Nataliia Kotova

CALCULATIONS OF WALL ELEMENT FOR QUICK-SAFE BUILDING

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Bachelor's thesis
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Degree program in Civil Engineering
Oulu University of Applied Science

ABSTRACT

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Nowadays there are a lot of areas which are exposed by negative influence of natural phenomena such us earthquakes, floods, tsunamis and hurricanes. It is a challenge to organize some comfortable and spacious place for accommodation of casualties and providing the first aid for them.

On the basis of the above, light and quickly mounted, demountable and relocatable structures, which names are quick-safe buildings are the best solution. The aim of this research was to choose the material for the wall structures and determine the thickness of the wall structures sufficient to resist the load and keep the stable climate inside the building, considering the outside temperature and other weather conditions.

In this research three ways for wind load calculation are presented: according to the European standards, according to the American standards, according to the standards of the Russian Federation. Also a bending moment analysis according to strength of material were made.

During the research a calculation of the wind load and a bending moment analysis were made. The wall structure of a quick-safe building was designed.

A quick-safe building could be used by a government during a disaster recovery as a temporary residence for casualties.

Keywords:
Quick-safe building
Wind load
Structural model
Bending moment analysis

CONTENTS

1. INTRODUCTION

A project of quick-safe buildings was started by students JAMK University of Applied Science. The main aim of the project is to design a structure for areas ruined by natural phenomena. Organization and construction of a camp for casualties is a hard task. Above all, the medical aid should be well organized and have enough safe space for placement of hurts. Due to the fact that most of casualties become homeless and the restoration of their own houses or searching the place for temporary accommodation takes a time, it is important to provide comfortable conditions with the vital things.

A group of students of JAMK University of Applied Science designed a model of a quick-safe building during their research. This model includes identical elements. These elements could be easily combined together. As the elements are identical, they could form rooms with various configurations and purposes.

Finally, another group of the same university worked at the details of the model more thoroughly. This group analyzed the information about the emergency accommodation and determined the optimal parameters of size of wall element (figure 1).

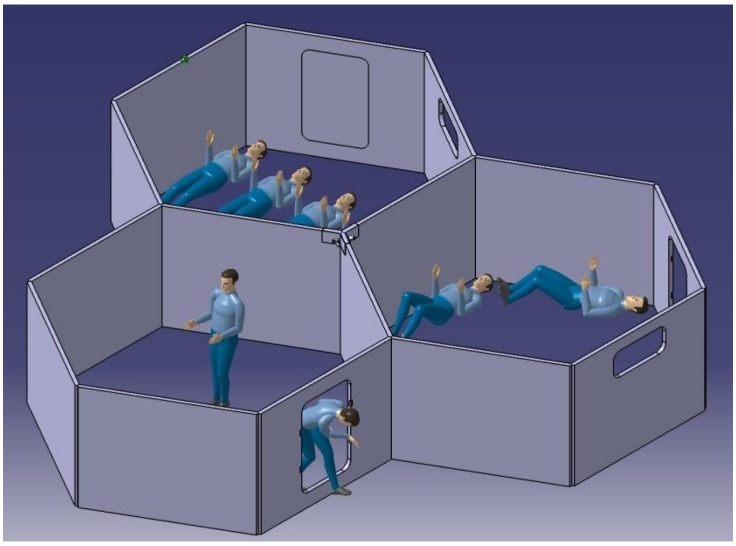


FIGURE 1. Configuration of quick-safe building (Hantunen T., Hölttä T., Mäkelä L. &Salmi H. 2011. Katastrofitalo.)

The best size of a wall element is 1600mm x 2000mm x 50 mm. That conclusion is a result of experiment and has the best parameters for the transportation. This size ensures the easement of packaging and transportation. Finally, the wall structure was supplemented by doorways and window opening. These apertures allow to protect buildings against rainwater, snow, heat losses, and allow the light penetrate inside.

As a result of these two researches the model of the quick-safe building with parameters was designed. At the next stages, engineering calculations for the parts of construction should be made. With this in mind and the wide range of weather conditions for this type of buildings, many factors should be considered in the calculations.

This research includes highlighting of the potentially dangerous areas, temperature analysis of these areas, design the structural model of wall element, identifying the loads acting on the wall, modeling the loads on the construction and estimation of the wall thickness.

The main aim of the research was to determine the configuration of the materials, to identify the load on the wall constructions. Due to the fact that the potentially dangerous area covers a rather big territory, the calculations can be made by different methods from different countries. There are the three ways in this research:

-According to the European standards;

-According to the American standards;

-According to the standards of the Russian Federation.

2. ANALYSES OF TERRITORIES AND ENVIROMENT TEMPERATURE

2.1. Potentially dangerous areas

To pick up the maximum values of loads to a construction of a quick-safe building for further computations, it was necessary to analyze the territories on the world map (appendix 1). Primarily it was necessary to pick out potentially dangerous areas where a dangerous situation could appear. Areas placed nearly the boundaries of lithospheric plates are seismically hazardous areas (figure 2).

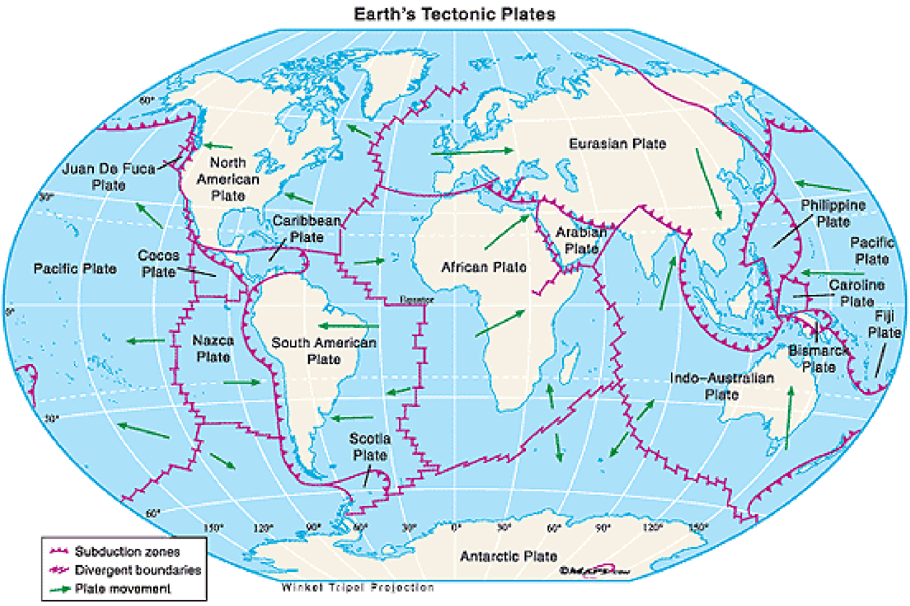


FIGURE 2. Boundaries of the lithospheric plates (Maggelan geographix 1991. Date of retrieval 29.10.2015)

Every movement of each plate has negative consequences such as earthquakes, tsunamis and floods. That was the reason for the selection and analyses of countries which are placed near the boundaries of lithospheric plates for the research. The group of the most dangerous instable territories is called the Ring of the Fire and is shown in figure 3 (U.S. Geological Survey, a bureau of the Department of the Interior 2015. Date of retrieval 29.10.2015).

The list of the countries and cities for the climate analysis from Canada to Australia can be seen below:

Columbia, Bolivia, Peru, Ecuador, Chili, Argentina, Russia (The Kamchatka Peninsula), Japan, Philippines, Indonesia, New Zealand, Burma, Bangladesh, Bhutan, Nepal, India, Tajikistan, Kyrgyzstan, Uzbekistan, Iran, Azerbaijan, Georgia, Turkey.

FIGURE 3. The Ring of the Fire placement (Valnet Inc 1997. Date of retrieval 29.10.2015)

Different kind of strong winds are also dangerous and become a reason of distractions and disasters. There are several types of strong winds: tornado, hurricane and typhoons (American Metrology Society 2012, Date of retrieval 29.10.2015). Each of them has its own nature and zone of emergence and zone of spread. Hurricanes are placed on the north-east part of Pacific Ocean and Atlantic Ocean. Typhoons active at the north-west part of Pacific Ocean in Japan, Korea and East Part of Russia. The emergence of tornados is typical for North and South America, Europe and East part of Russia.

2.2.Temperature influence

Due to the fact that the dangerous area covers a rather big territory, it is necessary to determine the areas with the highest and the lowest temperature values. Since the hazardous areas are placed quite widely, the lowest and the highest temperature should be determined. As a result, a table was created (table 1). This table includes data about the highest and the lowest temperatures in countries which are placed in dangerous areas.

