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Represent

Report on the theme:

The wind loads  
in building

# CONTENTS

<b>Introduction.....</b>	<b>2</b>
<b>Part I. Wind loads. ....</b>	<b>3</b>
1. Regulatory value of wind load:.....	3
a) For buildings with medium numbers of stories .....	3
b) For buildings higher then 75 meters (high-rise buildings) .....	4
2. Calculation of total wind loads affecting buildings and constructions. ....	5
3. Usage of wind tunnel.....	6
4. Defining of distributed wind loads affecting building surfaces. ....	7
<b>Part II. Cases of influence of wind loads. ....</b>	<b>8</b>
1. Resonance conditions.....	8
2. Galloping.....	8
3. Divergence.....	10
<b>Part III. Wind force influence on maintenance of constructions.....</b>	<b>12</b>
1. Provision of comfortable conditions of building maintenance. ....	12
2. Discomfort induced by internal and external winds. ....	12
3. Influence of oscillations caused by wind on the human organism during normal use of high-rise buildings and comfort criteria defined by these oscillations.....	13
<b>Conclusion. ....</b>	<b>13</b>

## Introduction.

Various theoretical aspects of calculations of both buildings in general and their separate structural parts in particular were presented at the conference. We would like to overview existing in designing of installations on the territory of the Russian Federation practical sides of calculation of high-rise buildings and buildings with small and medium numbers of stories.

**Part I. Wind loads.**

**1. Regulatory value of wind load:**

**a) For buildings with medium numbers of stories**

Calculation of buildings consists of several stages.

The first stage is defining the regulatory value of wind load.

It is defined according to the map of wind zoning that was being created for an extended period of time and is based on numerous experiments. This map shows areas with various values of wind pressure. Knowing the location of construction it is necessary to accept the regulatory value corresponding with the area.

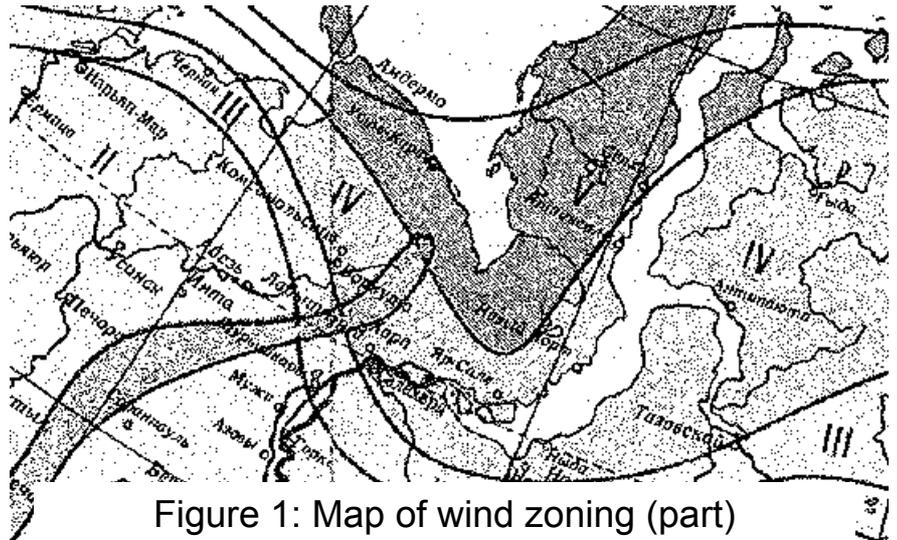


Figure 1: Map of wind zoning (part)

The next stage is considering the type of location and unevenness of distribution of wind load on the height of the building.

According to norms of the Russian Federation there are 3 types of areas:

- A) Open territories;
- B) Undulating ground;
- C) City territories.

For each type of area distribution of wind load for each type of area will differ from the other. In Table 1 coefficient K considers loads for different heights for the city type of location.

