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READING A LANDSCAPE

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Abstract

I have traveled often through the streets of my country by car, motorcycle, bicycle and on foot, and each time the landscape has always accompanied me like a faithful companion. Whenever I stopped to look at this land, whether up close or from afar, I continually see with eyes scrutinizing every detail of every corner. There is an irresistible attraction that has always pushed me to immerse myself in that view, as if it was a gentle reminder to enjoy that beauty.

The landscape does not exist by itself: the landscape exists when people observe the terrain and the landscape becomes subjective based on their personal experience of that view. But the landscape is also objective when it becomes the bearer of the cultural identity of a land and of its people.

The landscape may seem eternal and unchanging in its vastness and its characteristics, but in reality landscapes do change like a living being, giving us the feeling of a "permanent transformation" that is the great charm of the landscape.

The landscape is like a book that we can read, with its own grammar, signs and meanings, or it is like a musical score with its own notes, rhythms and pitches. Each element that makes up the landscape can contribute to the concept of beauty if it is harmoniously linked with the others. Unfortunately there are too many cases in which human intervention creates grammatical errors in the text or false notes in the music. As a whole, the landscape is a significant indicator of social transformation and the level of quality of life of a community.

Keywords

Landscape, terrain, painting, natural scenery, view, perception.

Definition of Landscape

"Landscape is a certain part of the terrain, as it is conceived by people, whose character derives from the natural and / or human factors and their interrelations."

(European Landscape Convention - Florence - 2000)

"View: a panoramic scene of a given point of a terrain, with reference to its characteristic natural beauty or of places of historical and artistic interest; all the complexities of the natural assets that are a fundamental part of the ecological environment to defend and preserve."

(Encyclopedic Italian Dictionary Treccani)



Figure 1. The landscape is like a book to read

Landscape = Subject + Nature (Michael Jacob)

"A view is not a landscape when nature is randomly scattered upon a piece of land; a view is transformed to a landscape by nature in its individuality and by the human eye."

(Georg Simmel, Philosophy of the landscape).

"A section or expanse of rural scenery, usually extensive, that can be seen from a single viewpoint."

(Thesaurus.com)

"A large area of countryside, especially in relation to its appearance."

(Cambridge Dictionary)

"All the visible features of an area of land, often considered in terms of their aesthetic appeal."

(Oxford Dictionary)

"A painting, drawing, photograph, depicting natural scenery."

(British Dictionary)

"The landscape is the shape of the environment." (Barocchi R., Italian Urban Dictionary)

Components of the landscape

Environment: everything (that part of the Universe) in the surroundings or conditions in which a person, animal, or plant lives or operates.

Landscape: a section or expanse of rural scenery, usually extensive, that can be seen from a single viewpoint.;

View: the landscape as you see it from a certain place looking in a certain direction;

Picture: how each of us perceives a certain view; a design or representation made by various means (as painting, drawing, or photography) that is so vivid or graphic as to suggest a mental image or give an accurate idea of something.

Perceiver: a person who becomes aware of, knows or understands a certain landscape at a certain time, from a certain point, looking in a certain direction.

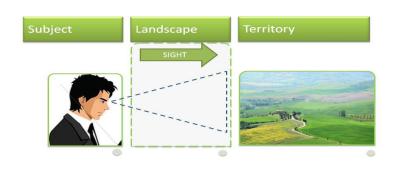


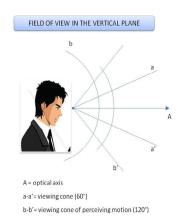


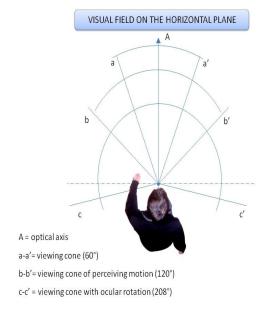
Figure 2, 3. Romantic paintings with people seeing landscapes

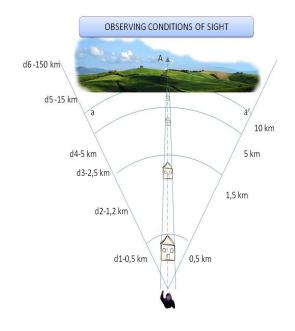


Figure 4. Guidi Palace - Poppi - Italy - 1930









A = optical axis

a-a'= viewing cone (60°)

d1 = Proximity area (recognition of small details)

d2 = Near contest area distance between 0,5 and 1,2 km (good recognition of the scene's elements)

d3 = Intermediate context area distance between 1,2 and 2,5 km

d4 = Away context area distance between 2,5 and 5 km

d5 = Wide area (descending recognition of large elements) distance between 5 and 15 km $\,$

d6 = Backdrops also up to 150 km with high profiles and clear sky

Figure 5. A landscape exists when people look at it: note the optical axis and visual fields above

Looking at a landscape

The landscape is what we see: this is how our sight attaches to a point; it is an impression of the senses. The perception of a landscape is therefore a sentimental impression. Look far and near: depending on where you live, landscapes train the eye to a different visual depth. The great plains of the great nations (USA, Russia) train the eye for long, faraway gazes at the breadth and depth of a terrain, while the hilly and constructed nations (Italy) train the eye for shorter views because the landscape is restricted in size and is developed in small plots (patchwork landscape.)

Significance of the landscape

What does "landscape" means? The answers are varied, depending on the perceiver, such as: the urban planner, the architect, the farmer, the geographer, the philosopher, the psychologist, the optometrist, the anthropologist, the painter, the musician, the tourist.

The image that each of us has of a place so dependent on local forms, which are the same for everyone. However, the perceiver's point of view, the direction in which the perceiver looks and the perceiver's personality contribute to how the image of those forms, such as a forest is perceived.

This image will vary depending on the perspective compared to an ordinary person, such as a poet, a ranger, an architect, a naturalist and so on.

According to scientists, the landscape is a combination of a set of objects and the relationships between them. According to historians, a landscape is the result of evolution of nature and human action In fact, when a building committee examines a building project in an area subject to landscape constraints it does not examine the plant or the calculations, but how the shape correlates with the appearance of the place where it will be built.

But there is an ultimate meaning from a symbolic point of view in which we can bring them back together: the landscape speaks of the person to person expression and reproduction of past and present cultural identity, either, in harmony or in contrast with each other. At the same time, the meaning of the landscape is produced in the encounter with the person who experiences, transforms and explores it with curiosity and or enchantment.

The basic concept is that the landscape does not exist as an objective reality: it is born of the sensory stimulus, it is an act of perception. The perception of the landscape is through space that represents the meeting point between me (the subject) and it (the landscape).







Figure 7. A woman enjoying a view of the Crete Senesi - Italy



Figure 8,9. Views of Crete Senesi - Italy

That space is a function of the perceiver's point of view, which is not only physical but also based on what the perceiver expects to see. The landscape thus has a subjective component: the landscape is born when someone sees it. So "we are our landscapes."

There are no landscapes without humans: a country or a terrain can exist without us, a landscape cannot exist without us. An example of how a landscape can change the perception of a terrain is with the Crete Senesi, a natural, wild but charming area south of Siena, in Tuscany, Italy: a horrible and depressed landscape in the past (low agricultural productivity, uninhabitable, impractical) which has become a beautiful landscape in the present (untouched natural landscape).

Conceptually speaking, a landscape is the opposite of a terrain with simply its collection of trees, grass, hills, and so on; it is something more. For example, maps fail to represent the scenery of a landscape.

Julius Verne describes in "Around the World in 80 Days", the spatialization of the world: in that case the subject is moving. Today, with the rise of globalization (since 1969, when two computers first communicated with each other), time and space are intertwined. On the web there is no longer the subject / object separation: the world economy operates at the same time in unison.

"Today, after more than a century of electronic technology, we have extended our central nervous system so that it has become a global embrace, abolishing the limits of space and time with regard to our planet."

(Herbert Marshall McLuhan)

So in today's world, distinguishing between space and time has little meaning: to appreciate the landscape as a subject, it is necessary to leave behind this modern concept and return to our natural, human experience of space and time. What models do we have to evaluate ourselves in the world? For this we need the landscape: the landscape can preserve our collective humanity.

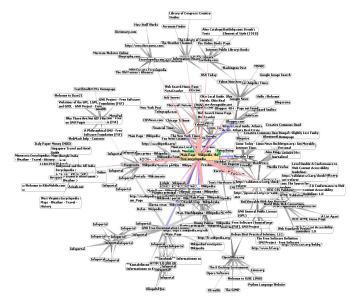


Figure 11. A graphic representation of the internet



Figure 10. Julius Verne "Around the World in 80 Days"



Figure 12. The landscape is a work of art (Waitakere - New Zealand)

The landscape is made up of places that "speak" to us about the way they were born, formed and layered. They communicate by revealing their identity or recognizing and interacting with other identities. There are two in landscape concept traditions:

- 1. The "cognitive landscape" understands landscapes as a set of "things," of tangible elements, and (possibly) the processes that formed them (traditionally called "substantialist").
- 2. The "narrative landscape" understands landscapes as a reflection of cultural processes (cultural tradition).

There are landscapes that many of us do not like (or even do not attract our attention) because we do not understand them; if we do not understand how they are formed, then tell us nothing. But if somebody explains this, then it is likely that those landscapes (such as artwork illustrated by an expert) peak our interest. History and social sciences on the one hand, natural sciences on the other, are the bodies of knowledge that help us understand landscapes, to make "friends" with us. So, landscapes (i.e., the terrain that evokes our emotions, feelings and sense of belonging) are not fixed; they can grow and multiply in our perception as we learn about them. And, our tendency to react strongly if we see "our landscapes" threatened will increase, even for landscapes in distant places, to which we affection.

Statements about the landscape

The land belongs to its owners, but the landscape belongs to those who can appreciate it.

The landscape is the most beautiful energy that you can get for nothing.

A landscape is the magic of a sunset, the bridge that brings together people and nature.

The landscape is not only the result of the relationship between people and environment: it is the best indicator of health of this relationship.

The landscape is that which is around us (that is, after all, "the country"), and arouses in us emotions, feelings, and in particular a sense of belonging.

Do not govern the landscape but the human behavior acting upon it.



Figure 14. The landscape is a work of art (Volterra - Italy)



Figure 13. A view of Val d'Orcia - Italy

Because the novelty of the world today is this: that more and more landscapes are "ours" because we are increasingly mobile and "possess" many more landscapes than past generations.

Every place has a landscape and every landscape takes on values.

The landscape and art are closely related entities because in the landscape there is nature, and art is the right arm of nature. To this a landscape is like a picture that is a work of art.

Cultural approach to the landscape

The image of nature and landscapes owes much to the aesthetic representations derived from paintings, travel accounts and postcards to the extent that we think about the landscape as a cultural construction. This landscape-image relationship over time refers to the cultural construction of the landscape and the false choice between the "authentic" and the "inauthentic:" the authentic landscape is an invention or better, a cultural construction. Yet this false choice has determined, and still determines, the aesthetic appreciation of the landscape, its recognition as something beautiful and worthy of being observed.

The recognition of what is beautiful finds its aesthetic explanation, for example, with Sienese painters and with photographers who have "frozen" the landscape of the Crete and Chianti to make them one of the most favorite and desired images both locally and worldwide. Photographs of green pastures, sunflower fields, the hay bale decorating the barren hills, cypresses as the only shrub that stand out amid the arid expanses, are very well known in the tourist imagination. Contemplation, for that matter, is the first act of the foundation of the landscape: it exists through our eyes (although there is also space), and ethnological analysis can focus on the ways in which people who relate to the landscape tend to mold it, define it, build it, and through these practices, define their own identity.

Appropriating the places where people live provides the opportunity to tame the landscape, turning it into

something familiar, something to recognize creating a feeling of "home."

The urbanite looks at the landscape with a desire to go to live in the country, to return to nature, as if they had lost a part of their roots in the frantic city life. The lifestyle is slower, the shops are very welcoming, the shopkeepers are more friendly. Everything is known by everyone, you can count on the things that you see, the neighbor is a friend, respects you, and will not ignore you as in the city life. It's very different than living in a condo and shopping at the supermarket. Those who decide to live in the country recover serenity from their daily life spent in the car half the day taking their children to school or the gym or going to the market. For those reasons or even for economic ones, people who live in city make the trip out of town for the weekend or go in a farm to curl up in nature.

The modern way to experience the countryside by an urbanite produces environmental changes to the land: the country takes all the comforts of the city away, so urbanites build garages, perimeter walls, gates. The urbanite who goes to live in the country does not like the shit of the hens, the stench, or the mud. The urbanite has an aesthetic approach to life, while the farmer has a utilitarian approach to life.

For farmers, the beauty is utilitarian: an ox, a sunset, a tree are beautiful if they are useful to them. An uncultivated field is ugly to the farmer because BEAUTY = PROFIT. As for the urbanite, an uncultivated field can be beautiful. If an olive tree is not pruned, it's useless for the farmer, while it may be pretty for the urbanite. So, there are different perspectives of the countryside and the landscape:

- For those who go to live in the country ---> romantic vision, need for city services, lawn;
- For those who have always lived in the country
 economic and utilitarian perspective. LANDSCAPE
 SURVIVAL



Figure 15. The country peoples' conception of landscape (1908- Italy)



Figure 16. The romantic painter's conception of landscape

Read and listen to the landscape

Perception is a simultaneous phenomenon that recognizes the landscape in continuous harmony with the model of holistic continuity of Gestalt:

The whole is more than the sum of its individual parts (basic Gestalt principle)

Walking through a terrain you will find invisible landscapes made of scents and sounds that interact with the person looking at the landscape. There is an order in the landscape, a grammar similar to a musical score, a landscape's music or "Soundscape." You can find this musical symphony anywhere in a landscape. If you shoot a 360° photo of a landscape, there are repetitions and sequences to the different parts of the landscape: combining a sound to every part produces music, music specific and exclusive to that location.

We must avoid the urbanite's experience of estrangement from the countryside that leads them to look for opportunities to exploit landscapes rather than live in peace and harmony with the environment. Care of the landscape requires integration between people and the environment, an approach that bridges the gap between us humans as subjects observing the nature that surrounds us..

We can only know the landscape by going through it.

Even if a landscape has been altered as a result of social and cultural norms or human use, we have to walk through the landscape rather than watch it from the outside in order to understand it. The correct way to learn about the landscape is to spend adequate time, to go slowly, and to be far from the frenetic rhythm of daily life. The best approach to understanding the landscape is to follow your curiosity as a process of discovery rather than being confined to the constraints of the goals to be achieved pacing quickly through its paths.

This is the delightful mobile landscape in which we move slowly along to perceive its fine textures. When our body is moving slowly in space we understand the culture and the meanings of the elements of the landscape that we can see; these give us a sense of pleasure and of comfort.. We experience the enjoyment of the landscape when we rediscover the integration of space and time. In view of vulnerability of landscapes and the risk factors that effect the space and time balance, we must safeguard them from interventions and restoration.

Economy and landscape

The landscape is now considered so valuable that it cannot be reproduced; it functions as an economic driver of an area and production systems connected to it, and is threatened by the globalization of markets and the loss of competitiveness of large production areas. From this point of view, not only are the roles of diversity and historical identity competitive factors, but also the restoration and design of new landscapes can combine qualitative and production goals.

The distinctive landscape is not the result of any particular agriculture, nor a generic idea of a "return to nature" or "abandonment of nature;" these are not effective ways to achieve the sustainability of development. It is common to confuse the landscape with nature conservation, while the advantage of economic development, derives from the value of the landscape, this does not take responsibility for its quality into account. This should be a smart balance between land management and a beautiful landscape. Because a beautiful landscape is the result of good care of the land rather it its image, we can instantly tell if a landscape is beautiful or ugly standing in front of its panorama: the sense of beauty is the result of a harmony that originates from the way the land is used.



Figure 17. Walking along the Chianti area (Italy)



Figure 18. Walking along the Crete Senesi area (Italy)



Figure 19. Vitaleta chapel (San Quirico d'Orcia-Tuscany- Italy)

A good landscape which identifies a location, is a need for all of us. A good landscape produces a sense of well-being, a bad landscape produces malaise. The landscape also affects our actions and our choices: wine from a nice area can be considered better than one from a place that is not considered a quality location; a degraded landscape reduces destructive inhibitions and contributes to social decay and crime (the theory of the broken window).

A good landscape also has great economic importance. In Italy tourism produces about 30% of the gross national product, but it would not exist if there was no tourism for beautiful and interesting places to go and see. When we search for the house we wish for, if we can afford a home "with view," this costs significantly more than a comparable house that overlooks a courtyard or on a busy road. The same situation applies to hotels: rooms with views cost more than those with no views.

The fact that the beauty of a landscape is a need and has economic value, its cost is now under study. For example, Francesco Marangon and Tiziano Tempesta, agricultural economists have estimated the economic value of the beauty of a vineyard to be around one thousand euro per hectare (Marangon F., T. Storm, The impact on the landscape of the hilly wine-growing. An economic assessment of Friuli DOC zone - Venezia Giulia.

What then is the value of the beauty of a landscape? How much is the value of a view, the view from an exact point in the terrain? The subject is fascinating: surely the real estate market takes this into account with its economic guidelines. This point is a challenge, which is to be able to provide an exact economic value to a specific landscape. But the overall question is: what is the value of beauty?



Figure 20. A very natural landscape (Waitakere – New Zealand)

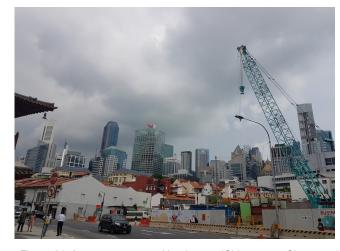


Figure 21. A very constructed landscape (Chinatown – Singapore)



Figure 22. A good countryside landscape (Monteoliveto-Tuscany-Italy)



Figure 23. A bad countryside landscape (Mondello-Sicily-Italy)



Figure 24. A new Italian style villa Bramasolo (Bejing-China)



Figure 25. The new Italian style village Bramasolo (Bejing-China)



Figure 26. Ambrogio Lorenzetti: "Effetti del Buon Governo in campagna", 1338-1339 (Sala della Pace, Palazzo Pubblico, Siena-Italy)



Figure 27. Typical "cabreo", an agricoltural map of 1775 (Monterspertoli, Tuscany-Italy)

The landscape has already become a marketing tool in the world: for example in Beijing (China) a "Tuscan village" was rebuilt to sell new villas to rich Chinese people who lives in the polluted capital, using the Italian style, and the charm of the beautiful Tuscan landscape (Italian). On a sign at the entrance of the village it is written:

"Italian lifestyle, romantic and comfortable lifestyle, full of beautiful sunshine, sunflowers, beautiful peace, brilliant Italian temperament, an optimistic desire to sunlight."

Evolution of the landscape

The landscape may seem eternal, unchanging in its vastness and its characteristics but in reality landscapes change like a huge living being: the landscape changes with seasonal variations (natural reasons) and with changes produced by human activity (artificial reasons). Both of these causes change the fields crops (seasonality and agricultural production cycles) and introduce new elements (modeling of the terrain, buildings). The feeling of "permanent variability" is the great charm of the landscape.