TABLE 1. Maximum and minimum annual temperature in the potentially dangerous areas (World Wide Travel Organization 2010. Date of retrieval 29.10.2015)

	Country (City)	max	min
1	Turkey (Kars)	25	-12
2	Turkey (Adana)	34	5
3	Georgia (Tiflis)	32	-2
4	Iraq (Kirkoek)	42	4
5	Iran (Teheran)	35	-2
6	Turkmenistan (Ashabad)	35	-2
7	Afghanistan (Mimana)	34	-2
8	Tajikistan (Dusanbe)	35	-3
9	Pakistan (Zhob)	35	2
10	India (New Delhi)	40	10
11	India (Patna)	38	10
12	Nepal (Katmandu)	29	3
13	Bangladesh (Chittagong)	30	12
14	Myanmar (Burma) Akuab	33	14
15	Indonesia (Padang)	32	23
16	Philippines (Baguio)	33	20
17	Japan (Nagasaki)	30	2
18	Japan (Sapporo)	21	-7
19	Russia (Ust-Kamtjatsk)	20	-18
20	Russia (Petropawlowsk)	19	-41
21	Canada (Vancouver)	17	-1
22	USA (San Francisko)	22	5
23	Mexico (Mazatlan)	30	22
24	Colombia (Cali)	23	11
25	Ecuador (Guayaguil)	28	20
26	Peru (Lima)	26	5
27	Bolivia (Santa Cruz)	29	15
28	Argentina (Mendoza)	32	3
29	Argentina (LagoArgentino)	18	-3

To make it clear, all the temperature data was brought into the diagram with the highest and the lowest temperature. As is shown in the diagram, the highest temperature is in Iraq (+42ºC) and the lowest in Russia (-41ºC).

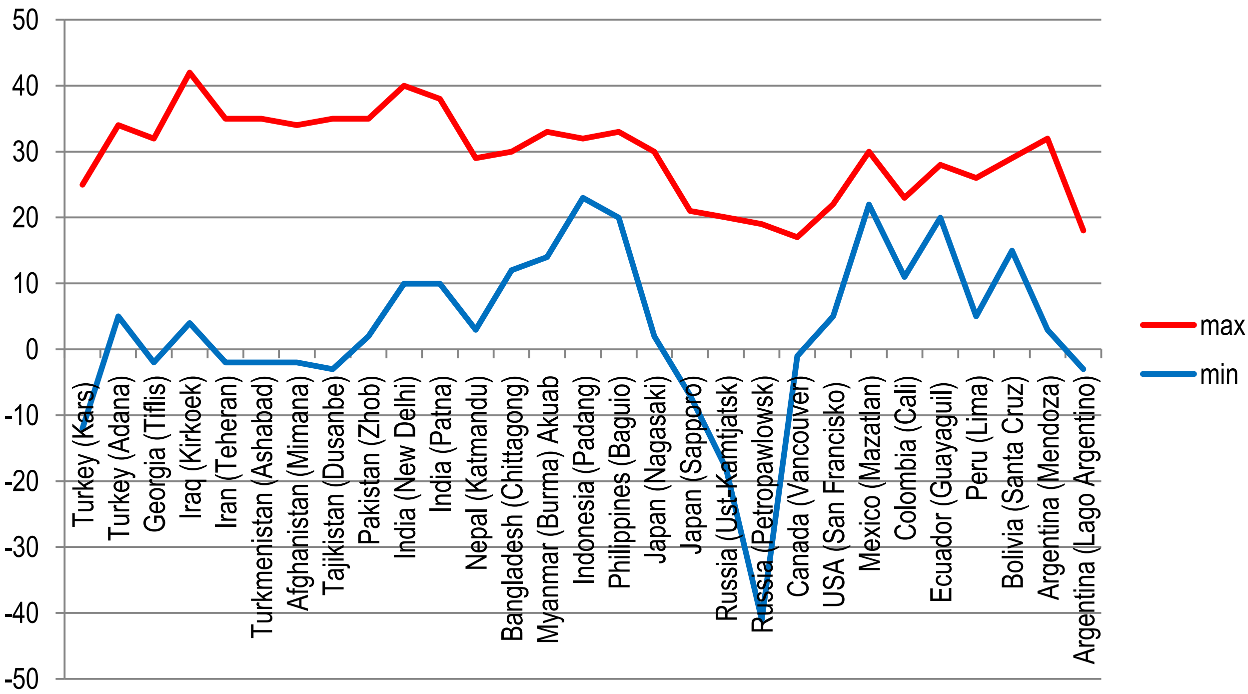


DIAGRAM 1. Level of the highest and the lowest temperature on the potentially dangerous areas.

2.3. Materials

As was mentioned earlier, the lightweight and strong structures are suitable for quick-safe buildings. Materials for this kind of structures should be strong, light-weight, rodent-proof, rot proof, waterproof and thermal insulation properties. During the first meetings and previous researches EPS (expanded polystyrene) was chosen as insulation for the wall structures. EPS possesses a wide range of advantages. The EPS panels are classified by the compressive strength. For the research EPS150 was chosen. This type of EPS is suitable for structures subjected the mechanical loads. The constructional data for EPS150 are given in table 2. As in the previous research the approximate size of the wall element was determined, the thickness of 50 mm was selected for the EPS filler.

TABLE 2. Constructional data for EPS150 (Environmental product declaration for expanded polystyrene (EPS) foam insulation (without flame retardant, density 25 kg/m^3), EPS150. 2013)

Name	Value	Unit
Compressive strength	150	kPa
Bending strength	200	kPa

In spite of the facts that EPS has sustainable cellular structure and keeps a rigid form, the wall structures should be covered by more rigid, resistant to mechanical influences and loads material than EPS. Wall structures for the quick-safe buildings should be designed as reusable, transportable and durable. Above all the quick-safe buildings include spaces for various purposes. The wide range of composite materials such as sandwich structure panels are covered by materials of different strength.

There are several types of covering materials for sandwich-panels with EPS inside such as galvanized steel, polyvinylchloride, OSB panels, structural insulated panels (SIP panels) and aluminum. At the first project meeting aluminum foil or teflon (a new material) were mentioned as a covering material for the panels. Because of lack of the information about technical characteristics of teflon, the better known material was considered in the research task.

In the case of quick-safe buildings the OSB and SIP covered panels are not suitable because of low water-resistant. Also these kinds of panels should be covered by other facade materials. In contrast with other materials this type of panels are heavy. That is why these materials are not suitable for the research task.

Aluminum has the best features among the metal coverings. This material is light weight and enough tough (table 3). The thickness of the aluminum covering of sandwich panels usually varies between 0,3 mm and 0,5 mm. For the further computations the thickness of 0,5 mm was used.

TABLE 3. Constructional data for aluminum (Aluminium-Guide.ru 2013. Date of retrieval 29.10.2015.)

Name	Value	Unit
Compressive strength	35	MPa
Bending strength	110	MPa

3. DESIGN OF WALL STRUCTURE FOR QUICK-SAFE BUILDING

3.1. Wind loads

Since the quick-safe building includes only one floor and the self weight of the constructions is not high, the main and the most dangerous load is wind load (figure 4). As was mentioned earlier, the area of potentially dangerous territories is wide. Hence, the value of the wind load is changing from the lowest to the highest.

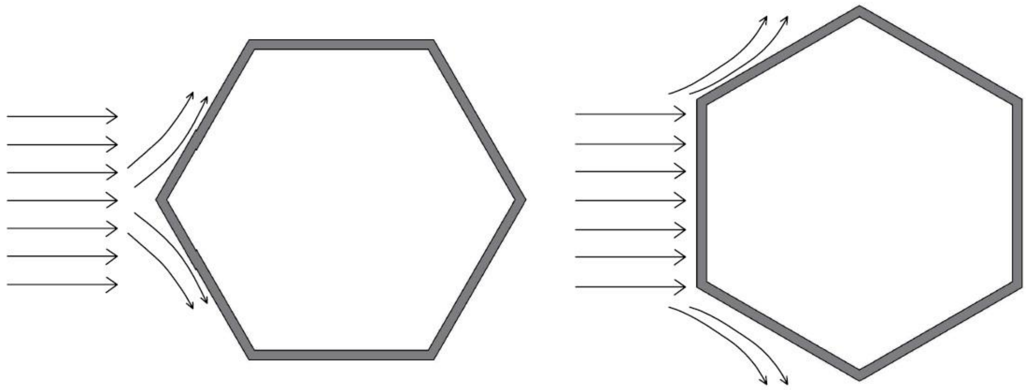


FIGURE 4. Spread of the wind at the wall structure of the building

3.1.1. Estimation of wind loads according to Eurocode standards

According to the Eurocode 1991-1-4 the basic wind velocity can be calculated by formula 1.

$$v_{\mathrm{b}} = c_{dir} \cdot c_{\mathrm{season}} \cdot v_{\mathrm{b},0} \quad (1)$$

where:

v_{b} is a basic wind velocity, defined as a function of wind direction and time of year at 10 m above ground of terrain category II;

$v_{\mathrm{b},0}$ is a fundamental value of the basic wind velocity;

c_{dir} is a directional factor;

c_{season} is the season factor.

First, a terrain category was chosen. There are five terrain categories in the Eurocode classification. In accordance with Annex A of the Eurocode 1991-1-4, the potentially dangerous territory relates to the terrain category III. These terrains include area with a regular coverage of vegetation or buildings or with isolated obstacles with separations of a maximum 20 heights of obstacles (such as villages, suburban terrain, and permanent forest). Also the terrain category 0 is suitable. This category includes sea and coastal areas exposed to the open sea.

