017$$

b) Determination of dynamic coefficient $\xi_i$

The dynamic coefficient $\xi_i$ shall be determined according to the parameter $\varepsilon_i$ and logarithmic reduction $\delta$.

Parameter $\varepsilon_i$ shall be determined according to formula (4.4)

$$\varepsilon_i = \frac{\sqrt{\gamma W_o}}{940 f_i}$$

Where:

$\gamma$ - reliability coefficient of wind load, taken equally to 1.2;

$f_i$ – the $i^{th}$ oscillation frequency;

$W_o$ – equal to 950 N/m$^2$.

This building was made of reinforced concrete, so $\delta$ = 0.3. Basing on graph of Figure 1, it may determine the dynamic coefficient $\xi_i$ as given in Table D.4

**Table D.4: Dynamic coefficient $\xi_i$i respective to two first types of vibration**

| **$f_i$ (Hz)** | | **ε** | | **ξ** | |
|---|---|---|---|---|---|
| 1$^{st}$ type | 2$^{nd}$ type | 1$^{st}$ type | 2$^{nd}$ type | 1$^{st}$ type | 2$^{nd}$ type |
| 0.16 | 1.002 | 0.22 | 0.036 | 2.14 | 1.45 |

c) Determination of dynamic component of wind load

From values of $M_j$, $\xi_i$; $\psi_i$ and $y_{ji}$, we determine the standard values of dynamic component of wind load $W_{\rho(ji)}$.

Designed value of dynamic component of wind load shall be defined by formula (4.10):

$$W^{tt}_{\rho(ji)} = W_{\rho(ji)}\gamma\beta$$

Where:

$\gamma$ – Reliability coefficient of wind load, $\gamma$ shall be equal to 1.2;

$\beta$ – Correction coefficient of wind load by time; $\beta$ shall be equal to 1.0.

Results of standard values and designed values of dynamic component are given in table D.5.

Table D.5: Values of $W_{p(ji)}$ and $W^{tt}_{p(ji)}$

| Storey | High level z (m) | $W_{p(ji)}$ (kN) | | $W^{tt}_{p(ji)}$ (kN) | |
|---|---|---|---|---|---|
| | | 1st type | 2nd type | 1st type | 2nd type |
| 2 | 1146,42 | 0,6068 | 1,2971 | 0,7282 | 1,5565 |
| 3 | 1146,42 | 2,3259 | 4,6741 | 2,7911 | 5,6089 |
| 4 | 1146,42 | 5,1462 | 9,6308 | 6,1754 | 11,5569 |
| 5 | 1146,42 | 8,8762 | 15,3843 | 10,6520 | 18,4612 |
| 6 | 1146,42 | 13,5959 | 21,5505 | 16,3151 | 25,8606 |
| 7 | 1146,42 | 19,1523 | 27,4708 | 22,9828 | 32,9650 |
| 8 | 1146,42 | 25,3210 | 32,5547 | 30,3582 | 39,0656 |
| 9 | 1146,42 | 32,3043 | 37,2061 | 38,7652 | 44,6474 |
| 10 | 1146,42 | 39,8945 | 39,0204 | 47,8734 | 96,8245 |
| 11 | 1146,42 | 47,9172 | 39,6760 | 57,5006 | 47,6112 |
| 12 | 1146,42 | 56,4792 | 38,3930 | 67,7750 | 46,0716 |
| 13 | 1146,42 | 65,2435 | 35,1771 | 78,2922 | 42,2125 |
| 14 | 1146,42 | 74,5191 | 29,8898 | 89,4229 | 35,8678 |
| 15 | 1146,42 | 84,0643 | 22,7430 | 100,8772 | 27,2917 |
| 16 | 1146,42 | 93,5927 | 14,0901 | 112,3112 | 16,9081 |
| 17 | 1146,42 | 103,4975 | 3,8659 | 124,197 | 4,6390 |
| 18 | 1146,42 | 113,5146 | -7,4792 | 136,2175 | -8,9966 |
| 19 | 1146,42 | 123,3801 | -19,4791 | 148,0561 | -23,3749 |
| 20 | 1146,42 | 133,5152 | -32,2353 | 160,2182 | -38,6824 |
| 21 | 1146,42 | 143,4481 | -45,0933 | 172,1377 | -54,1119 |
| 22 | 774,59 | 103,7928 | -39,4398 | 124,5514 | -47,3278 |