We, living mainly in cities, are not aware of the transformations of the streets, the shops, the signs, and other urban indicators of change because we have adapted to the reality that the city should transform itself. The natural or countryside landscape is assumed to be unchangeable and would always remain the same because it constitutes our "cultural stillness" in which to entrust our certainties. In fact, the landscape changes, like us, like our lives, like our society.

For centuries the landscape didn't have great changes: little changes in cities, little changes in countryside until the second world war.



Figure 28. The seasonal changes of the landscape (Villa near San Quirico d'Orcia, Gladiator movie set, Tuscany-Italy)



Figure 29. The seasonal changes of the landscape (Villa near San Quirico d'Orcia, Gladiator movie set, Tuscany-Italy)

The crisis and disintegration of sharecropping (which exploded at the end of the last war for reasons both economic and social) was born along with landscapes covered by urbanization, the abandonment of the countryside or planned reforestation. New rural landscapes, much more uniform than the old ones, were products of the market conversion resulting from the reorganization of the economic system now based on crop specialization, automation, and large corporations or directly managed by small business owners. This is at the cost of a large number of farmhouses and villas that were almost always converted to non-agricultural use or not infrequently left in a state of neglect.

These aerial images of the camps in 1954 shows very jagged small plots and with almost complete exploitation of the soil. For centuries the landscape had the same image. After almost 60 years, an aerial photo in 2013 of the same place, shows that the land is unrecognizable: crops changed, there are few but extended plots, and wooded areas are enhanced. The end of sharecropping and the depopulation of the countryside along with automation have led to specialization of the utility of the land. These changes in land use and thus of the landscape are continuous and incessant because they are related to the use that people make, which in turn change in response to changing society.

In Italy, for example, in 94 years (1911 to 2005) we have witnessed:

- Agricultural land was reduced from 22 to 12 mlnha

- The wood is increased from 5 to 10 mlnha
- The total population increased from 35 mln to 60 mln
- The population of the country has decreased by 15 million (43% of 35 million) to 4 million (6% of 60 million).
- From 1990 to 2005, the urbanization in Italy has eroded agricultural land to 8,200 ha / year.
- From 1954 to 2003 Florence has doubled the urban area but the population has remained the same.

How can we take care of the terrain and therefore the landscape? The approach to caring for agricultural terrain has become almost exclusively economic, which for centuries has consolidated the image of a rural landscape to be very small (the farmer always had the hoe behind him). This is food for thought for further investigation on the best development of the land.

Examples of mistakes in the landscape

The landscape evolution is a long process which needs a right time according to the entity of the change.

In fact when new developments of villages in the countryside are planned and realized, they raise a lot of discussions and debates that sometime take on very hard tone because that plan change quickly the cultural identity of the place.



Figure 30. The impressive changes of the landscape at Argenina (Chianti area-Tuscany-Italy)

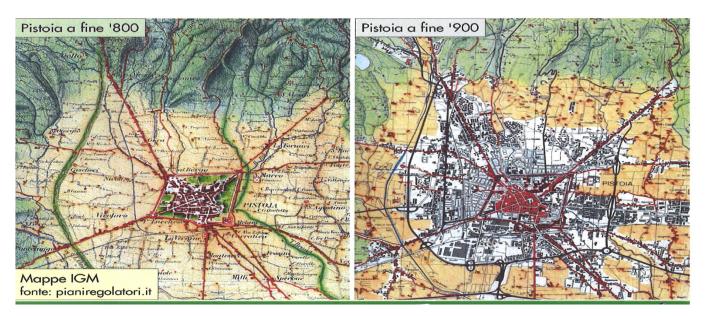


Figure 31. Development of the city of Pistoia – end 1800 end 1900 (Pistoia-Tuscany-Italy)



Figure 32, 33, 34. Cases of villages developments on hill positions (Tuscany-Italy)

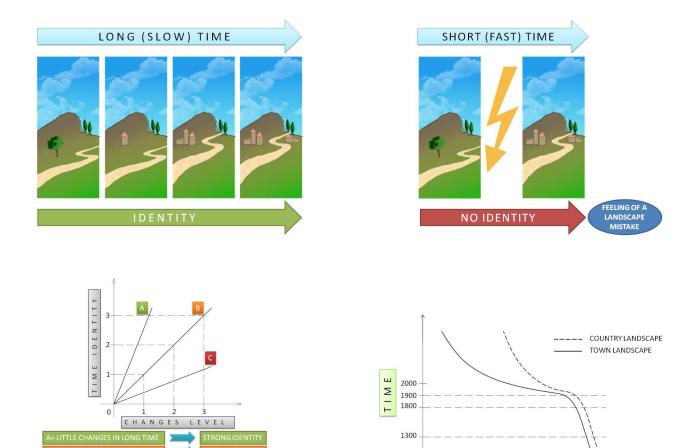


Figure 35. Identity and changes in time





HARMONY LEVEL

Figure 36, 37. Cases of industrial buildings without any connection with the landscape: they could be anywhere and everywhere in towns or industrial areas (Tuscany-Italy)







Figure 38, 39, 40. A wrong color of a single building can destroy the beauty of a landscape-Solar panels and wind turbines can't be located in the middle of a natural landscape but are in direct contact with the existing constructions (Tuscany-Italy)





Figure 41, 42. Two examples of good landscape: the design and construction of these structures are perfectly integrated with the terrain (Gerfalco-Italy/ Village in Oman)





Figure 43, 44. The landscape is art: like in a museum where you sit and enjoy the view





Figure 45, 46. The landscape is art: outdoor eco-museum of the landscape (Chianti)

Landscape and art

The landscape has a structure of signs and each contains a precise value: the space we see has a precise grammatical reading but always depends on the subject. Science has an objective gaze, while art has a subjective gaze (art shows us the inclinations of our unconscious mind.) The landscape can be interpreted as a product of physical and morphological sedimentation as well as cultural and aesthetic images, making it recognizable and valuable to the perceiver. Some of these striking landscape images, metaphors and figures that have been described through the centuries have come to compose a contemporary aesthetic heritage that are closely linked to the collective recognition and identification of a particular location.

The Tuscan landscape is one of the most famous examples of the process of aestheticism that "invented" a certain image of the terrain. The development of the landscape's importance stems from the stories of writers and the performances of artists in the Anglo-Saxon Grand Tour who describe how they hiked into the Tuscan countryside to find what they felt they had lost in the lives of their neo-industrial cities. That's the vision of the Tuscan countryside and the garden as a work of art.

"People have built the scenery as if they had only its beauty in mind." This is myth: in reality the landscape is beautiful because of a balanced and respectful use of the garden in which modern intensive farming produces a useful livelihood.

The myth of the Florentine painters in the '500s represents medieval-construction. Then the Anglo-Saxon romantic painters emphasized the aesthetic elements of the landscape. The painters of the '900s instead were more realistic by creating a vision of the landscape as seen from

the inside (cows, chickens, farm houses.) The Tuscan landscape has always and still evokes agreement that this represents quality of life. And Tuscan wine is the fruit of the beautiful Tuscan landscape.

"Tuscan wine is like a postcard; by drinking the wine and closing our eyes we can see a hill and everything about the countryside come alive. Inside the wine glass is poetry. "And I drink the landscape" said Semboloni Giuseppe, the farmer.

As the great historian Braudel wrote immediately after the Second World War, "The Tuscan landscape is the most touching landscape in the world" and then Desplanques wrote: "The Tuscan countryside was built as a work of art."



Figure 47. A bridge is used as an art gallery (Colle Val d'Elsa)



Figure 48. The landscape in cinema: a scene from The Gladiator (2000) (Val d'Orcia-Tuscany-Italy)



Figure 49. This photo of an landscape can be considered art (Tuscany-Italy)

The value of the landscape

So far, we have discussed in this article how the landscape is important for our well-being. We look for places with views that elicit a sense of harmony, vitality or uniqueness: that which is harmonious is not hostile, that which is lively is cheerful, that which is unique introduces novelty and therefore inspires interest. As human beings, we all share the instinct to flee places with views that elicit a sense of disorder, of flatness, or of boredom. A balanced and well cared for landscape produces calmness, psychological safety and aesthetic enjoyment; an imbalanced, mistreated and neglected landscape produces dissonance and discomfort. Dissonance and diversity can produce a beautiful landscape just as in any art form such as poetry, paintings or music, provided they are not frivolous and chaotic. A salient character of the landscape is its identity. A landscape is beautiful even when it is unsettled and transforming; it is unattractive when it contains impurities that are foreign and act like poison that ruin the natural elements or environment of the terrain. For example, imagine a building with a pitched Mediterranean style roof placed on a beautiful, peaceful Tuscan mountain; this should provoke a sense of disharmony since this building would be a discordant element the landscape.

Moreover, it would be simplistic to consider landscapes only as aesthetic sources of enjoyment. If pleasure is an important quality of the landscape, the degree of comfort or discomfort that it produces is linked to more complex and less obvious variables, which are a precondition for a viable countryside. Some ancient ruins can be aesthetically pleasing because they touch a sense of romance that is still present in our culture, however their presence in an open landscape is more functional than it would be in a habitable landscape. A high tech building can be beautiful as a tourist attraction, but can be emotionally draining as a place of work or daily life because it lacks any sense of culture or natural beauty.

The quality of the landscape then comes in varying degrees according to its aesthetic appeal, such as the order, the balance, the diversity the cultural identity the perceiver resonates with as well from as any picturesque disorder.

The Italian landscape is not just a natural phenomena; it has been shaped over the centuries by human activity. This landscape is steeped in history and has been represented by Italian and non-Italian writers and artists in their poetry, paintings and frescoes. In Italy, a different and complementary art form inspired these naturalists to adapt this landscape to their own works of art by applying the concept of a "view," so that a painting of a landscape could evoke positive feelings in almost the same way as those experienced by observing a real landscape from a window or a hill.

Art. Number 9 of the Italian Constitution reads: "the Republic promotes the development of culture and scientific and technical research. Protecting the landscape and the historical and artistic heritage of the Nation." "It's the synthesis of a centuries-old process that has two main features: the public priorities on private property and the

close link between protecting cultural heritage and landscape protection," Salvatore Settis wrote.

"In our study of the contexts of landscapes, everything appears solid and stable, the result of the tireless, intricate and endless efforts of human activity. These innumerable, unidentifiable modifications, whose main iconography is preserved, is infinitesimal in the moment and at the time appears relatively unchanged over the course of a human life. It is our landscapes that reveal the quality of our people in a supreme, well organized synthesis of visible memory.. Landscapes are not shapeless masses of the sum of their parts, but complex environmental entities in which millions of involuntary, spontaneous and self-regulated activities have merged into a harmonious whole. This is an anthropological and historical harmony rather than a purely aesthetic or a purely scientific one; we should learn to read, appreciate and care for the landscape, which deserves our education so that we are knowledgeable and understand its proper use," Andrea Caradini (FAI) wrote.



Figure 50. Italian National Day of The Landscape

"The Italian landscape represents all of Italy in its complexity and beauty, and leaves out the interplay between a great nature and a great history, a heritage to defend and even, in large part, to be exploited. The sacredness of the value of the landscape is a regulatory cornerstone; ethical, social and political development is to be defended and protected before and above any development proposal that, if it is detached from these principles, can be invasive, possibly jeopardizing not only to the beauty of the landscape, but also to the present and future functionality of the landscape including tourism," Vittorio Sgarbi wrote.

The protection and enhancement of the landscape safeguards the values that it expresses as a manifestation of cultural identity. In fact, if a landscape is considered to be good and beautiful, in the sense of it being harmonious, orderly or unique, it must also be identified with the place in which it is located.

Collective identity generates the landscape and the landscape contributes to producing collective identity.

The recognition of the value of a landscape is based on the identification of the following aspects:

- -Historical meaning: agrarian spaces represent outstanding examples of a landscape that is associated with a historical period or the most significant periods of our regional history;
- -Authenticity and integrity (high, medium, low): landscapes that are present in a given area for a long time, even many centuries;
- -Stability or very slow evolution over time: this is evaluated by comparing the maps and aerial photos of the 50s with the current ones, with regard to the permanence of key indicators such as the agricultural plot and the network of settlements and local roads;
- -Use of practices and techniques related to the tradition: organization characterized by a reduced use of external energy supplies, in terms of automation, irrigation, use of chemical fertilizers and agricultural chemicals;
- -Presence of traditional local economic cropping systems;
 - -Presence of hydraulic-traditional agricultural facilities;
 - -Presence of a traditional landscape mosaic;
- -Significant integrative harmony between productive, environmental and cultural elements.

Landscape as a common good: landscape protection

The landscape exists as a product of a terrain and as such can't be considered private property; it is common

property in the sense that it represents a sense of belonging (identity) in people who see it in person or in art.

Intervention on the landscape should be considered a shared common act: this is why there are rules to preserve the landscape. However, these preservation rules cannot only cover the technical aspects; landscape projects are in fact cultural/humanistic, non-technical initiatives, therefore the correct and appropriate professional for this work is the architect, who has a global vision and understands this to be a great responsibility.

In conclusion, the objectives to be achieved are: A. MEMORY:

- -Keeping alive the memory of our past, recent and distant, the landscape is a clear and tangible sign of how much the history, traditions, local knowledge, social and economic relationships have worked themselves out over the centuries. Identifying and knowing how to read those themes, identifying a syntax, a grammar, a language that binds these elements together would, in our view, act as a contemporary way to understand and share our history and our memories;
- Increasing participation in the theme and study of the landscape;
- To feed our collective, human appetite for a sense of identity and belonging, which we believe to be not only a source of psychological well-being, but also one of "bonding" to the "community."

B. PROTECTION:

- Protecting means to identify and recognize the landscape as a common good, as a heritage shared by the whole community, to which there are rights but also certain duties;

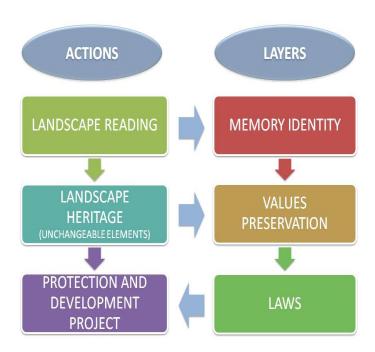


Figure 49. This photo of an landscape can be considered art (Tuscany-Italy)

- The biodiversity;
- The ethno-anthropological values.

C. PROJECT:

- Promoting opportunities not only for economic development;
- Supporting visible actions beyond the common focus on excellence and well-known approaches
- Encouraging development according to new growth paradigms;
 - Increasing its current resources.





Figure 52, 53. The beauty of the landscape: Val d'Orcia (Siena-Italy). Val d'Orcia is in the UNESCO World Heritage List

Conclusions

The landscape is one of the greatest values of our lives: it surrounds us and is always with us; even when we are distracted it is there, waiting for us, waiting for our watchful eyes. We must learn to look at and read the landscape with the "right eye," because when the landscape is read well, we see it in ourselves: in the landscape we find our identity. For this reason it is our duty to safeguard the landscape, not by imposing restrictions on it, but by expanding our knowledge about its physiological changes with wisdom and foresight, because taking action on

the landscape is like taking action on a work of art, the fruit of the secular work of humans and nature. The landscape is here for the common good and is an expression of the culture of a place and a society. The landscape is full of history and deserves respect and attention by all those working on one: architects, farmers, farm owners. The scenic beauty is the beauty of our lives: for this reason the landscape deserves that we educate ourselves about its proper use, and become well versed in the wide body of knowledge that has been studied and validated about them.

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CHANGE IN WOOD STRENGTH UNDER STATIC BENDING AND COMPRESSION ALONG FIBERS IN THE PROCESS OF TREE GROWTH

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Abstract

According to the basic principles of bionics, internal forces are formed in the tree trunk during its growth; these forces generate the strength and resistance of the tree to influence of wind loads and its own weight. When internal forces appear, the strength of wood cells starts developing. The inflow of nutrients is the most intense in the most strained parts of the trunk. The wood responds to external effects through increasing the thickness of cell walls, their density, the modulus of elasticity, etc. The central part of the trunk starts experiencing internal compressive stresses along fibers and tensile stresses dominate the peripheral areas. The paper substantiates the relationship between the size of the core zone and the stress-strain state of wood.

Under effects of internal forces the wood is formed during the growth of a tree as an anisotropic material having different tensile and compressive strengths along and across fibers. The hypothesis on parabolic distribution of internal forces along fibers is described making possible both determining the dimensions of the core and sap zones, and establishing mathematical correlation between the ultimate stress limits of wood during compression along fibers and under static bending. This was proved in numerous experimental studies made by different Russian and foreign research groups. According to calculations given in the paper, the ratio of the ultimate stress limits of wood of various species under compression along fibers to the ultimate stress limits under static bending depends on the nature of distribution of internal forces along the tree trunk. Application of computer technologies makes it possible to use the results obtained to produce sawn timber having required strength indicators.

Keywords

Tree growth, internal forces, along-the-fiber compression strength, static bending.

Introduction

During evolution the nature developed biological structures that have high strength and rigidity, ensuring the maximum vitality, e.g. bones of the human and animals skeleton, robust bone shells of the skull, tortoise shells, light and rigid bone structures of the bird skeleton, powerful jaw bones of predators, etc. (Grigorovich, 1952, Ivanov, 1934). The structural design of natural vegetation species indicates that during their growth the strongest fibers of bone tissues, wood and other materials are aligned in direction of applying the greatest stress and deformation, providing necessary strength at the expense of the strong frame (Razdorsky, 1934).

Since natural structure materials have different tensile and compressive strength, internal forces are formed in the process of their growth, providing reduction of stresses in the weakest zones of the bearing frame and increasing stresses in stronger areas. Thus, a continuous formation of material equal in strength takes place throughout the entire body under the minimum consumption during the whole period of growth.

For example, wind loads and rocking of trees lead to reduction of stresses in fibers located in compressed zones of the trunk, making a component to effects of internal forces. At the same time, the total stress in a stronger stretched zone increases approximately twofold, as it is proved by the previous studies (Kuznetsov, 1950; Kübler, 1959; Belov, 1974; Glukhikh, Akopyan, 2016; Ashkenazi, 1978).

Inflow of nutrients, thickness of cell walls, density of the wood, modulus of elasticity increase in the most stressed parts of the tree trunk; the ratio of the width is changing in early and late zones of annual layers. All these processes ultimately lead to an increase in the strength of wood. This ensures the resilience of tree trunks.

Unlike man-made composites designed following the natural vegetable materials models, the natural materials belong to the "reactive" type: they change their structure and properties depending on external effects.

The studies of V. G.Temnov (Temnov, 1996, 2001) allowed formulating the "bionic principles of adjusting parameters of a stress-strain state in structures". This principle substantiates common laws of development of natural vegetable materials on the basis of a balanced interrelation between external and internal forces. This interrelation contributes to development of structures having high efficiency and survivability.