The value $v_{\mathrm{b},0}$ is given in the National Annex. Being that the research takes place in Finland, the National Annex for Finland gives $v_{\mathrm{b},0} = 21\ m/s$ for the mainland in the entire country.The recommended value for directional factor c_{dir} is 1,0.The quick-safe building is a transportable structure which may be used at any time of the year. In this case the value c_{season} should be equals to 1,0.

$$v_{\mathrm{b}} = 1 \cdot 1 \cdot 21 = 21\mathrm{m}/s$$

The next step is the determination of basic velocity pressure in accordance with formula 2:

$$q_{\mathrm{b}} = \frac{1}{2} \rho \cdot v_{\mathrm{b}}^2 \qquad (2)$$

where:

ρ is the air density, which depends on the altitude, temperature and barometric pressure to be expected in the region during wind storms.

The recommended value for air density in EN1991-1-4 is 1.25kg/m3. Hence, the basic velocity pressure can be determined according to formula 2.

$$q_{\mathrm{b}} = \frac{1}{2} 1{,}25 \cdot 21^2 = 275{,}625 \frac{kg}{m \cdot s^2} = 275{,}625 \frac{N}{m^2} = 275{,}625 Pa$$

After that the peak velocity pressure q_{p} can be determined in accordance with the following expression (Eurocode 1991-1-4, formula 4.8):

$$q_{\mathrm{p}} = c_e(\mathrm{z}) \cdot \mathrm{q_b} \qquad (3)$$

where:

$c_e(\mathrm{z})$ is the exposure factor.

The value q_p depends on the exposure factor $c_e(\mathrm{z})$. This factor should be defined from the diagram listed below in accordance with the height of the quick-safe building z=1,6m (figure 5).

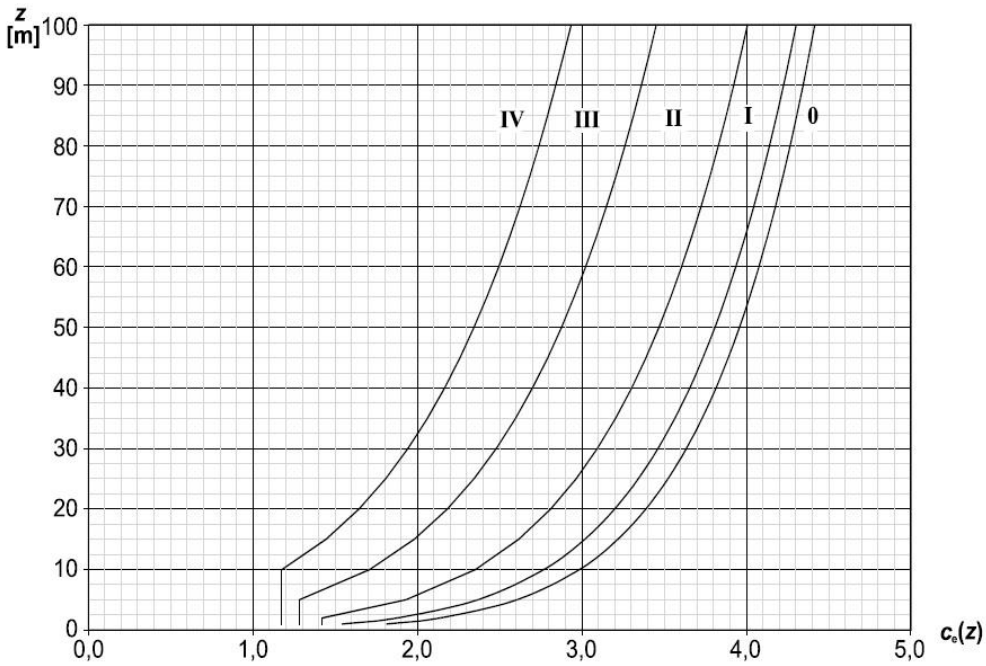


Figure 5. Illustration of the exposure factor $\boldsymbol{c_e(z)}$(EN 1991:2005, 2005)

According to the diagram, the value $c_e(\mathrm{z})$ equals 1,3. In this case the meaning of the peak velocity pressure according to formula 3 is:

$$q_\mathrm{p} = 1{,}3 \cdot 275{,}625 = 358{,}315\ Pa$$

The value of the peak velocity pressure for Finland is quite small. That was the reason to choose another country with Eurocode regulation where the wind conditions are much worse. The Cyprus territory is characterized as a territory with a high value of the wind speed.

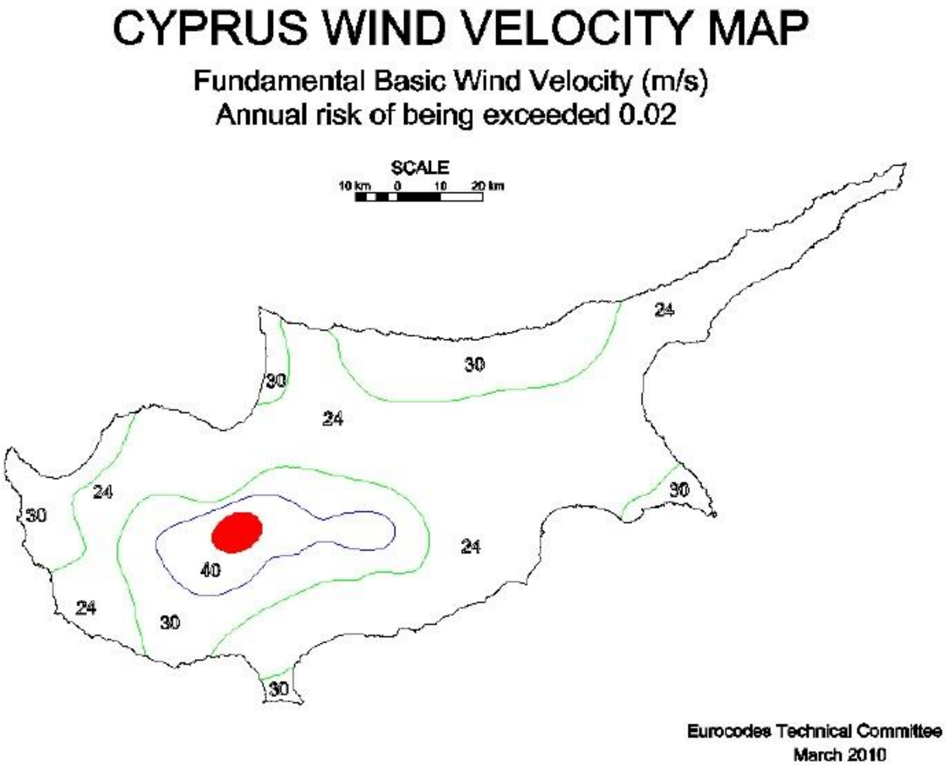


Figure 6. Cyprus wind velocity map (NA to CYS EN1991-1-4:2005,2010)

In accordance with the wind map of the National Annex of Cyprus the value $v_{b,0}$is 40 m/s (figure 6). The recommended value for directional factor c_{dir} is 1,0. A quick-safe building is a transportable construction which may be used at any time of the year. In this case the National Annex of Cyprus gives the value of the season factor $c_{\mathrm{season}} = 1{,}0$. Thereby the computations of the peak velocity pressure for Cyprus were made according to formulas 1, 2 and 3:

$$v_{\mathrm{b}} = 1 \cdot 1 \cdot 40 = 40 \text{ m}/s$$

$$q_{\mathrm{b}} = \frac{1}{2} 1{,}25 \cdot 40^2 = 1000 \text{ Pa}$$

$$q_{\mathrm{p}} = 1000 \cdot 1{,}3 = 1300\ Pa = 1{,}3\ kPa$$

Due to the fact that the wind load is a uniformly distributed load for the buildings with the height less than 5 meters, it is suitable to transform the obtained value of the wind pressure to the uniformly distributed load according to formula 4:

$$q_{EN} = q_p \cdot H \qquad (4)$$

where:

B is the width of the wall panel of the quick-safe building (m).

$$q_{EN} = 1{,}3 \cdot 1{,}6 = 2{,}08 \ \frac{kN}{m}$$

3.1.2. Estimation of wind loads according to USA standards

Further computations of wind load were made according to the USA regulation. In particular chapter 26 of ASCE/SEI 7 Minimum Design Loads For Buildings and Other Structures (ASCE 7-10) gives recommendations for a wind loads analysis.

The estimation of wind loads are divided by two groups: Main Wind-Force Resisting System (MWFRS) and Components and Cladding (C&C).

According to ASCE 7-10 a quick-safe building belongs to the group of low-rise building. This group includes enclosed or partially enclosed buildings with a mean roof height less than or equal to 60 ft (180 m) or the mean roof height does not exceed the least horizontal dimension. Besides that, groups of buildings divided by four risk categories in accordance with the table 1.5-1 of chapter 26, ASCE 7-10. The risk category for a quick-safe building is I.

The next step is the determination of the basic wind speed V for applicable risk category in accordance with the figures 26.5-1A, B or C, chapter 26, ASCE 7-10. The strongest basic wind speed V for the I risk category is 76 m/s (Florida, USA) from figure 26.5-1C.The ASCE7-10 gives formula 5 for the velocity pressure q_z:

$$q_z = 0{,}613 \ K_z K_{zt} K_d V^2 \left(\frac{\mathrm{N}}{\mathrm{m}^2}\right), \text{where V in m/s} \qquad (5)$$

where:

K_z is a velocity pressure exposure coefficient;

K_{zt} is a topographic factor (section 26.8 and fig. 26.8-1);

K_d is a wind directionality factor (section 26.6and table 26.6-1).