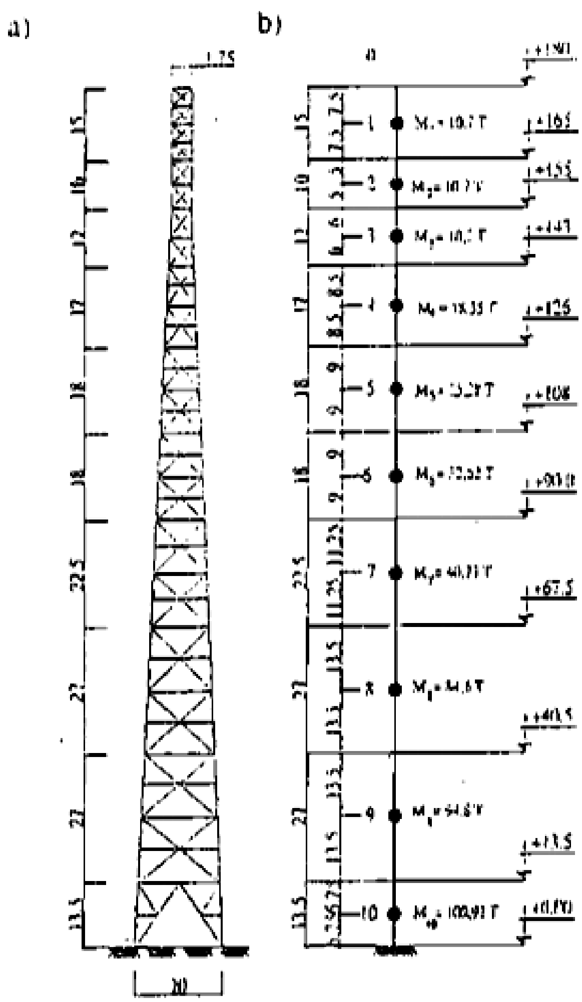
**D.2. Example 2: Determination of dynamic component of wind load acting on steel electric post.**

The electric post was built in zone II, B relief type with standard wind pressure equal to 95 daN/m$^2$. It has a spatial structure made of tube steel of different diameters. Post sections are square and its geometric dimension is given in Figure D.3a.

Choose the calculation model of post having undergrounded console bar with concentrated weights as given in Figure D.3b.

**D.2.1.** Determination of frequency and basic natural vibration of work

The basic free vibration frequency of work shall be calculated by formula (B.28), annex B.




| | Shapes, dimension | Bar sect (m2) | inertia moment of sect. (m2) | $\frac{J_1}{J}$ |
|---|---|---|---|---|
| 1 | ф168/20 0.875 | 0.037 | 0.029 | 1 |
| 2 | ф168/20 0.875 | 0.037 | 0.029 | 1 |
| 3 | ф168/20 1.093 | 0.037 | 0.045 | 0.645 |
| 4 | ф245/20 1.530 | 0.057 | 0.150 | 0.193 |
| 5 | ф273/20 2.300 | 0.070 | 0.400 | 0.072 |
| 6 | ф325/24 3.000 | 0.091 | 0.830 | 0.035 |
| 7 | ф325/31 3.879 | 0.125 | 1.800 | 0.016 |
| 8 | ф425/14 5.900 | 0.160 | 4.900 | 0.006 |
| 9 | ф425/14 7.600 | 0.166 | 9.500 | 0.003 |
| 10 | ф425/14 9.414 | 0.166 | 17.33 | 0.002 |

**Figure D.3. Geometric dimensions and calculation model of electric post:**

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{g y_H}{\sum_{j=1}^{n} P_j y_j^2}}$$

Where:

$P_j$: the weight of the i$^{th}$ work section, in kN;

$Y_H$, $y_j$ – the displacement at peak and center of the i$^{th}$ section caused by the force in 1kN placed at work peak.

Calculation results of $y_H$, $y_j$, and $P_j$, $y_j^2$ are given in table D.6

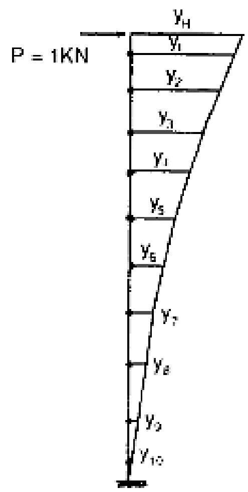



**Figure D.4. Displacements $y_H$ and $y_j$ caused by force P = 1kN placed at the work peak**

**Table D.6. Values of $y_j$ and $P_j$, $y_j^2$**

| No | $Y_j$(m) | $P_j$(kN) | $P_j y_j^2$(kN.m$^2$) |
|---|---|---|---|
| $y_H$ | $6,20.10^{-2}$ | | |
| $y_1$ | $5,10.10^{-2}$ | 104,967 | $27,30.10^{-2}$ |
| $y_2$ | $3,43.10^{-2}$ | 104,967 | $12,35.10^{-2}$ |
| $y_3$ | $2,37.10^{-2}$ | 104,967 | $5,896.10^{-2}$ |
| $y_4$ | $1,51.10^{-2}$ | 180,014 | $4,104.10^{-2}$ |
| $y_5$ | $0,89.10^{-2}$ | 247,997 | $1,964.10^{-2}$ |
| $y_6$ | $0,51.10^{-2}$ | 320,002 | $8,323.10^{-3}$ |
| $y_7$ | $0,26.10^{-2}$ | 399,954 | $2,704.10^{-3}$ |
| $y_8$ | $0,98.10^{-3}$ | 830,024 | $7,792.10^{-3}$ |
| $y_9$ | $0,33.10^{-3}$ | 929,988 | $1,013.10^{-4}$ |
| $y_{10}$ | $0,10.10^{-4}$ | 990,025 | $1,198.10^{-7}$ |
| | | Total | 0,529 |

So the first natural vibration frequency of work shall be:

$$f_1 = \frac{1}{2 \times 3,14}\sqrt{\frac{9,81 \times 6,2 \times 10^{-2}}{0,529}} = 0,17\,Hz < f_L = 4,1Hz$$

Thus, the dynamic component of wind load must take into account both wind speed impulse and inertia moment of the work. In this example, to simplify the issue, it must consider only effect of the 1st natural vibration on dynamic component of wind load.