In contrast to natural structures, the artificial composite and other materials lack active regulation of stress-strain states in response to external effects (Glukhikh, Akopyan, 2013).

Modern literature gives no information on results of studies on the effect of stress-strain states in tree trunks, generated during their growth, on the strength and rigidity of wood products used in construction (Ylinen, 1956; Kollmann, 1951; Kuffner, 1978; Cucera, 1970).

Methods

In order to establish the relationship between distribution of internal forces in sections of tree trunks, we reviewed the results of studies by Finnish scientist A. Ylinen (Ylinen, 1952, 1956), German scientist H. Kübler (Kübler, 1959) and Russian researchers Ye. K. Ashkenazi (Ashkenazi, 1978), S. V. Belov (Belov, 1974) and A. I. Kuznetsov.

It was found in all papers listed that the wood fiber was stretched at the periphery of the tree trunk section; the fibers in its central part featured compression. To describe this phenomenon, H. Kübler suggested using logarithmic functions whereas A.I. Kuznetsov and A. Ylinen suggested using a parabolic function to estimate distribution of internal forces along the radius of the cross section. Having analyzed the parabolic law proposed by H. Kübler, Ye. K. Ashkenazi noted that distribution of internal forces along the radius of the tree section was unbalanced. Presumably, Ye. K. Ashkenazi made this conclusion by analyzing the stress diagram in the radial section without taking into account the spatial surface distribution of internal forces having paraboloid shape.

Taking into account the function of internal forces for the particular case in the form of a paraboloid (Figure 1) we would obtain:

$$\sigma = \frac{4(\sigma_R + \sigma_0)}{d^2} * (z^2 + y^2) - \sigma_0$$
 (1)

where σ — internal forces at the point with coordinates y and z;

 $\sigma_{o'}$, σ_{R} are internal forces at the points in the center and at the outline of the section;

d is the diameter of the studied section.

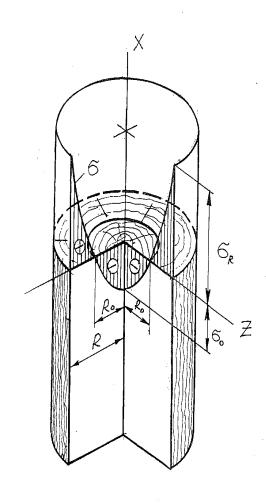


Figure 1. Distribution of internal forces along the radius of the tree trunk section

Dimensions of zones with internal tensile and compression forces can be established using equation (1):

$$R_0 = \sqrt{\frac{\sigma_0 d^2}{4(\sigma_R + \sigma_0)}}$$
 (2)

Considering the equation of equilibrium, the ratio of stresses in the center and at the outlines of the section can be obtained as follows:

(1)
$$\sum X = \frac{\pi d^2}{4} \left[\sigma_R - \frac{\sigma_R^2}{2(\sigma_R + \sigma_0)} - \frac{\sigma_R \sigma_0}{\sigma_R + \sigma_0} \right], \quad (3)$$

from where the value of σ_{R} = σ_{o} can be obtained. (4)

Taking into account the latter equation, the radius of the central (compressed) zone can be obtained through equation (2):

$$R_0 = 0.707 \frac{d}{2} = 0.707R \tag{5}$$

In accordance with Figure 2, at a critical wind speed aligned along the plane of the wind pressure, the total stress at point 1 at outlines of the section decreases to zero in the compression zone, whereas the total stress is increasing by a factor of two in the tension zone at point 2 and remaining unchanged at the center of the section.

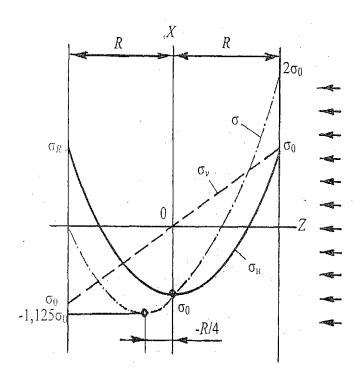


Figure 2. Correlation of the core zone size with the nature of changing in internal forces

At critical wind pressures the total stress can be analyzed using equation (4), taking into account bending of the tree trunk:

$$\sigma = \frac{{}^{2}\boldsymbol{\sigma}_{R}}{R^{2}}(z^{2} + y^{2}) + \frac{\boldsymbol{\sigma}_{R}}{R}Z - \boldsymbol{\sigma}_{0}$$
 (6)

Through seeking an extremum of this function for the diametrical cross section in the plane of the wind pressure we can find the maximum value of the total stress in the compression zone:

$$\frac{d\sigma}{d} = -4\frac{\sigma_0}{R^2}z - \frac{\sigma_0}{R} = 0 \tag{7}$$

from where $Z_0 = -R/4$

The maximum value of compression stress is equal to:

$$\boldsymbol{\sigma}_{MAX.P} = \frac{{}^{2}\boldsymbol{\sigma}_{R}}{\boldsymbol{R}^{2}} \left(-\frac{R}{4}\right)^{2} + \frac{\boldsymbol{\sigma}_{R}}{R} \left(-\frac{R}{4}\right) - \boldsymbol{\sigma}_{R} = -\frac{9}{8}\boldsymbol{\sigma}_{R}$$
(8)

As the tree grows, the extreme point is gradually displaced along the radius from the center of the tree section, and a limiting compressive stress develops along fibers amounting to 1.125 of the stress value at the center of the section.

The maximum stress in the tension zone can reach the following value:

$$\sigma_{\text{max.}p} = \frac{2\sigma_R}{R^2} R^2 + \frac{\sigma_R}{R} R - \sigma_R = 2\sigma_R$$
 (9)

Given the nature of the total stress distribution in the compression zone (the core zone), it can be assumed that the limiting compressive stress under critical wind pressure contributes to development of the wood strength under compression along fibers; at the same time, the maximum tensile stress at the point on the surface of the sap zone contributes to development of the wood strength under static bending. On this basis, the ratio of the wood strengths limits under static bending and compression along fibers can be written as follows:

$$\frac{\boldsymbol{\sigma}_{BI}}{\boldsymbol{\sigma}_{BC}} = \frac{2\boldsymbol{\sigma}_{R}}{1,125\boldsymbol{\sigma}_{R}} = 1.778 \tag{10}$$

A similar calculation can be made for other cases of internal forces distribution that would be different from the one we have considered (Table 1).

Results

The results of the studies are shown in Table 1. The more complex is the function, the greater is the radius of the core zone. The type of distribution of the total stress under given wind loads affects the position of the extreme compression zone and the ratio of the wood strength limits under static bending and compression along fibers. Increasing of the area of core section leads to smooth increase in the ratio of strength limits under bending and compression along fibers.

PROCESS OF TREE GROWTH

Table 1. Correlation of the size of the core zone and wood strength under static bending and compression along fibers

Law of internal forces changing according to the section radius	Radius of the core zone Ro	Stress in the center of the trunk section	Maximum tensile stress at the point at the section outlines	Maximum compression strength	Maximum tensile strength at wind loads	Ratio of strength limits under static bending and compression along fibers
Logarithmic law [H. Kübler]	0.606R	-σ ₀	0.5σ ₀	-σ ₀	$\sigma_{_0}$	1
Conical distribution	0.667R	-σ ₀	$0.5\sigma_{_0}$	-σ ₀	σ_0	1
$\sigma_{_{\rm H}} = k_2 r^2 + b_0$	0.707R	-σ ₀	$\sigma_{_0}$	$-1.125\sigma_{_{0}}$	$2\sigma_0$	1.778
$\sigma_{_{\rm H}} = k_4 r^4 + b_0$	0.76R	-σ ₀	$2\sigma_0$	-1.8255σ ₀	$4\sigma_{_0}$	2.191
$\sigma_{H} = k_6 r^6 + b_0$	0.794R	-σ ₀	$3\sigma_0$	-2.65σ ₀	6σ ₀	2.265
$\sigma_{\scriptscriptstyle \rm H} = k_{\scriptscriptstyle 8} r^{\scriptscriptstyle 8} + b_{\scriptscriptstyle 0}$	0.818R	-σ ₀	$4\sigma_{_0}$	$-3.519\sigma_{_{0}}$	$8\sigma_0$	2.273
$\sigma_{H} = k_{10} r^{10} + b_{0}$	0.836R	-σ ₀	$5\sigma_0$	$-4.414\sigma_{_{0}}$	$10\sigma_{_0}$	2.265
$\sigma_{H} = k_{12} r^{12} + b_{0}$	0.85R	-σ ₀	$6\sigma_0$	-5.327σ ₀	$12\sigma_{_0}$	2.253
$\sigma_{H} = k_{14} r^{14} + b_{0}$	0.862R	-σ ₀	$7\sigma_0$	-6.5σ ₀	$14\sigma_{_0}$	2.24
$\sigma_{H} = k_{2}r^{2} + k_{1}r + b_{0}$	0.686R	-σ ₀	4/3 σ ₀	-		1.524
$\sigma_{_{\rm H}} = k_{_4}r^4 + k_{_2}r^2 + b_{_0}$	0.731R	-σ ₀	$2/3\sigma_0$	-1.295σ ₀	$8/3\sigma_0$	2.05
$\sigma_{H} = k_6 r^6 + k_2 r^2 + b_0$	0.768R	-2σ ₀	$4\sigma_{_0}$	$-3.495\sigma_{_{0}}$	$8\sigma_{_{0}}$	2.289
$\sigma_{_{\rm H}} = k_8 r^8 + k_2 r^2 + b_0$	0.79R	-2σ ₀	$5\sigma_0$	$-4.4058\sigma_{_{0}}$	$10\sigma_{_{0}}$	2.27
$\sigma_{\text{\tiny H}} = k_{12}r1^2 + k_2r^2 + b_0$	0.8206R	-2σ ₀	$7\sigma_0$	-5.905σ ₀	$14\sigma_{_0}$	2.37
$\sigma_{\text{\tiny H}} = k_{14} r^{14} + k_2 r^2 + b_0$	0.833R	-2σ ₀	$8\sigma_0$	-6.7768σ ₀	16σ ₀	2.36
$\sigma_{_{\rm H}} = k_{_{14}} r^{14} + k_{_4} r^4 + b_{_0}$	0.829R	-2σ ₀	$9\sigma_{_{0}}$	-7.6697σ ₀	$18\sigma_0$	2.347

The functions of internal forces and total stresses assumed in the studies are confirmed by experimental data obtained for tree species growing in Europe, Asia, Africa, North and South America; they were taken from the literature sources (Table 2, 3).

Additional theoretical studies are required to describe the species that do not fit the functions derived.

For some tree species, the ratio of the strength limits under static bending and compression along fibers indicates a fairly simple function describing the internal force distribution. For example, for the Quercus robur this distribution is subject to the law of the fourth-degree paraboloid. The radius of the core zone of 0.76R confirms this assumption.

The poplar with the core radius of 0.794R has distributions according to the law of the sixth-degree paraboloid. The fourteenth-degree paraboloid characterizes the spruce wood with the radius of the core zone of 0.862R.

The alder wood with the core radius of 0.731R almost fits with the complex internal forces distribution function having variables of second and fourth degrees.

The nature of the change in internal forces can be established for any wood species according to the size of the core zone, which corresponds to a certain ratio of strength limits under static bending and compression along fibers.

Table 3 compares strengths under static bending and compressionalong fibers for coniferous woods of the USA and Canada.

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Table 2. Values of strength limits under compression along fibers and under static bending for domestic wood species with moisture content above 30% (Volynsky, 2006)

Species	Strength lim	Ratio of strength limits under static bending and compression along fibers	
	Compression along fibers Static bending		
Scots pine (Pinus sylvestris)	21.2	49.5	2.335
Kedar (Pinus sibirica)	18.5	42.3	2.286
Persian walnut (Juglans regia)	23.8	60.7	2.55
Aspen (Populus tremula)	19.2	45.4	2.36
Silver fir (Abies alba)	19.4	44.7	2.30
Khingan fir (Abies nephrolepis)	18.4	45.2	2.45
Caucasian fir (Abies nordmanniana)	19.9	48.4	2.43
Siberian fir (Abies sibirica)	17.5	40.4	2.31
Manchurian fir (Abies holophylla)	16.6	42.0	2.53
Poplar (Populus)	17.8	40.3	2.26
Manchurian ash (Fraxinus mandshurica)	29.3	67.2	2.29
Common ash (Fraxinus excelsior)	32.5	74.3	2.28
Oxycarpous ash (Fraxinus oxycarpa)	40.2	88.8	2.21
Green ash (Fraxinus pennsylvanica)	33.3	71.6	2.15
Black locust (Robinia pseudoacacia)	41.6	97.5	2.34
European birch (Betula pendula)	22.4	59.7	2.66
Black birch (Betula dahurica)	21.0	66.2	3.15
Iron birch (Betula schmidtii)	37.3	82.7	2.217
Siberian yellow birch (Betula costata)	25.6	66.9	2.61
Beech (Fagus)	25.9	64.6	2.49
Elm (Ulmus)	25.2	59.1	2.34
Horbeam (Carpinus)	26.5	73.3	2.76
Pear tree (Pýrus)	26.7	63.4	2.37
Aleppo (Quercus araxina)	29.7	56.2	1.89
Caucasian oak (Quercus macranthera)	28.7	54.4	1.89
Georgian oak (Quercus iberica)	30.9	58.8	1.90
Chestnut-leafed oak (Quercus castaneifolia)	33.9	82.9	2.44
English oak (Quercus robur)	31.3	67.8	2.18
Spruce (Picea)	19.6	43.9	2.24
Willow (Salix)	16.8	41.6	2.47
Maple (Acer)	28.2	77.7	2.75
Lime tree (Tilia)	24.2	54.2	2.24
Larch (Larix)	25.3	61.7	2.44
Alder (Alnus)	23.6	49.4	2.09

Table 3. Comparison of strengths under static bending and compression along fibers, obtained for coniferous woods of the USA and Canada according to the data by N. L. Leontiev and V. N. Volynsky, moisture content is above 30%.

Species	Strength	Ratio of strength limits under	
	Compression along fibers	Static bending	static bending and compression along fibers
Douglas fir (Pseudotsuga menziesii)	24.9	52	2.09
Western Douglas fir	26.7	53	1.99
Coastal Douglas fir	26.1	53	2.03
Northern Douglas fir	23.9	51	2.14
Southern Douglas fir	21.4	47	2.20
White spruce (Picea glauca)	17.7	39	2.21
Engelmann spruce (Picea engelmannii)	15	32	2.14
Red spruce (Picea rubens)	18.3	40	2.19
Sitka spruce (Picea sitchensis)	17.6	37	2.11
Black spruce (Picea mariana)	17.7	37	2.09
Virginian juniper (Juniperus virginiana)	24.6	48	1.96
Engelmann spruce (Picea engelmannii)	19.4	39	2.01
California cedar (Calocedrus)	21.7	43	1.99
False cypress (Chamaecyparis)	22.3	46	2.07
Yellow cedar (Cupressus nootkatensis)	21	44	2.10
Atlantic white cedar (Chamaecyparis thyoides)	16.5	32	1.94
Bald cypress (Taxodium distichum)	24.7	46	1.87
Lawson cypress (Chamaecyparis lawsoniana)	21.6	46	2.13
American larch (Larix laricina)	21.6	47	2.18
American larch (Larix laricina)	24	50	2.09
Western larch (Larix occidentalis)	30.5	60	1.97
Balsam fir (Abies balsamea)	16.5	34	2.06
Balsam fir (Abies balsamea)	16.8	36	2.15
Noble fir (Abies procera)	20.8	43	2.07
Grand fir (Abies grandis)	20.3	40	1.97
California white fir (Abies concolor var. lowiana)	19	40	2.11
Amabilis fir (Abies amabilis)	21.6	44	2.04
Amabilis fir (Abies amabilis)	19.1	38	1.99
White fir (Abies concolor)	20	41	2.05
Subalpine fir (Abies lasiocarpa)	15.9	34	2.14
Subalpine fir (Abies lasiocarpa)	17.2	36	2.10
Sequoia (Sequoia sempervirens)	21.4	41	1.92
Jack pine (Pinus banksiana)	20.3	41	2.02
Jack pine (Pinus banksiana)	20.3	43	2.12
Eastern white pine (Pinus strobus)	16.8	34	2.03

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Eastern white pine (Pinus strobus)	17.9	35	1.96
Virginia pine (Pinus virginiana)	23.6	50	2.12
Spruce pine (Pinus glabra)	19.6	41	2.10
Longleaf pine (Pinus palustris)	29.8	59	1.98
Ponderosa pine (Pinus ponderosa)	16.9	35	2.02
Ponderosa pine (Pinus ponderosa)	19.6	39	1.99
Pitch pine (Pinus rigida)	20.3	47	2.32
Sand pine (Pinus clausa)	23.7	52	2.20
Western white pine (Pinus monticola)	16.8	32	1.91
Western white pine (Pinus monticola)	17.4	33	1.90
Short leaf pine (Pinus echinata)	24.3	51	2.10
Red pine (Pinus resinosa)	18.8	40	2.13
Red pine (Pinus resinosa)	16.3	34	2.09
Loblolly pine (Pinus taeda)	24.2	50	2.07
Pond pine (Pinus serotina)	25.2	51	2.03
Sugar pine (Pinus lambertiana)	18	38	2.12
Shore pine (Pinus contorta)	18	38	2.12
Shore pine (Pinus contorta)	19.7	39	1.98
Slash pine (Pinus elliotii)	26.3	60	2.29
Northern white cedar (Thuja occidentalis)	13.7	29	2.12
Northern white cedar (Thuja occidentalis)	13	27	2.08
Western red cedar (Thuja plicata)	19.1	36	1.89
Western red cedar (Thuja plicata)	19.2	36	1.88
Eastern hemlock (Tsuga canadensis)	21.2	44	2.08
Eastern hemlock (Tsuga canadensis)	23.6	47	2.00
Western hemlock (Tsuga heterophylla)	23.2	46	1.99
Mountain hemlock (Tsuga mertensiana)	19.9	43	2.16

As many as 38 wood species out of 172 wood species of the United States, Canada, South Asia, tropical countries of Africa and South America, mentioned by V. N. Volynsky (Table 2, 3), have an increased ratio of strength limits under static bending and compression along fibers (similar to some domestic wood species). In order to analyze the internal forces in sawn timber made of these types of wood, it is required to establish the function of their distribution along the volume of the tree trunk.

As shown by two last calculations, the distribution of internal forces can be described by a more complicated function comprising a set of fairly simple functions considered in this work. The results of the studies have both scientific and practical interest in the production of structural timber and building woodwork.

The nature of the distribution of internal forces along the volume of the tree trunk makes it possible to predict formation of wood defects during its growth.

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FAST ASSEMBLY OF QUALITY SUSPENDED VENTILATED FACADES

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Abstract

Previously understudied new structural and technological concepts of various types of modern suspended ventilated facades (SVF) applicable in Russia by 2017 were researched by a system and analysis method to determine their advantages and disadvantages. Theoretical bases and the algorithm for the development of the optimal technological solution for the installation of SVF were worked out with the aid of the methods of multi-criteria optimization. The structure and the operating sequence were substantiated for the rational technology of integrated mechanized process of SVF elements installation. Alternate improved technological solutions were developed for installation of heat insulating, framing and facing SVF elements with the account of the most important optimality criteria. These criteria include minimum labor intensity and machine time, minimum cost, enhanced quality and safety.