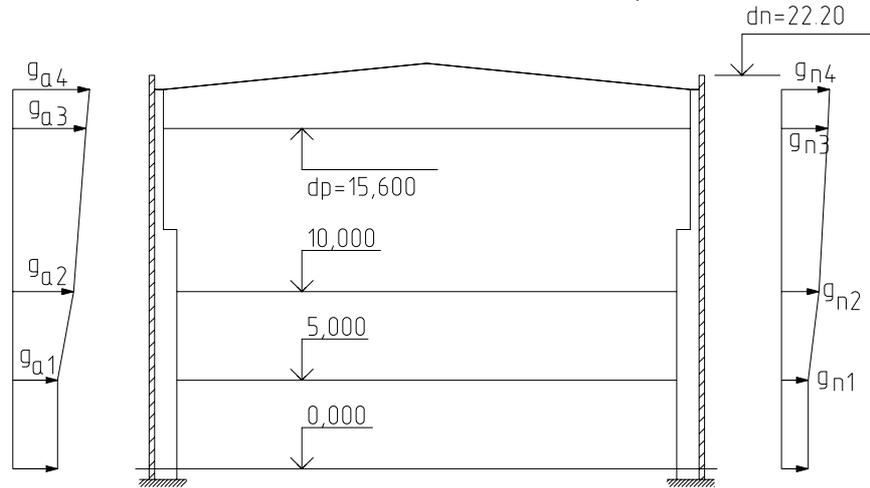
Table 1: Calculated values of wind pressure on the height of buildings

Height, meters	Coefficient K for cities
≤5	0.4
10	0.4
20	0.55
40	0.8
60	0.8
80	1.0
100	1.15

After basic parameters of wind influences at the location of construction have been defined it is possible to begin collecting wind loads on wall enclosures of the building.

Figure 2: This chart is used for collection of loads on building

An approximate chart used for collection of wind loads is presented in drawing 2 where two components of wind load are depicted – the active one ( $g_a$ ) and the passive one ( $g_p$ ). Active load is load affecting the upwind side of the building. The area of rarefaction created by an additional force appears on the downwind side.



The building is divided into elements by height, for which the wind pressure is founded. For example, if the building is higher than 5 metres, force must be applied at the first point-mark of 5 metres and so on. The last point-mark of application of force is located at the top of the wall; coefficient for such a point-mark is found by interpolation.

The moment and the traversal force influencing the construction are determined by the value of applied forces. Since wind is an uneven load in terms of time, reserve coefficient  $\gamma_f = 1.4$  is accepted in calculations.

**b) For buildings higher than 75 meters (high-rise buildings)**

Regulatory value of wind pressure (dynamic pressure)  $w^*$  is defined according to the following formula:

$$w^* = w_0 K_1 K_2 \tag{1}$$

with:  $w_0$  – regulatory value of wind pressure at the level of 10 metres above ground level corresponding with a 10-minute averaging interval; for example, for St. Petersburg which is located in the II wind area  $w_0 = 0,30$  kPa (30 kilogram-force/m<sup>2</sup>).

Table 2

Averaging interval	10 min	2 min	1 min	10 sec	3 sec
Correction factor of average speed $K_1$	1.00	1.10	1.15	1.29	1.41
Correction factor of average wind pressure $K_2$	1.00	1.21	1.32	1.66	1.99

Values of correction factors for average values of speed and wind pressure depending on the averaging interval quoted in Table 2. Calculations should consider  $K_2 = 1.99 \approx 2$  value, because short gusts possess the most energy; they last about 3 seconds and there are 6-7 of them in a 10-minute interval.

From now on we will take the value of wind pressure at maximum height of the building (construction) level H as representative value  $w^*$  defined according to formula (1):

$$w^* = w_0 K_{1H} K_2 \tag{2}$$

with:  $K_{1H}$  – value of coefficient  $K_1$  at height  $H$  above ground level.

**2. Calculation of total wind loads affecting buildings and constructions.**

Under total wind loads in affecting a building (a construction) in the  $XYZ$  frame of reference (drawing 3)