The basic natural vibration in this case can be taken nearly approximate to elastic line of system, caused by the force P = 1kN placing at peak, given in table D.6.

D.2.2. Determination of standard values of static component of wind load acting on designed parts of work

The standard value of static component shall be defined by the formula (4.11)

$$W_j = W_o k(z_j)c$$

Where:

$W_o$ – equal to 95 daN/m$^2$ = 0.95kN/m$^2$;

$k(z_j)$ – factor taking into account the change of wind pressure by height;

c – frontal resistance coefficient for works having spatial frame and hollow tower, shall be determinated by the following formula:

$$c = c_x(1+\eta)k_1$$

a) Determination of the frontal resistance coefficient

$c_x$ – aerodynamic coefficient for an independent flat frame

$$c_x = \frac{1}{A}\sum c_{xi}A_i$$

Where:

$c_{xi}$ – aerodynamic coefficient of the i$^{th}$ member defined in table 6 of TCVN 2737:1995;

$A_i$ – Projection area of the i$^{th}$ member on the luff surface of frame;

A – Area limited by perimeter of frame

For more details, see column section No. 7 for the aerodynamic coefficient of each member given in table D.7

**Table D.7 The aerodynamic coefficient $c_{xi}$ of each bar of the column section No.7**

| No | Diameter (m) | Length of bar (m) | Number of bar | $R_e$ | $c_{xi}$ |
|---|---|---|---|---|---|
| 1 | 325 | 22.50 | 2 | $3.672,10^5$ | 0.70 |
| 2 | 28 | 27.60 | 2 | $0.316,10^5$ | 1.20 |
| 3 | 168 | 17.78 | 1 | $1.898,10^5$ | 1.10 |
| 4 | 114 | 15.28 | 1 | $1.288,10^5$ | 1.20 |

$$A_7 = (3.875 \text{ x } 2 + 0.325) \text{ x } 22.5 = 181.69 \text{ m}^2$$

$$\sum c_{xi} A_{i7} = 2\times0.325\times22.5\times0.7 + 2\times0.028\times27.6\times1.2 +$$
$$+ 0.168\times17.78\times1.10 + 0.114\times15.28\times1.20 = 17.468 m^2$$

So coefficient $c_x$ shall be equal to:

$$c_x = \frac{1}{181.69}\times17.468 = 0.096$$

$\eta$ – factor depending on occupation coefficient $\varphi$ of the structure and $R_e$.

The occupation coefficient $\varphi$ shall be defined by the following formula:

$$\varphi = \frac{\sum A_i}{A}$$

$$\sum A_{i7} = 2\times0.325\times22.5 + 2\times0.028\times27.6 + 0.168\times17.78 + 0.114\times15.28 = 20.9m^2$$

Thus,

$$\varphi_7 = \frac{20.90}{181.69} = 0.115$$

For the section 7, refer to table above, we have $\eta_7 = 0.95$

$k_1$ – factor depending on wind direction, refer to the table $k_1$ = 1.2 x 0.9 (0.9 is here the factor for tower combined from single steel)

So the frontal resistance coefficient shall be:

$$c_7 = 0.094 \text{ x } (1+0.95) \text{ x } 1.2 \text{ x } 0.9 = 0.206$$

b) Determination of coefficient taking into account wind load change by the height $k(z_j)$.

For the section 7, at the high level $z_7$ = 78.75m, with relief of B type, we have $k_7$ = 1.446.

The standard value of static component of wind load at the section 7 shall be:

$$W_7 = 0.95 \times 1.446 \times 0.206 = 0.28298 \text{ kN/m}^2.$$

**D.2.3.** Determination of dynamic component of wind load on works

The standard value of dynamic component of wind load shall be determined according to formula (4.3). When considering only basic oscillation, this formula will be:

$$W_{pj} = M_j \xi \psi y_j$$

Where:

$M_j$ = weight of the j$^{th}$ part of work having center at the height z;

$\xi$ - the aerodynamic coefficient respective to basic oscillation;

$y_j$ – the relative transversal displacement for the j$^{th}$ work part at the height z, corresponding to basic oscillation;

$\psi$ – Coefficient determined by dividing work into n parts, between each part, the wind load is regarded as constant.

a) Determination of $\psi$:

Coefficient $\psi$ shall be determined according to formula (4.5). When considering only basic oscillation, this formula will be:

$$\psi = \frac{\sum_{j=1}^{n} y_j W_{Fj}}{\sum_{j=1}^{n} y_j^2 M_j}$$

Where:

$y_j$ – approximate to values given in column 2 of table D.6;

$W_{Fj}$ - Standard value of dynamic component of wind load acting on the j$^{th}$ part of work, respective to the 1$^{st}$ oscillation taking into account only the effects of wind speed impulse, shall be defined by the formula (4.6).

$$W_{Fj} = W_j \zeta_i \nu S_j$$

Where:

$W_j$ – determined in section D.2.2; $W_7$ =0.28298 kN/m$^2$;

$\zeta_j$ – dynamic pressure coefficient of wind load in the j[th] part of work;

$\nu$ – The correlative space coefficient that is taken equally to $\nu_1$ corresponding to the basic oscillation.