Effects of the most important factors related to labor intensity and cost improvement of construction operations as well as increase of SVF useful life under various building conditions were defined and substantiated by experimental construction of residential buildings with SVF facing.

With the aid of the methods of alternate technological design and multi-criteria optimization, 4 optimized variants of technological solutions for installation of thermal insulation, frame and facing elements in SVF systems were developed with the account of the 4 most important consumer optimality criteria: minimum labor intensity and machine time, minimum cost, enhanced quality, maximum quality and safety. The scientific significance of the results is that the major factors affecting optimization of technological modes of various SVF designs were identified and studied. Their use allows reducing the labor intensity of works to 0.55–1.79 man-shift per 1 sq. m of facade area.

Keywords

Front elevation, assembling, labour inputs, optimization, ventilation.

Introduction

At the Saint Petersburg State University of Architecture and Civil Engineering the authors in cooperation with A.Ye. Piskun, and on the basis of his work, performed a further theoretical justification of the rational technological solution development for SVF design. The work objective is scientific substantiation and development of improved variants for design of suspended ventilated facades optimized in terms of the following criteria: minimum labor intensity and machine time, minimum cost, improved quality and safety during construction of residential buildings. The object of study is construction process and struc-

tural-and-technological solutions for design of improved rational variants of suspended ventilated facades for the purposes of erection of various types of residential buildings in Russia.

Methods

Comparative variant technological design, technical-and-economic system analysis of engineering solutions, full-scale experiments with SVF fragments, theoretical modeling, test measuring and studying technological parameters of walling processes for residential buildings,

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mathematical statistics and the probability theory while solving optimization problems.

Dependencies (new and important for reducing labor intensity and cost as well as for enhancing simplicity and technological effectiveness of works) of increase in labor intensity on increase in area of mounted SVF elements, their weight and other impact factors were defined with optimality criteria of minimum cost, labor intensity and maximum quality. With use of mathematical statistics methods

mathematical models that approximate the discovered dependencies were calculated. With the aid of the on-site measurement method new important dependencies of decrease in labor intensity during SVF design on the impact of the most important natural climatic factors — extremely low temperatures and wind velocity — were determined. High technical and economic efficiency and constructability were proved for the application of improved and efficient SVF solutions, intended for residential buildings in

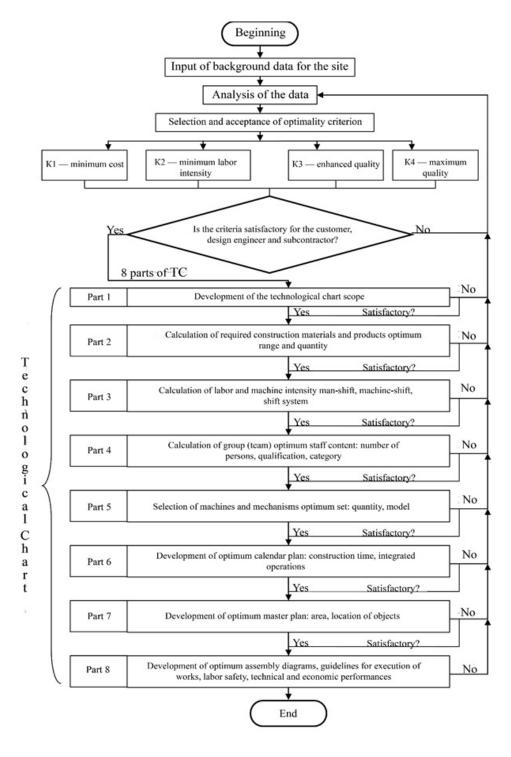


Figure 1. Theoretical bases for the development of optimal technological solution for installation of SVF with the aid of the method of step-by-step multi-criteria optimization

terms of labor intensity and cost of work, effective useful life of heat insulating structures and their repairability.

With the aid of the methods of alternate technological design and multi-criteria optimization, 4 optimized variants of technological solutions for installation of thermal insulation, frame and facing elements in SVF systems

were developed with the account of the 4 most important consumer optimality criteria: minimum labor intensity and machine time, minimum cost, enhanced quality, maximum quality and safety. The scientific significance of the results is that the major factors affecting optimization of technological modes of various SVF designs were identified and studied. Their use allows reducing the labor intensity of works to 0.55–1.79 man-shift per 1 sq. m of facade area.

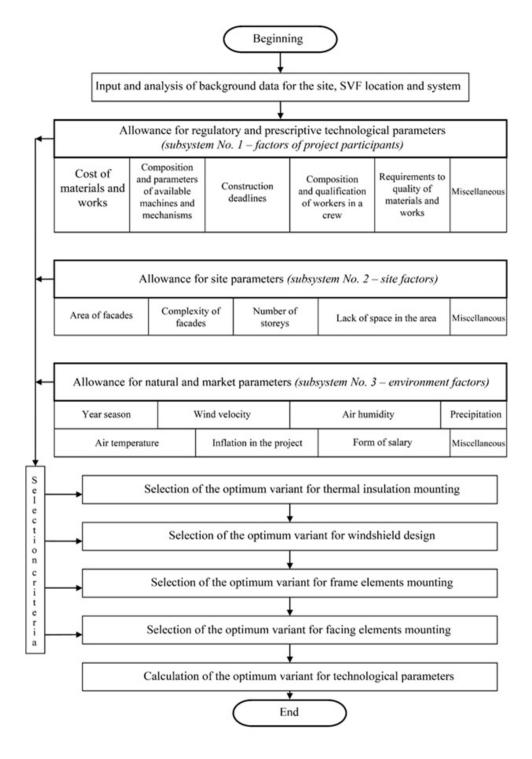


Figure 2. Algorithm for the development of the optimal technological solution for installation of SVF with the aid of the method of step-by-step multi-criteria optimization

Case history

The authors' articles (Kazakov, 2011; Badjin et al., 2015) and those of A.Ye. Piskun, Candidate of Engineering Sciences, (Piskun, Kazakov, 2008a; Piskun, Kazakov, 2008b) as well as the materials of such papers further development in 2010-2016, formed the basis of the investigation. For that purpose modeling of optimum technological solutions was carried out for design of residential building SVF based on the minimum cost and safety criteria. Impact regularities of the key factors affecting technological solutions for SVF design were discovered and studied.

Results

Theoretical models, algorithms and recommendations for the development of rational solutions and various technologies of SVF design were elaborated (figure 1, 2).

It is suggested to consider mineral wood rigid tiles made of basalt fiber as optimum thermal insulation. The following may be considered as optimum fencing: fiber cement sheets, sheets of vinyl siding, reconstituted granite tiles. The following may be considered as the frame: galvanized and stainless steel umbrella-type self-drilling bolts and bolts.

Taking into account the 4 most important consumer optimality criteria, i.e. minimum labor intensity and machine time, minimum cost, improved quality and maximum quality, 1 improved variant of rational technological solutions for installation of thermal insulation, frame and facing elements in SVF systems (figure 3) was developed.

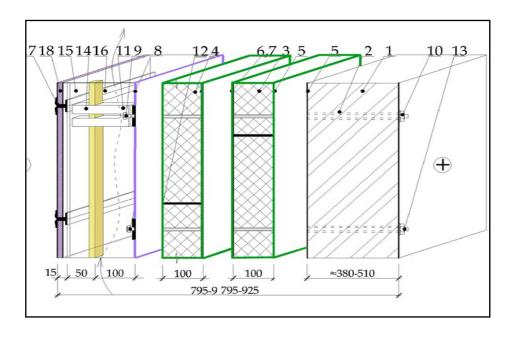


Figure 3. SVF design technology corresponding to Variant 4 in terms of optimality criterion K3 – maximum quality (recommended for use in case of unrestricted financial resources and labor force): 1 – ceramic brick laying; 2 – drilling of bolt holes; 3, 4 – installation of mineral wool plates in 2 (two) overlapping layers; 5-8 – fixing of Tyvek membrane; 9, 12 – installation of passing bolts; 10, 13 – nuts installation; 11, 15 – mounting of horizontal and vertical guiding profiles, stainless steel; 14 – bracing; 16 – leaving a gap; 17 – mounting of shaped panel strips; 18 – mounting of granite tiles

New dependencies (important for improvement of technological effectiveness of works) of labor intensity increase on the increase of the area of mounted SVF elements, their weight and other impact factors with the criteria of optimum minimum cost, labor intensity and maximum quality were determined.

With the use of mathematical statistics methods mathematical models that approximate the discovered dependencies were calculated. With the aid of the on-site measurements method that enabled further determination of important and new dependencies of labor efficiency decrease during SVF design on the impact of the most important natural climatic factors, i.e. extremely low temperatures and wind velocity (Kazakov, 2011).

Further, technical and economic efficiency of applying rational solutions for design of residential building SVFs

were studied. The analysis of variants for SVF design technologies were performed according to the results of experimental construction. The mounting cost was 2.25–3.95 thousand rubles per 1 sq. m of facade area; that is 1.3–1.6 times cheaper in comparison with existing traditional methods of non-ventilated facade design. The above results allowed to further substantiate the technological chart of suspended ventilated facade design based on the most popular and significant optimality criteria – minimum labor intensity and cost of works (figure 4, 5).

The technological chart specifies its scope, outlines the major data on work organization and production technology during mounting of ventilated facade elements, determines requirements to work quality, accident prevention, occupational safety and fire prevention measures, sets forth the need for material and technical resources, calculates labor intensity and work schedule.

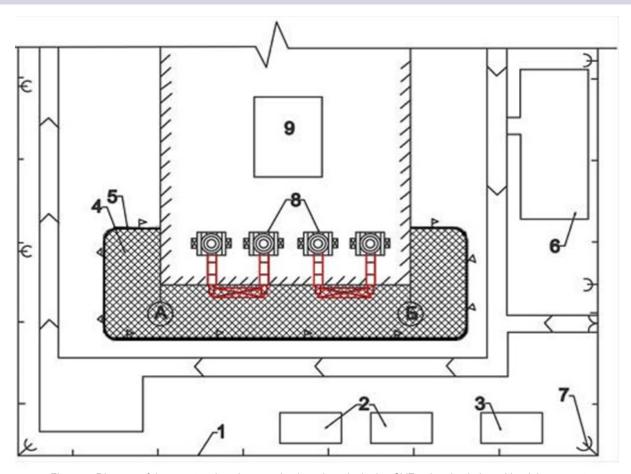


Figure 4. Diagram of the construction site organization when designing SVF rational solution with minimum costs in a multistorey building: 1 – fences of construction site; 2 – workshop, sanitary and amenity facilities for workers; 3 – materials and equipment store; 4 – work area; 5 – boarders of dangerous area for people to stay when suspended cradles are in operation; 6 – outdoor storage area for mineral wool tiles, frame elements film, facing panels; 7 – lightening tower; 8 – 2 (two) suspended cradles; 9 – residential building with SVF

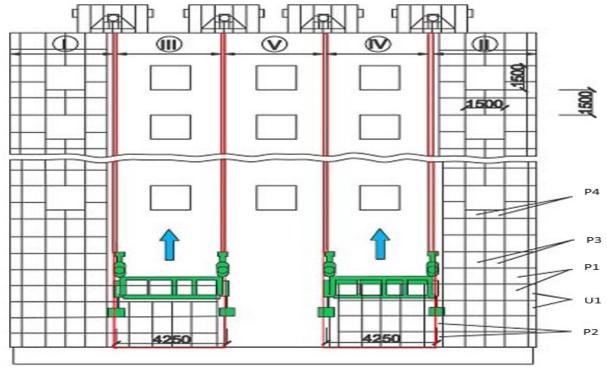


Figure 5. Diagram of facade breakdown into vertical grips when designing SVF rational solution with minimum costs in a multistorey building

Legend to the Figure 5: — work performance direction; I, III, V — vertical grips for the 1st and 2nd mounter crews working in the first suspended cradle; II, IV — vertical grips for the 3rd and 4th mounter crews working in the second suspended cradle. Facing panels: P1 — 1000x900, P2 — 1000x700, P3 — 1000x750, P4 — 750x500, U1 — 1000x200.

Table 1. Comparative analysis of the technological parameters of 4 improved SVF design methods.

Parameter	Variant 1 - minimum cost	Variant 2 - minimum labor intensity	Variant 3 - enhanced quality	Variant 4 - maximum quality
Application - building appearance	individual, social	social	commercial	elite
Bearing wall	mass concrete	precast reinforced concrete	mass reinforced concrete	ceramic brick
Frame	steel	galvanized steel	stainless steel	stainless steel
Insulant	2-layer mineral wool	2-layer mineral wool	3-layer mineral wool	3-layer mineral wool
Suspended facing	vinyl siding, vertical racks	large fiber- cement facade panels	reconstituted granite tiles	granite tiles
Frame fasteners	plastic, umbrella- type studs	galvanized steel, rawbolts	stainless steel, rawbolts	stainless steel, bolts
Crew, people	1-2	1-2	2-3	2-3
Mounting labor input, man-shift per 1 sq. m of facade (mean calculated results)	0.62	0.52	1.31	1.89
Cost, thousand rubles/sq. m	2.17	3.12	3.1	3.95
Insulant fastener	glue	plastic, umbrella- type clips	steel, umbrella-type self-drilling bolts	steel, bolts
Technology index	0.662	0.655	0.650	0.645

It allowed for the further comparative analysis of the technological parameters of 4 improved SVF design methods (Table 1) (Piskun, Kazakov, 2008b).

Figure 6 shows one of the discovered and studied important dependencies, i.e. lowering of SVF mounting labor intensity depending on the impact factor "increasing area of a suspended facing unit".

In conclusion, an assessment of effectiveness of the developed improved methods of HVF installation was performed under systematic consideration of the following 5 types of effectiveness at all stages of their life cycle and the type of materials (Badjin et al., 2015; Badjin et al., 2013; Sychev and Sharipova, 2015; Sychev and Kazakov, 2015).

- 1. Effectiveness of production of HVF elements is a characteristic of the sub-system of HVF structures manufacturing, which meets 9 criteria such as variety of types, total number of elements, material intensity, labor intensity, stress and strain, mechanization of manufacturing processes, accuracy of geometric shapes, size of elements, assembling and availability.
- 2. Transportation effectiveness is a characteristic of the subsystem of HVF products transportation, which meets 6 criteria such as variety of types, variety of weights, transportation costs, enlargement of prefabricated elements, loading of the rolling stock, mechanization of loading and unloading.
- 3. Effectiveness of installation works is a characteristic of the subsystem of HVF structures installation, which meets 10 criteria such as labor intensity, performance of wet processes, stress and strain, mechanization of processes, work rate, homogeneity of building cells, homogeneity of work zones and tiers, homogeneity of structural elements, convenience of assembling for welding, allowance for tolerances.
- 4. Operational effectiveness is a characteristic of the HVF in the subsystem of operation with account for the requirements of serviceability, operating costs, energy saving and automation, labor intensity and minimizing of heating costs.
- 5. Effectiveness of upgrading and reconstruction is a characteristic of the subsystem that takes into account the following criteria: improvement of technical performance of residential buildings, further improvement of heat protection of walls when adopting new standards, replacement of old-fashioned facing works for new types, spatial planning changes, use of new technologies, new mechanisms and equipment so that the building would meet modern requirements to safety and comfort of living.

At the same time, it is proposed that the overall effectiveness of HVF structures implies the degree of simplicity, availability, speed and ease of implementation with standard means of mechanization and a small number of semiskilled workers, a set of construction and engineering solutions for installation of facades of residential buildings, their operation, further upgrading and reconstruction meeting modern requirements to quality, safety and rates of construction processes and operations.

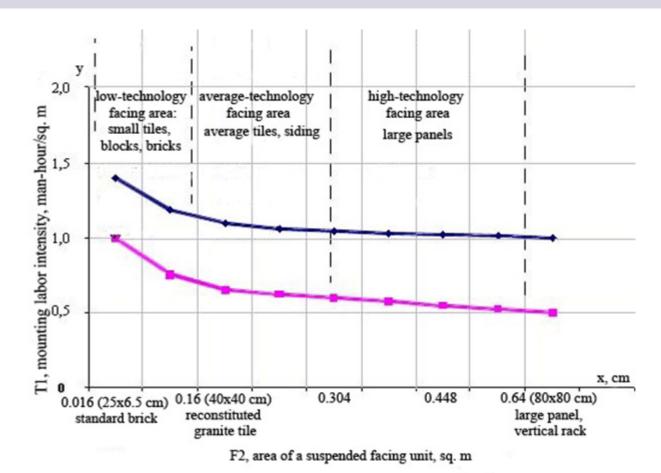


Figure 6. Dependence of increase in SVF mounting labor intensity on impact factor – "increasing area of a suspended facing unit": upper curve — production values according to the re-

sults of measurements during the construction process, lower curve — theoretical values

The calculated values of integral criteria for effectiveness turned out to be 0.665, 0.654, 0.652 and 0.650 for 4 technological solutions, corresponding to a high degree of simplicity, efficiency and industriality of construction and installation works.

Conclusions

- 1. It is shown that the new rational SVF solutions adequate to various types of residential buildings under construction in Russia are variants of performing of the following successive and fully-mechanized operations:

 1) anchor fixing of thermal insulation (large-size mineral (glass) wool rigid tiles on a bearing wall. (2) installation of steam and wind protection membranes (polyethylene and special films). (3) mounting of the frame vertical and horizontal profiles (galvanized or stainless steel on self-drilling bolts with anchor and fragmentary bolt fixing as per calculations to a bearing wall. (4) suspending of external facing panels with leaving an air gap as per calculations (sheets of vinyl siding, ceramic siding, fiber cement sheets, vertical racks, reconstituted granite tiles).
- 2. With the aid of systematic synthesis and modeling methods new theoretical models, algorithms and recommendations for developing new rational technologies of SVF design were developed. The models can be used when developing projects for construction organization and projects for performing of works in design and con-

tractor organizations. A new multifactor model of complex impact of the most significant factors (weight and sizes of insulation boards, hinged panels, elements of steel frames and fasteners, air gap width, building height, weather conditions) on optimization of technological parameters (labor intensity, machine time spending, crane equipment, cost, technological effectiveness) was substantiated.