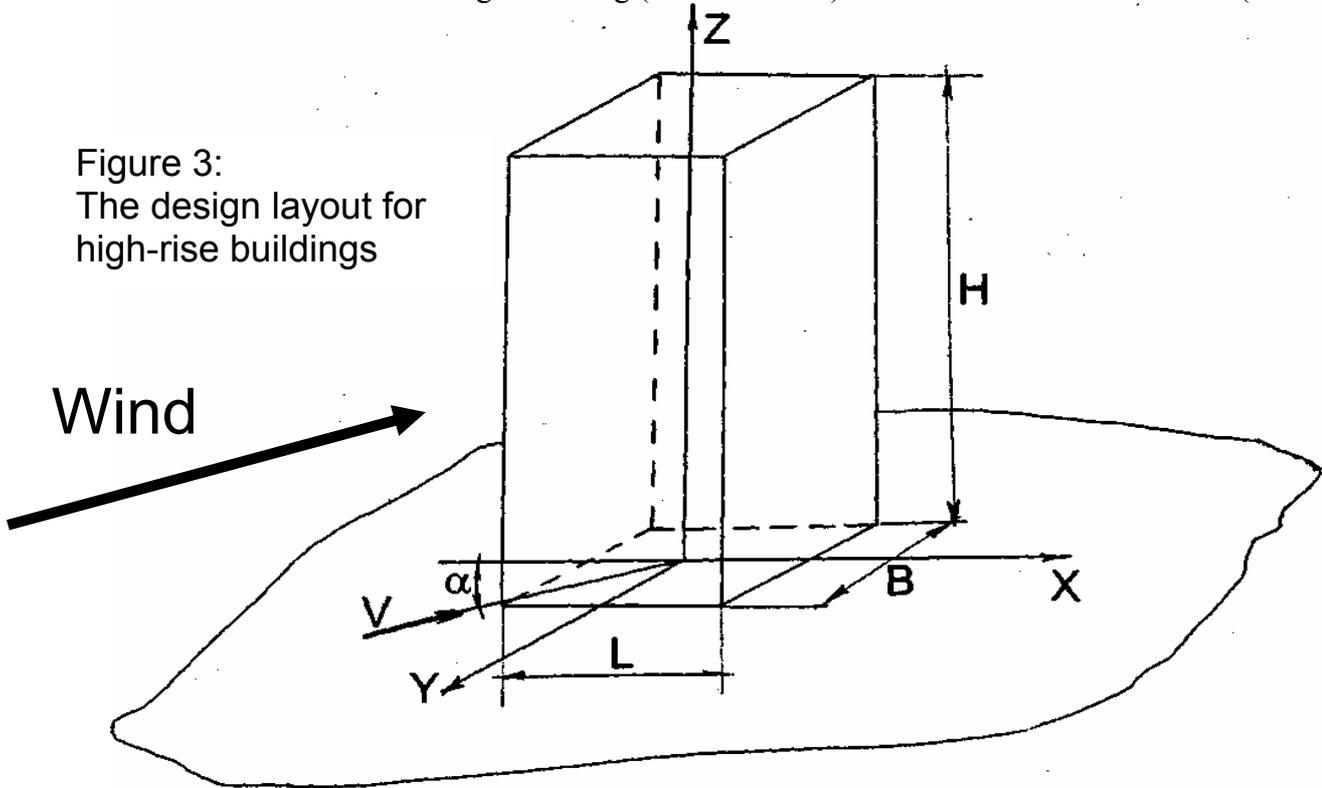


Figure 3:  
The design layout for  
high-rise buildings

connected with the concerned object we understand forces of wind influence directed on X, Y and Z axes:

$$\begin{aligned}
 F_x &= \omega_{*H} \times L \times C_x(\alpha); \\
 F_y &= \omega_{*H} \times B \times C_y(\alpha); \\
 F_z &= \omega_{*H} \times H \times C_z(\alpha);
 \end{aligned}
 \tag{3}$$

and moments caused by wind influence around these axes:

$$\begin{aligned}
 M_x &= \omega_{*H} \times L^2 \times m_x(\alpha); \\
 M_y &= \omega_{*H} \times B^2 \times m_y(\alpha); \\
 M_z &= \omega_{*H} \times H^2 \times m_z(\alpha);
 \end{aligned}
 \tag{4}$$

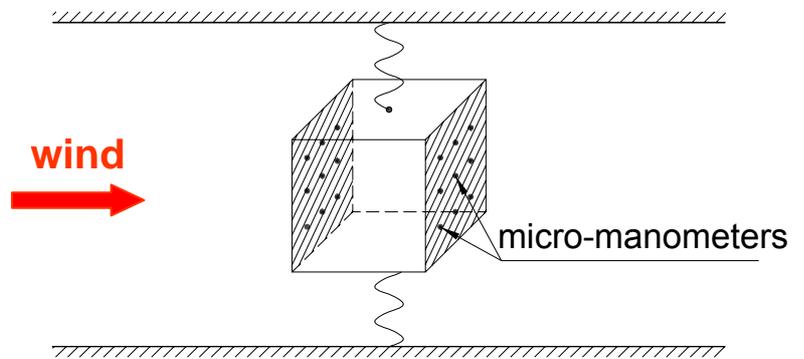
Dimensionless aerodynamic coefficients:  $C_x(\alpha)$ ,  $C_y(\alpha)$ ,  $C_z(\alpha)$ ,  $-m_x(\alpha)$ ,  $m_y(\alpha)$ ,  $m_z(\alpha)$  - are determined for each particular building (construction) as a result of tests of a model of the building (construction) in the wind tunnel with circular alteration  $\alpha$ .