In considering section 7, it has a weight M = 40.77t, placed at height of 78.75m. Work is built on B type relief, if referring to table, $\zeta_7 = 0.404$.

The correlative space coefficient $\nu_1$ shall be determined according to parameters $\rho$, $\chi$ and oscillation type.

We have: $\rho$ = D with D equal to the luff width of electric post in the section at the 2/3 height of post.

$$\rho = D = (20 - 1.75)\times\frac{2}{3} + 1.75 + 0.325 = 14.242m$$

$$\chi = H = 180 \text{ m};$$

Taken from table 4 and 5, $\nu_1 = 0.616$.

$S_7$ – The luff area shall be taken from the table of area limited by perimeter of post, $S_7 = A_7$.

Thus: $$W_{F7} = 0.28298\times 0.404\times 0.616\times 181.69 = 12.79525kN$$

By the similar way above, we can determine the values of $W_{Fj}$ for other parts of work. Results are given in table D.8

**Table D.8 Values of $W_{Fj}$, $y_{j1}$, $M_j$**

| No | $W_{Fj}$(kN) | $y_{j1}$ | $M_j$ (t) |
|---|---|---|---|
| 1 | 5.1237 | $5.1.10^{-2}$ | 10.70 |
| 2 | 3.34778 | $3.43.10^{-2}$ | 10.70 |
| 3 | 3.86710 | $2.37.10^{-2}$ | 10.70 |
| 4 | 6.75861 | $1.51.10^{-2}$ | 18.35 |
| 5 | 8.64151 | $0.89.10^{-2}$ | 25.28 |
| 6 | 10.12816 | $0.51.10^{-2}$ | 32.62 |
| 7 | 12.79525 | $0.26.10^{-2}$ | 40.77 |
| 8 | 17.94117 | $0.98.10^{-3}$ | 84.61 |
| 9 | 14.56051 | $0.33.10^{-3}$ | 94.80 |
| 10 | 8.94394 | $0.10.10^{-4}$ | 100.92 |

$$\sum y_j W_{Fj} = 0.7541$$

$\sum y_j^2 M_j = 0.0538$

$\psi_1 = \dfrac{0.7541}{0.0538} = 14.017$

b) Determination of dynamic coefficient ξ

The dynamic coefficient ξ shall be determined according to Figure 1 depending on the parameter ε and the logarithmic reduction of oscillation δ.

Parameter ε shall be defined by the formula (4.4)

$$\varepsilon = \frac{\sqrt{\gamma W_o}}{940 f}$$

Where:

γ – reliability coefficient of wind load, γ = 1.2;

$W_o$ – standard value of wind pressure, $W_o = 950 N/m^2$;

f – frequency of basic oscillation

So: $$\varepsilon = \frac{\sqrt{1.2 \times 950}}{940 \times 0.17} = 0.21$$

Because work is a steel pillar type, the logarithmic reduction of frequency δ = 0.15.

Refer to the table, we can have value of dynamic coefficient ξ = 2.8.

c) Determination of $W_{pj}$ and $W_{pj}^{tt}$

From values of $M_j$, ξ, ψ and $y_{j1}$ found above, it can determine standard value of dynamic component of wind load $W_{pj}$ acting on work parts.

Designed value of dynamic component shall be defined by the formula (4.10)

$$W_{pj}^{tt} = W_{pj} \gamma \beta$$

Where:

γ – reliability coefficient of wind load, γ = 1.2

β – Correction coefficient of wind load upto assumed using time of work. For work with life of 50 years, β = 1.

Calculation results of $W_{pj}$ and $W_{pj}^{tt}$ values are given in Table D.9

**Table D.9: Values of $W_{pj}$ and $W_{pj}^{tt}$**

| The $j^{th}$ work part | Weight $M_j$(t) | $y_{i1}$ | $W_{pj}$(kN) | $W_{pj}^{tt}$ (kN) |
|---|---|---|---|---|
| 1 | 10,70 | $5,1.10^{-2}$ | 21,417 | 25,700 |
| 2 | 10,70 | $3,43.10^{-2}$ | 14,404 | 17,285 |
| 3 | 10,70 | $2,37.10^{-2}$ | 9,953 | 11,944 |
| 4 | 18,35 | $1,51.10^{-2}$ | 10,887 | 13,064 |
| 5 | 25,28 | $0,89.10^{-2}$ | 8,830 | 10,596 |
| 6 | 32,62 | $0,51.10^{-2}$ | 6,529 | 7,835 |
| 7 | 40,77 | $0,26.10^{-2}$ | 4,160 | 4,992 |
| 8 | 84,61 | $0,98.10^{-3}$ | 3,254 | 3,905 |
| 9 | 94,80 | $0,33.10^{-3}$ | 1,228 | 1,473 |
| 10 | 100,92 | $0,10.10^{-4}$ | 0,040 | 0,048 |

**D.3. Example 3:**

Determine the dynamic component of wind load acting on concrete reinforcement chimney built in region IIB. Chimney height H = 180m, made of concrete mark M250 ($E_b = 2.8.10^7$ kN/m$^2$), the inertia moment of chimney bottom section $J_o$ = 1020m$^4$; area of bottom section $F_o$ = 40.1m$^2$; the inertia moment of chimney top section $j_H$ = 22.1m$^4$; area of foundation base $F_m$ = 615m$^2$. The lining layer of chimney body is based on concrete reinforcement consoles and made from refractory bricks. There is a heat insulated mineral wool layer between concrete wall and lining layer.

