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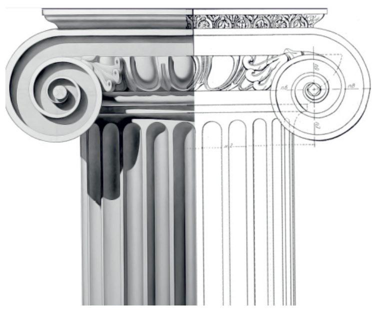

CONTENTS

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PREVENTION OF ROUND TIMBER LATERAL CRACKING IN WOODEN HOUSE CONSTRUCTION

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Abstract

The article is devoted to the most widespread defect of regularized round timbers in wooden house construction, i.e. their lateral cracking in the process of further use of buildings and structures. A method is proposed to cut lateral saw kerfs in the round timber surface upon timber rounding, which almost completely excludes appearance of cracks on exposed surfaces. Saw kerfs are cut in the exterior surfaces of round timber on the opposite side of the simultaneously manufactured technological notch.

According to the results of theoretical and experimental studies, it was ascertained that the saw kerf is the main factor which excludes appearance of lateral cracking in regularized round timber. Taking into account the technological notch, the optimal depth of a saw kerf should not be more than 35% of the round timber cross-section radius.

The absence of visible lateral macro-cracks on exposed surfaces of round timber will improve the appearance of a building and prolong its service life. Macro-cracks appear at the bottom of the technological notch and at the bottom of the saw kerf which serve as stress concentrators. Such stresses occurring due to the hygroscopic moisture gradient along the round timber cross-section radius and anisotropy of wood shrinkage in points with stress concentrators can exceed the limit values upon extension in the tangential direction, wherefore macro-cracks will form in the areas with stress concentrators.

According to estimates, additional energy consumption for making a lateral saw kerf will be 1–2%.

Keywords

Wooden house construction, technological notch, crack formation, round timber cracking.

Introduction

Industrial production of wooden houses is one of the most promising directions in the domestic housing development. Global tendencies and long-term foreign experience in the field of low-rise housing construction prove the high effectiveness of house prefabrication and its competitiveness according to such criteria as comfort and design, individuality and design simplicity, environmental friendliness and manufacturability.

However, the global crisis partially manifested in the contraction of the market of newly introduced dwelling substantially affected the production volumes of woodworking enterprises of the building sector. Development of wooden house construction is the main way to increase the internal consumption of timber products in our branch of industry.

When analyzing round timber cracking in block houses, we shall pay attention to the fact that, in most cases, macro-cracks form at the bottom of technological notches (Figure 1). These are macro-cracks that get out to the round timber end. The technological notch is a stress concentrator where the danger of cracking is somewhat less than in saw kerfs, however, it may be a problem. Any cut, a hollow on the round timber surface, a saw kerf form increased tensile stresses, leading to material crippling, i.e. formation of deep lateral cracks.

Thus, when selecting a point for a saw kerf, a macro-crack appearance site shall be pre-defined — it appears at the bottom of a saw kerf.

A lateral saw kerf in the non-exposed surface of round timber leads to the appearance of the second stress concentrator, which jointly with a technological notch shall provide decrease of tensile stresses on the surface of round timber upon drying out.

Any capillary porous material, including timber, starts drying out from the surface. If moisture of surface zones is below the limit of the hygroscopic property, sizes decrease and wood shrinkage occurs. However, the shrinkage of the round timber surface layer is impeded by its significant inner part where wood moisture is above the limit of the hygroscopic property and there is no shrinkage. As a result, the surface layer of round timber is subjected to stretching and, therefore, compresses the inner part.

Figure 1. Crack on the surface of the technological notch

The material is subjected to the radial compression throughout the entire cross-section. In the circumferential direction, tensile stresses act on the periphery, whereas in the central zone we observe compressing stresses. In this case, the highest risk of crack formation exists in the initial period of drying out, when hygroscopic moisture decreases in surface layers only. When tensile stresses reach limit values, a pattern of micro-cracks forms on the round timber surface, which increase with their development, consolidate, forming larger cracks, which finally form a macro-crack, when being combined with other similar cracks. This macro-crack becomes more prevalent and reaches a medullary sheath. It can be assumed that, upon formation of such crack in evenly drying out round timber, internal shrinkage stresses will completely disappear.

If a crack has a small depth, then reduction of stresses will be partial. Further drying out will lead to new stress buildup and further crack development. The crack development process does not end with the alignment of hygroscopic moisture throughout the round timber cross-section.

Among other requirements, a wooden house shall have appearance which complies with modern requirements. Timber rounding allows obtaining a construction material of a proper geometric shape. However, in due course time, house appearance deteriorates due to internal shrinkage stresses and formation of deep cracks. To develop activities for the reduction of the crack formation risk, it is necessary to study changes in the internal stress value of round timber upon drying out.

Study Technique. In this view, the work of Shevchenko V. A. and Feller M. N. (Shevchenko, Feller 1962, 1964) shall be noted. The authors considered a case of hygroscopic moisture distribution in a circular cross-section according to the second-order paraboloid law.

To solve the task relative to the initial drying stage, we accepted moisture distribution according to the sixth-order paraboloid law (Figure 2).

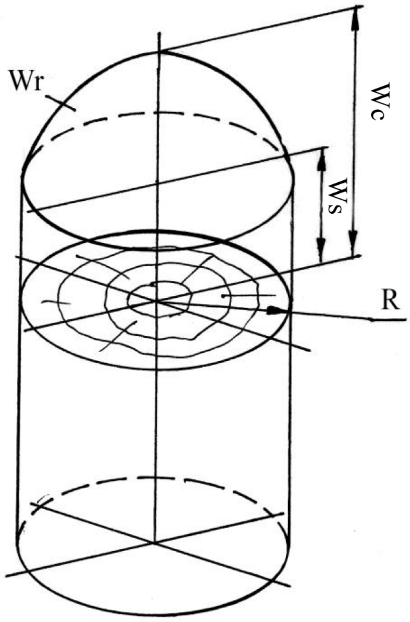

Figure 2. Distribution of hygroscopic moisture hroughout the round timber cross-section

The hygroscopic moisture function will take the following form:

$$W = W_c - \frac{W_c - W_s}{R^6} \cdot r^6 \quad (1)$$

where *Wc, Ws* — wood moisture in the center and on the surface of round timber, %.

Internal stresses in wood are conditioned by the hygroscopic moisture variation, anisotropy of the structure and properties in various structural directions.

Assuming that we have an elastic cylindrical body, annual rings of which represent concentric circumferences, and constant elasticities of which do not depend on the wood moisture content, it is possible to consider it to be an orthotropic and cylindrically anisotropic body, the anisotropy axis of which coincides with the longitudinal geometric axis, and radial and tangential axes are perpendicular to it.

Solving the plane task using elasticity theory methods, we use the following differential equation for an orthotropic and cylindrically anisotropic body (Glukhikh, Akopian, 2010):

$$\frac{r^4\partial^4 F}{E_t \partial r^4}+\frac{r^3\partial^3 F}{E_t \partial r^3}-\frac{r^2\partial^2 F}{E_r \partial r^2}+\frac{r\partial F}{E_r \partial r}=\frac{r^8}{100}(42K_t-6K_r)\frac{W_c-W_s}{R^6} \qquad (2)$$

where E_t, E_r are constant elasticities of wood in radial and tangential directions; K_t, K_r are timber shrinkage factors in radial and tangential directions; W is the function of hygroscopic moisture distribution throughout the round timber cross-section.

General solution of differential equation (2):

$$F-F_0+F_1+C_1+C_2 r^2+C_3 r^{1+\alpha}+C_4 r^{1-\alpha}+\frac{3E_t(W_c-W_s)7K_t-K_r}{2352-48\alpha^2\cdot 50R^6}\cdot r^8 \qquad (3)$$

The circumferential stress can be calculated after finding integration constants and corresponding conversions according to the following equation:

$$\sigma_t=\frac{(K_t-K_r)(W_h-W_c)}{100(1-\alpha^2)}E_t\left(1-\alpha\frac{R^{1-\alpha}}{r^{1-\alpha}}\right)+ \\ +\frac{7K_t-K_r W_c-W_s}{49-\alpha^2\cdot 100}E_t\left(7\frac{r^6}{R^6}-\alpha\frac{R^{1-\alpha}}{r^{1-\alpha}}\right) \qquad (4)$$

where W_h is the wood hygroscopicity limit, %.

Equation (4) shows that in points of the round timber cross-section contour, the circumferential stress is the same, irrespective of its diameter. Table 1 and Figure 4 below provide stress calculation results according to the obtained equations for the following data: K_r = 0.2%; K_t = 0.3%; E_r = 500 MPa; W_h = W_c = 30%; W_c - W_s = 1%; α^2 = 0.5; R = 5 cm.

Table 1. Changes in stresses along the round disk radius during drying

	r, cm						
Stress	0.1	0.2	1.0	2.0	3.0	4.0	5.0
σ_r, kg/cm²	-137.94	-103.55	-45.82	-28.16	-19.0	-11.27	0
σ_t, kg/cm²	-83.03	-58.56	-17.74	-5	4.095	22.84	76.25

When the hygroscopic moisture variation is 1%, upon initial drying, circumferential stresses reach approximately half of the wood tensile strength in the tangential direction.

Saw kerfes in non-exposed surfaces will not affect the appearance of round timber and, in combination with the technological notch, will allow decreasing surface tensile stress values. This will allow reducing the risk of crack formation on exposed surfaces. Micro-cracks will definitely appear, but the prevailing crack (its functions are performed by the cut saw kerf) already exists. It will ensure decrease in tensile stresses on the surface and thereby prevent appearance of another macro-crack.

Thus, cutting of a saw kerf beforehand predetermines the location of the prevailing macro-crack allowing avoiding its appearance on the round timber exposed surface. A macro-crack which forms at the bottom of the saw kerf deepens into round timber. This will not worsen the building appearance.

The issue of crack formation in round timber has not been studied enough, therefore, the depth of saw kerfs, their number and width in the house construction technology are not always determined and are often not substantiated.

At the first stage of solving the task, the even drying-out of round timber is considered upon the absence of the hygroscopic moisture gradient. In this case, the reason of the appearance of internal stresses is anisotropy of the wood structure and properties.

Shrinkage strains in the circular cross-section (without saw kerfs) in radial and tangential directions are inter-related and are not realized completely.

When a saw kerf is cut from the contour to the round timber cross-section center, both radial and tangential shrinkage are freely and fully realized and stresses in external layers are significantly reduced.

It is obvious that there is no need to make lateral saw kerfs to the medullary sheath. Firstly, the torsional and bending stiffness of round timber can be impaired. Secondly, the energy consumption needed to make a saw kerf increases, the production cost of a wooden house will increase as well. Thirdly, the saw kerf depth shall be determined according to the reduction of circumferential stresses on the exposed surface of round timber in the house wall to safe values ensuring the absence of macro-cracks while in use.

Two solutions of crack formation tasks are known. The first one is to select functions which have discontinuity in crack sites. The second one is to select functions which allow meeting conditions on crack margins. Functions shall depend on two coordinates: radial and angular.

If there is a possibility to consider conditions on crack margins, then it is mathematically easier to solve the second task. The first task is more complicated, therefore, the second option was selected.

As in the previous case, the fourth-order differential equation in partial derivatives in polar coordinates served as the basis of the solution (2). In the absence of axial symmetry in the task with the lateral saw kerf, the stress function *F(r,θ)* contains components with trigonometric functions of angle cosine mθ .

The numerical solution of the task resulted in obtaining the system of 20 equations with 20 unknown variables, which was solved with the use of EXCEL. Coefficients of unknown variables and free members of equations were found for the same data as in the first part of the task for the entire circle without a saw kerf.

The solution of the equation for the circumferential stress σ_t allows obtaining values of this stress in points on the circle contour depending on the saw kerf depth.

For each saw kerf depth value, 20 equations were generated and solved with the use of a computer (depth values: 1 cm, 2 cm, 3 cm, 5 cm, 7 cm, 9 cm, 9.9 cm, 10 cm). 120 equations were solved with the use of EXCEL.

Research Results

Table 2. Values of circumferential stresses in points on the contour at θ = 180° depending on the saw kerf depth

Stress, MPa	Saw kerf depth, cm						
	0	1	3	5	7	9	10
σ_t	5.935	5.642	4.88	3.86	2.47	0.93	0.021

Calculation results are shown in Figures 3 and 4.

Figure 5 shows changes in the circumferential stress σt in points on the round timber cross-section contour with the change in angle θ.

With the increase in the saw kerf depth, maximum stresses in the tensile and compressed areas of the cross-section decrease and, in the perfect scenario, when the cross-section of round timber is circular, they disappear completely. This proves the hypothesis that if all annual layers in the cross-section are cut (i.e. there are no intact annular circles), stresses do not appear upon even drying-out.

With the increase of the lateral saw kerf depth, the stress on the round timber exposed surface decreases. At the saw kerf depth equal to a quarter of the round timber diameter, the stress decreases by a factor of 2.5 from 5.935 to 2.37 MPa and, therefore, the cracking risk is reduced, since this stress is less than the wood tensile strength in the tangential direction (Ugolev, 1971).

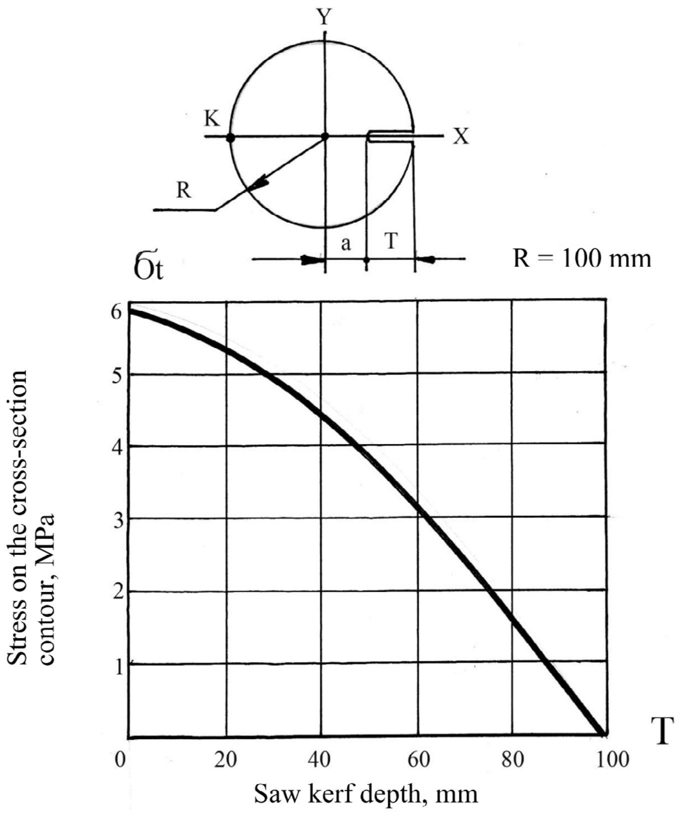

Figure 3. Reduction of the circumferential stress in "K" point with the saw kerf depth increase

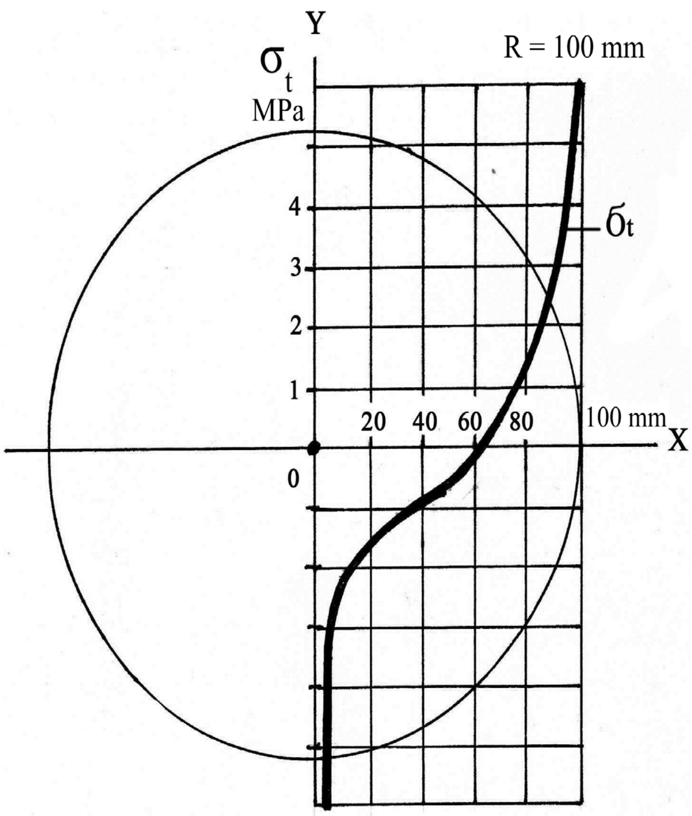

Figure 4. Changes in the circumferential stress along the radius of round timber with the cross-section diameter d = 20 cm without a saw kerf

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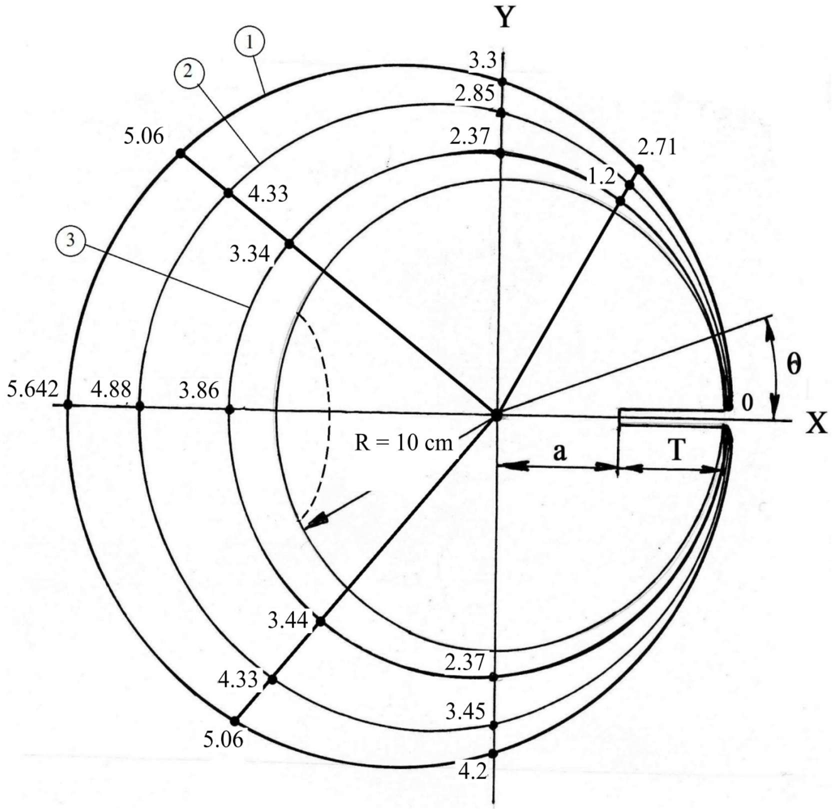

Figure 5. Changes in the circumferential stress depending on the angle θ at the depth of 1-T = 1 cm; 2-T = 3 cm; 3-T = 5 cm

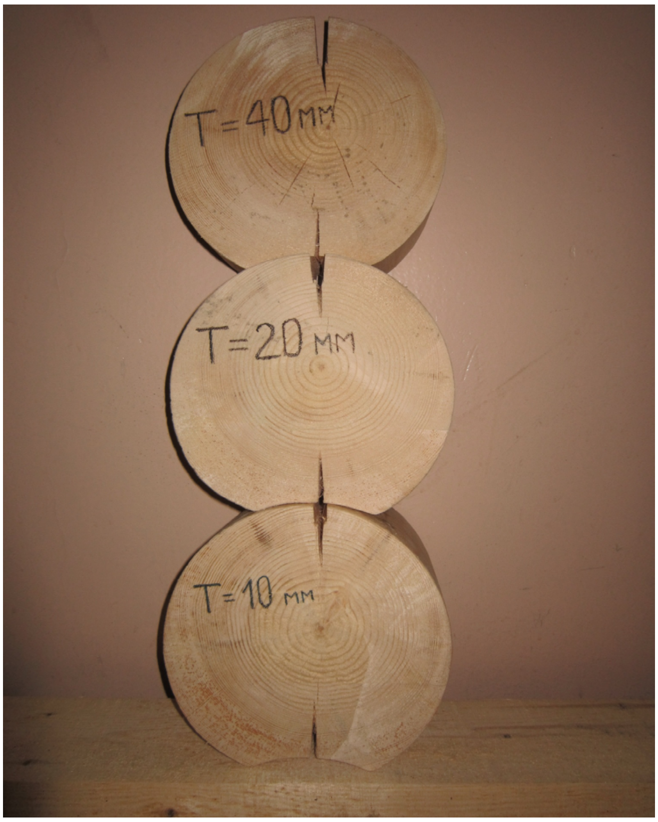

Figure 6. Crack position is defined by the location of the stress concentrator

Table 3. Results of experimental studies of crack formation in round timber with a lateral saw kerf

	Saw kerf depth, mm	No. of samples, pcs	Sample size		Macro-crack size, mm		
			Disk diameter, mm	Thickness, mm	width	depth	location
Cut width — 2.4 mm	10	5	200	50	6.2	88	saw kerf
					6.6	71	saw kerf
					7.2	73	saw kerf
					6.1	64	saw kerf
					7.0	75	saw kerf
	20	5	200	50	5.9	63	saw kerf
					5.3	72	saw kerf
					4.7	49	saw kerf
					5.5	57	saw kerf
					5.7	70	saw kerf
	40	5	200	50	3.8	60	saw kerf
					4.3	54	saw kerf
					4.0	60	saw kerf
					4.3	58	saw kerf
					4.5	56	saw kerf
	70	5	200	50	2.4	30	saw kerf
					2.1	30	saw kerf
					2.6	30	saw kerf
					2.1	30	saw kerf
					2.1	30	saw kerf
	100	5	200	50	-	-	saw kerf
					-	-	saw kerf
					-	-	saw kerf
					-	-	saw kerf
					-	-	saw kerf
	10	5	300	50	8.3	94	saw kerf
					7.9	110	saw kerf
					7.7	102	saw kerf
					8.7	93	saw kerf
					8.2	115	saw kerf
	20	5	300	50	7.0	92	saw kerf
					6.4	87	saw kerf
					6.1	101	saw kerf
					7.1	84	saw kerf
					6.8	91	saw kerf
	40	4	300	50	4.8	74	saw kerf
					5.3	67	saw kerf
					4.7	72	saw kerf
					5.2	71	saw kerf
	70	5	300	50	3.6	80	saw kerf
					3.9	71	saw kerf
					3.1	80	saw kerf
					4.0	80	saw kerf
					2.9	75	saw kerf
	150	5	300	50	-	-	saw kerf
					-	-	saw kerf
					-	-	saw kerf
					-	-	saw kerf
					-	-	saw kerf

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When a crack appears, the stress abruptly decreases. Upon further drying-out of round timber, the stress begins to increase again, and when tensile strength is reached upon tension in the tangential direction, this promotes further crack development. This process is cyclic and it occurs unless the wood moisture reaches the equilibrium value under conditions subjecting round timber.

When there are simultaneously a technological notch and a lateral saw kerf, no visible cracks on the round timber exposed surface were observed (Figure 6).

Conclusion

Technologically, a lateral saw kerf can be cut in production conditions together with notch making.

The optimal saw kerf depth shall not exceed 35% of the round timber cross-section radius.

To cut a saw kerf, increase in the energy consumption by 1–2% is necessary. However, this will result in improved appearance of a building and increase in its service life.

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A SITE-BASED PRACTICAL IMPROVISATION FOR THE ANALYTICAL DETERMINATION OF ASPECT RATIO

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Abstract

'Aspect Ratio', a commonly used indicator to describe typical urban geometry is computed as the average ratio of the building heights 'H' to the canyon width 'W'. Its determination techniques in the present urbanization scenario is bound by certain assumptions which falter as most cities across globe does not project a well-planned street profile. An urban canyon factor is of most significance in climatic and air quality studies.

The study showcases how the standard assumptions cited in literatures for Urban Morphological Analysis cannot apply to most urban canyons in any townships that have evolved rampantly. The present research recommends a rationally feasible methodology of analytically ascertaining and representing Aspect Ratio for variant street canyons. The research objective envisaged selection of 3 random locations encompassing heterogeneous street canyon geometries. At each of these locations its land-use pattern and road network was mapped for a radius of 250m by supervised-classification to assist in extracting the canyon geometry features, namely building height and road width across all the streets.

The revised methodology judiciously delves upon when stations also have plots without pre-defined boundaries for creation of layouts. The logic encompasses complete dimensional analysis, and accounts for all four directions, the dynamic road width and building length measured along street about each focal point. The present research recommends this technique for a study of any magnitude; and encompassing just a street or even an entire city; as it's practically applicable to any site condition and does away with errors due to the 'idealistic' assumptions.

Keywords

Aspect, canyon, dimensional, elevation, ratio, urban.

Introduction

A typical urban morphology is often projected as an urban canyon comprised of the walls of adjacent buildings, the street between them and the air volume enclosed within it (Nicholson Sharon, 1975). 'Aspect Ratio', a commonly used indicator; is computed as the average ratio of the building heights 'H' to the canyon width 'W' (Oke, 1988a). 'Aspect Ratio' is hence also denoted as H:W (Steyn, 1980).

The profiling of an urban canyon is based on the universally accepted 'Classification of Canyons' as Avenue (Figure 1), Regular (Figure 2), Narrow (Figure 3), and Deep (Figure 4); i.e. based on the Aspect Ratio values as <0.5, 1, >1 and >2 respectively (Afiq et. al, 2012).