- 3. With the aid of the methods of alternate technological design and multi-criteria optimization the 4 optimized variants of technological solutions for installation of thermal insulation, frame and facing elements in SVF systems were developed taking into account the 4 most important consumer optimality criteria: minimum labor intensity and machine time, minimum cost, enhanced quality, maximum quality and safety. The scientific significance of the results is that the major factors affecting optimization of technological modes of various SVF designs were identified and studied. Their use allows for the reduction of labor intensity of works to 0.55–1.88 man-shift per 1 sq. m of facade area.
- 4. Dependencies (new and important for the reduction of labor intensity and cost as well as for enhancing simplicity and technological effectiveness of works) of increase in labor intensity on increase in area of mounted SVF elements, their weight and other impact factors were defined with optimality criteria of minimum cost, labor intensity and maximum quality. With the use of mathemati-

cal statistics methods mathematical models that approximate the discovered dependencies were calculated. With the aid of the on-site measurement method new important dependencies of decrease in labor intensity during SVF design on the impact of the most important natural climatic factors — extremely low temperatures and wind velocity — were determined. Dependencies (new and significant for rational organizing of works for fully-mechanized mounting) of changing labor intensity and cost on the most important impact factors — changing of facade area, weight and sizes of the installed structural elements, types of units and their joints — were discovered.

5. Studies in technological effectiveness of applying rational methods of SVF design with the aid of expert assessment methods proved a quite high level of technological effectiveness of the developed solutions with integrated account for factory, transport, mounting and operational technological effectiveness as well as technological effectiveness of upgrading and reconstruction. Besides, the integral technological effectiveness criterion of the developed SVF variants was equal to 0.665-0.650 which corresponds to a high degree of simplicity, economic efficiency and industrial efficiency of performed construction and mounting works and contributes to enhancing the overall performance of the housing construction process.

- 6. The experience of using the developed SVF technologies together with the rational solutions by construction companies of Saint Petersburg in 2010-2016 has showed the sufficient convergence of theoretical estimate performance indicators with practical assessments of the facts of experimental construction and operation. Along with that, reasonable variants of works technology with rational SVF parameters differ from the conventional methods of SVF design by the following advantages: more cost effective consumption of available construction materials, lower labor intensity, ease in work operations performance, lower discounted value taking into account the operation stage with repairs. The competitive advantage of the construction work market is that the developed technology variants allow for the performance of works by a crew consisting of just 2-3 semiskilled (grades 3-5) workers — mounter and facing worker — virtually yearround, including at subzero temperatures as per the data (See www.expertiza-negos.ru).
- 7. The obtained results can also be used in development of new designs of sandwich panels, which would have prefabricated fixing of the hinged facade or its part. This would increase rates of construction and its quality, as installation of the facade at heights is very labor consuming, especially in bad weather.

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VIBRATION ACTIVATORS IN THE CONSTRUCTION TECHNOLOGY

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Abstract

The paper covers designing methods of original structures for vibration activators on the basis of balanced eccentric vibration exciters, which can be used in designs of mixers, feeders and other processing equipment in order to increase intensity and effectiveness of their work. Regularity of the oscillation amplitude, providing stable intensive vibration effect on the processed material, regardless of its structural and rheological properties (size distribution, binder type, etc.), in combination with the constant frequency is a well-known advantage of these vibration activators.

The distinctive advantage of the considered vibration exciters from the point of view of machine vibration isolation is a balance of oscillating masses and, as a consequence, reduction of dynamic loads on external objects. The paper presents description of the design; the process of interaction with the treated medium revealing the following property of the balanced eccentric vibration activators: static (dynamic) balancing of the system, set in the air medium, is not affected when dipping the vibration activator into the mix.

The paper presents methods of balancing adjustment of vibration activators at the design stage and examples of calculations.

Keywords

Vibration exciter, kinematic excitation of oscillations, design technology, dynamic balance.

Introduction

Development of vibration technology is characterized by appearance of vibration machines for different purposes and application design. A variety of types and modifications of vibration machines, as well as conditions of their use provide a number of specific requirements to their principal design, structural execution and performance of their drives — vibration exciters (Belokobyl'skiy et al., 2008; Bauman and Bykhovskiy, 1977; Verstov, et al., 2013; Chelomey, 1981a; Den-Gartog, 1960; Emel'yanova et al., 2009; Blekhman, 1994).

Types of vibration exciters (vibrators) are divided into four main groups by their construction design: inertial (unbalanced, centrifugal), crank mechanisms (excen-

tric), electromagnetic and reciprocating (pneumatic and hydraulic) (Efremov and Lobanov, 2008; Efremov et al., 2011a; Efremov et al., 2011b; Kuzmichev, 2013; Efremov and Lobanov, 2009).

It is reasonable to use the method of internal vibration protection of an object, allowing reduction of the level of vibration on the environment, on the one hand, and maximization of vibration effect on the treated material, on the other hand, during the design of vibrating machines and equipment.

Below we consider designs and methods of designing of balanced excentric vibration activators, hereinafter referred to as vibration exciters, in which forced vibrations are carried out due to a flat rotational kinematic pair ex-

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ecuted as an elbow (a crank or an excentric sleeve), as shown in Figure 1.

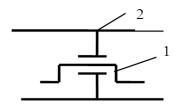


Figure 1. Excentric kinematic pair. 1 — crank; 2 — body

Excentric vibration exciters are referred to vibration exciters with kinematic excitation of vibrations.

Regularity of the oscillation amplitude, providing stable intensive vibration effect on the processed material, regardless of its structural and rheological properties (size distribution, binder type, etc.), in combination with the constant frequency is a well-known advantage of these vibration exciters.

The distinctive advantage of the considered vibration exciters from the point of view of machine vibration isolation is a balance of oscillating masses and, as a consequence, reduction of dynamic loads on external objects (drive, body, operating personnel, engineering structures, etc.).

Design description

The design of the vibration exciter includes the following main parts: bearing drive crankshaft installed on main bearings; the body fixed on rod bearings installed via excentric sleeves on the main drive shaft and balances to ensure a dynamic balance (Romanovskiy, 2010; Serebrennikov and Kuzmichev, 1999; Kuzmichev and Lyalinov, 2015; Banfill, 2011).

The flow diagram of vibration exciters is given in Figure 2.

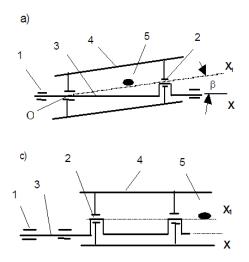
The body of an excentric vibration exciter performs a complex rotational motion consisting of a displaceable mo-

tion formed with rotation of the crankshaft around axis X and relative rotation around symmetry X1. If axes X and X1 of displaceable and relative rotations are parallel, then the movement of the vibrator can be called plane-parallel. If symmetry axis X1 intersects X axis in the point "O", then the motion of the vibrator is called precessing. The body of such exciters, hereinafter called precessing, makes motions during the rotation of the crankshaft, which is called a regular precession with nutation angle ß.

Unlike gyroscopes, the angular rate of rotation of the excentric exciter body around symmetry axis X1 is substantially less that the angular rate of rotation around axis X.

Bearings are considered to be main (1), if axis X of the crankshaft rotation passes through its center; bearings are considered to be rod (2) if they are installed along axis X1 of the relative rotation of the vibrator. We will consider a vibration exciter to be inboard if the oscillating weight mounted on connecting rod bearings is located between the main bearings (Figure 2a), and to be console, if the oscillating weight is situated behind one of the extreme main bearings (Figure 2b, c). The following variants are possible during designing: oscillating gravity center is located between the connecting rod bearings or behind the extreme crank bearing. Precessing type console vibration exciters are reasonable to be designed three-point. In this case the connecting rod bearing is situated at the point of application of the inertia resultant of centrifugal forces, and the second support executed as a resilient element is located between the main bearings (Figure 2d).

Static unbalance is typical of plane-parallel type vibration exciters, and dynamic unbalance is typical for precessing type vibration exciters. The balance (static or dynamic) implies a state of the vibration exciter as a technical system in the process, in which the reaction of main bearings against centrifugal forces and moments equals to zero, i.e. the degree of transmission of dynamic loads onto supporting pillars, the foundation and the drive, is rather small.



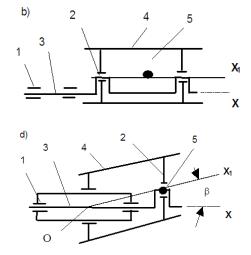


Figure 2. Schemes of typical vibration exciters: a) inboard, precessing, four-point; b, c) console, plane-parallel, four-point; d) console, precessing, three-point. 1 — main bearings, 2 — rod bearings, 3 — drive shaft, 4 — vibration exciter body, 5 — center of oscillating mass gravity. X is an axis of vibration exciter rotation; X1 is the main central axis of the exciter body inertia

It is completely impossible to eliminate the imbalance in actual design of exciters. Therefore, it can be assumed with sufficient practical accuracy that the imbalance ratio equaling the ratio of maximum centrifugal loads in crank bearing 1 to its value in connecting rod bearing 2 should be 0.01...0.02. However, it is rather difficult to determine the unbalance ratio when designing, taken all errors of geometrical dimensions and material density during manufacturing of exciter parts. Therefore, the permissible unbalance can be determined by the highest amplitude of oscillation of the vibration machine body (frame). The value of the body oscillation amplitude is determined by the constraint $A\omega^2 \leq 0.5g$, where ω , A is the frequency and amplitude of vibrations of the vibration machine body (frame), respectively.

Methods

Let us consider the work of a vibration exciter in the medium (Figure 3).

The exciter shaft rotates at a constant angular rate of the motor. Torque occurring on the exciter shaft is a sum of the moments of internal forces (friction in bearings, seals, etc.) and the moment of external forces $M=eP_c$.

P is a driving force applied to the connecting rod bearing, which is equal to M/e and directed at the angle of 90 degrees to the crank; Q is a centrifugal force directed along the crank; P_c is the power of the medium resistance which is also applied to connecting rod bearings and is rotated by 90 degrees clockwise with respect to the centrifugal force.

In order to achieve static (dynamic) balance of the system, i.e. when reactions in main bearings 1 equal zero, it is necessary that the sum of all external forces acting in connecting rod bearing (bearings) 2 would equal to zero. It is obvious that the driving force P equals to the power of the medium resistance P_c in value and is opposite in sign. To balance the centrifugal force Q it is necessary to place counterweights, creating an opposite directed force equal in value. The above said can be written in the form of a constraint:

$$P = P_c; Q = P \tag{1}$$

The constraint (1) reveals the following property of excentric balanced vibration exciters: static (dynamic) balancing of the system, carried out in the air, is not affected when dipping the exciter into the mix.

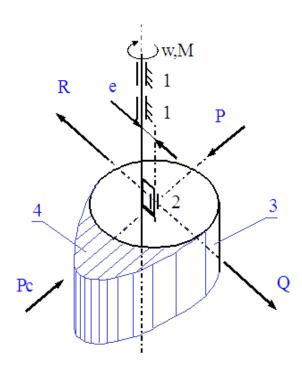


Figure 3. Scheme of driving forces acting on the vibration exciter, dipped in the mix: 1, 2, 3 — the main and connecting rod bearings, as well as the exciter body, respectively; 4 — diagram of the drag force of the medium; *M* is an external force moment (on the drive shaft); e is excentricity (oscillation amplitude); Q is a centrifugal force produced by the rotation of unbalanced masses; R is a centrifugal force produced by the rotation of a counterweight; P is a driving force applied to the connecting rod bearing; P_c is resistance force of the mix (the force preventing rotation of the exciter in the medium); w is the drive shaft rotation rate

Method of vibration exciter balancing

The vibration activator balancing method is based on the known positions of rotors balancing, which always can be brought into a state of dynamic equilibrium with two corrective masses arranged in two unspecified correction planes (Chelomey, 1981b).

The calculation task includes the following:

- 1. determination of the value and location of the resultant of centrifugal forces generated by rotation of unbalanced (fluctuating) masses:
- 2. determination of the counterweight mass and places of their location on the main drive shaft providing static (dynamic) balancing the unbalanced masses.

Unbalanced weight is the total mass of vibrating elements in the design of a vibration exciter, the center of gravity of which is located on main central inertia axis X_a .

When calculating according to item 1 it is recommended not to include the weight of the connecting rod bearing assemblies in the unbalanced mass in order to simplify the design process and reduce the calculation procedure.

Calculation according to Item 1.

Unbalanced mass of the vibration exciter can be represented as a sum of linear distributed and concentrated lengthwise masses.

The most common (possible) typical schemes for precessing exciters are presented in Figures 4a, b, c, d, e, f, g. Resultants of centrifugal forces arising as a result of circular body vibrations are defined by the following formulas for typical schemes presented in Figure 4:

$$Q_i = \int_a dQ_i = \int_a \omega^2 q_i(tg\beta)xdx \tag{2}$$

where dQ_i is a prime centrifugal force.

After substitution of the values of distributed loads into the equation (2) and their integration within appropriate limits we will obtain the following:

a)
$$q_i = const; Q_1 = \omega^2 q_1 g \beta \int_0^l x dx = \frac{1}{2} \omega^2 q_1 l^2 g \beta$$

b)
$$q_2 = const; Q_2 = \omega^2 q_2 g \beta \int_{l_1}^{l} x dx = \frac{1}{2} \omega^2 q_2 (l^2 - l_1^2) g \beta$$

c)
$$q_3 = q^* (1 - \frac{x}{l})$$

$$Q_3 = \omega^2 q^* t g \beta \int_{0}^{l} (1 - \frac{x}{l}) x dx = \frac{1}{6} \omega^2 q^* l^2 t g \beta$$

d)
$$q_4 = q^* (1 - \frac{x - l_1}{l - l_1})$$

$$Q_{4} = \omega^{2} q^{*} g \beta \int_{l_{1}}^{l} (1 - \frac{x - l_{1}}{l - l_{1}}) x dx =$$

$$= \frac{1}{6} \omega^{2} q^{*} (l^{2} + l l_{1} - 2l_{1}^{2}) g \beta$$

$$e) q_{5} = q^{*} \frac{x}{l} \int_{0}^{l} Q_{5} = \omega^{2} q^{*} t g \beta \int_{0}^{l} \frac{x}{l} x dx = \frac{1}{3} \omega^{2} q^{*} l^{2} t g \beta$$

$$f) q_{6} = q^{*} \frac{x - l_{1}}{l - l_{1}}$$

$$Q_{6} = \omega^{2} q^{*} t g \beta \int_{l_{1}}^{l} \frac{x - l_{1}}{l - l_{1}} x dx = \frac{1}{6} \omega^{2} q^{*} (2l^{2} - ll_{1} - l_{1}^{2}) t g \beta$$

$$g) Q_{7} = \sum_{l}^{n} M_{i} l_{i} \omega^{2} t g \beta$$

Diagrams of centrifugal forces and points of application of their resultants for standard circuits of distributed loads are presented in Figures 5a, b, c, d, e, f (letter designations correspond to the typical schemes in Figure 4).

Coordinate L_i of the application points of the resultant of centrifugal forces is determined by the following formulas based on the equation (2):

$$L_{i} = \frac{\int_{\ell} dM_{i}}{Q_{i}} = \frac{\int_{\ell} x dQ_{i}}{Q_{i}} = \frac{\int_{\ell} \omega^{2} q_{i}(tg\beta)x^{2}dx}{Q_{i}}$$
(3)

where dM_i s a prime static moment of centrifugal forces in relation to the point O.

After substitution of the values of distributed loads and corresponding centrifugal forces into the equation (3) and their integration within appropriate limits we will obtain the following:

a)
$$L_1 = \frac{2}{3}I$$

$$L_2 = \frac{2(l^3 - l_1^3)}{3(l^2 - l_1^2)}$$

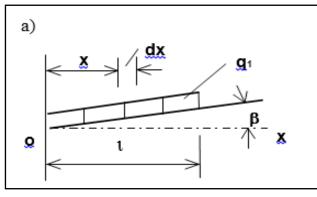
c)
$$L_3 = \frac{l}{2}$$

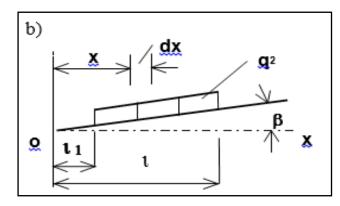
$$L_4 = \frac{1}{2} \frac{(l^3 + l^2 l_1 + l_1^2 - 3 l_1^3)}{(l^2 + l_1 - 2 l_1^2)}$$

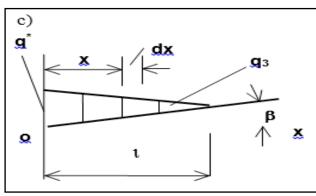
e)
$$L_5 = \frac{3}{4}I$$

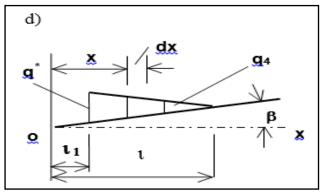
f)
$$L_6 = \frac{1}{2} \frac{(3f^3 - II_1^2 - f^2I_1 - I_1^3)}{(2f^2 - II_1 - I_1^2)}$$

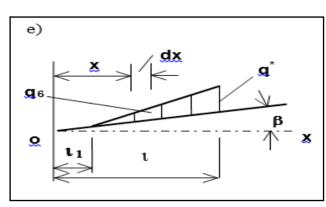
g)
$$L_7 = \frac{\sum_{i=1}^{n} M_i I_i^2 \omega^2 t g \beta}{Q_7}$$

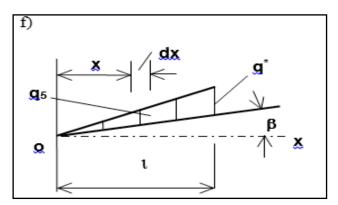












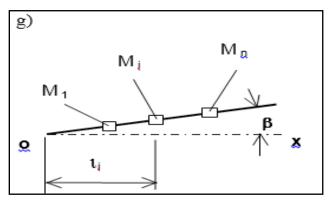


Figure 4. Typical schemes of distributed and concentrated masses: X is the current coordinate; q_{ij} is the distributed load; M_{ij} is the concentrated mass; I is the length

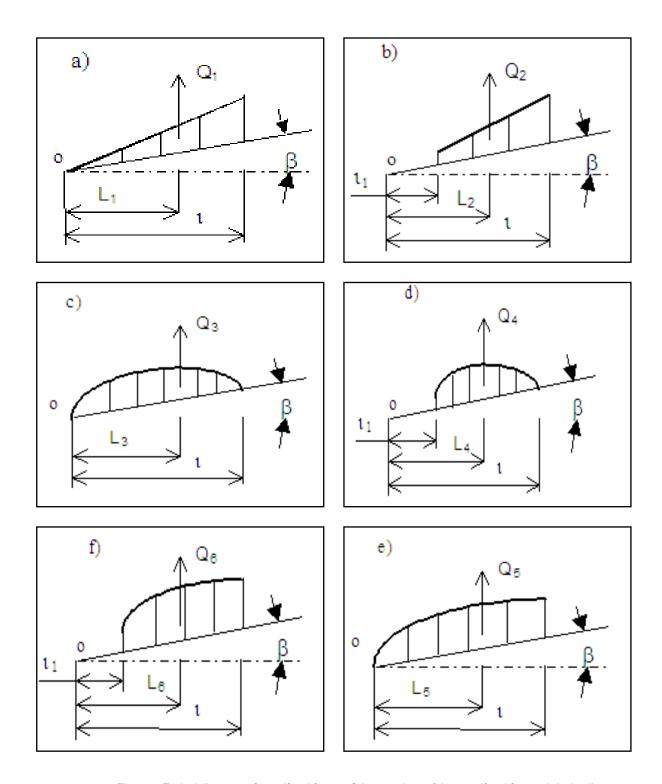


Figure 5. Typical diagrams of centrifugal forces: Q_i is a resultant of the centrifugal forces; L_i is the distance from the point O to the point of application of the resultant of centrifugal forces

Example. Let unbalanced exciter body elements be presented in the form of distributed masses q_1 and q_2 and concentrated mass M as shown in Figure 6.