Volume weight of materials making chimney body and lining shall be:

$$q_{th} = 24\text{kN/m}^3;\ q_l = 14\text{kN/m}^3$$

The area of cross section of body and lining part respective to the average level of chimney shall be:

$$F_{th} = 5.2\text{m}^2;\ F_l = 6.56\text{m}^2$$

The chimney top height is of 10m and made of acid resistant brick with longitudinal steel reinforcement. Compression coefficient $C_z$ = 60000 kN/m$^2$. Geometric layout of chimney is given in Figure D.5a.

Divide chimney into 15 parts, mass of each part shall be placed at the center of each section. Dynamic calculation diagram is given in Figure D.5b.

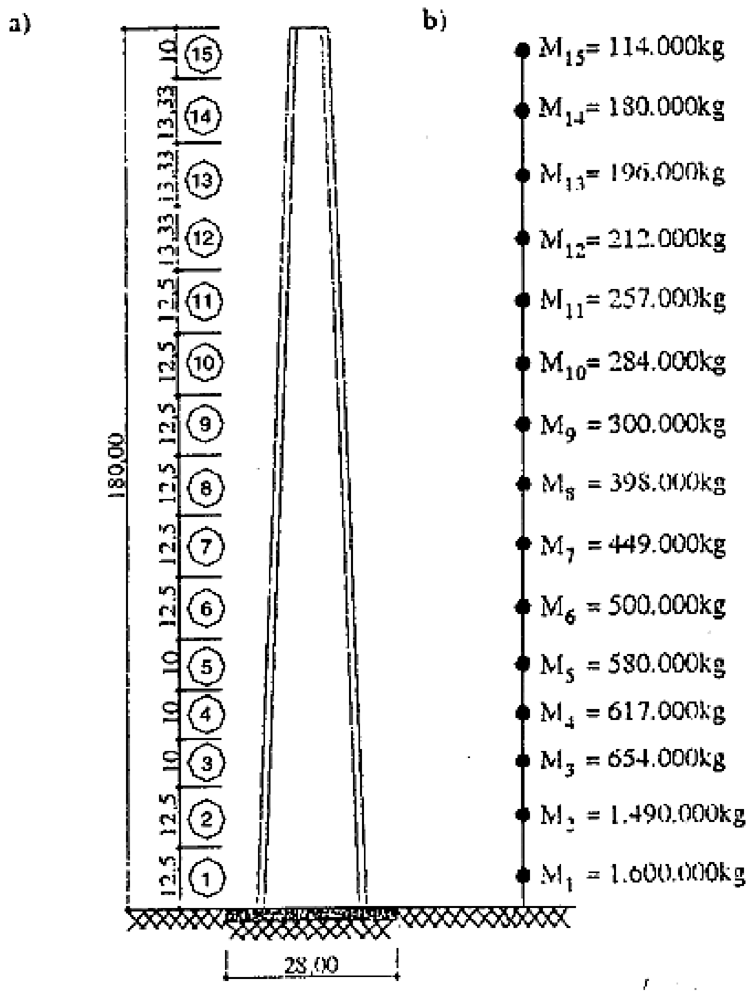



**Figure D.5. Geometric layout and calculation diagram of chimney**

**D.3.1.** Determination of frequency and types of natural vibration of work

**D.3.1.1.** Determination of natural vibration frequency

The $i^{th}$ natural vibration frequency ($f_i$) of chimney type work, taking into account compression deformation, shall be defined according to formula (B.29), annex B.

$$f_1 = \frac{\lambda \tau_{o1}}{2\pi H^2}\sqrt{\frac{Eg}{q}}$$

Where:

H – Chimney height calculated from foundation surface, H = 180m;

E – Elastic moment of chimney materials, E = $2.8.10^7$ kN/m$^2$;

$\tau_o$ - inertia radius of chimney bottom section (m), shall be defined by the formula:

$$\tau_o = \sqrt{\frac{J_o}{F_o}} = \sqrt{\frac{1202}{40.1}} = 5.475m$$

q – Volume weight of chimney body, shall be defined by the formula (B.31)

$$q = q_{th} + q_l \frac{F_l}{F_{th}}$$

So: $$q = 24 + 14 \times (5.2/6.56) = 35.10kN/m^3$$

$\lambda_i$ – coefficient respective to the i[th] oscillation, depending on parameters:

$$\frac{J_H}{J_o} = 0.022; \quad \alpha = \frac{2EJ_o}{C_z F_m H^3} = 0.00026; \quad \frac{H}{\tau_o} = 35.76$$