Rationale for Study

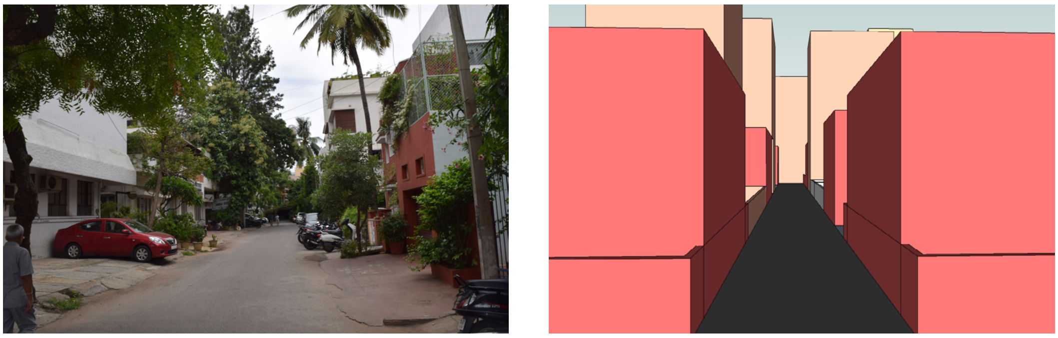
Several researchers have tried to establish the relationship of canyon geometry for a city with its Climatic variations (Yamashita et.al, 1986; Oke, 1981; Gopinath, 2014), Energy balance (Marciotto et.al, 2010; Oke, 1988b), Wind flow pattern (Chang and Meroney, 2003), Air quality (Chan et.al, 2003) etc. The present research postulates that, as long as the street geometry is restricted to urban micro-climate studies (single/isolated monitoring points); the cited assumptions are more or less sufficient. However, if the ambit extends to a macro-level with a single representative value from a multitude of H:W values, then the existing logics in literatures do not suffice (Gopinath et.al, 2014) thereby demanding further research in improvisation for better representation of canyon framework in terms of H:W, and the present study attempts to resolve this research lacunae.

Research Methodology

The research objective envisaged selection of 3 random locations encompassing heterogeneous mix of street canyon geometries ranging from wide to deep, in Bengaluru, India.

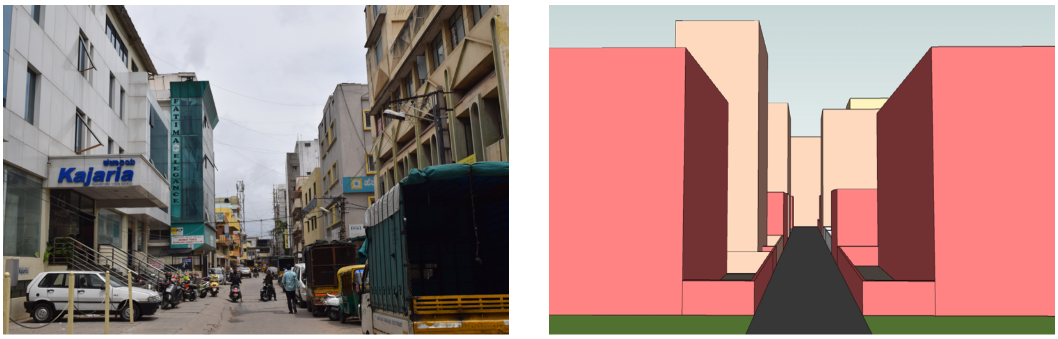
a b

Figure 1. An Avenue Canyon: a – A Typical Avenue Canyon; b – Representation of a typical Avenue Canyon



a b

Figure 2. A Regular Canyon : a – A Typical Regular Canyon ; b – Representation of a typical Regular Canyon



a b

Figure 3. A Narrow Canyon : a – A Typical Narrow Canyon ; b – Representation of a typical Narrow Canyon

a b

Figure 4. A Deep Canyon : a – A Typical Deep Canyon ; b – Representation of a typical Deep Canyon

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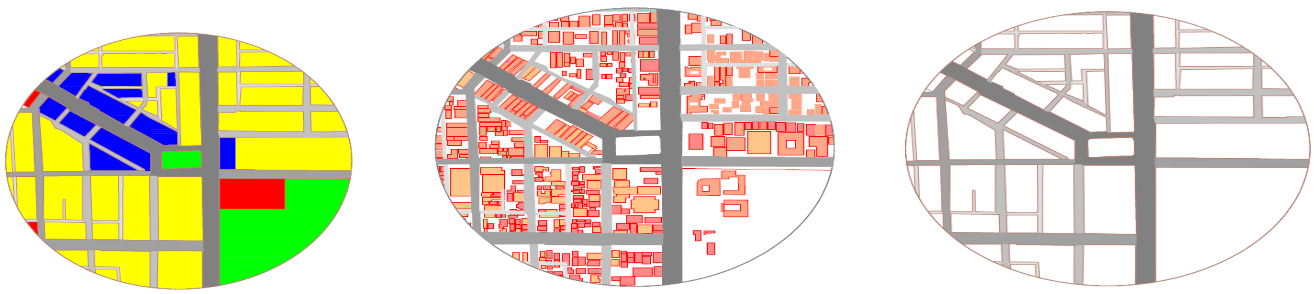
At each of these locations its land-use pattern and road network was mapped for a radius of 250m by supervised-classification to assist in extracting the canyon geometry features, namely building height and road width across all the streets. Further the canyon geometry across these stations was logically reasoned for Aspect Ratio with logics cited in literatures. Figures 5 to 7 highlight the extracted "urban-fabric" along with legend (Figure 8) for the 3 sample stations in Bengaluru (India).

Inferential Outlook

As may be observed, these extracted features showcase an outright preview of non-applicability for the prime assumption made in urban climatology i.e., "the streets are uniform and of infinite length, with same height buildings laid in a well-planned phased manner" (Nicholson, 1967). Primarily it is obvious that this prime assumption can only be applicable to township profiles with idealistic and well-planned canyons (Figures 5a, 5b & 5c); and eventually ignores contributions from within urban canyons with buildings that are scattered very close to each other (Figure 6a), or non-uniformly (Figure 7a), or with 'abrupt' canyons (Figure 9).

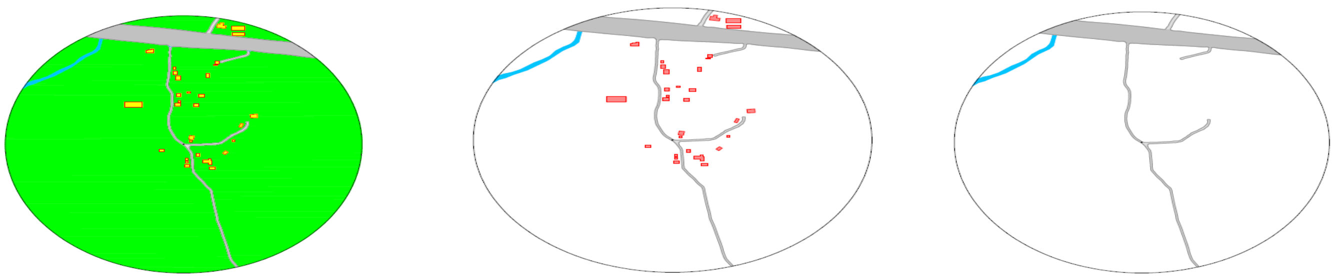


a b c

Figure 5 (a, b, c). Land-use, Building-height and Road Network of a well-planned locality in Bengaluru

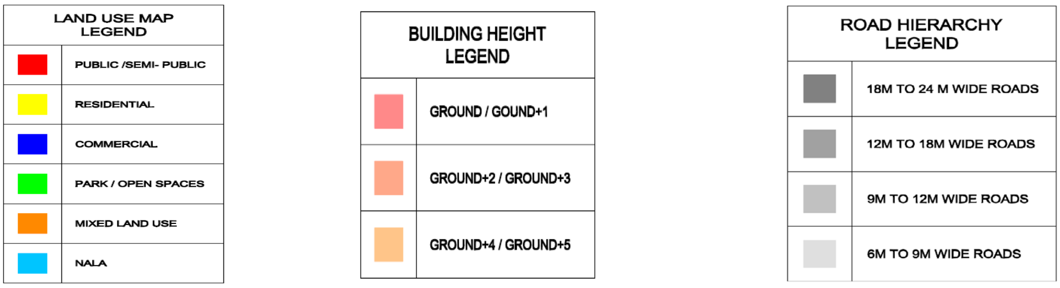
a b c

Figure 6 (a, b, c). Land-use, Building-height and Road Network of an ill-planned locality in Bengaluru



a b c

Figure 7 (a, b, c). Land-use, Building-height and Road Network of a peri-urban locality in Bengaluru



a b c

Figure 8 (a, b, c). Legends for Land-use, Building-height and Road Network for Figures 3, 4, 5

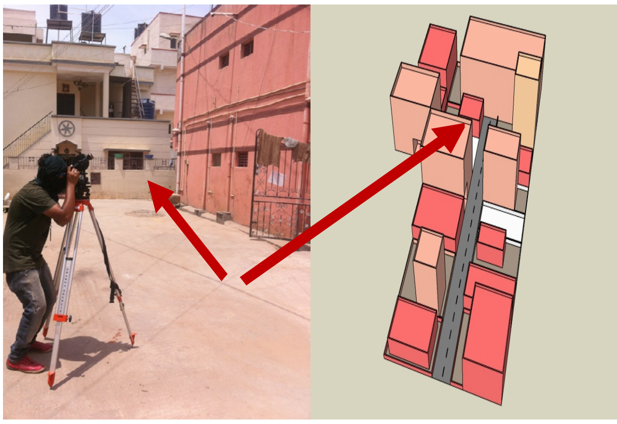


Figure 9. An Abrupt Canyon

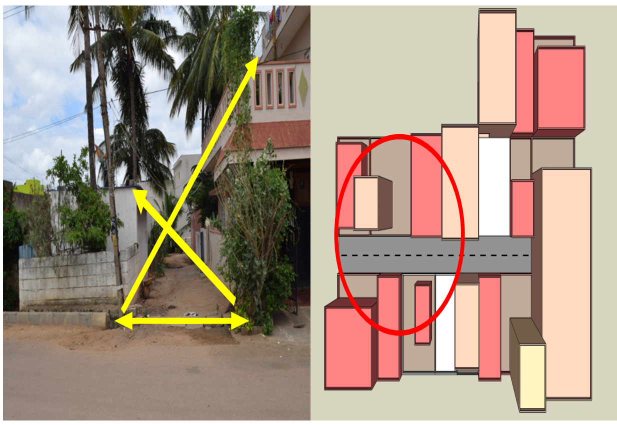


Figure 10. Sample inorganic Canyon Layout

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In the present urbanization context; the cited assumption falters especially in developing and underdeveloped nations wherein most cities does not project a well-planned profile in terms of their building framework (Figure 6b) or street alignments (Figure 6c). Hence, even the underdeveloped layouts are at a similar risk (Figure 7b and Figure 7c).

This argument was defended by extracting a random layout from the station depicting inorganic canyon profile. Processing of Figure 4c to obtain canyon profiling about each street; revealed that there were certain streets wherein the buildings were constructed as and at dead-ends (Figure 9), irregularly (Figure 10) and very often with variable heights (Figure 11). Hence these clearly depict violation of "uniform canyon & uniform building height" theory. Figure 12 also signifies the non-applicability of the definition of canyon that has been deftly incepted to urban studies as "a street with buildings lined up continuously along both sides" (Oke, 1981).

There exists streets in Bengaluru (India) wherein there are random open spaces facing the buildings, which due to legal reasons can sustain as so, for several years and decades to follow. This situation triggers two potential debates. First, under these circumstances can the classification of canyons as ‘short’, ‘medium’ and ‘long’ (Afiq et. al, 2012) be applicable? The length of canyon (L) and height ‘H’ illustrates the street canyon as Short when L/H=3, as Medium when L/H=5 and as Long when L/H=7 (Ahmad, 2005). Second, whether this urban situation can even be termed as a canyon? Geographically speaking canyon is “a shallow portion with steep abutments on ‘either’ sides”.

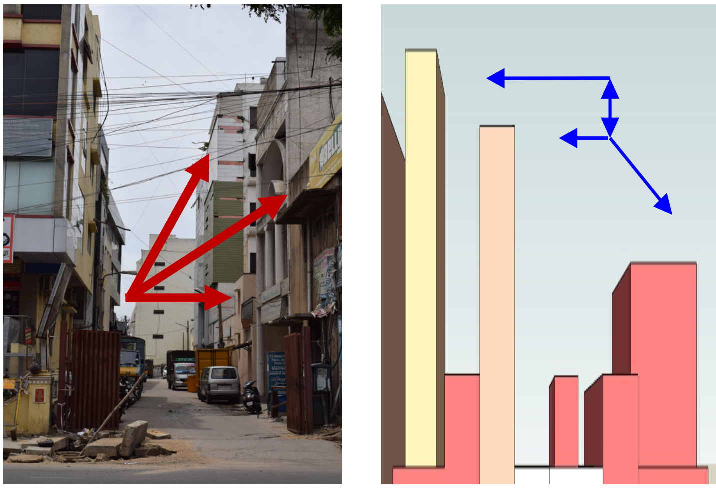

Figure 11. Irregular Building heights

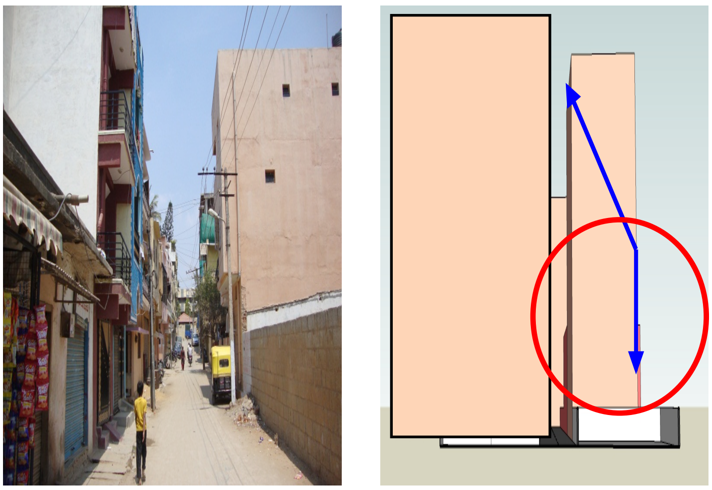

Figure 12. Tall buildings facing Empty site

For further introspection; the influence of a 'Deep' canyon in practicality can be marginalized due to differential heights of houses facing each other. For instance, the practical value of > 2 can be achieved if an undeveloped or vacant plot is facing a very 'tall' building as depicted in Figure 12. A further addendum to this issue is the dwarfing effect from two more site-based situations. Firstly, wherein a tall building exists behind an empty site that faces a street, as depicted in Figure 13. Secondly, when the building that's constructed behind an existing house is much taller than it, as depicted in Figure 14.

The practical act of shifting the observatory in researches have been oriented about randomly or approximating at the mid-point of home's total length. This is a concern since, the concept of fixed length of houses (dimension as measured along streets) is not a reality even in a modernized metropolitan such as Bengaluru (India) that hold plots of varying and irregular dimensions. Hence errors may creep in due to the relative deviation of the facing heights observed along oppositely facing buildings. This may be due to factors such as the wall-edges of oppositely facing houses are not at 0° with each other (Figure 15), or when the adjoining houses share a common load-bearing wall (Figure 16), and this situation may also arise in case of an empty site facing a house (Figure 12).

To summarise the findings from site-based conditions, the idealised site-based conditions are far from what the developed, developing and underdeveloped nations present under the guise of Urbanisation upon their townships (Rajesh Gopinath et.al, 2015). Consequently, the assumption for 'urban canyon' does not apply to all townships, and hence their application in climate research and air quality studies can introduce erroneous outcomes.

Therefore to overcome the limitations posed by complex urban configuration, the present study has developed a 'logic-based' improvised computation tool for any township irrespective of its 'canyon' geometry and components. The same is presented as Equation 1:

$$\frac{H}{W} = \frac{\left(\frac{\sum H_i \times L_i}{\sum L_i}\right)}{\left(\frac{\sum W_i}{n}\right)} \qquad (1)$$

Herein 'H_i' is the mean of 'derived' heights from all directions about each measuring point, 'L_i' is the distance between each observatory, 'W_i' is the width of full street for every observatory on the carriageway, and 'n' is the number of times the observatory has been shifted for taking 'angle of elevation'.

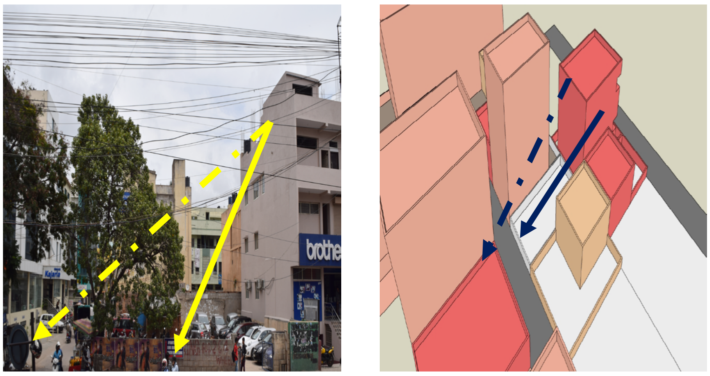

Figure 13. Dwarfing effect on empty site

Figure 14. Dwarfing effect on house

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$$H_i = (Tan\ \alpha_i \times W_i) + S_i \qquad (2)$$

The logic for deriving mean 'H' is depicted in Equation 2, wherein W_i refers to width of the road and 's_i' is the respective intercept. In literatures, the respective mean of H_1 and H_2, and the sum of W_1 and W_2, methodology facilitates to obtain Aspect Ratio (Oke, 1988b). The revised logic however has considered all directions irrespective of the presence or absence of buildings, and hence multiple angles of elevation (α_i) ought to be measured above 'line-of-sight'. Subsequently, the angles of elevation measured alongside axis of street could be or may not be 0° about each observatory, subjected to presence or absence of an abrupt canyon. This improvisation is based on the argument that an abrupt canyon has a skewed H:W and hence must be included wherever applicable. In this context, it is to be also noted that in certain literatures the value of 'W' was not practically quantified and was considered as uniform about each measuring point along the entire canyon (Chen-Yi Sun et.al, 2009). This is especially a setback in case of most streets in Bengaluru (India) wherein width of carriageway is dynamic.

The study also ignores the effect of edges (Equation 3). The improvised logic (Figure 18) overcomes these limitations, as it strives to shift observatory w.r.t. edge of buildings (Figure 17); and not mid-point of each building length. Also the methodology always maintains focal point on street itself; thereby overcoming hurdles offered by taller buildings overlooking empty sites and shorter buildings. Hence, this ensures contribution of the 'taller' house as well to H:W.

Figure 15. Sample Street View

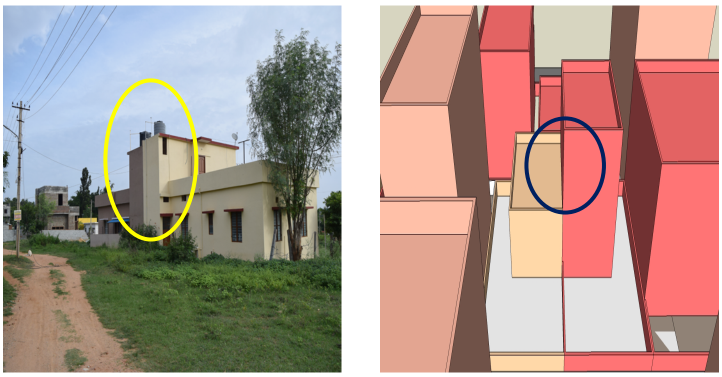

Figure 16. Sample Street View

Figure 17. Edge and site based measurements

Figure 18. Supervised Classification

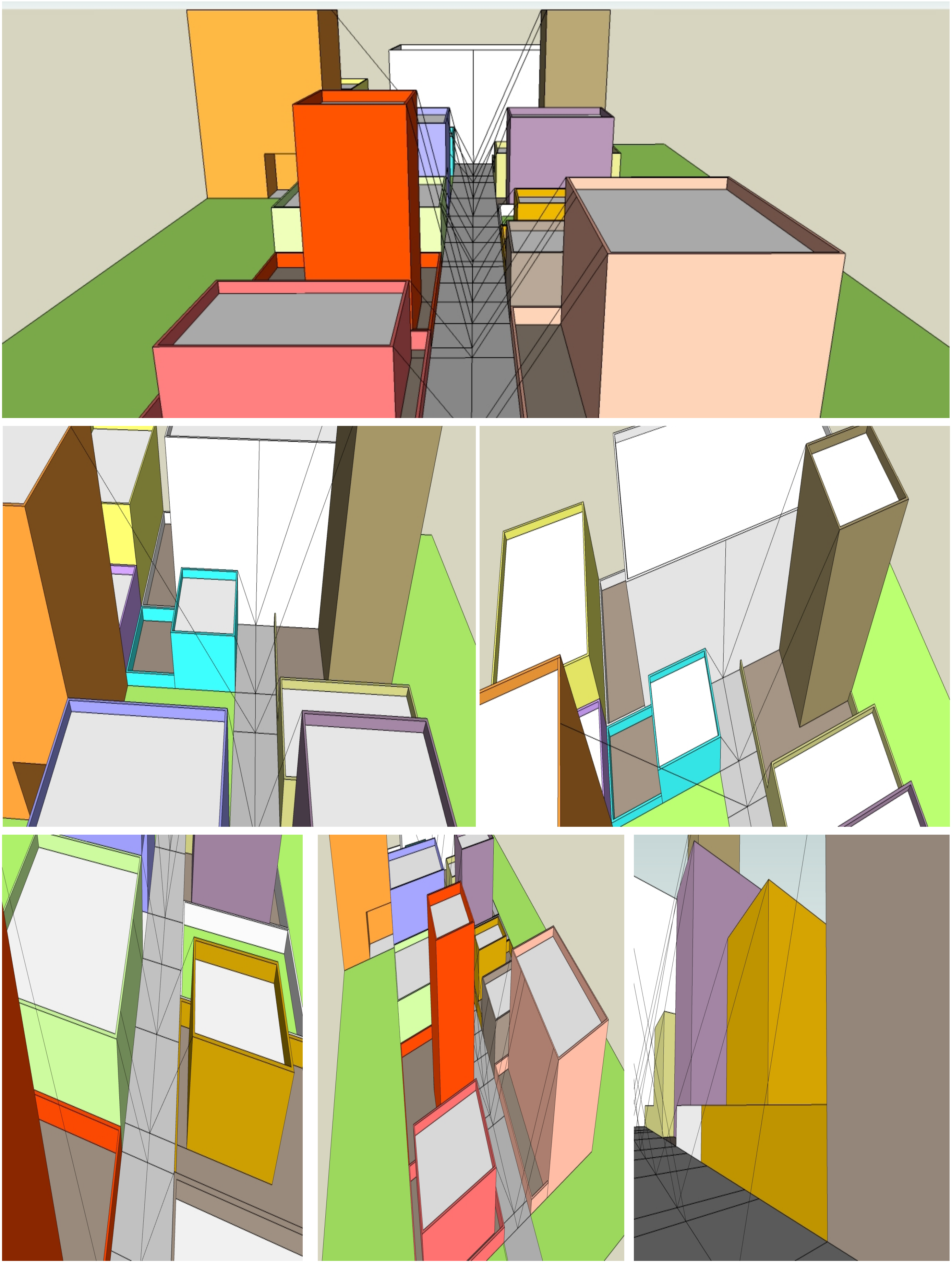

Figure 19. Compilation of artistic impression for Methodology as per Revised Logic by Authors

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$$H/W = (\Sigma Hi \times Di)/(\Sigma Di) / W \quad (3)$$

This revised logic and methodology needs to be judiciously worked upon when stations also have plots without pre-defined boundaries for creation of layouts. For this the latest town map or updated google satellite images needs to be procured and adequately analyzed for effective supervised classification on site (Figure 18). On a macroscale aspect, this was magnanimously ignored in the literatures, as the focus was laid only on developed urban canyons. Also the representative Aspect Ratio value for a station was often considered to be the largest value (Marlos et.al, 2013) thereby potentially reflecting at the effect of outliers. Herein by this new-logic, the representative Aspect Ratio shall be a mean of all H:W contributory values, and also the addition of undeveloped observatories will eventually dip the H:W value.

Conclusion

The H:W ratio basically describes how tightly or loosely spaced the buildings are with respect to their heights. Its determination techniques in the present urbanization scenario is bound by certain assumptions which falter as most cities across globe does not project a well-planned street profile. In the present research a logically-improvised analytical approach has been described which precisely estimates Aspect Ratio. The present research recommends this technique for a study of any magnitude; and encompassing just a street or even an entire city; as it's practically applicable to any site condition and does away with errors due to the 'idealistic' assumptions.

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CALCULATION OF FREIGHT RAIL TRANSPORT ENERGY EFFICIENCY BY BARTINI CRITERION L6T-4

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Abstract

The need to attract the squared speed as the major factor in forming the assessment of the energy intensity of the object motion and the medium resistance is noted. Author's approach to the calculation of freight rail transport energy efficiency is based on the use of Bartini Criterion L6T-4 and the entity of *Transfer* with *Tran* dimensionality. The energy efficiency factor of cargo movement is represented in the form of the ratio between the inevitable dissipation of the cargo movement energy and total costs of the energy supply of transportation, incurred by the railway complex.

As an example, the calculation of *Bothnia Line* railway complex freight transport energy efficiency was performed. Assessment of the railway complex freight transport energy efficiency at a speed of 120 km/h performed with the use of *Transfer* equals to η = 15.8 %. This allows assessing the technological paradigm of the railway transport as very far from the perfection.

Keywords

Rail transport, squared speed, *Transfer*, *Tran*, energy efficiency, life cycle.

Introduction

The objective of the author's studies (Kotikov, 2001, 2005a, 2005b, 2006a, 2006b, 2017) is to develop a new methodological approach to the assessment of energy efficiency of transport and provided transport services considering the squared speed of the transport object delivery. This approach is related to the development of Robert Bartini's ideas on *LT*-systematization of physics laws on the basis of a pair of coordinate parameters Length (*L*) – Time (*T*) (Bartini, 1965, 1974). The core of this approach is to form the ratio between the transferred transport output to the destination point (considering the squared speed of the freight transfer — transfer service S) and the specific embodied energy consumption of the transport complex for this freight transfer. Convergence of dimensionalities of two mentioned ratio variables is provided at the Transfer principle entity level with the dimensionality *L6T-4* (Aleinikov, 2007) of Bartini *LT*-table.

The case study that was examined in the work (Kotikov, 2017) with the example of freight delivery by means of a single truck KamAZ-5320 at a speed of 60 km/h has shown low energy efficiency (from the point of view of utilization of the full taken solar energy) of such freight transportation — up to 11 %.