### 3. Usage of wind tunnel

All high-rise buildings are complex and responsible constructions and practically all of them are raised with unique projects; therefore, in order to provide exactness in calculations of wind load for such buildings it is necessary to pre-model aerodynamic conditions for a specific building on a specific site with the help of a wind tunnel.

The model is fastened inside the wind tunnel. Numerous small sensors are fastened on the surface and the wind tunnel is turned on. After data has been collected the model is rotated about  $10^\circ$  relative to approach flow (the angle of wind is changed). Tests go on till data on how the designed building acts with every wind direction is collected. Special methods are used to calculate parameters of the future building after this.

Figure 4: The principal layout of aerodynamic tube



**4. Defining of distributed wind loads affecting building surfaces.**

Knowledge of distributed wind loads affecting building surfaces (walls, the roof) is necessary for evaluation of strain appearing in construction elements secured to bearing connections of the building. Strain from pressure (rarefaction) affecting a constructive element  $S$  is calculated by the following formula

$$F_p = \omega_{*H} \times S \times C_p \quad (5)$$

in which coefficient of pressure  $C_p$  is the sum

$$C_p = C_{p1} + C_{p2}. \quad (6)$$

In formula (6) dimensionless factor  $C_{p1}$  equals absolute maximum value of rarefaction coefficient on building surface; dimensionless factor  $C_{p2}$  equals absolute maximum value of positive pressure coefficient on building surface. Since the maximum value of  $C_{p2}$  always equals one formula (6) accepts the following form

$$C_p = C_{p1} + 1 \quad (7)$$

All elements of building surface including the roof must be calculated considering both external overpressure by formulas (5) and (7) and discharge acting from the external surface of the building by formulas (5) and (8)

$$C_p = - (C_{p1} + 1) \quad (8)$$

The present recommendation excludes errors in dangerous direction while defining load on external surface elements of the building connected with possible presence of “aerodynamic passes” inside the building when, for example, the external side of a surface element is affected by pressure and the internal side of the same element is connected (by an “aerodynamic pass”) to a part of the building where there is a discharge area on the surface.

**Part II. Cases of influence of wind loads.**

**1. Resonance conditions.**

For calculations of resonance conditions related to periodical shredding of vortices from building surface during airflow it is necessary to define the frequency of these breaks. This frequency is characterized by Struhal's pure number

$$Sh = \frac{N \times D}{V},$$

where  $N$  is the frequency of shredding of vortices in hertz,  $D$  is the characteristic size of body,  $V$  is the upcoming airflow speed. The  $Sh$  value is defined by the cross-section formula of streamline building, the angle of upcoming airflow  $\alpha$  in relation to axis  $X$ , connected with the streamline building (drawing 1), Reynolds' number  $R_e = \frac{D \times V}{\nu}$ , where  $\nu$  is the air kinematic viscosity coefficient.

**2. Galloping.**

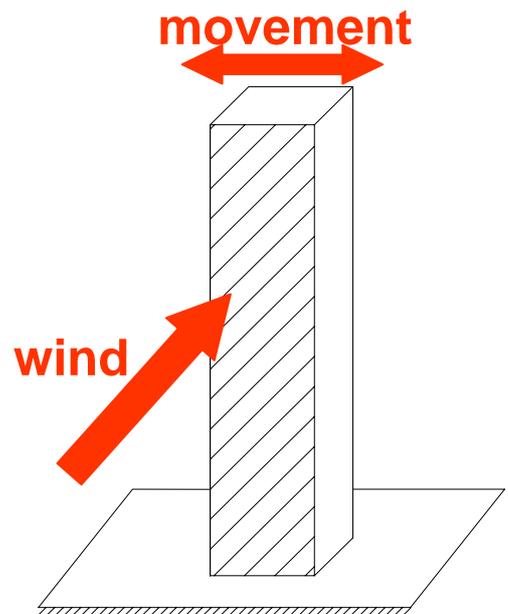
Galloping is the dynamic unstableness of yielding constructions with a particular cross-section shape (for example, rectangular) under influence of upcoming airflow. Movements take place perpendicular to airflow with a frequency which is significantly smaller then frequency of shredding of vortices.