According to diagram of Figure B.2, annex B, we have coefficient λ corresponding to three first types that are:

$$\lambda_1 = 4.9; \lambda_2 = 18.7; \lambda_3 = 35$$

So, the natural vibration frequency of chimney according to three first types shall be:

$$f_1 = \frac{4.9 \times 5.475}{2 \times 3.14 \times 180^2} \sqrt{\frac{2.8 \times 10^7 \times 9.81}{3510}} = 0.369Hz$$

$$f_2 = 1.4 \text{ Hz}$$

$$f_3 = 2.6 \text{ Hz}$$

Because $f_3 < f_L$ ($f_L$ is the critical value of natural vibration frequency of chimney having a logarithmic reduction $\delta = 0.15$; according to table 2, we have $f_L = 4.1$), in this example, for the simplification, we take into account only effect of three first oscillation types.

**D.3.1.2.** Determination of natural vibration types

The i[th] natural vibration amplitude at the point j of chimney shall be defined by the formula (B.32):

$$y_{ji} = \frac{1}{1 + k\frac{h_j}{H}} \left[ \sin\frac{\pi h_j}{2H} + A_i \sin\frac{3\pi h_j}{2H} + B_i \sin\frac{5\pi h_j}{2H} \right]$$

**Where:**

$$k = 0,75\left(\frac{J_H}{J_o} - 1\right) = 0,75\left(\frac{22,10}{1020} - 1\right) = -0,73$$

$h_j$ – the height from chimney bottom to the point in consideration (m);

$A_i$, $B_i$ - Coefficient respective to types of oscillation;

With $\frac{J_H}{J_o} = 0.022$; $\alpha = \frac{2EJ_o}{C_z F_m H^3} = 0.00026$; $\frac{H}{\tau_o} = 35.76$ according to Figure B.3, annex B, we have:

$A_1 = 0.197$; $A_2 = 5.8$; $A_3 = 9.5$

$B_1 = 0.011$; $B_2 = -1.5$; $B_3 = 27$;

Calculation results of values $y_{ji}$ of three first types of oscillation are given in table D.9

**Table D.10: Relative transversal displacement of 3 first types of oscillation**

| Part | Height of each part (m) | Level z(m) | $y_{j1}$ | $y_{j2}$ | $y_{j3}$ |
|---|---|---|---|---|---|
| 15 | 10,00 | 175,00 | 4,300 | -22,20 | 63,50 |
| 14 | 13,33 | 163,33 | 3,610 | -16,40 | 39,60 |
| 13 | 13,33 | 150,00 | 2,890 | -8,96 | 4,78 |
| 12 | 13,33 | 136,67 | 2,300 | -2,53 | -23,80 |
| 11 | 12,50 | 123,75 | 1,830 | 3,32 | -40,05 |
| 10 | 12,50 | 111,25 | 1,450 | 6,36 | -44,45 |
| 9 | 12,50 | 98,75 | 1,080 | 12,08 | -32,00 |
| 8 | 12,50 | 86,35 | 0,795 | 9,25 | -9,42 |
| 7 | 12,50 | 73,75 | 0,594 | 8,85 | -10,90 |
| 6 | 12,50 | 61,25 | 0,422 | 7,04 | 29,45 |
| 5 | 10,00 | 50,00 | 0,304 | 6,03 | 39,75 |
| 4 | 10,00 | 40,00 | 0,216 | 4,55 | 42,60 |
| 3 | 10,00 | 30,00 | 0,148 | 3,32 | 37,55 |
| 2 | 12,50 | 18,75 | 0,083 | 1,96 | 26,20 |
| 1 | 12,50 | 6,25 | 0,027 | 0,605 | 9,25 |

**D.3.2.** Determination of standard value of static component of wind load acting on designed parts of work

The standard value of static component of wind load $W_j$ at the height z in comparison with standard level shall be determined by the formula (4.11)

$$W_j = W_o k(z_j)c$$

Where:

$W_o$ – standard value of wind pressure, $W_o$ = 95daN/m$^2$ = 0.95kN/m$^2$;

$k(z_j)$ – coefficient taking into account the wind pressure change by height, taken from table 7;

c – aerodynamic coefficient. For cylindrical work, make the average value. According to table 6, TCVN 2737:1995, take c = 0.8.

Calculation results of values $W_j$ are given in table D.10

**Table D.11. Values of $W_j$ corresponding to designed parts of work**

| **Part** | **Level $h_j$(m)** | **k** | **$W_j$(kN/m$^2$)** |
|---|---|---|---|
| 15 | 175,00 | 1,67 | 1,2692 |
| 14 | 163,33 | 1,65 | 1,2540 |
| 13 | 150,00 | 1,63 | 1,2388 |
| 12 | 136,67 | 1,60 | 1,2160 |
| 11 | 123,75 | 1,57 | 1,1932 |
| 10 | 111,25 | 1,54 | 1,1704 |
| 9 | 98,75 | 1,51 | 1,1476 |
| 8 | 86,35 | 1,47 | 1,1172 |
| 7 | 73,75 | 1,43 | 1,0868 |
| 6 | 61,25 | 1,38 | 1,0488 |
| 5 | 50,00 | 1,34 | 1,0184 |
| 4 | 40,00 | 1,28 | 0,9728 |
| 3 | 30,00 | 1,22 | 0,9272 |
| 2 | 18,75 | 1,11 | 0,8436 |
| 1 | 6,25 | 0,90 | 0,6840 |