In the present article, attempts to assess the energy efficiency of freight delivery by means of rail transport are made. Methodical extension with regard to the article (Kotikov, 2017) is the active use of the Life Cycle Assessment (LCA) for transport complex and execution of the design study covering energy costs of the main functional constituent elements of the complex: creation, technical support, working process (ISO 14040-2006 and 14044-2007; Arvesen, 2012; Chester, 2010; Jeswani, 2010; Kuczenski, 2016; Merchan, 2017; Yue, 2015).

Problems and methods

A fragment of R. Bartini *LT*-table (Bartini, 1965) in the interpretation of A. Aleinikov (Aleinikov, 2007) serves as a methodological canvas for the study (Kotikov, 2017) and is given in Figure 1.

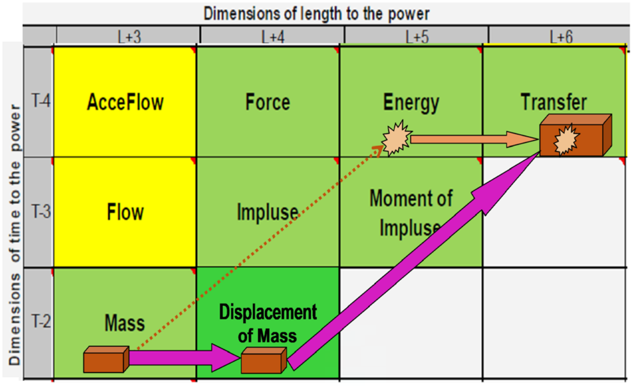

Figure 1. Part of matrix of physical laws as a canvas for analysis

The upper branch in Figure 1 (Mass – Energy – Transfer) reflects the freight mass transfer Mnet to the composition of the transport carrier, thus, forming the mass:

$M_{gross} = M_{net} + M_{carr}$. Here M_{carr} is a specific part of the transport carrier mass, associated with the freight mass M_{net}. Hereinafter, the mass M_{gross} with the energy consumption E_{Σ} is transferred over distance *L* to the destination point, thus, forming real value for *Transfer* S_{gross} index.

Here $E_{\Sigma} = E_{Emb} + E_{Supp} + E_{Input}$, where E_{Emb}, E_{Supp} and E_{Input} — utilization of specific parts of energy, respectively:

- embodied in the transport carrier and infrastructure;
- designed for technical support;
- input and directly consumed for transportation.

All three components are in shares associated with the mass Mgross and transportation distance *L*.

The dashed line from Mass to Energy means a relation between the Demand (object mass transfer) and Supply (availability of transfer means and infrastructure with preliminary embodied energy, as well energy for support and input).

The lower branch in Figure 1 (Mass – Displacement of Mass – Transfer) represents a pro-cess of the formation of the ideal, illusory assessment of transport service *Transfer* S_{net} (net-process) for abstract transfer of net-mass of the freight Mnet over distance *L* at speed *V*. Strictly speaking, the Customer is interested in the implementation of these factors (he is not interested in transfer of gross-mass M_{gross}, realized by an energy-intensive carrier under the conditions of the real transport complex).

Transfer of the transport object itself is absolutized. The object is transferred from the initial to the final point with conditional consideration of energy costs for overcoming of the Earth's gravitational field (proportional to the squared speed of the transfer). Everything connected with energy costs for manufacture of the transport carrier structure, erection of the traveling construct, overcoming of the carrier motion resistances, motion control, technical operation, etc. is put to the "upper branch". This provides a possibility of numerical assessment of the correlation between the transport object transfer by means of real transport under real conditions and the absolutized motion of the transport object which is the utmost effective to the geoid of the Earth.

The ratio $\eta = S_{net} / S_{gross}$ characterizes the level of excellence of the carrier type in the existing technological paradigm within the scales of the development of solar energy.

Let us make an attempt to calculate energy efficiency index η for rail transportations.

A distinctive feature of the calculation for the specific embodied energy of the transport complex using the author's method is the reduction of energy costs for the life cycle of all complex components to the life cycle of the transport carrier. Under consideration of the total mileage of the transport carrier within its life cycle, this provides a direct possibility to calculate energy costs for the performance of a particular transportation.

Case Study

Calculation for high-speed rail transport shall be conducted on the basis of the data of *Bothnia Line* located in the north of Sweden and put into operation in 2010 (Stripple, Uppen-berg, 2010; Trafikverket, 2017). It is a single-track high-speed rail line laid along the hilly and creeky coast from *Hoga Kusten* Airport through *Ornskoldsvik* to Umea.

The line allows movement at a speed of up to 250 km/h. However, operating speeds for freight traffic are limited at a level of 120 km/h (a calculation shall be performed for this speed below).

General characteristics of *Bothnia Line*:

- length of the trunk line — 190 km;
- total length of 140 bridges — 11 km;
- total length of 16 tunnels — 25 km;
- maximum axial load — 25 tons at a speed of 120 km/h;
- basic traction type — electric (95 %), 15 kV, 16 2/3 Hz AC;
- rolling stock — locomotive RE460 (*Loc 2000*) with standard cars;
- signal system — *European Rail Traffic Management System* (ERTMS);
- declarative annual volume of transported freight — 2,623,665 t/year;
- transport operation — 506,367,424 t-km/year;
- construction budget — 15 bln.

Warranty period for locomotive RE460 (*Loc 2000*) — 40 years. This time period shall be used as a basis for the Life Cycle Assessment, which, in its turn, shall define the energy efficiency index by analogy with operation (Kotikov, 2017).

As it can be seen from the general characteristics, Bothnia Line is sufficiently energy intensive object. The study (Stripple, Uppenberg, 2010) includes the detailed calculation of energy costs for construction (E_{Emb}), technical support of the infrastructure (E_{Supp}) and operation (E_{Input}) of this railway. These researchers performed an analysis of energy consumption as per the chain Extraction and processing of raw materials — Transportation — Manufacture of semifinished products — Transportation

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— Manufacture of structural elements — Transportation — Creation of *Bothnia Line* railway components.

The following components were included in the railway life cycle analysis:

1. Railway track foundation analysis.
2. Railway track analysis.
3. Railway electric power and control system analysis.
4. Railway tunnel analysis.
5. Railway bridge analysis.
6. Passenger station and freight terminal analysis.
7. Passenger and freight train traffic analysis.
8. Railway infrastructure analysis.
9. Railway passenger and freight transport analysis.

Let us provide the Life Cycle Assessment results with regard to energy consumption (Stripple, Uppenberg, 2010) in Figure 2. The figure shows general calculation results for the whole life cycle including energy consumption for construction elements, maintenance elements and all operation elements.

It can be seen that the entire system functioning life cycle requires energy consumption $E_{\Sigma LC}$ = 2.3 • 10^{10} MJ, including, for example, energy consumption for transport operations by means of constructed railway 1.21 • 10^{10} MJ (52.6% of all energy consumption).

The pre-defined annual volume of transported freight amounting to 2,623,665 t/year with forecast number of trains per year of 7,679 allows for the following: 2,623,665/7679 = 341.7 t/train. Thus, total transport operation of the locomotive for the whole life cycle on the railway *Bothnia Line* W_{LC} = 341.7 • 9,600,000 = 3,280,320,000 t•km.

The transport service *Transfer* of the size of 1 *Tran* is equal to the effective work spent for moving of a freight with the mass of 1 ton over the distance of 1 km with an average-travel speed of 1 km/h. Dimensionality of a unit of this service — t•km^3/h^2 (Kotikov, 2001, 2017).

Further, 1 *Tran* = 1 t•(km/h)^2•km = 1,000 kg × (1/3.6)^2 m^2/s^2 × km = 77.16 J•km. Thus, 1 *Tran* can be represented as the energy with the value of 77.16 J, necessary for moving a 1-ton transport object over 1 km under conditions of the Earth's gravitational field at a speed of 1 km/h.

Train *Re 460 (Loc 2000)* while moving 1 ton of freight at a speed of 120 km/h over a distance of 1 km, provides the volume of services $S_{net.km}$ = 1 × 1 × (120^2) = 14,400 *Tran* = 14,400•77.16 = 1,111 MJ/t•km. That is, the "absolutely net" energy costs related to the service for transportation of the named 1-ton freight for a distance of 1 km at a speed of 120 km/h are equal to $S_{net.km}$ = 1,111 MJ (and they do not depend on the type of the transport carrier, but charac-ter-ize the level of energy scattering during movement of 1 ton weight at a distance of 1 km in the gravitational field at a delivery speed of 120 km/h).

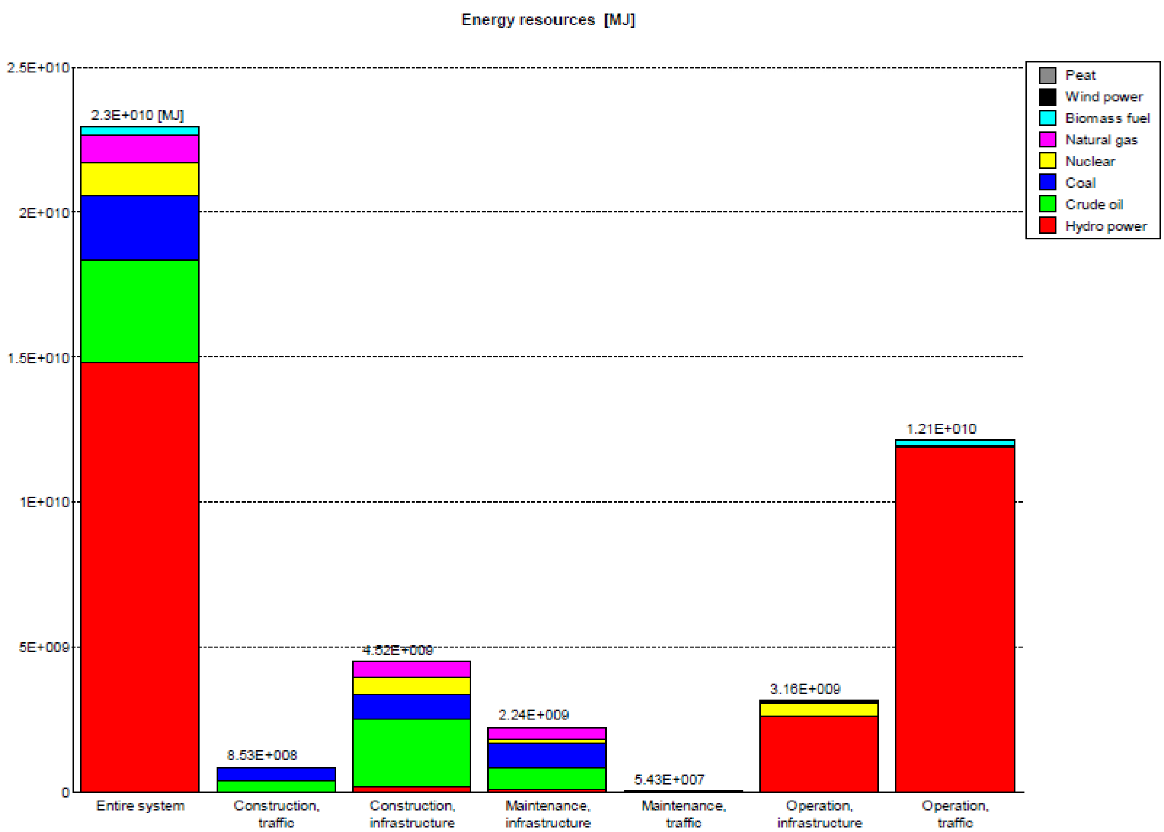

Figure 2. Use of initial energy resources for provision of the Bothnia Line railway life cycle

Then, total transport service of the railway for the life cycle (upon transportation of freights at a speed of 120 km/h) shall amount to S_{LC} = 1,111 MJ/t•km × 3,280,320,000 t•km = 3.644 • 10^9 MJ.

Thus, 2.3 • 10^{10} MJ of energy shall be embodied into the railway complex to render the transportation service — performance of transport operation of a value of 3,280,320,000 t•km with transportation of freights at a speed of 120 km/h (with the inherent dissipation of 1.111 MJ of energy for every ton of freight for every 1 km of transportation distance).

The value η = S_{LC} / $E_{\Sigma LC}$ = 3.644 • 10^9 MJ / 23 • 109 MJ = 0.158 = 15.8 % represents the energy efficiency index for the process of transportation at a speed of 120 km/h performed by the railway complex of *Bothnia Line*.

Conclusion

The obtained numerical value of energy efficiency of railway transport η = 15.8 % is rather conventional because the chosen example has sporadic character. Moreover, the provided study allowed, in the author's opinion, firstly, developing a methodical basis for the assessment of energy efficiency of transport objects on the basis of the entity *Transfer* of dimensionality L6T-4 and, secondly, comparing energy efficiency levels of two transport modes (as per the studies (Kotikov, 2006, 2017), for motor transport, η = 5–11%).

Apparently, levitation and space transport shall have high energy efficiency due to high transfer speeds and low resistances of motion environments. However, the data base for the corresponding assessments is of non-distinct character yet.

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METHODOLOGY FOR THE IMPROVEMENT OF CONTROL FUNCTIONS FOR TRAFFIC OF ROAD VEHICLES USING SYSTEMS OF THE AUTOMATIC RECORDING OF ADMINISTRATIVE VIOLATIONS

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Abstract

Relevant issues of the implementation of systems of the automatic photo-video recording of administrative violations in the field of ensuring road safety are considered. The promising directions of forming control functions for traffic of road vehicles (RV) using systems of the automated control of transportation vehicles are substantiated. A model of the development of multipurpose automated control systems for traffic of road vehicles is developed. Characterization of life cycle stages with regard to the existing systems of the automated photo-video recording of administrative violations in road traffic taking into account features of their operation is carried out.

A result of the carried out research is a developed technique for the optimal implementation of operational and technical control facilities in the field of ensuring road safety (RS), an obtained dependence of financial expenditures for the maintenance of the complex operability during service life, as well as of a level of decrease in the accident rate at specific sites of the street and road network or individual territorial entities of the Russian Federation.

Keywords

Automatic photo-video recording facilities, administrative violations in road traffic, automated control, life cycle, effectiveness, road vehicles.

Introduction

One of the criteria of transfer to a new level in the development of road vehicles and technology of their use is the wide-spread implementation of continuous monitoring and conditions of their operation. The development of smart transport systems (STS) is the most promising direction of scientific studies in the world. Such systems provide the possibility of the intelligent interaction with single road vehicles or with a traffic flow by means of information and communication technologies in order to improve the effectiveness of the above-ground transport use and enhance the improvement of road safety (GOST R ISO 14813-1-2011).

Methods

Ensuring road safety is a complex problem. The practice of the formulation of scientific and technical tasks and managerial decision making in this field gives evidence of the need of accounting the hierarchy of the structure of road and transport systems and technologies being implemented in them, time-to-time variability of street and road network characteristics, technical characteristics of the fleet of road vehicles and probabilistic nature of conditions of their functioning (GOST R ISO 14813-1-2011).

The road and transport accident rate depends on various reasons of technical, technological, organizational, and methodological nature. The analysis of statistical data confirms that reserves of the improvement of the mechanism ensuring road safety by the operational practice are far from being exhausted (Safiullin, Kerimov, 2016). TThe foregoing explains the relevancy of the task to bring the operational control system of the road and transport accident rate in compliance with principles of road safety system management.

A multiple regression analysis was carried out to analyze the influence of various factors on the number of road traffic accidents (RTA) in individual regions of the Russian Federation. The following were accepted as factors:

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- specific index, characterizing the ratio of the number of vehicles to the number of issued regulations on administrative violations (x_1), vehicle/unit;
- the amount of paid traffic tickets*10^5 (x_2), RUR;
- number of stationary automatic recording facilities (ARF) (x_3), pcs.;
- number of portable ARFs (x_4), pcs.;
- number of transportable ARFs (x_5), pcs.;
- number of mobile ARFs (x_6), pcs.;
- availability of a sign of ARF action (x_7), pcs.;
- population density in the region (x_8), person/km^2;
- transport density in the region (x_9), unit/km^2;
- mileage of automotive roads (x_{10}), km;
- population of the region*106 (x_{11}), persons;
- territory of the region (x_{12}), km^2;
- number of vehicles in the region (x_{13}), units.

The number of RTAs (Y) is accepted as the accident rate index. To analyze the interrelation between the considered parameters, the statistical data for 2014 characterizing the influence of various factors on road safety in regions under study are used: Moscow, Moscow Region, Saint Petersburg, Leningrad Region, the Republic of Tatarstan, Voronezh Region, Saratov Region (Table 1).

The analysis shows that factors x_9, x_{10} and x_{12} have the maximum influence on the RTA index. Factor x11 has the greatest influence, on which the RTA number depends by 88.4%, i.e. 0.942 = 0.884. Other factors are less significant (Safiullin et al., 2016).

Table 1. Statistical data characterizing the influence of factors on road safety

Factors	Voronezh Region	Moscow	Moscow Region	Saint Petersburg	Leningrad Region	Republic of Tatarstan	Saratov Region
RTA	3,555	11,312	9,042	8,222	4,074	5,399	3,101
x_1	3.62	12.23	5.90	1.76	1.13	7.82	0.99
x_2	1,127.65	5,490.53	1,100.32	329.66	255.88	2,892.65	224.65
x_3	39	708	186	66	66	201	26
x_4	62	301	15	22	22	296	49
x_5	1	5	0	0	0	0	0
x_6	1	0	8	0	0	17	1
x_7	38	70	89	75	75	39	42
x_8	44.60	4,822.10	160.70	3,566.70	21.02	56.57	24.66
x_9	13.72	261.50	18.22	521.63	8.13	9.14	6.73
x_{10}	11,602	737	27,229	531	13,662	22,267	11,799
x_{11}	2.33	13.11	7.33	5.13	1.70	3.84	2.50
x_{12}	52,216	2,511	44,379	1,439	83,008	67,847	101,240
x_{13}	716,388	656,766	808,847	750,623	682,385	620,688	681,453

Table 2. Correlation between various indices influencing road safety in regions under study

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12	Column 13	Column 14
Row 1	1													
Row 2	0.7006	1												
Row 3	0.6309	0.9661	1											
Row 4	0.7784	0.9146	0.9456	1										
Row 5	0.3582	0.8471	0.9028	0.7459	1									
Row 6	0.6170	0.7745	0.8657	0.9164	0.6247	1								
Row 7	-0.0135	0.3447	0.2029	-0.0014	0.4564	-0.3061	1							
Row 8	0.6576	0.0693	0.0303	0.2433	-0.3201	0.0869	-0.2376	1						
Row 9	0.7833	0.4937	0.5811	0.7048	0.3753	0.7284	-0.3927	0.3635	1					
Row 10	0.5812	0.0701	0.1305	0.2457	0.0165	0.2687	-0.3751	0.3776	0.8460	1				
Row 11	-0.2555	-0.0234	-0.2194	-0.3086	-0.1017	-0.5378	0.7263	-0.0178	-0.7904	-0.7518	1			
Row 12	0.9445	0.8273	0.7912	0.9123	0.5141	0.7981	-0.0420	0.4713	0.7691	0.4255	-0.2804	1		
Row 13	-0.8416	-0.5010	-0.4813	-0.5665	-0.2383	-0.5580	0.2044	-0.4632	-0.8621	-0.8174	0.5411	-0.7373	1	
Row 14	0.2554	-0.3062	-0.4788	-0.3000	-0.7354	-0.3066	-0.2250	0.6157	-0.0472	0.1898	0.1893	0.0763	-0.2757	1

It can be seen from the correlation table that some factors are correlated. For example, factors x_1 and x_2 have a relation estimated by the value of 0.96, and x_2 and x_3 — by the value of 0.95. Practically all factors have the positive correlation with RTAs, i.e. their increase leads to the increase in the RTA number.

Factors x_6, x_{10} and x_{12} have a negative correlation with RTAs, their increase leads to the decrease in the RTA number. A multiple regression analysis of the influence of factors x_8, x_9 and x_{11} on the RTA number was carried out according to the Stat graphics program.

Table 2 presents statistical characteristics of the obtained dependence: equation factors, estimates of their reliability by t-criterion, the analysis of the influence degree of factors on the dependent variable (i.e. coefficients of multiple determination).

All coefficients are statistically significant and describe the influence on the dependent variable by 94.4%.

Table 3. Statistical characteristics of the obtained mathematical model

		Standard	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
CONSTANT	1,326.05	698.759	1.89772	0.1540
x_8	-1.09546	0.528357	-2.07333	0.1298
x_9	10.5527	3.81843	2.76361	0.0699
x_{11}	1,033.04	172.974	5.97221	0.0094

The mathematical model has the following form:

$$y = 1326{,}05 - 1{,}09546 * x_8 + 10{,}5527 * x_9 + 1033{,}04 * x_1 \quad (1)$$

By the degree of influence, factors have the following arrangement: x_8, x_{11}, x_9. The influence of factors is statistically significant.

The influence of factors x_1, x_2, x_3 *and* x_8 on RTAs has also a good statistically significant model:

$$y = 2379{,}24 + 1543{,}63 * x_1 - 3{,}9134 * x_2 + 9{,}4035 * x_3 + 1{,}0307 * x_8 \quad (2)$$

Statistical characteristics of the obtained model are presented in Table 4.

Table 4. Statistical characteristics of the mathematical model

		Standard	*T*	
Parameter	*Estimate*	*Error*	*Statistic*	*P-Value*
CONSTANT	2,379.24	377.889	6.29614	0.0243
x_1	1,543.63	193.139	7.99232	0.0153
x_2	-3.91341	0.472106	-8.28924	0.0142
x_3	9.40355	3.09578	3.03754	0.0934
x_8	1.0307	0.153725	6.70487	0.0215

The developed mathematical model shows the dependence of the RTA number on factors x_1, x_2, x_n. The specified factors affect the management, technological and methodological aspects of the problem — tightening of road traffic regulations (RTR). The analysis of the obtained model shows that the main contribution to the accident rate is made by the number of registered transportation vehicles in a specific region — x_1. The specified factor is considered in the model through a standard indicator — the number of vehicles per one photo-video recording (PVR) device. The recommended provision of the region with the automatic recording facilities is one complex per 6,500 transportation vehicles (Safiullin, Vorozhejkin, 2016; Kerimov, 2015).

Main Body

Life cycle stages of the facilities of automatic photo-video recording of RVR violations are presented in Figure 1.

The developed diagram of the life cycle of automatic photo-video recording facilities includes four stages (Kerimov, 2015).

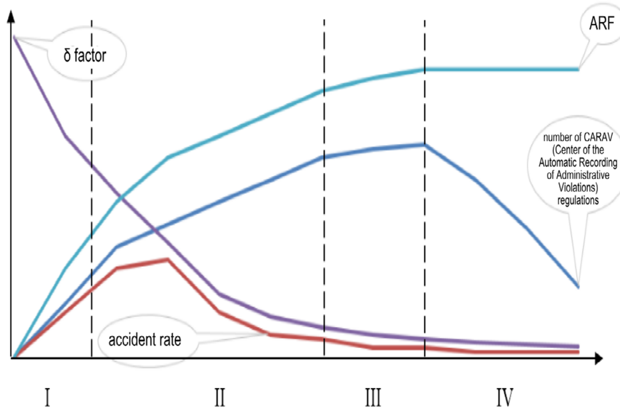

Figure 1. ARF life cycle diagram

Stage 1 — "local influence on the accident rate", whereon the increase in a number of systems of photo-video recording and debugging of their operation take place. At this stage, a noticeable growth of the revealed violations occurs. A result is a decrease in the accident rate in places of system location, however, the influence on the total accident rate turns out to be insignificant (Safiullin, Kerimov, 2016).

Stage 2 — "beginning of the system influence on the accident rate", at which ARF have stable operation. A number of systems is constantly increasing, a choice of places for installation is carried out on the basis of the focal analysis of RTAs. The detectability of violations of road traffic regulations increases. The influence on the accident rate on street sections equipped with ARFs is observed. The application of simulants and signal simulators is possible to improve the effectiveness of the ARF system at this stage. It is also necessary to apply operating systems of photo-video recording periodically in places of their use.

Stage 3 — "period of increase in the system influence of ARFs on the accident rat". A gradual decrease in the

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number of revealed administrative violations is observed at this stage, since the level of awareness of drivers of wide-spread control of traffic increases. As a consequence, the accident rate decreases. At the same time, the increase in the number of ARFs continues. Systems are installed in all newly revealed accident clusters and potentially dangerous locations and reach a required value at the end of the stage.

Stage 4 — "period of stable operation of a photo-video recording system", whereby the stabilization of all indices occurs. Therefore, further increase in the number of photo-video recording systems is inexpedient (Safiullin et al., 2016). When implementing these facilities in regions of the Russian Federation, flooding with photo-video recording systems is observed, and afterwards their effectiveness decreases. Accordingly, tasks and targets of their application as well as possibilities of these systems have to be changed. In this regard, the further development of the ARF interaction with smart on-board systems of automotive vehicles is of great importance.

An information and analysis system (IAS) and recommendations for its development are proposed to improve information exchange between smart on-board systems of automotive vehicles and automatic photo-video recording facilities (Figure 2).

The information and analysis system of interaction of smart on-board transport systems (SOBTS) with automatic photo-video recording facilities will allow ensuring the effectiveness of road vehicle use, improve road safety, solve social tasks on transportation performance and reduce environmental loads due to the extension of ARF functional capabilities (Safiullin,Vorozhejkin, 2016). A mechanism of the interaction of this system with the transportation vehicle is shown in Figure 3.