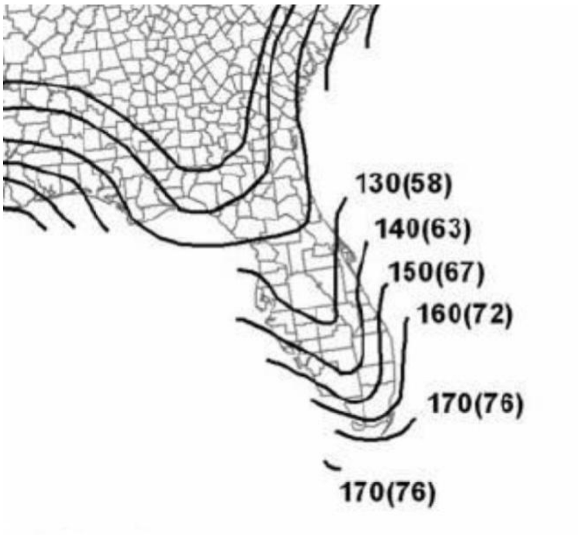


FIGURE 7. The fragment of the figure 26.5-1c with Florida

The wind directionality factor K_d equals 0,85 for the Main Wind Force Resisting System from Table 26.6-1. For the buildings with a mean of roof height less than or equal 30ft (9,1m) exposure category B from chapter 26.7 is suitable. Location of quick-safe buildings does not meet all of the conditions specified in Section 26.8.1. In this case the topographic factor K_{zt} equals to 1. For the H=1,6 m the velocity pressure coefficient K_z equals to 0,70 for exposure category B from the Table 28.3-1. To sum up the above, the velocity pressure should be determined by formula 5:

$$q_z = 0{,}613 \cdot 0{,}7 \cdot \ 1 \cdot 0{,}85 \cdot 76^2 = 2106{,}709 \left(\frac{\mathrm{N}}{\mathrm{m}^2}\right) = 2{,}107 \left(\frac{\mathrm{kN}}{\mathrm{m}^2}\right)$$

Further, the obtained value of the wind pressure was transformed to the uniformly distributed load according to formula 6:

$$q_{ASCE} = q_z \cdot H \tag{6}$$

$$q_{ASCE} = 2{,}107 \cdot 1{,}6 = 3{,}371 \ \frac{kN}{m}$$

3.1.3. Estimation of wind loads according to Russian Federation standards

As has been noted the territory of Petropavlovsk-Kamchatsky is a potentially dangerous area in Russia placed on the East of country (figure 8).

FIGURE 8. Petropavlovsk-Kamchatsky on the map of the Russian Federation

There is a very severe climate in the city with a cold short summer and a long winter. This is the coldest place according to the temperature analyses in this research.

The estimation of the value of the wind pressure is described in the normative document of the Russian Federation SP20.13330.2011 "Loads and actions". There are eight wind pressure districts in accordance with that document. As it shown in figure 9, the territory of Petropavlovsk-Kamchatsky locates in the VII district of map of the Russian Federation of division into districts by the wind pressure (SP20.13330.2011 appendix ZH, maps 3 and 3a). The full version of the maps placed in Appendices 2 and 3 of the research.

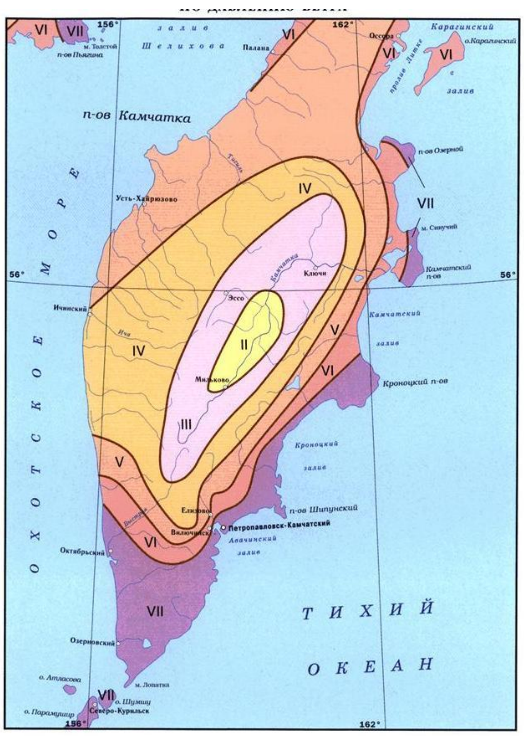


FIGURE 9. Districts of the Kamchatka peninsula in accordance with the map of the Russian Federation of division into districts by the wind pressure (SP 20.13330.2011 appendix ZH, maps 3 and 3a)

There are three terrain categories in SP 20.13330.2011: A,B and C. For the further calculations the values for the category B will be used. This terrain category is characterized as urban areas, large forests and other areas covered by the 10 meters regularly altitude of obstacles and that is the most suitable category for the Petropavlovsk-Kamchatsky.

According to SP 20.13330.2011, the wind load of the structure should be calculated as a sum of the average and the pulsation components. In the case where the height of the building is less than 40 m and the location in the terrain category A and B, the pulsation component of wind load is not taken into account. The height of the quick-safe building is 1,6 meters and it is placed in the terrain category B. Hence, the pulsation component of the wind load was not taken into account in computations. In this case the meaning of the average wind load was determined by the next formula:

$w_m = w_0 k(z_e) c.$(7)

where

w_0 is a normative value of a wind pressure (*SNiP 2.01.07-85*, 2010, item 6.4)*;

k is a coefficient which takes into account the variation of a wind pressure for an equivalent altitude (z_e) (*SNiP 2.01.07-85*, 2010, item 6.5)*;

c is an aerodynamic coefficient (*SNiP 2.01.07-85*, 2010, item 6.6)*.

The normative value of wind pressure depends on the wind pressure district. The values are given in table 4 listed below. The normative value of the wind pressure equals to *85 kPa* for the VII district of map of the Russian Federation of division into districts by the wind pressure.

TABLE 4. Normative value of the wind pressure depends on the wind district (SP20.13330.2011, 2011)

Wind districts	Ia	I	II	III	IV	V	VI	VII
w_0, kPa (kgf/m^2)	0,17 (17)	0,23 (23)	0,30 (30)	0,38 (38)	0,48 (40)	0,60 (60)	0,73 (73)	0,85 (85)

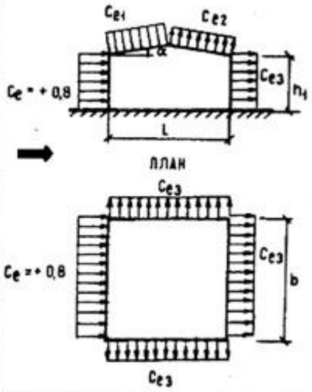
The SP20.13330.2011 gives a table for the coefficient k depending on the height of a building and the terrain category (table 5). Hence, for a quick-safe building with the height of 1,6 meters placed on the terrain category B, the meaning of the coefficient k equals *0,5*.

TABLE 5. Values of the coefficient taking into account the change of wind pressure range adjustment (SP20.13330.2011, 2011)

Height z, meters	Coefficient ***k*** for Terrain Categories		
	A	B	C
<= 5	0,75	0,5	0,4

The aerodynamic coefficient *c* depends on the roof configuration. The full table can be seen in Appendix 4 of SNiP2.01.07-85*. As the roof structure was not fully designed in the previous researches, in that case three types of roof are considered: dome cover, planar cover and double-slope cover. As can be seen from table 6 the aerodynamic coefficient c is 0,8 for three types of roof. Thereby the normative value of an average component of the wind load for terrain B and the height less than 5 m above the ground was found:

$$w_m = 0{,}87 \cdot 0{,}5 \cdot 0{,}8 = 0{,}348\ (kN/m^2)$$

<table>
<tr><th>Номер схемы</th><th>Схемы зданий, сооружений, элементов конструкций и ветровых нагрузок</th><th>Определение аэродинамических коэффициентов c</th><th>Примечания</th></tr>
<tr><td>1</td><td>Отдельно стоящие плоские сплошные конструкции.
Вертикальные и отклоняющиеся от вертикальных не более чем на 15 ° поверхности:
наветренные
подветренные</td><td>$c_e = +0,8$
$c_e = -0,6$</td><td>–</td></tr>
<tr><td>2</td><td>Здания с двускатными покрытиями

