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PRESERVING IDENTITY OF HISTORICAL ENVIRONMENTS IN SIBERIA: A CRITICAL LITERATURE REVIEW

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Abstract
Introduction: Currently, the projects related to the development of identical historical environments in Siberia, Russia, are predominately inconsistent. Yet there is an opportunity to find a more holistic approach to sustaining local heritage, which could address local cultures and identities through an understanding of how the location, as well as specific spatial and architectural practices, evolve. **Purpose of the study:** The study aimed to establish a theoretical and methodological framework for sustaining the local identity in architectural terms. **Methods:** According to the methodological recommendations of Groat and Wang, such methods as critical literature review and logical argumentation were used. **Results:** The research came to the conclusion that the city identity can be unfolded through two or more congruent layers of existence. This study deals with architectural heritage and society as two types of such layers. It suggests that the local identities of historical environments could be sustained by a combination of the following methods: 1) looking to the past, through analyzing the city's fabric and searching for "social traces" and semiotic meanings; 2) looking to the future, through using participatory design methods. This methodology should be further tested on specific historical environments in Siberia. The critical literature review will provide researchers and practitioners in the field with a fundamental theoretical framework.

Keywords
Architecture, philosophy of architecture, identity, heritage, participatory practice, sustainable development.

Introduction

Over the past century, Russia experienced two major political turning points. This, among other factors, has led to a systemic crisis of national cultural identity, including the rejection of the values of the past and fundamental cultural norms and concepts, and the erratic development of the historical architectural environment, which has been mirroring social processes. City-dwellers seem to lack any feeling of attachment to their environments, while the inconsistent development of the built environment and the resulting changes in the structure of social processes are becoming increasingly visible. International methodologies, such as, for instance, critical regionalism (Frampton, 1983), have highlighted the need to find local regional patterns and techniques with the potential to ensure the continuity of historical and cultural layers, create a sense of belonging and identity, and preserve the past in ways that guarantee cultural diversity and survivability. At the same time, the above methodology does not provide operational tools or answers on how to integrate new development projects into traditional social life. Nonetheless, there is an opportunity to develop a more holistic approach to sustaining local historical places, which would address local cultures and identities through an understanding of how the location and specific spatial practices evolve. It is currently argued in Russia that the preservation of cultural layers is one of the essential elements needed for nurturing national consciousness and a sense of national belonging (V. V. Putin). In this context, how can we enhance, or at least preserve, the complex city identity? How can we ensure the development continuity in historical environments while shaping the city identity? What issues exist within this field, what methods and tools? Thus, the purpose of this review was to explore the existing identity-oriented approaches to the sustainable development of historical architectural environments, in order to suggest a methodology or strategy that could potentially be applicable in Siberia, Russia, as well as to provide researchers and practitioners in the field with a fundamental theoretical framework.

Methods

We selected critical literature review and logical argumentation (Groat and Wang, 2013) as the primary methods of this study. The literature for the study was provided by the Scientific Libraries of the

Siberian Federal University and the University of Cologne.

Results and Discussion

The phenomenon of identity has been investigated by a large and growing body of literature around the world (Benwell and Stokoe, 2006; Castells, 2009; Krinsky; 2004; Torabi and Brahman, 2013). For Castells, identity is "the process by which social actors build their own meaning according to cultural attributes" (Castells, 2009). Fundamentally, identity could be unfolded through the "congruity" of two or more layers of existence, or two or more interrelated phenomena: "the feeling of having a close association or connection with something" (Oxford Dictionary). Researchers today tend to decode the city identity (Bold et al. 2017; Brand, 1995) by employing the notion of heritage: "The deeper understanding of the historically contingent and embedded nature of heritage allows us to go beyond treating heritage simply as a set of problems to be solved and enables us to engage with debates about the production of identity, power and authority throughout society" (Harvey, 2001). Thus, out of a variety of components within identity, this study will focus on "heritage", understood as a "process", which, in and of itself, already encompasses many layers, along with the dimension of time. Further decomposition of the notion of identity leads to the essential social component congruent with heritage. Many researchers decode the phenomenon of heritage through tradition (which encompasses both resilience and dynamics), through inclusion, and through "knowledge transfer" and "social traces" (Araoz, 2011; Dymitrow, 2013; Hewitt and Pendlebury, 2014; Lowenthal, 1998; Pendlebury, 2013; Pendlebury and Porfyriou, 2017; Riegl, 2011; Townshend and Pendlebury, 1999). Waterton and Watson (2015) argue that today's researchers of heritage are concerned with the problems of participation, which implies construction and engagement. Smith (2007) defines heritage as a cultural process: "Heritage is a multilayered performance... that embodies acts of remembrance and commemoration while negotiating and constructing a sense of place, belonging and understanding in the present". Orbaşli (2017) adds, "Thus, conservation is increasingly becoming a process of negotiation, as the management of cultural heritage becomes based on models of consultation and participation, that are intended to give those 'affected' by a site a 'voice'". In other words, scholars define heritage as a process that encompasses communication, negotiation, engagement, assembling, meaning creation, and knowledge transfer (Smith, 2004, 2007; Smith and Waterton, 2013; Waterton and Smith, 2010). In addition, heritage is now "judged under ethical and moral criteria" (Munoz-Vinas, 2012); this concept is also enshrined in the conventions and widely published (Australia ICOMOS, 1999, 2013; Drury and McPherson, 2008; Nara, 2015).

The focus of modern science on studying complex self-developing systems significantly restructures scholarly ideals and norms, transforming the ideal of value-neutral research (Styopin et al., 1996). These transformations of the general set of scientific principles, shifting from "Objective" or "Scientific" to "Ethical", also determine the transformation of the core ideas within heritage concepts. Thus, perceiving the heritage process as a self-developing system with internal ethics and a significant social component, researchers recommend searching for the local sustainable concepts of heritage as an organic and natural part of social reality.

Several authors have noted that the focus in architectural heritage studies has shifted to such concepts as engagement, meaning, and identity, which are relatively new in theory (Waterton and Watson, 2015). Thus, researchers who gravitate to collaborative heritage as a concept claim to observe the positive effects of community engagement in the heritage process (Drury and McPherson, 2008; Yung et al., 2016). However, Pendlebury (Pendlebury et al., 2004), one of the pioneers in the field of public participation in conservation, outlines significant controversies within the recent heritage policies. Indeed, the new concept destabilizes conventional heritage discourse: "The heritage debate has continued to flex and flow since the 1980s and has gained considerable momentum over the past three decades" (Waterton and Watson, 2015). Rather than introducing certain approaches and doctrines, it has created further division and arguments. Thus, the controversies around the notions of authenticity, national identity, the power-relational values, social cohesion, etc., as well as the critique of the commodification of the above, while yielding occasional stabilizing solutions, have not yet resulted in universal wisdoms. Moreover, "heritage has become a global concern with powerful new players who are now engaged in conservation practice and research" (Orbaşli, 2017). Dragouni (2018) argues that "there is still a long way to go until we can firmly argue that community participation has been truly and fully embraced in the field... Until then, there is an imminent need for on-going critical analysis of and reflection on the topic at both theoretical and practical levels". Discourse on the subject is still "young", although it does have many undeniably significant achievements, and is worth applying to different case studies.

When it comes to the existing research, potential sub-topics, and approaches relevant to the participatory heritage process, we note that studies are broadening in scope. As Orbaşli (2017) notes, "By the end of the twentieth century, however, conservation had clearly evolved in two separate strands: conservation as an approach and conservation as a science". Waterton and Watson (2015) single out two perspectives within heritage research, one of which is based on approaching heritage as "operational practice" (operations management, including marketing, finance, human resources, hospitality, catering, and retailing), while the other perceives heritage as a form of "cultural practice" (sociological, cultural, social geographical and anthropological thinking). This subject is becoming more and more interdisciplinary, bringing in a wide variety of concepts (Barelkowski, 2009; Greider and Garkovich, 1994; Murzyn-Kupisz, 2013; Murzyn-Kupisz and Działek, 2013; Poulios, 2014; Stephens and Tiwari, 2015). Generally speaking, approaches have changed significantly. Research is currently: focusing attention on the largely vernacular historic cityscapes rather than on "grand, monumental" architecture; encompassing intangible components; and zooming in on local identities rather than valuing national significance. Finally, we are currently seeing a notable shift in heritage significance from "expert" evaluation to participatory evaluation.

However, the ongoing focus on democratization, human rights and social justice, control, power, decision-making, ethics, and so on remains relatively obscured in Russia. Generally, the subject of Russian heritage, let alone the heritage of Siberia, is quite poorly represented in international science, with rare exceptions (Deschepper, 2018). A review of the latest Russian academic literature has revealed the following picture. First, formal academia in Russia is strictly formalized and institutionalized, divided into disciplinary "tracks". Research dedicated to historical environments belongs to a track called "Theory and History of Architecture, Restoration and Reconstruction of Architectural Heritage", specifically the "Architecture" section, which is currently related to the "technical" field of studies. Consequently, interdisciplinary knowledge is a rare occurrence in formal Russian academia. Classical researchers of architectural heritage in Russia are usually busy with describing the past. Their studies are largely historiographic (Burdin, 2013; Merkulova and Merkulova, 2013; Meyerovich, 2016; Mishakova and Mikhaleva, 2014; Slabukha, 2016; Tsaryov, 2012), reviewing archives, dealing with notions of "typology", "styles", "method", "context", "composition", "visual integration", etc. (Dutsev, 2014; Samolkina, 2015; Stafeyev, 2015; Zaitsev, 2013), or investigating specific technical aspects. Some researchers study the semantics of traditional architecture and its elements, such as wood carving, decorative elements, etc., which, in their opinion, helps to reveal messages left behind by the societies of the past (Barabanov, 2013; Myasnikova and Volskaya, 2014; Sergeyev, 2000). Their insights have allowed for publishing extensive descriptions of the history of architecture and urban development in Russia and Siberia. Siberian researchers A. V. Slabukha and V. I. Tsaryov, who wrote major works on the development of Siberian architecture, hold a unique spot in Siberian heritage research (Slabukha, 2016; Slabukha and Sayenko, 2016; Tsaryov, 2012). However, while investigating the impact or implications of heritage and architecture, and while rethinking heritage procedures or describing heritage practice, researchers tend to miss the fact that heritage is a socially constructed phenomenon with prescribed values. The concept of Siberian heritage is therefore not explicitly formulated.

Architecture researchers in Russia make some limited effort to break the disciplinary limits, by criticizing the existing approaches to architectural heritage or proposing new ones (Aidarova, 2012; Bal'zannikova, 2014; Bolotskikh et al., 2017; Chaynikova, 2018; Devyatova, 2016; Galeev, 2017; Gumenyuk, 2012; Lepeshkina et al., 2018; Markovich and Luchkova, 2011; Okhotnikova, 2019; Orlenko, 2017; Romanova and Malevich, 2013; Selivanenko, 2015; Viktorova, 2014); or by investigating the cultural effects of specific architectural phenomena (Dayub, 2009; Lobanov, 2010; Nazarova et al., 2017; Pavlova, 2016). Some researchers discuss the aspects of how socialist monuments and heritage are perceived in a post-socialist country (Nagornaya and Petukhova, 2014; Oganesyan, 1996; Ryzhkova, 2016; Snopek, 2013). Shulgin (2004) considers heritage as a factor of socio-cultural development. Sedov (2011) gives a comprehensive overview of the perception of the architectural monuments in Russia, while Pereslegin (2015) explores the formation and development of the bodies responsible for conservation and heritage protection, as well as their interaction with society. However, researchers usually state the problem and emphasize its importance, but rarely propose comprehensive methods for socially-oriented heritage processes or present a reading of the social connotations within the historical built space. One of the rare exceptions is a study by Solovyova and Anisimova (2014), dedicated to historical environments and the tools of their development and analysis in Vologda. A unique stance is expressed by Glazychev (https://www.glazychev.ru), who comprehensively researched the phenomenon of city environments, starting to question the participatory approaches to the formation of historical environments at the end of the 20th century. However, some Russian works from the last third of the 20th century still defer to the official system of heritage research and practice. At the same time, "unofficial", practice-based research appears more free, dynamic, and experimental. Archnadzor (http://www.archnadzor.ru/category/wise/), "Re-school" (led by Narine Tyutcheva), MARCH architectural school, and Strelka Institute in Moscow have started to gradually change the practice.

The "social" component in environmental

practice appeared as a theme within such tracks of Russian research as “Sociology” and “Culture Studies”, which considered urban environments from their own disciplinary positions (Abysheva, 2005; Akhnayeva, 2004; Butakova and Sidorova, 2015; Chernetskaya, 1999; Chernyayeva, 2004; Donguzova, 1998; Fedorov and Ovcharova, 2012; Fedorova, 2016; Kaiser, 2010; Kogatko, 2007; Kostenko, 2004; Pomozova, 2012; Serikov, 2007; Smirnova, 2004; Soboleva, 2014; Suchorukov, 2002; Tsepelev, 2014; Zlotnitsky, 2008). Some researchers are exploring the new challenges of democracy and participation (Agapova, 2015; Donguzova, 1998; Obertas and Petukhov, 2015). One cannot overestimate the valuable contribution made by the thesis of sociologist Serikov (2007), who proposed a mechanism for managing historical centers as a complex socio-economic phenomenon, from an administrative point of view. Vilkovsky (2010) provided a comprehensive overview of the existing published theories on the sociology of architecture. However, the isolated positions of sociologists and culture studies experts appear insufficient for considering the complex heritage practice from an architectural point of view.

Thus, the subject of city identity could be elaborated on in research through understanding and analyzing the congruent layers of heritage as a process (reviewed in the temporal dimension), as well as by analyzing the heritage’s social context and associated values. To summarize, various Russian researchers from different fields have tried to suggest possible changes in the approaches to Russian heritage. However, the prevailing themes are more technical, focused on the so-called “operational issues” (Waterton and Watson, 2015), while critical analysis from the cultural perspective, along with specific methods, is generally lacking, especially when it comes to regions with such unique development as Siberia. The general concept of Siberia’s heritage is not formulated explicitly; the subject of possible sustainable heritage processes either has a limited presence in Russian literature or is absent from it altogether. Thus, we believe that it is necessary to research the possibility of sustainable, collaborative heritage processes in the Yenisei basin in Siberia, as the first step of a possible journey toward city identity construction.

Quite often in Russia, heritage monuments or buildings are perceived as separate entities. However, such monuments are usually part of a holistic urban fabric or environment, where all elements evoke the same feelings and have the same links with traditions, habits, and beliefs. “Places remember, and they do it through their monuments, architectural style of their buildings, inscriptions on walls, etc.” (Hayden, 1995). Harrison’s philosophy of “becoming”, where the notions of place and life, in a broad sense, closely connect time and “living beings” into “generations of continuities in particular places” (Harrison and Rose, 2010), provides a better reading of heritage contexts. The Historic Urban Landscape (HUL) concept is an attempt to avoid the isolation of buildings, as physical objects, from their wider cultural environment, with its multi-layered history of meanings. Thus, a more “holistic” approach is needed to address the fragments of the spatial fabric in complex historical environments, which include intangible aspects and social traces.

Geographically, the number of researchers investigating the democratization of heritage is exponentially growing, encompassing representatives from different parts of the world (Amin, 2018; Murzyn-Kupisz and Działek, 2013; Paez et al., 2013; Salman et al., 2018; Yalegama et al., 2016; Yung et al., 2016). For instance, Maciuika (2014) showed differences in the approaches to reconstruction in various national and cultural contexts, according to ideological standpoints at a specific time and in a specific location. He used Asian cultures as an example: “Shinto religious tradition involves the complete reconstruction of the sacred Shinto Jingu Shrine in Ise, Japan, every 20 years”. Waterton and Watson (2015) suggested that the role of non-Western researchers and the development of local heritage discourses is significant for this mission. Geographically, Siberia is not a part of Europe or the West – but what about culturally or mentally?

When it comes to time frames, the collapse of the Soviet Union is the latest significant change that radically influenced all aspects of existence in Russia (Charley, 2010). Architecture, heritage, planning, conservation, and design are no exception. According to Slabukha (2014), since the beginning of the 1990s, work on the identification and state protection of monuments has been paused, so that in Siberia, the status of heritage has been reduced dramatically, and some monuments and memorial places have been completely lost. In addition, as Tunbridge and Ashworth (1995) explained, “The present selects an inheritance from an imagined past for current use and decides what should be passed on to an imagined future”. Thus, today’s heritage is widely acknowledged as an agent of assembling multiple futures. Lowenthal (2015) argued, “Every act of recognition alters survivals from the past. Simply to appreciate or protect a relic, let alone to embellish or imitate it, affects its form or our impressions. Just as selective recall skews memory and subjectivity shapes historical insight, so manipulating antiquities refashions their appearance and meaning. Interaction with a heritage continually alters its nature and context, whether by choice or by chance”. Harrison (2015) perceived heritage as an ongoing act of assemblage, which occurs in the process of discussing past values, guided or conditioned by the conscious, responsible outlook to the future.

Indeed, the heritage and identity of the future are constructed in the present. Thus, the framework of heritage connotations from different periods, in combination with socially-inclusive methods of sense-retrieval, would widely inform the heritage process on the way to identity construction.

Conclusions

City identity can be unfolded through two or more congruent layers of existence, such as architectural heritage and society. Sustainable development of architectural heritage is a complex process (involving communication, negotiation, engagement, assemblage, meaning creation, and knowledge transfer), which expands beyond conventional heritage protection, and multiple bodies and stakeholders get involved in the journey toward sustaining the city identity. Heritage is a process that requires looking ahead and looking back at the same time. Considering the above, the human component can be integrated into the heritage process and sustained by a combination of the following methods: 1) looking to the past: analyzing the city's structures and forms, searching for social traces and semiotic meanings; 2) looking to the future: using participatory design methods. This could be achieved through an approach encompassing desk studies alongside with on-site surveys, fieldwork, and participation. This is still an emerging study subject, worth experimenting with at locations, especially in such unique regions as Siberia. Thus, all of the above can become a hypothesis to be tested out in specific Siberian environments.

This literature review has built a broad theoretical base and outlined a set of approaches that currently exist in the field. With that in mind, we aim to propose and develop research that would question the possibility of sustainable, collaborative heritage processes in Siberia, as the first step on a possible journey toward constructing the city identity. The research will propose a set of analytical tools for a preliminary design study on heritage and culminate with suggesting a methodology for establishing sustainable heritage processes and providing continuity and survivability while taking into consideration the critical evaluation given in this paper and the limitations discovered.

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References

Abysheva, Yu. Yu. (2005). *The problem of shaping a city's image: the social and governance aspect.* Author's Abstract of PhD Thesis in Social Sciences. Nizhny Novgorod: Lobachevsky State University of Nizhny Novgorod.

Agapova, D. (ed.) (2015). *The culture of involvement: the museum as a space for dialogue and cooperation.* Saint Petersburg: CEC ArtsLink, 157 p.

Aidarova, G. N. (2012). Problems and methodology of historic preservation in Kazan. *News of the Kazan State University of Architecture and Engineering*, No. 2 (20), pp. 9–15.

Akhnayeva, N. A. (2004). *The phenomenon of St. Petersburg identity: structural and functional analysis*. Author's Abstract of PhD Thesis in Social Sciences. Saint Petersburg: Saint Petersburg State University.

Amin, H. M. T. M. (2018). The impact of heritage decline on urban social life. *Journal of Environmental Psychology*, Vol. 55, pp. 34–47. DOI: 10.1016/j.jenvp.2017.12.002.

Araoz, G. F. (2011). Preserving heritage places under a new paradigm. *Journal of Cultural Heritage Management and Sustainable Development*, Vol. 1, No. 1, pp. 55–60. DOI: 10.1108/20441261111129933.

Australia ICOMOS (1999). *The Burra Charter*. Birwood, VIC: Australia ICOMOS, 23 p.

Australia ICOMOS (2013). *The Burra Charter: The Australia ICOMOS Charter for Places of Cultural Significance*. [online] Available at: http://openarchive.icomos.org/id/eprint/2145/ [Date accessed July 27, 2021].

Bal'zannikova, E. M. (2014). Preserving urban objects of historical and architectural heritage. *VESTNIK MGSU (Monthly Journal on Construction and Architecture)*, No. 1, pp. 15–24.

Barabanov, A. A. (2013). Socio-cultural, and semantic principles of the revitalization of the industrial heritage. *Eco Potential*, No. 3–4, pp. 236–247.

Barelkowski, R. (2009). Involving social participation in the preservation of heritage: the experience of Greater Poland and Kujavia. *WIT Transactions on Ecology and the Environment*, Vol. 122, pp. 435–446.

Benwell, B. and Stokoe, E. (2006). *Discourse and identity.* Edinburgh: Edinburgh University Press, 328 p.

Bold, J., Larkham, P. J. and Pickard, R. (eds.) (2017). *Authentic reconstruction : authenticity, architecture and the built heritage*. London: Bloomsbury Academic, 352 p.

Bolotskikh, L. V., Romantsova, Ye. B. and Galtsova, O. I. (2017). The Issues of preserving architectural heritage in Russian towns. *Stroitelstvo i Nedvizhimost*, No. 1, pp. 61–65.

Brand, S. (1995). *How buildings learn : what happens after they're built*. New York: Penguin Books, 256 p.

Burdin, Ye. A. (2013). *Preserving cultural heritage sites in the USSR (1917–1991). Study guide.* Ulyanovsk: Ulyanovsk State Pedagogical University, 109 p.

Butakova, D. A. and Sidorova, N. V. (2015). Image of Siberian city in its residents impressions (by example of sociological survey conducted in Irkutsk). *Proceedings of Irkutsk State Technical University*, No. 4 (99), pp. 221–224.

Castells, M. (2009). *The power of identity. The information age: economy, society, and culture. Vol. II.* 2nd edition. Malden, MA; Oxford, UK: Wiley-Blackwell, 584 p.

Charley, J. (2010). The shadow of economic history: the architecture of boom, slump and crisis. *Architectural Research Quarterly*, Vol. 14, Issue 4, pp. 363–372. DOI: 10.1017/S1359135511000157.

Chaynikova, O. O. (2018). Special features of the process of restoration of architectural monuments - cultural symbols of power. *VESTNIK MGSU (Monthly Journal on Construction and Architecture)*, No. 2 (113), pp. 170–189. DOI: 10.22227/1997-0935.2018.2.170-189.

Chernetskaya, A. A. (1999). *Social space in daily life.* Author's Abstract of PhD Thesis in Social Sciences. Saratov: State Technical University of Saratov.

Chernyayeva, T. I. (2004). *The architectonics of social space.* Author's Abstract of DSc Thesis in Social Sciences. Saratov: State Technical University of Saratov.

Dayub, A. V. (2009). *The place of architecture in the process of social environment transformation.* Author's Abstract of PhD Thesis in Philosophy. Saint Petersburg: Saint Petersburg State University.

Deschepper, J. (2018). Between future and eternity: a Soviet conception of heritage. *International Journal of Heritage Studies,* Vol. 25, Issue 5, pp. 491–506. DOI: 10.1080/13527258.2018.1467949.

Devyatova, Yu. A. (2016). A comprehensive approach to architectural design in historical city environments. *Architecton. Proceedings of Higher Education*, No. 1 (53), 5.

Donguzova, Ye. I. (1998). *The sociological aspects of managing the architectural transformation of cities*. Author's Abstract of PhD Thesis in Social Sciences. Ufa: Bashkir State University.

Dragouni, M. (2018). Engaging heritage, engaging communities. *International Journal of Heritage Studies*, Vol. 25, Issue 3, pp. 329–332. DOI: 10.1080/13527258.2018.1493702.

Drury, P. and McPherson, A. (2008). *Conservation principles, policies and guidance*. London: English Heritage, 72 p.

Dutsev, M. V. (2014). *The concept of artistic integration in contemporary architecture.* Author's Abstract of DSc Thesis in Architecture. Nizhny Novgorod: Nizhny Novgorod State University of Architecture and Civil Engineering.

Dymitrow, M. (2013). Degraded towns in Poland as cultural heritage. *International Journal of Heritage Studies*, Vol. 19, Issue 7, pp. 613–631. DOI: 10.1080/13527258.2012.681681.

Fedorov, V. V. and Ovcharova, A. Zh. (2012). City phenomenon: value-semantic aspect. *Bulletin of the Moscow State Region University. Series: Philosophy*, No. 2, pp. 25–30.

Fedorova, O. S. (2016). The analysis of cultural, architectural and artistic factors of the city image formation. *Journal of Siberian Federal University. Humanities and Social Sciences*, Vol. 9, No. 8, pp. 1874–1879.

Frampton, K. (1983). Towards a critical regionalism: six points for an architecture of resistence. In: Foster, H. (ed.) *The Anti-Aesthetic. Essays on Post-Modern Culture*. Port Townsend, WA: Bay Press, pp. 16–30.

Galeev, S. A. (2017). Architecture and conservation of natural, cultural and spiritual heritage. *The Heritage Institute Journal*, No. 3 (10), 3.

Greider, T. and Garkovich, L. (1994). Landscapes: the social construction of nature and the environment. *Rural Sociology*, Vol. 59, Issue 1, pp. 1–24. DOI: 10.1111/j.1549-0831.1994.tb00519.x.

Groat, L. N. and Wang, D. (2013). *Architectural research methods*. 2nd edition. Hoboken, NJ: John Wiley & Sons, 468 p.

Gumenyuk, L. S. (2012). Heritage and society: history versus architecture entity. *Vestnik of Saint Petersburg University. Series 6. Philosophy. Culturology. Political Science. Law. International Relations*, No. 3, pp. 5–9.

Harrison, R. (2015). Beyond "natural" and "cultural" heritage: toward an ontological politics of heritage in the age of anthropocene. *Heritage & Society*, Vol. 8, Issue 1, pp. 24–42. DOI: 10.1179/2159032X15Z.00000000036.

Harrison, R. and Rose, D. (2010). Intangible Heritage. In: Benton, T. (ed.) *Understanding Heritage and Memory*. Manchester: Manchester University Press, pp. 238–276.

Harvey, D. C. (2001). Heritage pasts and heritage presents : temporality, meaning and the scope of heritage studies. *International Journal of Heritage Studies,* Vol. 7, Issue 4, pp. 319–338. DOI: 10.1080/13581650120105534.

Hayden, D. (1995). *The power of place : urban landscapes as public history*. Cambridge, MA: London: MIT Press, 316 p.

Hewitt, L. E. and Pendlebury, J. (2014). Local associations and participation in place : change and continuity in the relationship between state and civil society in twentieth-century Britain. Planning Perspectives, Vol. 29, Issue 1, pp. 25–44. DOI: 10.1080/02665433.2013.802655.

Kaiser, N. Yu. (2010). *The transformation of Russia's image in public opinion among people living in a provincial region in the Russian Federation.* Author's Abstract of PhD Thesis in Philosophy. Barnaul: Altai State University.

Kogatko, D. G. (2007). *Russian identity as a cultural and civilizational phenomenon.* Author's Abstract of PhD Thesis in Social Sciences. Saint Petersburg: Saint Petersburg State University of Service and Economics.

Kostenko, Yu. O. (2004). *Issues of managing the city's social space under conditions of contemporary society transformation: regional aspect*. PhD Thesis in Sociological Studies. Ufa: Bashkir State Agrarian University.

Krinsky, C. (2004). State of the field: studies of identity in modern architecture. *Anales del Instituto de Investigaciones Estéticas*, Vol. 26, No. 85, pp. 31–47. DOI: 10.22201/iie.18703062e.2004.85.2182.

Lepeshkina, M. N., Dridze, D. B., Popova, Ye. A., Omelyanenko, G. B., Dubrovin, I. F., Maslova, K. N. and Kalitseva, Yu. O. (2018). *Development of Eurasian cities. A review of development features.* Moscow: Archsovet, 454 p.

Lobanov, A. V. (2010). *Communication spaces in architecture: genesis and development trends.* Author's Abstract of PhD Thesis in Architecture. Nizhny Novgorod: Nizhny Novgorod State University of Architecture and Civil Engineering.

Lowenthal, D. (1998). *The heritage crusade and the spoils of history*. Cambridge: Cambridge University Press, 358 p.

Lowenthal, D. (2015). *The past is a foreign country – revisited*. Cambridge: Cambridge University Press, 680 p.

Maciuika, J. V. (2014). The historic preservation fallacy? Transnational culture, urban identity, and monumental architecture in Berlin and Dresden. In: Diefendorf, J.M. and Ward, J. (eds.) *Transnationalism and the German City. Studies in European Culture and History.* New York: Palgrave Macmillan, pp. 239–260. DOI: 10.1057/9781137390172_15.

Markovich, O. B. and Luchkova, V. I. (2011). Adaptive using of architecture monuments. In: *New Ideas of New Century: Proceedings of the International Scientific Conference at Pacific National University*, Vol. 1, pp. 391–396.

Merkulova, M. Ye. and Merkulova, M. M. (2013). *Wooden buildings in Krasnoyarsk in the 19th and early 20th century.* Krasnoyarsk: Siberian Federal University, 140 p.

Meyerovich, M. G. (2016). *From garden cities to social cities: the main architectural and urban planning concepts in the USSR (1917 – first half of the 1930s).* Author's Abstract of DSc Thesis in Architecture. Nizhny Novgorod: Nizhny Novgorod State University of Architecture and Civil Engineering.

Mishakova, O. E. and Mikhaleva, K. A. (2014). From history of development of museological thought of architecture monuments as objects of cultural heritage. *Austrian Journal of Humanities and Social Sciences*, No. 9–10, pp. 27–31.

Munoz-Vinas, S. (2012). *Contemporary theory of conservation*. London: Routledge, 239 p.

Murzyn-Kupisz, M. (2013). The socio-economic impact of built heritage projects conducted by private investors. *Journal of Cultural Heritage*, Vol. 14, Issue 2, pp. 156–162. DOI: 10.1016/j.culher.2012.04.009.

Murzyn-Kupisz, M. and Działek, J. (2013). Cultural heritage in building and enhancing social capital. *Journal of Cultural Heritage Management and Sustainable Development*, Vol. 3, Issue 1, pp. 35–54. DOI: 10.1108/20441261311317392.

Nagornaya, M. S. and Petukhova, E. I. (2014). Architecture sotsgorod as heritage: European experience and Russian prospects. *Management in Modern Systems*, No. 4 (4), pp. 16–26.

Nara (2015). Nara + 20: On heritage practices, cultural values, and the concept of authenticity. *Heritage & Society*, Vol. 8, Issue 2, pp. 144–147. DOI: 10.1080/2159032X.2015.1126115.

Nazarova, M. P., Barkovskaya, A. Yu. and Nikitina, D. V. (2017). Palace of Culture as social and cultural centerpiece of a typical Soviet city (the case of the Palace of Culture named after Yu. A. Gagarin, Volgograd). *Vestnik Volgogradskogo Gosudarstvennogo Arhitekturno-Stroitel'nogo Universiteta. Seriya: Stroitel'stvo i Arhitektura*, No. 50 (69), pp. 401–411.

Obertas, O. G. and Petukhov, V. V. (2015). Architectural aspects of identity of Vladivostok as European city in the Pacific Region. *Fundamental Research*, No. 11, Part 7, pp. 1352–1357.