**D.3.3.** Determination of dynamic component of wind load

Standard value of dynamic component of wind load acting on the j[th] part (with height z) corresponding to the i[th] oscillation type shall be defined by the formula (4.3).

$$W_{p(ji)} = M_j \xi_i \psi_i y_{ji}$$

Where:

$M_j$ – weight concentration of the j[th] part of work;

$\xi_i$ – Dynamic coefficient respective to the i[th] oscillation;

$y_{ji}$ – relative transversal displacement of the j[th] part center respective to the i[th] oscillation;

$\psi_i$- coefficient defined by dividing the work into n parts between each part range, wind load can be regarded as constant.

a) Determination of $\psi_i$

Coefficient $\psi_i$ shall be defined by the formula (4.5)

$$\Psi_i = \frac{\sum_{j=1}^{n} y_{ji} W_{Fj}}{\sum_{j=1}^{n} y_{ji}^2 M_j}$$

With $W_{Fj}$ – standard value of dynamic component of wind load acting on the j[th] part of work, corresponding to different oscillation types while taking into account only the wind speed impulse, dimensional force, shall be defined by the formula:

$$W_{Fj} = W_j \zeta_i \nu D_j h_j$$

Where:

$W_j$ – already determined in table D.10;

$D_j$, $h_j$ – width and height of the luff side respective to the j[th] part;

$\zeta_j$ – Dynamic pressure coefficient of wind load at the height z, corresponding to the i[th] part of work, see table 3;

$\nu$ – Correlative space coefficient of dynamic pressure of wind load that is determined basing on parameters $\rho$, $\chi$ and type of oscillation, we have $\rho$ = D (D is the mean diameter of chimney and equal to 9m).

$$\rho = 9\text{m};\ \chi = H = 180\text{m}.$$

From table 4 and table 5, we have: for the 1st oscillation type, $\nu_1 = 0.63$; for the 2nd and 3rd type of oscillation, $\nu_2$ and $\nu_3$ shall be equal to 1.

Calculation results of $W_{Fj}$ are given in table D.11.

**Table D.12 : Values of $W_{Fj}$**

| Part | High level z (m) | $h_j$ (m) | $d_j$ (m) | $\zeta_j$ | $W_j$ (kN/m$^2$) | $W_{Fj}$ (kN) | |
|---|---|---|---|---|---|---|---|
| | | | | | | 1st type | 2nd and 3rd type |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 15 | 175.00 | 10.00 | 5.80 | 0.376 | 1.2692 | 17.4356 | 27.6787 |
| 14 | 163.33 | 13.33 | 6.10 | 0.378 | 1.2540 | 24.2823 | 38.5433 |
| 13 | 150.00 | 13.33 | 6.50 | 0.381 | 1.2388 | 25.7638 | 40.8950 |
| 12 | 136.67 | 13.33 | 6.90 | 0.385 | 1.2160 | 27.1278 | 43.0600 |
| 11 | 123.75 | 12.50 | 7.30 | 0.388 | 1.1932 | 26.6145 | 42.2453 |
| 10 | 111.25 | 12.50 | 7.80 | 0.392 | 1.1704 | 28.1816 | 44.7327 |
| 9 | 98.75 | 12.50 | 8.30 | 0.396 | 1.1476 | 29.7040 | 47.1492 |
| 8 | 86.35 | 12.50 | 8.80 | 0.400 | 1.1172 | 30.9688 | 49.1568 |
| 7 | 73.75 | 12.50 | 9.57 | 0.407 | 1.0868 | 33.3355 | 52.9134 |
| 6 | 61.25 | 12.50 | 10.30 | 0.413 | 1.0488 | 35.1342 | 55.7686 |
| 5 | 50.00 | 10.00 | 11.00 | 0.422 | 1.0184 | 29.7827 | 47.2741 |
| 4 | 40.00 | 10.00 | 11.70 | 0.429 | 0.9728 | 30.7615 | 48.8278 |
| 3 | 30.00 | 10.00 | 12.40 | 0.443 | 0.9272 | 32.0878 | 50.9330 |
| 2 | 18.75 | 12.50 | 13.10 | 0.460 | 0.8436 | 40.0328 | 63.5442 |
| 1 | 6.25 | 12.50 | 14.10 | 0.514 | 0.6840 | 39.0381 | 61.9653 |

From values of $M_j$; $y_{ji}$ and $W_{Fj}$, we can determine the coefficient $\psi_i$ respective to 3 first types of oscillation:

$$\Psi_1 = 0.0052;\ \psi_2 = 0.00045;\ \psi_3 = 0.00011$$

b) Determination of dynamic coefficient $\xi_i$

The dynamic coefficient $\xi_i$ shall be determined depending on parameter $\varepsilon_i$ and the logarithmic reduction of oscillation δ.