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<tr><th></th><th></th><th>0</th><th>0,5</th><th>1</th><th>≥ 2</th></tr>
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20
40
60</td><td>0
+0,2
+0,4
+0,8</td><td>−0,6
−0,4
+0,3
+0,8</td><td>−0,7
−0,7
−0,2
+0,8</td><td>−0,8
−0,8
−0,4
+0,8</td></tr>
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<tr><td>≤ 1
≥ 2</td><td>−0,4
−0,5</td><td>−0,5
−0,6</td><td>−0,6
−0,6</td></tr>
</table>
</td><td>1. При ветре, перпендикулярном торцу зданий, для всей поверхности покрытия $c_e = -0,7$.
2. При определении коэффициента v в соответствии с п. 6.9 $h = h_1 + 0,2\ l$tgα</td></tr>
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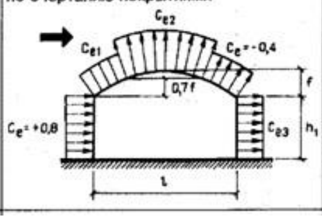
</td><td>
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−0,1
−0,7</td><td>+0,4
+0,2
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+0,7
+0,7</td></tr>
<tr><td>c_{e_2}</td><td>Произвольное</td><td>−0,8</td><td>−0,9</td><td>−1</td><td>−1,1</td><td>−1,2</td></tr>
<tr><td colspan="7">Значение c_{e_3} принимается по схеме 2</td></tr>
</table>
</td><td>1. См. примеч. 1 к схеме 2.
2. При определении коэффициента v в соответствии с п. 6.9 $h = h_1 + 0,7f$</td></tr>
</table>

TABLE 6. Wind load schemes and aerodynamic coefficient c (SNiP 2.01.07-85, 2010)*

The next step was the search of the design value of the wind load. In the research the wind load was presented as a uniformly distributed load for the height less than 5 m. The design value of the wind load is $q_{w,a}$ - the active wind pressure can be calculated according to formula 8.

$$q_{wa} = w_m \cdot \gamma_f \cdot \gamma_n \cdot H\ (kN/m) \tag{8}$$

where

γ_f=1,4 is a reliability coefficient for the load (SNiP2.01.07-85*, 2010, item 6.11);

γ_n is areliability coefficient for the structure liability(SNiP2.01.07-85*,2010, appendix 7, item 2);

H is a structure width (m).

There are three levels of responsibility of a building according to SNiP2.01.07-85*: I – increased (for buildings whose failure result to the serious economic, social and environmental impact), II – normal (for buildings and constructions of mass construction such as residential, industrial, public and other buildings), III – low (for seasonal and auxiliary buildings: greenhouses, summer pavilions, warehouses and other).Given these points the special situation, possible human condition and durable of camp placement it is suitable to choose the II level of responsibility. In this case γ_n is 0,95.

$$q_{wa} = 0{,}348 \cdot 1{,}4 \cdot 0{,}95 \cdot 1{,}6 = 0{,}926(kN/m)$$

3.1.4. Comparison of results

In accordance with the previous computations the highest value of the wind pressure was obtained by the ASCE calculation. But the difference between the q_{ASCE} and q_{EN} was nearly two times bigger. Anyway, in case of using the quick-safe building in the territory of Europe and Asia the computations for the value q_{EN} must also be made. At the next step the resulting force and bending moment should be determined for the wall structure. For that aim a suitable structural model was designed.

3.2. Model of wall construction

For the further calculation the structural model was designed. The wall in the structure was substituted by a bar in case of the quick-safe building wall element. There are three main types of supports: roller, pinned (hinged) and fixed support for the structural models (figure 10).

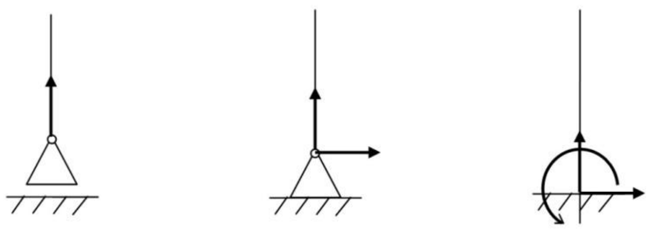

FIGURE 10. Types of supports and reactions

The quick-safe building includes wall panels combined together. The structural model of the wall was designed with taking into account the neighbor walls. The model was designed as a beam with a hinged and a roller supports (figure 11).

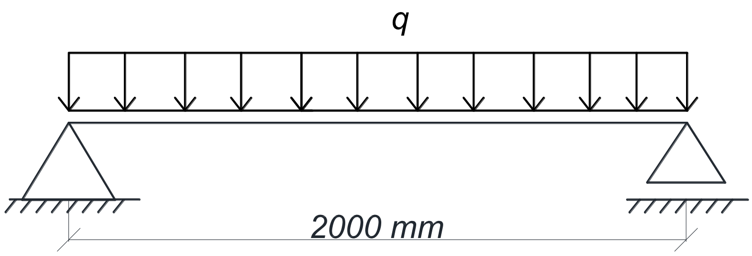

FIGURE 11. The structural model of the wall structure

3.3. Bending

For the structures with a height less than 5 meters, the wind load is a uniformly distributed load. Due to the specifics of the structural model and the fact that the load is uniformly distributed there are two suitable types of diagrams for the structural model:

- a linear shear force diagram Q (figure 12);
- a bending moment diagram M as a square parabola with convexity in direction of the load (figure 12).

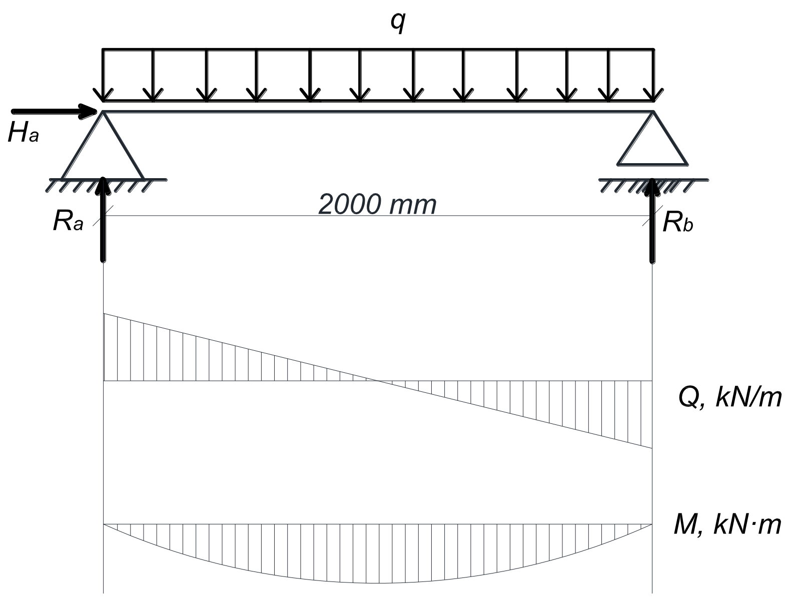

FIGURE 12. Structural model of the wall structure, shear force and moment diagram

Further, the reactions of supports were determined. The length of the bar was replaced by l .For the point A, where the hinged support of the structural model was placed, the system of three equilibrium equations 9 was made:

$$\begin{cases} \sum x = 0 \\ \sum y = 0 \\ \sum M_A = 0 \end{cases} \tag{9}$$

$$\begin{cases} H_A = 0 \\ R_A + R_B - ql = 0 \\ ql\frac{l}{2} - R_B l = 0 \end{cases}$$

$$\begin{cases} H_A = 0 \\ R_A = ql - R_B \\ R_B = q\frac{l}{2} \end{cases}$$

$$\begin{cases} H_A = 0 \\ R_A = q\frac{l}{2} \\ R_B = q\frac{l}{2} \end{cases}$$

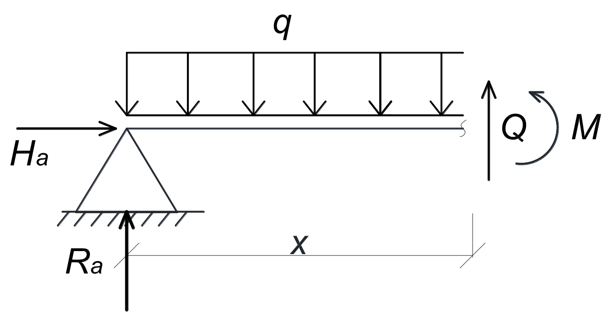

FIGURE 13. An arbitrary section of the structural model

For an arbitrary section of the structural model (figure 13) the system of three equilibrium equations 10 was made:

$$\begin{cases} \sum x = 0 \\ \sum Y = 0 \\ \sum M_{section} = 0 \end{cases} \tag{10}$$

$$\begin{cases} H_A = 0 \\ Q + R_A - qx = 0 \\ M - qx\dfrac{x}{2} = 0 \end{cases}$$

$$\begin{cases} H_A = 0 \\ Q = qx - R_A \\ M = \dfrac{qx^2}{2} \end{cases}$$

Considering the parabolic form of the moment diagram, an extremum meaning should be determined according to formula 11:

$$\frac{dM}{dx} = 0 \qquad (11)$$

$$Q = 0$$

Hence, the extremum meaning of the bending moment diagram is located where the Q equals 0. The computations of the reaction of support was completed, the length x of the arbitrary section and then the value of the extremum meaning of the bending moment were determined (figure 14):