Oganesyan, M. G. (1996). *Modernization of the residential areas built in the 1920s–1930s and their protection as urban planning monuments.* PhD Thesis in Architecture.Yerevan: Yerevan Institute of Architecture and Construction.

Orbaşli, A. (2017). Conservation theory in the twenty-first century: slow evolution or a paradigm shift? *Journal of Architectural Conservation*, Vol. 23, Issue 3, pp. 157–170. DOI: 10.1080/13556207.2017.1368187.

Orlenko, N.I. (2017). Problems of protection, restoration, and modern adaptation of architectural monuments. In: *Research, Education, and Experimental Design. Abstracts of Presentations at the International Research and Practice Conference, Vol. 1*. Moscow: Moscow Architectural Institute, pp. 133–134.

Paez, D., Basabe, N. and Gonzalez, J. L. (2013). Social processes and collective memory: a cross-cultural approach to remembering political events. In: Pennebaker, J. W., Paez, D. and Rime, B. (eds.) *Collective Memory of Political Events*. New Jersey: Psychology Press, pp. 159–186.

Pavlova, M. (2016). International experience of architectural heritage preservation and implementation in urban life. *Archyort*, No. 2, pp. 16–24.

Pendlebury, J. (2013). Conservation values, the authorised heritage discourse and the conservation-planning assemblage. *International Journal of Heritage Studies*, Vol. 19, Issue 7, pp. 709–727. DOI: 10.1080/13527258.2012.700282.

Pendlebury, J. and Porfyriou, H. (2017). Heritage, urban regeneration and place-making. *Journal of Urban Design*, Vol. 22, Issue 4, pp. 429–432. DOI: 10.1080/13574809.2017.1326712.

Pendlebury, J., Townshend, T. and Gilroy, R. (2004). The conservation of English cultural built heritage: a force for social inclusion? *International Journal of Heritage Studies,* Vol. 10, Issue 1, pp. 11–31. DOI: 10.1080/1352725032000194222.

Pereslegin, N. V. (2015). *History of the formation and development of architectural heritage protection bodies in Moscow in the context of their interaction with society in the Soviet period.* PhD Thesis in Architecture. Moscow: Moscow Institute of Architecture (State Academy).

Pomozova, N. B. (2012). *Symbols as a tool for shaping civic identity: a comparative analysis of Russia and China.* Author's Abstract of PhD Thesis in Philosophy. Moscow: MGIMO University.

Poulios, I. (2014). Discussing strategy in heritage conservation: Living heritage approach as an example of strategic innovation. *Journal of Cultural Heritage Management and Sustainable Development*, Vol. 4, Issue 1, pp. 16–34. DOI: 10.1108/JCHMSD-10-2012-0048.

Riegl, A. (1903). *Der Moderne Denkmalkultus: Sein Wesen Und Seine Entstehung*. Vienna: Zentral-Kommission Für Kunst-Und Historische Denkmale, 65 p.

Romanova, L. S. and Malevich, S. S. (2013). Adaptation of historical buildings to modern conditions. Experience of Tomsk Restoration School. *Vestnik Tomskogo gosudarstvennogo arkhitekturno-stroitel'nogo universiteta. Journal of Construction and Architecture*, No. 4 (41), pp. 115–126.

Ryzhkova, T. S. (2016). Features of perception and evaluation of architectural monuments of socialist period in the Federal Republic of Germany. *National Association of Scientists*, No. 10 (26), pp. 5–6.

Salman, M., Malik, S., Tariq, F. and Khilat, F. (2018). Conservation analysis of Gali Surjan Singh: a study of architectural and social aspects. *Journal of Architectural Conservation*, Vol. 24, Issue 2, pp. 134–151. DOI: 10.1080/13556207.2018.1488203.

Samolkina, Ye. G. (2015). *Specifics of the newest wooden architecture in Russia.* PhD Thesis in Architecture. Nizhny Novgorod: Nizhny Novgorod State University of Architecture and Civil Engineering.

Sedov, V. V. (2011). Architectural monuments in Russia: national perception of antiquity. [online] Available at: http://arheologpskov.ru/index.php/nasledie/37-pamyatnik-arkhitektury-v-rossii-osobennosti-natsionalnogo-vospriyatiya-drevnosti [Date accessed January 22, 2020].

Selivanenko, A. M. (2015). “Cultural tourism” as one of the forms of preservation of architectural and historical monuments. *The Scientific Opinion*, No. 8, pp. 182–185.

Sergeyev, A. A. (2000). *Semiotic interpretation of the creative concepts of Russian architecture.* PhD Thesis in Architecture. Yekaterinburg: Ural State Academy of Architecture and Art.

Serikov, A. A. (2007). *Development of the historical center of a large city as a focus of social design.* Author’s Abstract of DSc Thesis in Social Sciences. Nizhny Novgorod: Volgo-Vyatskaya Academy of Public Service.

Shulgin, P. M. (2004). Historical and cultural heritage as a special regional resource and socio-economic development factor. *Universe of Russia. Sociology. Ethnology*, Vol. 13, No. 2, pp. 115–133.

Slabukha, A. V. (2014). Questions of history of studying and preservation architectural heritage in Siberia round the Yenisei River. *Proceedings of the 2nd International Research and Practical Conference “Modern Issues in Architecture, Urban Planning, and Design”.* Krasnoyarsk: Siberian Federal University. [online] Available at: http://conf.sfu-kras.ru/city2014/participant/12655 [Date accessed March 20, 2020].

Slabukha, A. V. (2016). Determining the historical and cultural value of architectural heritage sites (Part 2): criteria and method in modern expert praxis. *Man and Culture*, No. 6, pp. 9–22. DOI: 10.7256/2409-8744.2016.6.20767.

Slabukha, A. V. and Sayenko, I. A. (2016). *The Problems of Revealing, Studying, Reconstruction and Restoration of Architectural Heritage of Siberia.* Krasnoyarsk: Siberian Federal University, 35 p.

Smith, L. (2004). *Archaeological theory and the politics of cultural heritage*. London: Routledge, 272 p.

Smith, L. (2007). *Uses of heritage*. London: Routledge, 368 p.

Smith, L. and Waterton, E. (2013). *Heritage, communities and archaeology*. London: Bloomsbury, 144 p.

Snopek, K. (2013). *Beliaevo Forever.* Moscow: Strelka Press, 59 p.

Smirnova, N. A. (2004). *Regional identity in the context of contemporary Russian society*. PhD Thesis in Sociological Studies. Volgograd: Volgograd State University.

Soboleva, K. V. (2014). *Visual strategies of social identification in a contemporary Russian city (as exemplified by St. Petersburg).* Author’s Abstract of PhD thesis in Social Sciences. Saint Petersburg: Herzen State Pedagogical University.

Solovyova, D. N. and Anisimova, L. V. (2014). Adaptive design techniques in the historical environment as a way to preserve the unique character of cities. In: Volkova, T. F. (ed.) *Theory and Practice of Environment Design: Proceedings of the 6th International Research and Practice Conference*. Penza: Penza State University of Architecture and Construction, pp. 69–72.

Stafeyev, I. S. (2015). Accounting for the urban planning role during the restoration of architectural memorials. In: Balzannikov, M. I., Galitskov, K. S., Akhmedova, Ye. A. (eds.) *Traditions and Innovations in Civil Engineering and Architecture. Urban Planning. Collection of Articles.* Samara: Samara State University of Architecture and Civil Engineering, pp. 206–209.

Stephens, J. and Tiwari, R. (2015). Symbolic estates: community identity and empowerment through heritage. *International Journal of Heritage Studies*, Vol. 21, Issue 1, pp. 99–114. DOI: 10.1080/13527258.2014.914964.

Styopin, V. S., Gorokhov, V. G. and Rozov, M. A. (1996). *Philosophy of science and technology*. Moscow: Gardarika, 400 p.

Torabi, Z. and Brahman, S. (2013). Effective factors in shaping the identity of architecture. *Middle-East Journal of Scientific Research*, Vol. 15, Issue 1, pp. 106–113. DOI: 10.5829/idosi.mejsr.2013.15.1.2357.

Townshend, T. and Pendlebury, J. (1999). Public participation in the conservation of historic areas: case-studies from North-East England. *Journal of Urban Design*, Vol. 4, Issue 3, pp. 313–331. DOI: 10.1080/13574809908724453.

Tsaryov, V. I. (2012). *History of urban development in Siberia.* Krasnoyarsk: Siberian Federal University, 12 p.

Tsepelev, A. Yu. (2014). *Social modeling of regional identification: the sociological and managerial aspect.* PhD Thesis in Sociological Studies. Moscow: Institute of Sociology of the Russian Academy of Sciences.

Tunbridge, J. E. and Ashworth, G. J. (1995). *Dissonant heritage : the management of the past as a resource in conflict*. Chichester; New York: John Wiley, 299 p.

Viktorova, L. A. (2014). The process of preservation of monuments of architecture. Save or ruin? *Architecture and Construction of Russia,* No. 10, pp. 24–31.

Vilkovsky, M. (2010). *Sociology of architecture.* Moscow: Russian Avant-Garde Foundation, 592 p.

Waterton, E. and Smith, L. (2010). The recognition and misrecognition of community heritage. *International Journal of Heritage Studies*, Vol. 16, Issue 1–2, pp. 4–15. DOI: 10.1080/13527250903441671.

Waterton, E. and Watson, S. (2015). *The Palgrave Handbook of Contemporary Heritage Research*. London: Palgrave Macmillan, 586 p. DOI: https://doi.org/10.1057/9781137293565.

Yalegama, S., Chileshe, N. and Ma, T. (2016). Critical success factors for community-driven development projects: a Sri Lankan community perspective. *International Journal of Project Management*, Vol. 34, Issue 4, pp. 643–659. DOI: 10.1016/j.ijproman.2016.02.006.

Yung, E. H. K., Lai, L. W. C. and Yu, P. L. H. (2016). Public decision making for heritage conservation: a Hong Kong empirical study. *Habitat International*, Vol. 53, pp. 312–319. DOI: 10.1016/j.habitatint.2015.12.004.

Zaitsev, A. (2013). *Contextualism as a stillistic movement in arhitecture in the end of the 20th – beginning of the 21st century.* PhD Thesis in Architecture. Nizhny Novgorod: Nizhny Novgorod State University of Architecture and Civil Engineering.

Zlotnitsky, Ye. E. (2008). *Social mechanism of managing the brand of a region*. PhD Thesis in Sociological Studies. Moscow: State University of Management.

СОХРАНЕНИЕ ИДЕНТИЧНОСТИ ИСТОРИЧЕСКОЙ СРЕДЫ В СИБИРИ: КРИТИЧЕСКИЙ ОБЗОР ЛИТЕРАТУРЫ

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Аннотация

В настоящее время проекты, связанные с развитием уникальной исторической среды в Сибири, в основном, противоречивы. Тем не менее, есть возможность найти более целостный подход к сохранению местного наследия, который мог бы учитывать местные культуры и самобытность через понимание того, как развивается историческая среда, а также через конкретные пространственные и архитектурные практики. **Цель исследования:** Создать теоретическую и методологическую основу для поддержания местной идентичности с архитектурной точки зрения. **Методы:** В соответствии с методологическими рекомендациями Грота и Вана использовались такие методы, как критический анализ литературы и логическая аргументация. **Результаты:** Было обнаружено, что понятие «городская идентичность» может раскрываться через два или более конгруэнтных «слоя». В данном исследовании рассматриваются архитектурное наследие и общество как два из возможных «слоев». Предположительно, локальная идентичность исторической среды может быть сохранена в процессе неразрушающего развития с помощью сочетания следующих методов: 1) обращение к прошлому посредством анализа структуры города и поиска “социальных следов” и семиотических значений; 2) взгляд в будущее с использованием методов соучаствующего проектирования. Было решено протестировать методологию на конкретных исторических условиях Сибири. Приведённый критический обзор литературы предоставит исследователям и практикам в данной области базовую теоретическую основу.

Ключевые слова

Архитектура, философия архитектуры, идентичность, наследие, партисипация, устойчивое развитие.

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IMPACT OF SCULPTURES IN LANDSCAPE DESIGN: CASE OF GREATER IQBAL PARK, LAHORE

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Abstract

Introduction: A landscaped area is always appealing when designed according to a certain theme and purpose, as is the case with the sculptures in the Greater Iqbal Park. **Purpose of the study:** We aimed to analyze the influence of ornamental sculptures on people visiting the Greater Iqbal Park situated in Lahore, Pakistan. The objective was to evaluate the importance of the sculptures' presence in the park, to review the visitors' opinions on the subject, and to analyze how the sculptures blend in with other elements of the park. **Methods:** An important aspect of the study is the combination of data collected through observations, pictures, and questionnaires. **Results and discussion:** 65% of visitors to the park are satisfied with the sculptures' placement and the lighting around them. The sculptures depicting a bent tree, birds, musical instruments, and a peacock are aesthetically pleasing and alluring for the visitors. The reliefs reference art from the Mughal era, and the material is durable, tough, and weather-resistant. **Conclusions:** The visitors like to have sculptures in the park, which increases the park's appeal, especially for children, who can learn visual lessons about shapes and history. The study will help designers with creating variety and inspiring interest through sculptures, especially those related to historical events and complementing their surroundings.

Keywords

Sculptures, landscape design, Greater Iqbal Park, Lahore, Pakistan.

Introduction

The landscape is the visible aspect of an area, its landforms and interactions with natural or man-made features. Landscapes have a wide variety of features, including: the physical elements of geophysically defined landforms, such as mountains and hills as well as water bodies, such as rivers, lakes, ponds, and seas; living organisms, including indigenous vegetation; man-made elements, including different forms of land use, buildings, and structures; and transitory elements, such as lighting and weather conditions (Dumas et al., 2007; Woudstra and Fieldhouse, 2000). Landscapes can be both natural and man-made (also called built landscapes). The natural landscapes on Earth include mountain landscapes, coastal landscapes, and riverine landscapes. Natural landscapes are made up of a variety of geographical features known as landforms: hills, caves, valleys, etc. (Booncham et al., 2011).

Parks, by contrast, are designed by humans to provide an area of natural, semi-natural, or planted space, set aside for human enjoyment and recreation or the protection of wildlife or natural habitats. Parks may consist of grassy areas, rocks, soil, and trees, but may also contain buildings and other artifacts, such as monuments, fountains, or playground sculptures. People value the time they spend in city parks, whether playing basketball, having a picnic, or more. Along with these expected leisure amenities, parks can also provide measurable health benefits, from direct contact with nature and a cleaner environment to opportunities for physical activity and social interaction (Cushing and Pennings, 2017; Woudstra and Fieldhouse, 2000).

Public parks are often the "engine" that drives tourism in many communities. In a simplified tourism model, visitors use some mode of transportation to leave their homes and travel to attractions, which are supported by various kinds of services, such as hotels/motels, restaurants, and retailing (Farooq and Kamal Arif, 2020). The attractions and support services provide information and promote their offerings to target groups that they have identified as potential visitors (Booncham et al., 2018). Parks are commonly thought of as the venue for "fun and games", but that is only one of the roles they play in a metropolitan environment. Urban parks, which broadly include parkland, plazas, landscaped boulevards, waterfront promenades, and public gardens, significantly define the layout, real estate value, traffic flow, public events, and the civic culture of our communities. With open spaces, our cities and neighborhoods are enhanced with sculptures and gain beauty, breathing room, and value. City parks and open spaces improve our physical and psychological health, strengthen our communities, and make our cities and neighborhoods more attractive places to live and work. Numerous studies have demonstrated the social, environmental, economic, and health benefits that parks bring to a city and its people. Including parks and recreation facilities in urban planning can promote active lifestyles, build healthy communities, and lower healthcare and transportation costs (Farooq, 2020; Özgüner and Kendle, 2006).

The park reviewed in our paper is the Greater Iqbal Park, formerly known as Minto Park and renamed after renovation and expansion. This urban park is located on the outskirts of the Walled City of Lahore, Pakistan. Noted as the home of Minar-e-Pakistan, the 125-acre park includes an artificial lake that spreads over a four-acre territory with an 800-feet-long musical fountain. Other attractions include a soft rail, a library, an open-air gym, and a food court (Fatima et al., 2017; Shah et al., 2018; Yahya, 2020). The objectives of this study can be summarized as follows:

- To analyze the blend between the sculptures and other elements of the park.
- To evaluate the importance of the sculptures' presence in the park from the visitors' standpoint.
- To analyze the visitors' opinions on the presence of sculptures in the park.

Literature Review

"A sculpture is a three-dimensional art form that provides an important visual way of understanding form and space". A sculpture can be figurative or abstract, but regardless, its purpose is to make humans aware of themselves and their environment (Woudstra and Fieldhouse, 2000). There are many types of sculptures: portrait busts, allegorical and equestrian figures, funerary sculptures, garden sculptures, figurines. Abstraction and assemblage are the dominant forms of modern sculpture.

Garden Sculptures

Many gardens have sculptures that are used to enhance the beauty of the surrounding environment. The landscaper must choose the site for the garden sculpture carefully and thoughtfully, in order to enhance the garden and give emphasis to design and plantings throughout the year. The height of the sculpture in relation to the viewer's eye level, as well as the height of plants and other sculptures, is a crucial aspect of the setting. This cannot be perfectly controlled, as the eye level varies depending on body height (between 1.40 and 1.80 m) and changes according to the laws of perspective as the viewer approaches (Booncham and Chantachon, 2019).

If the sculpture rests on the grass, it gives a more casual impression: symbolically, the sculpture shares the same ground as humans, animals, and gardens; it grows from the same earth that nurtures the surrounding vegetation. Manipulating closeness and distance to the sculpture through garden design is an important tool in controlling the viewer's experience. The impact of the sculpture is made up of its different views, varying in angles and distance. Garden designers often use sculptures as focal points. Focusing on the sculpture slows down the viewer's journey through the garden's expanse, as they stop and examine the sculpture. This allows for discovering the garden gradually rather than sweeping through it and having a superficial experience; the garden becomes enlarged in the viewer's perception. Texture – the surface material quality – is a crucial aesthetic dimension of both garden design and sculpture. It is explored through touch, but also visually. Sculpture textures may vary depending on the material and the use of tools (Lambert, 2006; Warkentin, 2010).

Color in sculptures and plants is yet another means of manipulating the space and directing the visitor's attention: it can be used to create depth or simulate flatness. Warm colors like reds, yellows, and oranges make the object visually closer to the viewer. Cool colors like greens and blues visually move the object further away. Complementary colors are attracted to one another (red to green, blue to orange, yellow to purple) and catch the viewer's attention. Bright colors stand out against more gray or toned-down colors (Dumas et al., 2007; Ives, 2018).

Relevance of Sculptures in Landscape Design

Sculptures can do what plants alone cannot: they add symbolic meaning, trigger positive memories, and often touch the human heart, creating a sensation of peace and inner joy. Sculptures function as an integral part of many ceremonies and events. Often unnoticed, they give a visual reference for emotional experiences throughout the passage of human life. Outdoor sculptures are always a surprising delight. Sculptures can make a very dramatic statement, and their placement is important. Some of them are site-specific, some are functional, and some are welcoming. Sculptures can also be transformed by the wind, season, or time of day (Ives, 2018). One of the most beautiful attractions in Lahore is the Greater Iqbal Park, which displays fountains and flowers. This landscaped attraction is a project of the Lahore Development Authority (LDA). The idea of this park was to convert the barren area between the Iqbal Park and Badshahi Mosque into something more entertaining, like a theme park.

Historical Background of the Greater Iqbal Park

The Minto Park (now the Greater Iqbal Park) was named after Lord Minto Gilbert Elliot (1751–1814), the Ninth Indian Governor-General between 1807 and 1813. The vast grassy stretches around Minar-e-Pakistan are most famous for hosting the All-India Muslim League's gathering that passed the Pakistan Resolution of March 23, 1940, which provided the decisive impetus to the movement leading up to the division of British India in 1947. The 203-foot high Minar-e-Pakistan tower was built between 1960 and 1968 at the Greater Iqbal Park to commemorate the first official call for a separate homeland for the Muslims of India. This monument was completed on October 21, 1968, at an estimated cost of Rs 7,058,000. The money was raised by imposing an additional tax on cinema and horse racing tickets at the demand of Akhtar Husain, the then Governor of West Pakistan (Fatima et al., 2017; Yahya, 2020).

The park was renovated by the Punjab government within 13 months, at a cost of Rs 981 million. The Greater Iqbal Park lies on the outskirts of the Walled City, which happens to be the cultural heart of Lahore. The salient features of the Greater Iqbal Park in Lahore are the statues of Quaid-E-Azam, Allama Iqbal, Fatima Jinnah, and Sir Syed Ahmed Khan, along with the renovated and preserved Minar-E-Pakistan, thematic food courts depicting cultures and heritages of all provinces of Pakistan, the Heritage Museum that highlights the history of the Pakistan Movement, elaborate walkways, gardens, pavements, dancing fountains, and a baradari pavilion. Since this park is near the historic Mughal Buildings, its pavements and fountains are laid out in the Mughal architecture style, featuring geometric patterns similar to those used in the historic buildings. On weekends, multiple families come out here to enjoy picnics in an environment of waterfalls and fountains. This project is indeed a great relief for the citizens, as it has provided the much-needed parking and recreational facilities (Shah et al., 2018; Yahya, 2020).

Research Methodology

This paper is based on quantitative research, which was done by collecting data through observations, pictures, and questionnaires. The questionnaires were filled by the visitors who were coming to the park. They needed to answer questions on how important they found the sculptures and how the sculptures influenced them during their visit to the park. The scope of this study is parks with ornamental sculptures in Pakistan, made for the general public to visit. The sample is the Greater Iqbal Park in Lahore, where many huge ornamental sculptures are present.

Data Analysis

The study was divided into two parts: visual analysis and survey analysis, as explained below:

Visual Analysis

Figure 1 shows a sculpture of a peacock in the Greater Iqbal Park, a symbol of peace and beauty. As the peacock is considered the symbol of beauty, the sculpture is surrounded by plain grasslands to highlight its importance. It enhances the beauty of the park.

Figure 2 shows a great blend of art and culture in the Greater Iqbal Park. This sculpted relief features factual depictions of various historical events. The relief has images of Pakistan's freedom-fighting leaders and views of different historical buildings, reminding the Pakistani people of their history and worthy place in the world.

Figure 3 shows a tree-like sculpture with a metal body and colorful flower pots. It enhances the beauty of the park; moreover, the pots can be used for planting small plants.

Figure 4 shows a light pole encircled by a sculpture that enhances its beauty and makes it more appealing to visitors.

Figures 5 and 6 show different functional sculptures that can be used for planting small plants in pots, while also enhancing the beauty of the park.

Figure 7 shows a musical instrument sculpture.

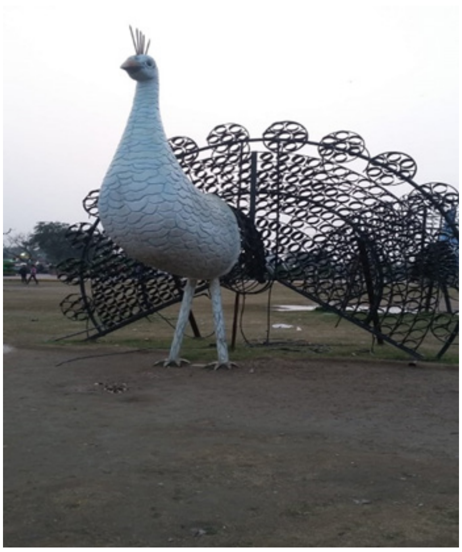

Figure 1. Sculpture of a peacock in the Greater Iqbal Park (source: the authors)

Figure 2. Relief in the Greater Iqbal Park (source: the authors)

It is an art form that has a profound impact on the people visiting the park.

Figure 8 shows a colorful sculpture of a sparrow that gives the viewer a chance to observe the bird's beauty and innocence from close-up.

Figure 9 shows a bud coming out of a flower pot. Its shape enhances its surroundings.

Figure 10 shows a book enclosed in a glass case, documenting a series of historical events that occurred in the past years.

Figure 11 shows a small roofed area where park visitors can enjoy a meal and rest in a fragrant shady place.

Figure 12 shows a passageway covered completely in ornamental plants. It recreates a natural environment.

Figure 13 shows a sculpted peacock, with a white body and yellow flowers for feathers.

Survey Analysis

The analysis of the survey aims to evaluate the

Figure 3. Tree-like sculpture for hanging flower pots (source: the authors)

Figure 5. Pole with flower pots in the Greater Iqbal Park (source: the authors)

Figure 4. Sculpture with a light pole in the Greater Iqbal Park (source: the authors)

Figure 6. Curved pole with a flower pot in the Greater Iqbal Park (source: the authors)

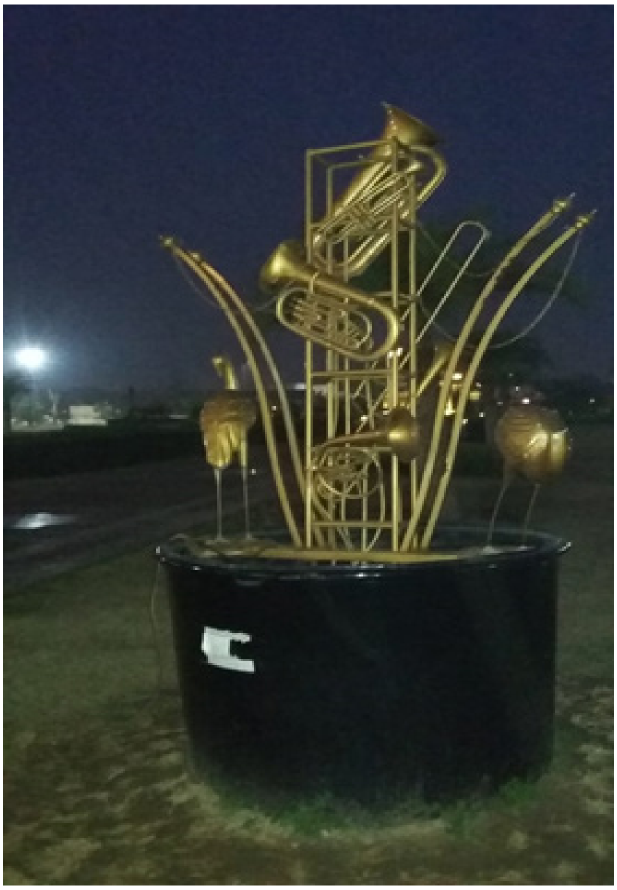

Figure 7. Sculpture of musical instruments in the Greater Iqbal Park (source: the authors)

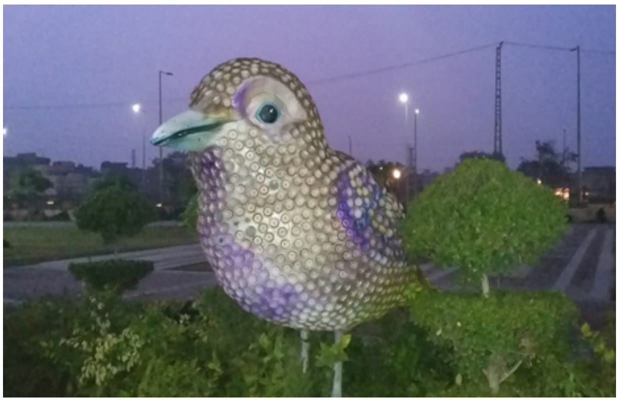

Figure 8. Sculpture of a bird in the Greater Iqbal Park (source: the authors)

Figure 9. Sculpture of a bent bud in the Greater Iqbal Park (source: the authors)

Figure 10. Sculpture of a book in the Greater Iqbal Park (source: the authors)

Figure 11. Gazebo in the Greater Iqbal Park (source: the authors)

Figure 12. Heart-shaped sculptures with flowers in the Greater Iqbal Park (source: the authors)

Figure 13. Sculpture of a peacock with flowers on its tail (source: the authors)

influence of the ornamental sculptures in the park and analyze the visitors' opinions on the matter.

Figure 14 shows that 9% of respondents like the sculptures, 64% like the trees and flowers, and 27% like the dancing fountain at the Greater Iqbal Park. We can conclude that 64% of visitors to the Greater Iqbal Park enjoy looking at its trees and flowers.

Figure 15 shows that 30% of visitors spend 10–20 minutes in the Greater Iqbal Park, 25% spend 30–60 minutes, and 45% spend more than 1 hour. The conclusion is that 45% of those who come to the Greater Iqbal Park spend more than 1 hour there.

Figure 16 shows that 75% of visitors feel relaxed, 10% do not feel relaxed, and 15% feel neutral. We can conclude that 75% of people feel relaxed during their time in the Greater Iqbal Park.

Figure 17 shows that 65% of visitors think that the park has a positive impact, 5% think that the park has a negative impact, and 30% think that the park has a neutral impact. We can therefore summarize that 65% of people think that the Greater Iqbal Park has a positive impact on them.

Figure 18 shows that 45% of respondents think that having sculptures is necessary for a park, 15% think that it is not necessary, and 40% think that it can go either way.

Figure 19 shows that 79% of respondents are comfortable with the placement of sculptures in the Greater Iqbal Park, 10% think that the placement of sculptures is poor, and 11% are neutral on the subject. Our conclusion is that 79% of visitors are comfortable with the placement of sculptures in the Greater Iqbal Park.

Figure 20 shows that 35% of respondents like realistic sculptures, 20% like abstract sculptures, and 45% like both. This prompts the conclusion that

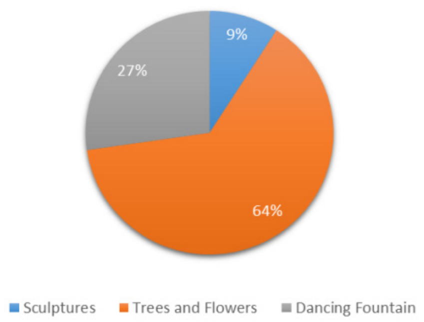

Figure 14. Opinions on the presence of sculptures in the park

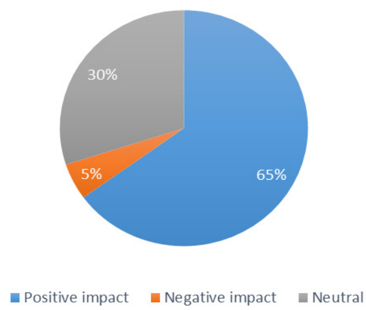

Figure 17. Park's impact on visitors

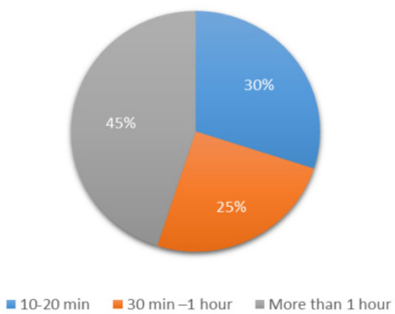

Figure 15. Duration of stay in the park

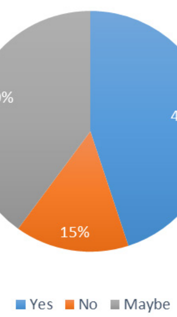

Figure 18. Necessity of sculptures in the park

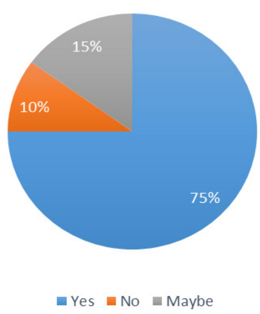

Figure 16. Impressions of visitors staying in the park

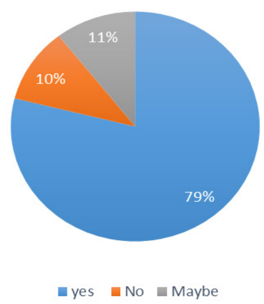

Figure 19. Comfort with the placement of sculptures in the park

45% of park visitors enjoy both realistic and abstract sculptures.