When applying the method of superposition (the method of independence of acting forces), resultants of centrifugal forces is determined taking into account the following expressions (2a, b, g).

$$Q = Q_1 + Q_2 + Q_7 = \omega^2 t \ g\beta(\frac{1}{2}q_1 l_1^2 + \frac{1}{2}q_2(l^2 - l_1^2) + M \ l)$$
(4)

and the point of its implementation (distance L) is determined considering the following expressions (3a, b, g):

$$L = \frac{Q_1 L_1 + Q_2 L_2 + Q_7 L_7}{Q} = \frac{\omega^2 g \beta(\frac{1}{3} q_1 l_1^3 + \frac{1}{3} q_2 (l^3 - l_1^3) + M l^2)}{Q}$$
(5)

Expression (6) is valid on the same basis as the expression (4); here M_p is the reduced mass (weight of unbalanced elements of the exciter body modified to the point of the resultant application); $Ltg\beta$ is the value of the excentricity of the resultant application point (oscillation amplitude).

$$Q = M_p \omega^2 L t g \beta \tag{6}$$

Comparing expressions (4) and (6) we will get:

$$M_{p} = \frac{1}{L} \left(\frac{1}{2} q_{1} l_{1}^{2} + \frac{1}{2} q_{2} (l^{2} - l_{1}^{2}) + M l \right)$$
 (7)

When using the concept of reduced mass, calculations are simplified, as the multiplier $\omega^2 tg\beta$ can be ignored in the expressions (4) and (5).

The circuits of distributed masses presented in Figure 4 cover almost all possible subpossibilities of unbalanced elements at the body of a vibration exciter.

In the case when the exciter body oscillates with the constant amplitude (plane-parallel vibration exciter), calculation of centrifugal force and the point of its application is as follows:

- the unbalanced mass m of the vibration exciter and the position of its center of gravity distance L from the end face of the body is determined with known methods;
- the resultant of centrifugal force is calculated by the formula Q= $me\omega^2$, where e is the magnitude of the crank eccentricity (oscillation amplitude); is the angular rate of rotation of the drive crankshaft of the vibration exciter.

Calculations by Item 2.

The design author has the right to determine locations of correction planes (location of counterweights) in each case depending on the task of vibration exciter designing.

In this sense, the task of dynamic balancing is a creative task for the designer in terms of rational designing of vibration exciters.

Design diagrams of dynamic balancing of vibration exciters that are relevant to schemes in Figures 2a, b, c, d are shown in Figures 7a, b, c, d.

The concept of design diagrams is as follows. The main beam (bearing drive crankshaft of the vibration exciter) pictured as a bottom line rests on support 1 (main bearings). There is auxiliary bar *A* (vibration exciter body, unbalanced mass) shown as a top line, which rests on support 2 (connecting rod bearings).

Centrifugal loads occurring due to unbalanced masses (from the vibration exciter body) during rotation of the bearing drive shaft are depicted in the form of the resultant Q, R, R_3 , R_4 are centrifugal loads from connecting rod bearing assemblies.

- R_{1} , R_{2} are centrifugal loads in connecting rod bearings appearing from the centrifugal force Q.
- P, P, P₂ are counterbalancing forces (centrifugal forces generated during rotation of counterweights mounted on the drive shaft). Geometrical dimensions L_i establish connection between the acting forces.

The magnitude of forces P, P_1 , P_2 and distances L_3 , L_4 determining the location of counterweights are to be estimated.

The procedure of calculations is the following:

- 1. the layout of counterweights (a counterweight) is determined in terms of design;
- 2. centrifugal loads R_1 , R_2 in connecting rod bearings caused by the centrifugal force Q are defined with static methods;
- 3. the centrifugal forces R, R_3 , R_4 arising from oscillation of rod bearing assemblies are determined by the formula: $R_i = m_i e_i \omega^2$, where m_i is the weight of the bearing assembly; e_i is the value of the sleeve excentricity;
- all above stated forces are summarized taking into account the sign of forces direction;
- 5. all necessary values of centrifugal forces gained by counterweights are calculated in accordance with conditions of the statics in order to determine dynamic balancing and installation location of counterweights;
- 6. geometrical dimensions of counterweights (a counterweight) are selected and their (its) weight is determined; these inputs will provide the target centrifugal force.

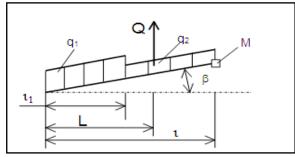
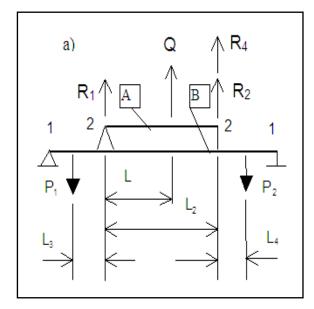
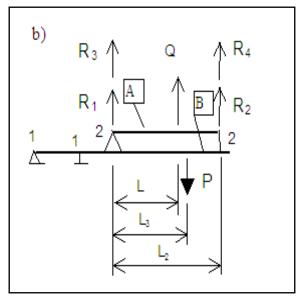
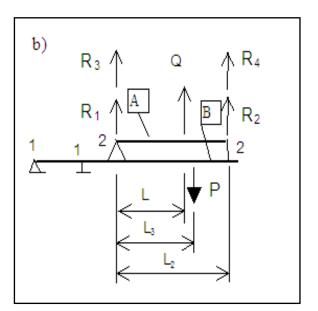


Figure 6. Design model







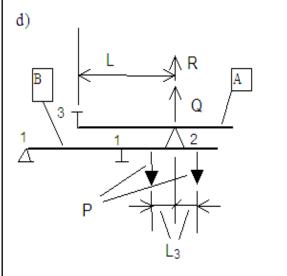


Figure 7. Design diagrams of dynamic balancing

$$P = m^* \ v \ \omega^2 \tag{8}$$

where m is the balance weight; y is the distance from the center of gravity of the counterweight to the rotation axis; ω is the angular rate of rotation of the vibration exciter shaft.

Dynamic balancing (balance of the vibration exciter) for the above stated examples is carried out under the following conditions:

$$\begin{split} \sum P_i &= 0 \,; \qquad \sum M_i = 0 \\ \text{a)} \ P_1 = R_1; \ P_2 = R_2 + R_4 \qquad \qquad P_1 L_3 = P_2 L_4 \\ \text{b)} \ P = R_1 + R_2 + R_3 + R_4; \qquad \qquad PL_3 = (R_2 + R_4) L_2 \\ \text{c)} \ P_1 = 1/2 (R_1 - R_3), \ R_1 > R_3 \text{ symmetrical arrangement of} \\ P_2 = 1/2 (R_2 + R_4) \qquad \qquad \text{counterweights} \\ -P_1 = 1/2 (R_1 - R_3), \ R_3 > R_1 \text{ symmetrical arrangement of} \end{split}$$

d) The design involves one connecting rod bearing which is installed at the point of application of the resultant of centrifugal forces.

 $P_2=1/2(R_2+R_4)$ counterweights (reverse direction)

P=1/2(Q+R) symmetrical arrangement of counterweights

If a geometric shape of the counterweight corresponds to the one showed in Figure 8 then the main design parameters are determined by the following formulas:

$$y = \frac{2}{3\pi} \frac{D^2 + Dd + d^2}{D + d}; F = \frac{\pi (D^2 - d^2)}{8}; \delta = \frac{m^*}{F\rho}$$
 (9)

where F is the cross-section area of the counterweight. The required thickness of the counterweight is calculated on the basis of the outer and inside diameter of counterweights.

If unsatisfactory results are received in terms of the layout of counteweights on the vibration exciter body (assuming the impossibility of design arrangement), compensation planes or the design of the vibration exciter body is changed and the calculation is repeated. In this sense, the tasks of designing are expressed in successive approximations to obtain the desired results.

When developing the manufacturing of vibration activators, it is recommended that oscillating parts of a test article are weighed and compared with target inputs. In case of divergence between target and actual weights by more than 2%, the weight of the counterweight (counterweights) should be specified.

Conclusions

Methods of designing of vibration activators are developed on the basis of balanced excentric vibration exciters that meet the requirements of durability of their operational life and their reliability. They can be used in the design of mixers, feeders and other processing equipment in order to increase intensity and effectiveness of their work. The publications (Kuzmichev, 2013; Romanovskiy, 2010; Serebrennikov and Kuzmichev, 1999; Kuzmichev and Lyalinov, 2015) present results of use of vibration activators in mixing processes for building materials.

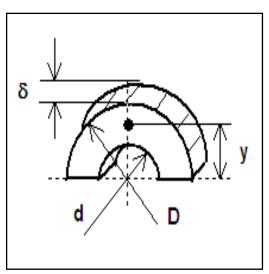


Figure 8. Counterweight. d is the outer diameter, D is the inside diameter, δ is thickness, and y is the center of gravity.

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SUBSTANTIATION OF THE REPLACEMENT INTERVAL OF CONSTRUCTION MACHINES BY THE TARGET RELIABILITY LEVEL

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Abstract

The article presents results of researches in the field of ensuring operational capability of complex technical objects using the example of construction machines. Methods of determining the replacement interval of elements in accordance with the accepted at the present time progressive operating strategy — by technical condition, in accordance with the current reliability level, determined by statistical or parametric characteristics of replaced units — are considered. Replacement is performed before reaching of limiting values of characteristics. Parametric characteristics are measured in the process of unit condition diagnostics, and statistical characteristics are determined on the basis of operational information.

Keywords

Construction machines, transport-technological machines, reliability, operation, technical condition, repair.

Introduction

Provision of operational capability of complex technical objects, which include transport-technological machines (TTM), in particular, excavators, is carried out through maintenance and repair (M&R). Since the machine life generally exceeds manifold the life of its constituent components, replacement of elements, which spent their resource, is performed during M&R. Replacement is performed in accordance with the progressive operating strategy accepted at the present time — by technical condition (TC). TC assessment is performed based on the current reliability level which is determined by statistical or parametric characteristics of replaced units. Replacement is performed before reaching of limiting values of characteristics.

Parametric characteristics are measured in the process of unit condition diagnostics (for example, volumetric efficiency of the pump). However, not all units have measurable parameters (for example, high-pressure hoses of the hydraulic system). Such elements are replaced on the basis of statistical characteristics.

Limit values of reliability level indices and TC parameters of elements are selected taking into account the object type, its use, structural scheme of its reliability, and pattern (or determination method) of the limit state. A transportation vehicle can serve as an object type example. Let us consider two types of transportation vehicles, i.e. passenger

aircraft and agricultural tractor. Failure of an important element of the aircraft in flight will lead to disaster and in the tractor — to halt in a field. Consequences of the failure differ significantly, therefore, patterns of the limit state will be different too. For the aircraft, the limit state is the probability value of the failure in flight, conditioned by safety requirements. For the tractor, the probability value of the failure is conditioned by requirements of the economic practicability of its use. The structural diagram is determined by the availability of element redundancy. In the aircraft, most systems are reserved; in the tractor — only the braking system is reserved.

Dynamics of the current values of TC parameters of elements in operation is traced through carrying out the periodic diagnostics according to the schedule of carrying out M&R activities or through continuous diagnostics with special devices built into the operated object, and observations of the staff. Dynamics of current values of reliability level indices is assessed based on the collection of statistical information on element failures.

Planning activities on maintenance, repair and replacement of elements is carried out taking into account the operation specifics of objects. For example, for transport construction machines (gas pipelines) used seasonally in places, which are hard-to-reach to carry out maintenance and repair, the interval between repairs will be long. Therefore, the resource stock of machine elements prior to repair or replacement shall be increased. The scope of repair and replacement works also increases before the operation season. Such method of M&R by the condition can be called preventive.

Subject, problems and methods

The study subject is TTM as a complex technical system consisting of elements, replacement interval of which determines the reliability of the machine as a whole.

The problem, solved in the article, is development of methods for the substantiation of the unit replacement interval. Methods of statistical analysis and forecasting are used.

Assessment of machine elements reliability using the queuing theory

Many researchers (Bujaczek, 2013; Repin and Evtjukov, 2015; Protasov and Nikolaychuk, 2011; Chernyavsky and Shadchin, 2010) propose to assess the reliability of machines with the help of the queuing theory (QT). A scheme of change in states of elements replaced by the time to failure, drawn up according to QT methods, is presented in Figure 1.

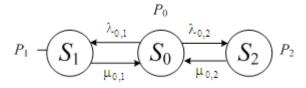


Figure 1. Marked out graph of states of the element replaced by time to failure: S — element states (S0 — operable, S1 — scheduled replacement, S2 — unscheduled replacement); λ — failure rates; μ — repair rates; P — probabilities of states

Intensities of transitions between states are determined by the following equation:

$$\lambda_{0i} = (T_f)^{-1}, \mu_{0i} = (T_r)^{-1}$$
(1)

where T_{i} — time to i-th failure (i = 1 — scheduled maintenance, i = 2 — unscheduled maintenance); T_{i} — restoration time after i-th failure.

The total failure rate:

$$\lambda = \lambda_{0.1} + \lambda_{0.2} \tag{2}$$

Kolmogorov equations for the described case have the following form:

$$\begin{cases} P_0 \ \lambda_{0.1} = P_1 \mu_{1.0} \\ P_0 \ \lambda_{0.2} = P_2 \mu_{2.0} \\ P_0 + P_1 + P_2 \end{cases}$$

Solving the system, we get:

$$P_0 = (1 + \frac{\lambda_{0.1}}{\mu_{1.0}})^{-1}; P_1 = P_0 \frac{\lambda_{0.1}}{\mu_{1.0}}; P_2 = P_0 \frac{\lambda_{0.2}}{\mu_{2.0}}$$
(3)

Example.

Let the replacement interval (time between repairs — T_{sm} (life of a node for scheduled maintenance)) of the high pressure hose (HPH) of the bucket hydraulic cylinder be 5,000 machine hours. ($T_{sm} = T_{ft} = 5,000$ machine hours), replacement duration time — 0.5 h ($T_{rt} = 0,5$ h). Mean time to

failure $T_{r2} = \overline{T}_f = 6,500$ machine hours. Mean restoration time after the HPH sudden failure — 5 h ($T_{r2} = 5$ h). It is required to determine probabilities of states and the actual need for replacements.

The example solution is given in Appendix G. As a result of the calculation by equations (1-3), state probabilities are obtained:

 $P_{\rm 0}$ = 0.999, $P_{\rm 1}$ = 9.991·10⁻⁵, $P_{\rm 2}$ = 7.686·10⁻⁵, showing a very high reliability of HPH. This method is suitable for assessing the reliability of the machine as a system of elements, and that makes it possible to calculate such important indices of the machine as the availability factor and percentage of uptime, but does not give a proper idea of the operational reliability of elements and does not allow determination of the actual need for their replacement. For example, the operation experience shows that one of six HPHs stops operating until the scheduled date of replacement. To assess the probability of failure-free operation of the element prior to the date of its replacement, it is more preferable to use methods of the probability theory.

Determination of parameters of time-before-failure distribution laws

Deadlines of scheduled replacements are fixed according to the known resource of components. Naturally, the period of the scheduled time before component failure till the time of its replacement shall not exceed the mean time before failure (MTBF). The statistical distribution of HPH resource, as well as of the most of non-repairable components, is subject to the normal law. The normal law describes well the distribution of random variables at significant effect of equivalent factors. Characteristics of the normal distribution law of random variable T (for example,

time to failure of a machine, node) are determined by the following expressions:

- probability distribution function:

$$F(T) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} \exp\left(-\frac{(T - \overline{T}_f)^2}{2\sigma^2} dt\right)$$

- probability of failure-free operation:

$$P(T) = 1 - F(T)$$

- distribution density:

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} \exp(-\frac{(T - T_f)^2}{2\sigma^2})$$

- root mean square deviation:

(4)
$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (T_i - \overline{T}_f)^2}{N-1}}$$

where \overline{T}_f — mathematical expectation of a random value (mean time to failure, average service life, etc.).

In interpretation for the considered case of HPH reliability analysis, probability distribution function F (T) shows the probability of element failure before the date of its scheduled replacement.

(6) $\overline{T}_{\rm f} = 6500$ $T_{\rm sm} = 5000$ T, \overline{T}_f , σ 1 - P(T, 6500, 1500) P_0 0,8 The probability 2 - F(T, 5500, 1000) 0,6 3 - F(T, 6500, 1500) 0,4 4 - P₀=P(5000, 6500, 1500)=0,841 5 - F(5000, 5500, 1000)=0,309 0,2 6 - P_f =F(5000, 6500, 1500)=0,159 4000 6000 8000 T, moto hours 2000

Figure 2. Graph of failure-free operation probability (line 1) and functions of HPH time-to-failure probability distribution (lines 2 and 3): T_{sm} — life of a node for scheduled maintenance; P_{o} , Pf — probability of failure-free operation or failure of a node before the time of the scheduled repair, respectively

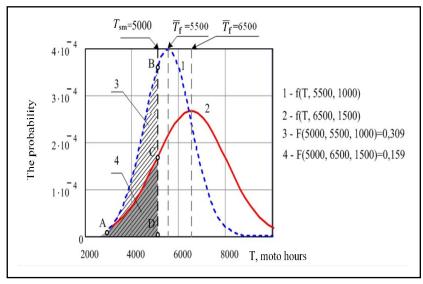


Figure 3. Graph of HPH time-before-failure probability distribution density (designations are the same as in Figure 2)

The use of Mathcad mathematical environment significantly facilitates the work on the analysis of the operational information. Therefore, for the statistical analysis of data on time to failure, which are subject to the normal law, the Mathcad software was developed (Repin et al., 2012; Repin et al., 2016). The following statistical characteristics should be defined to determine parameters of the distribution law and construct a histogram: sample volume; minimum, maximum and mean arithmetic (mathematical expectation) sample values; root mean square deviation (Figure 2).

In Figure 3, graphs of HPH time-before-failure probabili-

ty distribution density f (T, \overline{T}_f , σ) are presented. Marked areas of graphs to the left of T_{sm} line (figures ABD and ACD indicated with numbers 3 and 4) correspond to probabilities of HPH failure before the date of the scheduled replacement.