The mechanism of interaction lies in the transfer of two information flows from RVs to the IAS. The external flow of

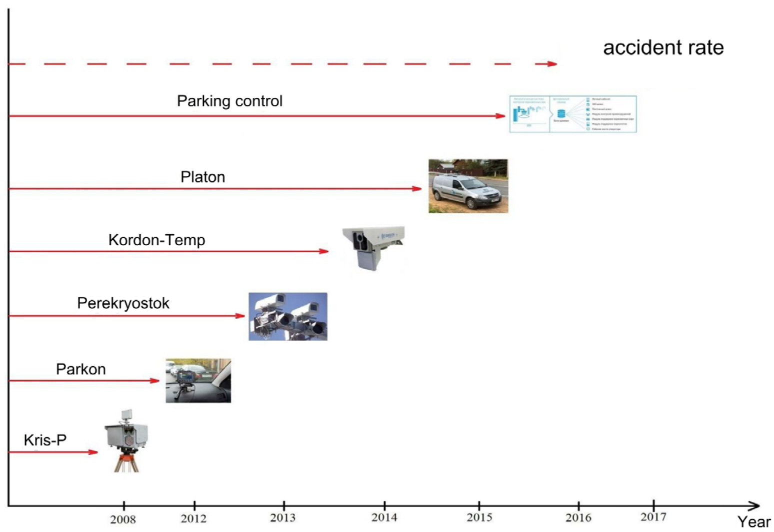

Figure 2. Development of automatic photo-video recording facilities in the territory of the Russian Federation

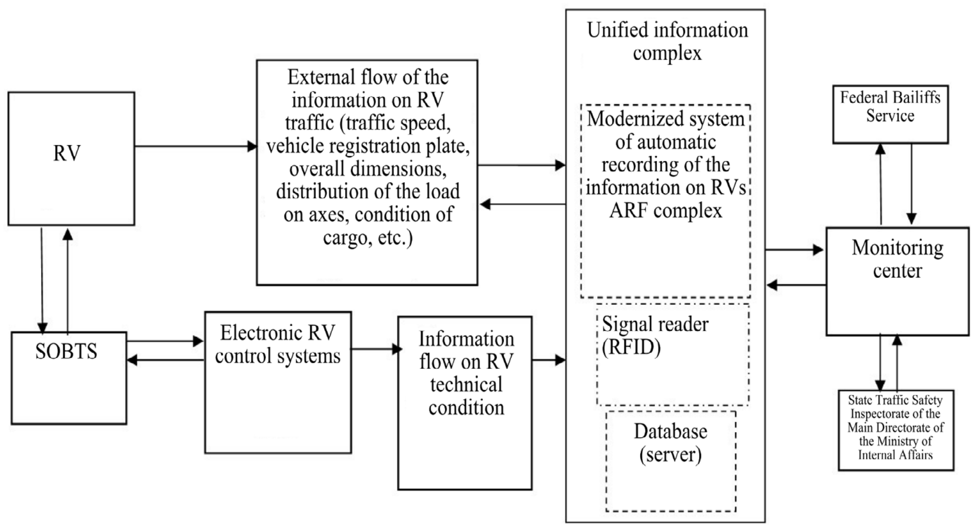

Figure 3. Mechanism of the interaction of the information and analisys system with road vehicles

information carries data on the vehicle movement (namely, vehicle registration plate, movement speed, RV dimensions, etc.). After information processing by the system and verification according to databases of state authorities, the system, in its turn, transmits a backward signal to a RV, which can carry information about probable discomfort traffic on the way of further running, a warning about the necessity to reduce the speed, a notice about violation of parking rules, etc. (Safiullin, Belikova, 2015).

Table 5. Functional capabilities of the multipurpose information and analysis system

Function	Description
F_1	Compulsory speed limitation
F_2	Verification according to databases of RVs being on the wanted list
F_3	Compulsory stop upon actuation of a red traffic light
F_4	Transfer of the identification number
F_5	Transfer of the information about the RV driving speed at the given moment
$F_{5'}$	Transfer of the information about the RV driving speed for a certain section
F_6	Transfer of the information about the RV technical condition

The difference of this system from the existing ones lies in the possibility of carrying out the information exchange in the duplex mode and exercising influence on RVs, which will make these systems much more effective in comparison with the systems, which are functioning at present.

Table 6 presents existing and prospective functional capabilities of automatic photo-video recording facilities in the territory of the Russian Federation.

Table 6. Existing and prospective functional capabilities of automatic photo-video recording facilities

Functions of automatic photo-video recording facilities (existing)	Functions of automatic photo-video recording facilities (prospective)
F_5	F_1
$F_{5'}$	F_2
	F_3
	F_4
	F_6
	F_n

On the basis of the analysis of these functions, a model of the development of multipurpose systems of automated control of RV traffic was developed, which has the following form (Safiullin, Kerimov, 2017):

$$W_1 = f(F_5, F_5) \rightarrow W = f(F_1, F_2, F_3, F_4, F_5, F_{5'}, F_6, \ldots, Fn), \quad (3)$$

where W_1 — function of parameters operating at the given moment; W — function of those parameters to be reached (prospective).

The assessment of the influence of facilities of automatic recording of violations of road traffic regulations on the accident rate can be carried out according to the developed diagram of the sequence of the determination of ARF application effectiveness presented in Figure 4. The following designations are accepted in the diagram:

C_{op} —ARF operation cost, RUR;

C_C — cost of one ARF complex, RUR;

η_{OR} — rate of allocations for M (maintenance) and OR (operating repair) of ARFs per year, %.

A_{ic} — ARF assembly of ARFs, installation and adjustment of a complex, RUR;

S_{op} – salary of operators, RUR;

S_{tech} – salary of technicians, RUR; S_{dr} — salary of RV drivers, RUR;

P — the number of ARF, pcs.;

C_M — cost of annual maintenance, RUR per year;

i – rate on credit, %; n — service life, per year

SI_{SCCC} — specific capital investments for the construction of a speed control complex, RUR;

$SI_{ARFinstallation}$ — specific capital investments for the installation of an ARF, RUR;

k_2 — coefficient of the increase in expenditures for ARFs;

E_{SIGN} — expenditures for a road sign, RUR;

$E_{SIGNinstallation}$ — expenditures for the installation of a road sign, RUR;

m — the number of road signs, pcs.

D^{b}_{RTA} — damage from RTA in the basic version, RUR;

N^{c}_{RTA} — annual RTA number in the basic version, units;

D^{p}_{RTA} — damage from RTA in the projected version, RUR;

N^{p}_{RTA} – annual RTA number in the projected version, units;

$\delta_1, \delta_2, \delta_3$ — ARF influence on road safety according to the following rates: RTA number, the number of wounded, the number of fatalities.

Conclusion

In order to assess the influence of the automatic recording system on road safety, it is necessary to carry out the study at two levels: at the first level, it is necessary to carry out the absolute assessment of RTAs; at the second level, it is necessary to analyze the influence of automatic recording systems on the RTA number from the viewpoint of a place of RTA occurrence and types [5]. The implementation of "the correlation recording system" allows assessing in practice the efficiency of use of various technical facilities of automatic recording of violations of road traffic regulations, as well as a degree of their influence on

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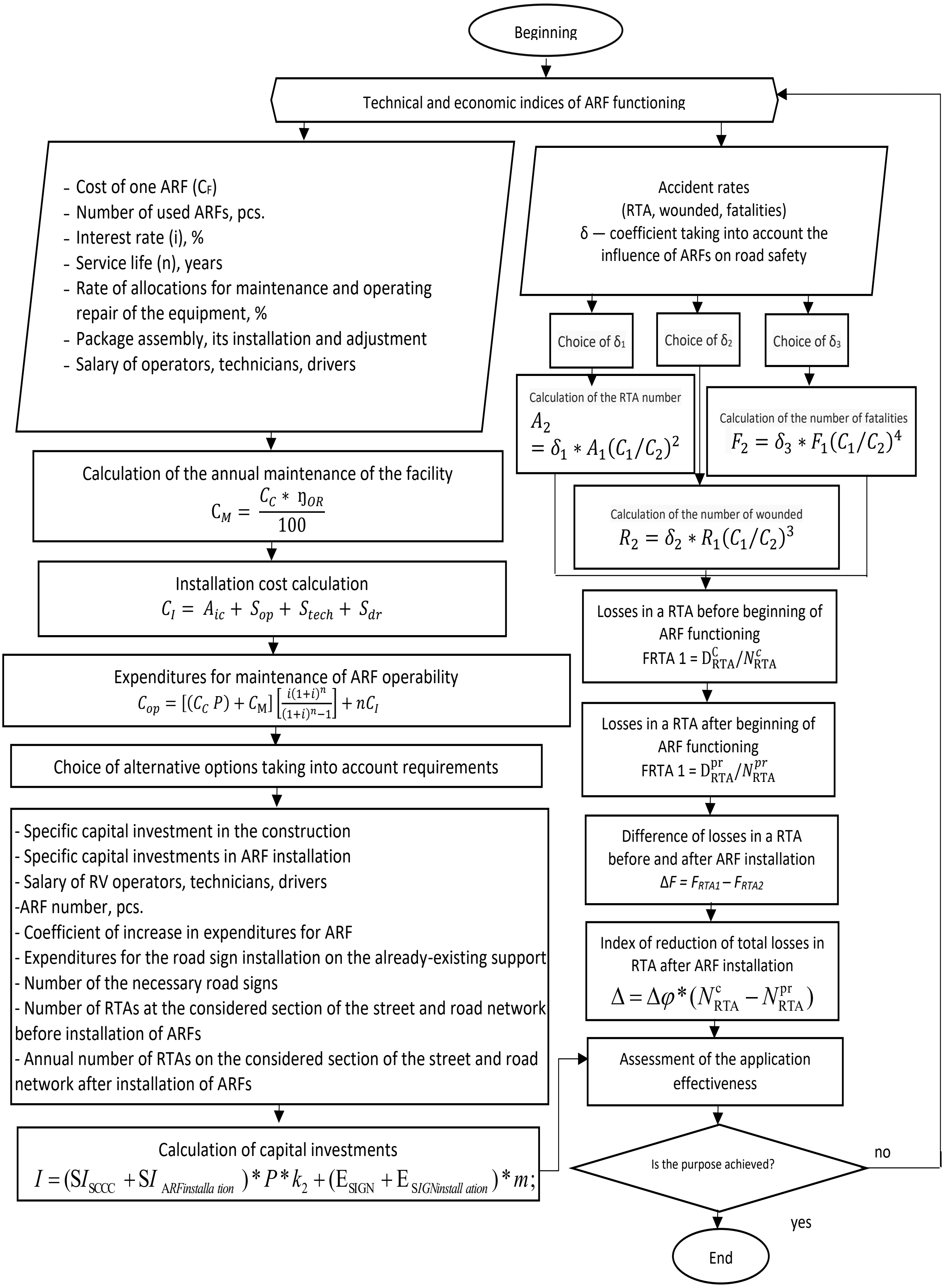

Figure 4. Diagram of the sequence allowing to determine the effectiveness of the application of automatic photo-video recording facilities for recording of administrative violations in road traffic

the accident rates. The formulated scientific and technical task is solved with the use of methods and software tools implementing the developed systemic criterion (Safiullin et al., 2015; Safiullin et al., 2016; Safiullin, Kerimov, 2017).

Summary

Based on the carried out study, the methodological approaches for the improvement of traffic control functions when using automatic recording systems, determining their effective application, are defined. The mathematical model of ARF effectiveness assessment upon realization of administrative procedures for traffic control in order to improve road safety is developed.

The ARF life cycle is determined. The information and analysis system of the interaction of smart on-board systems of automotive vehicles with automatic photo-video recording facilities is developed.

The specified system will allow determining the development model of multipurpose systems of automated traffic control to ensure the effectiveness of the use of the above-ground transport due to the extension of ARF functional capabilities.

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IMPROVEMENT OF THE SYSTEM FOR ACCOUNTING OF PARAMETERS DURING CONSTRUCTION OF MOTOR ROADS

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Abstract

In the article, a necessity to improve the system for accounting of parameters for additional factors of technical condition of vehicles and road environment facilities allowed for during design and construction of motor roads is substantiated. A procedure for the determination of circumstances and causes of road accidents, taking into account transport, technical and operating conditions, has been developed. An improved algorithm of expert examination with the application of a non-destructive method with use of diagnostic equipment of dynamic impact is offered.

The accounting system includes an algorithm of expert examination of road accidents which provides parametric characteristics of objects and conditions for their existence to ensure procedure functioning. Criteria to identify "weak"-sections of motor roads are proposed. A model for the implementation of expert examination taking into account parameters of the subsystem "Vehicle–Road" is proposed. A possibility to determine the risk of road accidents, "weak" sections of operated motor roads, development of an automated data base on motor roads, application of research results in expert opinions upon analysis and reconstruction of road accidents is substantiated.

Keywords

Motor road, road surface, vehicle, parameters, expert examination of road accidents.

Introduction

Improvement of the system for parameters accounting in construction of motor roads is based on the introduction of additional factors of technical condition of vehicles and road environment facilities allowed for during design and construction of motor roads in expert examination. Expert examination represents a set of successive systematic theoretical and practical methods or actions aimed at identifying the causes and factors that led to a failure in the Driver–Vehicle–Road–Environment (DVRE) system. A failure in the system means operating trouble of one of the key components, i.e. Vehicle, Driver, Road or their combinations, including the Environment component, which, in their turn, cease to perform their assigned functions partially or totally, leading to violations in safe operation of the entire system. Analysis of operating troubles or failure prevention are possible through qualitative expert examination. Scientific studies of some parameters of the subsystem "Vehicle–Road" condition, performed by scientists Nemchinov M. V., Vasiliev A. P., and Domke E. R., are aimed at braking performance and characteristics of wheel adhesion with the road surface during operation and reconstruction of the latter (Nemchinov, 1985; Vasiliev, 2005; Domke, 2012; Kurakina, Evtyukov, 2015). Scientists Suvorov Yu. B., Kikot I. M. and others (Suvorov et al., 1990) were engaged in diagnostic studies of elements of operated motor roads at sections where road conditions affected traffic safety. Kiryukhin G. N. proved the relevance of road surface diagnostics and determination of traffic flow characteristics with the use of a wide range of devices and equipment for testing and diagnostics of motor roads (Kurakina, 2017; Kurakina et al., 2017).

Expert studies are supported by various procedures, algorithms, methods, strategies, techniques and equipment, depending on the purpose of the expert study, its complexity and the number of questions posed. Subjects of various researches are reviewed in works of such scientists as Borovskiy B. E., Ilarionov V. A., Evtyukov S. A., Zamarayev I. V., and Stolyarov V. V. (Ilarionov 1989; Evtyukov, Vasiliev, 2012). However, during construction, the system of accounting for the main parameters of the subsystem "Road" is specified by regulatory documents of the construction industry. Mutual complex study of the condition of "Vehicle–Road" subsystem parameters should be carried out at all stages of construction, operation and reconstruction in order to prevent emergency conditions (Kurakina, Evtyukov, 2017; Kurakina et al., 2017; Kurakina, 2014a; Kurakina, Evtyukov, 2014).

The potential for improvement of the system for parameters accounting during construction of motor roads is aimed at applying the procedure of road and transport expert study in a non-destructive manner. Application of the proposed procedure is also possible on operated sections of motor roads. The field of its application includes road accident expert examination and technical expert examination of motor vehicles, as well as analysis of road surface condition parameters and determination of its residual life.

Subject, tasks and methods

The study subject is parameters of ground transport and road infrastructure facilities' condition.

The study tasks include the following:

- obtaining actual data on the parameters of the "Vehicle–Road" subsystem condition with the use of modern automated multifunctional diagnostic equipment;
- development of a procedure and its algorithm to improve the reliability of determining circumstances and causes of road accidents, and, therefore, the accuracy of calculations in expert opinions;
- identification of "weak" sections of motor roads;
- development of a data base on motor roads with account for the studied parameters of the "Vehicle–Road" subsystem condition, affecting the risk of road accidents, determining places of possible accidents, and the development of activities for their timely prevention.

Methods for implementing the set tasks include methods of analysis of properties and opportunities for improvement of complex multifunctional systems, such as static and systematic methods, mathematical methods, computational methods, probability theory, data processing theory with regard to research results, and information technologies.

Results and discussion

In order to provide methodological support of the road accident expert examination algorithm, it is necessary to take into account parametric characteristics of objects and conditions for their existence to ensure procedure functioning. First of all, it is necessary to consider that expert studies are carried out on the roads of categories IA, IB, IC, II, III, IV, V and take into account characteristics and conditions established mostly during the construction of motor roads:

- geometry of road environment facilities (GREF);
- transport and operating conditions (TrOC);
- technical and operating conditions (TechOC);
- characteristics of road infrastructure facilities (CRIF).

Obtaining information about GREF, TrOC, TechOC, and CRIF is possible be means of analytical, diagnostic and computational methods of obtaining and processing parametric characteristics (Kurakina, 2014b, 2014c, 2015).

Mathematically, the model of expert study procedure implementation with account for parameters of the "Vehicle–Road" subsystem can be represented in the following form:

$$\mathrm{Y} = f(\mathrm{X}) \tag{1}$$

where X — parameters applied and obtained during the study.

Taking into account methods of obtaining and processing of parameters during the study, the value X of the sum of all characteristics and conditions can be represented in the following form:

$$\left\{ \begin{array}{l} \sum\limits_{i=1}^{n} X^{A} = f(x_i^{A}) \\ \sum\limits_{i=1}^{n} X^{D} = f(x_i^{D}) \\ \sum\limits_{i=1}^{n} X^{C} = f(x_i^{C}) \end{array} \right\} \tag{2}$$

where $f(x_i^A)$ are parameters, their characteristics and conditions determined analytically, i.e. $f(x_i^D)$ — diagnostically and $f(x_i^C)$ — with computational methods, i – the number of obtained values of the studied parameters.

Taking into account 2 equation, we obtain a set of values of parameters, obtained during road accident investigation with analytical, diagnostic and computational methods.

Therefore, taking into account 1 equation and parameters to be determined, the accounting during expert study, involving numerous parameter values, will be characterized by parameters involved in the study.

Evaluation of parametric characteristics of objects and conditions represents an expert opinion on the results of the study aimed at the following:

- determination of a technical possibility to prevent road accidents;
- compliance of the obtained values of vehicle and road infrastructure condition parameters with the requirements of legal documents;
- identification of "weak" sections of motor roads;
- determination of road accident risks;
- development of an automated road data base (ARDB) on "weak" sections.

The studied parameters of the technical condition of vehicles and road infrastructure are grouped into blocks included into the general algorithm of the expert study in a non-destructive manner.

GREF

BLOCK A

Number of traffic lanes

Shoulder-to-shoulder width and width of shoulders

Parameters of road environment facilities	Highway	Expressway	Ordinary motor roads (low-speed road), categories					
	IA	IB	IC	II		III	IV	V
Total number of traffic lanes, pcs.	4 and more	4 and more	4 and more	4	2	2	2	1
Width of the traffic lane, m	3.75	3.75	3.75	3.5	3.75	3.5	3.0	4.5
Width of the shoulder, m	3.75	3.75	3.75	3.0	3.0	2.5	2.0	1.75
Width of the pullover near the shoulder, m	0.75	0.75	0.75	0.5	0.5	0.5	0.5	–
Width of the hard shoulder, m	2.5	2.5	2.5	2.0	2.0	1.5	1.0	–
Minimum width of the central dividing strip without guardrails, m	6.0	6.0	5.0	5.0	–			
Minimum width of the central dividing strip with guardrails along the road center, m	2 m + guardrail width							
Width of the safety pullover near the dividing strip, m	1.0							

Width of the pullover

Width of the hard shoulder

Width of the central dividing strip

Figure 1a. Block A parameters: number of traffic lanes, width from shoulder to shoulder and shoulder width, width of the pullover, hard shoulder and dividing strip

GREF

Condition and materials of margin strips

Conditions for margin strips

- sections with the traffic intensity exceeding 6 ths. vehicles/day;
- sections with complex soil and hydrological conditions;
- populated localities;
- approaches to places of intersections and junctions of roads at the same level;
- sections of roads with insufficient visibility;
- curves of minimum radius and less than minimum radii in plan, maximum longitudinal slopes;
- exits and entrances to intersections and junctions of roads at different levels and approaches to them;
- snow covered areas;
- wind-risk and fog-risk areas.

Condition and materials of stopping lanes

Conditions for stopping lanes

- populated localities and approaches to them;
- approaches to intersections and junctions at the same level;
- approaches to artificial structures;
- road accident concentrations according to road conditions;
- locations of roadside services, observation platforms and recreational areas, near monuments, etc.;
- wind-risk and fog-risk areas;
- curves less than the minimum radius, with longitudinal grades exceeding maximum values.

BLOCK A (continued)

Parameters of the road environment facility	Requirements to the condition of margin strips and stopping lanes			Margin strip materials
	Road category	Width of the margin strip, m	Length of the stopping lane, m	
Margin strip	I–II	0.75	≤ 100	Binding materials, broken stone, gravel, grass
Stopping lane	III–IV	0.5	≤ 100	
	V	≤ 0.5	–	

Figure 1b. Block A parameters: condition and materials of the margin strip and stopping lane

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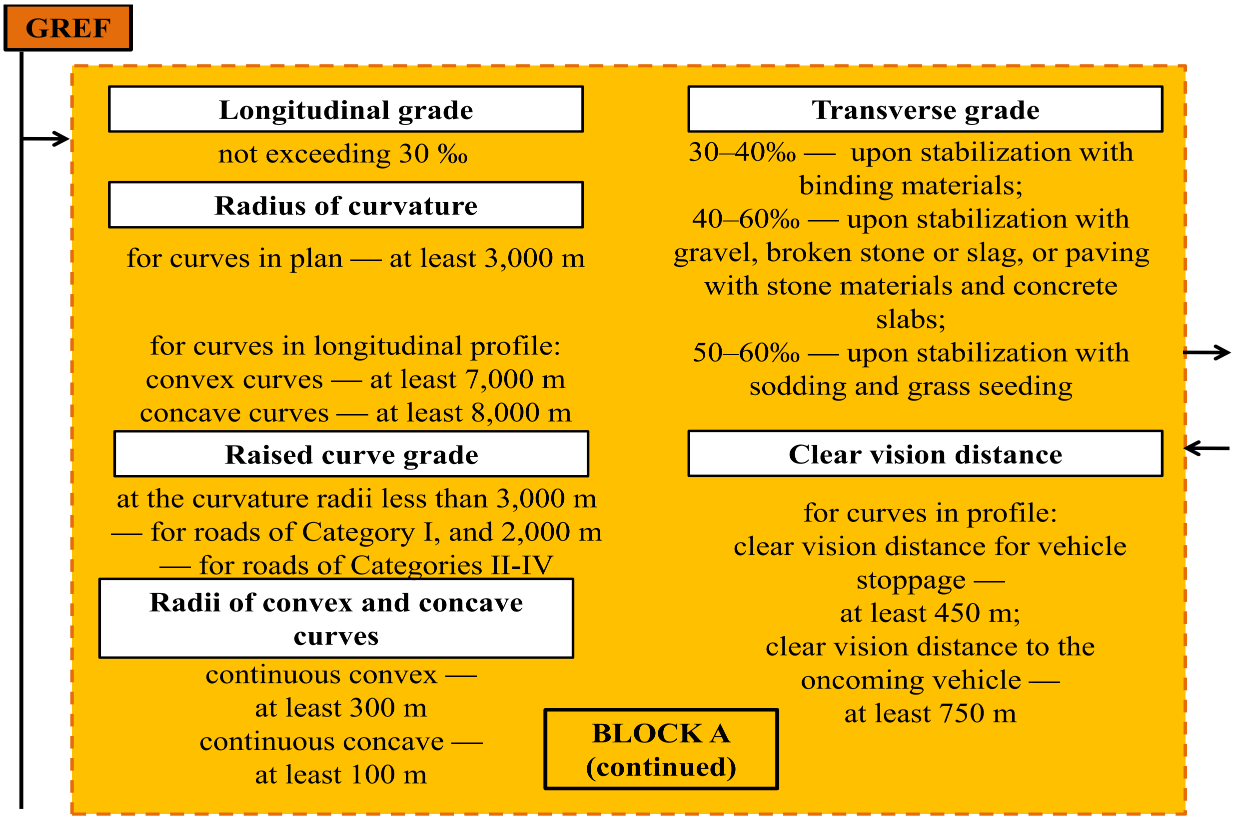
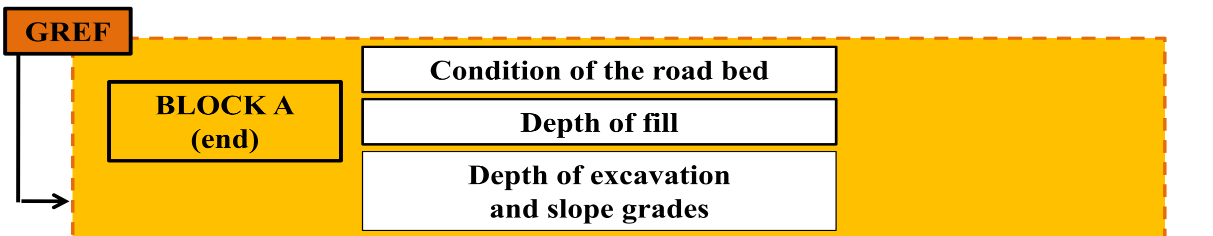


Figure 1c. Block A parameters: longitudinal and transverse grades, raised curve grade, curvature radius, convex and concave curves, clear vision distance



Soils	Slope height, m	Maximum slope grade
Rocky:		
weakly efflorescent	Up to 16	1:0.2
Easily efflorescent:		
non-softenable	Up to 16	1.05–1:1.5
softenable	Up to 6	1:1
	More than 6, up to 12	1:1.5
Macrofragmental	Up to 12	1:1–1:1.5
Sandy, clayey homogeneous of hard, semi-hard and low-plasticity texture	Up to 12	1:1.5
Fine barkhan sands	Up to 2	1:4
	From 2 to 12	1:2
Eolian soil	Up to 12	1:0.1–1:0.5 (arid area) 1:0.5–1:1.5 (beyond the arid area)

Figure 1d. Block A parameters: condition of the road bed, depth of fill, depth of excavations, slope grade