Figure 21 shows that 75% of respondents like sculptures that are decorated with flowers, 20% do not like such sculptures, and 5% are uncertain about whether or not they like them. The conclusion, therefore, is that 75% of respondents are appreciative of sculptures that are decorated with flowers.

Figure 22 shows that 40% of respondents characterize the sculptures of the Greater Iqbal Park as historical, 30% think the sculptures are modern, and 30% think the sculptures are cultural. In other words, 40% of people think that the sculptures of the Greater Iqbal Park are historical.

Figure 23 shows that 75% of people think that the sculptures of the Greater Iqbal Park have good lighting around them, 5% think that the sculptures do not have good lighting, and 20% are not sure about the lighting. We can conclude that 75% of the people visiting the Greater Iqbal Park think that the local sculptures have good lighting around them.

Figure 24 shows that 15% of people think that the sculptures are easily recognizable by children, 20% think that they are not easily recognizable, and 65% think that they might be easily recognizable by children. We conclude that 65% of respondents are uncertain about whether children can recognize the sculptures.

Figure 25 shows that 60% of respondents think that the sculptures of the Greater Iqbal Park help children with recognizing figures related to historical events, 5% think that they do not help, and 35% think that they might do so. We conclude that 60% of people consider the sculptures of the Greater Iqbal Park helpful when it comes to children's education.

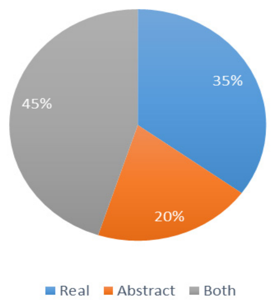

Figure 20. Responses to sculpture realism

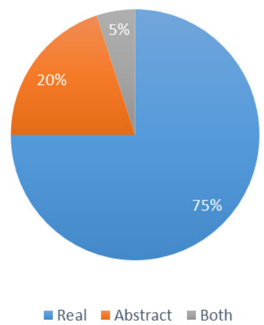

Figure 21. Responses to sculptures decorated with flowers

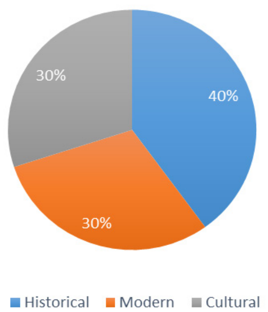

Figure 22. Types of sculptures that visitors can distinguish

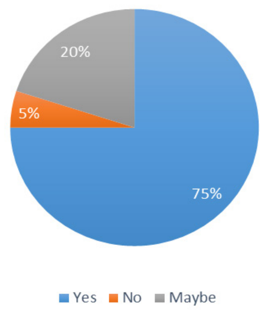

Figure 23. Sculpture lighting quality

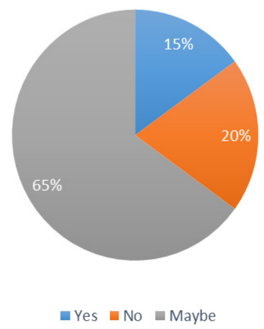

Figure 24. Recognition of the sculptures by children

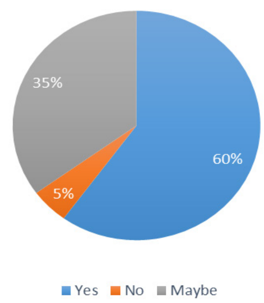

Figure 25. Sculptures' help with children's learning about national history

Figure 26 shows that 70% of people think that sculptures add beauty to the landscape, 5% think that sculptures do not add beauty, and 25% think that sculptures might add beauty to the landscape. We conclude that 70% of respondents think that sculptures do add beauty to the park's landscape.

Figure 27 shows that 60% of visitors like metal sculptures, 10% like plastic sculptures, and 30% like sculptures made of both plastic and metal. The conclusion is that metal sculptures are preferred by 60% of respondents.

Figure 28 shows that 30% of respondents think that the size of sculptures in the park is appropriate, 15% think that the size of the sculptures is not appropriate, and 55% think that the size might be appropriate. In conclusion, 55% of respondents believe that the size of sculptures in the Greater Iqbal Park might be appropriate.

Figure 29 shows that 20% of people think that the park needs more sculptures, 10% think that the park does not need more sculptures, and 70% think that more sculptures might be needed in the park. In other words, 70% of respondents think that the Greater Iqbal Park might need more sculptures.

Summary and Conclusion

The landscape encompasses the visible features of an area of land, often considered in terms of their aesthetic appeal. At the same time, a park is a large public garden or area of land used for recreation. It consists of grassy areas, rocks, and trees, as well as different sculptured elements. Sculpture is a branch of visual arts that operates in three dimensions. Their main function is to direct movement through space and to enclose space, as well as to add symbolic meaning. Designing a garden in a way that manipulates the perception of the sculptures' proximity or distance is an important tool for controlling the viewer's experience. Color in sculpture is yet another means of manipulating space and directing the viewer's attention.

The Greater Iqbal Park was formerly known as Minto Park, renamed after renovation and expansion. This urban park is located on the outskirts of Lahore, Pakistan. It has a number of appealing features: a soft rail, a library, an open-air gym, and a food court, an outstanding plantation, sculptures, as well as elaborate walkways, gardens, pavements, dancing fountains, and a baradari pavilion. Since this park is near the historic Mughal Buildings, its pavements and fountains are laid out in the Mughal architecture style, featuring geometric patterns similar to those used in the historic buildings.

This paper analyzed and focused on the importance of, and need for, different sculptures in any park, with special reference to the Greater Iqbal Park. The sculptures of a bent tree, birds, a musical instrument, a peacock, etc. are aesthetically pleasing and alluring for the visitors. The paper examined the materials used for making these sculptures, their placement, and how they attract viewers through their form and shape. While the park covers a huge area for recreation, most of the sculptures can be easily

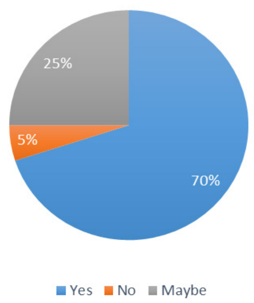

Figure 26. Adding beauty to the park with sculptures

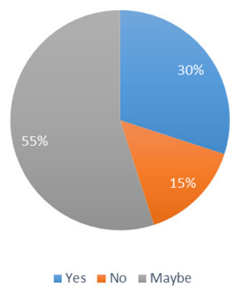

Figure 28. Visitors' opinions on the size of sculptures in the park

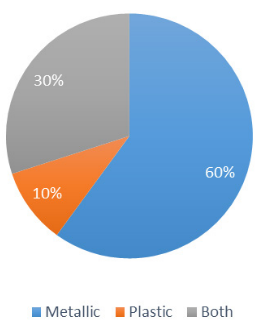

Figure 27. Visitors' attitude to the material used for sculptures

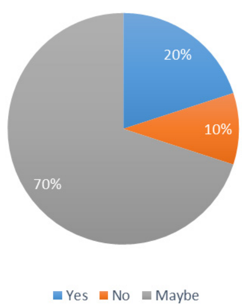

Figure 29. Need for more sculptures

seen from the distance because of their size. We acknowledged the purpose of different sculptures, noting that they are beautifully carved and symbolic. The materials used include bricks, cement, clay, steel, and plaster of Paris. The integrated topiaries and other flowers embellish the environment, while also creating a healthy atmosphere for the visitors. The pavements are decorated with heart-shaped arches. Most of the seating arrangements are inside gazebos, which both enhance the space and protect the visitors against unfavorable climatic conditions.

The visitors are enjoying the landscape of the Greater Iqbal Park. Most of them are comfortable with the placement and sizes of sculptures. The visitors, especially children, responded positively to having sculptures in the park because these sculptures are easily recognizable and are creating an educational environment for the children. References to the Mughal Buildings can be easily seen in various sculptures, such as the relief sculptures, especially considering the proximity of the Walled City to the park. The material used for making the sculptures is durable, tough, and weather-resistant. The finished product is instantly appealing to the eye. Most of the park visitors consider that there are enough sculptures in the Greater Iqbal Park. Adding more sculptures may make the environment cluttered and confusing. The Greater Iqbal Park is a comfortable place where people can take their families and show them the great history of Pakistan. The sculptures are a great addition to the park and the authors personally liked every sculpture. Our favorite, however, was the relief showing certain historical events.

References

Booncham, A. and Chantachon, S. (2019). Contemporary sculptures: Decoding the body of aesthetic knowledge suitable for public parks. *Journal of Cultural Approach*, Vol. 20, No. 37, pp. 62–71.

Booncham, A., Chantachon, A. and Lao-Akka, S. (2011). Contemporary sculptures: Decoding the body of aesthetic knowledge suitable for public parks. *American Journal of Applied Sciences*, Vol. 8, Issue 12, pp. 1302–1306. DOI: 10.3844/ajassp.2011.1302.1306.

Booncham, A., Chantachon, A. and Lao-Akka, S. (2018). Analysis of the aesthetics of contemporary sculptures suitable for public parks in Thailand. *Thai Journal of East Asian Studies*, Vol. 22, No. 1, pp. 2–18. DOI: 10.14456/ijeas.2018.1.

Cushing, D. F. and Pennings, M. (2017). Potential affordances of public art in public parks: Central Park and the High Line. *Proceedings of the Institution of Civil Engineers – Urban Design and Planning,* Vol. 170, Issue 6, pp. 245–257. DOI: 10.1680/jurdp.16.00042.

Dumas, C. F., Burrus, R. T. Jr., Diener, E., Payne, J. and Rose, J. (2007). Valuing the recreational benefits of sculpture in public parks. *Journal of Park and Recreation Administration*, Vol. 25, No. 2, pp. 29–41.

Farooq, S. (2020). Psychological impact of landscape principles on human beings: A case study of Safari Villas Park Bahria Town, Lahore, Pakistan. *Pure and Applied Biology*, Vol. 9, No. 3, pp. 1820–1830. DOI: 10.19045/bspab.2020.90194.

Farooq, S. and Kamal Arif, M. (2020). Analysis of green living walls: Individual awareness about its functional value and aesthetical quality. *Civil Engineering and Architecture*, Vol. 8, No. 4, pp. 444–449. DOI: 10.13189/cea.2020.080406.

Fatima, H. S., Abrar, A. and Shehzadi, R. (2017). Assessment of the Impacts on Water Quality of the Area by Landscaping Activities of Greater Iqbal Park Project, Lahore, Pakistan. *Journal of Coastal Zone Management*, Vol. 20, Issue 3, 1000448. DOI: 10.4172/2473-3350.1000448.

Ives, C. (2018). *Public parks, private gardens: Paris to Provence*. New York: Metropolitan Museum of Art, 204 p.

Lambert, D. (2006). The meaning and re-meaning of sculpture in Victorian public parks. In: Eyres, P. and Russell, F. (eds.) *Sculpture and the Garden*. London; New York: Routledge, pp. 99–110.

Özgüner, H. and Kendle, A. D. (2006). Public attitudes towards naturalistic versus designed landscapes in the city of Sheffield (UK). *Landscape and Urban Planning*, Vol. 74, Issue 2, pp. 139–157. DOI: 10.1016/j.landurbplan.2004.10.003.

Shah, S. A., Shah, A. A. and Li, X. (2018). Assessment of the history and cultural inclusion of Public Art in Pakistan. Preprints. DOI: 10.20944/preprints201802.0117.v1.

Warkentin, J. (2010). *Creating memory: A guide to outdoor public sculpture in Toronto*. Toronto: Becker Associates, 347 p.

Woudstra, J. and Fieldhouse, K. (eds.) (2000). *The regeneration of public parks.* London: E & FN Spon, 196 p.

Yahya, A. A. (2020). The construction of ideology in political discourse: A deictic analysis. International *Journal of Applied Linguistics & English Literature*, Vol. 9, Issue 2, pp. 1–14. DOI: 10.7575/aiac.ijalel.v.9n.2p.1.

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STRUCTURAL FEATURES OF A WATER INTAKE FACILITY FOR MOUNTAIN AND SUBMOUNTAIN RIVERS

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Abstract

Introduction: The rate of urbanization is currently high. Therefore, it is important to use various elements and devices for water intake and water supply. **Purpose of the study**: We aimed to consider and analyze the structural features of a water intake facility for mountain and submountain rivers. **Methods**: In the course of the study, we used the synergistic research principle and statistical analysis. We analyzed the types of water supply networks at mountain rivers and identified the features of water intakes at water sources of this type. **Results**: A description of water intake features under flood conditions in the Amur Region, exemplified by the Bureya River, was obtained. The mountain rivers have an uneven runoff, which fluctuates not only throughout the year but also throughout the day. The water supply of the mountain and submountain areas shapes the idea of hydrological control over the regime of the mountain rivers. This paper will help to study changes in the average water inflow over the years and thus facilitate an accurate and detailed description of the water inflow characteristics in the Bureya reservoir when planning the water-energy modes of the hydroelectric power plant.

Keywords

Structural features, water intake, mountain area, submountain area, hydrological characteristics.

Introduction

The beginning of the 21st century is characterized by active industrial and agricultural development and urban growth, which has led to a sharp increase in water consumption from surface sources, including seas, rivers, reservoirs, and lakes. In Russia, especially in the Far East, the use of water and energy resources in the mountain and submountain areas is largely motivated by the nature of the terrain. Mountain ranges dominate the terrain of the Far East and northeastern Siberia. Due to the high indices of the economy, industrial production, agriculture, and construction in the Far East, the use of water resources in agriculture is highly relevant for the aforementioned territories. Water intake is carried out in the mountain and submountain areas; this has a major impact on the types of irrigation systems. This study presents a novel approach as it describes the specifics of water intake in the current emergency conditions at the Bureya hydroelectric power plant (Amur Region). Research on the construction of water intakes in such areas has been carried out for a long time. The energy supply capacity of the mountain and submountain watercourses is largely related to river morphology (Artamonov and Kroshkin, 1972; Kroshkin, 1980).

The problems of water intake in the mountain and submountain river basins have been studied by such prominent researchers as S. T. Altunin (1964), K. F. Artamonov and S. S. Satarkulov (1972), N. F. Daneliya (Daneliya, 1964; Daneliya et al. 1960), I. S. Rumyantsev and V. F. Matseya (1988), I. I. Levi (1967), K. V. Popov (1956), S. V. Semyonov (1950), Ya. V. Bochkaryov (Bochkaryov, 1969; Bochkaryov and Lugovoi, 1971), B. I. Melnikov (1989, 1994), A. I. Rokhman (1983), G. V. Sobolin and I. K. Rudakov (1964), A. V. Filonchikov (1990), A. Polad-Zade (1964), F. B. Bashirov (1986), A. I. Chavtorayev (1958), A. S. Babkin (2019), and Ya. I. Kaganov (1979).

During the construction of the first water intake structures in the USSR, the focus was mainly on increasing the use of water resources and reducing the number of negative factors affecting the structure of water intake facilities (Akhmedov and Mamedov, 1990). There were proposals for water intake structures for mountain rivers, including a catchment dam and a curvilinear water intake pocket equipped with a bottom sill at the entry point. The disadvantage of this structure is the roiling of bottom sediments, which contributes to the pollution of sedimentation tanks.

The available devices with a mechanical drive, including segment gates, do not ensure automatic regulation of the water level in the upper pool of hydraulic structures. The invention described by

S. T. Altunin (2015), V. N. Bukhartsev and N. P. Lavrov (2015), S. V. Sobol et al. (2016) aims to create such an automatic regulator. In addition, a variation of this invention has already been described in the scientific literature (Filonchikov, 1990; Surface water resources, 1973; Western Caspian Basin Water Management Board, 2020).

The proposed automatic regulator differs from the available ones in that the segment gates are mounted on one axis: one rigidly, and the other with the possibility of rotation. In other words, one of the gates has a rigid connection, and the other has a flexible connection with a floating drive placed in a shaft communicating with the lower pool.

When analyzing the history of the development, design, and construction of water intake facilities on the mountain rivers, it is necessary to pay attention to the features of the water intake facilities described in the works of Y. Ma et al. (2020), A. Wałęga et al. (2019), M. J. Brandt et al. (2016), O. K. Mawardi (1981), L. E. Armstrong and E. C. Johnson (2018), C. A. Morrissey et al. (2018), V. M. Silverthorn et al. (2018a, 2018b), Ya. I. Kaganov (1970, 1981), and P. Chattopadhyay (2006).

The features of water intake facilities on the mountain rivers include the following:

1) the presence of wide floodplains with pebble deposits and shallow unstable (walker) branches and arms;

2) strong fluctuations in costs; water discharges during floods can exceed those during low-water periods by 1000 times or more, and floods (from melting snow and from showers) usually come suddenly;

3) a significant amount of sediment, especially during flood periods; in addition, the sediment pieces in the mountain rivers are generally much larger than in the lowland rivers, and some rivers even periodically carry a significant amount of mud and rocks, including very large ones (the so-called mudflows);

4) in order to purify water from rocks and other components, the design must include special sedimentation tanks and filtering plants;

5) protection against possible structural damage and destruction during mudflows must also be taken into consideration;

6) a large number of various pump equipment units is installed to supply water, requiring reliable fixation.

Most of the water intake facilities are in unusable technical condition and need an upgrade. Technical and economic efficiency and environmental safety are important aspects as well. Some studies do consider the means of improving the structures for the intake of the underflow in the mountain and submountain rivers. Researchers propose a water intake facility of a combined type, which has the advantage of solving all environmentally and technically important issues (Babkin et al., 2018; Loginov, 2014).

Another option for increasing the life of water intake facilities is taking technical measures and ensuring their efficiency. Naumova et al. (2019) consider the methods of increasing the efficiency of operational measures to reduce sediment transportation in the intakes of irrigation systems. The efficiency of operational measures within a specific field was studied in detail in relation to the MASSCOTE approach modernizing irrigation management (Garcez-Restrepo et al., 2007; Hobbs et al., 1989; Kadiresan and Khanal, 2018; Luo et al., 2017; Renault et al., 2007).

A typical aspect of foreign studies is the predominance of the ecological aspect over economic considerations; most Russian studies, in the meanwhile, are aimed at eliminating technical flaws to achieve better economic benefits, as evidenced by the works of A. V. Klovsky and D. V. Kozlov (2016) as well as A. R. Paz et al. (2007).

This study aims to determine if it is possible to improve the efficiency of short-term planning for the water-energy modes of operation at the Bureya hydroelectric power plant and develop a method for short-term forecasting of water inflow into the Bureya reservoir, based on the hydrological data of model and meteorological forecasts.

Methods

The study is based on the synergistic principle of studying the structure of water intake facilities and includes statistical analysis.

Results and Discussion

The mountain rivers have certain qualities that distinguish them from the rivers in other regions of the country. They are characterized by large slopes in the upper sections, which leads to high flow rates and shallow depths. With the passage of rainstorms, the risk of flooding increases rapidly. The rivers transport a large amount of sediments, both bottom and suspended. Slush and bottom ice appear in winter. Mudflows are a common occurrence on the mountain rivers. In the submountain areas, changes in river channels are often observed. All of the factors above make water intake extremely complicated (Khapkova, 2013; Verbitskaya and Romansky, 2016). Therefore, water intake in the submountain areas is carried out from underground sources whenever possible.

Typology of Water Intake Facilities

For supplying water to small settlements and industrial enterprises on small rivers with an unstable open water flow, in the presence of an underflow, a combined water intake can be used. This type of water intake uses both open-flow and underflow intake (Arykova and Zholayev, 1961; Kaganov, 1981). Due to the structural complexity of water intake facilities, as well as the fact that water supply usually requires large volumes of water, the most expedient solution is the integrated use of the mountain rivers, which simultaneously satisfies the needs of water supply, hydraulic power engineering, and irrigation. With sufficient depths and water flow rates in the river, and in cases when no more than 25–30% of water is withdrawn, shore water intakes are arranged with bottom water intake, combined with first-stage pumps, with the introduction of sedimentation tanks into the structures for preliminary clarification (Figure 1). In the slush-bearing foothill areas, it is possible to use bucket water intakes and water intakes with the side discharge of water from the river by open canals.

The use of shore water intake facilities with bottom water intake, combined with first-stage pumps and the introduction of sedimentation tanks into the structure for preliminary clarification, is widespread in Western Siberia. The Tom River is one such example (Figure 2). The source of the Tom River is located in Khakassia, on the western slopes of the Abakan ridge. The water supply network on the Tom River was originally represented by the excavation of gravel-pebble deposits along the shore and a shore-type water intake. Later on, it was modernized via transition to bucket water intake. Its construction and operation served as the basis for substantiating the project of an infiltration gallery (Polad-Zade, 1964).

In the submountain areas, it is common for infiltration water intake facilities to use the underflow and groundwater (Gartsman et al., 2009; Vehvilainen, 1994). These facilities allow the river water to be pre-filtered through the soil of the river bank or the river bottom, as opposed to flowing directly from the river (Figure 3).

Infiltration water intake facilities (vertical wells, horizontal coastal and underflow drains and galleries) are quite widespread. Krasnoyarsk, Abakan, Kyzyl, Ulan-Ude, Bolshekamensk, Bikin, Suchan, and many other Siberian and Far Eastern towns and cities are supplied with drinking water exclusively from the underground runoff of channel sediments (Abilov, 2008; Akhmedov et al., Patent).

The use of water intake is expedient when the thickness of the aquifer is low. This excludes the possibility of using the groundwater reserves for covering seasonal water shortages.

The technical and economic efficiency of this invention is determined by an increase in the reliability of water intake, without reducing productivity, even if the gallery's entire section is flooded with groundwater, and if the water level in the well drops to a level that does not ensure the normal operation of the pump.

For insufficient river depths and insufficient water supply during certain periods, as well as when more than 25–30% of water is withdrawn, water intake facilities use diversion weirs. They have weir sills, undersluices, undersluice pockets, sand traps, gravel traps, and slush ice chutes installed in their water intake segments (Figure 4).

In the mountain areas with high and medium elevation, bottom lattice water intakes with sediment-intercepting and water intake galleries, which are also placed on the weir sills, are the most common. They allow for collecting water at shallow depths.

River intakes are used in the foothill areas of large rivers, and sometimes in the upland areas, provided that there is a stable channel with water depths, which, under minimal conditions and with slush ice run, are sufficient for water intake (Figure 5).

Water intake follows two main schemes: bottom water intake (using submerged water inlets) and surface water intake (using water intake buckets or side water discharge with an open canal).

On large rivers with bottom water intake, shore-type water intakes are used, combined with first-stage pumping stations. They are similar to water intakes used on the lowland rivers but include sedimentation tanks. There are river intake structures in the form of open canals that extend from the river at an angle to its axis, without any regulating structures or devices to wash off sedimentation.

The disadvantages of these structures include the following: a discrepancy between the amounts of water entering the canal, on the one hand, and con-

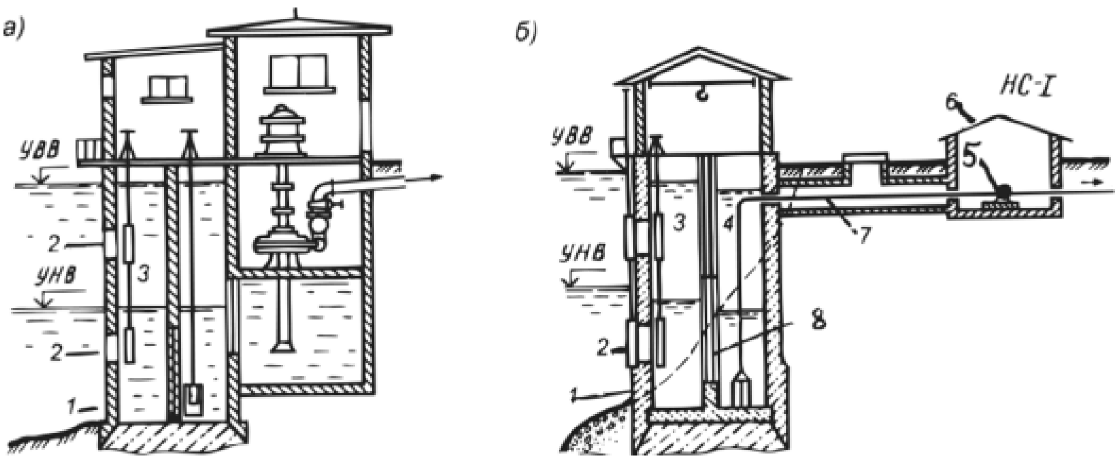

Figure 1. Water intake facilities with bottom water intake (a – combined with a pumping station; b – of a separate type; 1 – water intake well; 2 – entrance windows; 3, 4 – receiving and suction chambers, respectively; 5 – grids; 6 – suction lift pipelines; 7 – pumps; 8 – pumping station)

Figure 2. Water intake facility on the Tom River

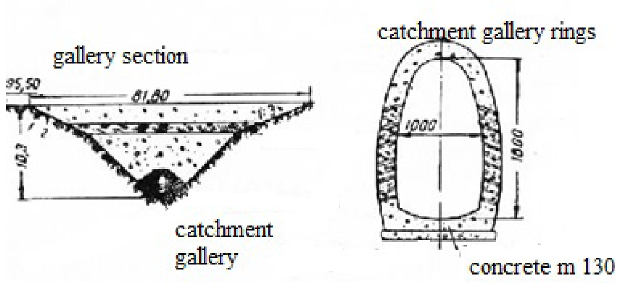

Figure 3. Infiltration water intake facility

Figure 4. Water intake with diversion weirs at the Bureya hydroelectric power plant (https://fishki.net/2603030-sejchas-stroitsja-v-rossii-post-nomer-19-nizhne-burejskaja-gjes.html)

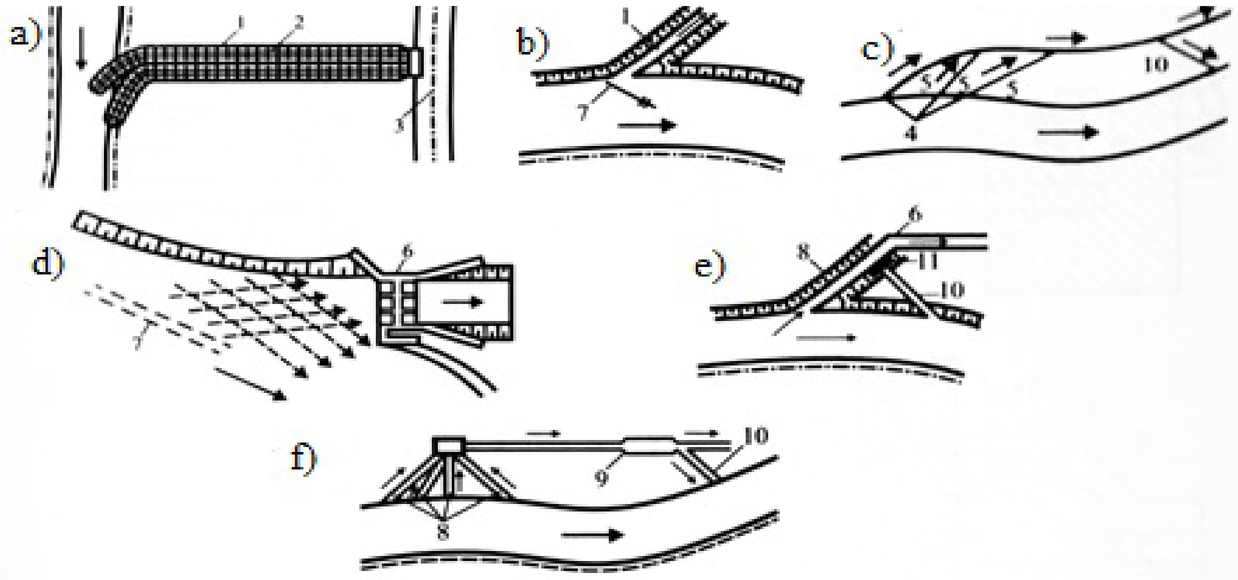

Figure 5. Main types of river intakes (a, b – water intakes with open canals without regulator sluices; c – multi-head water intake; d – water intake with a regulator sluice in the canal head; e – water intake with ditches and a regulator sluice, operating remotely from the river bed; f – multi-head water intake with ditches, regulator sluices, and sedimentation tanks: 1 – canal; 2 – weirs; 3 – water intake with a first-stage pumping station; 4 – canal heads; 5 – cofferdams; 6 – regulator sluices; 7 – stream-directing systems, designed by M. V. Potapov; 8 – ditches; 9 – sedimentation tanks; 10 – discharge canals; 11 – discharge canal sluices)

sumption rates, on the other hand; canal flooding; the ingress of a large amount of bottom sediments both into the water intake and further into the main canals, which leads to forced water supply disruptions; and the high operating costs of cleaning and repairing water intake facilities.

On rivers with shallow depths and a large quantity of slush, it is common to set up shore water intakes with a developed water intake front line (low, but with wide openings). They are often combined with a longitudinal gallery or transverse drain to capture underflow waters.

In the foothill areas of rivers with high slush content, abundant sediments, and depth levels that are insufficient for water intake, the use of buckets is widespread. The buckets may be completely buried in the bank or partially extended into the channel, with an upstream or downstream water inlet.

Water Intakes on the Mountain and Submountain Rivers: Their Features, Advantages, and Disadvantages

Bottom lattice water intakes are the most widespread type of water intakes on the mountain and high-mountain river reaches carrying large amounts of sediments of coarse fractions. It is a sill that blocks the channel and rises above the bottom of the river. A water intake gallery is cut into it and covered from above by the lattice. Water passes through the lattice and enters the inclined water intake gallery, through which it flows into a chamber with a washing device. Then, it is discharged through a canal, tunnel, or pipeline to a sedimentation tank or directly to the consumer. It is recommended to use bottom lattice water intake facilities on rivers with a slope of 0.02 and sandy bottom sediments in the flow of up to 6 mm in size, in the amount below 25% of the total volume of sediments. The length of the lattice is set to be approximately equal to the width of the river bed during the low-water period. The specific consumption of the withdrawn water is 0.08–0.5 m^3/s per 1 meter of the lattice.

Water intakes on the mountain rivers are represented by a variety of structures, all with their own advantages and disadvantages. The results of reviewing those are summarized in Table 1.