$$qx - R_A = 0$$

$$qx = R_A$$

$$qx = q\frac{l}{2}$$

$$x = \frac{l}{2}$$

$$M\left(\frac{l}{2}\right) = \frac{q\left(\frac{l}{2}\right)^2}{2}$$

$$M\left(\frac{l}{2}\right) = \frac{ql^2}{8}$$

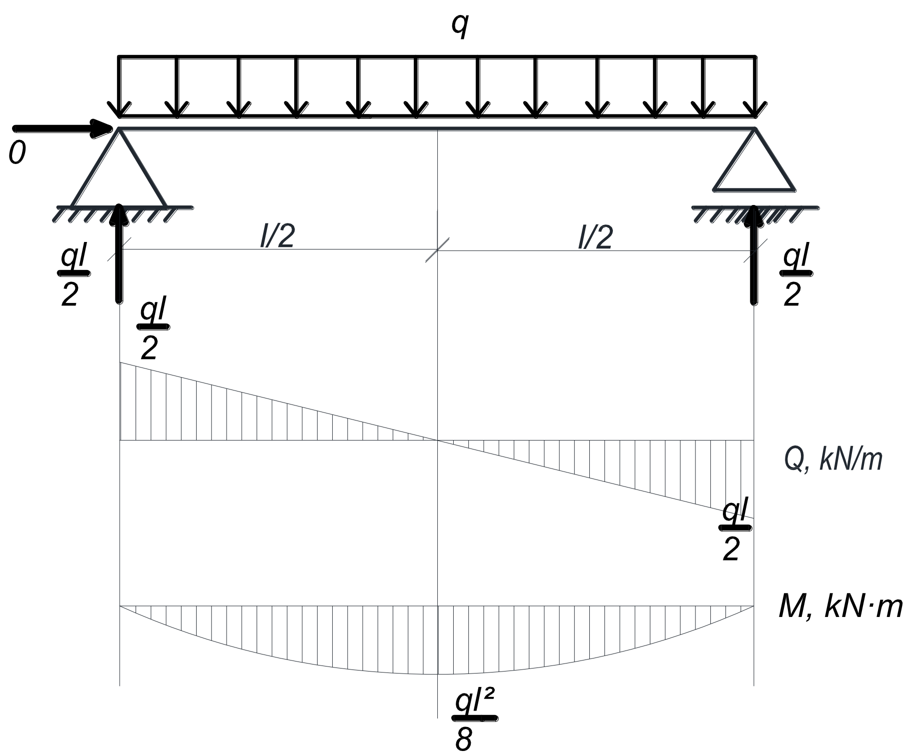

FIGURE 14. Shear force and bending moment diagram with values

Previously the values q_{EN} and q_{ASCE} were determined. For the obtained values the reactions of supports and the moment were determined. Firstly, by the American Standards:

$$R_{A,ASCE} = R_{B,ASCE} = q_{ASCE}\frac{l}{2} = 3{,}371 \cdot \frac{2{,}0}{2} = 3{,}371\ kN$$

$$M_{ASCE} = \frac{q_{ASCE}\, l^2}{8} = \frac{3{,}317 \cdot 1{,}6^2}{8} == 1{,}061\ kN \cdot m$$

Further the computations by the Europe standards were made:

$$R_{A,EN} = R_{B,EN} = q_{EN}\frac{l}{2} = 2{,}08 \cdot \frac{2{,}0}{2} = 2{,}08\ kN$$

$$M_{EN} = \frac{q_{EN}\, l^2}{8} = \frac{2{,}08 \cdot 1{,}6^2}{8} == 0{,}666\ kN \cdot m$$

As it was mentioned earlier, the wall structure is a sandwich panel. Sandwich panel consists of two different materials with different characteristics (figure 16). That fact was considered in the further computations.

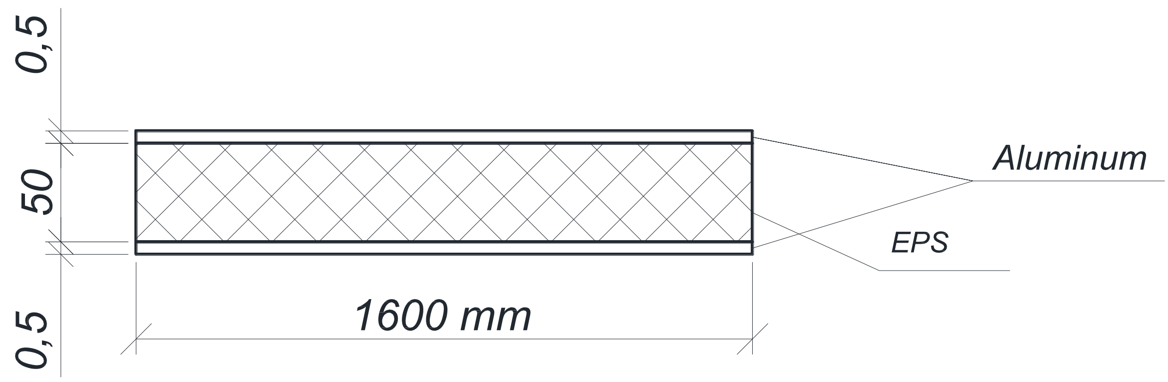

FIGURE 15. A scheme of the sandwich panel for a quick-safe-building

Beer, Johnston, Dewolf and Mazurek (2011, 464) give a procedure for the cross-sections where different materials are bonded together. According to the procedure, a transformed section corresponds to an equivalent section entirely of one material. As the cross section includes two types of materials, the ratio of modules of elasticity should be determined (table 6).

TABLE 7. Modules of elasticity for the materials

Material	Designation	Modules of elasticity (GPa)
Aluminum	E_{al}	70
EPS	E_{EPS}	3,5

There is a transform coefficient for the further computations for the transformed section as a ratio between modules of elasticity of two materials, which the section combines. The section was replaced by aluminum. The transform coefficient for the cross section was determined with formula 12:

$$n_{al} = \frac{E_{EPS}}{E_{al}} \quad (12)$$

$$n_{al} = \frac{3{,}5}{70} = 0{,}05$$

The computations of properties of cross-section were determined for the further computation. At first, the total height of cross-section h was calculated by formula 13:

$$h = h_1 + 2 \cdot t_c \quad (13)$$

where

h_1 is a height of inside cross-section (mm);

t_c is a thickness of covering material (mm).

$$h = 50 + 2 \cdot 0{,}5 = 51\ mm$$

Further, the moment of inertia of the cross-section can be determined. As the cross-section consists of two different materials, several values must be determined. A moment of inertia for the aluminum covering can be made by the formula 14:

$$I_c = \frac{b}{12}(h^3 - h_1^3) \tag{14}$$

where

b is a width of cross-section (mm).

$$I_c = \frac{1600}{12}(51^3 - 50_1^3) = 1020133{,}333\ mm^4$$

The next step is computations of moment of inertia for the inside material (EPS) of cross-section. It can be calculated by the formula 15:

$$I_1 = \frac{b \cdot h_1^3}{12} \tag{15}$$

$$I_1 = \frac{1600 \cdot 50^3}{12} = 16666666{,}667\ mm^4$$

For the transformed section the moment of inertia I must be also determined according to formula 16:

$$I = I_c + n \cdot I_1 \tag{16}$$

$$I = 1020133{,}333 + 0{,}05 \cdot 16666666{,}667 = 1853466{,}666\ mm^4$$

For the extremum meaning of the moment in the cross-section the design condition must be checked (formula 17):

$$f_{Rd} \geq \sigma_{Ed} \tag{17}$$

where:

σ_{Ed} is the design stress of bending under the given load (kPa);

f_{Rd} is the ultimate bending stress (kPa).

For the design situation the value σ_{Ed} can be determined (formula 18):

$$\sigma_{b,max} = \frac{M \cdot y}{I} \tag{18}$$

where

M is the extremum meaning of the bending moment for the cross-section (N·mm);

y is the length between the neutral axis and the distant fiber of the cross-section (mm).

Due to the fact that the cross-section consists of two materials, the design condition should be checked for the outer surface of covering material and for the outer surface of inside material. As the computations in the research were presented by two standards, the first computations for the design condition were made according to the values by the American standards. The value $\sigma_{Ed,c}$ for the outer surface of metal covering was calculated by formula 19:

$$\sigma_{Ed,c} = \frac{M_{ASCE} \cdot y_c}{I} \tag{19}$$

where

y_c is a length between the neutral axis of the cross-section and the outer surface of covering material according to formula 20 (mm).

$$y_c = \frac{h}{2} \tag{20}$$

$$y_c = \frac{51}{2} = 25{,}5\ mm$$

$$\sigma_{Ed,c} = \frac{1061000 \cdot 25{,}5}{1853466{,}666} = 14{,}59\ MPa$$

The design condition for the outer surface of the covering material is placed below:

$$f_{Rd,al} \geq \sigma_{Ed,c} \quad (21)$$

$$f_{Rd,al} = 110MPa > \sigma_{Ed,c} = 14{,}59\ MPa$$

The design condition for the transformed section is satisfied.