Development of an optimization model of the number of replacements by unit costs and reliability of replaceable elements

As the basis of probabilistic models for determination of time to failure before preventive maintenance, the idea of minimizing the weighted-average costs for repairs was laid, proposed by prof. Ye.I. Zaitsev. As weighting factors for two alternatives (emergency repair, caused by a sudden failure, and preventive repair), the risk of missing failure (Repin et al., 2012) (corresponds to F (T_{sm})).

$$R_{sm} = \int_{0}^{T_{p}} f(T) dT = F(T_{sm}) = 1 - P(T_{sm})$$
 (8)

and the risk of cost overrun for preventing failures (corresponds to the probability of failure-free operation):

$$R_{pm} = \int_{T_{cm}}^{0} f(T)dT = P(T_{sm})$$
 (9)

are used, correspondingly, where f(T) — time-to-failure

distribution density with the mathematical expectation \overline{T}_f ; $T_{\rm sm}$ — life of a node for preventive maintenance.

Costs, which are subject to minimization, are determined by the following equation:

$$Z=Z_{sm}\cdot R_{sm}+Z_{pm}\cdot R_{pm}=Z_{sm}[1-P(T_{sm})]+Z_{pm}\cdot P(T_{sm})\to min$$
 (10)

where $\mathbf{Z}_{\rm sm}$ - total costs for emergency maintenance, $\mathbf{Z}_{\rm pm}$ - total costs for preventive maintenance.

If we express cost components through average costs of emergency $C_{\scriptscriptstyle Sm}$ (taking into account damage D - direct damage, for example, from working liquid losses and collateral to stop of works)) and preventive $C_{\scriptscriptstyle pm}$ maintenance, then we will obtain:

$$Z = \frac{T_{overhaul} \{ (C_{sm} + D) \cdot [1 - P(T_{sm})] + C_{pm} \cdot P(T_{sm})}{T_{sm}}$$
(11)

where $T_{overhaul}$ / T_{sm} is the number of operational (repair) cycles at the specified finite time to failure $T_{overhaul}$ (for example, before the overhaul).

For a considered example, the Mathcad software is also developed. In Figure 6, results of calculating optimal element replacement intervals are presented by minimum costs in a repair cycle for various *D* damage values.

The calculation is carried out for two types of replaceable elements of single-bucket excavators (SBE): high-pressure hoses (HPH) and bucket teeth.

Mean time to failure (\overline{T}_f) of HPH is commensurable with time to failure before the overhaul (6,500 and 8,000 machine hours, respectively), therefore, the number of replacements in the period between repairs does not exceed two, and that reduces the demonstrative ability of some diagrams. However, for HPH, the impact of damage, related to the sudden failure, is significant (D — up to 10,000 RUB), since in case of HPH collapse, a large amount of expensive working fluid outflows.

For bucket teeth, \overline{T}_f 400–500 machine hours, therefore, the number of replacements for elements with different reliability indices differs significantly. Figure 4 shows the effect of reliability characteristics of replaceable elements on the value of optimal element replacement intervals, calculated by minimum costs in a repair cycle. The use of this analysis method makes it possible to approach the spare parts procurement optimization from the viewpoint of "price–quality".

Elements replaced according to their condition with reliability level control

Features of operation and replacement of units:

- main reliability characteristics of elements replaced according to their condition with reliability level control are resource values of a new T_{new} and replaced T_{rep} units as a result of repair, characterized by time to failure in machine hours:
- the resource of the replaced (repaired) element is related to the resource of a new element through the resource restoration factor K_r i.e. $T_{rep} = T_{new} \cdot K_r$ (for hydraulic actuator units, $K_r = 0.3 0.8$);
- realization of the resource by time to failure is subject to the normal distribution law;
- dynamics of the time before failure by time is described by the exponential law $T_f(t) = T(1) \cdot \exp(-\beta_t \cdot t)$;
- distribution of the planned annual time to failure of a machine is subject to the uniform law.

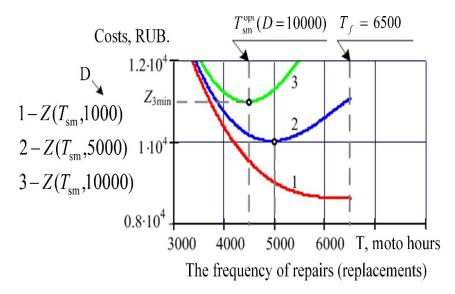


Figure 4. Results of calculating optimal element (HPH) replacement intervals by minimum costs in a repair cycle for various D damage values (RUB). 1-1000, 2-5000, 3-1000

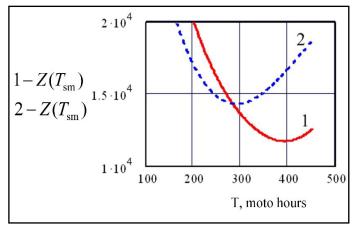


Figure 5. Effect of reliability of replaceable elements (bucket teeth) on the value of optimal element replacement intervals, calculated by minimum costs in a repair cycle (see characteristics in Table 1)

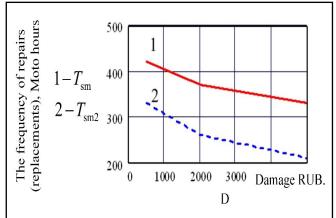


Figure 6. Effect of the damage value from sudden failures of the equipment element (tooth) and its characteristics on the value of optimal replacement intervals (using excavator tooth as an example)

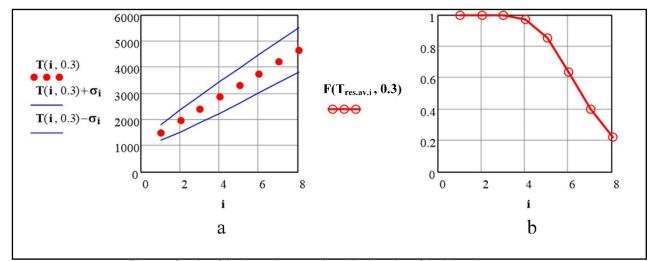


Figure 7. Graphs of the dependence on the ordinal number of the i-th replacement: a — intervals of the element replacement; b — probability of the element failure after the *i*-th replacement before the expiry of the machine mean life T_{res.av.}

Table 1. Characteristics of the replaced element (using excavator tooth as an example)

Element	\overline{T}_f , machine hours	σ, machine hours	C _{pm} , RUB	C _{sm} , RUB	D, RUB
No. 1	550	100	500	800	1,000
No. 2	450	120	400	700	1,000

Determination of the replacement number of elements for the machine life taking into account the scattering of replaced element resource values

Let the average machine resource be $T_{\rm res.av.}$. Without taking into account scattering of the element resource, the total number of necessary spare parts n per one machine before writing-off will be determined by the following relation:

$$Z = \frac{(T_{res. a v.} - T_{new})}{T_{rep} n} = \frac{(T_{res. a v.} - T_{new})}{T_{rep}}$$
(12)

Taking into account the probable resource deviation for the normal law of its distribution, the number of spare elements is determined as follows. Let us specify the average resource before the first replacement of a particular element T_{new} , root mean square deviation of the resource for both new and replaced elements, σ and resource restoration factor K_r . By the time of the first replacement the average resource will be $T_1 = T_{new}$, by the time of the second replacement $T_2 = T_{new} + T_{rep} = T_{new}$ (1 + K_r), by the time of the i-th replacement:

$$T_i = T_{now}[1 + K_r(i - 1)]$$
 (13)

Let us assume that the root mean square deviation of the resource at all replacements of elements does not change: $\sigma 1 = \sigma 2 = \sigma$.

However, considering the graph of the density distribution, it is possible to note that scattering of resource values along the axis of time to failure will increase with each replacement by the value of 4σ (Figure 11, curves 2 and 4).

To avoid increase in the uncertainty of the resource value after the *i*-th replacement, it is proposed (Repin and

Evtjukov, 2015) to calculate the root mean square deviation of the resource according to the following equation:

$$\sigma_i = \sigma \sqrt{i} \tag{14}$$

The distribution density of the new element resource T_{new} and the total resource of the new and replaced elements $(T_{new} + T_{rep})$ are represented by curves 1 and 3. Therefore, the element failure probability at each replacement:

$$F(T) = \phi \{ (T_{res, a, v} - T_{new} - T_{new} \cdot K_r (i-1)] / \sigma \sqrt{i}$$
 (15)

where F {...} —Laplace's function, which is determined by the table of normal distribution function values.

The total number of element replacements required for a single machine taking into account scattering of the resource:

$$z = \sum_{i=1}^{8} F_i(T_i)$$
 (16)

Example. The life of a hydraulic actuator $T_{res} = 4,000$ hours, the resource of a safety valve $T_{new} = 1,500$ hours, the root mean square deviation of the resource $\sigma = 300$ hours, restoration factor $K_z=0,3$."

The task is to determine the required number of safety valves to ensure the service life of the hydraulic actuator. The solution, fulfilled in the Mathcad program, is shown in Figure 11 and 12.

Based on the solution, shown in Figure 7b, the number of spare safety valves taking into account resource scattering:

$$z = \sum_{i=1}^{8} F_i \cong 6$$

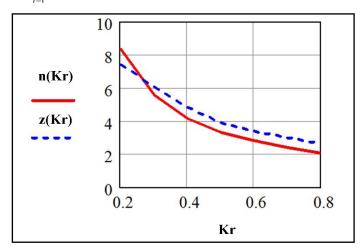


Figure 8. Graphs of the dependence of the element replacement number on the resource restoration factor Kr: n — without taking into account resource scattering (equation 12); z — with taking into account resource scattering (equation 16)

It should be noted that the number of element replacements essentially depends on the resource restoration factor K_r . The dependence of the number of replacements n and z on the resource restoration factor K_r is presented graphically in Figure 8.

To increase the value of the failure-free operation probability, it is needed to reduce the intervals of the element replacements.

Elements, replaced according to their condition with control of parameters of the technical condition

In dynamics of technical condition parameters of the machine elements, it is possible to distinguish certain features of operation and replacement of units (elements) according to their condition with control of parameters:

- in the operation process, their main parameter *Xi* characterizing the element operational capability changes;
- limit state is determined by the limiting value of the parameter $X_{\rm lim}$;
- to predict the time to replace the element, the law of variation X (T), and the limit parameter value should be known.

Predicting the residual resource

In the theory of recognition and forecasting, there are two main approaches to the problem of forecasting: probabilistic and deterministic (Repin et al., 2011; Jiang et al., 2014; Makhutov and Reznikov, 2015; Makhutov et al., 2013; Trukhanov, 2014).

Prediction of deterministic (functional) processes is carried out by interpolating (searching of the intermediate value of the function in the interval) or extrapolating (searching of the value of the function beyond the interval). In this case, at first, the analytical expression of the function under study is revealed, and then the prediction is carried out. When predicting deterministic processes with little prediction time, the Lagrange interpolating polynomial is used. When there is little information about the controlled function, the least squares method is used. Empirical formulas are used in the form of functions: fractionally linear, power, exponential, logarithmic, and others.

Example. Predicting the residual resource of the geartype pump NSh-46U based on materials of volumetric efficiency change of 20 pumps Data on the change in volumetric efficiency with time to failure are shown in Table 2.

Table 2. Data on the change in the pump volumetric efficiency with time to failure

Pump	Time to failure T, thous. h						
	0.0	0.4	0.8	1.2	1.4		
1	2	3	4	5	6		
No. 1	0.932	0.929	0.889	0.864	0.859		
No. 2	0.945	0.945	0.925	0.896	0.866		
No. 3	0.925	0.914	0.894	0.860	0.825		
No. 4	0.959	0.966	0.946	0.921	0.895		
No. 5	0.946	0.946	0.926	0.898	0.869		
No. 6	0.941	0.938	0.918	0.888	0.858		
No. 7	0.934	0.928	0.908	0.877	0.845		
No. 8	0.972	0.968	0.958	0.934	0.910		
No. 9	0.971	0.968	0.948	0.922	0.897		
No. 10	0.955	0.960	0.940	0.913	0.887		
No. 11	0.923	0.922	0.892	0.857	0.822		
No. 12	0.964	0.962	0.952	0.928	0.903		
No. 13	0.953	0.957	0.937	0.909	0.882		
No. 14	0.943	0.941	0.921	0.891	0.861		
No. 15	0.932	0.925	0.905	0.872	0.839		
No. 16	0.939	0.925	0.855	0.814	0.773		
No. 17	0.915	0.900	0.880	0.843	0.807		
No. 18	0.935	0.930	0.910	0.878	0.846		
No. 19	0.921	0.939	0.889	0.853	0.818		
No. 20	0.923	0.921	0.891	0.856	0.821		
Stand. dev. — σ	0.016	0.019	0.027	0.031	0.035		
Coef. of variation	0.017	0.020	0.030	0.035	0.041		
Upper level of efficiency values: $U1 = \eta + \sigma$	0.958	0.958	0.941	0.915	0.889		
Average value of the volumetric efficiency: η	0.941	0.939	0.914	0.884	0.854		
Lower level of efficiency values: $U2 = \eta - \sigma$	0.925	0.920	0.887	0.853	0.819		

Distribution of pump efficiency values at the same time to failure is subject to the normal law (Figure 9 and 10).

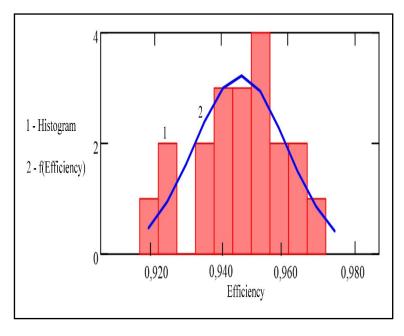


Figure 9. Histogram of the efficiency values distribution with regard to the new pump (T = 0) and graph of the normal distribution law density

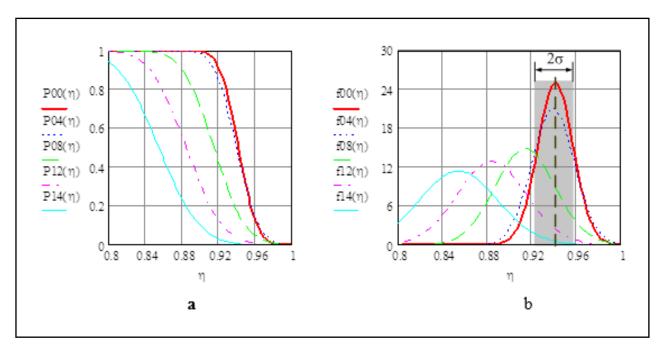


Figure 10. Graphs of the dependence on time to failure: where a — probabilities of entering pump efficiency values within the interval not lower than predetermined by the curve $P(\eta)$; b — densities of the normal distribution law with regard to efficiency values (in designation of probability and density, figures show time to failure in hundreds of hours)

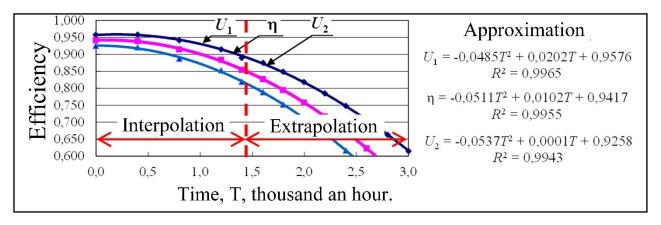


Figure 11. Results of the analysis and predicting the pump efficiency dynamics in Excel

For all 20 pumps, the averaged curve (characteristic) of the change in volumetric efficiency with time to failure T is constructed by finding the mathematical expectation in the middle of time-to-failure intervals (Figure 10).

Approximation of the obtained curve is made by finding parameters with the use of the least squares method and has the following form:

$$\eta = a T^2 + b T + c \tag{17}$$

By means of this curve, prediction of efficiency values — the average value (expressions for η) with an interval of scattering $\pm \sigma$ (expressions for U1, U2) is performed.

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REDUCTION IN TANGENTIAL FROST HEAVING FORCES BY THE PILE GEOMETRY CHANGE

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Abstract

The subject of research is shallow foundations in seasonally freezing soils. One of the main reasons of reaching by foundation structures limit states in the strength and position stability is such hazardous natural phenomenon as the frost heave of soils. The goal of this work is reduction of the negative effect of frost heaving forces on shallow foundations. The technique is suggested for protection of underground structures from the effect of the freezing soil. A bored pile with the upper inverted cone was developed allowing partial neutralization of tangential frost heaving forces due to the vertical component of frost heaving forces acting normally to the pile lateral surface. Use of the method will lead to increase in the life of structures, decrease in their erecting and operating cost.

Keywords

Underground structures, frost heave, stress-strain state, normal and tangential forces, pulling load, bored pile, inverted cone.

Introduction

In cold regions at the seasonal decrease of air temperature cooling and freezing of the soil take place due to formation of ice lenses. It leads to increase in the soil mass volume and rising of its surface. When limiting expansion of the freezing soil by foundations of buildings and structures, significant frost heaving forces are developed. The hazardous natural process of the soil frost heave effects negatively on foundations of buildings and underground structures, causing the collapse of structures. This is noted by N. N. Morareskul (1950), B. I. Dalmatov (1954), V. D. Karlov (1998), O. R. Golli (2000), J. Modisette (2014), T. Kibriya (2015), M. Babaei (2016) and many other authors in their papers.

Existing methods of the shallow tunnels protection from the frost heaving effect provide for two basic approaches.

The first approach is in the corresponding *calculation* of structures which are capable to *accept frost heaving* forces without failure.

The second approach assumes decrease in the heaving forces effect on structures. Towards this end in view, various engineering and melioration procedures, as well as chemical, thermal and constructive methods are applied. However, the majority of them form an additional expense item for designing, mounting and operation. More rational is the search of solutions in the structure itself without additional elements and proce-

dures. Methods of protection based on the use of effective structures are of interest.

Such structures can be pile foundations accepting all constant and temporary loads, including frost heaving forces. Pile foundations are capable to neutralize to some extent heaving forces causing differential rising of structures. Besides, the use of piles allows mechanizing the arrangement process of underground parts of buildings, reducing volumes of earthworks, maximally reducing sizes of trenches and excavation pits.

Stress-strain state of a pile in the seasonally freezing soil is defined mainly by tangential frost heaving forces taking pulling effect on a pile. Generally, tangential heaving forces are neutralized due to the friction on the pile lateral surface located in the thawed ground. It is ineffective, as it requires the significant length of piles. Reduction of the length is possible at decreasing heaving forces due to the optimization of the structural concept of piles, particularly of their shapes.

The calculation of piles for pulling forces was carried out by many authors (Dalmatov et al., 1975). Authors noted that stress-strain state of the pile and the soil around it at pulling loads significnalty depends on the structure and shape of the pile. Afterwards, the optimization of shapes of piles operating in clayly heaving soils was studied by O. P. Medvedeva (1992). The author considered piramydally prismatic driven piles with the lower cone narowing to the pile base. As a result of the work, the increased load-car-

rying capacity of the piramydally prismatic pile on the action of tangential frost heaving forces, without taking into account normal forces, was designated. Simultaneously, studies of pyramid-shaped, trapezoid-shaped, lozenge-shaped foundations and foundations in the form of flattened cone directed with the larger base downward were carried out at the NIIOSP [Research institute of foundation and underground constructions] (1980). Later on, studies of operation of hollow biconical piles in heaving soils were carried out under the supervision of B.S. lushkov and A.B. Ponomarev (1987).