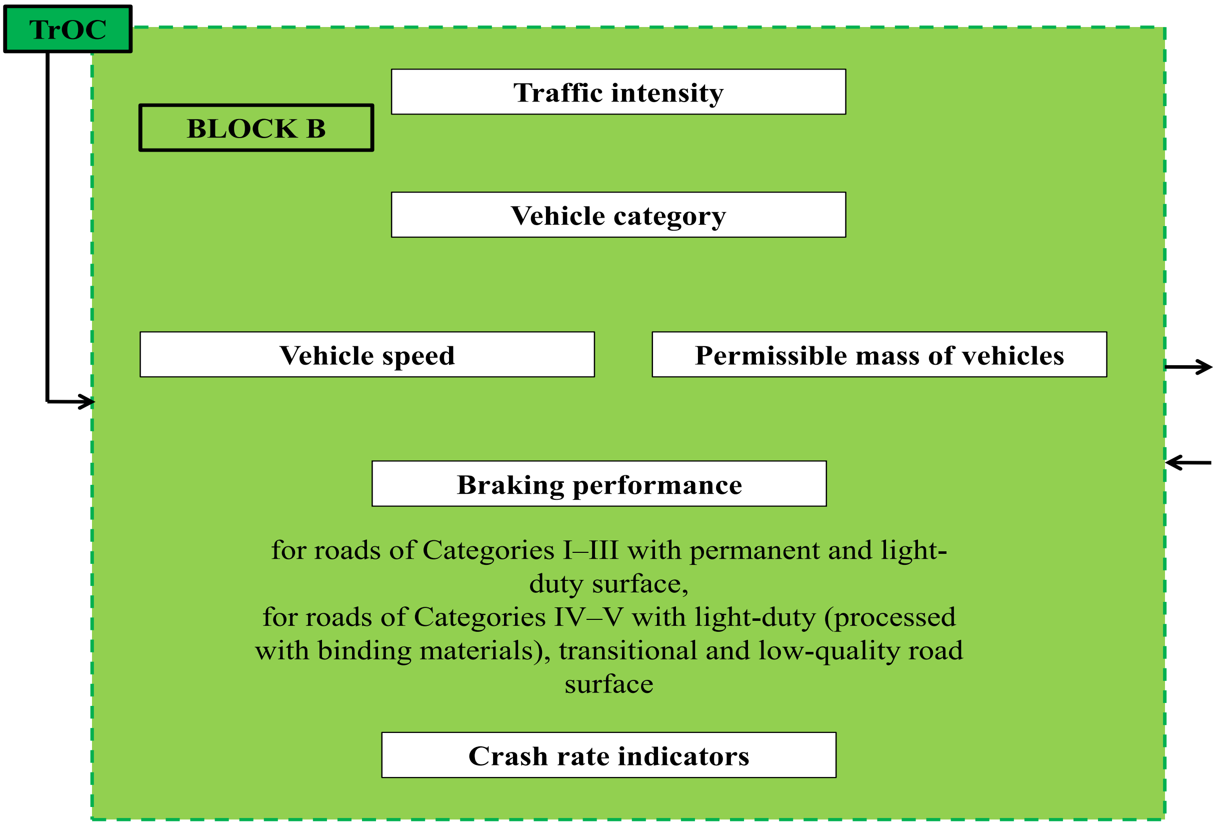


Figure 2. Block B parameters: traffic intensity and vehicle category, speed, permissible mass, crash rate, braking performance

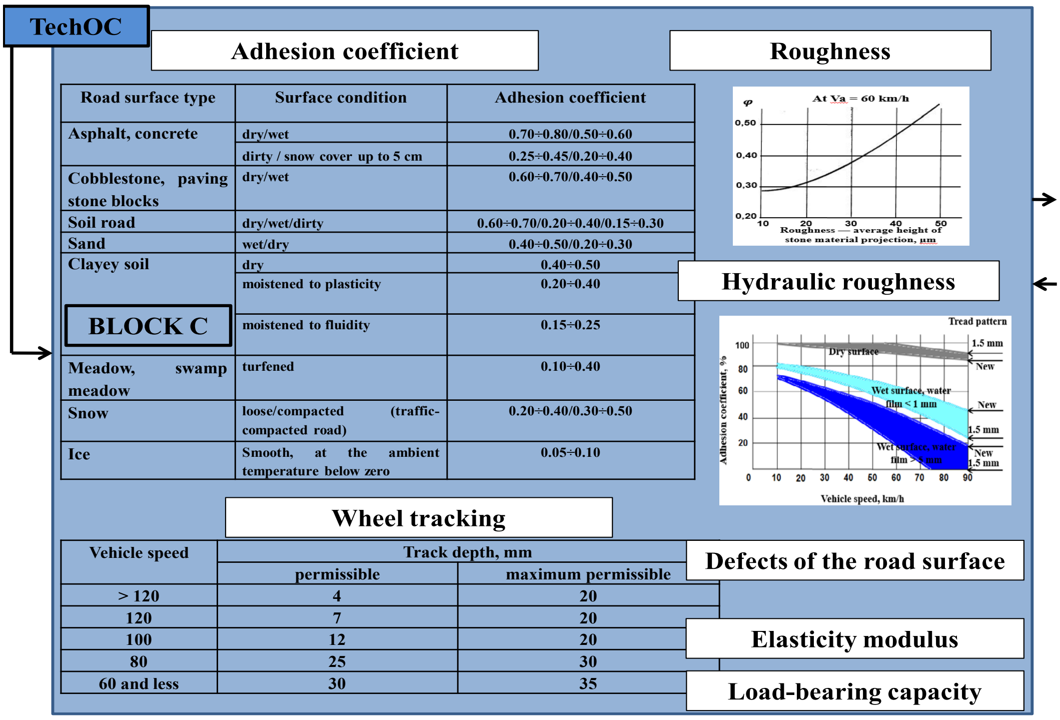


Figure 3. Block C parameters: coefficient of adhesion, wheel tracking, surface roughness, presence of defects, elasticity modulus, load-bearing capacity of the surface

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Block A in Figure 1 (a, b, c, d) includes parameters related to GREF (geometry of road environment facilities). Block B includes parameters characterizing TrOC (transport and operating conditions) (Figure 2). Block C in Figure 3 represents parameters that occur under certain technical and operating conditions (TechOC). Coefficient of adhesion of the vehicle tire with the road surface is a multi-value parameter since its values differ for different types of surfaces and conditions. CRIF (characteristics of road infrastructure facilities) in Block D of the expert study accounts for such parameters as the type and condition of artificial structures (bridges, overpasses, tunnels), condition of the pipe culvert system, presence of driver location signs, lighting, railroad crossings, availability of properly functioning means of technical organization of road traffic (MTORT).

Obtaining information on values of parameters of technical condition of vehicles and road infrastructure, including GREF, TrOC, TechOC and SRIF, is possible with the help of diagnostic equipment. Regulatory sources were used in compiling Blocks A–C, as well as Block D.

The dependence of the expert study, conducted by a diagnostic method, during which parameters of the "Vehicle–Road" subsystem condition were determined, has the following form:

$$\begin{aligned} \Upsilon(X^{D}) = f(&N_{i}, W_{pull.}, W^{sh.}_{m\arg.}, W^{cent.}_{div.str.}, \\ &S^{sh}_{m\arg}, L_{stop.}, i, i_{trans}, i_{r}, R_{curve}, S_{cl}, R_{convex}, R_{concave}, \\ &Z, h_{f}, \angle_{slope}, I_{veh}, M_{1} \div O_{2}, V_{a}, G_{veh}, K_{P}^{I-V}, \\ &N_{acc}, ACC_{abs}, ACC_{rel}, \varphi, t, r, r_{h}, E, \\ &D_{r.s.}, T_{a.s.}, T_{drain}, T^{signs}_{loc}, T_{light}, T_{rail}, MTORT), \end{aligned} \quad (3)$$

where N_i is the number of lanes; W_{pull} is the pullover width, m;

$W^{sh}_{m\arg}$ is the width of the shoulder margin strip, m; $W^{cent}_{div.str.}$ is the width of the central dividing strip, m; $S^{sh}_{m\arg}$ is the margin strip of the shoulder, m;

L_{stop} is the stopping strip, m; i is the longitudinal grade, per mille; i_{trans} is the transverse grade, per mille; i_R is the raised curve grade, per mille; R_{curve} is the curve radii in plan, m; S_{cl} is the clear vision distance to the object, m; R_{convex} is the radii of convex curves in profile, m; R_{convex} is the radii of convene curves in profile, m; Z is the structure of the road bed; h_f is the depth of fill, m; h_e is the depth of excavations, m; $\angle_{slope}$ is the slope grade; I_{veh} is traffic intensity, vehicles/day;

M1÷O2 are the categories of vehicles from M1 to O2 ; Va is the vehicle speed, km/h; Gveh is the vehicle mass, t; is the coefficient of braking performance of the vehicle; Nacc is the number of road accidents; ACCabs is the absolute crash rate; ACCrel is the relative crash rate; φ is the coefficient of adhesion of the vehicle tire with the road surface; t is the depth of the road track (wheel tracking), cm; r is the roughness of the road surface, average height of material projection, μm; rh is the hydraulic roughness; E is the modulus of elasticity, MPa; Dr.s. are defects of the road surface; Ta.s. are artificial structures; Tdrain is the condition of the drainage system; is presence of driver location signs; Tlight is availability of lighting; Trail is presence of railway crossings; MTORT is equipping with technical means of road traffic organization.

The algorithm for implementing the procedure in order to increase the reliability of determination of circumstances and causes of road accidents is presented in the form of a block diagram of successive stages (Figure 4). It is necessary to determine tasks and objectives of the examination and desired results before the study.

Obtaining of the input data or additional information on parameters of vehicles and road infrastructure is possible with the help of diagnostic equipment; requirements and characteristics are presented in Blocks A–D. An important step is to determine the compliance of the actual parameters obtained. It is determined following their comparison with the standard values and establishment of deviations of the obtained values from the reference ones. Thus, the opportunity to define causes of the road accident more precisely increases.

Evaluation of actual values of parameters of vehicle and road infrastructure condition is carried out by means of their comparison with the reference values, which are standard. This allows for the identification of the guilty party of the accident. For example, the cause of an accident is in defects of the road surface (pits, potholes), and their geometric parameters do not meet the requirements of legal documents. The guilty party in this case is the road organization or service that failed to timely repair the dangerous site. Thus, untimely work of road maintenance services in winter (ice, snow) would also increase the risk of accidents. Therefore, recording of parameters and qualitative analysis of the accident site are important aspects in compilation of information about the accident and case materials (Kurakina et al., 2017; Federal State Budgetary Institution ROSDORNII, 2015).

Wheel tracks, deflections of the road surface and changing of the surface condition during operation also contribute to the increase of accidents. Periodic monitoring and assessment of technical condition of operated road surfaces are essential for ensuring the operational status and throughput of roads. Therefore, the necessity to carry out road accident investigation and, as a result, assessment of the road surface condition and determination of its residual life, are substantiated. The following criteria are suggested to identify "weak" sections of roads:

- the hazard level of road sections;
- the level of accident stability;
- safe traffic conditions;
- service life of the road surface.

Measurement and determination of each of the criteria are based on condition and service life parameters.

The developed algorithm for expert examination of road accidents in a non-destructive manner would allow

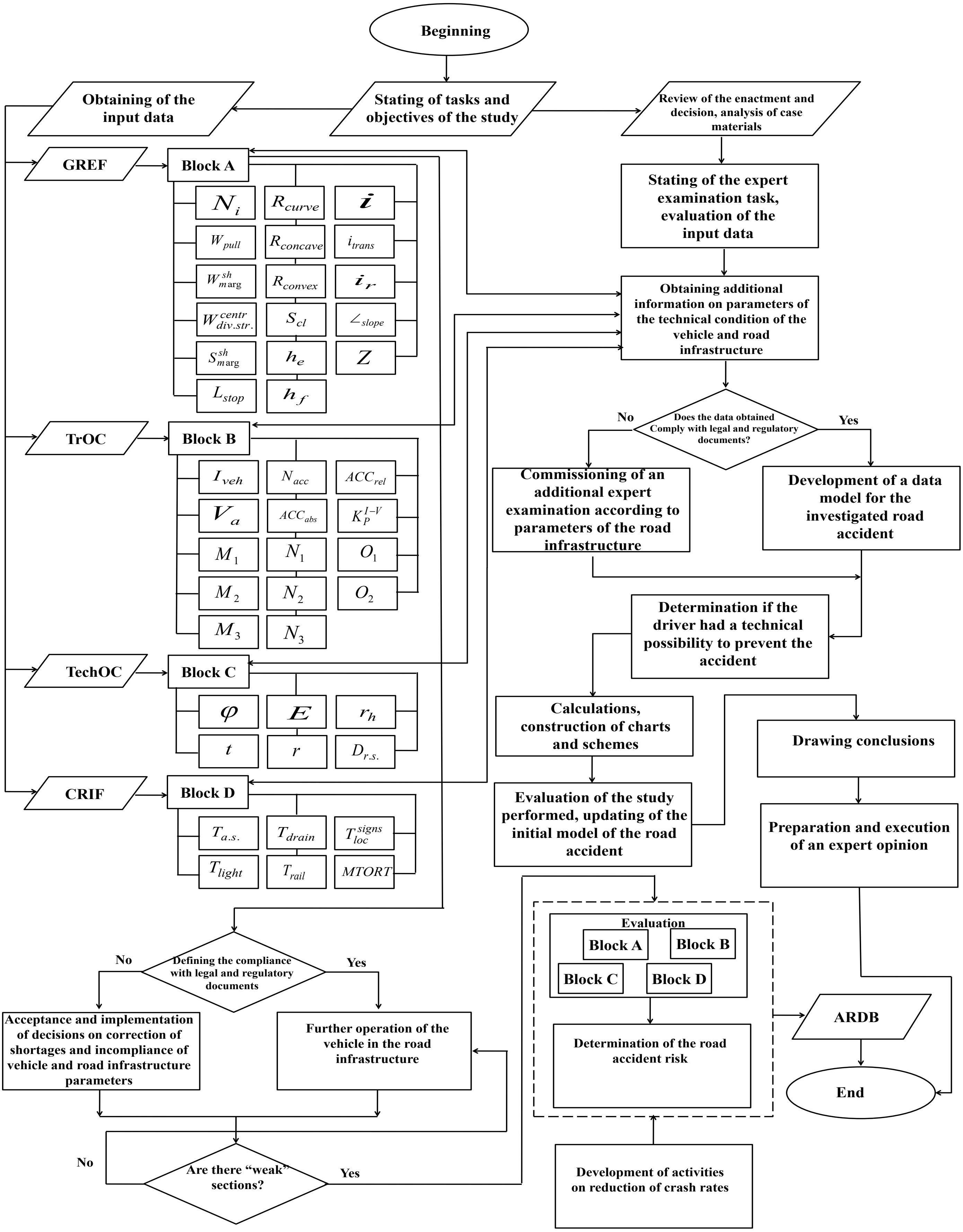

Figure 4. Algorithm of the expert study in a non-destructive manner

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solving problems in many areas, taking into account the interaction of complex structures with a multitude of parameters – with regard to vehicles and road infrastructure. agnostic studies are carried out by setting dynamic loads with Dynatest FWD (Kurakina, 2016, 2017).

The basis of the algorithm of expert studies in a non-destructive manner for revealing "weak" sections of roads is the new industrial guidance document "Recommendations for accounting and analysis of road accidents on the roads of the Russian Federation". According to this document, assessment of the general crash rate and trends in its change is carried out; sections of the concentration of accidents are identified; characteristic types of road accidents are determined for the sections of their concentration; effective management decisions and measures to improve traffic safety at the sections of road accidents are developed (Federal State Budgetary Institution ROSDORNII, 2015).

Determination of the accident risk is based on the establishment of factors contributing to an emergency situation. The studies risk factors include parameters of vehicle and road infrastructure condition, presented earlier, and conditions of their operation (time period, weather, climate and spatial conditions). Thus, the more information is analyzed and actual values are obtained, the fuller and more accurate are the results of determining emergency and accident risks, as well as the results of expert examination.

The automated road data base (ARDB) currently exists in the form of software products of individual organizations that perform diagnostics and assessment of technical and operating conditions and parameters of motor roads. However, the analyzed sources do not provide information on road sections characterized by high accident rate, low quality of the road surface and structural layers, life cycle of which is not large considering these parameters in the aggregate, that is, "weak" road sections. Introduction of this concept into practice will increase the information value of the status of the road data necessary for conducting expert studies.

Conclusion

In order to improve the system for accounting different parameters during construction of motor roads, it was suggested to take into account qualitative and quantitative characteristics of the traffic flow, vehicle braking processes, strength of the road surface by the elasticity modulus, determination of accident concentration sections by the risk of their occurrence, as well as their impact on prediction of the crash rate. Analysis of the technical characteristics of the non-destructive equipment and engineering measurements in determination of the parameters of the "Vehicle–Road" subsystem made it possible to select the diagnostic unit Dynatest FWD, substantiating such choice with the purpose, actualness and relevance of its practical application, safety of engineering measurements, convenience, speed of obtaining and processing of information, and a high possibility to analyze the entire range of the studied parameters.

In order to obtain a complete solution of the set tasks, more comprehensive parameters of the "Vehicle–Road" subsystem condition were proposed to make it possible to predict the occurrence of the road accident risk, including accident concentration sections, as well as to increase the reliability of conclusions and accuracy of calculations in expert opinions.

The developed procedure of expert studies in a non-destructive manner allows expanding the ways to ensure road safety and, consequently, increasing the overall effect of the road safety increase by introducing additional and previously not accounted factors into the study.

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CALCULATION OF TANGENTIAL FROST HEAVE STRESSES BASED ON PHYSICAL, MECHANICAL AND STRESS-STRAIN BEHAVIOR OF FROZEN SOIL

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Abstract

Development of northern territories opens up new opportunities for social and economic development of the society. However, designing construction facilities in such areas is complicated by special features of the severe climate; frost heave of soils is one of its manifestations. Normal frost heave forces under the foundation base can be neutralized by foundation embedment below the seasonal frost line. In these conditions, tangential heave stresses will act on the lateral surfaces of foundations, causing uneven lifting of structures, which will lead to the violation of the structure integrity. Regulatory and technical literature recommends determination of tangential frost heave stresses on the basis of generalized tabular data or experimentally, which is not always possible.

A relevant technique for calculating tangential stresses is required, which takes into account climatic and hydrogeological conditions of the construction site. In this article, an attempt is made to reveal those aspects of originating and development of tangential frost heave stresses, which would allow carrying out their calculation. To solve this problem, the existing research experience, features of the cryogenic structure, mechanical and stress-strain behavior of frozen soils were analyzed. A relationship of tangential frost heave stresses with specific cohesion and moisture of frozen soil was revealed on the basis of the analysis.

A point of view, according to which tangential frost heave stresses are a result of maximum compressive heave stresses, directed along the normal to the lateral surface of the foundation, was emphasized too; this allowed relating tangential heave stresses with the frozen soil deformation modulus. Based on the above statements, formulas for calculating tangential frost heave stresses were obtained. The calculation method for determining these stresses would provide the possibility of designing cost-effective and safe structures in areas with the severe climate.

Keywords

Wetness, boundary layer, tangential stresses, deformation modulus, frost heave, specific soil cohesion.

Introduction

In cold regions at the seasonal decrease of air temperature, cooling and freezing of the soil take place, which lead to increase in its volume, i.e. frost heave. Upon limitation of the surface expansion of foundations and embedded structures, normal stresses arise in soils that cause development of forces, which are tangential to these surfaces. Up to date, tangential frost heave stresses, acting on embedded structures, are determined either by generalized tables in regulatory documents, or experimentally. However, the latter is not always possible.

A question arises about the technique of calculating stresses for practical designing. Development of the calculation method, first of all, requires a study of the mechanism of originating and development of specified force factors. According to the existing concepts, tangential frost heave stresses develop upon freezing-up and subsequent interaction of the soil with the foundation material. However, understanding of heterogeneity of interacting media, which are the foundation and the soil, requires the development of these ideas and possible introduction of additional provisions in the definition of the stress-strain state of the "foundation–freezing soil" system. Theoretical prerequisites for this study are modern concepts of the cryogenic structure, mechanical and stress-strain behavior of the frozen soil, as well as existing concepts of the tangential stresses development staging.

The loading factor is an increase in soil volumes at freezing, leading to the formation of a stressed zone around the foundation. The effect of impact of the soil, expanding during freezing in this zone, are normal stresses, which, in their turn, cause stresses and shear forces directed tangentially to the foundation lateral surface.

The following tasks were set: to determine in which layer of the stressed zone shear stresses develop, leading to the development of tangential forces; this calculated layer will determine the qualitative and quantitative picture of the interaction; to reveal properties of interacting media, which would allow calculating tangential stresses; to establish a relationship of the stress value with mechanical and stress-strain properties of media. This would allow obtaining a technique for calculating stresses.

Background

In northern regions, dangerous natural process of frost heave of soils is one of manifestations of the severe climate. Normal stresses and stresses, tangential to foundation surfaces, develop under the influence of frost heave. Tangential stresses cause uneven lifting of structures, leading to their integrity violation and failures of buildings and infrastructure facilities. The influence of tangential stresses on structures is noted in works of B. I. Dalmatov (1954), V. D. Karlov (1998), M. F. Kiselev (1971), A. L. Nevzorov (2000), R. Sh. Abzhalimov (2006), D. Ladanyi (1998), J. P. Modisette (2014), and T. Kibriya (2015). Consideration of frost heave effect is a required condition for designing safe buildings and structures. Analysis of technical literature (https://ohranatruda.ru/ot_biblio/normativ/data_normativ/46/46329/) has shown that at the present time there is no generally accepted technique in regulatory documents for calculating tangential frost heave stresses, which is the reason to use recommended tabular values in practical designing or determinate stresses experimentally. However, tabular data do not allow taking into account the entire range of soil and climatic conditions, as well as their possible combinations. These data were obtained by results of experiments, which were carried out for a limited number of soils. Experimental determination of tangential heave stresses on a particular site is not always possible due to limited terms of execution of project documentation and amounts of financing. Experimental estimation, which provides for full-scale or laboratory researches, extends designing terms and implies for an additional item of expenditures for surveying and designing works. A full-scale experiment requires a term, corresponding to the period of negative temperatures of the atmospheric air, tools for measuring tangential heave stresses and special trained technical personnel. Methods of field measuring of tangential stresses are represented in works of B. I. Dalmatov (1954), V. D. Karlov (1998) N. A. Tolkachev (1964), E. A. Marov (1974), E. D. Ershov (1986), A. G. Alekseev (2006), H. Jiang (2015). A laboratory experiment is impossible without proper premises, special certified equipment and scientific and technical maintenance. Methods of the laboratory determination of frost heave forces are shown in the Guidelines (1973). Researches on frost heave on models in laboratory conditions were conducted by E. D. Ershov (1985), V. R. Parmesvaran (1981), Thomas H. (2009), Y.-H. Hyang (2015), and F. Ming (2015).

A question regarding effectiveness of the experimental approach, more inherent to scientific research, to prediction of tangential frost heave stresses during practical designing arises. The use of the approved method for calculating tangential frost heave stresses, based on fundamental studies of frost heave, would allow designing safe structures.

In Russia, the basic theory of frost heave, including the description of normal and tangential stresses, was developed by N. A. Tsytovich (1973), B. I. Dalmatov (1988), and S. S. Vyalov (1959). Abroad, the physics of frost heave is presented in works of R. L. Harlan (1973), J.-M. Konrad (1980), and S. S. L. Peppin (2012). E. Penner (1974, 2010), S. Frankenstein (2002), K. W. Biggar (2011), and S. Hiroshi (2011) were engaged in determining values of tangential stresses and frost heave forces. According to the existing concepts, the formation of tangential stresses is determined by forces of soil adfreezing with the lateral surface of the foundation. Heave forces, which develop in the surrounding soil mass, tend to move the foundation upwards. At that, frozen soil shear relative to the foundation occurs. Static bonds of the soil adfreezing with the foundation (adfreezing strength) are violated. Dynamic bonds arise which are determined by the resistance to the displacement of the frozen soil layer relative to the lateral surface of the foundation — tangential heave forces.

According to the existing studies, the value of tangential frost heave forces is close to values of steady forces of soil adfreezing with the foundation material. This provision was represented in works by B. I. Dalmatov (1988), N. A. Tsytovich (1973) and S. S. Vyalov (1959). Adfreezing forces are understood as the resistance to frozen soil shear throughout the lateral surface of the foundation. The force of soil adfreezing with the foundation corresponds to the general force which is needed to be applied to it in order to break the bond with the soil frozen around. Thus, it is considered that displacement of the frozen soil relative to the foundation takes place between the foundation material and the soil.

The resistance to frozen soil shear is a function of main variables, which are physical, thermal physical and mechanical properties of the soil, characteristics of the foundation material. Properties of frozen soil are conditioned by its complex cryogenic structure, which, in its turn, is determined by the temperature, freezing rate, external load value and time of its action. Characteristics of the foundation material are related to the characteristics of roughness of its surface. The listed factors indicate heterogeneity of media interacting during shear. Whereas, for shear occurrence directly between the material and frozen soil, these two media shall be homogeneous. All this creates prerequisites for the development of existing provisions on the determination of tangential frost heave stresses.

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Theoretical prerequisites of the study

The analysis of the existing works devoted to cryogenic structures, mechanical properties and stress-behavior of frozen soil was carried out. As N. A. Tsytovich (1973) points out, frozen soil represents a four-component system consisting of soil particles, inclusions of ice, unfrozen film water and gaseous inclusions. The amount and phase states of components in the combination with natural properties of the soil determine its heterogeneous cryogenic structure. In this structure, soil particles are "aggregated" by ice-cement. The contact surfaces of particles of the soil and ice form numerous shear planes, which provide the possibility of frozen soil brittle fracture from shear stresses during shear.

Studies of the values of tangential frost heave stresses were carried out by B. I. Dalmatov, Y. D. Dubnov, N. A. Tsytovich, S. S. Vyalov and others. B. I. Dalmatov found a linear dependence of steady adfreezing resistance on temperature (Figure 1), and, based on this, a formula for specific tangential heave force was obtained:

$$\tau^{heave} = \frac{h_{heave.}}{h}\left(c + b\, t_{mean}\right)$$

where *c* and *b* are parameters of the straight line, determined in laboratory conditions and depending on the soil type and its moisture, c = 4–5 t/m^2; b = 1–1.5 t/0C·m^2;

h_{heave} is thickness of the layer subjected to heave;

h is depth of freezing, m;

t_{mean} is mean temperature of the soil within the layer h_{heave} by the time of its freezing completion.

The non-uniformity of tangential stresses development over time is shown by N. A. Tsytovich (1973), S. S. Vyalov (1959), B. I. Dalmatov (1988), and V. I. Puskov (1993).

Based on the current concepts of staging of the tangential stresses development, the author considered the work of interacting media. At the first stage, shear with soil mass isolation occurs relative to the thin boundary layer of this soil, located on the lateral surface of a pile and frozen together with it. In this case, tangential shear stresses have a significant value, but a small period of activity. These stresses can be characterized as a short-term, almost instantaneous shear occurring when the soil reaches the ultimate resistance to shear.