The value $\sigma_{Ed,1}$ for the outer surface of inside material was calculated by formula 22:

$$\sigma_{Ed,1} = n \cdot \frac{M_{ASCE} \cdot y_1}{I} \quad (22)$$

where

y_1 is a length between the neutral axis of the cross-section and the outer surface of inside material according to formula 23 (mm).

$$y_1 = \frac{h}{2} - t_c \quad (23)$$

$$y_1 = \frac{51}{2} - 0{,}5 = 25\ mm$$

$$\sigma_{Ed,1} = 0{,}05 \cdot \frac{1061000 \cdot 25}{1853466{,}666} = 0{,}716\ MPa$$

The design condition for the outer surface of the inside material is placed below:

$$f_{Rd,EPS} \geq \sigma_{Ed,1} \quad (24)$$

$$f_{Rd,al} = 0{,}200\ MPa < \sigma_{Ed,c} = 0{,}716\ MPa$$

The design condition for the transformed section is not satisfied. Hence, the inside material must be taken out of account. In that way, the covering material must be enough strength for the full load. The maximum strength by the given loads was determined with formula 25.

$$\sigma_{Ed,c} = \frac{M_{ASCE} \cdot y_c}{I_c} \tag{25}$$

$$\sigma_{Ed,c} = \frac{1061000 \cdot 25{,}5}{1020133{,}333} = 26{,}522\ MPa$$

The design condition for the covering material can be seen below:

$$f_{Rd,al} = 110MPa > \sigma_{Ed,c} = 26{,}522\ MPa$$

The design condition for the transformed section is satisfied.

3.4. Axial load

In connection with the polygonal form of a quick-safe building, the angle between the adjacent walls is 120º. Hence, the angle between the bars of the structural model is the same. As the bars are connected together, the reaction of support R_a is taken by the adjacent bar (figure 16). That is the reason to determine axial load N (formula 23).

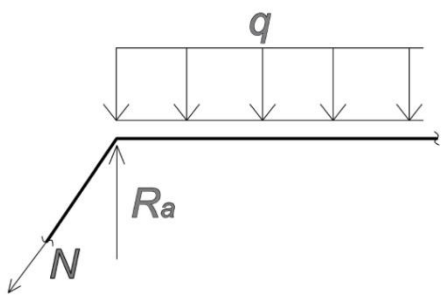

FIGURE 16. The angle element of the model of the quick-safe building

$$N = \frac{R_a}{\cos 30°} \tag{26}$$

The computations for the axial load were made according to the values by the American standards:

$$N_{ASCE} = \frac{3{,}371}{\cos 30°} = 3{,}892\ kN$$

The computations for the axial load were made according to the values by the Europe standards:

$$N_{EN} = \frac{2{,}08}{\cos 30°} = 2{,}402\ kN$$

The design condition for analysis by the axial loads (compression forces) can be seen below (formula 27):

$$N_{cd} \geq N \tag{27}$$

Where

N is a design compression force under the given load (kN);

N_{cd} is the ultimate compression force (kN).

Hence, the value N_{cd} must be determined according to formula 28:

$$N_{cd} = \sigma_{cd} \cdot A \tag{28}$$

Where

σ_{cd} is ultimate compression strength (MPa);

A is the area of the transformed section according to the formula 29 (mm^2).

$$A = A_c + n \cdot A_1 \tag{29}$$

Where

A_c is area of covering material;

A_1 is area of inside material.

$$A = 1600 \cdot 5 + 0{,}05 \cdot 1600 \cdot 50 = 4800\ mm^2$$

Hence, the value N_{cd} can be determined by formula 28:

$$N_{cd} = 35 \cdot 4800 = 168000\ N = 168\ kN$$

The design condition for analysis by the axial loads (compression forces) by the American standards can be seen below (formula 30):

$$N_{cd} \geq N_{ASCE} \tag{30}$$

$$N_{cd} = 168\ kN > N_{ASCE} = 3{,}892\ kN$$

The design condition for analysis by the axial loads (compression forces) by the American standards is satisfied.

The design condition for analysis by the axial loads (compression forces) by the Europe standards can be seen below (formula 31):

$$N_{cd} \geq N_{EN} \tag{31}$$

$$N_{cd} = 168\ kN > N_{EN} = 2{,}402\ kN$$

The design condition for analysis by the axial loads (compression forces) by the Europe standards is satisfied.

4. RESULTS

As a preparation work for this research several analyses were made: the analysis of potentially dangerous areas, the analysis of environment temperatures (the highest and the lowest environment temperatures) and the analysis of suitable materials for walls for a quick-safe building.

The most dangerous areas are the areas placed nearly the boundaries of lithospheric plates (seismically hazardous areas), areas placed near the open water (different kind of strong wind, floods). For instance, Peru, Chili, Nepal, India, Japan, Korea, South America are potentially dangerous areas. The highest temperature is in Iraq (+42ºC) and the lowest in Russia (-41ºC).

According to the analysis of materials, composite panels (sandwich panels) were chosen for the wall structures. The sandwich panel consists of two materials: the EPS insulation and the aluminum covering.

On the grounds of the analyses, the calculations with the worst values were made. As the area of potentially dangerous territories was wide, three variants of wind load analyses were elaborated in the research according to: the European standards Eurocodes, the Russian standards SP and the American standards ASCE. The highest value of wind load was determined according to the American standards, where q equals 4,214 kN/m. However, the computations were also made by the European Standards. In this case the highest value of wind load was q equals 2,6 kN/m.

During the research a structural model of the wall structure of a quick-safe building was designed. The structural model was designed as a bar with hinged and roller supports. The bending moment and shear force diagrams were made for the structural model. After that, a wind load was determined. According to the American Standards the maximum value of bending moment M equals 1,061 kN·m, the maximum value of shear force Q equals 3,371 kN. According to the European Standards the maximum value of bending moment M is equal to 0,666 kN·m, the maximum value of shear force Q is equal to 2,08 kN.

The next step of the calculations was to verify the design condition by the normal stresses and the design condition for analysis by the axial loads (compression forces). The structure is satisfied both conditions in both cases of computations. Thereby the final size of the wall panel is 1600mm x 2000mm x 51mm.

5. DISCUSSION

The design of quick-safe buildings makes it possible to take care of people around the world in the hardest time. The structure of quick-safe buildings should correspond to many criteria.

During this research a lot of data was collected. The terrains with the worst conditions were surveyed. The materials and parameters of the walls were chosen through the computations of the wind load and the load influence analyses. Besides of these important things the research is a small part of the project of a quick-safe building.

The next steps of the project should be choice of roof and floor materials, design of the openings and anchoring to the ground (instead a foundation). In the end of the project, each step should be worked out from the investor (manufacturer) through the production, warehousing, delivery and assembly to people, who need this.

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APPENDICES

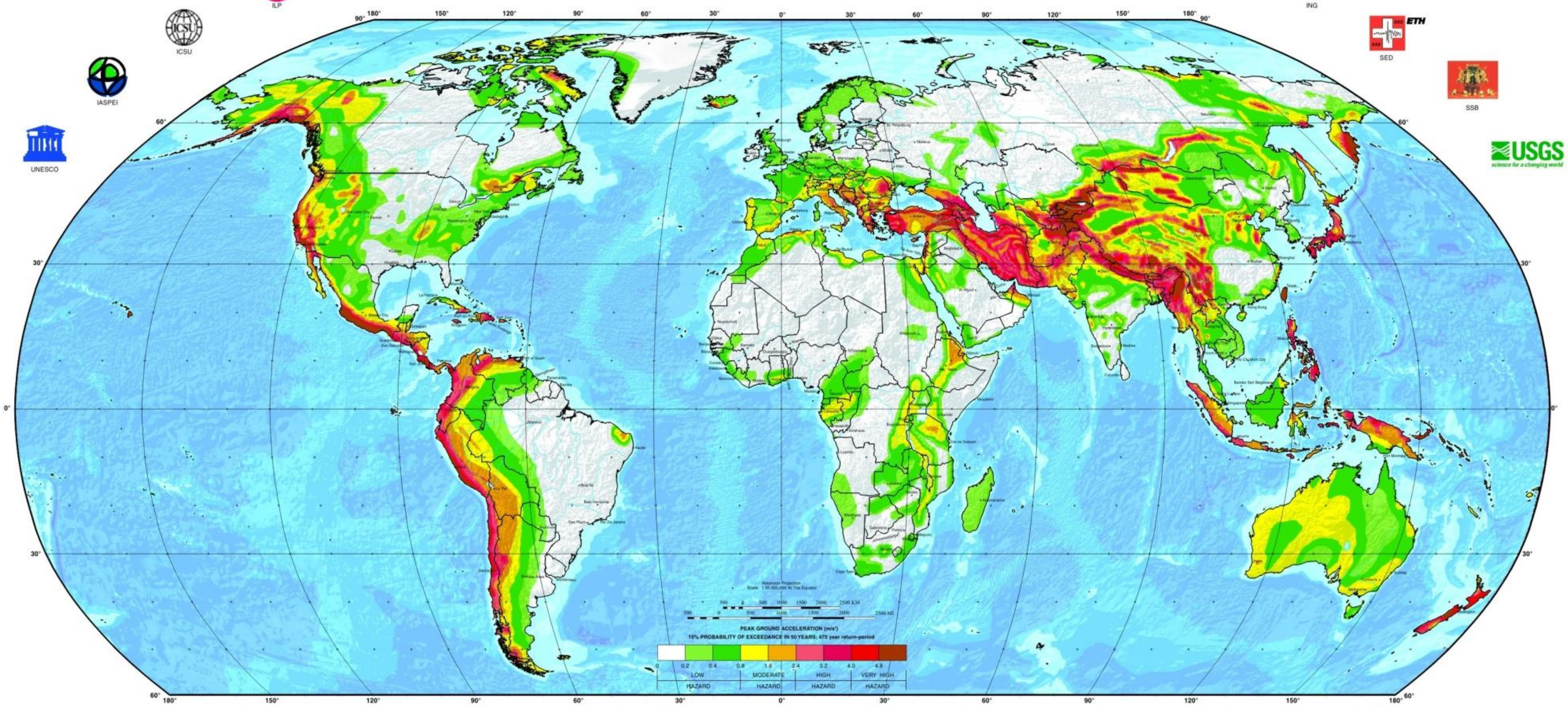
Appendix 1	The global seismic hazard map (Global Seismic Hazard Assessment Program. 2015. Date of retrieval 29.10.2015.)
Appendix 2	SP 20.13330.2011 appendix ZH, map 3
Appendix 3	SP 20.13330.2011 appendix ZH, map 3a