Table 1. Types of water intakes, their advantages and disadvantages

Type of water intake facility	Features	Advantages	Disadvantages
Water intake facility with bottom water intake	Integrated use of the mountain rivers, which simultaneously meets the needs of water supply, hydraulic power engineering, and irrigation	Used for supplying water with low rates, withdrawn from rivers that have high banks, making it difficult or even impossible to make an open canal in earth cuts	Depth of location, characterized by the formation of large amounts of sediments
Infiltration water intake facility	River water does not come directly from the river and is instead pre-filtered through the soil of the river bank or bottom	Under favorable hydrogeological conditions and provided that water quality is sufficiently good, the water can be used without additional purification	The expediency of water intake depends on the width of the floodplain and the capacity of the filtering soils
Water intake facilities with diversion weirs	The water intake segments feature sills, undersluices, undersluice pockets, sand traps, gravel traps, and slush ice chutes	They can be used in the case of insufficient river depths and insufficient water supply during certain periods, as well as when more than 25–30% of water is withdrawn	Rapid sediment clogging, possible breakdown of multiple structures
Bottom lattice water intake facilities with sediment-intercepting and water intake galleries	Water intake occurs from a certain depth, through a lattice at the water intake inlet	Used for both one-side and two-side water supply. The water intake section can occupy the spillway front entirely or in part	Such systems carry a large amount of stream and suspended sediments, which are discharged into sedimentation tanks. Sediment accumulation
River intake systems	The water comes from the river at the natural water level	The systems usually take up to 20% of the river discharge and are constructed on stable concave river banks to reduce the flow of sediment into the canals. This is the most environmentally friendly type	Discrepancy between the amounts of water entering the canal, on the one hand, and consumption rates, on the other hand; canal flooding; the ingress of a large amount of bottom sediments both into the water intake and further into the main canals, which leads to forced water supply disruptions; and the high operating costs of cleaning and repairing water intake facilities

The water intake facilities considered in this paper are typical of the Russian Far East.

In summer, cyclones come to the territory of the Amur River basin, bringing heavy rains. As a result, floods occur on rivers. During the emergency situation in August 2020, water consumption increased due to the high level of water filling the reservoir at the Bureya hydroelectric power plant. On August 17, 2020, the upstream level at the Bureya hydroelectric power plant reached 254.00 m (whereas the normal headwater level at the plant is 256 m). At 08:00 a.m., the inflow to the dam site was 4010 m^3/s. Today, up-to-date observation data on the Roshydromet network and forecast meteorological data come from the Internet resources of the Far Eastern Regional Research Hydrometeorological Institute and SKM Market Predictor. The former provides observation and forecast data obtained using the WRF mesoscale atmospheric model (Babkin, 2019), the latter provides forecast data from the ECMWF (European Centre for Medium-Range Weather Forecasts, 2016), adapted for the Russian Federation, as part of the Nonlinear Automatic Forecast Calibration (NAFC) project. Data from both sources are received by the 41st meteorological station located near the catchments of the Zeya and Bureya reservoirs and within their territory. After data collection and their initial check for gross errors, the data are placed in the corresponding database tables and formatted as files to be loaded into the flow formation model (Motovilov et al., 2017).

The system works in automatic mode, requesting data from the relevant sources every day according to a certain schedule. A key feature of the system used is that all incoming data, including forecast data, for all days get stored, allowing for verifications and quality checks of the forecasts received.

Hydrological forecasts are checked with the use of data on the actual daily water inflow to the Bureya reservoir, posted on the website of PJSC RusHydro.

The observation results are presented in Table 2.

Table 2. Bureya HPP data for August 2020 under flood conditions

Date of measurement	Average water inflow, m^3/s	Water level in the reservoir, m	Flow through the dam, m^3/s
August 17, 2020	4,010	254.00	2,300 ± 300
August 20, 2020	8,955	254.66	5,870
August 25, 2020	7,300	237.39	6,100
September 9, 2020	3,195	256.04	3,200 ± 300
September 11, 2020	3,075	256.03	2,300 ± 300

For comparison, Table 3 presents the Bureya HPP data for August 2016 (at that time the plant was operating in normal mode).

Table 3. Bureya HPP data for August 2016

Date of measurement	Average water inflow, m^3/s	Water level in the reservoir, m	Flow through the dam, m^3/s
August 14, 2016	2,620	252.43	2,250 ± 300
August 19, 2016	3,860	252.66	5,000 ± 400
August 29, 2016	3,295	252.02	3,200 ± 300
September 10, 2016	3,078	252.00	2,850 ± 300
September 15, 2016	2,890	252.00	-

The Bureya hydroelectric power plant has a dam-type water intake system. According to the observation results, under flood conditions on the Bureya River, a sharp increase in the average water inflow was observed between August 17, 2020, and August 25, 2020. The river regime changed due to heavy rainfall. The river runoff increased for a number of reasons: more abundant precipitation on the windward mountain slopes; less intense evaporation due to the lower temperature; precipitation reaches the river faster and along a shorter path due to the large surface slopes. This explains the sharp increase/decrease in the average inflow over such a short time (Borsch et al., 2016; Gartsman and Gubareva, 2007; Silverthorn et al., 2018a).

Observations of the hydroelectric power plants' average water inflow for the same periods in 2018 and 2020 are presented in the diagram in Figure 6.

The diagram shows a two-fold increase in the average water inflow at the end of August in 2020 as

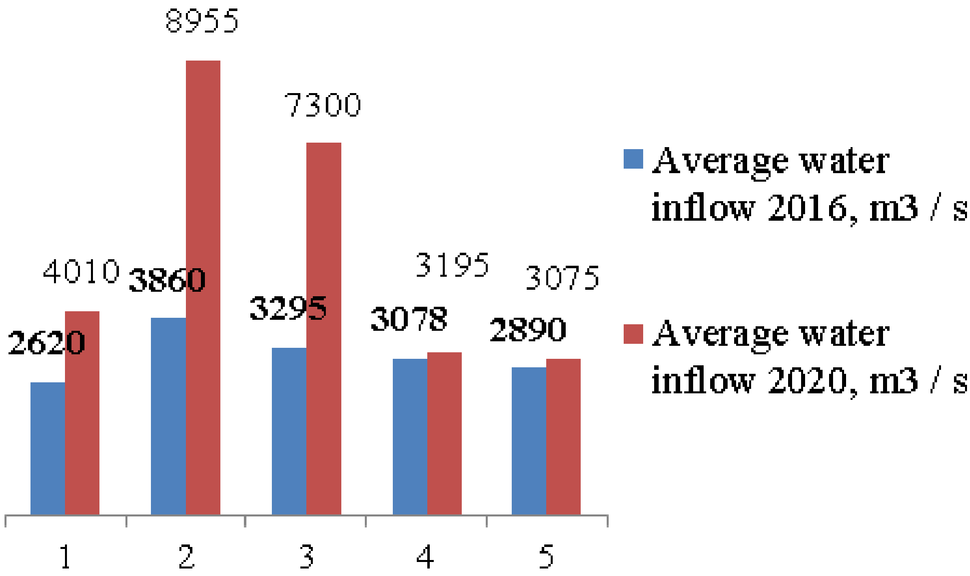

Figure 6. Diagram of hydroelectric power plants' average water inflow, by years (where 1–5 is the number of measurements)

compared to 2018. Further study of flood situations in the catchment area of the mountain rivers of this type will help to prevent emergencies in the Russian Far Eastern climate.

A study was performed to examine the water intake of the Bureya River in conditions when the reservoir was filled with large quantities of water. Research shows that the mountain rivers are characterized by fluctuating runoff not only throughout the year but also throughout the day. Sterile spills at the Bureya hydroelectric power plant began on August 17. For three days, an average of 7,900 cubic meters per second arrived in the reservoir every day. The maximum inflow was 9,010, while 5,870 cubic meters passed through the hydroelectric power plant. During the flood period, the plant's reservoir retained more than 600 million tons of water. On August 20, the upstream level rose to 254.66 m (whereas the normal headwater level is 256 m).

The catchments of the mountain and submountain areas shape the idea of hydrological control over the mountain rivers. This study identifies the main types of water intake facilities that are used in the Russian Far East, along with their features, advantages, and disadvantages.

As part of the study, we considered the water intake structure at the Bureya hydroelectric power plant.

Our insights will allow for predicting the inflow of water into the Bureya reservoir and drawing attention to the long-term dependence between emergencies and the capacity of the reservoir. This paper will help to study changes in the average water inflow over the years, which, in turn, will facilitate an accurate and detailed description of the water inflow characteristics in the Bureya reservoir when planning the water-energy modes of the hydroelectric power plant.

Conclusion

The paper discussed the main types of water intake structures on the mountain and submountain rivers, identified their disadvantages and the specifics of taking water from sources of this type. The catchments in the mountain and submountain areas shape the idea of hydrological control over the mountain rivers. In this study, we identified the main types of water supply networks structures that are used in the Russian Far East. This paper is the initial stage of assessing the accuracy and detail level of the water inflow descriptions in the Bureya reservoir when planning the water-energy operation modes of the hydroelectric power plant.

References

Abilov, R. S. (2008). *Development of a rational design of a water intake facility for mountain rivers and its study*. PhD Thesis in Engineering. Baku.

Abilov, R. S. (2015). Water intake for mountain rivers. *Scientific Journal of Russian Scientific Research Institute of Land Improvement Problems*, No. 3 (19), pp. 150–158.

Akhmedov, B. A. M. and Mamedov, N. M. (1990). *Water intake structure for mountain rivers*. Patent No. SU1544881A2.

Akhmedov, V. M., Muslimov, A. M. and Abilov, R. S. *Water intake facility.* Patent No. 980064.

Altunin, S. T. (1964). *Water intake facilities and water reservoirs*. Moscow: Kolos, 429 p.

Armstrong, L. E. and Johnson, E. C. (2018). Water intake, water balance, and the elusive daily water requirement. *Nutrients*, Vol. 10, Issue 12, pp. 19–28. DOI: 10.3390/nu10121928.

Artamonov, K. F. and Kroshkin, A. N. (1972). Issues of hydrotechnical classification of channel sections and hydrometry of mountain rivers. In: *Morphology of river channels and their modeling*. Leningrad: Gidrometeoizdat, pp. 18–23.

Artamonov, K. F. and Satarkulov S. S. (1972). Water intake facility combined with a bypass structure. *Issues of Water Management (Hydraulic Engineering)*, Issue 21, pp. 50–54.

Arykova, A. I. and Zholayev, R. Zh. (1961). *Improved type of water intake with a bottom lattice gallery*. Alma-Ata: Academy of Sciences of the Kazakh SSR, 82 p.

Babkin, A. S. (2019). *Water intake structure for receiving water from mountain and foothill rivers for small HPP*. Patent No. RU2694189C2.

Babkin, A. S., Atabiev, I. Zh., Bukreev, V. P. and Bakhtin B. M. (2018). Improvement of the design of underflow intake facility in mountain and submountain rivers. *Environmental Engineering*, No. 5, pp. 36–41. DOI: 10.26897/1997–6011/2018–5–36–41.

Bashirov, F. B. (1986). *Water intake facilities on mountain rivers*. Moscow, 46 p.

Bochkaryov, Ya. V. (1969). *Hydraulic automation of mountain water intake facilities.* Frunze: Kyrgyzstan, 185 p.

Bochkaryov, Ya. V. and Lugovoi, A. S. (1971). Water distribution and metering in the canals of the foothill zone using water outlets/flow stabilizers (VSR-1). *Proceedings of Skryabin Kyrgyz Agricultural Institute. Engineering Series*, Issue 16, Vol. 4, pp. 21–24.

Borsch, S. V., Burakov, D. A. and Simonov, Y. A. (2016). Technique of operational computation and forecast of daily river inflow into Zea river reservoir. *Proceedings of the Hydrometeorological Research Center of the Russian Federation*, Vol. 359, pp. 106–127.

Brandt, M. J., Johnson, K. M., Elphinston, A. J. and Ratnayaka, D. D. (2016). Intakes. In: Brandt, M. J., Johnson, K. M., Elphinston, A. J. and Ratnayaka, D. D. (eds). *Twort's Water Supply.* 7th edition. Butterworth-Heinemann, pp. 205–233. DOI: 10.1016/B978–0–08–100025–0.00006–5.

Bukhartsev, V. N. and Lavrov, N. P. (2015). *River hydraulic structures. Intake and diversion waterworks: a study guide*. Saint Petersburg: St. Petersburg Polytechnic University, 112 p.

Chattopadhyay, P. (2006). *Flowmeters & flow measurement*. New Delhi: Asian Books Private Limited, 452 p.

Chavtorayev, A. I. (1958). *Lightweight water intake facilities on mountain rivers*. Moscow: Selkhozgiz, 127 p.

Daneliya, N. F. (1964). *Water intake facilities on rivers with abundant bottom sediments*. Moscow: Kolos, 336 p.

Daneliya, N. F., Bunyatyan, L. B. and Bulgak, Yu. Yu. (1960). Headworks in the mountain and submountain areas of the Transcaucasia rivers. *Proceedings of the All-Union Scientific and Technical Meeting on Water Intake Facilities and Channel Processes*, Vol. 1, pp. 119–128.

European Centre for Medium-Range Weather Forecasts (2016). *ECMWF IFS CY41r2 High-Resolution Operational Forecasts. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory.* DOI: 10.5065/D68050ZV.

Filonchikov, A. V. (1990). *Design of automated water intake facilities on mountain rivers*. Frunze: Kyrgyzstan, 376 p.

Garcez-Restrepo, C., Vermillion, D. and Muñoz, D. (2007). *Irrigation management transfer. Worldwide efforts and results.* Rome: Food and Agriculture Organization of the United Nations, 62 p.

Gartsman, B. I. and Gubareva, T. S. (2007). Forecast of the rainfall flood hydrograph on the Far East rivers. *Russian Meteorology and Hydrology*, Vol. 32, No. 5, pp. 328–335.

Gartsman, B. I., Gubareva, T. S., Bugaets, A. N. and Makagonova, M. A. (2009). Short-term forecast of water inflow into the reservoir of the Bureya HPP. *Gidrotekhnicheskoe Stroitel'stvo*, No. 1, pp. 11–20.

Hobbs, B. F., Stakhiv, E. Z. and Grayman, W. M. (1989). Impact evaluation procedures: theory, practice, and needs. *Journal of Water Resources Planning and Management*, Vol. 115, Issue 1, pp. 2–21. DOI: 10.1061/(ASCE)0733-9496(1989)115:1(2).

Kadiresan, K. and Khanal, P. R. (2018). Rethinking irrigation for global food security. *Irrigation and Drainage*, Vol. 67, Issue 1, pp. 8–11. DOI: 10.1002/ird.2219.

Kaganov, Ya. I. (1970). On the qualitative similarity of the laws of variation in the flow characteristics in the downstream of hydraulic structures. *Proceedings of Central Asian Research Institute of Irrigation (SANIIRI)*, Issue 120, p. 273.

Kaganov, Ya. I. (1979). *Hydrogeology and flow regulation.* 2nd edition. Moscow: Kolos, 384 p.

Kaganov, Ya. I. (1981). *Channel reshaping in the regulation of rivers in the mountain/foothill zone*. Lviv, 120 p.

Khapkova, M. G. (2013). *Experience of using infiltration structures in Krasnoyarsk*. [online] Available at: https://vodanews.info/wp-content/uploads/2016/10/NDT_3_5_Krskom.pdf [Date accessed: September 17, 2020].

Klovsky, A. V. and Kozlov, D. V. (2016). Recommendations on arrangement and operation of bottom circulation sills under the conditions of damless water intake from small mountain rivers of III group. *Environmental Engineering*, No. 1, pp. 38–43.

Kroshkin, A. N. (1980). *Guidelines for the design of means to stabilize the channel process at low-dam water intake from the rivers of the mountain-foothill zone*. Frunze: Soyuzavtomatika, 82 p.

Levi, I. I. (1967). *Simulation of hydraulic phenomena.* Leningrad: Energiya, 235 p.

Loginov, G. I. (2014). *Hydraulic processes in water intake from small mountain rivers.* 2nd edition. Bishkek: Publishing House of Kyrgyz-Russian Slavic University, 196 p.

Luo, F., Ma, W., Sun, C., Tian, M. and Zhou Y. (2017). Analysis of the performance of government investment and interventions to promote small-scale irrigation works in China's major grain-producing areas-based on the two-step model of Malmquist-FGLS. *Irrigation and Drainage,* Vol. 66, Issue 3, pp. 293–304. DOI: 10.1002/ird.2109.

Ma, Y., Chang, J., Guo, A., Wu, L., Yang, J. and Chen, L. (2020). Optimizing inter-basin water transfers from multiple sources among interconnected river basins. *Journal of Hydrology*, Vol. 590, 125461. DOI: 10.1016/j.jhydrol.2020.125461.

Mawardi, O. K. (1981). Energy storage for electric utilities. In: Manassah, J. T. (ed.) *Alternative Energy Sources.* New York: Academic Press, pp. 687–732. DOI: 10.1016/B978–0–12–467102–7.50009–X.

Melnikov, B. I. (1989). Automated water intake facility with a sediment-intercepting gallery for small mountain rivers. In: *Hydraulic automation of irrigation systems and irrigation technology. Proceedings of Kyrgyz Agricultural Institute*. Frunze, pp. 17–26.

Melnikov, B. I. (1994). Improvement of structures, methods of justifying calculations and design of structures and their hydraulic automation tools for the head sections of irrigation systems in the foothill zone. Author's Abstract of DSc Thesis in Engineering. Bishkek: KAA.

Motovilov, Y. G., Balyberdin, V. V., Gartsman, B. I., Gelfan, A. N., Moreydo, V. M. and Sokolov, O. V. (2017). A short-term forecast of the water inflow to the Bureya reservoir on the basis of ECOMAG model with the use of meteorological forecasts. *Water Sector of Russia: Problems, Technologies, Management*, No. 1, pp. 78–102.

Naumova, T. V., Kusher, A. M. and Pikalova, I. F. (2019). Improving the efficiency of operational measures on reducing the sediment capture in the irrigation system water intake. *Vestnik MGSU*, Vol. 14, Issue 9, pp. 1167–1179. DOI: 10.22227/1997–0935.2019.9.1167–1179.

Paz, A. R., Collischonn, W., Tucci, C. E. M., Clarke, R. T. and Allasia, D. (2007). Data assimilation in a large-scale distributed hydrological model for medium-range flow forecasts. *Quantification and Reduction of Predictive Uncertainty for Sustainable Water Resources Management (Proceedings of Symposium HS2004 at IUGG2007, Perugia, July 2007). IAHS Publ. 313*, pp. 471–478.

Polad-Zade, A. (1964). *Water intake facilities on mountain rivers*. Baku: Azerneshr, 103 p.

Popov, K. V. (1956). *Hydraulic structures.* Moscow: Selkhozgiz, 438 p.

Renault, D., Facon, T. and Wahaj, R. (2007). *Modernizing irrigation management – the MASSCOTE approach.* Rome: Food and Agriculture Organization of the United Nations, 207 p.

Rokhman, A. I. (1983). *Hydraulic research and development of automatic gates for mountain water intake facilities on small mountain rivers*. Author's Abstract of PhD Thesis in Engineering. Moscow: MGMI.

Rumyantsev, I. S. and Matseya, V. F. (1988). *Hydraulic structures*. Moscow: Agropromizdat, 430 p.

Semyonov, S. V. (1950). *Dam water intakes on mountain rivers and their improvement.* Author's Abstract of PhD Thesis in Engineering. Frunze.

Silverthorn, V. M., Bishop, C. A., Elliott, J. E. and Morrissey, C. A. (2018a). An assessment of run-of-river hydroelectric dams on mountain stream ecosystems using the American dipper as an avian indicator. *Ecological Indicators*, Vol. 93, pp. 942–951. DOI: 10.1016/j.ecolind.2018.05.086.

Silverthorn, V. M., Bishop, C. A., Jardine, T., Elliott, J. E. and Morrissey, C. A. (2018a). Impact of flow diversion by run-of-river dams on American dipper diet and mercury exposure. *Environmental Toxicology and Chemistry*, Vol. 37, Issue 2, pp. 411–426. DOI: 10.1002/etc.3961.

Sobolin, G. V. and Rudakov, I. K. (1964). *Mountain lattice water intake facilities*. Frunze: KirgINTI, 143 p.

Sobol, S. V., Sobol, I. S. and Yezhkov, A. N. (2016). *Fundamentals of energy construction: a study guide*. Nizhny Novgorod: Nizhny Novgorod State University of Architecture and Civil Engineering, 160 p.

Vehvilainen, B. (1994). The watershed simulation and forecasting system in the National Board of Water and the Environment. *Publications of the Water and Environment Research Institute*, No. 17, pp. 3–16.

Verbitskaya, Ye. M. and Romansky, S. O. (2016). Results of testing short-term real-time forecasts of the mesoscale model WRF-ARW “KhAB-15” in the localities of the Far East Region of Russia. In: Alekseyeva, A. A. (ed.) *Results of testing new and improved technologies, models and methods of hydrometeorological forecasts*, No. 43, pp. 32–62. Moscow, Obninsk: IG-Sotsin.

Wałęga, A., Malik, N., Radecki-Pawlik, A. and Plesiński, K. (2019). The cyclical nature of hydrological regime of a mountain and upland river in the upper Vistula catchment in the multi-year period of 1984–2012: A potential tool for paleohydrology analysis. *Quaternary International*, Vol. 504, pp. 195–201. DOI: 10.1016/j.quaint.2018.01.025.

Water intake structure for mountain sections of rivers (1963). *Proceedings of the Academy of Sciences of the Kyrgyz SSR*, Vol. 5, Issue 3, pp. 53–58.

Western Caspian Basin Water Management Board (2020). *Plan of the integrated use and protection of water bodies in the Terek River basin (Russian part of the basin)*. [online] Available at: http://zkbvu.ru/documents/skiovo_terek_ru.php [Date accessed: October 17, 2020].

Surface water resources of the USSR (1973). Vol. 8. North Caucasus. Leningrad: Gidrometeoizdat.

DOI: 10.23968/2500-0055-2021-6-4-34-41

SCHEDULING WORK UNDER INTEGRATED URBAN DEVELOPMENT USING THE METHOD OF UNCERTAIN RESOURCE COEFFICIENTS

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Abstract

Introduction: Planning integrated development of a residential area involves determining the composition of the objects to be built and creating an appropriate integration mechanism, backed up by a generalized work schedule. The existing methods of forming integrated work schedules do not use a systemic approach, based on a universal mathematical model, to describe the organizational and technological aspects of construction. **Methods:** The present study uses the method of uncertain resource coefficients to demonstrate a mechanism for systemically describing organizational and technological construction processes. We present a way of adapting this method to forming a generalized construction schedule during integrated development. The proposed adaptation mechanism is based on managing schedule calculations by rationally influencing the elements of the linear equation system that describes the organizational and technological processes. **Results and Discussion:** The solutions presented in the paper are fully consistent with the calculations obtained by different flow methods of organizing construction, as well as with the critical path method used in project management programs. The method described in the paper has been implemented in well-known project management software, *Microsoft Project,* as a macro program in the *Visual Basic for Applications* programming language, making it possible to form, calculate, and optimize a schedule for integrated territory development using the unified software toolkit.

Keywords

Calendar construction scheduling, organizational and technological construction plan, temporal collisions of calendar schedules, admissible work scheduling, project management software.

Introduction

The fundamentals and main principles underpinning the integrated development of residential areas are reflected in the Urban Planning Code of the Russian Federation (Garant, 2021) and can be listed as follows:

- The aim of developing urban areas is to ensure favorable and comfortable living and use.
- Urban planning activities must consider all factors: economic, environmental, man-made, and social.
- The government is responsible for providing the population with favorable living conditions.

Article 65 of the Urban Planning Code, “Types of Integrated Urban Development”, can serve as the framework for implementing the principles presented.

A large number of scientific works have been published on the topic of integrated urban development. We shall not aspire to comprehensively cover the entirety of integrated development research, presenting instead a brief overview. Babenko (2013) studied general issues and prospects of implementing the concept of integrated urban development in large Russian cities. In turn, Lychkovsky and Sayenko (2017) provided specific data on the ratio of residential spaces to the total size of infrastructure and amenities required for creating essential comfortable living conditions. In this regard, it should be noted that the make-up of construction projects is defined as early as during initial planning, which points to the need for considering the future building contractors’ specialization and requires their hierarchical integration. Public-private partnerships would be the most rational framework for such integration (Voronina and Fentisova, 2016).

A rational consequence of using any integration mechanism is the development of a generalized work schedule that helps synchronize the construction of various facilities as part of integrated urban development. This kind of consolidated work scheduling has been referred to with various terms at different times and for different reasons: integrated consolidated construction schedules, generalized network models, multi-projects, etc. The name change has its own background, but that subject is more relevant to historiographic studies. In this paper, it would be more appropriate to consider how to make generalized (integrated) work scheduling calculations.

The formation of work schedules can be based on different aspects of construction organization. For instance, it can focus on lean construction (Petrochenko, 2018) or on accelerated construction (Leach, 2010). We focus on obtaining such an integrated development schedule that would ensure the synchronization of construction tasks, subject to a systemic description of the organizational and technological plan under various time constraints.

The calculation of integrated work scheduling is a consistent attribute of project management software. As an example, we can cite such well-known software products as *Primavera* (Bovteyev and Tsvetkov, 2008) and *Microsoft Project* (Kupershtein, 2010). Further in the study, we will use the capabilities of *Microsoft Project*, since it allows for addressing special tasks relevant to work scheduling in the *Visual Basic for Applications* programming language. The calculation of work scheduling in this software and its counterparts is based on the critical path method. The result of calculating the overall schedule is obtained through step-by-step sorting of all preceding tasks and events affecting the time characteristics of subsequent tasks.

Here it should be noted that such step-by-step calculation can be significantly complicated by the fairly high likelihood of various time conflicts or collisions. This can be explained by the fact that planning the development of a given site cluster may be accompanied by multiple resource and time constraints. However, because sequential calculation is embedded in project management software, each iteration performed at each step is accompanied by a message that it will be impossible to complete the given task at the given time due to scheduling conflicts. Next, *Microsoft Project* and similar software offer the following recommendations:

- to change the type of constraints;
- to remove the ties between conflicting tasks;
- to make the tasks shorter;
- to change the dates related to work scheduling.

If the task is complex, then all of the recommendations above apply to the simple subtasks therein. In other words, unpredictable time conflicts arise during the calculation of an integrated schedule, and the step-by-step elimination of time conflicts makes the calculation much more labor-intensive and creates various hidden errors.

Network planning methods are not the only basis for designing calendar schedules in construction. Flow methods of construction organization are also used in global construction practice. They can have different names in different studies (El-Rayes and Moselhi, 1998; Selinger, 1980). Flow-type organization of integrated urban development, geared for application in the Russian Federation, was described by Chelnokova (2016). She also emphasized the need to determine a rational sequence of projects in integrated urban development (Chelnokova, 2015). To implement the process of finding an optimal sequence, various algorithms are used, mainly based on the principle of targeted option sorting (Hejducki and Rogalska, 2011; Rogalska et al., 2008).

Yet if an optimal solution is being searched through targeted sorting (Chelnokova, 2015; Hejducki and Rogalska, 2011; Rogalska et al., 2008), a situation may occur where it will become impossible to actually complete development under the criterion selected. This happens because the purely mathematical search for an optimal construction sequence overlooks the possible spatial constraints affecting facility commissioning. For example, a facility may be fully built, but its commissioning may be hindered by the construction of other facilities. This collision is quite predictable when *BIM* modeling is used to visualize the cluster development process (Bolotin and Dadar, 2020; Bolotin et al., 2019). However, in this case, construction sequence optimization is needed, based not on the targeted sorting principle as outlined in (Chelnokova, 2015; Hejducki and Rogalska, 2011; Rogalska et al., 2008), but on the principle of exhaustive sorting of all options, in the form of macro software (Bolotin et al., 2011). This can be explained as follows: if previously obtained optimal options need to be scrapped, the exhaustive sorting principle will always offer some other backup options.

Our analysis exposes the causes of ineffective planning under integrated urban development, which directly depend on the non-systemic approach to calculating the overall construction scheduling. Thus, there is a need to develop a new approach to eliminating time conflicts, based on replacing step-by-step iterations with a systemic definition and analysis of calculation procedures.

Methods

The approach that we propose is related to using the method of uncertain resource coefficients, which was described in a number of works, e.g. by Bolotin et al. (2005). Let us consider its essence. During the initial stage of calculating the total duration of construction, the assumption is that each of the work tasks is performed within the minimum possible time t_{min}, and thus that the labor resources are at their maximum, R_{max}.

$$t = t_{min} + a \cdot t_{min}, \tag{1}$$

where a is the unknown resource coefficient; its introduction allows for determining the addition to minimum duration, defined as a linear dependence.

The functional relationship between the resource coefficient and the value of unknown resources R is defined by the following equation:

$$a = (R_{max}/R)\text{-}1. \quad (2)$$

If we assume for the duration of individual work tasks to be minimal, the total estimated construction duration will also equal the minimum value, T_{min}. This gives us a reference point for assigning the corresponding directive duration of construction T_d, which should have a larger value. As a result, the $T_d - T_{min}$ difference will have a positive value. This difference represents the time reserve that can be used to increase the duration of individual tasks or to minimize the initially assigned resources. According to Bolotin et al. (2005), if the duration of all types of work is represented in accordance with Eqs. (1) and (2), minimizing the labor resources will be equivalent to maximizing the sum total of work duration.

In order to explain how to adapt the uncertain resource coefficient method to the task at hand, let us consider one case study of integrated urban development. Figure 1 shows the corresponding organizational and technological plan.

The integrated urban development comprises 9 buildings. They include: 4 panel buildings designed as permanent residences, 2 brick buildings (hostels) designed as temporary residences, and 3 buildings with educational functions, including a school, a kindergarten (day care), and a youth art center. For facilities of this kind, it is not too difficult to determine the minimum work duration because there are corresponding recommended values defined by the construction duration norms (Repository for legal documents, standards, regulations, and specifications, 2021).