Wihhin these researches, D. S. Repetskii analyzed the stress-strain state of a single biconical pile under conditions of the soil frost heave (2011). A. O. Dobrynin stated decrease in the effect of frost heaving forces on the biconical-shaped pile cluster (2012). B. S. Yushkov supposed that forces, which retented the pile from rising, arised at the upper cone part of the pile. The author recommended the method for calculation of biconical pile with taking into accout the retenting force. The method complexity lies in need of the availability of data on the value of the soil surface rising at the frost heave. Among foreign researchers, George R. Newton (Amoco Production Company, 1972) presented a combined pile structure, suitable for permafrost regions, with the layer of water-saturated seasonally freezing soil.

The author concluded that when using this design solution, the force, which prevented rising of a pile, appeared in the process of freezing of the soil moisture. However, the value of retenting force factors and the pile designing technique are not given. Based on said, it is possible to conclude that researches in the field of pile shape optimization are advanced, but insufficient for the practical application and require the further development. To use suggested design solutions in the practical designing, calculation procedures of piles geometric characteristics with due account for actual hydrogeological conditions of a site are required. Technological elaborations for arrangement of piles are needed too.

Materials and methods

This paper deals with application of piles of the optimized design upon practical designing of structures on seasonally freezing soils. A pile design, resistant to the effect of frost heaving forces, and a method for its calculation are suggested. The design of suggested bored pile is implemented with the upper inverted cone, which has calculated geometric parameters. The design solution and the calculation diagram of the pile are shown in Figure 1.

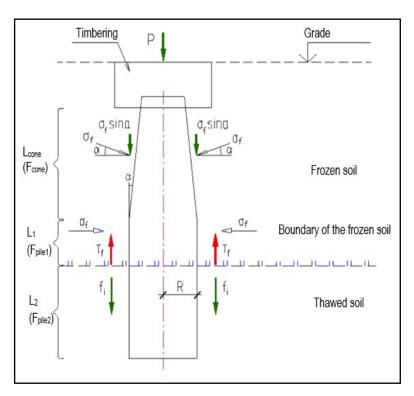


Figure 1. Design solution and calculation diagram of the pile with the upper inverted cone Pulling forces: r_i — tangential frost heaving forces acting upon the pile section located in the frozen soil; forces retenting the pile in the soil: P— the sum of external constant load and the own weight of the pile; f_i — friction forces throughout the pile lateral surface in the thawed zone; $\sigma_i \sin \alpha$ — the component of the normal heaving forces within the inverted cone located in the frozen soil; F_{cone} , F_{pilet} , F_{pile2} , — areas of surfaces indicated on the diagram of pile sections

The value of the pile rising (the vertical movement) is a criterion of the assessment of the pile resistence to the action of frost heaving forces. Rising of the pile foundation at the soil frost heave takes place mostly due to tangential forces, formation of which is determined by forces of soil adfreezing with the lateral surface of the foundation. Heaving forces, developing around the pile, tend to move the pile upwards. At that, the frozen soil sliding relative to the foundation occurs. Static bonds of the soil adfreeze with the foundation are decoupled. Dynamic bonds between the pile and the soil appear, determined by the resistence to the displacement of the frozen soil layer relative to the pile — tangential heaving forces.

The main idea of the research lies in the neutralization of tangential frost heaving forces by the pile design solution. In order to implement this idea, the objective was set to determine the force factor compensating pulling tangential forces due to the pile static potential. It is achieved by shaping the upper part of the pile as an inverted cone. The force factor is the vertical component of heaving forces acting normally to the lateral surface of the pile cone. This component appears due to the incline of the cone surface, it is directed from the daylight surface and partially neutralizes tangential forces, which are pulling the pile.

Scientific novelty of the research consists in the following:

predicted, taken into accout by the calculation transformation of frost heaving forces, acting normally to the pile lateral surface, into the positive forces retenting the pile in the soil upon its pulling-out by tangential heaving forces; the value of the obtained retenting force is determined by the cone slope angle;

obtaining of expressions for geometrical parameters of the pile, which are optimal for the neutralization of tangential heaving forces.

The negative effect of vertical normal heaving forces on the timbering is prevented by arrangement under the timbering of the draining anti-heaving crush-rock pad with the inclination from piles. For protection from silting-up, the arrangement of a geoweb is possible. As an example, a pile pitching unit with the inverted cone in the base of a shallow tunnel is given (Figure 2). The coarse fraction crush-stone pad without compaction is provided. It ensures removal of the moisture, causing heaving, from the timbering. Uncompacted crush-rock pad, having some yielding, compensates the effect of the heaving soil, located lower than the crush-rock pad, on the timbering.

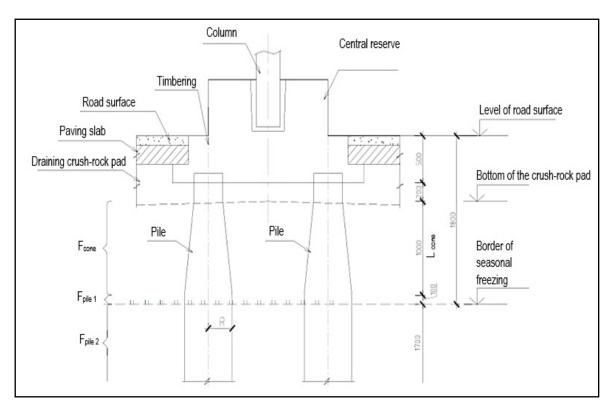


Figure 2. Pile pitching unit with the upper inverted cone in the base of a shallow tunnel

Besides, the bored pile is easier to manufacture than a prefabricated pile upon the arrangement of structures distant from industrial sites for production of reinforced concrete elements.

In order to assess indices of the developed pile, theoretical and experimental researches were conducted.

Experimental researches in the pile with the upper inverted cone within the cone section proved occurence of the vertical component of frost heaving forces acting normally to the pile lateral surface. The experiment, carried out under conditions of the soil frost heave, showed that rising of the pile with a cone was less than rising of the pile without a cone. Besides, the reactive earth back pressure develops in the cone element upon the action of the tangential frost heaving forces, which also prevents the pile from rising.

Based on results of the experiment, it was also noted that, with the exception of listed main factors, several phenomena also take part in the formation of stress-strain state of the pile with the upper inverted cone. Thus, when pulling out the pile with the inverted cone, some volume of soil above it in the form of flattened heaving cone moves upwards together with the pile. This factor also exerts the retenting effect on the pile. Loads from the heaving cone, not taken into account in the calculation; forces of soil resistance to the uplift, acting throughout its lateral surface, create some strength reserve for the pile with the inverted cone.

According to results of the analytical calculation, the formula was obtained for the calculation of the pile cone slope angle which is optimal for bearing of frost heaving forces. The cone slope angle is selected in such a way as to ensure compliance of the vertical retenting component of normal heaving forces with that portion of the pulling tangential forces which are not compensated by the external load on the pile and its own weight. The value of the retenting component is calculated from the condition of equilibrium of the pile in the soil at its pulling-out by the tangential frost heaving forces.

Equation (1) of equilibrium of the pile in the soil:

$$\tau_f \cdot F_{cone} + \tau_f \cdot F_{pile1} - f_i \cdot F_{pile2} - P - \sigma_f \cdot \sin \alpha \cdot F_{cone} = 0$$

where σf is the normal soil frost heave stress on the lateral surface of the pile;

τ, is the tangential stress of the soil frost heave, exerting the pulling action on the pile;

f, is the calculated resistence of an i-layer of the soil on the lateral surface of the pile pier in the thawed soil, exerting the retenting effect on the pile;

P is the sum of the external load and own pile

 F_{pile1} is the area of the pile lateral surface in the frozen soil without taking into account the cone;

 ${\it F_{\rm pile2}}$ is the area of the pile lateral surface in the thawed soil;

 $F_{\mbox{\tiny cone}}$ is the area of the pile lateral surface of the pile cone section;

 α is the slope angle of the pile lateral surface of the pile cone section.

Let us transform the equation (1):

$$\begin{aligned} & \tau_f \cdot F_{cone} - (-\tau_f \cdot F_{pile1} + f_i \cdot F_{pile2} + P) - \sigma_f \cdot \sin \alpha \cdot \\ & \cdot F_{cone} = 0 \end{aligned} \tag{2}$$

Let us designate the expression in brackets by 'd':

$$d = -\tau_f \cdot F_{pile1} + f_i \cdot F_{pile2} + P \tag{3}$$

After substitution (3) the equation (2) will take the

$$\tau_f \cdot F_{cone} - \sigma_f \cdot \sin \alpha \cdot F_{cone} - d = 0 \tag{4}$$

Let us preliminarily determine the cone area (Figure 3) based on two assumptions:

1)
$$F_{cone} = 2 \cdot \pi \cdot r_{mid} \cdot L$$

2) $tg \alpha \approx \sin \alpha$

The cone radius in the midsection according to Figure 3 will be:

$$\begin{split} r_{mid.} &= \frac{R+r}{2} = \frac{R+(R-x)}{2} = \frac{2 \cdot R - x}{2} = \\ R-0.5 \cdot x &= R-0.5 \cdot L \cdot \sin \alpha \\ \text{where } t \ g\alpha = \frac{x}{L} \Rightarrow x = L \cdot t \ g\alpha = L \cdot \sin \alpha \end{split}$$

Then the cone area:

$$F_{cone} = 2 \cdot \pi \cdot L = 2 \cdot \pi \cdot L \cdot (R - 0.5 \cdot L \cdot \sin \alpha) =$$

$$= 2 \cdot \pi \cdot L \cdot R - \pi \cdot L^2 \cdot \sin \alpha$$
(5)

Equation (4) after substitution of Fcone (5) and further transformation will take the form of the quadratic equation (6):

$$\sigma_f \cdot \pi \cdot L^2 \cdot \sin^2 \alpha + (-\sigma_f \cdot 2 \cdot \pi \cdot L \cdot R - \tau_f \cdot \pi \cdot L^2) \cdot \\ \cdot \sin \alpha + (\tau_f \cdot 2 \cdot \pi \cdot L \cdot R - d) = 0$$
 (6)

where L is the length of the upper inverted cone of the pile; R is the larger radius of the upper inverted cone.

Parameters of the quadratic equation:

$$a = \sigma_f \cdot \pi \cdot L^2$$

$$b = -\sigma_f \cdot 2 \cdot \pi \cdot L \cdot R - \tau_f \cdot \pi \cdot L^2$$

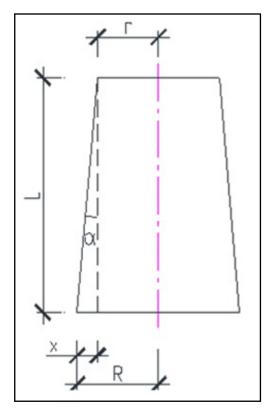


Figure 3. Diagram to the cone area determination

$$c = \tau_f \cdot 2 \cdot \pi \cdot L \cdot R - d = 0$$
$$D = b^2 - 4 \cdot a \cdot c$$

Discriminant of the quadratic equation after transformation will take the form:

$$D = \tau_f^2 \cdot \pi^2 \cdot L^4 + 4 \cdot \sigma_f \cdot \pi \cdot L^2 \cdot (\sigma_f \cdot \pi \cdot R^2 - \tau_f \cdot \pi \cdot L \cdot R + d)$$

Roots of the equation will be $\sin \alpha$ — the sine of the slope angle of the upper inverted cone of the pile which is needed for fulfilment of the equilibrium condition of the pile in the soil:

$$x_{1,2} = \sin \alpha = \frac{-b \pm \sqrt{D}}{2 \cdot a} \tag{7}$$

$$x_{2} = \sin \alpha = \frac{(2\sigma_{f}\pi R + \tau_{f}\pi L^{2}) - \sqrt{\tau_{f}^{2}\pi^{2}L^{4} + 4 \cdot \sigma_{f}\pi L^{2}(\sigma_{f}\pi R^{2} - \tau_{f}\pi R + d)}}{2\sigma_{f}\pi L^{2}}$$
(8)

Technologically, the bored pile with the upper inverted cone is arranged with the help of the casing pipe which has the upper part of the cone shape with the smaller base on the daylight surface. The casing pipe is dipped into the borehole, a reinforcement cage is installed in the design position, a tremic pipe is dipped and pouring of the concrete is performed in one operation with the application of vibrators. After removing the tremic pipe, the casing pipe remains in the borehole for the period of pile concrete maturing the stripping strength. Then the casing pipe is extracted. Backfilling of the upper cone in layers and compaction are performed. Due to the structural features of the pile, the backfilling with the local soil is performed and it does not require delivery of the dry non-heaving soil.

The bottleneck of this method is probable complications with extracting of the casing pipe caused by the adhesion of the solidifying concrete mixture with its internal surfaces. These problems are solved by application of release agents and lubricants, preventing adhesion of the concrete mixture with the pipe material, onto the casing pipe internal surfaces. Before starting works it is needed to perform the corresponding preparation of the casing pipe internal surfaces. In order to prevent the concrete mixture adhesion to the casing pipe, various lubricants are used: "Krystal M22" technological lubricant (Mas Prom company); lubricant agents of the German company "Elaskon Sachsen GmbH & Co.KG", composite material AXC-0028MP (German company PEMCO) and others.

The sequence of technological operations for arrangement of the pile with the upper inverted cone is shown in Figure 4.

Another variant of the technology is the pile construction with the help of a permanent casing pipe with the upper cone-shaped part. The pipe material is low-cost plastic. Effective features are the possibility to combine technological operations for protection of borehole walls and arrangement of the cone concrete forms, as well as exclusion of the casing pipe extraction operation.

Results

Thus, the slope angle of the pile inverted cone which is optimal for the neutralization of heaving forces is determined from the condition of pile equilibrium in the soil. Summarizing the research, we will show calculation results of slope angles of the upper inverted cone of piles, installed in the foundation of the same structure under various soil conditions. Initial soil conditions for the calculation of heaving stresses are specified in Table 1. Slope angles of the pile cone " α " at the specified constant load "P" are calculated by equaion (8) taking into account characteristics of soils and frost heaving stresses. The calculation results are represented in Table 2.

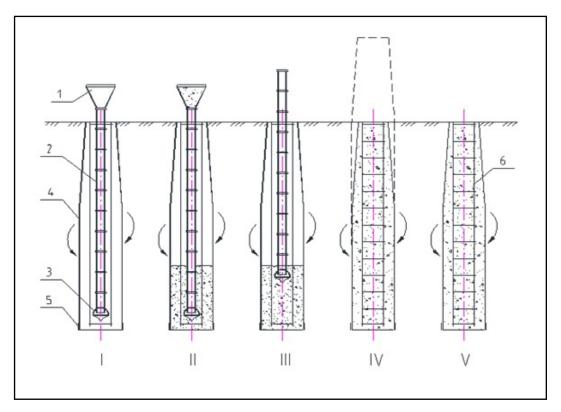


Figure 4. Sequence of operations in the pile concreting: I — performance of the borehole and installation of the tremic pipe; II — concreting the pile; III — extracting the tremic pipe; IV — extracting the casing pipe; V — finished pile.

1 — receiving hopper for concrete mixture; 2 — tremic pipe; 3 — quality control device for pouring of concrete mixture; 4 — casing pipe; 5 — cutting tip of the casing pipe; 6 — reinforcement cage

Table 1. Characteristics of soils.

Type of soil	Specific weight, γ, kN/m3	Natural humidity, w, unit fraction	Plasticity index, Lp, unit fraction	Index of liquidity, LL, unit fraction	Void volume ratio, e, unit fraction	Degree of humidity, Sr, unit fraction	Specific cohesion, s, kPa	Deformation modulus, E, MPa
Sand clay								
Soil No. 1	18.0	0.29	0.11	0.66	0.83	1.0	24	7.1
Soil No. 2	19.8	0.32	0.15	0.52	0.8	0.95	19	9.7

Table 2. Values of slope angles of the pile cone for two types of soil.

Type of soil	D, m	L, m	L ₁ , m	L ₂ , m	P, kN	tf, kPA	of, kPA	fi, kPA	SP, cm²/ hour·°C	α, degree
Soil No.	0.6	1.0	0.1	1.7	164.3	166.64	132	14.8	0.019	8.0
Soil No. 2	0.6	1.0	0.1	1.7	164.3	179.85	154	20.4	0.021	8.6

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Notes to table 2:

σf is the normal stress of the soil frost heave on the pile lateral surface (Tretiakova, 2016);

rf is the tangential stess of the soil frost heave which is pulling the pile; the value of the tangential frost heaving forces on the pile lateral surface is determined by the author in dependence on humidity and specific adhesion of frozen soil particles (2016);

fi is the calculated resistance of a soil i–layer on the pile lateral surface in the thawed zone;

SP is the segregated soil potential, cm²/hour · °C;

P is the sum of the external load and own pile weight;

 L_{τ} is the length of the pile section in frozen soil without taking into account the cone;

 L_2 is the length of the pile section in the thawed soil;

L is the length of the pile cone section;

D is the pile diameter;

 α is the slope angle of the lateral surface of the pile cone section.

Correspondingly selected geometrical parameters of the pile upper cone provide conditions for formation of the package of retenting forces exceeding the sum of pulling loads, that allows ensuring integrity of above-fundamental structures in any soil conditions.

The suggested variant of the arrangement technology of the pile with the upper inverted cone allows combining operations for protection of borehole walls and arrangement of the concrete form for the inverted cone, that defines its effectiveness.

Conclusion

The method for protection of buildings and structures in cold regions from the effect of freezing soil is the application of effective piles of the worked out design with increased resistence to pulling-out by the frost heaving forces. This design solution is supported by results of theoretical calculations and in-situ experiments.

Originality and novelty of the solution lies in the use for the frost heave control of forces of the same nature.

Presence of the inverted cone in the pile structure leads to appearance of heaving forces components retenting the pile from rising. The design solution which is reflected in the paper contains the method of practical calculation of pile geometrical characteristics, which are optimal for the heaving forces neutralization in certain soil conditions. This method represents the theoretical contribution into the solution of the problem of decrease in the effect of the frost heaving forces on structures in cold regions.

Practical significance of the research lies in the elimination of additional costs for protection from the frost heave at stages of designing, erection and operation due to the use for this purpose of pile foundations of the structure.

The durability of this design solution in comparison with other methods is obvious.

Discussion

Despite the fact that theoretical and experimental works for the determination of parameters of the pile under study were carried out, still a number of problems needs to be solved for the wide practical application of such piles in the construction industry.

- The reliability degree of obtained formulas will be higher with the increase in the number of experiments, carried out in different soil conditions. Therefore, it is reasonable to keep on conducting experiments in different climatic areas, to which the phenomenon of the soil frost heave is inherent.
- In order to increase the applicability of formulas in practical designing, the development of calculation software is required. Calculation suites will allow an engineer to avoid labour-intensive calculations, increasing the creative component of desinging process connected with making non-standard alternative decisions, as well as developing this technique.

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