Appendix 1

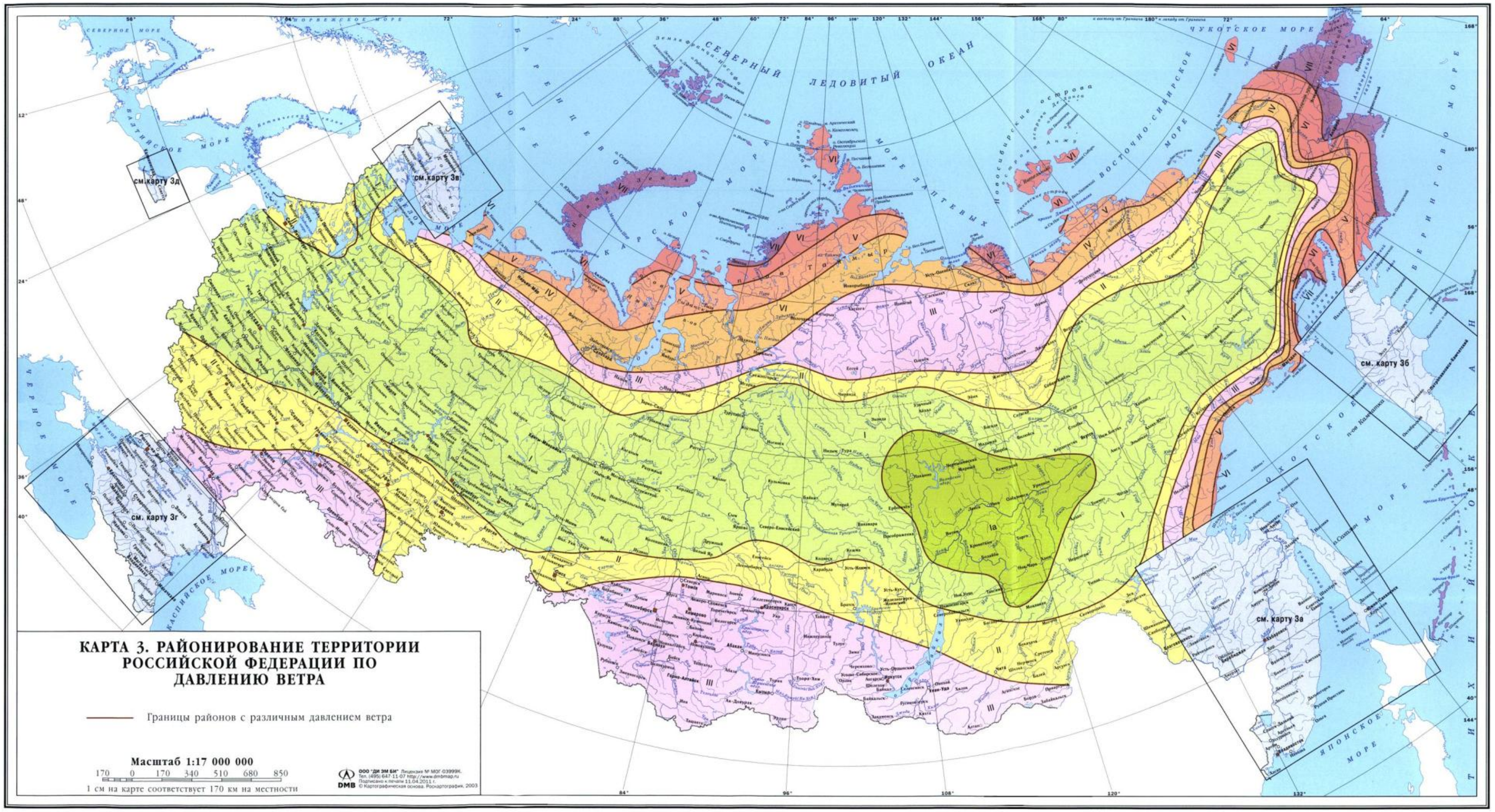
GLOBAL SEISMIC HAZARD MAP

Produced by the Global Seismic Hazard Assessment Program (GSHAP), a demonstration project of the UN/International Decade of Natural Disaster Reduction, conducted by the International Lithosphere Program.

Global map assembled by D. Giardini, G. Grünthal, K. Shedlock, and P. Zhang
1999



Appendix 2


КАРТА 3. РАЙОНИРОВАНИЕ ТЕРРИТОРИИ РОССИЙСКОЙ ФЕДЕРАЦИИ ПО ДАВЛЕНИЮ ВЕТРА
Границы районов с различным давлением ветра
Масштаб 1:17 000 000
1 см на карте соответствует 170 км на местности
см. карту 3а
см. карту 3б
см. карту 3в
см. карту 3г
см. карту 3д

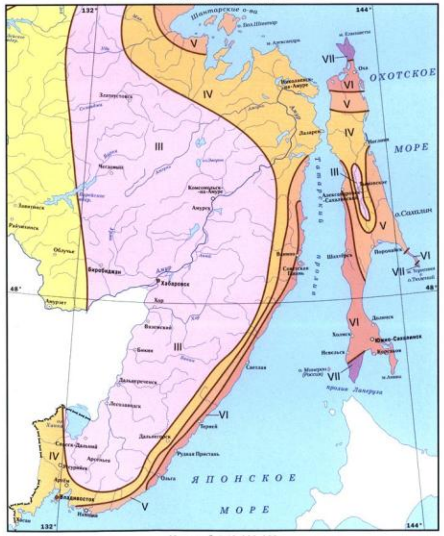
Appendix 3

ДОПОЛНЕНИЯ К КАРТЕ 3. РАЙОНИРОВАНИЕ ТЕРРИТОРИИ РОССИЙСКОЙ ФЕДЕРАЦИИ ПО ДАВЛЕНИЮ ВЕТРА

—— Границы районов

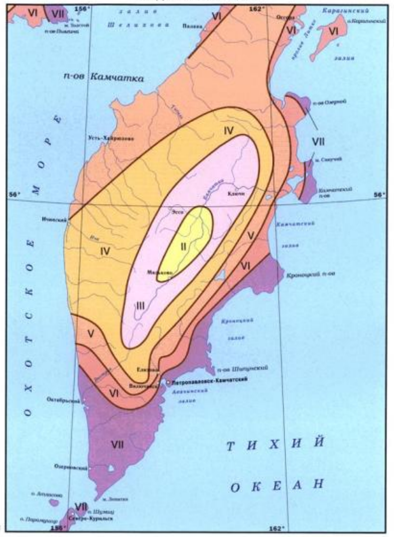
ООО "ДИ ЭМ БИ" Лицензия № МОГ-03999К. Тел. (495) 647-11-07 http://www.dmbmap.ru
Подписано к печати 11.04.2011 г.

КАРТА 3а.
РАЙОНИРОВАНИЕ ТЕРРИТОРИИ ПРИМОРСКОГО КРАЯ И ОСТРОВА САХАЛИН ПО ДАВЛЕНИЮ ВЕТРА



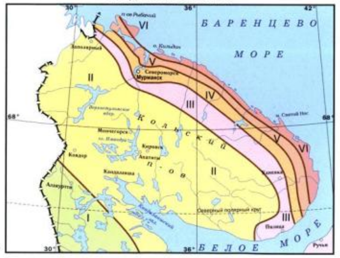
Масштаб 1:10 000 000
1 см на карте соответствует 100 км на местности

КАРТА 3б.
РАЙОНИРОВАНИЕ ТЕРРИТОРИИ ПОЛУОСТРОВА КАМЧАТКА ПО ДАВЛЕНИЮ ВЕТРА



Масштаб 1:7 000 000
1 см на карте соответствует 70 км на местности

КАРТА 3в.
РАЙОНИРОВАНИЕ ТЕРРИТОРИИ КОЛЬСКОГО ПОЛУОСТРОВА ПО ДАВЛЕНИЮ ВЕТРА

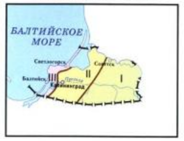


Масштаб 1:7 000 000
1 см на карте соответствует 70 км на местности

КАРТА 3г.
РАЙОНИРОВАНИЕ ТЕРРИТОРИИ КАВКАЗА ПО ДАВЛЕНИЮ ВЕТРА

Масштаб 1:7 000 000
1 см на карте соответствует 70 км на местности

КАРТА 3д.
РАЙОНИРОВАНИЕ ТЕРРИТОРИИ КАЛИНИНГРАДСКОЙ ОБЛАСТИ ПО ДАВЛЕНИЮ ВЕТРА



Масштаб 1:7 000 000
1 см на карте соответствует 70 км на местности