Parameter $\varepsilon_i$ shall be defined by the formula (4.4)

$$\varepsilon_i = \frac{\sqrt{\gamma W_o}}{940 f_i}$$

Where:

γ - reliability coefficient of wind load, taken equally to 1.2;

$f_i$ – the $i^{th}$ natural vibration frequency.

$W_o$ – equal to $950 N/m^2$;

The building in this case has δ = 0.15. According to figure 1, we can determine the dynamic coefficient $\xi_i$

$$\xi_1 = 2.4;\ \xi_2 = 1.75;\ \xi_3 = 1.56$$

x

c) Determination of dynamic component of wind load

From values of $M_j$, $\xi_j$, $\psi_j$ and $y_{ji}$, we can determine the standard value of dynamic component $W_{p(ji)}$.

Designed value of dynamic component of wind load shall be defined by the formula (4.10)

$$W^{tt}_{\rho(ji)} = W_{\rho(ji)}\gamma\beta$$

Where:

γ – Reliability coefficient of wind load, γ shall be equal to 1.2;

β – Correction coefficient of wind load by time; β shall be equal to 1.0.

Results of standard values and designed values of dynamic component are given in table D.12.

**Table D.13: Values of $W_{p(ji)}$ and $W^{tt}_{\rho(ji)}$**

| Part | Level z (m) | $W_{p(ji)}$(kN) | | | $W^{tt}_{p(ji)}(kN)$ | | |
|---|---|---|---|---|---|---|---|
| | | Type 1 | Type 2 | Type 3 | Type 1 | Type 2 | Type 3 |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 15 | 175.00 | 61.1770 | -19.9301 | 12.4221 | 73.4124 | -23.9161 | 14.9066 |
| 14 | 163.33 | 81.0951 | -23.2470 | 12.2317 | 97.3141 | -29.8964 | 14.6780 |
| 13 | 150.00 | 70.6917 | -13.8298 | 1.6077 | 84.8300 | -16.5957 | 1.9292 |
| 12 | 136.67 | 60.8515 | -4.2238 | -8.6583 | 73.0230 | -5.0686 | -10.3899 |
| 11 | 123.75 | 58.6947 | 6.7193 | -17.6625 | 70.4336 | 8.0631 | -21.7950 |
| 10 | 111.25 | 51.3926 | 14.2241 | -21.6624 | 61.6712 | 17.0690 | -25.9949 |
| 9 | 98.75 | 40.4352 | 28.5390 | -16.4736 | 48.5222 | 34.2468 | -19.7683 |
| 8 | 86.35 | 39.4880 | 28.9918 | -6.4336 | 47.3856 | 34.7902 | -7.7203 |
| 7 | 73.75 | 33.2849 | 31.2925 | 8.3983 | 39.9419 | 37.5510 | 10.0779 |
| 6 | 61.25 | 26.3328 | 29.1375 | 25.2681 | 31.5994 | 34.9650 | 30.3217 |
| 5 | 50.00 | 22.0047 | 27.5420 | 39.5624 | 26.4057 | 33.0505 | 47.4749 |
| 4 | 40.00 | 16.6324 | 22.1079 | 45.1037 | 19.9588 | 26.5295 | 54.1244 |
| 3 | 30.00 | 12.0796 | 17.0988 | 42.1410 | 14.4956 | 20.5186 | 50.5692 |
| 2 | 18.75 | 15.4340 | 22.9982 | 66.9892 | 18.5208 | 27.5978 | 80.3871 |
| 1 | 6.25 | 5.3914 | 7.6230 | 25.3968 | 6.4696 | 9.1476 | 30.4762 |

## Reference documents

1 Load and action – Design standard TCVN 2737:1995 – Hanoi Construction publishing House

2 Truong Tuong Dinh – Calculations of wind load and manual for wind resistance calculations – Publishing house of Dong Te University – Shanghai 1990 (in Chinese)

3 Report summarizing theme 26B.03.01 "Study on calculation method of work taking into account earthquake and storm loads" – Institute for construction economy and science -1998.

4 Report summarizing theme 02.15.14 – RO1 "Some methods for storm protection in construction" - Institute for construction economy and science 1992

5. Э Симиу, Р Скалан - Воздействие ветра на здания и сооружения. Москва Стройиздат 1984, 358 с.

6. Руководство по расчету зданий и сооружений на действие ветра. Москва Стройиздат, 1978, 216 с.

7. G.A. Dobrodzicki, Flow Visualization in the National Aeronautical Establishment's Water tunnel. Aeronautical Report No.LR - 557. National Research Council of Canada. Ottawa, 1972.

8. G.e. Mattingly, An experimental Study of the Three - Dimensionnality of the Flow Around a Circular Cylinder, Report No. BN295, Institute for Fluid Dynamics and Applied Mathematics, University of Maryland, College Park, Md. , June 1972.

9. C. Farell, O.Güven and F.Maisch, "Mean Wind loading on Rough - Walled Cooling Towers", J.Eng. Mech. Div., ASCE, 102, No.EM 6, Proc. paper 12647 (1976) 1059 - 1081

10. Ray W.Clough, Joseph Penzien. Dynamics of Structures.

11. C.S. Durst, "Wind speeds over short periods of time". Meteor. May., 89 (1960) 181 - 186.