In Figure 1, each rectangle is labeled with the individual task's name, as well as task duration in weeks. The durations of all the work tasks (in weeks), calculated using the critical path method, are shown under respective rectangles. All panel buildings are integrated into a single construction flow, with a specified order of construction for each building. The calculations show that the last building of the given flow can be commissioned into operation 177 weeks after the start of construction. The brick hostel buildings form a separate construction flow; these are to be completed within 99 weeks. The third construction flow includes the educational buildings, all of which will be completed by the 135th week. That said, there are two types of time constraints imposed on this flow: work must start not earlier than within 1 year (52 weeks) and end not later than in 3 years (156 weeks). As a result, the estimated final construction deadline for the above urban cluster

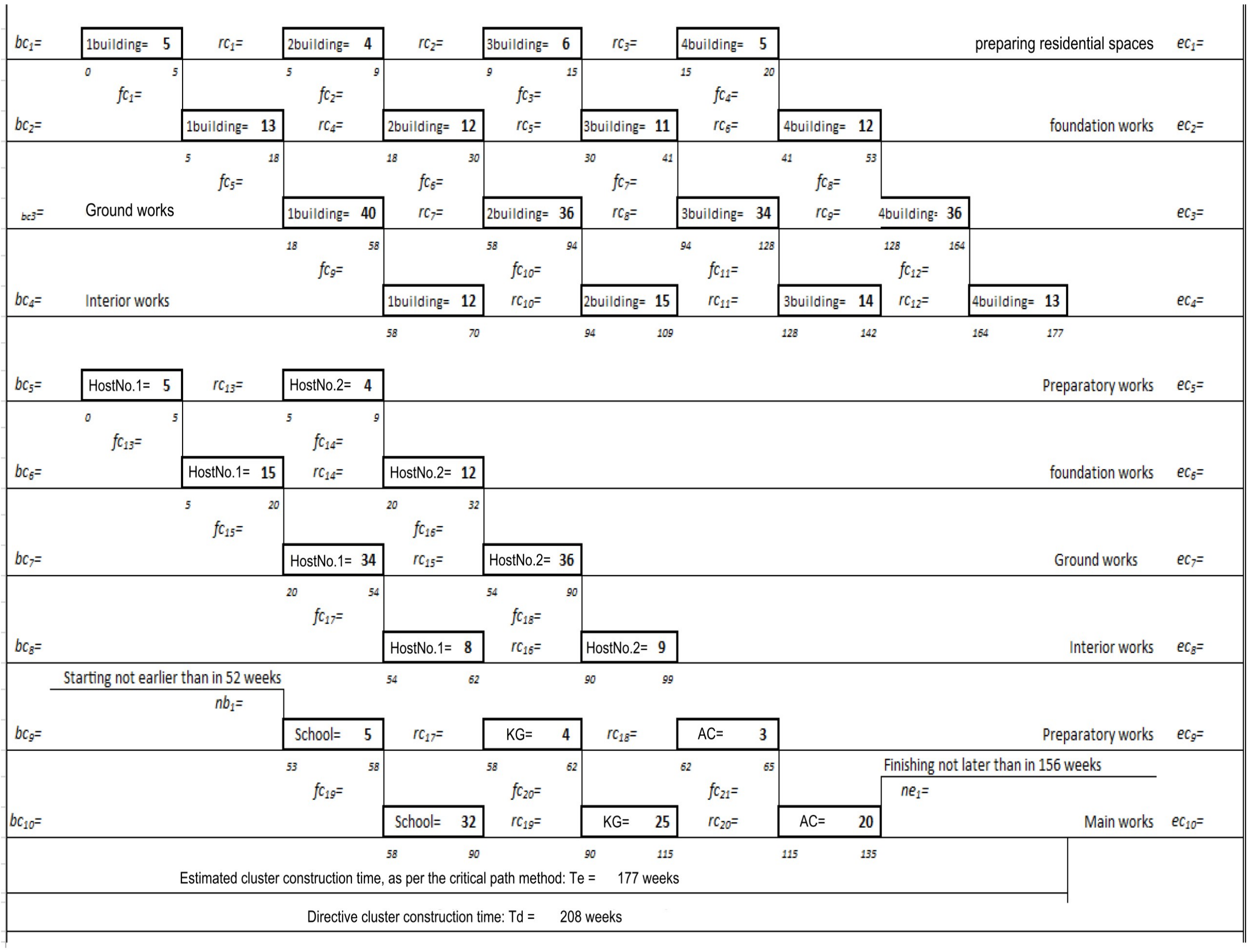

Figure 1. Case study for an organizational and technological plan of integrated urban development

is 177 weeks. However, the official schedule set by the administrative authorities is limited to 4 years, or 208 weeks.

As per the method of uncertain resource coefficients, any organizational and technological plan can be described with a system of linear equations. The composition of variables included in the system of equations is illustrated in Figure 1. Related tasks of the same type have resource connections denoted as rc_k. The total number of such connections for the organizational and technological plan in question is 20. The related tasks determining the technological sequence for the execution of different work task types are linked with frontal connections denoted as fc_j. Their total number in this particular case is 21. The variables determining task duration from the overall project beginning to the completion of initial tasks of each type are defined as beginning connections: bc_i. The variables determining task duration from the completion of the final tasks of each type to the overall project end are defined as end connection: ec_i. The total number of both types of connections is equal to the total number of work types, i.e. 10. The same number of variables defines the unknown resource coefficients found via Eq. (2).

The timing for each of the tasks included in the total work schedule can be limited. The “starting not earlier than” restriction type is defined by the relevant date, whereas the difference between this date and the unknown beginning of work execution is defined by a variable designated as nb_l. The “finishing not earlier than” restriction type is also defined by the relevant date, whereas the difference between this date and the unknown end of work execution is defined by a variable designated as ne_l. The plan shown in Figure 1 includes one example of each such restriction type. This brings the total number of variables shown in Figure 1 to 73.

The equations describing the organizational and technological plan are classified into three groups. The first group of equations includes resource equations, comprising tasks of one type. Let us present two examples of resource equations.

$$bc_1 + 20a_1 + rc_1 + rc_2 + rc_3 + ec_1 = 188. \quad (3)$$

$$bc_2 + 48a_2 + rc_4 + rc_5 + rc_6 + ec_2 = 160. \quad (4)$$

The plan presented in Figure 1 is ultimately described by 10 resource equations.

As noted above, the technological sequence determining the order of the first and second work types at each of the sites is defined by a respective frontal connection. Therefore, a frontal equation is composed for each such connection. Two equation examples are shown below.

$$bc_1 + 5a_1 + fc_1 + 48a_2 + rc_4 + rc_5 + rc_6 + ec_2 = 157. \quad (5)$$

$$bc_1 + 9a_1 + rc_1 + fc_2 + 35a_2 + rc_5 + rc_6 + ec_2 = 164. \quad (6)$$

The plan shown in Figure 1 is described by 12 frontal equations for the group of residential buildings, 6 equations for the group of hostels, and 3 equations for the group of educational institutions. Overall, we have 21 frontal equations.

The third group limits the time for the execution of individual tasks and is therefore defined as a group of restricted equations. This group is represented by two equations.

$$nb_1 + 12a_9 + rc_{17} + rc_{18} + ec_9 = 144. \quad (7)$$

$$bc_{10} + 77a_{10} + rc_{19} + rc_{20} + ne_2 = 79. \quad (8)$$

As a result, the organizational and technological plan shown in Figure 1 is described by 33 equations that include 73 variables. The ultimate system of equations, formed as described above, perfectly identifies the organizational and technological plan of integrated urban development.

In linear programming, a system of equations of this kind is called a simplex (Bunday, 1989), and its optimized solution has two stages. The first stage involves searching for a feasible basic solution via forming an artificial target function. As noted in (Bunday, 1989), the assumption is that the order of introducing variables into the feasible basic solution does not matter for most problems solved using the linear programming method. However, it is possible to demonstrate that for the problem we have set, the order of variable input defines the flow organization method for construction works (Afanasyev, 1990).

The second stage involves forming an optimization solution for the system of linear equations, which can be focused on minimizing labor resources. This is achieved with the following target function:

$$Z = 20a_1 + 48a_2 + 146a_3 + 54a_4 + 9a_5 + 27a_6 + 70a_7 + 17a_8 + 12a_9 + 77a_{10} \rightarrow max\,. \quad (9)$$

This target function defines the maximization of the total duration for all work tasks included in integrated urban development. In the case study presented, the estimated duration is 177 weeks, whereas the corresponding directive duration is 208 weeks. This determines the time reserve necessary to minimize 10 types of resources.

Let us presents calculations for the maximum number of options using the principle of exhaustive sorting of all construction sequence options. It can be determined by multiplying the number of options for each of the distinguished flows. The first flow includes 4 facilities, which gives 4!=24 rearrangement options, while the second flow has 2 rearrangement options, and the third flow has 6 rearrangement options. Thus, we obtain 288 development options, and this number determines the limit of computational complexity regarding this problem.

Results and Discussion

If all resource connections in the initial simplex matrix are moved to the end, then it becomes possible to obtain the solution for the system of equations with zero values of resource connections, by searching for the next basic variable with a forced return to the beginning. This solution is shown in Figure 2.

Figure 2 shows the values of basic variables that determine the duration of corresponding connections. The number of basic variables is equal to the number of equations. If (Figure 2) a corresponding variable is missing after the equation sign, it means that the given variable is free, and its value is, by definition, zero. This option of solving the problem shows that all resource connections have turned out to be free variables. This means that the feasible basic solution is equivalent to the method of calculating construction flow organization during continuous resource usage. The calculation also shows that, in order to fully complete building the given cluster, construction activities can be launched at later dates of event occurrence. This occurs because the beginning connections are entered into the basis first, followed by the end connections. If you change the order of input, you can get the solution for earlier dates of event occurrence.

After assessing the obtained work schedule, we can conclude that it is inexpedient to form generalized scheduling in accordance with the principle of continuous resource usage. In fact, large breaks between adjacent tasks in the technological work sequence are quite typical of this type of scheduling. For example, the completion of preparatory works for the fourth building should be followed by a 21-week break, which is found unacceptable in real-life construction.

In the proposed method, eliminating such shortcomings takes just a change in the order of introducing variables into the basis. If the variables modeling the frontal connections are placed at the end of the simplex matrix, this will yield a solution with zero values of frontal connections (Figure 3). In addition, the end connections could be moved to the top position in the simplex, bringing the problem solution closer

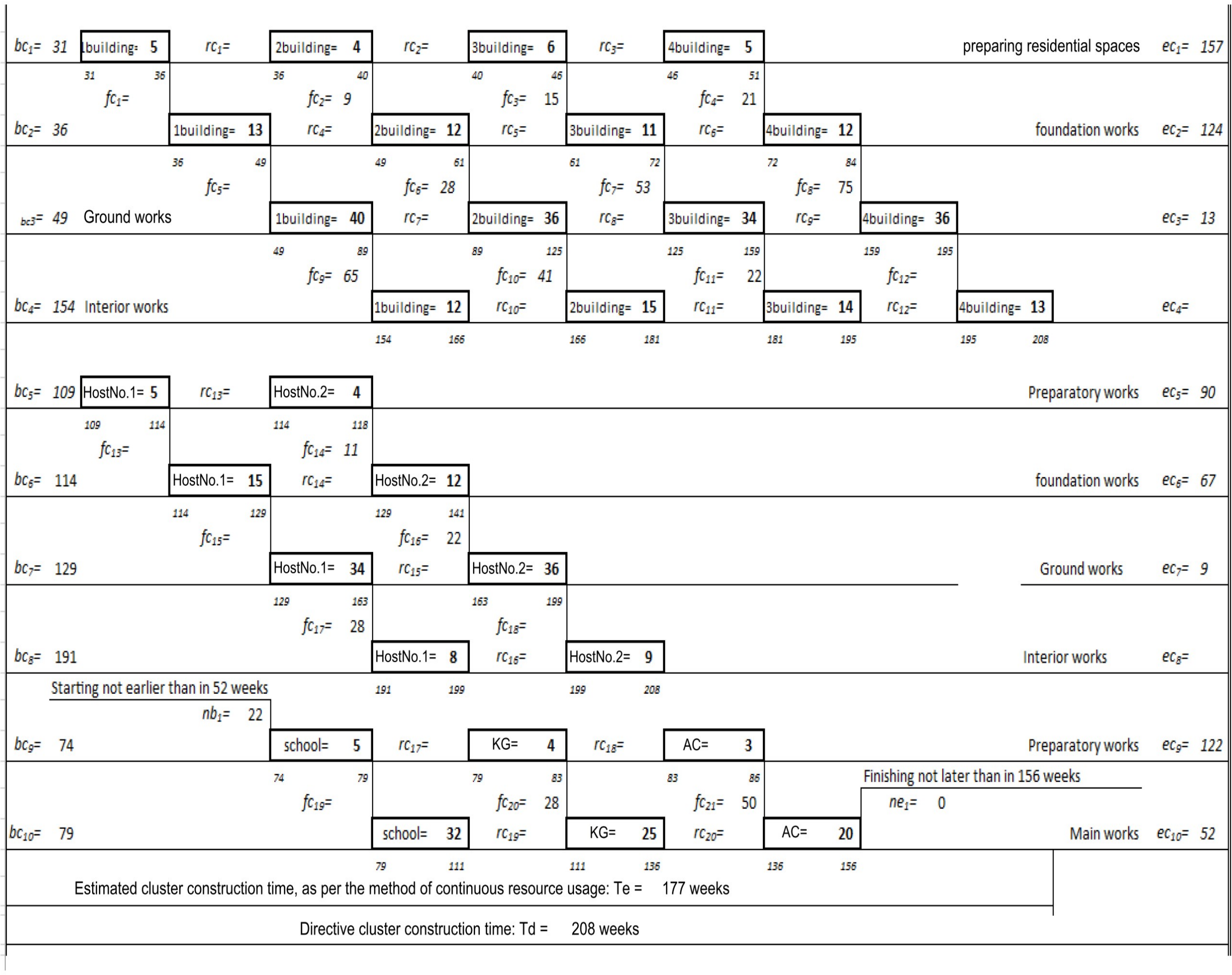

Figure 2. Calculating the schedule of integrated urban development when resource usage is continuous

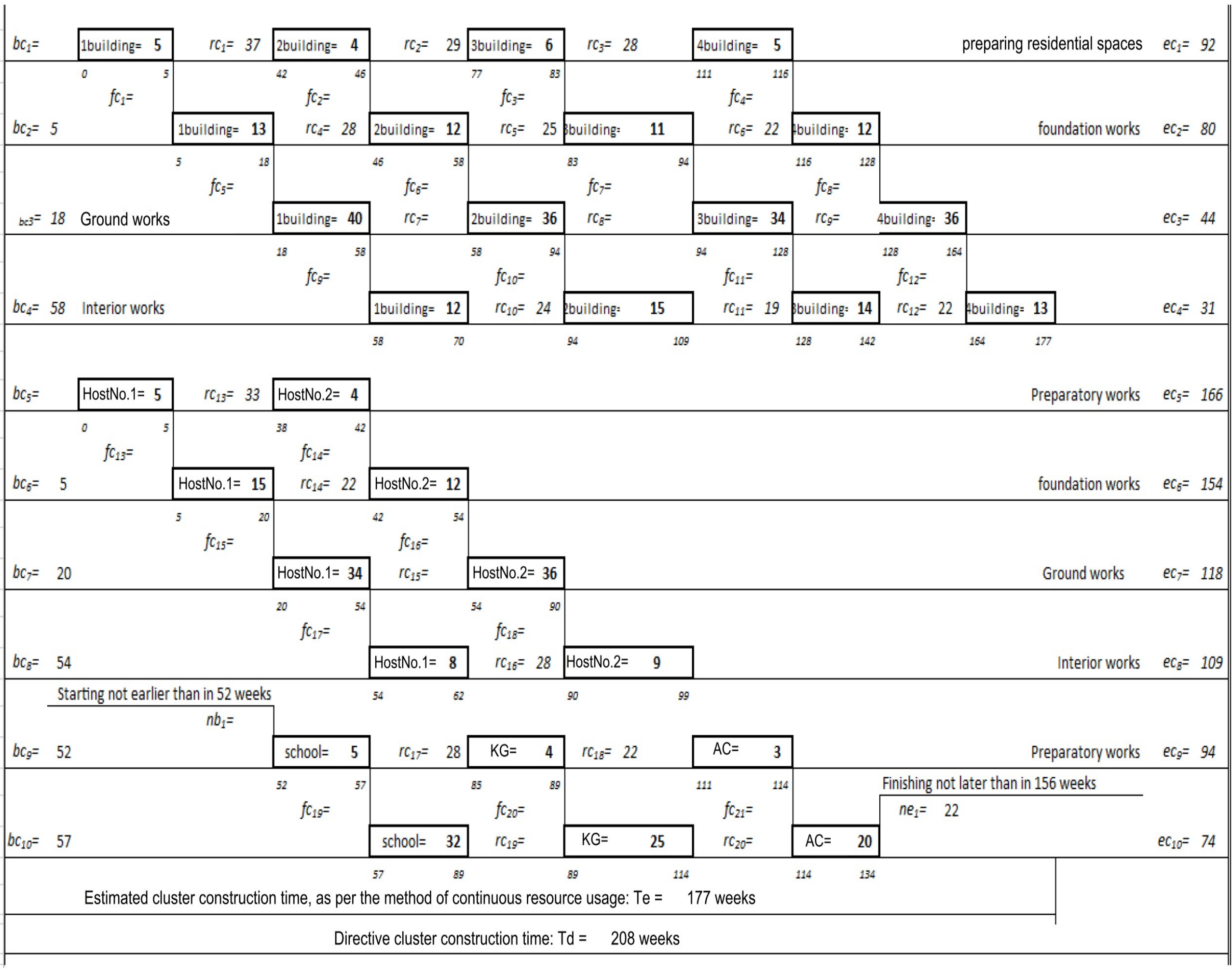

Figure 3. Calculating the schedule of integrated urban development for the case study territory with the use of the method of uncertain resource coefficients, provided that the work scope is continuously expanding

to calculating earlier dates of event occurrence.

As can be seen from Figure 3, the solution obtained fully corresponds to the calculation of construction flow organization, using the method with a continuous expansion of work scope, as described in a number of monographs (Afanasyev, 1990; Hejducki and Rogalska, 2011). In addition to the solution options reviewed, it is possible to obtain an alternative solution, which corresponds to the traditional use of the critical path method.

Moreover, it is possible to obtain an admissible solution in cases when the number of basic variables is lower than the number of equations. This situation reflects the inconsistency of the resulting equation system, due to the aforementioned time collision. The following procedure has been developed and implemented in order to address this collision. In the equation that lacks the basic variable, it is necessary to change all signs to the opposite. Then the standard algorithm for finding the basic solution needs to be re-applied to the new system of equations. The resulting solution will be a basic solution, albeit not admissible because the basic variables will have negative values. Negative values can be included in time lags when connections are formed between those work tasks that can partially be completed simultaneously. If the work conditions allow, it is also possible to increase the maximum amount of labor resources so that the negative time reserve reaches zero. Other options, found through transforming the system of equations describing integrated urban development scheduling, are also viable.

Conclusion

This study is aimed at adapting the method of uncertain resource coefficients to form generalized construction schedules for integrated urban development. The proposed adaptation mechanism is based on managing work scheduling calculations through a rational impact on the elements of the linear equation system describing the organizational and technological plan of construction activities.

References

Afanasyev, V. A. (1990). *Construction workflow.* Moscow: Stroyizdat, 302 p.

Babenko, S. V. (2013). Problems and prospects of implementing complex development concept in capital cities of Russia. *Journal of Legal and Economic Studies*, No. 2, pp. 137–140.

Bolotin, S. A., Biche-ool, Kh. V. and Dadar, A.-K. Kh. (2019). Scheduling visualization methodology in Autodesk Revit 2018. *Bulletin of Civil Engineers*, No. 6 (77), pp. 179–185. DOI: 10.23968/1999–5571–2019–16–6–179–185.

Bolotin S. A. and Dadar, A. H. (2020). Methodology of setting priorities in integrated development of territories using BIM software and project management. *Real Estate: Economics, Management*, No. 1, pp. 57–62.

Bolotin, S. A., Dadar, A. Kh., Meshchaninov, I. Yu. and Oolakaj, Z. Kh. (2011). Energy and resource saving objects' reconstruction sequence elimination with the regard for heterogenous limitations for the search for optimum. *Bulletin of Civil Engineers*, No. 3(28), pp. 60–65.

Bolotin, S. A., Klimov, S. E. and Simankina, T. L. (2005). Optimization of resource distribution under calendar scheduling using the method of uncertain resource coefficients. *Scientific Herald of the Voronezh State University of Architecture and Civil Engineering. Construction and Architecture*, No. 1, p. 101.

Bovteyev, S. V. and Tsvetkov, A. V. (eds.) (2008). *Managing investment construction projects on the basis of Primavera.* Moscow, Saint Petersburg: PMSOFT, Saint Petersburg State University of Architecture and Civil Engineering, 455 p.

Bunday, B. (1989). *Basic linear programming*. Moscow: Radio i Svyaz, 176 p.

Chelnokova, V. M. (2015). Determination of rational priority of project construction in calendar planning of complex development of the territory. *Bulletin of Civil Engineers*, No. 2 (49), pp. 102–106.

Chelnokova, V. M. (2016). Features of calendar scheduling of complex development of the territory by the development organization. *Bulletin of Civil Engineers*, No. 3 (56), pp. 136–142.

El-Rayes, K. and Moselhi, O. (1998). Resource-driven scheduling of repetitive activities. *Construction Management and Economics*, Vol. 16, Issue 4, pp. 433–446. DOI: 10.1080/014461998372213.

Hejducki, Z. and Rogalska, M. (2011). *Time coupling methods construction scheduling and time/cost optimization.* Wroclav: Oficyna Wydawnicza Politechniki Wroclawskiej, 91 p.

Kupershtein, V. I. (2010). *Microsoft Project 2010 in project management.* Saint Petersburg: BKhV-Peterburg, 416 p.

Leach, L. (2010). *On time and on budget. Critical chain project management.* Moscow: Alpina Publisher, 354 p.

Lychkovsky, D. A. and Sayenko, I. A. (2017). Integrated development as a priority for the development of urban areas. *Economic Development Research Journal,* No. 6, pp. 128–134.

Petrochenko, M. V. (2018). *Organization and planning in construction. Fundamentals of lean construction.* Part 1. Study guide. Saint Petersburg: Publishing House of Polytechnic University, 208 p.

Repository for legal documents, standards, regulations, and specifications (2021). *Construction Rules and Regulations SNiP 1.04.03-85. Norms of construction duration and backlog in the construction of enterprises, buildings, and structures.* [online]. Available at: http://docs.cntd.ru/document/1200000622 [Date accessed November 21, 2021].

Rogalska, M., Bożejko, W. and Hejducki, Z. (2008). Time/cost optimization using hybrid evolutionary algorithm in construction project scheduling. *Automation in Construction*, Vol. 18, pp. 24–31.

Selinger, S. (1980). Construction planning for linear projects. *Journal of the Construction Division*, Vol. 106, Issue 2, pp. 195–205.

Garant (2021). Urban Planning Code of the Russian Federation No. 190-FZ dated December 29, 2004. [online]. Available at: https://base.garant.ru/12138258/ [Date accessed November 21, 2021].

Voronina, N. V. and Fentisova, I. V. (2016). Development of public-private parthership in the complex housing development of territories. In: Kourov, V. F. (ed.) *Current Issues in the Economic Development of Enterprises, Industries, Sectors, and Territories. Proceedings of the International Research and Practice Conference. In 2 volumes. Vol. 2.* Khabarovsk: Pacific National University, pp. 33–36.

ФОРМИРОВАНИЕ РАСПИСАНИЯ РАБОТ ПРИ КОМПЛЕКСНОМ ОСВОЕНИИ ТЕРРИТОРИИ МЕТОДОМ НЕОПРЕДЕЛЕННЫХ РЕСУРСНЫХ КОЭФФИЦИЕНТОВ

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Аннотация

При планировании комплексного освоения селитебной территории определяется состав строящихся объектов, под который создается соответствующий интеграционный механизм, функционирующий на основе формирования обобщенного расписания работ. Существующие методы формирования комплексных расписаний работ не используют системный поход при описании организационно-технологической схемы строительства, базирующийся на универсальной математической модели. **Методы:** В настоящем исследовании, использующем метод неопределенных ресурсных коэффициентов, показан механизм системного описания организационно-технологической схемы строительства. Представлена адаптация этого метода к решению задачи по формированию обобщенного расписания строительства при комплексном освоении территории. Предлагаемый механизм адаптации основан на управлении расчетом расписания работ посредством рационального воздействия на элементы системы линейных уравнений, описывающих организационно-технологическую схему. **Результаты и обсуждение:** Представленные в статье решения полностью соответствует расчетам, полученным с помощью разных поточных методов организации строительства, а также используемому в программах управления проектами методу критического пути. Описанная в статье методика реализована в широко известной программе управления проектами типа *Microsoft Project* в форме программы-макроса на языке программирования *Visual Basic for Applications,* что позволяет формировать, рассчитывать и оптимизировать расписание по комплексному освоению территории с помощью единого программного инструментария.

Ключевые слова

Календарное планирование строительством, организационно-технологическая схема строительства, временные коллизии календарных графиков, допустимое расписание работ, программы управления проектами.

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APPLICATION OF ANALYTICAL SOLUTIONS FOR BENDING BEAMS IN THE METHOD OF MOVEMENT

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Abstract

Introduction: Usually, to analyze statically indeterminate rod systems, the classical displacement method and pre-prepared tables for two types of rods of the main system are used. A mathematically correct representation of local loads with the use of generalized functions makes it possible to find an accurate solution of the differential equation for the equilibrium of a beam exposed to an arbitrary transverse load. **Purpose of the study:** We aimed to obtain analytical expressions for functions of deflection, rotation angles, transverse forces, and bending moments depending on four types of local loads for beams with different boundary conditions, so as to apply accurate solutions in the displacement method. **Methods:** We propose an analytical form of the displacement method to analyze rod structural models. For beams exposed to different types of transverse load (uniformly distributed force, concentrated force, or a couple of forces), accurate analytical solutions were obtained for functions of deflection, bending moments, and transverse forces at different types of beam ends' restraint. This is possible due to the fact that concentrated load and load in the form of the moment of force can be specified by using unit column functions. By transforming Mohr's integrals, using integration by parts, we show that the system of canonical equations of the displacement method was obtained based on the Lagrange principle. **Results:** Based on the analysis of a statically indeterminate frame, the effectiveness of the proposed analytical method is shown as compared with the classical displacement method.

Keywords

Rod systems, displacement method, beam bending equation, Mohr's integral, mathematical model, work of internal forces, work of external forces, Lagrange principle.

Introduction

Rod systems (beams, frames, trusses, combined structures) are widely used in the construction of various structures (Babanov, 2011; Ignatyev, 1979; Leontyev et al., 1996). To perform stress-strain analysis of such structures, the displacement method is usually used (Ilin et al., 2005; Maslennikov, 1987; Maslennikov et al., 2020).

Currently, almost all structural calculations are performed with the use of computer technologies, which makes it possible to automate the process and ensure a quite high accuracy of the calculations (Akimov and Mozgaleva, 2014; Karpov, 2006, 2010, 2011; Kobelev, 2018).

It is not difficult to obtain an accurate solution of the differential equation for the equilibrium of a beam exposed to distributed load (Korn and Korn, 1974; Smirnov, 1967). However, obtaining an accurate solution for beams exposed to local loads mentioned above, described by delta functions, presents particular mathematical difficulties (Belostochny, 1999; Korneyev, 2011; Mikhailov, 1980). When a concentrated load is described by delta functions, it means that the load is applied to the point, and that is impossible in real practice. In the course of structural calculations for structures having various irregularities or exposed to local loads, the mathematical apparatus of the theory of generalized functions is widely used (Alyukov, 2011, 2012; Belostochny, 1999; Ilin et al., 2005; Kobelev, 2018; Kobelev and Lukashevich, 2020a, 2020b; Mikhailov, 1980; Mikhailov et al., 1990). To specify correctly the location of stiffeners reinforcing a shell, Karpov (Ilin et al., 2005) introduced special unit column functions equal to the difference between two unit functions and showed how to describe local loads applied to a small area, by using those functions. In this case, finding an accurate solution of the equation for the equilibrium of a beam exposed to local loads does not present any challenges (Belostochny, 1999; Korneyev, 2011; Mikhailov et al., 1990).

Analytical displacement method

Let us examine in detail the essence of the displacement method used to analyze statically indeterminate frames (Babanov, 2011; Ilin et al., 2005; Maslennikov, 1987; Maslennikov et al., 2020). In the analysis of frame systems, to obtain the main system of the displacement method, the following additional connections are introduced: angular connections preventing the rotation of joints in areas with no full joints, and linear connections preventing linear displacements.

After that, in the main system, unit generalized displacements (angular or linear) are specified in the direction of the introduced connections, and then, in sequence, reactions in these connections from the displacements and external load (force factors) are determined based on conformity of the main system to the specified one.

If we denote these reactions by r_{kj}, and unknown generalized displacements by Z_j. then overall reactions in the j^{th} introduced connection in the system with n unknown quantities will be equal to

$\sum_{j=1}^{n} r_{kj} Z_j + r_{kF}$, where r_{kF} is the reaction in the k^{th} connection from the external load.

In the displacement method, the sum of reactions in the additional connections from the displacement of these connections and the external load is equal to zero, i.e.:

$$\sum_{j=1}^{n} r_{kj} Z_j + r_{kF} = 0. \quad (1)$$

Here, $\sum_{j=1}^{n} r_{kj} Z_j$ is the sum of the works of internal forces on virtual displacements; r_{kF} is the sum of the works of external forces on virtual displacements.

Since reactions in additional connections act in the direction of the specified unit displacements, then the work of internal forces on these displacements is positive, and the work of external forces on virtual displacements, in the direction of additional connections preventing the displacement of joints of the main system, is negative. Therefore, the main system of the displacement method is based on the following: in equilibrium, the work of the rod system's internal forces on virtual displacements is equal to the work of external forces on virtual displacements, i.e. the displacement method uses the same idea as the Lagrange principle of virtual displacements.

The main system of the displacement method consists of individual rods, having uniform cross-section, of two types: rigid support – rigid support and rigid support – joint.

These rods are statically indeterminate beams, analyzed in structural mechanics by using the force method at various transverse loads, with their ends analyzed in terms of unit displacements. That is why, when performing calculations with the displacement method, pre-prepared tables are used (Maslennikov, 1987; Maslennikov et al., 2020).

However, to determine the stress-strain state of statically indeterminate beams, it is possible to find an analytical solution to the problem by integrating the differential equation of the deflection curve of the beam, using not only equilibrium equations (static relations) but geometric relations (kinematic relations) and boundary conditions as well.

Let us consider the work of various force factors on corresponding displacements. If a force factor is transverse load $q(x)$, which may be represented by distributed load, concentrated force, or the moment of a couple of forces, it does work on displacements $w(x)$, i.e. the work of the load is equal to $q(x)w(x)$.

If a force factor is bending moment $M_x = EJ_x \chi_1(x)$, then it does work on displacement $\chi_1 = -w''(x)$, which is a function of the curvature of the elastic line of the beam, i.e. the work of the moment is equal to $M_x \chi_1(x)$.

If a force factor is transverse force Q_x, then it does work on displacement, which is the angle of cross-section displacement that, due to its smallness, is replaced by tangent, i.e. the work of the transverse load is equal to $Q_x w'(x)$.

It would be logical to think that the work of the force on some displacement is always positive. However, in structural mechanics, it is believed that it can be negative if the direction of the force does not coincide with the direction of virtual displacements. Therefore, Eq. (1) takes the plus sign.