If a body characterized by a mass of  $m$  per unit length is fastened elastically, has linear damping qualities and oscillates in airflow, then its total resistance to oscillation in broadside direction is written in the following form

$$\left[ 2m\zeta\omega + \frac{1}{2}\rho VB \left( \frac{dC_L}{d\alpha} + C_D \right) \right] \times \dot{y}, \quad (9)$$

where  $\zeta$  is relative structural damping,  $\omega$  is intrinsic frequency of building oscillation,  $\rho$  is air density,  $V$  is upcoming airflow speed,  $B$  is characteristic size of building cross-section,  $\dot{y} = \frac{dy}{dt}$  is the speed of structure element movement perpendicular to  $V$  speed;  $C_L$ ,  $C_D$  - coefficients of lift and element resistance in axes related with resulting vector of airflow speed.

Figure 5: The principal layout of "galloping" case



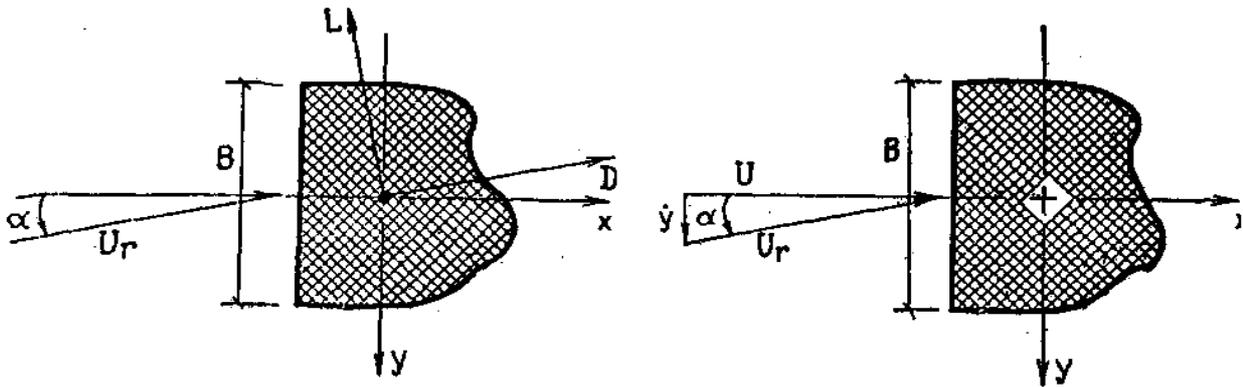


Figure 6: Cross-section of elastic-fixed body

Coefficients  $C_L(\alpha)$  and  $C_D(\alpha)$  are expressed through coefficients  $C_x(\alpha)$  and  $C_y(\alpha)$  defined in a connected frame of reference:

$$C_L = -C_x \sin(\alpha) - C_y \cos(\alpha)$$

$$C_D = C_x \cos(\alpha) - C_y \sin(\alpha)$$

Structure damping in formula (9)  $2m\zeta\omega$  is always positive. The sign of aerodynamic decrement  $\frac{1}{2}\rho VB\left(\frac{dC_L}{d\alpha} + C_D\right)$  is defined by the sign of factor  $\frac{dC_L}{d\alpha} + C_D$

If  $\frac{dC_L}{d\alpha} + C_D > 0$  then total resistance to oscillation is always positive and galloping does not appear. An essential (but insufficient) condition of appearance of galloping is a known criterion of Glauert-Den Gartog

$$\frac{dC_L}{d\alpha} + C_D < 0 \tag{10}$$

It is quite sufficient for many buildings to test conditions (10) with circular change of upcoming airflow angle. In case if in some range of angles a condition (10) is met, it is necessary to view equality deriving from (9):

$$2m\zeta\omega + \frac{1}{2}\rho VB\left(\frac{dC_L}{d\alpha} + C_D\right) = 0,$$

with the help of which (considering (10)) it is possible to define critical speed value  $V_k$  at which galloping rate begins:

$$V_k = \frac{4m\zeta\omega}{\rho B\left(\frac{dC_L}{d\alpha} + C_D\right)}$$

### 3. Divergence

If a streamline construction (building in general or its particular element) has a small thickness ratio (relation of thickness to size of construction in the direction of airflow) then when origin of attack angle the construction will be subject to rotational moment. With particular forms of construction cross-section the pointed rotational moment will tend to increase the attack angle value. Increasing of attack angle (if it allows construction righting moment) leads to increasing of swirling aerodynamic moment. Increasing of wind speed could lead to rotational moment (which increases proportionally to speed square) exceeding righting moment which will lead to collapse of the construction.