In this case, ultimate shear strength of particles of the frozen soil boundary layer connected with the surface of the embedded structure, which is practically its "part", is of the paramount importance. Generation of tangential shear stresses is conditioned by overcoming total cohesion of frozen soil particles, corresponding to the ultimate resistance of the soil and ice to shear; normal pressure of the freezing soil on the lateral surface of the foundation.

The activity period of ultimate (instantaneous) tangential shear stresses τ_{inst}, causing shear with the isolation of soil aggregates in the boundary layer is replaced by the period of decay (stress relaxation), which continues up to the stabilization of the constant soil shear rate throughout the lateral surface of a pile at stresses, which reached the value of τ_{steady}. Further, the second stage of steady-state tangential stresses τsteady begins; these stresses appear when the frozen soil massif is uniformly displaced relative to the boundary layer. The massif displacement occurs due to micro-displacements in the boundary layer, in which a part of bonds (least strong) is already broken at the stage of short-term shear. Here tangential stresses have less importance, but they act during almost the entire freezing period and determine the actual picture of the development of tangential frost heave stresses throughout the lateral surface of the pile. This is confirmed by researches of B. I. Dalmatov (1958), N. A. Tsytovich (1973) and S .S. Vyalov (1959). A diagram of the dependence of shear resistance on time by B. I. Dalmatov is shown in Figure 1b.

At the second stage, relaxation of stresses from τ_{inst} to τ_{steady} occurs, mainly due to the reduction of frozen soil cohesion forces, under the action of the continuous load from frost heave forces. This phenomenon was described in experiments of S. S. Vyalov (1959).

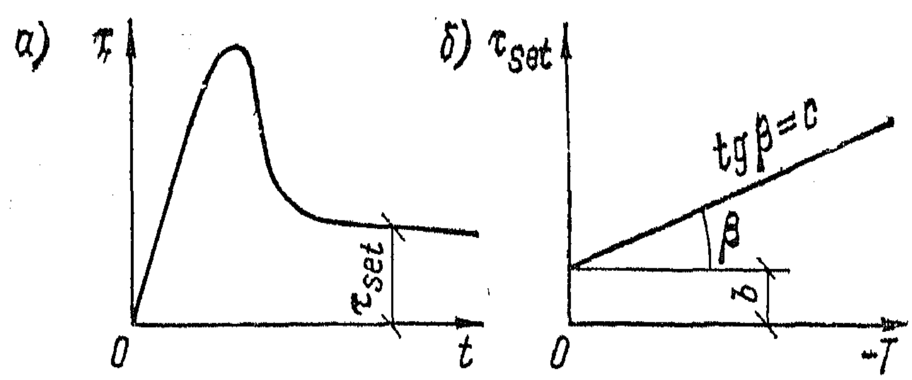

Figure 1. a) graph of dependence of shear resistance on time; b) graph of dependence of steady adfreezing resistance on soil temperature (B. I. Dalmatov, Y. D. Dubnov).

Characteristic change in cohesion of frozen soils over time, which forms the prevailing part of their shear resistance, is also illustrated in dependences of N. A. Tsytovich (1963). The studies, carried out by S. S. Vyalov (1959) and N. A. Tsytovich (1973), showed that cohesion forces (the main strength characteristic of frozen soil), decreased under the action of shear stresses over time, as a rule, within 1/3 –1/5 c_{inst}. Also, the internal friction angle decreases for clays at continuous shear.

Methods of calculation of tangential frost heave stresses

Special features of the cryogenic structure and mechanical properties of frozen soils allowed assuming that shear stresses caused by soil heave occur not along the "foundation–freezing soil" boundary, but in the boundary freezing layer adjacent to the foundation. This proposition is substantiated by aspects considered above, which are the theoretical prerequisites of this study: heterogeneity of interacting continuous media — the foundation material and freezing soil; and the ability of frozen soil for brittle fracturing.

The effect of constrained heave impact near the lateral surface of the foundation is represented by significant compressive forces, leading to the development of shear stresses, which are realized throughout numerous shear planes formed due to different shear strength of soil components in the calculated boundary layer. Mechanical properties of ice are analyzed in the work of V. V. Bogorodskiy (1983). Tangential forces are the resultant factor of these shear stresses. Violation of bonds between particles of the soil and ice is needed for origination of shear deformations. Shear in any elementary fragment will take place between ice layers or along the boundary of ice and mineral interlayers due to the lower shear strength of soil particles. In some approximation, it is possible to estimate the distribution of shear deformations according to the percent ratio between the soil and ice. This allowed establishing a relationship of the value of tangential frost heave stresses with the soil moisture, since the amount of ice inclusions in the frozen soil is determined primarily by the moisture of the latter; as well as with the specific cohesion of soil and ice particles. In view of the foregoing, the total cohesion of frozen clay-bearing soil at the first stage of the development of tangential stresses can be expressed in the following form:

$$c^{inst} = c^{inst}_{soil} \cdot (1 - 1.09 \cdot w) + c^{inst}_{ice} \cdot 1.09 \cdot w = c^{inst}_{soil} - 1.09 \cdot w \cdot c^{inst}_{soil} + c^{inst}_{ice} \cdot 1.09 \cdot w \quad (1)$$

After transformations, the following formula was obtained:

$$c^{inst} = c^{inst}_{soil} - 1.09 \cdot w \cdot \left(c^{inst}_{soil} - c^{inst}_{ice}\right) \quad (2)$$

where c^{inst}_{soil} is soil specific cohesion, corresponding to the ultimate resistance, kPa; c^{inst}_{ice} is ultimate ice resistance to shear, kPa; *w* is soil moisture, unit fraction.

As B. I. Dalmatov points out, shear stresses originating in cohesive clay-bearing soils near the lateral surface of the foundation, are the following:

$$\tau = c + \sigma \cdot tg\varphi \quad (3)$$

where *c* is specific cohesion; *σ* is normal pressure; *φ* is internal friction angle.

It is assumed that the dependence (3) can be used to determine tangential shear stresses of frost heave, developing on the lateral surface of foundations, using basic variables of B. I. Dalmatov's formula for the specific tangential frost heave force. The B. I. Dalmatov's formula for the specific tangential frost heave force has the following form:

$$\tau^{heave} = \frac{h_{heave}}{h}\left(c + b\, t_{mean}\right)$$

where *c* and *b* are parameters of the straight line, determined in laboratory conditions and depending on the soil type and its moisture, c = 4–5 t/m^2; b = 1–1.5 t/0C·m^2;

h_{heave} is thickness of the layer subjected to heave;

h is depth of freezing, m;

t_{mean} is mean temperature of the soil within the layer hheave by the time of its freezing completion.

Main variables are mechanical properties of the soil, moisture, temperature of the frozen soil, thickness of the freezing soil layer by the time of its freezing completion.

As per the above, tangential stresses at the first stage can be expressed as follows according to equation (3):

$$\tau^{I}_{\max} = c^{inst} + p_{mean} \cdot tg\varphi_1 \quad (4)$$

where c_{inst} is total (instantaneous) cohesion of frozen soil particles, corresponding to the ultimate resistance, kPa;

p_{mean} is mean pressure on the lateral surface of the foundation contacting with the frozen soil, kPa;

φ_i is angle of internal friction between the soil and ice.

The mean pressure on the lateral surface of the foundation has the following form:

$$p_{mean} = \xi_i \cdot \gamma_i \cdot z_i \quad (5)$$

where ξ_i is coefficient of the lateral pressure of the soil and ice.

$$\xi_i = \frac{v_i}{1 - v_i}$$

γ_i is volume density of the soil and ice, kPa;

z_i is depth (thickness) of ith layer of the frozen soil, m;

v_i is Poisson's ratio for the soil and ice.

Substituting formulas (2) and (5) into formula (4), we obtain the maximum tangential frost heave stress within the boundary layer at the depth z_i at the specified soil moisture. This instantaneous stress is the ultimate shear strength of the frozen soil.

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$$\tau^I_{\max} = \tau^I_{inst} = \left[c^{inst}_{soil} - 1.09 \cdot w \cdot \left(c^{inst}_{soil} - c^{inst}_{ice}\right)\right] + \xi_{soil} \cdot \gamma_i \cdot z_i \cdot tg\varphi_{soil} \cdot (1 - 1.09 \cdot w) + \xi_{ice} \cdot \gamma_{ice} \cdot z_i \cdot tg\varphi_{ice} \cdot 1.09 \cdot w \quad (6)$$

At ***the second stage***, steady-state tangential stresses develop, which are more reliable indices than the short-term ones at the first stage. Steady-state stresses are characterized by a decrease in shear stresses due to a decrease in the specific cohesion of the soil and angle of internal friction for cohesive soils, according to N. A. Tsytovich (1973) and S. S. Vyalov (1959). Based on this, it is possible to determine the steady-state stresses from equation (6), replacing the instantaneous cohesion c_{inst} of the soil by its continuous value c_{con}.

$$\tau^I_{steady} = \left[c^{con}_{soil} - 1.09 \cdot w \cdot \left(c^{con}_{soil} - c^{con}_{ice}\right)\right] + \xi_{soil} \cdot \gamma_i \cdot z_i \cdot tg\varphi_{soil} \cdot (1 - 1.09 \cdot w) + \xi_{ice} \cdot \gamma_{ice} \cdot z_i \cdot tg\varphi_{ice} \cdot 1.09 \cdot w \quad (7)$$

Analyzing the moisture value ***w*** in equation (7), let us note that the ice formation in the freezing soil is conditioned by the total moisture content, including the pore moisture in the natural composition of the soil and the moisture entering as a result of migration.

$$w_\Sigma = w + w_{migr} \quad (8)$$

Let us substitute the total moisture content (8) instead of ***w*** into equation (7):

$$\tau^I_{steady} = \left[c^{con}_{soil} - 1.09 \cdot (w + w_{migr}) \cdot \left(c^{con}_{soil} - c^{con}_{ice}\right)\right] + \xi_{soil} \cdot \gamma_i \cdot z_i \cdot tg\varphi_{soil} \cdot \left(1 - 1.09 \cdot (w + w_{migr})\right) + \xi_{ice} \cdot \gamma_{ice} \cdot z_i \cdot tg\varphi_{ice} \cdot 1.09 \cdot (w + w_{migr}) \quad (9)$$

Let us determine the share of the migration moisture in the freezing soil, using the formula for heave deformation proposed by A. L. Nevzorov (2000). In this equation, the second summand is connected with the moisture entering the freezing zone due to migration forces:

$$h_{heave} = 0.09 \cdot (w_{sat} - w_w) \cdot \frac{\rho_d}{\rho_w} \cdot z + 1.09 \cdot SP \cdot \tau \cdot grad\, t \quad (10)$$

Then, the moisture forming due to water migration to the cold front, according to equation (10), will be:

$$w_{migr} = \frac{SP \cdot \tau \cdot grad\, t}{z} \quad (11)$$

After substitution of (11), equation (9) will take the following form:

$$\tau^I_{steady} = \left[c^{con}_{soil} - 1.09 \cdot \left(w + \frac{SP \cdot \tau \cdot grad\, t}{z}\right) \cdot \left(c^{con}_{soil} - c^{con}_{ice}\right)\right] + \xi_{soil} \cdot \gamma_i \cdot z_i \cdot tg\varphi_{soil} \cdot \left(1 - 1.09 \cdot \left(w + \frac{SP \cdot \tau \cdot grad\, t}{z}\right)\right) + \xi_{ice} \cdot \gamma_{ice} \cdot z_i \cdot tg\varphi_{ice} \cdot 1.09 \cdot \left(w + \frac{SP \cdot \tau \cdot grad\, t}{z}\right) \quad (12)$$

where c^{con}_{soil} is specific cohesion of soil particles, kPa;
c^{con}_{ice} is specific cohesion of ice particles, kPa;
w is natural soil moisture, unit fraction;
φ_{soil}, φ_{ice} are angles of internal friction of the soil and ice, respectively;
ξ_{soil}, ξ_{ice} are coefficients of the lateral pressure of the soil and an ice, respectively;
γ_{soil}, γ_{ice} are volume weights of the soil and ice, respectively, kN/m^3;
z is depth of soil freezing in the vertical direction; thickness of the soil layer in the horizontal direction, m;
SP is segregated soil potential, m^2/h·°C;
τ is freezing time, hours;
grad t is temperature gradient, 0C/m.

Let us simplify equation (12), substituting c^{con}_{soil} and c^{con}_{ice} by the values c_{soil} and c_{ice}, and τ^I_{steady} by τ_{steady}:

$$\tau = \tau_{steady} = \left[c_{soil} - 1.09 \cdot \left(w + \frac{SP \cdot \tau \cdot grad\, t}{z}\right) \cdot (c_{soil} - c_{ice})\right] + \xi_{soil} \cdot \gamma_i \cdot z_i \cdot tg\varphi_{soil} \cdot \left(1 - 1.09 \cdot \left(w + \frac{SP \cdot \tau \cdot grad\, t}{z}\right)\right) + \xi_{ice} \cdot \gamma_{ice} \cdot z_i \cdot tg\varphi_{ice} \cdot 1.09 \cdot \left(w + \frac{SP \cdot \tau \cdot grad\, t}{z}\right) \quad (13)$$

As it was noted above, main variables of the B. I. Dalmatov's formula for specific tangential heave strength are the following: mechanical properties of the frozen soil, moisture, temperature of the frozen soil by the time of its freezing completion, thickness of the freezing layer. As it was mentioned above, main variables of equation (13) are the following: mechanical properties of the frozen soil, moisture, temperature gradient within the frozen layer; freezing time, segregated soil potential (characterized by heave velocity, moisture migration rate and temperature gradient), and thickness of the freezing layer.

The reason of the generation of tangential stresses on the lateral surface of the foundation is maximum normal compressive stresses developing when limitating expansion of the heaving soil during its freezing. This proposition was used in obtaining the *method for calculating tangential frost heave stresses*. The relationship of tangential stresses with normal frost heave stresses was found by V. I. Puskov (1973). V. I. Puskov notes that "in the absence of a local load, on the soil surface in the layer of seasonal freezing, volume deformation *f* is completely realized in the direction of the vertical axis and includes, besides f_z, lateral heave deformations transformed in the direction of *z* axis by the arising lateral pressure σ_{fb}".

Stating methods for determining heave deformations, V. D. Karlov (1998) in his DSc thesis noted that "the considered methods also allow determining the value of specific forces of soil frost heave depending on the degree of constraint of heave deformations". And the degree of constraint of heave deformations, in its turn, conditions normal frost heave stresses, which can be traced in works of various authors. For example, according to N. A. Tsytovich (1973), "the order of the maximum value of normal frost heave forces can be estimated based on the values of pressures which ice crystals develop upon the constrained water freezing". According to E. D. Ershov, "stresses in freezing rocks are conditioned by the exclusion of heave deformations". Thus, the existing studies allowed expressing tangential frost heave stresses with the use of the Coulomb law in dependence to horizontal normal frost heave stresses σ_x:

$$\tau = \sigma_x \cdot tg\varphi \quad (14)$$

where σ_x is frost heave stress normal to the lateral surface of the foundation according to the formula obtained by the author (2016); φ is angle of internal friction of the frozen soil or ice.

The author obtained the formula for calculating horizontal frost heave stresses σ_x(2016), considering properties of the frozen soil, depth (thickness) of the freezing layer and freezing conditions:

$$\sigma_x = \sigma_{heave} = 1.09 \cdot SP \cdot \tau \cdot grad\,t \cdot \frac{E_M}{z} \cdot \left[1 - e \cdot \left(1 - w_w \cdot \frac{\rho_d}{\rho_w} - 1.09 \cdot w \cdot \frac{\rho_d}{\rho_w}\right)\right] \cdot k_{an} \quad (15)$$

where E_M is modulus of frozen soil deformation; w is natural moisture of the soil; w_w is moisture by unfrozen water; e is porosity factor of the soil; z is depth of soil freezing in the vertical direction; thickness of the soil layer in the horizontal direction; *SP* is segregated soil potential; τ is freezing time; *grad t* is temperature gradient; ρ_d is density of the dry soil; ρ_w is density of free water; ρ_d / ρ_w is a factor of conversion of the mass moisture into the volume moisture; k_{an} is an anisotropy factor of the frozen soil, taking into account the direction of freezing and frost heave stresses.

Then equation (14) for tangential frost heave stresses will take the following form:

$$\tau = \left\{1.09 \cdot SP \cdot \tau \cdot grad\,t \cdot \frac{E_M}{z} \cdot \left[1 - e \cdot \left(1 - w_w \cdot \frac{\rho_d}{\rho_w} - 1.09 \cdot w \cdot \frac{\rho_d}{\rho_w}\right)\right] \cdot k_{an}\right\} \cdot tg\phi \quad (16)$$

Due to the unfrozen water, the soil moisture is determined as a function of the plastic limit moisture (in unit fractions), according to Regulations SP 25.13330.2012:

$$w_w = K_w \cdot w_p$$

where k_w is a factor taken from table B.3 [Regulations SP 25.13330.2012] in dependence to the index of plasticity and soil temperature; w_p is soil moisture at the plastic limit.

Kujala found that the segregated potential SP ($mm^2/h \cdot °C$) was in correlation with the heave velocity h_v (mm/day):

$$SP = 1.1 \cdot v_h = mm^2 / hour \cdot {}^0C$$

where v_h is heave velocity, mm/day.

The mean temperature gradient for the layer *z* is calculated as the ratio of the mean winter temperature to 0.5 z.

$$grad\,t = \frac{t_{bf} - t_s}{0.5 \cdot z} \approx \frac{t_s}{0.5 \cdot z}\ {}^0C/cm$$

where t_{bf} is temperature at the beginning of freezing $t_{bf} \to 0$; t_s is mean winter temperature; *z* is thickness of the freezing edge (freezing layer).

The time of freezing amounts to:

$$\tau = \frac{z}{v_n}$$

where v_n is soil freezing velocity.

Equation (15) after the substitution of values will take the following form:

$$\sigma_x = 1.09 \cdot 1.1 v_h \cdot \frac{z}{v_n} \cdot \frac{t}{0.5z} \cdot \frac{E_M}{z} \cdot \left[1 - e \cdot \left(1 - w_w \cdot \frac{\rho_d}{\rho_w} - 1.09 \cdot w \cdot \frac{\rho_d}{\rho_w}\right)\right] \cdot k_{an} \quad (17)$$

After transformations we get the following:

$$\sigma_x = 2.4(m/{}^0C) \cdot \frac{v_h}{v_n} \cdot \frac{t \cdot E_M}{z} \cdot \left[1 - e \cdot \left(1 - w_w \cdot \frac{\rho_d}{\rho_w} - 1.09 \cdot w \cdot \frac{\rho_d}{\rho_w}\right)\right] \cdot k_{an} \quad (18)$$

Then, equation (16) will take the following form:

$$\tau = 2.4(m/{}^0C) \cdot \frac{v_h}{v_n} \cdot \frac{t \cdot E_M}{z} \cdot \left[1 - e \cdot \left(1 - w_w \cdot \frac{\rho_d}{\rho_w} - 1.09 \cdot w \cdot \frac{\rho_d}{\rho_w}\right)\right] \cdot k_{an} \cdot tg\varphi \quad (19)$$

It is rather difficult to determine the modulus of frozen soil deformation. In regulatory documents, it is recommended to determine this parameter experimentally. According to the recommendations of "Guidelines for Determining Physical, Thermal Physical and Mechanical Properties of Frozen Soils" (https://ohranatruda.ru/ot_biblio/normativ/data_normativ/48/48098/), the deformation modulus is the value reciprocal to the compressibility. The compressibility, in its turn, is determined depending on the volume weight ρ and soil moisture *w*.

Then the following basic physical values can be taken as parameters determining the value of tangential stresses in equation (19):

$$f(w, t, z, v_h, v_n, \rho, tg\varphi) = 0 \quad (20)$$

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Equation (20) makes it possible to determine similarity criteria of tangential stresses on the basis of methods of applying the similarity theory and dimension theory in the mechanics of frozen soils, which were stated in works of B. I. Dalmatov, V. D. Karlov, O. R. Golli and E. S. Ashpiz.

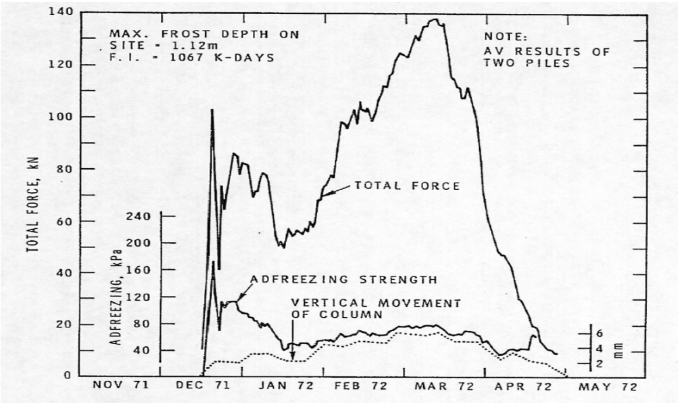

Figure 1. Part of matrix of physical laws as a canvas for analysis

Results

Based on equations (13) and (16), examples of calculating tangential heave stresses, acting on the lateral surface of the foundation in the clay-bearing soil are fulfilled. Despite some schematization, formulas give satisfactory results shown in Table 1. Comparison of stresses calculated by equation (13) and (16) with the values obtained by some other authors is presented in Table 2.

Table 1. Results of calculating tangential frost heave stresses

Equation No	Calculation formula	Value of tangential stresses, kN/m^2
13	$\tau = \left[c_{soil} - 1.09 \cdot (w + \frac{S\,P \cdot \tau \cdot grad\,t}{z}) \cdot (c_{soil} - c_{ice}) \right] + \xi_{soil} \cdot \gamma_i \cdot z_i \cdot t\,g\varphi_{soil} \cdot \left(1 - 1.09 \cdot (w + \frac{S\,P \cdot \tau \cdot grad\,t}{z} \right) + \xi_{ice} \cdot \gamma_{ice} \cdot z_i \cdot t\,g\varphi_{ice} \cdot 1.09 \cdot (w + \frac{S\,P \cdot \tau \cdot grad\,t}{z})$	152.7
16	$\tau = 2.4(m/{}^0C) \cdot \frac{v_h}{v_n} \cdot \frac{t \cdot E_M}{z} \cdot \left[1 - e \cdot \left(1 - w_w \cdot \frac{\rho_d}{\rho_w} - 1.09 \cdot w \cdot \frac{\rho_d}{\rho_w} \right) \right] \cdot k_{an} \cdot t\,g\varphi$	79

Conclusion

In order to increase the effectiveness of designing of underground structures in cold areas, a technique for calculating tangential frost heave stresses is required.

Based on modern concepts of the cryogenic structure, mechanical properties and strain behavior of the frozen soil, a correlation of tangential frost heave stresses with moisture and specific cohesion of frozen soil particles is ascertained. Based on this, a formula is obtained for calculating tangential frost heave stresses (14).

The reason of the generation of tangential stresses is compressive heave stresses, normal to the lateral surface of the foundation and leading to shear. Formula (16) for tangential stresses calculation is proposed, as a function of the specified normal pressure. The latter was obtained by the author (2016) on the basis of physical properties and strain behavior of the frozen soil, freezing conditions, and regularities of moisture migration.

The values calculated according to formulas (13) and (16) do not contradict the data of other researchers.

Table 2. Comparison of tangential frost heave stresses

Author of the study	Type of the study	Freezing depth, m	Tangential heave stress, kN / m^2	Mean tangential heave stress, kN / m^2
O. V. Tretiakova (2017)	Calculation	1.0	79–152.7	115.9
		0–0.5	270–300	
		0–1.0	140–160	
		0–1.5	120–135	
		0–2.5	100	
		0–3.5 and >	80	
R. Sh. Abzhalimov (2006)	Field study	120		120
D. Ladanyi, A. Foriero Figure 2 (1998)	Field study	1.12	60–160	120

Discussion

Currently, issues of the uneven distribution of tangential stresses throughout the depth and variability of their values over time remain controversial.

Studies of the frozen soil deformation moduli will help to take into account the non-uniformity of tangential stresses throughout the depth. These indices can be determined in laboratory conditions. In Russia, strength properties and strain behavior of frozen soils were studied by L. T. Roman (2016), R. Sh. Abzhalimov (2009, 2011) and others. Abroad, these issues were analyzed in the works of T. F. Azmatch (2011), K. W. Biggar (2011) and others. The carried out studies are useful for the increase of applicability of the calculating formulas obtained by the author.

An important role in the development of calculation techniques belongs to rheological properties of the soil, which determine the unevenness of tangential stresses over time.

Long-term soil strength is more relevant for assessing the suitability of the construction safety for the entire lifetime than the short-term breaking ultimate strength limit obtained during tests. This area represents a field for further researches.

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AIRPORT ENVIRONS — TASKS OF THE INTEGRATED DEVELOPMENT (USING THE EXAMPLE OF THE PULKOVO AIRPORT)

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Abstract

This article touches upon the relevant issue connected with a world-wide tendency to the development of territories around airports. Development directions of the Pulkovo Airport and its adjacent territories in Saint Petersburg and the Leningrad Region are considered. Core activities concentrating in airport zones and factors conditioning their attraction to these zones are revealed. The notion of an airport environ is disclosed and introduced. The research defines the urban-planning and economic factors which allow carrying out the economic regulation in zones adjacent to airports and their influence on the spatial development of such territories.

The assessment of a change in the land value in the Pulkovo environ during its commercial development and the analysis of factors which form this value are given in the article. A number of problems of territories, which are under influence of the Pulkovo Airport, are revealed. Relying on results of the world experience analysis, authors note that the development of territories, located in the zone under influence of the Pulkovo Airport, shall take place in accordance with the single concept of the urban planning which does not depend on the administrative belonging of the territory and takes into account long-term strategic tasks and tools of the effective management.

Keywords

Airport, Pulkovo, airport environs, aerotropolis, strategy, airport development zones.

Introduction

The contemporary state of the transformation of peripheral territories around the Pulkovo Airport within Saint Petersburg and the Leningrad Region denotes the necessity of the formation of the spatial development strategy capable to ensure the integration of the airport and the build-up territory formed around it with a new future site development and natural territories according to the stable model of the integrated development upon ensuring necessary public priorities.

The situation with the development of the territories around the airport leads to the fact that new forming zones of the extensive urban-planning development do not turn into a holistic and stable urban layout, but become discordant city fragments of the building-up in view of the insufficient attention to the role of the integrated development and integration of all territories around the airport with account for the natural framework maintenance.