In the classical displacement method, the coefficients of the unknown quantities and the free terms of the system of canonical equations are determined based on the equilibrium of the cut-off parts of the main system, containing additional angular and linear connections. If we use the theorem of reciprocal reactions and displacements (Babanov, 2011; Maslennikov, 1987), then the coefficients of the unknown quantities in Eq. (1) can be determined by Mohr's equation:

$$r_{kj} = \sum_{s=1}^{m} \int_0^{L_s} \frac{M_k^0 M_j^0}{EJ_s} dx, \quad (2)$$

where m is the number of integration sections along the entire frame for a rod with length L_s, with constant stiffness EJ_s; M_k^0 is the bending moment in the main system of the displacement method at the section $[0, L_s]$ from the unit displacement of the k^{th} introduced connection; M_j^0 is the bending moment in the main system of the displacement method at the section $[0, L_s]$ from the unit displacement of the j^{th} introduced connection. Here, $M_j^0 = -EJ_j \varphi''_j(x)$, $M_k^0 = -EJ_k \varphi''_k(x)$. Therefore:

$$w''_j(x) = Z_j \varphi''_j(x), \; w''_k(x) = Z_k \varphi''_k(x).$$

The free terms of the system of canonical equations of the displacement method are also determined by Mohr's equation:

$$r_{kF} = -\sum_{s=1}^{m} \int_0^{L_s} \frac{M_k^0 M_F^0}{EJ_s} dx = \sum_{s=1}^{m} \int_0^{L_s} \varphi''_k(x) M_F^0 dx, \quad (3)$$

where M_F^0 is the bending moment in the main system of the displacement method at the section [$0, L_s$] from the specified load.

By substituting the moments in Eq. (2), we obtain the following:

$$r_{kj} = r_{jk} = \sum_{s=1}^{m} \int_0^{L_s} EJ_s \varphi_k''(x) \varphi_j''(x) dx, \quad (4)$$

which is the work of internal forces from the unit displacements in the direction of additional connections. Based on the theorem of reciprocal virtual works, $\varphi_k''(x) = \varphi_j''(x)$. Then:

$$r_{kj} Z_j = \sum_{s=1}^{m} \int_0^{L_s} EJ_s \phi_k''(x) \phi_j''(x) Z_j dx = \frac{\partial \Pi}{\partial Z_j},$$

where $\Pi = \frac{1}{2}\int_0^{L_s} M_x Ç_1 dx =$

$$\frac{1}{2}\int_0^{L_s} EJ_j Z_j \varphi_j''(x) \varphi_j''(x) Z_j dx.$$

Thus, $\sum_{j=1}^{n} r_{kj} Z_j$ is the sum of the works of internal forces on virtual displacements.

By transforming the integral $\int_0^{L_s} \varphi_j''(x) M_F^0 dx$ with the double integration by parts, we obtain $\int_0^{L_s} \frac{d^2 M_F^0}{dx^2} . \varphi_j(x) dx.$ Since , $\frac{d^2 M_F^0}{dx^2} = -q,$

then: $\int_0^{L_s} \varphi_j''(x) M_F^0 dx = -\int_0^{L_s} q \varphi_j(x) dx.$

Therefore:

$$r_{kF} = \frac{\partial}{\partial Z_j} \sum_{s=1}^{m} \int_0^{L_s} \left[-q Z_j \phi_j(x) \right] dx = -\sum_{s=1}^{m} \int_0^{L_s} q \phi_j(x) dx, \quad (5)$$

which is the work of external forces on finite displacements.

Thus, the system of canonical equations of the displacement method (mathematical model for the deformation of rod systems) is obtained under the following condition: in equilibrium, the work of the rod system's internal forces on finite displacements is equal to the work of external forces on finite displacements. The same principle of developing a mathematical model for the deformation of rod systems is applied when the force method is used.

In the classical form of the displacement method for the formation of a system of canonical equations, it is necessary to construct in the main system, using corresponding tables, diagrams of bending moments from the sequentially specified unit displacements in the direction of additional connections M_i^0, where $i=1,2,....n$, and a diagram of bending moments M_F^0 from the external transverse load specified in a particular way. For instance, if the concentrated load is described by delta functions, then the function of bending moments $M(x)=-EJw''(x)$ contains points where the smoothness of the function is lost and sometimes breaks of continuity occur upon differentiation. If the function $w''(x)$ is characterized by discontinuity, then $w'''(x)$ does not exist, and the function $w(x)$ does not satisfy the equation for the equilibrium of a beam in bending $EJw^{IV}=q$. The diagrams mentioned are constructed for a beam fixed at the ends in a particular way.

In the course of the study, for different types of fixing the ends of a beam exposed to transverse load (uniformly distributed force, concentrated force, or the moment of a couple of forces), accurate analytical solutions were obtained for the function of deflection $w(x)$. This is possible due to the fact that concentrated load and load in the form of the moment of force can be specified by using unit column functions. In this case, by successive integration of the equation $EJw^{IV}=q$, it is possible to find deflection in the form of the continuous differentiable function of deflection $w(x)$, having derivatives $w'(x)$, $w''(x)$, $w'''(x)$, and $w^{IV}(x)$ Besides, to determine the coefficients of the unknown quantities r_{kj} and the free terms r_{kF} of the system of canonical equations of the displacement method, there is no need to construct diagrams of bending moments M_i^0 and M_F^0 since, due to the obtained analytical expressions for $w(x)$ and $w''(x)$, the moments indicated can also be specified in the form of analytical functions considering the characteristics of the applied load.

The proposed analytical method not only simplifies the analysis of rod systems but facilitates computing programming significantly.

Let us find an analytical expression for deflection $w(x)$ bending moment M_x , and transverse force Q_x for a beam with span L_s under the following types of transverse load q:

1. Uniformly distributed along the entire length of the beam $[0, L_s]$;
2. Uniformly distributed along a part of the beam $[x_1, x_2]$;
3. Concentrated, applied to some point α_1;
4. Moment of a couple of forces.

We consider two types of fixing the beam ends: rigid support at $x=0$ and $x=L_s$; rigid support at $x=0$ and hinged support at $x=L_s$. The $w(x)$, M_x, and Q_x expressions are determined at the unit value of the load and the arbitrary value of EI, where $M_x=-EIw''(x)$, $Q_x=-EIw'''$.

If , $I = \frac{h^3}{12} b$, where b is the width of the beam, then $q\left(\frac{\text{kN}}{\text{m}}\right)$ is obtained by multiplying the load $q_1 \cdot b\left(\frac{\text{kN}}{\text{m}^2}\cdot \text{m}\right)$.

Let us find an accurate solution to the equation for the equilibrium of the beam:

$$w^{\text{IV}} = \frac{q}{EI}. \tag{6}$$

Let the load q=const be uniformly distributed along the entire length of the beam *[0, L_s]*. In this case, taking into account the boundary conditions at *x=0(w(0)=0, w'(0)=0)*, the accurate solution to Eq. (6) will be as follows:

$$w(x) = \frac{q}{EI}\frac{x^4}{24} + C_1\frac{x^3}{6} + C\frac{x^2}{2}. \tag{7}$$

The C_1 and C_2 constants can be determined based on the boundary conditions at $x=L_s$.

If, at $x=L_s$, the beam is rigidly fixed, then $w(L_s)=0$, $w'(L_s)=0$, i.e.

$$\frac{q}{EI}\frac{L_s^4}{24} + C_1\frac{L_s^3}{6} + C_2\frac{L_s^2}{2} = 0.$$

$$\frac{q}{EI}\frac{L_s^3}{6} + C_1\frac{L_s^2}{2} + C_2 L_s = 0.$$

Whence it follows that:

$$C_1 = -\frac{qL_s}{2EI}, C_2 = \frac{qL_s^2}{12EI}. \tag{8}$$

Thus, if the load q is uniformly distributed along the entire length of the beam *[0, L_s]* , and both ends of the beam are rigidly fixed, then *w(x)* will take the form of Eq. (7) with account for Eq. (8) and $q=1$. The bending moment M_x and transverse force Q_x, at the unit value of the load, will take the following form:

$$M_x = -\frac{x^2}{2} - EI(C_1 x + C_2);$$
$$Q_x = -x - EIC_1. \tag{9}$$

Let the beam have a hinged support at $x=L_s$. In this case, the boundary conditions $w(L_s)=0$, $w''(L_s)=0$, shall apply, i.e.:

$$\frac{q}{EI}\frac{L_s^4}{24} + C_1\frac{L_s^3}{6} + C_2\frac{L_s^2}{2} = 0;$$

$$\frac{q}{EI}\frac{L_s^2}{2} + C_1 L_s + C_2 = 0.$$

Whence it follows that:

$$C_1 = -\frac{5qL_s}{8EI}, C_2 = -\frac{qL_s^2}{8EI}. \tag{10}$$

Thus, if the load q is uniformly distributed along the enitre length of the beam *[0, L_s]*, at $x=0$, it is fixed rigidly, and at $x=L_s$, it has a hinged support, then the function of deflection will take the form of Eq. (7) with account for Eq. (10) and the unit value of the load. The bending moment and transverse force at the unit value of the load will take the form of Eq. (9) at C_1 *u* C_2 in the form of Eq. (10).

Let the load be uniformly distributed along a part of the beam *[x1,x2]*. In this case, $q = P\overline{\delta}(x - á_1)$

where $\overline{\delta}(x - á_1) = u(x - x_1) - u(x - x_2)$;

$u(x - x_1)$ and $u(x - x_2)$ are unit functions.

The accurate solution to Eq. (6), considering that, at *x* = 0, the beam is rigidly fixed, will be as follows:

$$w(x) = \frac{P}{EI}\left[\frac{(x-x_1)^4}{24}u(x-x_1) - \frac{(x-x_2)^4}{24}u(x-x_2)\right] + C_1\frac{x^3}{6} + C_2\frac{x^2}{2}. \tag{11}$$

Let us consider a case when, at $x = L_S$, the beam is rigidly fixed. In this case, the conditions $w(L_s)=0$, $w'(L_s)=0$ shall apply, i.e.:

$$\frac{P}{EI}\left[\frac{(L_s-x_1)^4}{24} - \frac{(L_s-x_2)^4}{24}\right] + C_1\frac{L_s^3}{6} + C_2\frac{L_s^2}{2} = 0.$$

$$\frac{P}{EI}\left[\frac{(L_s-x_1)^3}{6} - \frac{(L_s-x_2)^3}{6}\right] + C_1\frac{L_s^2}{2} + C_2 L_s = 0.$$

Whence it follows that:

$$C_1 = \frac{P}{EIL_s^2}\left[\begin{matrix}\frac{(L_s-x_1)^4}{2} - \frac{(L_s-x_2)^4}{2} - \\ L_s(L_s-x_1)^3 + L_s(L_s-x_2)^3\end{matrix}\right];$$
$$C_2 = -\frac{P}{EIL_s^2}\left[\begin{matrix}\frac{(L_s-x_1)^4}{4} - \frac{(L_s-x_2)^4}{4} - \\ \frac{L_s}{3}(L_s-x_1)^3 + \frac{L_s}{3}(L_s-x_2)^3\end{matrix}\right]. \tag{12}$$

Thus, if $q = P\overline{\delta}(x - \pm_1)$, and the ends of the beam are rigidly fixed, then the *w(x)*, M_x, and Q_x expressions, at the unit value of the load *P* and C_1, C_2 in the form of Eq. (12), will be as follows:

$$w(x)=\begin{cases} C_1\dfrac{x^3}{6}+C_2\dfrac{x^2}{2}, \text{at } 0\le x\le x_1; \\ \dfrac{(x-x_1)^4}{24EI}+C_1\dfrac{x^3}{6}+C_2\dfrac{x^2}{2}, \text{at } x_1\le x\le x_2; \\ \dfrac{1}{24EI}[(x-x_1)^4-(x-x_2)^4]+C_1\dfrac{x^3}{6}+C_2\dfrac{x^2}{2}, \text{at } x_2\le x\le L_s, \end{cases}$$

$$M_x=\begin{cases} -EI(C_1x+C_2), \text{at } 0\le x\le x_1; \\ -\dfrac{(x-x_1)^2}{2}-EI(C_1x+C_2), \text{ at } x_1\le x\le x_2; \\ -\left[\dfrac{(x-x_1)^2}{2}-\dfrac{(x-x_2)^2}{2}\right]-EI(C_1x+C_2) \text{ at } x_2\le x\le L_s, \end{cases} \tag{13}$$

$$Q_x=\begin{cases} -EIC_1, \text{at } 0\le x\le x_1; \\ -(x-x_1)-EIC_1, \text{at } x_1\le x\le x_2; \\ -[(x-x_1)-(x-x_2)]-EIC_1, \text{at } x_2\le x\le L_s. \end{cases}$$

If, at $x=L_s$, the beam has a hinged support, then the conditions $w(L_s)=0, w''(L_s)=0$ shall apply, i.e.:

$$\frac{P}{EI}\left[\frac{(L_s-x_1)^4}{24}-\frac{(L_s-x_2)^4}{24}\right]+C_1\frac{L_s^3}{6}+C_2\frac{L_s^2}{2}=0;$$

$$\frac{P}{EI}\left[\frac{(L_s-x_1)^2}{2}-\frac{(L_s-x_2)^2}{2}\right]+C_1L_s+C_2=0.$$

Whence it follows that:

$$\begin{aligned} C_1&=\frac{P}{EIL_s^2}\left[\frac{(L_s-x_1)^4}{8}-\frac{(L_s-x_2)^4}{8}-\frac{3L_s^2}{4}(L_s-x_1)^2+\frac{3L_s^2}{4}(L_s-x_2)^2\right]; \\ C_2&=-\frac{P}{EIL_s^2}\left[\frac{(L_s-x_1)^4}{8}-\frac{(L_s-x_2)^4}{8}-\frac{L_s^2}{4}(L_s-x_1)^2+\frac{L_s^2}{4}(L_s-x_2)^2\right]. \end{aligned} \tag{14}$$

In this case, the $w(x)$, M_x, and Q_x expressions, at the unit value of the load P, will take the form of Eq. (13) with account for Eq. (14).

If the load is represented by concentrated force F(kN), applied to point $x=a_1$, then

$$\begin{aligned} &q=F\delta(x-á_1)=P\overline{\delta}(x-á_1)= \\ &P(u(x-x_1)-u(x-x_2)), \end{aligned}$$

where $\delta(x\text{-}a_1)$ is a delta function; $F=Pl_1$; $l_1=x_2\text{-}x_1$ is some small quantity.

In this case, $w(x)$, M_x, and Q_x will take the form of Eq. (13) and C_1, C_2 in the form of Eq. (12) if both ends of the beam are rigidly fixed, or Eq. (14) if, at $x=0$, the beam is rigidly fixed, and at $x=L_s$, the beam has a hinged support.

When the load is represented by the moment of a couple of forces, we have the following:

$$q=-F_1\delta(x-\alpha_1)+F_1\delta(x-\alpha)_2,$$

where F_1 (kN);

$$-F_1\delta(x-\alpha_1)=-P\begin{bmatrix}u(x-x_1)- \\ u(x-x_2)\end{bmatrix};$$

$$F_1\delta(x-\alpha_2)=P\begin{bmatrix}u(x-x_3)- \\ u(x-x_4)\end{bmatrix};$$

$$x_2-x_1=l_1; x_4-x_3=l_1.$$

In this case, considering that, at $x=0$, the beam is rigidly fixed, the accurate solution to Eq. (6) will be as follows:

$$w(x)=\frac{P}{EI}\begin{bmatrix}\frac{(x-x_1)^4}{24}u(x-x_1)+\\ \frac{(x-x_2)^4}{24}u(x-x_2)+\\ \frac{(x-x_3)^4}{24}u(x-x_3)-\\ \frac{(x-x_4)^4}{24}u(x-x_4)\end{bmatrix}+C_1\frac{x^3}{6}+C_2\frac{x^2}{2}. \quad (15)$$

If, at $x=L_s$, the beam is rigidly fixed, then $w(L_s)=0,\ w'(L_s)=0$, i.e.
Whence it follows that:

$$\frac{P}{EI}\begin{bmatrix}-\frac{(L_s-x_1)^4}{24}+\frac{(L_s-x_2)^4}{24}+\\ \frac{(L_s-x_3)^4}{24}-\frac{(L_s-x_4)^4}{24}\end{bmatrix}+$$
$$C_1\frac{L_s^3}{6}+C_2\frac{L_s^2}{2}=0;$$

$$\frac{P}{EI}\begin{bmatrix}-\frac{(L_s-x_1)^3}{6}+\frac{(L_s-x_2)^2}{6}+\\ \frac{(L_s-x_3)^3}{6}-\frac{(L_s-x_4)^3}{6}\end{bmatrix}+$$
$$C_1\frac{L_s^2}{2}+C_2L_s=0.$$

Thus, under the action of the unit load represented by the moment of a couple of forces and with the ends of the beam rigidly fixed, with account for Eq. (16), we obtain the following expressions for $w(x)$, M_x, and Q_x:

$$C_1=\frac{P}{EIL_S^2}\begin{bmatrix}-\frac{(L_S-x_1)^4}{2}+\frac{(L_S-x_2)^4}{2}+\frac{(L_S-x_3)^4}{2}-\frac{(L_S-x_4)^4}{2}+\\ L_S\begin{pmatrix}(L_S-x_1)^3-(L_S-x_2)^3-\\ (L_S-x_3)^3+(L_S-x_4)^3\end{pmatrix}\end{bmatrix};$$
$$C_2=-\frac{P}{EIL_S^2}\begin{bmatrix}-\frac{(L_S-x_1)^4}{4}+\frac{(L_S-x_2)^4}{4}+\frac{(L_S-x_3)^4}{4}-\frac{(L_S-x_4)^4}{4}+\\ \frac{L_S}{3}\begin{pmatrix}(L_S-x_1)^3-(L_S-x_2)^3-\\ (L_S-x_3)^3+(L_S-x_4)^3\end{pmatrix}\end{bmatrix}. \quad (16)$$

$$w(x)=\begin{cases}C_1\frac{x^3}{6}+C_2\frac{x^2}{2},\text{at } 0\le x\le x_1;\\ -\frac{(x-x_1)^4}{24EI}+C_1\frac{x^3}{6}+C_2\frac{x^2}{2},\text{at } x_1\le x\le x_2;\\ \frac{1}{24EI}[-(x-x_1)^4+(x-x_2)^4]+C_1\frac{x^3}{6}+C_2\frac{x^2}{2},\text{at } x_2\le x\le x_3;\\ \frac{1}{24EI}[-(x-x_1)^4+(x-x_2)^4+(x-x_3)^4]+C_1\frac{x^3}{6}+C_2\frac{x^2}{2},\text{at } x_3\le x\le x_4;\\ \frac{1}{24EI}[-(x-x_1)^4+(x-x_2)^4+(x-x_3)^4-(x-x_4)^4]+C_1\frac{x^3}{6}+C_2\frac{x^2}{2},\text{at } x_3\le x\le L_s.\end{cases}$$

$$M_x=\begin{cases}-EI(C_1x+C_2),\text{at } 0\le x\le x_1;\\ \frac{(x-x_1)^2}{2}-EI(C_1x+C_2),\text{at } x_1\le x\le x_2;\\ \left[\frac{(x-x_1)^2}{2}-\frac{(x-x_2)^2}{2}\right]-EI(C_1x+C_2),\text{at } x_2\le x\le x_3;\\ \frac{(x-x_1)^2}{2}-\frac{(x-x_2)^2}{2}-\frac{(x-x_3)^2}{2}-EI(C_1x+C_2),\text{at } x_3\le x\le x_4;\\ \frac{(x-x_1)^2}{2}-\frac{(x-x_2)^2}{2}-\frac{(x-x_3)^2}{2}+\frac{(x-x_1)^2}{2}-EI(C_1x+C_2),\text{at } x_4\le x\le L_s.\end{cases} \quad (17)$$

$$Q_x=\begin{cases}-EIC_1,\text{at } 0\le x\le x_1;\\ (x-x_1)-EIC_1,\text{at } x_1\le x\le x_2;\\ [(x-x_1)-(x-x_2)]-EIC_1,\text{at } x_2\le x\le x_3;\\ (x-x_1)-(x-x_2)-(x-x_3)-EIC_1,\text{at } x_3\le x\le x_4;\\ (x-x_1)-(x-x_2)-(x-x_3)+(x-x_4)-EIC_1,\text{at } x_4\le x\le L_s.\end{cases}$$

If, at $x = L_s$, the beam has a hinged support, then the conditions $w(L_s) = 0, \quad w''(L_s) = 0$ shall apply, i.e.:

$$\frac{P}{EI}\left[-\frac{(L_s-x_1)^4}{24}+\frac{(L_s-x_2)^4}{24}+\frac{(L_s-x_3)^4}{24}-\frac{(L_s-x_4)^4}{24}\right]+C_1\frac{L_s^3}{6}+C_2\frac{L_s^2}{2}=0;$$

$$\frac{P}{EI}\left[-\frac{(L_s-x_1)^2}{2}+\frac{(L_s-x_2)^2}{2}+\frac{(L_s-x_3)^2}{2}-\frac{(L_s-x_4)^2}{2}\right]+C_1L_s+C_2=0.$$

Whence it follows that:

$$C_1=\frac{-3P}{2EIL_s^3}\left[\begin{array}{l}-\frac{L_s^2(L_s-x_1)^2}{2}+\frac{L_s^2(L_s-x_2)^2}{2}+\frac{L_s^2(L_s-x_3)^2}{2}-\frac{L_s^2(L_s-x_4)^2}{2}\\+\frac{(L_s-x_1)^4}{12}-\frac{(L_s-x_2)^4}{12}-\frac{(L_s-x_3)^4}{12}+\frac{(L_s-x_4)^4}{12}\end{array}\right]; \quad (18)$$

$$C_2=-C_1L_s-\frac{P}{EI}\left[-\frac{(L_s-x_1)^2}{2}+\frac{(L_s-x_2)^2}{2}+\frac{(L_s-x_3)^2}{2}-\frac{(L_s-x_4)^2}{2}\right].$$

In this case, $w(x)$, M_x, and $Q_{x,}$ at the unit value of the load P , with account for Eq. (18), will take the form of Eq. (17).

Results

Let us suppose we have a single-disc frame (Figure 1). At $l=6.0$ m, $F = 16kN$, and $EJ=const$, it is required to determine the functions of deflection, rotation angles, and internal forces M, Q, N.

The frame is a statically indeterminate system. Let us determine the degree of its static indeterminacy n_{st}=3K-H=3·1-2=1, where *K* is the number of closed circuits, *H* is a single hinge. The frame has a rigid joint C and is constrained. The degree of its kinematic indeterminacy is as follows: $n_k=n_j+n_l$=1+0=1, where n_j is the number of rigid joints, n_l is the number of linear connections. Therefore, the calculations using the force method and the calculations using the displacement method are characterized by the same labor intensity. At first, let us analyze the frame using the analytical method in the form of the force method.

Under the assumptions taken, deflection of joint C of the frame is equal to zero. Therefore, by neglecting the impact of longitudinal forces on rod bending and introducing a dummy support in the cross-section C , we can switch from the constrained frame to a structural model in the form of a continuous beam with span $L=2l$ (Figure 3a).

By removing the dummy support, we will replace its action on the beam with an unknown reaction X_1 and consider the obtained main system of the force method. The differential equation of the deflection curve of the beam under the action of the unknown reaction X_1 and concentrated load F will be as follows:

$$EJw^{\mathrm{IV}}(\chi)=X_1\delta_{x1}-F\delta_{a1}.$$

The required function of deflection is determined as follows:

$$EJw(\chi)=X_1\psi_1(\chi)-F\psi_a(\chi),$$

where the $\Psi_1(x)$ and $\Psi_a(x)$ functions have the following form:

$$\begin{aligned}\psi_i(x)&=D_1\frac{x^3}{3!}+D_2\frac{x^2}{2!}+\\D_3x&+D_4+\frac{(x-x_i)^3_{\lrcorner}}{EJ3!};\\\psi_a(x)&=C_1\frac{x^3}{3!}+C_2\frac{x^2}{2!}+\\C_3x&+C_4+\frac{(x-a_1)^3_{\lrcorner}}{3!}.\end{aligned} \quad (19)$$

In what follows, the

$$\lrcorner=\begin{Bmatrix}0 \text{ at } x\le x_i\\1 \text{ at } x>x_i\end{Bmatrix}$$

symbol denotes the spline function.

The $\Psi_i(x)$ function integration constants, calculated for different boundary conditions (1 – rigid support, 2 – hinged support, 3 – free edge), are given in Table 1.

Table 1. Integration constants of the function $\Psi_i(x)$

Support X=0	D_1	D_2	D_3	D_4	Support $x=l$
1	$-\frac{d_i^2}{l}\left(1+\frac{2x_i}{l}\right)$	$\frac{x_i d_i^2}{l^2}$	0	0	1
1	$\frac{3d_i}{2l}\left(1-\frac{d_i^2}{3l^2}\right)$	$\frac{d_i}{2}\left(\frac{d_i^2}{l^2}-5\right)$	0	0	2
2	$\frac{d_i^2}{2l^2}(3-d_i)$	0	$\frac{d_i^2}{4}(d_i-5)$	0	1
2	$-\frac{d_i}{l}$	0	$\frac{d_i x_i}{6l}(l+d_i)$	0	2
1	-1	x_i	0	0	3
3	0	0	$-\frac{d_i}{2}$	$\frac{d_i^2}{6}(2l+x_i)$	1

where $d_1 = l - x_i$.

The integration constants of these functions are determined based on Table 1, following boundary conditions 2-2, corresponding to hinge fixing of the beam on supports A and B, $\Psi_1 = \Psi''_1 = 0;$ $\Psi_a = \Psi''_a = 0;$ at $x=0$ and $x=L$. $D_1=-0{,}5;\ D_2=D_4=0;\ D_3=9;$

$$C_1 = -\frac{3}{4};\quad C_2 = C_4 = 0;\quad C_3 = \frac{63}{8}.$$

Then, Eq. (19) takes the following form:

$$\psi'_i(x) = -\frac{x^3}{12} + 9x + \frac{(x-6)^3_{\lrcorner}}{3!},$$

$$\psi'_a(x) = -\frac{x^3}{8} + \frac{63}{8}x + \frac{(x-3)^3_{\lrcorner}}{3!}.$$

The unknown reaction of the dummy support X_1 can be determined based on the fact that there is no defection, $W(6)=0$, by solving the following equation: $X_1\Psi_1(6)\text{-}F\Psi_a(6)=0$ Then:

$$X_1 = F\frac{\psi_a(6)}{\psi_1(6)} = 16\frac{11\cdot 27}{12\cdot 36} = 11\text{kN}.$$

By differentiating the obtained function of deflection $w(x)$ of the dummy beam, we obtain analytical expressions for the functions of rotation angles, bending moments, and transverse forces:

$$EJ\gamma(x) = EJw'(x) = 11\Psi'_1(x) - 16\Psi'_a(x) =$$

$$11\left[9 - \frac{x^2}{4} + \frac{(x-6)^2_{\lrcorner}}{2}\right] - 16\left[\begin{array}{c}\frac{3}{8}(21-x^2)+\\ \frac{(x-3)^2_{\lrcorner}}{2}\end{array}\right];$$

$$M = -EJw''(x) = 16\psi''_a(x) - 11\psi''_1(x) =$$

$$16\left[-\frac{3}{4} - (x-3)_{\lrcorner}\right] - 11\left[-\frac{x}{2} + (x-6)_{\lrcorner}\right];$$

$$Q = EJw'''(x) = 16\left[\frac{3}{4} - U(x-3)\right] -$$

$$11\left[\frac{1}{2} - U(x-6)\right].$$

Having calculated their values in the design sections at $x=0$, $x=3\pm\varepsilon$, $x=6\pm\varepsilon$, and $x=12$, where $\varepsilon\to 0$, we construct M and Q diagrams in the continuous beam (Figures 2a, 2b), which can be transferred to the frame (Figure 3). The diagram of longitudinal forces N is constructed based on the Q diagram, assuming the equilibrium of the joint C. The diagrams of internal forces, obtained using the analytical method, correspond exactly to the results of the frame analysis using the classical force method and displacement method, and are represented below in Figure 3.

Due to the use of the mathematical apparatus of

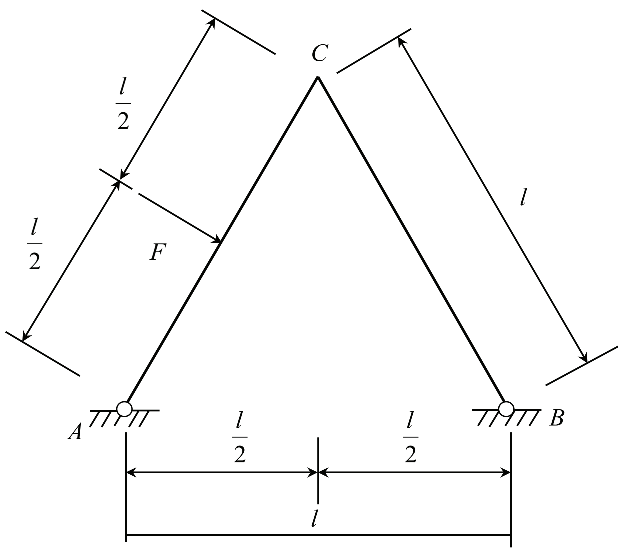

Figure 1. Single-disck frame

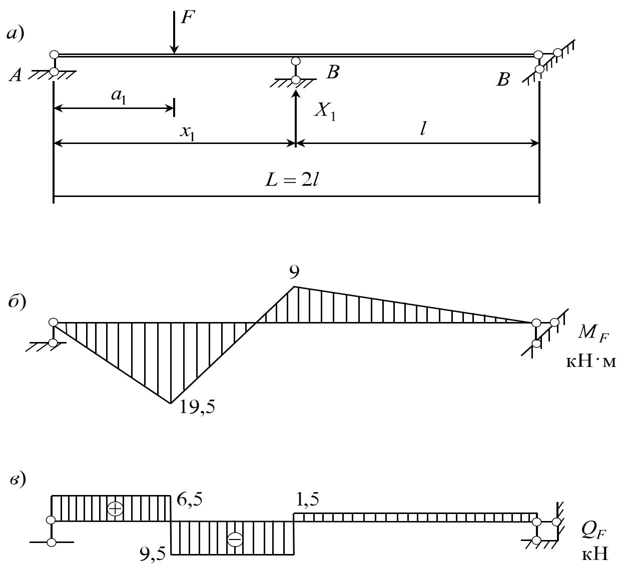

Figure 2. Structural model in the form of a continuous beam

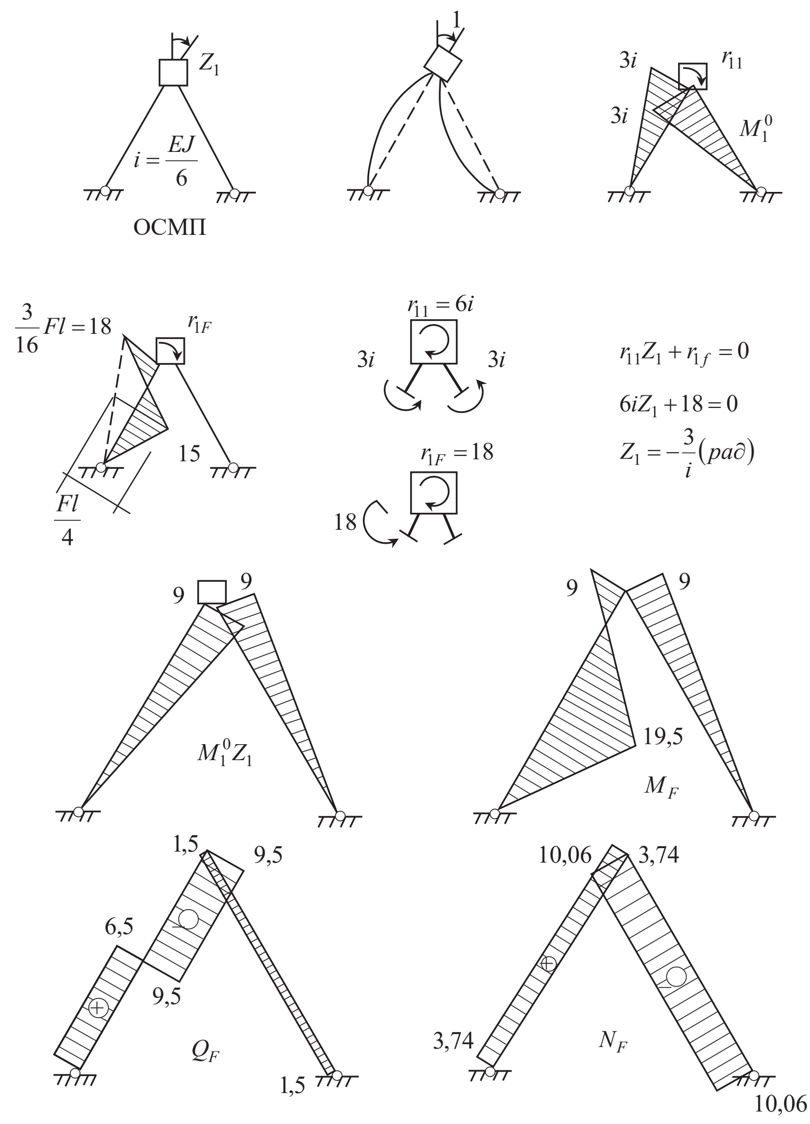

Figure 3. Diagrams of forces

generalized functions, all expressions of the required functions of deflection *w(x)*, rotation angles *w(x)*, bending moments *M(x)* , and transverse forces *Q(x)* ate obtained in the closed analytical form with no need to construct and multiply diagrams of bending moments by Mohr's equation in individual rods of the main system with the subsequent addition of the results.