For some forms of construction cross-section the dependence of aerodynamic moment on attack angle is such that the construction turns out to be stable in to divergence in a particular range of change of attack angle.

Collapse of Tacoma Bridge in 1950 can be taken as an example of destruction of a construction. It turned out to be divergence-labile.



Figure 7: Collapse of Tacoma Bridge

Condition of equality of aerodynamic rotational moment to another moment of construction is written down considering expression (4) in the following manner:

$$w_{*H}HL^2mz(\alpha) = G_a\Delta\alpha \quad (11)$$

where  $w_{*H} = \frac{1}{2}\rho V_{10}^2 K_1 K_2$  is the regulatory value of speed pressure at building height H

$$mz(\alpha) = mz(\alpha_0) + \left. \frac{dmz}{d\alpha} \right|_{\alpha=\alpha_0} \times \Delta\alpha,$$

$\alpha_0$  - angle of upcoming airflow,

$\Delta\alpha$  - change of angle  $\alpha$  because of building torsion,  $G_a$  - building stiffness coefficient during torsion.

Equality (11) can be written down as follows:

$$\frac{1}{2}\rho V_{10}^2 K_1 K_2 HL^2 \left[ mz(\alpha_0) + \left. \frac{dmz}{d\alpha} \right|_{\alpha=\alpha_0} \Delta\alpha \right] = G_a\Delta\alpha$$

which allows to define:

$$\Delta\alpha = \frac{\frac{1}{2}\rho V_{10}^2 K_1 K_2 H L^2 m z(\alpha_0)}{G_a - \frac{1}{2}\rho V_{10}^2 K_1 K_2 H L^2 \left. \frac{dmz}{d\alpha} \right|_{\alpha=\alpha_0}} \quad (12)$$

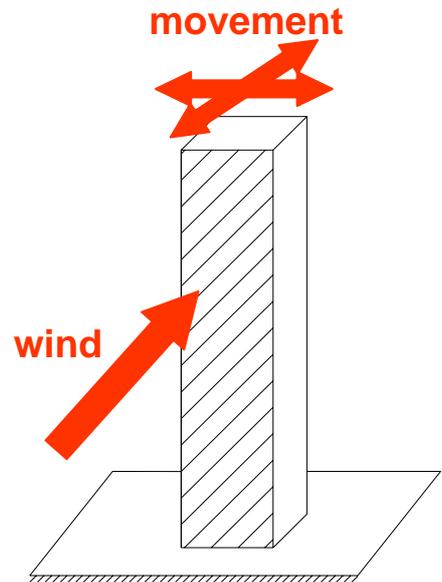
In practice divergence should be viewed in relation to particular elements of the building that have relatively small torsion stiffness.

**Part III. Wind force influence on maintenance of constructions.**

**1. Provision of comfortable conditions of building maintenance.**

Figure 8: High-rise building layout

Linear acceleration of the top floor is defined by calculation with the use of crude data on the building's construction mass distribution and rigidity, as well as maximum aerodynamic load displayed in the process of research. If the received maximum acceleration of the top floor is  $a_{max} < 0.08 \text{ m/cek}^2$  then the building meets comfort requirements in this parameter. Otherwise it is necessary to carry out constructive activities in order to lower the  $a_{max}$  value.