The lack of understanding of the necessity of the formation of the single social and economic strategy of the territory development in the zone under influence of the Pulkovo Airport, as well as resulting absence of the single strategy of the spatial development and the united urban-planning documentation lead to the inevitable fragmentary mixed-function and mixed-scale building-up with the lack of internal connections between individual territories, availability of conflict zones connected with mutual limitations, with ousting of natural components and appearance of blank spaces within zones of limitations related to the activity of the airport.

Modern theoretical models of the spatial development of zones around airports and the practice of their application can become the basis for revealing alternative approaches in the solution of many of the above problems in the spatial development of peripheral territories around the Pulkovo Airport within Saint Petersburg and the Leningrad Region.

Considering examples of the spatial development of territories in zones of airports of cities of the world, we can see to what extent the involvement andintegratedness of

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these territories in the urban agglomeration structure and intra-urban web changes the quality of the environment towards interests of the city and the man, allows using resources and features of such type of territories effectively. The main objective of this research is the determination of the development direction of the territories in the zone of the Pulkovo Airport in Saint Petersburg and the Leningrad Region. The Pulkovo Airport has the international status and is the only regular civil airport in Saint Petersburg and the agglomeration of Saint Petersburg. Issues concerning the transformation of the territory around the Pulkovo Airport are extremely sharp today, since the active development of these territories, which faced a number of problems being unsolved till now and which partly provoked them, has been carried out for the last fifteen years.

Following the value of the territories being transformed and planned for the transformation around the airport at the present time, there is a chance to change the situation in the city. Vast areas which are not well-developed yet could become binding zones and constitute parts of the extremely needed infrastructure, including transport and green infrastructures, ensuring sustainable development of the territories in the airport zone.

Subject, tasks and methods of the study

The modern stage of the transport infrastructure evolution began in the middle of the 19th century and continued in the 20th century passing active stages with the development of different types of the transportation. In the 21st century airports have become one of the key facilities of the transportation infrastructure, since they represent a type of transport that most effectively meets the requirements related to the population mobility. At the present time, airports cease to be exclusively infrastructure facilities, "becoming an integral part of the urban landscape" (Donnet, Keast, 2010), transform into more complicated spatial complexes. They evolved from "autonomous facilities on the periphery of cities" (Thierstein, Alain, 2010) into intermodal transfer hubs having potential to the concentration of economic, investment, and urban-planning activities. "At the present time, airports undergo the considerable development in the field of business, besides their primary aviation services, they develop a significant number of non-aviation services and gain a considerable part of income from the non-aviation production" (Kasarda, 2012). The gradual commercialization of the airport is explained by the influence of processes of globalization and liberalization (appearance of lowcosters, appearance of "hub and spoke" networks, creation of global alliances of airlines), and airports were to diversify income sources which gave an impetus to the development of business and the service sector in close proximity to the airport (Marcos, 2015).

There is only one regular civil Pulkovo Airport in Saint Petersburg, wherein the construction of a new terminal in 2013 was completed (http://www.pulkovoairport.ru/about/history). According to the data of the "Northern Capital Gateway" operator company of the Pulkovo Airport, the passenger traffic amounted to 13.4 million passengers in 2015; an increase in the passenger traffic up to 22 million passengers per year is planned by 2025.

For cities, similar to Saint Petersburg having on its periphery a large airport with the lack of the single development strategy for the zone around the airport, as well as a very low level of the urban-planning development, connectivity of the territory in this zone and the environmentally problematic situation, the necessity of the search of an optimal model of the transformation of territories in the airport zone is quite obvious. The effectiveness of the use of the territories in the zone around the airport within the framework of the search of a compromise between interests of developers and interests of the urban community becomes particularly important for Saint Petersburg.

The subject of this study is processes of the transformation of the territories around the Pulkovo Airport. The object of the study is the territory around airports. There is a number of zones in the Russian legislation which are allocated around airports. For example, the concept "aerodrome environs" (introduced by the Federal regulations of the use of the air space of the Russian Federation approved by Decree of the Government of the Russian Federation No. 138 as of March 11, 2010) is an area of the land or the water surface adjacent to an aerodrome within which (for purposes of ensuring safety of flights and avoidance of an adverse effect on the human health and the activity of organizations) a zone with special conditions of the territory use is established. There are notions of an approach funnel zone, a sanitary protection zone of the airport, a roadside clear zone of the airport, a zone of the housing construction ban and some other zones. However, all these zones are only zones of restrictions from the airport and they do not define such territory, within boundaries of which its influence on economic processes and, correspondingly, on the spatial and functional development is carried out. At the same time, such territory is formed around all large airport terminals. Its feature can be both the special legal regulation order focused on the development of such zone, and autogenous processes and various possible combinations. For example, in the USA and a number of other countries, such regulation zone is defined as an Airport Development Zone.

Airport development zones (ADZ) are special tax areas which grant privileges to taxpayers for economic projects in the special allocated airport zone. In fact, this is something like special economic zones in the Russian Federation. There are similar definitions for such allocated zones in many countries. However, in case when we bespeak territories, whereon economic development processes are connected with the airport activity, but development can be carried out both with allocation of special economic zones and without specially regulated tax or other conditions — the introduction of an individual notion is necessary. Within the context of this study, the notion of an "airport environ", which can be defined as "a territory around the airport connected with it not only by adjacent location but being under its economic, transport and "image" influence", is applied (Veretennikova, 2016). This definition considerably extends boundaries of the zone — ADZ and allows proceeding subsequently to the definition of urban-planning characteristics of this territory at its establishment.

The research tasks are the determination of factors and conditions influencing the transformation of the airport environs and, correspondingly, the formation of boundaries of such territories and the use of urban-planning and legal tools of their regulation. Various methods of a system spatial analysis of the territory, a land bank assessment method, a number of other methods are applied. In order to analyze a range of problems and determine ways of the transformation of the airport environs, the authors used materials of the implemented and completed works including those executed with their direct participation, as well as developed conceptual proposals for the territory development in the Pulkovo Airport zone executed in the course of the last ten years.

The most essential urban-planning factor allowing carrying out regulation in the similar zone is the factor of the establishment of a spatial boundary of such territory. However, its boundaries can change substantially with due account for the time, paces of the territory development and its regulation regimes. What determines boundaries of such territory? Key factors are the economic attractiveness of the territory, technical restrictions of the airport and the balanced stability of the spatial development with due account for the natural framework of the territory.

Let us consider how these factors of the development of the territories influence on the spatial development of the airport environs and to what extent this condition is applicable to Saint Petersburg.

Let us turn to the study executed by urbanists of the Dutch-Swiss company Güller Güller, headed by Mathis Güller and Michael Güller, in 2001, who proposed three categories of the economic activity by features of its connectivity with the airport:

– Aviation types of activity being a part of the maintenance of the airport.

– Activity connected directly with freight and passenger traffic flows (logistics, retail trade, hotels).

– Activity selecting an airport zone in view of its image, relative low land prices and good provision with an infrastructure (Güller, 2001).

If first two types of activity have already become rather habitual and inseparable from the airport, the recognition of the existence of the third one and understanding of the necessity of its regulation is lacking in Russia at the present time.

What types of activity are formed in airport zones and what attracts them? The carried out analysis of the airport environs of Europe, the USA, Russia and China shows that such territory has a high degree of the functional variety. It can include logistics parks and distribution centers, business and technological parks, industrial facilities, health care institutions, campuses, hotels and entertainment centers. Airports become "centers of the information, knowledge and competencies exchange" (Kasarda, 2012), which results in the allocation of science intensive companies of various profile near them. Large housing estates can also be situated within the airport environs, out of noise nuisance zones, and this is by far not the complete list of functions in such zones. Significant territories continue to occupy agriculture facilities taking into account vast zones of restrictions of the capital construction.

Why are the zones adjacent to airports so attractive in comparison with other territories? What makes them more economically attractive in comparison with many other territories?

It is the territory "image" (http://www.slideshare.net/IAUIDF/key-factors-of-attractiveness-for-airport-areas-and-the-special-role-of-human-resources). It is achieved through connection with a recognizable facility — the airport, where potential customers from all countries and regions of all levels arrive: from ordinary consumers to the economic and political establishment; through connection with modern high technologies with which the airport is associated; through high standards of the service and design, to which modern airports tend; through ultramodern architecture of complexes of airports; through the effective vicinity to those facilities which have been already allocated in such zone.

These are land prices. Airport zones remained unclaimed for the development for a long time due to the building-up restrictions. However, in the last 20 years, the modernization of the aviation park gradually reduced boundaries of restriction zones according to a number of indicators, and by a certain stage zones around airports turned out to be a considerable free land reserve situated relatively not far from the city. These territories were partially built up with various facilities of municipal and logistic purpose owners of which were ready to sell them or convert them for a different function taking into account the increased demand. Thus, the land value in the zones adjacent to airports was and partially remains low due to volumes of the free land bank.

It is the infrastructure of the airport environs which has significantly higher level of the development in comparison with any other new territories, and at the same time a considerably bigger potential in comparison with zones which have already formed. First of all, it concerns the transport infrastructure. The network of highways, including high-speed ones, makes such territories extremely attractive for the development of various functions both connected with freight traffic and with the transfer of the significant amount of people. The engineering development of the territory also influences the attractiveness of airport zones; however, this factor can be not developed enough since systems of available power of airports are often absolutely self-sufficient and cannot provide additional resources for the stimulation of environment.

A number of important urban-planning problems, to which insufficient attention is paid in Saint Petersburg, noted in studies of specialists, include ignorance of capabilities of the natural framework in the urban development

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(Nefedov, 2017). The situation, wherein the natural framework is not considered as the important functional and compositional part of the new urban landscape, becomes the result of a rapid growth of peripheral territories at the boundary of Saint Petersburg. It relates to all peripheral territories in Saint Petersburg. It is particularly relevant for the airport environs, i.e. those which are in the zone under influence of the airport situated on the periphery of Saint Petersburg, taking into account its "transboundariness" — location both in Saint Petersburg and the Leningrad Region. This territory is not taken into account in the system of the urban landscape in both territorial entities and it has been subjected to the most massive influence for the last period. At the same time, the territory has the enormous potential for the maintenance and development of the natural-landscape framework taking into account the conservation of large free and not built-up territories with woodlands, water bodies and natural landscape.

It is necessary to emphasize among the most noticeable problematic qualities the excessive building-up density of new multi-functional quarters in the total absence of internal ties both between them and between them and the airport. Forming chaotically arising built-up territories, including those in the form of individual large consolidated mono-functional zones, the urbanized environment excludes appearance of green corridors and leads to the formation of separate spontaneous temporary green "oases" in the zones, wherein according to technological characteristics of the airport, building-up is prohibited. The conflict situation to which this quality leads lies in the lack of the possibility to form a branched natural framework between individual territories and built-up quarters, destruction of separate formed natural biotopes and in the lack of the possibility to maintain natural green zones in the structure of separate territories. Such environment not only disrupts the ecological balance, but also forms alienation of the population from green spaces, losing zones of the potential rest of people.

At the same time, the zones around airports often have a high green potential throughout the entire world, and such potential contributes to their attractiveness and resistance to changes. For example, according to the opinion of J. Kasarda, the transformation of green zones around airports in China with the conservation of their natural and recreational nature is a priority. According to his opinion, the Chinese, when implementing their programs of the development of airports and zones around them, consider airports as “competitive assets” rather than "troubles and environmental threats", and many municipalities insist that they, i.e. the zones around airports, shall turn into green "environmental cities" (http://www.economist.com/news/china/21646245-chinas-frenzied-building-airports-includes-work-city-sized-projects-aerotropolitan-ambitions).

How do all these and other factors influence on the spatial development of the airport environs and what is

Table 1. Concepts of the development of the airport environs

Name of the concept	Author	Year	Description	Features
	Roeseler	1971		
	Freestone and Baker	2011		
Airport city	H. McKinley Conway	1980	More or less dense accumulation of enterprises connected with the airport on the territory of the airport and around it	A large volume of various service functions: trade, hotels, entertainment Focus on business Has qualitative characteristics inherent in the city: density, services, access quality
Aerotropolis	J. D. Kasarda	1991	Agglomeration around the airport (http://www.aerotropolis.com/)	Replication of services of the airport city Characterized by radial transport connections Similarity to "the airport corridor" concept "Dominating city" (Kasarda, 2012)
Airport corridor	Marije Schaafsma	2008	The airport corridor arises in the area which connects the airport with the city center	Situated between the airport and the city Contributes to the stable integration of the airport into the city structure Connected to the city and the region by highways and railway "Can become an obstacle for the chord urban development and lead to the growth of the fragmented line building-up" (Schlaack, 2010)
Airea	Johanna Schlaack	2010	"The matrix of the fragmented building-up islands connected with the airport" (Schlaack, 2010)	Building-up fragments can be situated at a large distance from the airport Has similar features with the concepts of “airport corridor” and "aerotropolis"

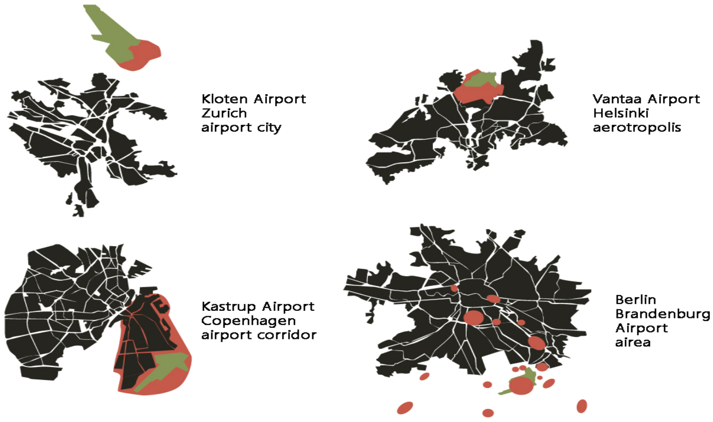

Figure 1. Examples of the formation of different models of the airport environs with the overlap on spatial urban patters

the connection of the city and the urban agglomeration with the airport? In different conditions, factors, which we considered above, begin to form the new urbanized territory in different ways. Availability of different prerequisites in the form of the development of some conditions or the shortage of others, as well as features of directions of the economic development of a city or an agglomeration, characteristics of the airport itself influence on the planning development as a whole. At the same time, the normative and economic controllability and adjustability of the development of the zones adjacent to airports in the presence of the common concept of the development of the city territory or the urban agglomeration in combination with the airport zone development or an individual concept of the airport environs is the essential difference of the formation of certain forms.

The spatial development of the airport environs can take various forms that follow from concepts of the development of the territories around airports, existing in the international practices (Table 1):

– Dense building-up on the territory or in close proximity to the airport which has qualitative characteristics of the city (airport city).

– Corridor building-up extended along the infrastructure connection between the city and the airport (airport corridor).

– City with the airport as the building-up core (aerotropolis).

– Building-up connected with the airport having the disperse nature (airea).

Further in the article (Figure 1), diagrams reflecting the practical formation of different models of the airport environs with overlap on the city spatial development are given. In particular, the cases when concepts turned out to be implemented most neatly and without distortions or are in the final phase of the formation are provided: airport city — within Kloten Airport in Zurich; aerotropolis — Vantaa Airport in Helsinki; airport corridor — Kastrup Airport in Copenhagen; airea — Willy Brandt Berlin Brandenburg Airport.

The research on the analysis of the formation and the development of the airport environs throughout the entire world conducted by the authors within the study of the development of the Pulkovo Airport shows that theoretical models proposed by different researchers and analyzed by the authors are not alternative or mutually exclusive formats of the development of the airport environs, but reflect various approaches to the solution of problems connected with the development of such territories. Upon comparison of the proposed theoretical models, it has been revealed that the principle of the integral urban layout is the cornerstone of all of them, i.e. all of them propose the formation of the united zone — with its connections with the airport, with the city and with subzones within such zone. This principle is not conflicting even in case with the distributed airea model. There are differences in the density organization of the zone adjacent to the airport and the priority of prospects of its development for a certain time interval connected with the development of the airport and the city. As a result, it is seen in terms of a considerable number of examples that it is extremely difficult to emphasize pure models implemented within transformations of the zones adjacent to airports. For example, in case with the Pulkovo Airport we can observe signs of three concepts at once: airport city, airport corridor and aerotropolis.

In Saint Petersburg, against the background of the active development of the territory around the airport, there is a problem in the lack of the worked-out strategy of the development of the airport environs and the concept of the air transport for the urban agglomeration as a whole influencing it. Moreover, the similar concept shall cover the issue of revealing the necessity of the appearance of new airports or the expansion of the existing airports and their influence on the urban agglomeration. The problem of the airport environs exists both for Pulkovo and a probable new airport which can appear within the boundaries of the Saint Petersburg agglomeration in the nearest 10–15 years. In order to reveal a current state of the problem, it is necessary to turn to the evolution of the territory development.

The evolution of the development of the airport environs in the Pulkovo Airport zone began in 1932 when "Shosseynaya" Aerodrome named by the adjoining railway platform was put into operation. The residential district “Aviagorodok” including several dwelling houses, a school, a shop and a first-aid post was raised together with the aerodrome construction. These are the first non-aviation functions which appeared in the airport environs. In 1951, a new building of "Shosseynaya" air terminal was opened according to the project of architect A. Gegello. Opening of the new airport terminal according to the project of A. Zhuk took place in 1973. The airport got the name of Pulkovo. Since the late 1990s, the gradual concentration of the activity around the airport has become more and more obvious. In 1986, a renovated air-terminal complex Pulkovo-2 was opened (http://www.pulkovoairport.ru/about/history).

For the Pulkovo territory, as well as for other Russian airports, the stage of the formation of the market land value in this zone and the privatization period prior to it, which began in 1991, became one of the key stages of the evolution of the development of the territories around them. Lands around the airport began to be actively developed. In 2013, the construction of a new Pulkovo terminal was completed.

The land value in the airport zone is formed taking into account the possibility of its use and reflects the market demand for certain facilities with due account for the competition and the market capacity, legal urban-planning regimes of the land use and airport restrictions including burdens imposed by radio navigation systems, height restrictions, safety requirements, environmental state of the land and the air basin, the current state and the planned development of the transport and engineering infrastructure. Additional restrictions could be imposed by the facilities functioning in the airport zone including such facility as the Pulkovo Observatory. Another significant factor is the development of the airport itself taking into account its capacity, the number of airlines and plans for the further transformation. Another considerable factor is the development of different functions, first of all, residential and production functions in the frontier zone which is actually not connected with the airport directly through functional connections, but influences the attractiveness of the arrangement of certain facilities in the airport zone.

What of these factors and how influenced the development processes at the Pulkovo Airport environs? It is possible to retrace the attractiveness of certain territories for investments with due account for their development and the market land value change.

The lands around the Pulkovo Airport before the privatization stage in 1991 were used, first of all, as agricultural and belonged to a number of large agricultural enterprises. As a result of the privatization, actually more than 4,000 ha were privatized and turned out to be involved in the turnover. Most of them ceased to be used as agricultural lands taking into account low economic effectiveness of this activity in the specified zone and the enhanced pollution of soil and the air basin in the airport zone.

The market land value in the Pulkovo Airport zone increased sharply in the range from 50% up to 250% during the last ten years (according to the data of ARIN LLC). Not more than40 % of the territory (according to the data of the authors, obtained in the course of works on updating (site plan Territories of the zone under influence of the Pulkovo Airport, as well as a number of other works executed by the order of the Investments and Strategic Projects Committee of Saint Petersburg during 2009–2012)) were in the ownership of the city and municipal authorities of the city and the region in the zone restricted by main roads adjacent to the airport by 2010.

A particular interest among developers in the last 8 years was drawn to lots whereon the construction of apartment buildings was allowed but in view of the underdevelopment of the transport and engineering infrastructure and the lack of the program of the full-scale environmental recovery of the territory, a considerable part of projects was not implemented. The attempt of the residential building-up in the technical zones of the airport resulted in the cancellation of a part of projects, and another part of projects had a considerable negative effect on the Pulkovo Observatory complex situated in the airport zone.

The active formation of the business zone in close proximity to the airport was restrained in many respects by the lack of large companies of tenants, on which similar facilities are focused. However, coming of companies related to PJSC Gazprom and opening of the largest exhibition site "Expoforum" resulted in a high degree of occupancy of office facilities and increase in the further demand for office areas in this district.

With the increase in the airport capacity and the development of business and exhibition functions around it, the development of hotel facilities became needed too. The development of trade functions was in many respects influenced by the active development of the residential development in the southern part of the city and the transport infrastructure development — the Saint Petersburg Ring Road and the Western High-Speed Diameter. At the same time, it is possible to retrace a gradual change of the attitude to the formation of shopping facilities in this zone. The commercial development around the Pulkovo Airport began mainly in 2006, when a large number of hypermarkets appears on the Pulkovo Highway; the drop in demand in the crisis period resulted in the low occupancy and attendance of trade and entertaining facilities, and, therefore, in the appearance of the term "cemetery of shopping centers" in 2008 ("Institute of Business Activity Problems" LLC, A. Shaskolskiy). However, the general development of the territory changed the market situation and made shopping facilities more attractive, which can be retraced at next stages of the territory development when five more large shopping facilities appeared in the airport zone.

The service and technological domain has actively developed in the last five years too. Representative offices of companies with their own sites selling equipment (transport and construction equipment) appear in the airport zone. At the same time, there is the development of forming industrial sites along Volkhonskoye Highway and Gorelovo, as well as in the adjoining part of Shushary. At the same time, the tendency towards the development of the peripheral territories adjacent to traffic arteries in the airport zone with the developed engineering infrastructure is observed. Other territories actually remain free. At the same time, it should be noted that practically all sites at certain time were or are available for active sale. The size of the sites being sold varies from 20 to 250 ha. Their considerable part is still on the market at the value of $ 30–120 per meter. The value in many respects depends on characteristics of the territory, however, taking into account sizes of plots, in general, they are diverse in respect of restrictions and urban-planning statuses. As a result, there is a considerable land bank of territories for the future development in the airport zone today, which is not involved in the development at the present time and does not include green zones. Actually, it is the territory having the area of 2,500 ha. A great part of these territories is not covered by the documentation on the territory planning approved or being developed at present. As we see, built-up territories are formed by separate locations which are not connected with each other and have no connections with the recreation.

Thus, in the Pulkovo Airport zone, prerequisites for the development of the territory within three concepts at once have been formed by now: the airport city in the form of the large scope of different service functions and the high density of the development in the zones connected with the arrangement of airport terminals; the airport corridor with regard to the active development of the territories along the highways connecting the airport and the city (first of all, it is the development along the Pulkovo Highway); the aerotropolis as the replication of services of the airport city around the expanded airport zone along the main radial highways (Figure 2).