Conclusions

For rod systems (beams, frames, trusses, combined structures), a mathematical model of deformation represents a system of linear algebraic equations, obtained based on the unified principle: in equilibrium, the sum of the works of internal forces on finite displacements in the structure is equal to the sum of the works of external forces on finite displacements. This principle makes it possible to apply the general approach to the analysis of statically indeterminate structural models, using the proposed analytical method unifying the classical displacement method, force method, and combined method on a single platform.

The proposed analytical method not only simplifies the analysis of statically indeterminate rod systems but facilitates significantly computing programming and analysis of the obtained results.

References

Akimov, P. A. and Mozgaleva, M. L. (2014). *Multi-level discrete and discrete-continuous for the local analysis of building structures*. Moscow: Moscow State University of Civil Engineering, 632 p.

Alyukov, S. V. (2011). Approximation of step functions in problems of mathematical modeling. *Mathematical Models and Computer Simulations*, Vol. 3, Issue 5, 661. DOI: 10.1134/S2070048211050036.

Alyukov, S. V. (2012). *Approximations of piecewise linear and generalized functions*. Germany: LAP LAMBERT Academic Publishing, 120 p.

Babanov, V. V. (2011). *Structural mechanics. In 2 volumes. Vol. 2.* Moscow: Academia Publishing Center, 288 p.

Belostochny, G. N. (1999). Analytical methods for the determination of closed path integrals of singular differential equations for the thermoelastic behavior of geometrically irregular shells. *Reports of Military Sciences Academy. No. 1. Volga Regional Office. Saratov*, pp. 14–26.

Ignatyev, V. A. (1979). *Analysis of regular statically indeterminate rod systems*. Saratov: Publishing House of Saratov University, 296 p.

Ilin, V. P., Karpov, V. V. and Maslennikov, A. M. (2005). *Numerical methods for solving structural mechanics problems. 2nd edition*. Moscow: ASV Publishing House, 426 p.

Karpov, V. V. (2006). *Mathematical modeling, model analysis algorithms, simulation experiment in the theory of shells*. Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering, 330 p.

Karpov, V. V. (2010). *Strength and stability of stiffened shells of revolution. In 2 parts. Part 1. Models and algorithms for the analysis of strength and stability of stiffened shells of revolution*. Moscow: Fizmatlit, 288 p.

Karpov, V. V. (2011). *Strength and stability of stiffened shells of revolution. In 2 parts. Part 2. Simulation experiment under static mechanical action.* Moscow: Fizmatlit, 248 p.

Kobelev, E. A. (2018). Method of variation approximations in the theory of nonlinear deformation of irregular spatial systems. *Bulletin of Civil Engineers*, No, 6 (71), pp. 30–36. DOI: 10.23968/1999–5571–2018–15–6–30–36.

Kobelev, E. A. and Lukashevich, N. K. (2020a). Solving the problem of unilateral contact of the slab with the strengthening beams by the method of variational approximations. *IOP Conference Series: Materials Science and Engineering*, Vol. 953, 012089. DOI: 10.1088/1757–899X/953/1/012089.

Kobelev, E. A. and Lukashevich, N. K. (2020b). Solving the contact problem when strengthening the slab with a beam using discontinuous functions. *IOP Conference Series: Materials Science and Engineering*, Vol. 962, 022046. DOI: 10.1088/1757-899X/962/2/022046.

Korn, G. and Korn, T. (1974). *Mathematical handbook (for scientists and engineers).* Moscow: Nauka, 831 p.

Korneyev, S. A. (2011). *Technical rod theory. Use of generalized functions to solve problems related to the strength of materials.* Omsk: Omsk State Technical University, 82 p.

Leontyev, N. N., Sobolev, D. N. and Amosov, A. A. (1996). *Fundamentals of structural mechanics of rod systems.* Moscow: ASV Publishing House, 541 p.

Maslennikov, A. M. (1987). *Structural analysis with numerical methods.* Leningrad: Publishing House of Leningrad State University, 224 p.

Maslennikov, A. M., Kobelev, E. A. and Maslennikov, N. A. (2020). *Fundamentals of structural mechanics of rod systems: study guide.* Saint Petersburg: Petropolis Publishing House, 342 p.

Mikhailov, B. K. (1980). *Plates and shells with discontinuous parameters.* Leningrad: Publishing House of Leningrad State University, 196 p.

Mikhailov, B. K., Kobelev, E. A. and Gayanov, F. F. (1990). *Structural analysis with the use of generalized functions.* Leningrad: Leningrad Civil Engineering and Construction Institute, 99 p.

Smirnov, V. I. (1967). *A course of higher mathematics. Vol. 2.* Moscow: Nauka, 655 p.

Zolotov, A. B., Akimov, P. A., Sidorov, V. N. and Mozgaleva, M. L. (2008). *Mathematical methods in structural mechanics (with fundamentals of the generalized function theory).* Moscow: ASV Publishing House, 336 p.

ПРИМЕНЕНИЕ АНАЛИТИЧЕСКИХ РЕШЕНИЙ ДЛЯ ИЗГИБА БАЛОК В МЕТОДЕ ПЕРЕМЕЩЕНИЙ

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Аннотация

Для расчета статически неопределимых стержневых систем обычно используют классический метод перемещений и заранее подготовленные таблицы для двух типов стержней основной системы. Математически корректное представление локальных нагрузок с помощью обобщенных функций позволяет найти точное решение дифференциального уравнения равновесия балки от воздействия произвольной поперечной нагрузки. **Целью работы** было получение аналитических выражений для функций прогибов, углов поворотов, поперечных усилий и изгибающих моментов от четырех видов локальных нагрузок для балок с различными краевыми условиями, чтобы затем использовать точные решения в методе перемещений. **Методы:** Предлагается аналитический вариант метода перемещений для расчета стержневых расчетных схем. Для балок, находящихся под действием различных видов поперечной нагрузки (равномерно-распределенной, сосредоточенной силы и пары сил), получены точные аналитические решения для функций прогибов, изгибающих моментов и поперечных сил при различных типах закрепления концов балки. Это удается сделать потому, что сосредоточенную нагрузку и нагрузку в виде момента силы можно задавать с помощью единичных столбчатых функций. Путем преобразования интегралов Мора методом интегрирования по частям показано, что система канонических уравнений метода перемещений получена на основе принципа Лагранжа. **Результаты:** На примере расчета статически неопределимой рамы показана эффективность предлагаемого аналитического метода по сравнению с классическим методом перемещений.

Ключевые слова

Стержневые конструкции, метод перемещений, уравнение изгиба балки, интеграл Мора, математическая модель, работа внутренних сил, работа внешних сил, принцип Лагранжа.

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AERODYNAMIC STABILITY OF BRIDGES WITH VARIOUS LEVELS OF STRUCTURAL DAMPING

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Abstract
Introduction: Structural damping is one of the most important parameters affecting the aerodynamic stability of bridge structures. **Purpose of the study:** We aimed to assess the effect that structural damping of a bridge structure has on its stability in a wind current. **Methods:** In the course of the study, we performed experimental studies of the aerodynamic stability in typical girder bridge structures (with two and four main girders) with different levels of structural damping, facilitated by a unique experimental unit: Large Research Gradient Wind Tunnel, courtesy of the National Research Moscow State University of Civil Engineering (NRU MGSU). **Results:** The results of the experimental studies show that, despite the general trend towards the decrease in the amplitude of bridge span structure oscillations as the structural damping level increases, the dependence between these parameters is nonlinear. When providing R&D support in the design of real-life structures, in case it is necessary to increase the aerodynamic stability of the superstructure by increasing the level of structural damping (changing the type of joints in structural elements, using mechanical damping devices), it is recommended to conduct experimental studies in wind tunnels to assess the effectiveness of a given solution.

Keywords
Bridge structure, structural damping, wind tunnel, experimental studies, sectional model.

Introduction

In the modern world, experimental studies of the aerodynamic stability of large-span bridge structures are an integral part of bridge design. It is very difficult to overestimate the importance of such studies, given the number of accidents involving bridge structures that occurred due to wind impact (Bas and Catbas, 2021; Maystrenko et al., 2017; Tan et al., 2020). In the Russian Federation, testing in wind tunnels is regulated by the following standards: Regulations SP 35.13330.2011 “Bridges and Culverts” and Regulations SP 296.1325800.2017 “Buildings and Structures. Accidental Actions”. The main methods for conducting such studies are full-scale modeling (Argentini et al., 2020; Miyata et al., 1992), studies with sectional models (Cermak, 2003; Diana et al., 2013; Reinhold et al., 1992), as well as numerical modeling in specialized software systems (Ageev et al., 2021; Diana and Omarini, 2020; Li et al., 2017). They are the subject of many works by Russian and foreign researchers, as well as of a number of regulatory documents (Highways England, 2020; National Research Council of Italy. Advisory Committee on Technical Recommendations for Construction, 2008).

Among others, the methodology for conducting experimental studies on dynamically similar sectional models is described in the scientific, technical, and regulatory literature in most detail and most comprehensively (Poddaeva et al., 2018; Wardlaw, 1980). The main similarity criteria, in this case, are the following: the Cauchy and Newton numbers (correspondence between the model’s and the real object’s distribution of masses and moments of inertia); the Scruton number (correspondence between the model’s and the real object’s logarithmic decrement of oscillations); and the Strouhal number (correspondence between the model’s and the real object’s frequency characteristics).

One of the most significant research insights is the dependence of the bridge span oscillation amplitude on the velocity of the wind flow at different angles of attack.

If experimental studies detect an unlimited increase in the amplitude of oscillations, this is likely to be caused by one of the phenomena of aerodynamic instability found unacceptable under the Regulations SP 35.13330.2011 and SP 296.1325800.2017, namely galloping, divergence or flexural-torsional flutter (Kazakevich, 2021; Solovyev, 2016). In this case, the most effective solution to the problem is to change the wind flow around the superstructure by making changes to the superstructure design (using deflectors, fairings, etc.) (SP 296.1325800.2017; Nagao et al., 1993;

Wardlaw, 1992).

When oscillations have a narrow velocity range (meaning that when the velocity increases, the oscillations stop), we can talk about the appearance of vortex excitation (Kazakevich, 2021). Here, the maximum value of the oscillation amplitude is important; it must be compared with the maximum permissible value of the vertical deflection of the bridge span. Despite the effectiveness of aerodynamic damping methods, in this case, designers often resort to increasing structural damping without changing the shape of the bridge span's cross-section. This can be linked to a change in the design features of the respective structure, such as changing the type of connection from welded to ordinary bolted, which increases the level of structural damping from 0.02 to 0.05. The main question, in this case, is the following: how significant is the drop in the oscillation amplitude going to be? What is even more important to know is the effect that the value of structural damping has on the oscillation amplitude of the bridge span when using different types of mechanical damping devices. The required mass of counterweights and other parameters of additional dampers directly depend on this.

Subject, tasks, and methods

As the target of our study, we chose one of the most common types of bridge structures: girder bridges with two and four girders (Figures 1–2).

For the purposes of this study, we used a unique experimental unit, the Large Research Gradient Wind Tunnel by the National Research Moscow State University of Civil Engineering (NRU MGSU), in a specialized test bench for static and dynamic tests of building structures.

The methodology for experimental studies of bridge structures' aerodynamic stability in sectional models is described in detail in the scientific and technical literature (Brownjohn and Choi, 2001; Diana et al., 2015). The main task of dynamic tests is to determine the amplitude of bridge span oscillations at various wind flow velocities and angles of attack. As measuring equipment, we used the RAS-T contactless laser displacement sensors by WayCon, which are included in the State Register of Measuring Instruments. The flow velocity in the wind tunnel was recorded with a Pitot-Prandtl tube and a differential pressure gauge.

The main requirement for the model is that it must retain geometric similarity and ensure that its distribution of masses and moments of inertia is consistent with the corresponding parameters of the real object (the Cauchy and Newton numbers mentioned in the introduction). Besides, the model must be as rigid as possible. This is necessary to maintain Scruton number similarity since metal spans with welded joints have a specific minimum level of structural damping. The frequency parameters of the real object are modeled with spring suspensions of a specialized test bench (Figure 3). The sensors are aimed at markers located in the corners of the model, making it possible both to determine the amplitude of the oscillations and to classify their mode.

The level of structural damping is measured with the free damped oscillation method. When subjected to a pulsed external load, the model begins to oscillate, while the sensors record its oscillogram (Figure 4). This oscillogram is analyzed in the software package. The rate of oscillation amplitude reduction is determined by the relative dissipation of energy. The corresponding value is the value of the logarithmic decrement.

The level of structural damping was adjusted with the help of special flexible inserts in the spring suspensions of the specialized test bench.

Results and discussion

Tables 1–2 show the dynamic parameters of the models obtained during bench tests.

Table 1. Correlations between the model and the real object (Model No. 1)

	Oscillation mode	Real object	Model	Velocity scale U*
Frequencies in the real object and the model	Bending	0.48 Hz	5.22 Hz	6.43
	Torsion	1.33 Hz	9.62 Hz	9.67

Table 2. Correlations between the model and the real object (Model No. 2)

	Oscillation mode	Real object	Model	Velocity scale U*
Frequencies in the real object and the model	Bending	0.596 Hz	6.1 Hz	6.8
	Torsion	1.36 Hz	12.15 Hz	7.8

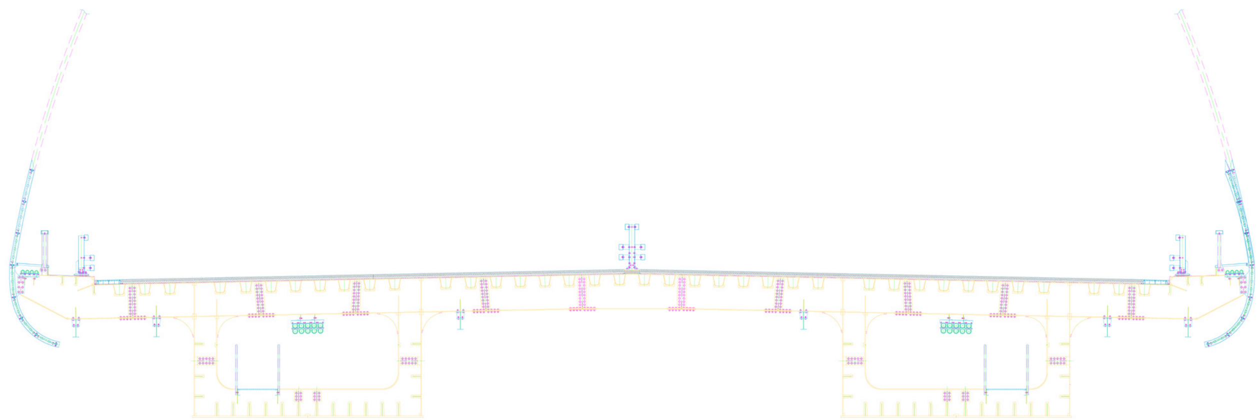

Figure 1. Cross-section of the bridge (Model No. 1)

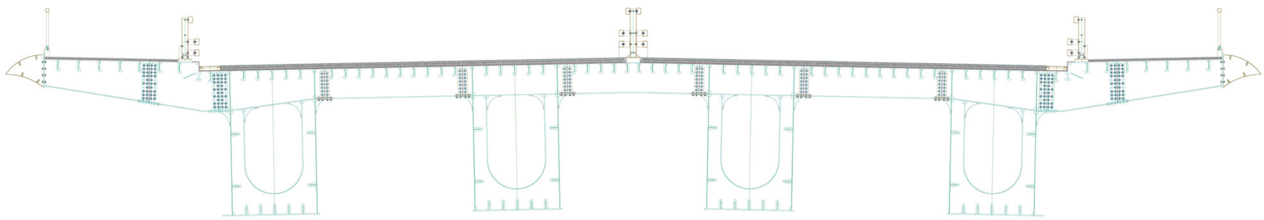

Figure 2. Cross-section of the bridge (Model No. 2)

Figure 3. Spring suspensions of the specialized test bench

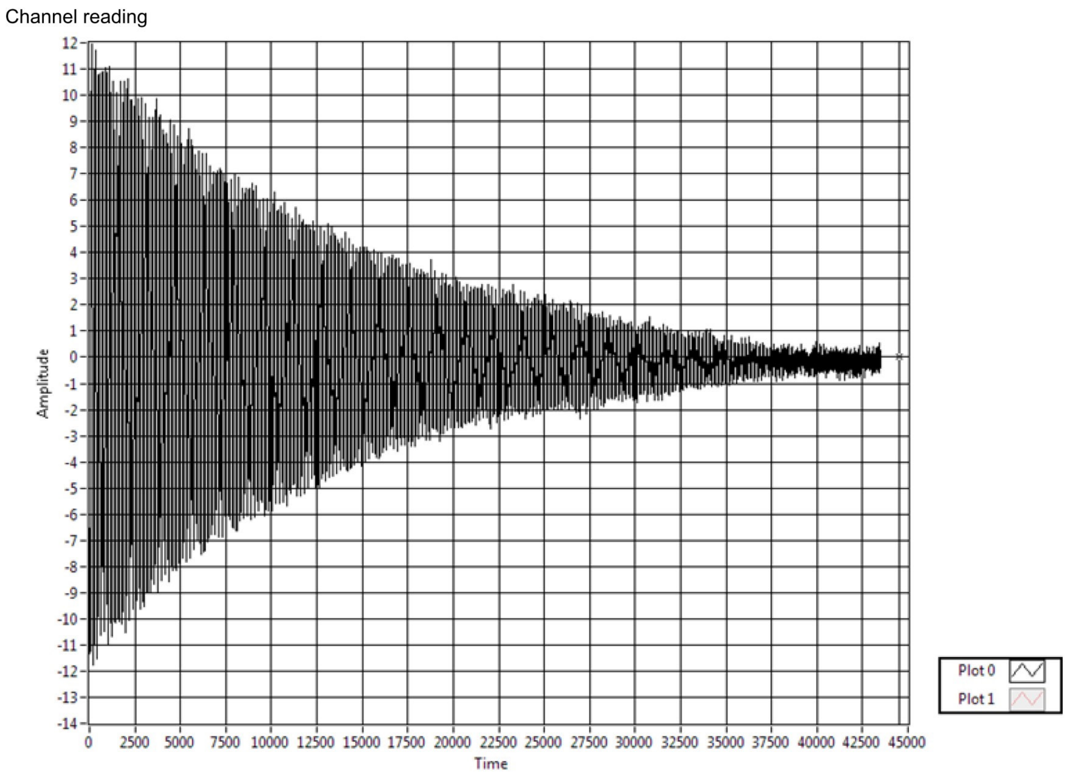

Figure 4. Oscillogram of the model's oscillations

The studies were carried out at the following levels of structural damping: 0.03, 0.045, 0.055, 0.07. The research results are presented as graphs that show the bridge span oscillation amplitude's dependence on the velocity of the wind flow.

As the most illustrative material, we selected those wind flow angles of attack where the phenomenon of span vortex excitation was detected. In this case, the oscillation frequency of the structure corresponds to the natural oscillation frequency recorded at the preliminary stage of the studies (Tables 1–2).

Figures 5–6 show the results for model No. 1 at the following wind flow angles of attack: –5° (downward flow) and +5° (upward flow).

Figures 7–8 show the results for model No. 1 at the following wind flow angles of attack: –3° (downward flow) and +3° (upward flow).

By analyzing the experimental study results, we obtained the ratio of the increase in structural damping (Δδ, %) to the corresponding decrease in the maximum oscillation amplitude (ΔA, %) for different models at different angles of attack (α).

Table 3. Ratio of the increase in structural damping (Δδ, %) to the corresponding decrease in the maximum oscillation amplitude (ΔA, %) for different models at different angles of attack (α)

Model No. 1						
α, º	–5			5		
Δδ, %	33	45	57	33	45	57
ΔA, %	12	39	66	17	39	69
Model No. 2						
α, º	–3			3		
Δδ, %	33	45	57	33	45	57
ΔA, %	6	39	70	19	44	59

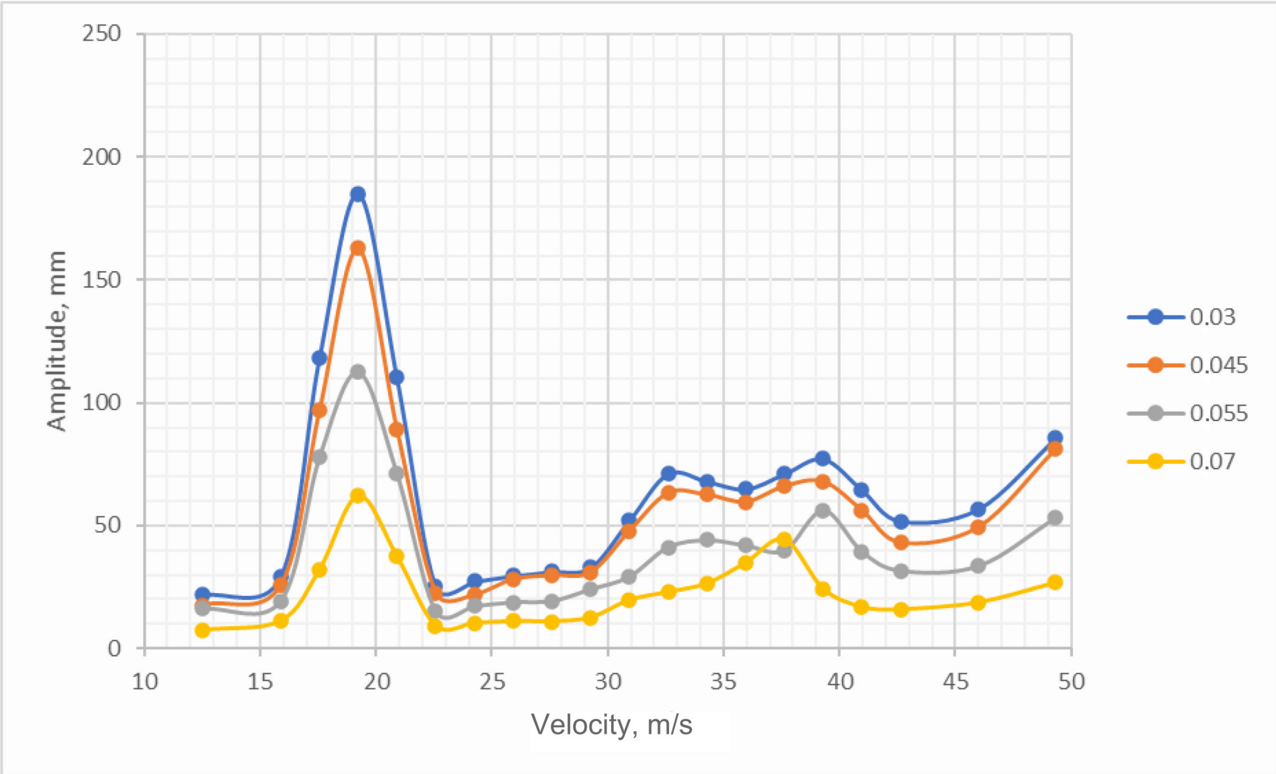

Figure 5. Oscillation amplitude's dependence on the wind flow velocity in the model at an angle of attack of –5°

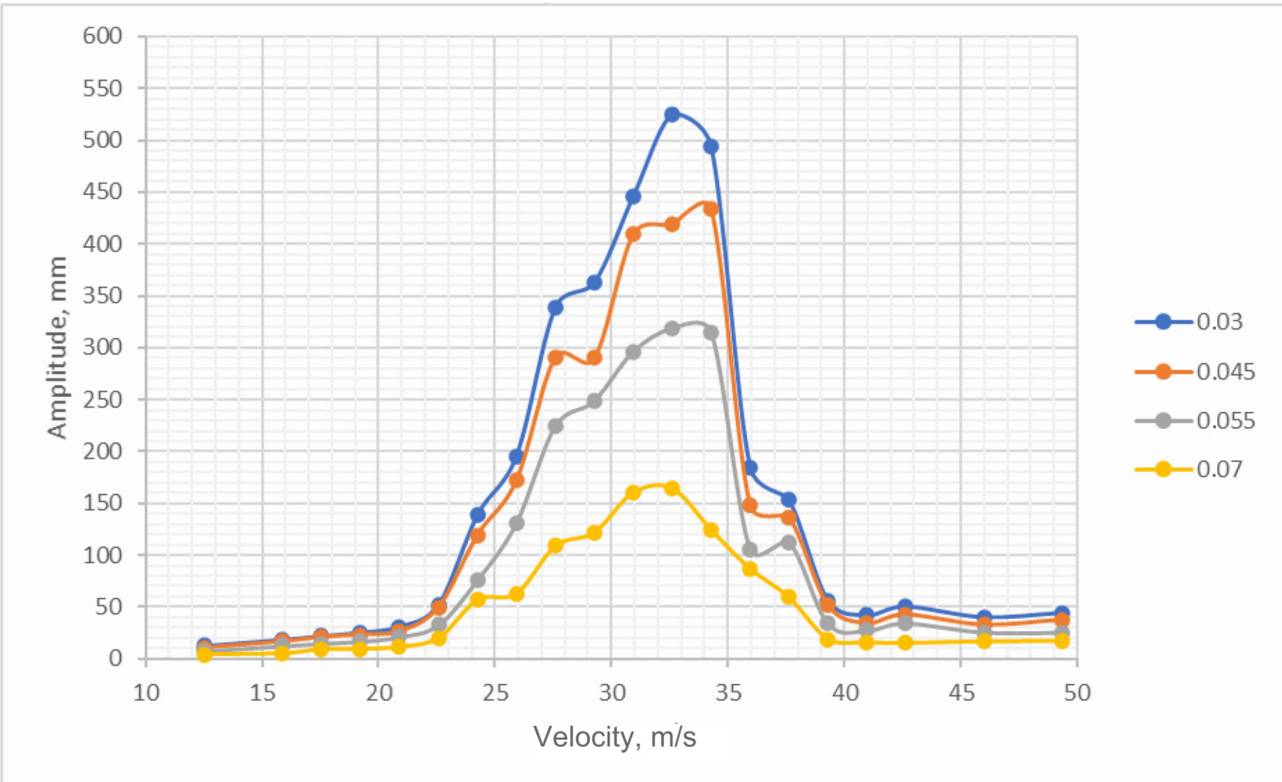

Figure 6. Oscillation amplitude's dependence on the wind flow velocity in the model at an angle of attack of +5°

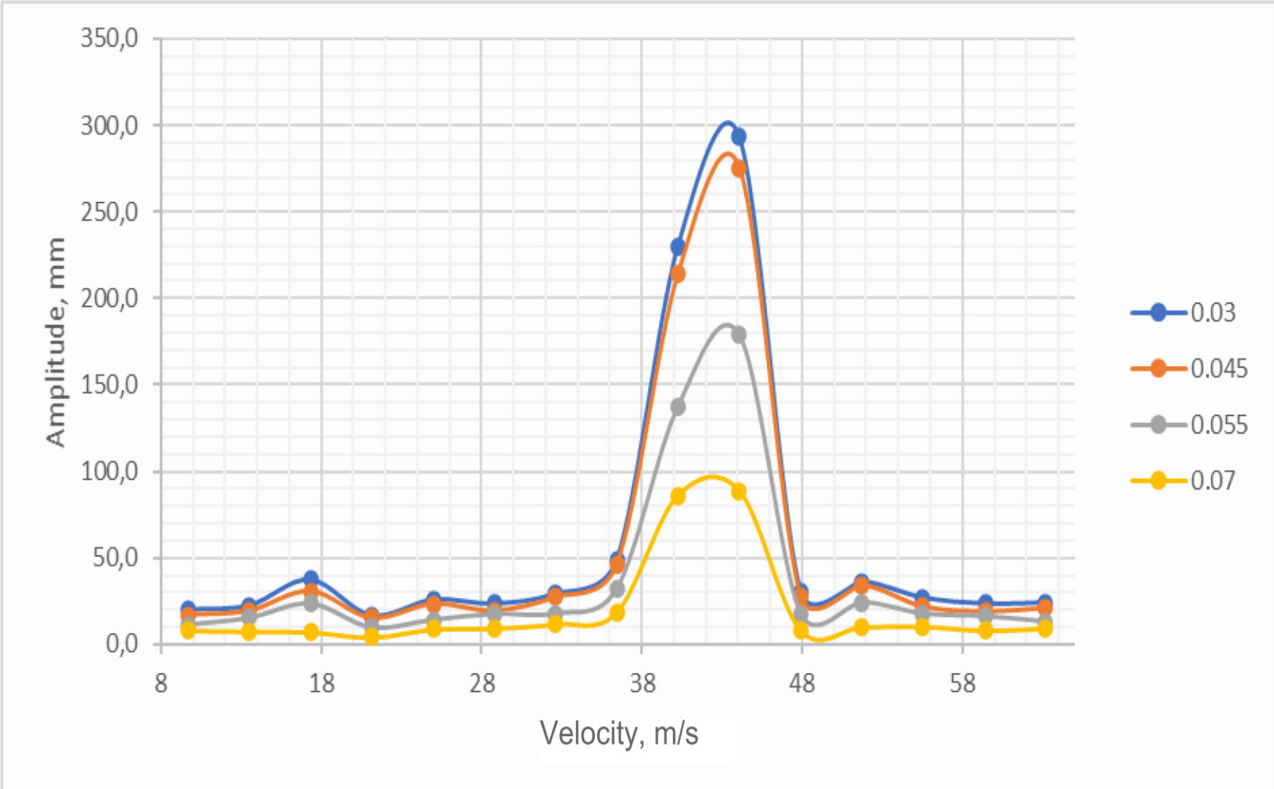

Figure 7. Oscillation amplitude’s dependence on the wind flow velocity in the model at an angle of attack of –3°

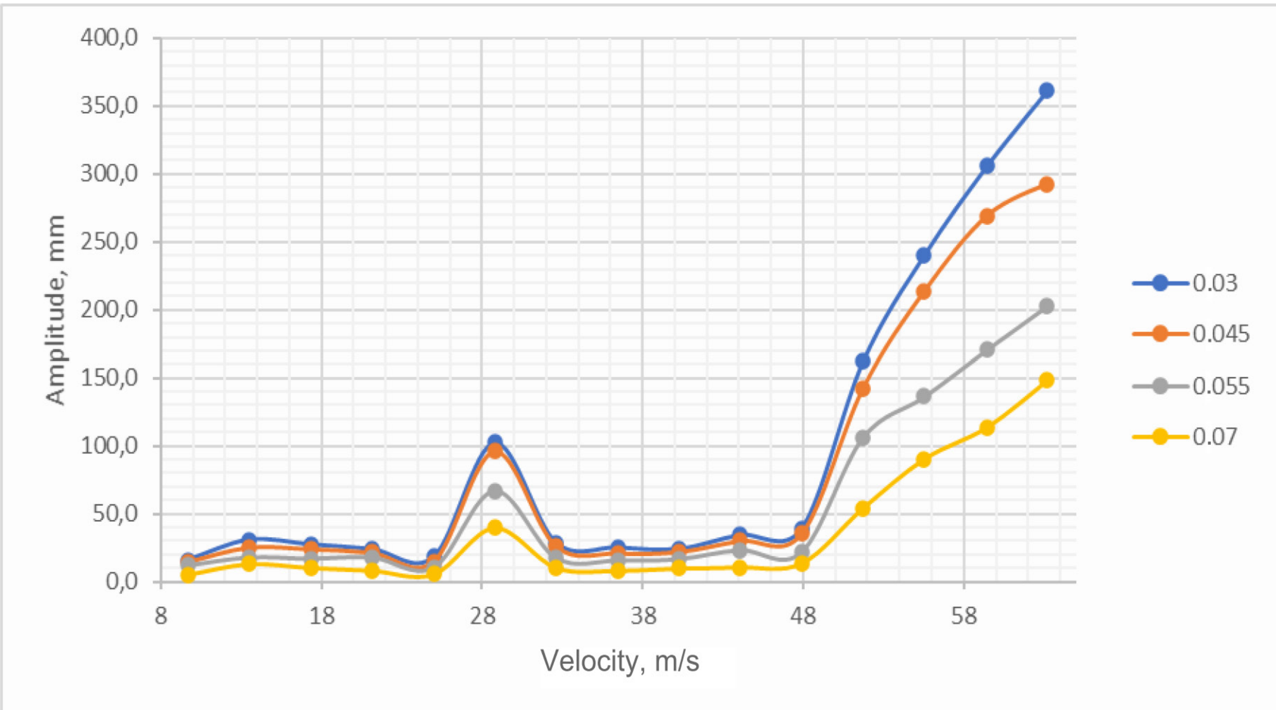

Figure 8. Oscillation amplitude’s dependence on the wind flow velocity in the model at an angle of attack of +3°

Conclusions

The results obtained show that, despite the general trend towards the decrease in the amplitude of bridge span structure oscillations as the structural damping level increases, the dependence between these parameters is nonlinear.