Defining of directions of airflow in pedestrian zones and of relative number of speed (attributed to wind speed on the building's height) is conducted on a model of the building in a wind tunnel with consideration of surrounding constructions. If during maximum average speed of upcoming airflow  $V_0 = 22 \text{ m/s}$  (with a 10-minute interval of averaging) the speed on pedestrian height does not exceed  $15 \text{ m/s}$  – pedestrian zones meet comfort requirements for speed value. If these speeds are more than  $15 \text{ m/s}$  on some interval of upcoming airflow angles, then this pedestrian zone must be equipped with special protective structures which decrease airflow speed. Speed overload capacity of  $15 \text{ m/s}$  with a 10-minute interval of averaging is chosen considering that this value corresponds with an average speed of  $21 \text{ m/s}$  with a three-second interval of averaging (see Table A), i.e. speed during gusts may exceed  $20 \text{ m/s}$ .

**2. Discomfort induced by internal and external winds.**

Constructions affected by wind loads must be solid enough and meet all reliability requirements. The building's suitability for use in conditions of wind forcing must also be considered in projecting flexible high-rise buildings. This requirement may be generally formulated as follows: constructions must be projected so people inside this building do not have uncomfortable feelings when the building is oscillates under wind influence.

Discomfort caused by wind also affects normal usability of open spaces inside built-up territory. Shapes of some buildings and compositions of open spaces may lead to appearing of relatively intensive local air currents. The designer's task on the stage of project development is to discover zones where such effects could cause unacceptable discomfortable conditions for those who will be using open spaces.

The concept of "unacceptable discomfort" which occupies the central place in the list of suitability requirements can be defined as follows. With any project one has to expect more or less regular appearance of discomfortable conditions of various levels caused by wind. Their repetition depends on the level of discomfort, project specifics and wind climate conditions of given area. Discomfort is unacceptable if a high frequency of appearance of discomfortable conditions is determined. Regulations constituting maximum acceptable average frequency of discomfortable conditions are known as comfort criteria. But it is more convenient to refer to the suitable parameter whose value corresponds with various levels of discomfort. When reviewing wind-caused oscillations of a building such parameter is the building's acceleration, and speed of surface wind for the given location is criterion characterizing pedestrian zone suitability for regular use. For development of comfort criteria there are set parameters characterizing various levers of discomfortable conditions for people. Moreover for various levels of discomfort (or, equally, for values of corresponding parameters) there are also set maximum possible

chances of their appearance.

Testing of the project’s compliance with requirements formulated in the present group of comfort criteria includes two stages: firstly, an evaluation of wind speeds under whose influence the viewed parameter will exceed values meeting comfort criteria (these values are commonly called critical) must be acquired; secondly, it is necessary to use appropriate climatological information to evaluate the frequency of appearance of these speeds. If frequencies defined this way are lower than acceptable ones (those meeting comfort criteria) then the project is considered to meet suitability for normal use requirements.

**3. Influence of oscillations caused by wind on the human organism during normal use of high-rise buildings and comfort criteria defined by these oscillations.**

There are the following correlation between various levels of discomfort and causing their acceleration:

**Table 3: Dependence of discomfort level on acceleration value**

Discomfort level	acceleration (in % from acceleration of gravity)
Oscillation:	
Imperceptible	0.5
Perceptible	0.5 – 1.5
Irritating	1.5 – 5
Extremely irritating	5 – 15
Intolerable	>15

There has been research on how people are influenced by vibrations reproduced on a dynamic simulation test bench with frequencies ranging from 0.1 Hz to 1 Hz. It has been determined that average perceptibility thresholds change from approximately 0.6 (for frequencies of 0.1 Hz order) to about 0.3% g (for frequencies of 0.25 Hz order). Oscillations became well perceptible and irritated people working at tables if accelerations exceeded 1.2% g. With accelerations over 4% g oscillations were characterized as strongly perceptible and people had difficulty walking. Oscillations were characterized as extremely irritating or simply intolerable when accelerations exceeded 5—6% g.

Comfort criteria being developed must be founded on extensive knowledge about the level at which people using the building are ready to deal with discomfort caused by accelerations from being affected by wind. One research suggested a simple comfort criterion – criterion limiting the average number of appearance of accelerations 1% g strong at the top floor of the building to not more than 12 times a year (this method was used in designing the World trade center).

**Conclusion.**

In designing buildings it is necessary not only to aim at acquiring durability, stability and safety of construction, but also to consider the necessity to provide comfortable conditions of building use; these conditions depend on oscillations caused by wind effect. Considering specially developed comfort criteria is crucial for reaching prolonged comfortable use of a building even at the stage of design. This provides for normal state of health and good efficiency of people staying inside the building for extended periods of time and it also provides comfort of pedestrians moving through territories near the building.