How was the attitude of the city and the region to the development of the territories around the airport in the last 15 years formed? It shall be noted that in Saint Petersburg and the Leningrad Region the tendency to the integrated development of the entire territory in the airport zone both for two territorial entities and within one territorial entity could not be retraced for a rather long time. The work package on the preparation for the development of urban territories in 2009 by the initiative of ISPC (Investments and Strategic Projects Committee) can be noted out of city initiatives of Saint Petersburg. As for the rest, city initiatives were limited to the development of the external transport infrastructure and the airport zone itself directly. The integrated development of the airport environs was provided neither jointly nor independently as a part of documents of the spatial planning of the city and the region. There was no and there is no even a separate type of functional and territorial zones with due account to the situation in the airport zone. As a result, solutions in all documents were limited to the allocation of separated functional zones without a single common development concept. The development of the documentation on the territory planning also did not take into account the integrated development or special function of territories, which can be seen by the nature of the allocation of territories (Figure 3). In particular, no united traffic scheme or formed natural and environmental framework of the territory were provided; boundaries of

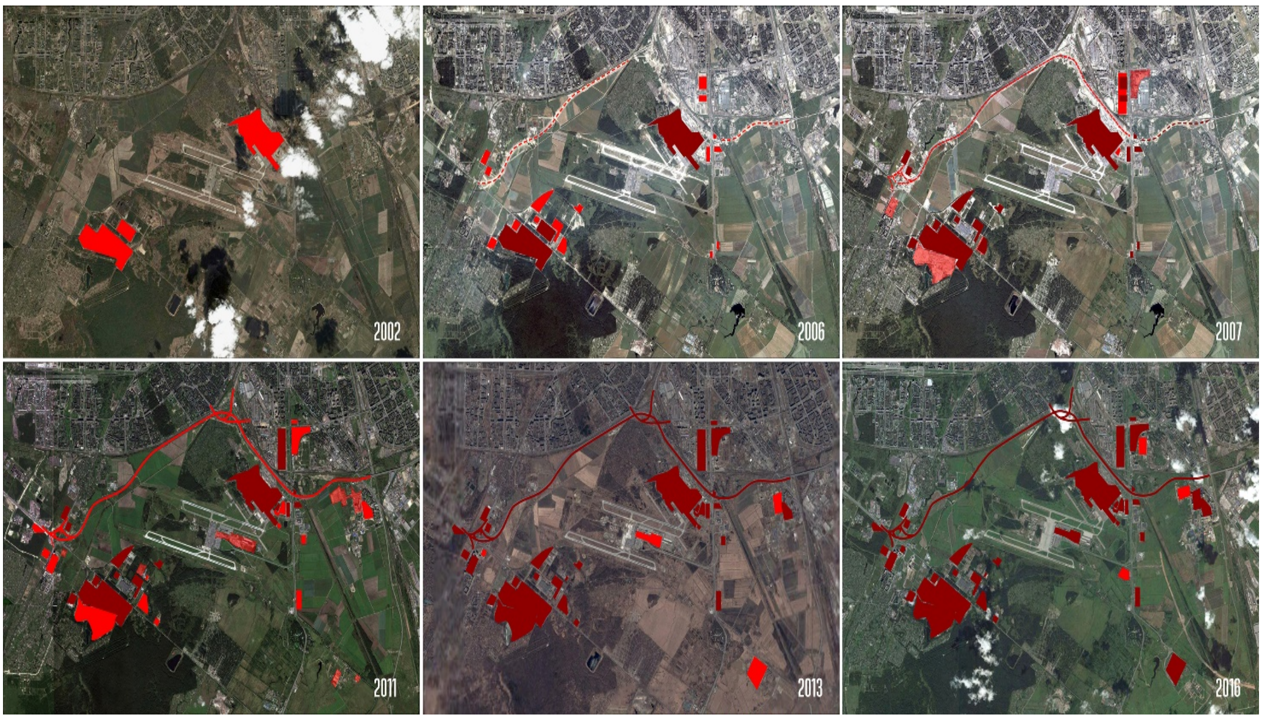

Figure 2. Dynamics of the development of the Pulkovo airport environs (based on Google maps)

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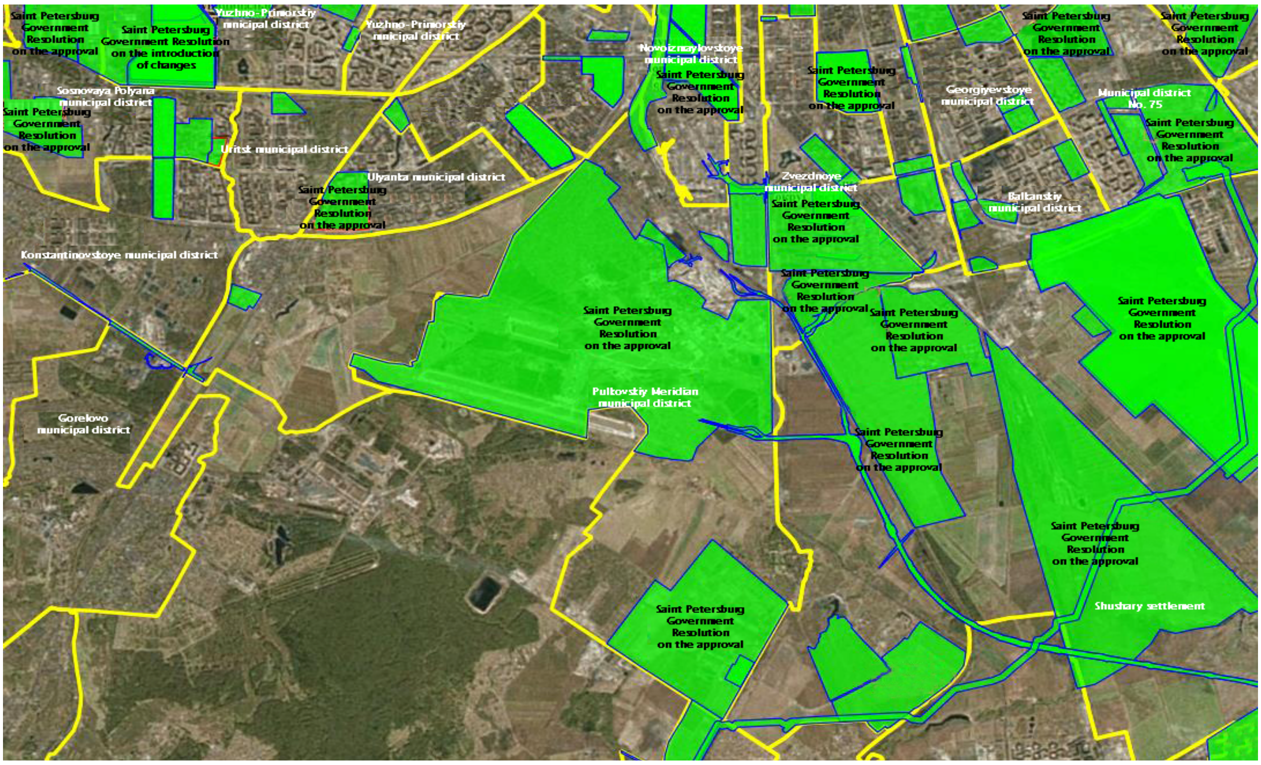

Figure 3. Approved planning designs in the zone of the Pulkovo Airport environs (Saint Petersburg)

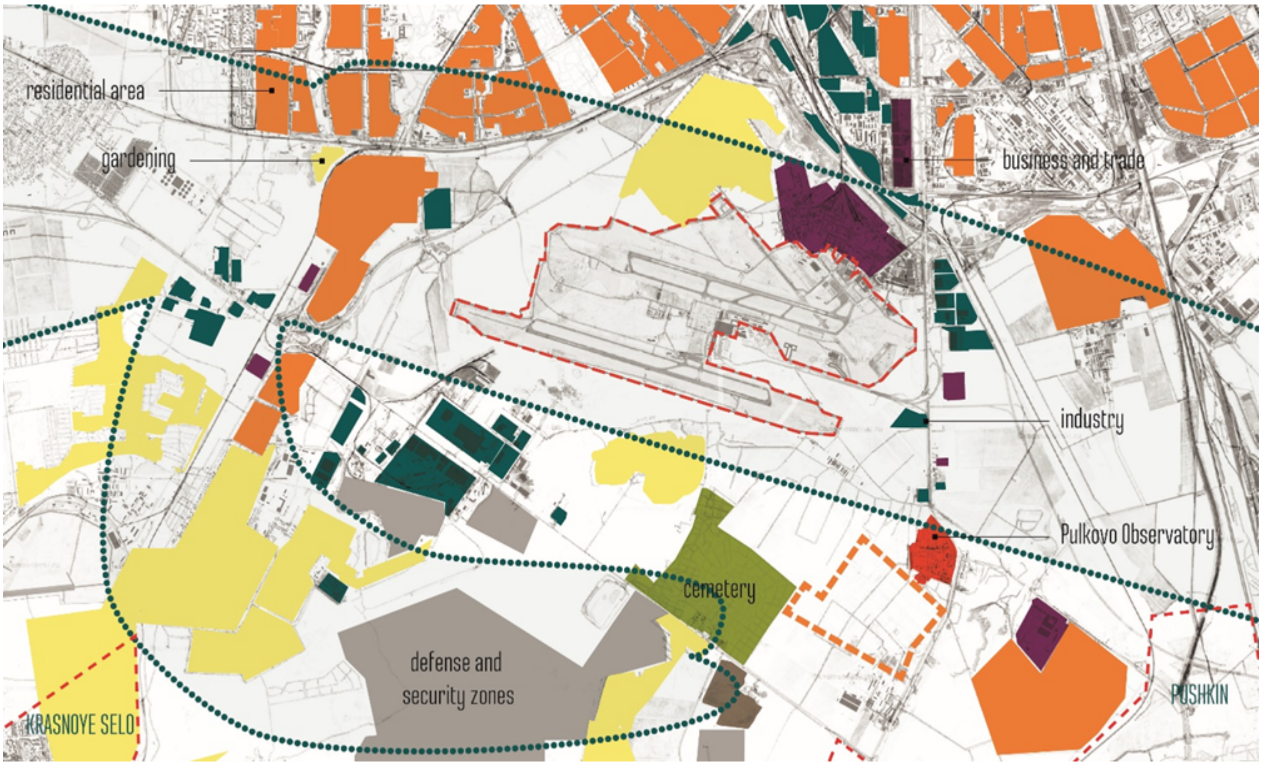

Figure 4. Existing functionality of the Pulkovo Airport environs

the allocated territories are not bound to the general spatial and planning development.

The results of the current state of the territories in the airport zone are presented on the following diagram (Figure 4). The shift of the urban-planning activity in Saint Petersburg towards the southern outskirts of the city has been observed in the last five years. The importance of the factor of proximity to the airport shows the increase in a number of large-scale developer projects; a number of large-scale housing projects including such projects as the satellite town of Yuzhniy are actively formed. Moskovskiy District becomes "the second district of the business activity in the Saint Petersburg agglomeration after the historical center" (Goncharova, Romanyuk, 2013). All transformations become prerequisites to the necessity of the integrated development of the airport environs in the Pulkovo Airport zone.

To determine the development direction of the Pulkovo Airport in Saint Petersburg, a number of problems at the territories, which are under its influence, have been revealed:

– imbalance of the forming building-up, its negative influence on the airport, natural environment and influence of separate facilities on each other;

– formation of the individual territorial enclaves which are not connected with the general urban-planning structure;

– lack of the developed transport infrastructure in the airport zone;

– "lack of the convenient and fast transport connection of the Pulkovo Airport with the central communication district of Saint Petersburg" (Laboratory of urban planning, 2015);

– incompleteness of the integrated transport system.

– inefficient use of the territory resource, undeveloped economic potential;

– high percentage of closed territories;

– lack of the integrated single concept of the development of the airport environs;

– unconformity of the urban-planning documentation.

Results

Considering the above-mentioned, the development of the territories around the airport of one of the largest cities is a naturally determined process which gains the spontaneous nature without any single development strategy. It results in the appearance of separate building-up clusters which are not connected with each other and with the surrounding territory. It should be noted that we mainly bespeak international airports in the largest cities having or striving for the "hub" status. Such scenario of the development as "coexistence" when "tasks of the territorial planning will remain focused on the decrease in the negative impact of the air transportation and the provision with the necessary land resources for the airport infrastructure construction in case of the growth of the passenger traffic" is suitable for less influential and small airports (Lezhava, Kudryavtsev, 2010).

At the present time, attempts of the building-up regulation in the airport environs have exclusively restrictive nature. In Russia, lands around airports are considered by town planners mainly as zones of the negative impact of the large facility of the transport infrastructure on surrounding settlements. And, consequently, the regulations restricting building-up near the airport become a reflection of such phenomenon. At the same time, the positive impulse which the airport can give to surrounding territories often remains unrealized. As a result, there is no initiative and no idea of how similar territories shall develop in general taking into account all existing restrictions. Moreover, the majority of researches deal with the issues of technical, transport and economic nature and do not touch upon the interconnection of the airport and the city. As a rule, they are focused on the solution of specific tasks, but not comprehensive problems. Though some of them recognize the necessity to manage and control the airport from the environmental, economic and legislative point of view, they often do not attribute adequate significance to the regional planning (Cipriani, 2012).

Conclusion

One of the most effective tools of the development of the Pulkovo Airport environs is the formation of a separate planning zone on its basis with the development of the single development strategy. This strategy shall not only reflect the integrated development of the territory, but it also shall have the designated spatial structure. For this purpose, it is required to take into account those techniques and methods which were worked out in the international practice during the last 20 years, and consider possibilities of their transformation in local conditions. In the situation with Saint Petersburg we still have an opportunity to set a vector of development to the airport environs in view of the availability of the territorial resource for the development around the airport. The single strategy shall be effective for the city and the agglomeration as a whole, take into account interests of all interested parties (the airport operator, the Government of Saint Petersburg and the Leningrad Region, investors and developers) [11]. The development of a renewed concept of urban planning independent of the administrative belonging with long-term strategic tasks and effective management tools is needed. The principle of urban-planning exterritoriality of the airport environs, which shall receive their own status and united urban-planning documentation, shall be taken as the basis of such concept. Such situation is possible both at the level of the decision of two territorial entities of the Russian Federation and by means of the preparation of relevant changes in urban-planning documents, in particular, the Town Planning Code of the Russian Federation, as it previously happened with the notion of transport hubs. The introduction of the notion of the airport environs to the legal urban-planning practice will allow establishing conditions for their comprehensive and effective development more efficiently.

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ENGINEERING FEATURES OF NO-DIG REPAIR OF OUTDOOR UTILITIES

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Abstract

Technological characteristics of the use of innovation methods for the no-dig repair of city infrastructure utilities, as well as prospects of the allocation of foreign technologies in Russia are considered in the work. The comparative analysis of technical and economic parameters of the pipeline section open-laying method with similar parameters of the most common no-dig repair technologies of gravity-flow discharge manifolds is reported with a specific example.

The authors made conclusions on the need to carry out additional further research on both the development of new domestic polymer materials and manufacture of the assembly equipment, and the improvement of the regulatory system for the development of new standard technological documentation for the wide introduction of promising technologies of no-dig repair of outdoor utilities in the construction practice.

Keywords

No-dig technologies, utilities, pipeline repair, renovation, recovery, discharge manifold.

Introduction

As the modern construction practice shows, the most competitive in terms of basic technical and economic parameters under conditions of dense urban development are technologies of no-dig repair and recovery of outdoor utilities and other underground facilities (Avdeeva et al., 2014; Verstov et al., 2008; Khramenkov et al., 2008).

No-dig technologies of recovery of outdoor utilities essentially represent overhaul of existing pipelines, since works are performed, as a rule, from existing wells (Kobelev, 2010), therefore, they do not need carrying out designing and surveying works, or additional expenditures for the construction site preparation, as well as design expertise and other approvals and financial investments, which are needed in new construction. The structure of costs for new construction and recovery of utilities with the use of no-dig technologies is shown in the diagram (Figure 1).

Subject, tasks and methods

In recent years, requirements to the quality of materials, which are applied in outdoor utilities of the municipal infrastructure, have been constantly increasing both in case of conventional open laying of pipelines and in case of no-dig methods of their renovation. The use of polymeric pipes and innovation technologies significantly facilitates and accelerates both the process of new utilities construction and repair of existing pipelines from conventional materials (Prodous, 2004).

At the present time, many large cities in Russia experience successful implementation of the program of reconstruction of existing water supply and sewerage utilities, which provides for fulfillment of works for renovation of outdoor utilities with the trenchless method in order to maintain the urban landscape and avoid traffic obstructions (Ministry of Construction of Russia, 2016; Orlov, 2012).

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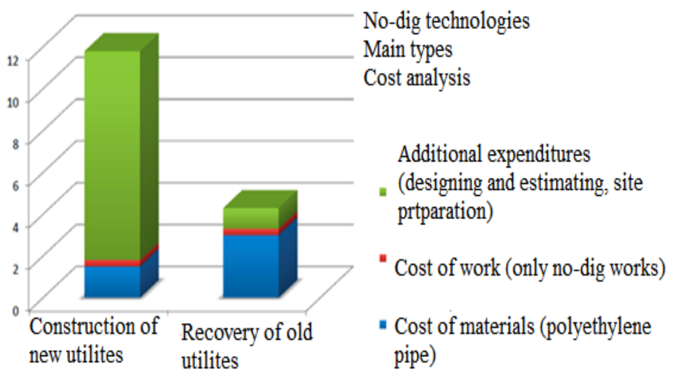

Figure 1. Cost structure of construction of new utilities and recovery of old utilities with the use of no-dig technologies

Besides, the use of no-dig technologies for renovation of urban underground utilities reduces the electric energy consumption by the power pumping equipment by 25–40% on the average, and, due to the use of pipes made of innovative polymer materials, it preserves and in some cases even increases the throughput of recovered pipelines (Verstov et al., 2008).

However, as the analysis of the existing regulatory base shows (Gosstroy of the USSR, 1987; GESNr 2001-66, 2008; Ministry of Construction of Russia, 2016), there is standard technological documentation for only some no-dig pipeline repair technologies. In the existing regulatory base, as a rule, there is no description of technological processes, data on the latest materials, necessary assembly equipment, which are actually used by contractors in the introduction of new methods of no-dig repair of outdoor utilities. In order to cut significant costs and time, which are needed for the development, agreement and approval of technological documentation for innovative methods of no-dig pipeline repair, contractors, with the consent of the customer, are forced to apply construction design documents, which, in most cases, only partly correspond to the specific no-dig technology used by the contractor at the site. The existing practice of drafting and agreeing calculations for a separate section of urban network under restoration is a very expensive procedure and has a lot of aspects which influence on the estimated cost of repairs. The lack of standard technological documentation and proper quality control of works performed by the contractor, as a rule, entails the non-compliance with the no-dig repair technology, which negatively affects the obtained results of pipeline recovery and often leads to increase of initial cost estimates for fulfillment of works.

Results of the study

The present article, using the example of comparison of carrying out works according to the open-laying technology applied to a section of urban DN 200 mm gravity-flow sewage manifold with a length of 100 running meters in accordance with Collection E9 of the Unified Norms and Prices (ENiR) (Gosstroy of the USSR, 1987), and the no-dig repair technology applied to an old pipeline in accordance with the State Estimate Norms for elements of construction and repair works GESNr 2001-66 (revision of 2008) (GESNr 2001-66, 2008), gives a brief description of technological processes and composition of works performed, machinery and equipment used, as well as results of the analysis of technical and economic parameters for compared technologies.

The technology of open laying of DN/OD 200/225 mm polypropylene corrugated double-layer inserted-joint pipe includes fulfillment of the following works:

- designing, agreeing and examination of the project;
- stopping of the road traffic, organization and agreeing of a scheme of a work site bypass route;
- removal of the road covering with disposal of concrete aggregates;
- mechanized soil development, trenching with wall fixing of frameworks, manual stripping of the bottom;
- disassembly of the existing manifold;
- arrangement of a sand base for pipes with layer-by-layer compacting;
- laying of new polypropylene inserted-joint pipelines;
- filling of pit holes, backfilling of the soil with layer-by-layer compacting in a trench;
- recovery of the road surface and improvement of adjacent territories along the entire pipeline route.

Machines and equipment used upon **open laying of DN/OD 200/225 mm polypropylene corrugated double-layer inserted-joint pipe**: a single bucket back-acting excavator, a bulldozer, an asphalt layer cutter, dump trucks, a truck crane, a diesel generator, an air compressor, a pneumatic rammer, an asphalt-spreader, an asphalt compactor, electric and hand tools.

Special features of work fulfillment: a long period of preparatory and installation works at each section of pipeline laying.

The technology of pulling a new SDR 17 DN 225 mm polyethylene 100 pressure pipe without destroying the existing pipeline includes such works as:

- designing, agreeing and examination of the repair project with the arrangement of excavation pits;
- stopping of the road traffic, organization and agreeing of a scheme of a work site bypass route for each section;
- removal of sections of the road covering with disposal of concrete aggregates;
- carrying out a set of earthworks for arrangement of excavation pits and dismantling of wells;
- backfilling of excavation pits with layer-by-layer compaction;
- recovery of the road surface in the excavation areas and improvement of the adjacent territory.

Machines and equipment used when **pulling a new SDR 17 DN 225 mm polyethylene 100 pressure pipe without destroying the existing pipeline**: equipment for mechanical cleaning and hydrodynamic flushing of a pipeline, TV inspection equipment, a hydraulic automatic winch or pneumatic tool for retraction of welded strings of polyethylene pipes, a welding machine for butt welding of polyethylene pipes, a single-bucket excavator, a truck crane, sheet piles, a dump truck, a diesel generator, an air compressor, pneumatic rammers, an asphalt-spreader, an asphalt compactor, electric and hand tools.

Special features of work fulfillment:

- a set of earthworks for arrangement of excavation pits and dismantling of wells at each assembly area shalle be carried out;
- a powerful winch is needed to pull a heavy string welded from measured sections of a pressure pipe;
- works on assembly of new inspection wells shall be carried out;
- recovery of the road surface in the excavation areas and improvement of the adjacent territory.

The technology of pulling a new SDR 17 DN 225 mm polyethylene 100 pipe with destruction of the existing pipeline with the help of a pneumatic drift hammer consists of the following technological processes:

- designing, agreeing and examination of the project;
- partial stopping of the road traffic, organization and agreeing of a scheme of a work site bypass route;
- removal of sections of the road covering with disposal of concrete aggregates;
- carrying out a set of earthworks for arrangement of excavation pits and dismantling of wells;
- preparation of a string of polyethylene pipes with welding of joints;
- installation of a winch on the metal shield base with subsequent dismantling;
- installation and dismantling of an anchor device, a rimer and a valve;
- assembly of a pneumatic hose, its pulling into the polyethylene pipe with subsequent dismantling;
- dragging of the string of polyethylene pipes with the help of the winch;
- closing of string ends;
- backfilling of excavation pits with layer-by-layer compaction;
- arrangement of inspection wells;
- recovery of the road surface in the excavation areas and improvement of the adjacent territory.

Machines and equipment used for pulling a new SDR 17 DN 225 mm polyethylene 100 pipe with destruction of the existing pipeline with the help of a pneumatic drift hammer: a special truck, a powerful pneumatic press machine, a hydraulic automatic winch with an adjustable head advance speed and effort, a welding machine for butt welding of polyethylene pipes, a compressor with a pressure of not less than 0.6 MPa for driving the pneumatic press machine, a device for control of pipeline bends of the repair section, a diesel generator, an excavator, a truck crane, sheet piles, a dump truck for soil removal, a diesel generator, jackhammers, pneumatic rammers, an asphalt-spreader, an asphalt compactor, electric and hand tools.

Special features of work fulfillment:

- a long and very noisy process of old pipeline destruction with possible significant displacement of soils.
- curved sections of the route cannot be used for driving;
- significant hindrances for the street traffic;
- high energy consumption, possible pollution of the environment.

The technology of sewage manifold recovery with the INSITUFORM method (sleeve of DN 200 mm) includes the following works:

- bypass of the route with opening of well covers;
- pumping and outflowing of waste waters through a temporary pipe;
- flushing of a pipe at siltation of not more than 30 % with the water suction and driving off a silt;
- inspection of the network state with a TV control device;
- breakdown of prominent parts of pipe connections in a well;
- technological process of sanitation with a heated DN 200 mm sleeve;
- pumping out of technological waters from wells;
- cutting out of a sleeve tail and chutes in wells with removal of wastes;
- TV inspection of the sleeve inner surface;
- sealing of joints of pipes and chutes in reinforced concrete wells.

The following equipment is used during these works: equipment for hydrodynamic washing and cleaning of pipelines, equipment for TV-inspection of pipes, a heat- and UV radiation generator, a conductor casing, a take-up catch for sleeve dragging out, a heat-resistant hose, a buffer, a rubber stopper, a mechanical or electric winch for pulling of the sleeve, a mobile process system for sleeve polymerization, a robot-cutter for making holes in the wall of a polymer pipe, electric and hand tools.

Special features of work fulfillment:

- a set of expensive special equipment is required;
- the technological process of preparation, installation and warm-up of the sleeve for its polymerization is very complex, long and continuous;
- the material of the sleeve, sewn from polyester fiber or fiberglass, is pre-impregnated with epoxy resins and delivered to the site in a sealed package;
- the sleeve is very sensitive to the ambient temperature, the impregnated material has a limited period of use, having harmful chemical effect on humans at the direct contact;
- not environmentally friendly and not subject to disposal.

Since the formation of a new pipe is carried out under the ground, it is very difficult to control the work quality until its completion. It is almost impossible to pull out a pipe in the installation process.

The technology of no-dig recovery of sewage pipelines with the FLEXOREN method (DN of 200 mm) includes the following works:

- the existing sewage manifold is flushed with a high pressure water jet at silting-up of not more than 30 % and is cleaned with other methods;

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- TV examination of the existing sewage manifold for detection of hidden connections, damages or displacements of pipes;
- pipes and assembly equipment are delivered and stored in the immediate proximity to the assembly site (usually on the sidewalk or the roadside);
- road traffic in the repair area is not stopped,

temporary barriers are installed around wells, not obstructing the traffic or movement of pedestrians;
- a fiberglass line is pushed from the feeding well into the receiving well, a winch pulling cable is then pulled with it;
- a pipe guide with an extension rod is installed in the feeding well and a guiding support is mounted above this well;
- a reversible block and an extension rod are mounted in the receiving well, and the winch is mounted above this well;
- sections of pipes are welded into a string with the help of welding rings with an embedded heating element;
- dragging and detaching of the meter template of a pipe;
- joining of the head to the string with its subsequent detachment;
- dragging the polyethylene pipe string into the existing sewage manifold through the well in the streamline direction with the help of the winch installed above the receiving well;
- filling of the annular space with light cement-sand mortar or foam concrete;
- jointing of inlet and outlet openings of the pipe and the well with cement mortar;
- control TV-inspection of the recovered sewage manifold and check of its tightness.

In order to carry out works according to the technology of no-dig recovery of sewage pipelines with the FLEXOREN method (DN 200 mm), the following machines and equipment are required: equipment for TV-inspection of pipelines, a welding machine for welding polyethylene pipes with couplings with embedded heating elements, a welding frame, pipe retainers, a pullout line, a winch, a guide support above the well, a concrete pump for annular space filling.

Special features of work fulfillment:
- a unique wall design and pipe flexibility for repair of gravity-flow sewage manifolds through wells;
- repair of the sewerage system is carried out without stopping the road traffic;
- operation of the sewage manifold is allowed in the process of its sanation;
- a continuous pipe completely covers the distance between wells;
- a significant increase in the throughput of the existing sewage manifold and a high degree of new pipe self-cleaning;
- does not interfere with the traffic and movement of the inhabitants of adjacent houses;
- a crew of 3 people can repair 200–300 m of pre-prepared sewage manifolds with the internal diameter from 100 up to 300 mm during a shift.

Results and discussion

The data of comparison of different technologies of open laying and no-dig repair of pipelines by costs and labor inputs are given in Table 1.

Table 1. Comparative economic parameters of technologies of open laying and no-dig repair of pipelines

Technology and reference to the regulatory document	Cost of materials, %	Labor inputs, %	Estimated cost, %
Technology of open laying of DN/OD 200/225 mm polypropylene inserted-joint pipe (ENiR E9-2)	51	83	67
Pulling of a new SDR 17 DN 225 mm polyethylene 100 pipe without destruction of the existing pipeline (TERr66-32)	29	36	32
Stretching of a new SDR 17 DN 225 mm polyethylene 100 pipe with destruction of the existing pipeline with a pneumatic drift hammer (TERr66-31)	24	42	33
Sewage manifold recovery with the INSITUFORM method DN=200 mm (TERr 66-41)	100	100	100
No-dig recovery of sewage pipelines with the FLEXOREN method DN 200 mm (TERr 66-40)	28	21	25

As it follows from the analysis of the obtained results, given in Table 1,

the application of innovative technologies of no-dig pipeline repair with the use of high-quality polymer materials is undoubtedly an economically effective long-term investment in the urban infrastructure in comparison with the use of the conventional open laying method. However, not nearly in all Russian cities, even in large ones, infrastructure enterprises can use modern no-dig technologies for laying new pipelines and repairing existing pipeline networks. Unfortunately, innovative no-dig technologies are up to now unavailable for a lot of housing and utilities enterprises due to the insufficient funding of regional programs of construction and repair of outdoor utilities.

Conclusion

1. Additional researches on both the development of new domestic polymer materials and manufacture of assembly equipment, and the development of cost-effective innovative technologies of no-dig pipeline repair are necessary for the large-scale implementation of no-dig methods of underground utilities recovery in the engineering practice.

2. There is an urgent need to improve the existing regulatory base and develop a new one for creation of standard technological documentation on innovative technologies of no-dig repair of outside utilities.

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