When increasing the aerodynamic stability of large-span bridge structures by means of increasing the structural damping level, it is necessary to make appropriate engineering calculations and thus determine the expected value of the oscillations’ logarithmic decrement after making structural changes. We further recommend conducting additional experimental studies in a wind tunnel in order to assess the effectiveness of the solution selected.

Compliance with these requirements will help both to ensure the reliability and safety of bridge structures and to optimize the costs of increasing structural damping.

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References

Ageev, N., Poddaeva, O., Churin, P. and Fedosova, A. (2021). Numerical simulation of the wind resonance of the bridge based on scale-resolving approaches. In: Balandin, D., Barkalov, K., Gergel, V. and Meyerov, I. (eds.) *Mathematical Modeling and Supercomputer Technologies. MMST 2020. Communications in Computer and Information Science*, Vol. 1413. Cham: Springer, pp. 93–104.

Argentini, T., Rocchi, D. and Somaschini, C. (2020). Effect of the low-frequency turbulence on the aeroelastic response of a long-span bridge in wind tunnel. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 197, 104072. DOI: 10.1016/j.jweia.2019.104072.

Bas, S. and Catbas, N. (2021). Bridge failures and mitigation using monitoring technologies. In: Gülkan, P., Caner, A. and Memisoglu Apaydin, N. (eds.) *Developments in International Bridge Engineering. Springer Tracts on Transportation and Traffic*, Vol. 17. Cham: Springer, pp. 43–52.

Brownjohn, J. M. W. and Choi, C. C. (2001). Wind tunnel section model study of aeroelastic performance for Ting Kau Bridge Deck. *Wind and Structures*, Vol. 4, Issue 5, pp. 367–382. DOI: 10.12989/was.2001.4.5.367.

Cermak, J. E. (2003). Wind-tunnel development and trends in applications to civil engineering. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 91, Issue 3, pp. 355–370. DOI: 10.1016/S0167–6105(02)00396–3.

Diana, G., Fiammenghi, G., Belloli, M. and Rocchi, D. (2013). Wind tunnel tests and numerical approach for long span bridges: the Messina bridge. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 122, pp. 38–49. DOI: 10.1016/j.jweia.2013.07.012.

Diana, G. and Omarini, S. (2020). A non-linear method to compute the buffeting response of a bridge validation of the model through wind tunnel tests. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 201, 104163. DOI: 10.1016/j.jweia.2020.104163.

Diana, G., Rocchi, D. and Belloli, M. (2015). Wind tunnel: a fundamental tool for long-span bridge design. *Structure and Infrastructure Engineering*, Vol. 11, Issue 4, pp. 533–555. DOI: 10.1080/15732479.2014.951860.

Highways England (2020). *Highway structures and bridges. Design. Design rules for aerodynamic effects on bridges.* DMRB Volume 1 Section 3 CD 363. Birmingham.

Kazakevich, M. I. (2021). *Fundamentals of structural wind impact assessment.* 2nd edition. Moscow: Publishing House of the Moscow Institute of Civil Engineering — Moscow State University of Civil Engineering, 180 p.

Li, Y., Xu, X., Zhang, M. and Xu, Y. (2017). Wind tunnel test and numerical simulation of wind characteristics at a bridge site in mountainous terrain. *Advances in Structural Engineering*, Vol. 20, Issue 8, pp. 1223–1231. DOI: 10.1177/1369433216673377.

Maystrenko, I. Y., Ovchinnikov I. I., Ovchinnikov, I. G. and Kokodeev, A. V. (2017). Failures and collapses of bridge constructions, analysis of their causes. Part 1. *Russian Journal of Transport Engineering*, Vol. 4, No. 4, 11.

Miyata, T., Yokoyama, K., Yasuda, M. and Hikami, Y. (1992). Akashi Kaikyo Bridge: Wind effects and full model wind tunnel tests. In: Larsen, A. (ed.) *Aerodynamics of Large Bridges*. London: Routledge, pp. 217–236. DOI: 10.1201/9781315136950-16.

Nagao, F., Utsunomiya, H., Oryu, T. and Manabe, S. (1993). Aerodynamic efficiency of triangular fairing on box girder bridge. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 49, Issues 1–3, pp. 565–574. DOI: 10.1016/0167-6105(93)90050-X.

National Research Council of Italy. Advisory Committee on Technical Recommendations for Construction (2008). *Guide for the assessment of wind actions and effects on structures.* CNR-DT 207/2008. Roma.

Poddaeva, O., Churin, P., Fedosova, A. and Truhanov, S. (2018). Investigation of the stability of a two-span bridge with the use of a high-precision laser displacement sensors. *IOP Conference Series: Materials Science and Engineering,* Vol. 317, 012020. DOI: 10.1088/1757–899X/317/1/012020.

Reinhold, T. A., Brinch, M. and Damsgaard, A. (1992). Wind tunnel tests for the Great Belt Link. In: Larsen, A. (ed.) *Aerodynamics of Large Bridges*. London: Routledge, pp. 255–267. DOI: 10.1201/9781315136950-19.

Solovyev, S. Yu. (2016). Aerodynamic stability of long-span bridges. *Transport of the Russian Federation*, No. 5 (66), pp. 47–50.

Tan, J.-S., Elbaz, K., Wang, Z.-F., Shen, J. S. and Chen, J. (2020). Lessons learnt from bridge collapse: A view of sustainable management. *Sustainability*, Vol. 12, Issue 3, 1205. DOI: 10.3390/su12031205.

Wardlaw, R. L. (1980). Sectional versus full model wind tunnel testing of bridge road decks. *Proceedings of the Indian Academy of Sciences Section C: Engineering Sciences*, Vol. 3, Part 3, pp. 177–198. DOI: 10.1007/BF02861559.

Wardlaw, R. L. (1992). The improvement of aerodynamic performance. In: Larsen, A. (ed.) *Aerodynamics of Large Bridges*. London: Routledge, pp. 59–70.

АЭРОДИНАМИЧЕСКАЯ УСТОЙЧИВОСТЬ МОСТОВ С РАЗЛИЧНЫМИ УРОВНЯМИ СТРУКТУРНОГО ДЕМПФИРОВАНИЯ

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Аннотация

Конструкционное демпфирование является одним из наиболее важных параметров, влияющих на аэродинамическую устойчивость мостовых сооружений. **Цель исследования:** Оценка влияния конструкционного демпфирования мостовой конструкции на ее устойчивость в ветровом потоке. **Методы:** Экспериментальные исследования аэродинамической устойчивости типовых балочных мостовых сооружений (с двумя и четырьмя главными балками) с различными уровнями конструкционного демпфирования на базе Уникальной научной установки «Большая исследовательская градиентная аэродинамическая труба» НИУ МГСУ. **Результаты:** На основании результатов, проведенных экспериментальных исследований, установлено, что несмотря на общую тенденцию снижения амплитуды колебаний пролетного строения мостового сооружения с увеличением уровня конструкционного демпфирования, зависимость этих параметров имеет нелинейный характер. При проведении научно-технического сопровождения проектирования реальных сооружений, в случае необходимости повышения аэродинамической устойчивости пролетного строения путем повышения уровня конструкционного демпфирования (изменение типа соединений конструкционных элементов, использование механических демпфирующих устройств), рекомендуется проведение экспериментальных исследований в аэродинамических трубах для оценки эффективности того или иного решения.

Ключевые слова

Мостовое сооружение, конструкционное демпфирование, аэродинамическая труба, экспериментальные исследования, секционная модель.

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A STUDY ON SUDDEN EXPANSION HYDRODYNAMIC PHENOMENA OCCURRING IN CYLINDRICAL PIPES

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Abstract
Introduction: This paper studies the frequency with which hydrodynamic parameters change in the sudden expansion section of axisymmetric pressure flow, based on the boundary layer equations. **Methods:** The suggested method reveals the regularity of changes in the hydrodynamic parameters of the flow in the transitional area, making it possible to obtain a velocity profile in any cross-section under common initial and boundary conditions. Based on the general solutions, we studied the hydrodynamic processes occurring in the transitional area of the effective sudden cross-section expansion within the axisymmetric pressure movement, in the following cases: a) when the velocity is constant at any point of the inlet face; b) when the velocity is distributed along the inlet face according to the parabolic law. Our calculations were carried out for different values of the expansion factor: $\alpha = \frac{a}{R} = 0.3;\ 0.5;\ 0.7.$ **Results:** Based on the results of the computer-aided experimental study, we obtained velocity diagrams along the length of the transitional area with constant and parabolic velocity distributions for fluid inflowing into the expanded section. We also determined the patterns of pressure distribution along the length of the relevant section.

Keywords
Transitional area, effective cross-section, sudden expansion, velocity, distribution.

Introduction

In transitional areas of the effective cross-section (cross-section input and output, sudden expansion and narrowing, etc.), rearrangement of the velocity field is accompanied by a change in hydrodynamic parameters. The theoretical aim of this study, focused on the transitional area, was to determine how regularly hydrodynamic parameters change along the pipe and to develop calculation methods for energy losses.

A number of theoretical and approximate calculation methods were developed for studying the hydrodynamic phenomena occurring in the transitional areas of the input section. Each calculation method is based on conclusions regarding the flow's nature, which are used in theoretical studies and result reviews. Such conclusions are often related to specific flow intervals; therefore, the results obtained have limited applicability. The first known study on flow velocity change patterns in the transitional area of a circular pipe input was carried out by Boussinesq (Boussinesq, 1891). The main goal of that study was to assess disturbances in the velocity profile based on the velocity profile in the stabilized area. It should be noted that the spread of the obtained results is essential, especially for input-adjacent sections of the pipe. Schiller, using the boundary layer theory principles, conducted research (Loitsyansky, 1973) on velocity rearrangement in the transitional input area, and developed an appropriate calculation methodology (Schiller, 1936). The obtained results provide good, consistent data on the central sections of the pipe when $r \leq R$. As for near-wall sections, this is where considerable disturbances occur (Targ, 1951).

Schlichting suggested a more accurate method for calculating the plane-parallel motion of the transitional input area (Schlichting, 1974). This method has been used to carry out a numerical integration of boundary layer equations. In addition to the numerical technique, Schlichting (1934) also suggested an analytical method for assessing the transitional area. This method is based on the idea that the flow range is divided into: a) the central section, where velocities are constant, b) the near-wall sections, where velocities keep changing according to the boundary layer regularity. The obtained solutions make it possible to reveal the velocity distribution pattern for any cross-section of the input section's transitional area. Yemtsev (1978) made use of the velocity parabolic distribution pattern in the boundary layer and constant velocity condition at the core. He arrived at similar conclusions. As a result, he found solutions for the velocity and pressure change in the plane-parallel motion input section of the transitional area.

Slyozkin (1955) and Targ (1951) studied the regularities in the hydrodynamic parameters' behavior in the transitional area of the pipe input section. By making successive approximations and simplifying the Navier–Stokes equations, they formulated the boundary problem. Analytical solutions to this problem allow for determining how regularly the velocity and pressure change. The results obtained are remarkably consistent with the findings of experimental investigations. Comparative analyses confirm the reliability of the results obtained. It should be noted that the aforementioned studies pertain only to the input sections of the pipe. However, velocity field changes take place not only in input sections but also in sections where the pipe's geometrical parameters change. Studies on regularities of changes in the flow's hydrodynamic parameters in the aforementioned sections are of considerable practical interest and importance.

A similar study was carried out by Chen (1973), where approximate solutions were found under cylindrical and plane-parallel isotherm laminar motion conditions, ensuring satisfactory accuracy of the results. Studies of hydrodynamic phenomena running in the input transitional area along fluid lines in the aforementioned section were carried out in a 3D environment by integration of the Navier–Stokes equations' finite elements (Young, 2016). The studies demonstrate velocity and pressure distribution curves. Comparative analysis of the results obtained via numerical method was provided in (Hornbeck, 1964). Studies carried out in the boundary layer of the input section, under fourth-power (four-step) velocity change conditions (Mohanty and Asthana, 1979), resulted in laws of velocity and pressure change. Studies on velocity and pressure change regularities in circular-section cylindrical pipes and under plane-parallel motion conditions followed the method developed in (Sparrow et al., 2004) for fluid lines of arbitrary section. The results obtained were subjected to comparative analysis.

Belyaev et al. (2015) developed a mathematical model for identifying the velocity and pressure fields when viscous incompressible fluid flows in 2D variable cross-section ducts in laminar flow mode. However, the solutions suggested are not applicable to determining the hydrodynamic parameters of the sudden expansion sections.

The studies listed above essentially present comments on phenomena occurring in the input section of the pipe. Meanwhile, hydrodynamic parameters' rearrangement processes also occur in other transitional areas. There are few papers dealing with this subject. By using the numerical integration of viscous-plastic fluid flow motion equations, researchers built flow lines and determined velocity and pressure changes along the axial direction within the sudden expansion section ($D/d = 4$) (Rocha et al., 2007). Mullin et al. (2009) carried out a thorough experimental investigation on the sudden expansion section. Using magnetic resonance imaging techniques, they successfully obtained quantitative estimates for velocity change in the transitional area. Hava and Rusak (2000) provided quantitative estimates for Navier–Stokes equations members under sudden symmetric and asymmetric expansion conditions. This results in the numerical integration of the nonlinear nonhomogeneous differential equations obtained by the researchers. Integration results were compared with experimentally obtained data. A number of important experimental investigations were conducted in the sudden expansion section (Fester et al., 2008). The researchers built a test rig and studied flows of both Newtonian and non-Newtonian fluids through sudden contractions of three diameter ratios of 0.22, 0.5, and 0.85.

Sarukhanyan et al. (2020) reviewed the change patterns in the hydrodynamic parameters of viscous fluid laminar motion in the transitional area of the input section within a cylindrical pipe of R radius under the initial arbitrary distribution of velocity conditions. Under such conditions, the viscous fluid is axisymmetric, and isotherm motion occurs. In the input section of the pipe, the velocity of fluid flow along the pipe walls, in accordance with the velocity diagram $u = \varphi(r)$, reaches zero, while the velocity diagram changes. These changes extend for a certain distance along the pipe. A boundary layer develops near the pipe walls. In the boundary layer, the velocity gradient $\frac{du}{dn}$ becomes too large; for this reason, friction force values increase as well, regardless of the μ viscosity coefficient. The boundary layer gradually spreads and covers the entire pipe. Therefore, studies on the transitional area should use boundary layer equations.

Prandtl (Loitsyansky, 1973; Schlichting, 1974) suggested using the Navier–Stokes equations for the boundary layer.

Furthermore, Prandtl (Loitsyansky, 1973; Schlichting, 1974) obtained equations for the boundary layer by simplifying the Navier–Stokes equations. Viscous forces mostly act in the boundary layer. For this reason, while simplifying the Navier–Stokes equations, Prandtl neglected those equation members that were too small in comparison with viscous forces. He derived simplified equations for the boundary layer. This allowed for finding the regularities of viscous fluid laminar motion in the transitional area of the circular cylinder's input section.

Theoretical Models

We shall now study the hydrodynamic phenomena typical of viscous fluid laminar motion within the sudden expansion segment of a cylindrical pipe's section (Figure 1). The pipe is considered rigid; the fluid, incompressible.

The sudden expansion of a circular cylindrical pipe causes fluid velocity field deformation. Our study

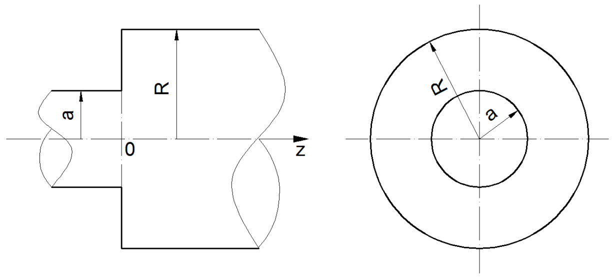

Figure 1. Sudden expansion segment: **a** – radius before expansion, **R** – radius after expansion

will concern viscous fluid laminar motion regularities in the velocity rearrangement section, using the same methodology as in research on the transitional area of the pipe's input section (Schlichting, 1974; Slyozkin, 1955). We shall use the following boundary layer equations for the cylindrical coordinate system (Loitsyansky, 1973; Schlichting, 1934):

$$u\frac{\partial u}{\partial r}+u\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial z}+\nu\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right). \quad (1)$$

$$\frac{\partial u}{\partial z}+\frac{1}{r}\frac{\partial(v\cdot r)}{\partial r}=0. \quad (2)$$

To simplify Eq. (1), we take into consideration the conclusion made in (Schlichting, 1934, 1974) according to which $v<<u$, hence $v=0$. We arrive at:

$$u\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial z}+\nu\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right), \quad (3)$$

where u and v are the components describing velocity in the direction of z and r coordinates.

To integrate nonlinear nonhomogeneous differential equations, we make the following assumption: the u coefficient of $\frac{\partial u}{\partial z}$ member is replaced by the average velocity of the effective cross-section.

$$u=u_0=\frac{2}{R^2}\int_0^R \phi(r)\,r\,dr, \quad (4)$$

where $u=\varphi(r)$ is the function of velocity distribution in fluid entering the sudden expansion section.

Following this assumption, the study of regular patterns in the change of the hydrodynamic parameters within the sudden expansion segment (Figure 1) is reduced to the integration of the following equations:

$$u_0\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial z}+\nu\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right). \quad (5)$$

$$\frac{\partial u}{\partial z}+\frac{1}{r}\frac{\partial(v\cdot r)}{\partial r}=0. \quad (6)$$

in case of the following initial and boundary conditions:

$$u=0,\ v=0, \text{ when } r=a\ \ z=0. \quad (7)$$

$$u=\varphi(r), \text{ when } z=0,\ 0\le r\le a. \quad (8)$$

$$u\to u', \text{ when } z\to\infty,\ 0\le r\le a. \quad (9)$$

where V' is the velocity of fluid in the stabilized section of the pipe, which is determined by the following equation:

$$\frac{1}{\rho}\frac{\partial P}{\partial z}=\nu\left(\frac{\partial^2 u'}{\partial r^2}+\frac{1}{r}\frac{\partial u'}{\partial r}\right). \quad (10)$$

Eq. (10) has the following solution:

$$u'=-\frac{1}{\rho}\frac{\partial P}{\partial z}\frac{R^2}{4\nu}\left(1-\frac{r^2}{R^2}\right)=2u_0\left(1-\frac{r^2}{R^2}\right), \quad (11)$$

where $u_0=\frac{V'_{\max}}{2}=-\frac{1}{\rho}\cdot\frac{\partial P}{\partial z}\cdot\frac{R^2}{8\nu}$ is the average velocity of the effective cross-section.

It follows from Eqs. (5) and (6) that, in each fixed section of the transitional area, $\frac{\partial P}{\partial r}=0$. Therefore, pressure in all points of the effective cross-section is equal and only changes when passing from one section to another $P=P(z)$.

Solution of Eq. (5) in case of (7), (8), (9) boundary conditions is Sarukhanyan et al (2020).

$$u(z,r)=-\sum_{k=1}^{\infty}C_k\left[J_0\left(\lambda_k\frac{r}{R}\right)-\frac{2J_1(\lambda_k)}{\lambda_k}\right]\exp\left(-\frac{\lambda_k^2}{R\cdot \mathrm{Re}}z\right)+2u_0\left(1-\frac{r^2}{R^2}\right), \quad (12)$$

$$0\le r<R$$

where $J_0(\lambda_k)$ is the zero-order Bessel function of the first kind, $J_1(\lambda_k)$ is the first-order Bessel function of the first kind, $J_2(\lambda_k)$ is the second-order Bessel function of the first kind. The eigenvalues of the problem are determined from the boundary condition, when $r=R$, $u=0$. As a result, we obtain

$$J_0(\lambda_k)-\frac{2J_1(\lambda_k)}{\lambda_k}=0 \quad \text{or} \quad J_2(\lambda_k)=0,$$

which means that the eigenvalues of the problem are the roots of the second-order Bessel function of the first kind. We use the boundary condition for determining the values of C_κ constant'coefficients (8) and obtain the following:

$$\varphi(r)=-\sum_{k=1}^{\infty}C_kJ_0(\lambda_k)\left[\frac{J_0\left(\lambda_k\frac{r}{R}\right)}{J_0(\lambda_k)}-1\right]+ 2u_0\left(1-\frac{r^2}{R^2}\right). \quad (13)$$

We shall now multiply the two sides of Eq. (13) by orthogonal functions equivalent to eigenfunctions:

$$\Phi_n\left(\lambda_n\frac{r}{R}\right)=\frac{8}{J_0(\lambda_k)}\left[\frac{J_0\left(\lambda_k\frac{r}{R}\right)}{J_0(\lambda_k)}-1\right], \quad (14)$$

and after integration in the $0\le r<R$ interval, we obtain C_k :

$$C_k=-\frac{8}{R^2J_0(\lambda_k)}\int_0^R\left[\varphi(r)-2u_0\left(1-\frac{r^2}{R^2}\right)\right]\left[\frac{J_0\left(\lambda_k\frac{r}{R}\right)}{J_0(\lambda_k)}-1\right]r\cdot dr. \quad (15)$$

Let us represent Eq. (15) in the following form:

$$C_k=-\frac{8}{R^2J_0(\lambda_k)}\left[L_1+\frac{u_0R^2}{2}\right], \quad (16)$$

where

$$L_1=\int_0^R\left[\frac{J_0\left(\lambda_k\frac{r}{R}\right)}{J_0(\lambda_k)}-1\right]\varphi(r)\cdot r\cdot dr. \quad (17)$$

Pressure change behavior along the pipe is obtained from Eq. (5), while velocity change is obtained from Eq. (12), which results in the following equation:

$$-\frac{1}{\rho}\cdot\frac{\partial P}{\partial z}=-\sum_{k=1}^{\infty}\lambda_k^2C_k\left[\begin{array}{c}\frac{\nu}{R^2}J_0\left(\lambda_k\frac{r}{R}\right)-\\ \frac{u_0}{R\cdot \mathrm{Re}}\left[J_0\left(\lambda_k\frac{r}{R}\right)-\frac{2J_1(\lambda_k)}{\lambda_k}\right]\\ \exp\left(-\frac{\lambda_k^2}{R\cdot \mathrm{Re}}z\right)\end{array}\right]+\frac{8u_0\nu}{R^2}. \quad (18)$$

It follows that in the boundary state when $z\to\infty$ in case of pressure distribution and laminar motion, pressure change regularities coincide:

$$\left(-\frac{\partial P}{\partial z}\right)_{z\to\infty}=\frac{8\rho u_0\nu}{R^2}. \quad (19)$$

By integrating Eq. (15), we determine the regularity of pressure change:

$$\frac{P_0-P}{\rho}=-\sum_{k=1}^{\infty}C_k\left[\begin{array}{c}\frac{\nu \mathrm{Re}}{R}J_0\left(\lambda_k\frac{r}{R}\right)-\\ u_0\left[J_0\left(\lambda_k\frac{r}{R}\right)-\frac{2J_1(\lambda_k)}{\lambda_k}\right]\\ \exp\left(-\frac{\lambda_k^2}{R\cdot \mathrm{Re}}z\right)\end{array}\right]+\frac{8u_0\nu}{R^2}z. \quad (20)$$

It follows from Eq. (20) that $P_0=P$ when $z=0$.

Results and Discussion

The solutions obtained are applicable to the general boundary and the initial conditions of the problem. By using general solutions, we can obtain new solutions, equivalent to the conditions provided for each special case. Let us now consider two special cases.

Case I. Let us assume that the velocity of fluid entering the sudden expansion section is constant at all points. Thus, we have $\varphi(r)=u_0^*=const$, $0\le r<a$, and define the value of L_1 accordingly:

$$L_1=\int_0^a u_0^*\left[\frac{J_0\left(\lambda_k\frac{r}{R}\right)}{J_0(\lambda_k)}-1\right]\cdot r\cdot dr= u_0^*\left[\frac{R\cdot\alpha J_1\left(\lambda_k\frac{a}{R}\right)}{\lambda_kJ_0(\lambda_k)}-\frac{a^2}{2}\right]. \quad (21)$$

By substituting L_1 in Eq. (16) and taking into consideration that $u_0=\frac{u_0^*a^2}{R^2}$, we obtain the values of C_k coefficients:

$$C_k=-\frac{8u_0J_1(\alpha\lambda_k)}{\alpha\lambda_kJ_0^2(\lambda_k)}. \quad (22)$$

Using the values of C_k coefficients that we obtained, we determine the dimensionless regularity of the velocity change in the transitional area:

$$\bar{u} = \frac{8}{\alpha}\sum_{k=1}^{\infty}\frac{J_1(\lambda_k\alpha)}{\lambda_k J_0(\lambda_k)}\left[\frac{J_0(\lambda_k\bar{r})}{J_0(\lambda_k)} - 1\right] \exp\left(-\lambda_k^2\bar{z}\right) + 2\left(1-\bar{r}^2\right), \qquad (23)$$

where $\bar{u} = \frac{u}{u_0}$, $\alpha = \frac{a}{R}$, $\bar{r} = \frac{r}{R}$, $\bar{z} = \frac{z}{R\cdot\mathrm{Re}}$ are the dimensionless values.

To plot the diagrams of velocity distribution in case of the transitional area's sudden cross-sectional expansion, when the velocity of fluid entering the sudden expansion section is constant, we carried out numerical calculations for $a=0.3;\ 0.5;\ 0.7$ cases, using Eq. (23). Figure 2 presents combined diagrams of various $(\bar{z})$ velocity distribution patterns in different sections of the transitional area, and Figure 3 shows the same velocity change curves in different sections when $a=0.7$. The resulting graphs reveal the hydrodynamic picture of the processes occurring in the transitional area, which is important for the correct design of various hydraulic systems.

The plotted diagrams of velocity distribution in the transitional area enable the conclusion that the velocity diagram of fluid entering the sudden expansion section with a constant velocity undergoes a sudden change. Specifically, velocity increases in the center and decreases near the walls. Moreover, a motion of fluid in the opposite direction can be observed as well. This pattern, which starts at a certain $\bar{z}$ = 0.2 velocity in the direction of the motion, subsequently weakens, and at the end of the transitional area, we arrive at the parabolic distribution of the velocity.

Figure 4 shows graphs $\bar{u} = f(\bar{z})$ of velocity change along the length of the pipe at

$$\bar{r} = \frac{r}{R} = 0;\ 0.2;\ 0.4;\ 0.6;\ 0.8;\ 0.9$$

points of the effective cross-section, for the $a=0.7$ case. It follows from the diagram of velocity rearrangement along the length of the pipe that in the cross-section of the sudden expansion entrance segment, the pattern of constant velocity distribution $u_0^*=const$ becomes deformed, and velocity gets rearranged in the direction of the motion. At the end of the transitional area, the pattern of the velocity change becomes parabolic.

From the curves obtained, we derive the stabilization length. Given that in $\bar{r} = 0$, the velocity equals $\bar{u} = 0.99$, we obtain $\bar{z} =$ 0.174.

By substituting the values of C_k coefficients from Eq. (22) in Eq. (20), we arrive at the pressure distribution function for the sudden expansion section.

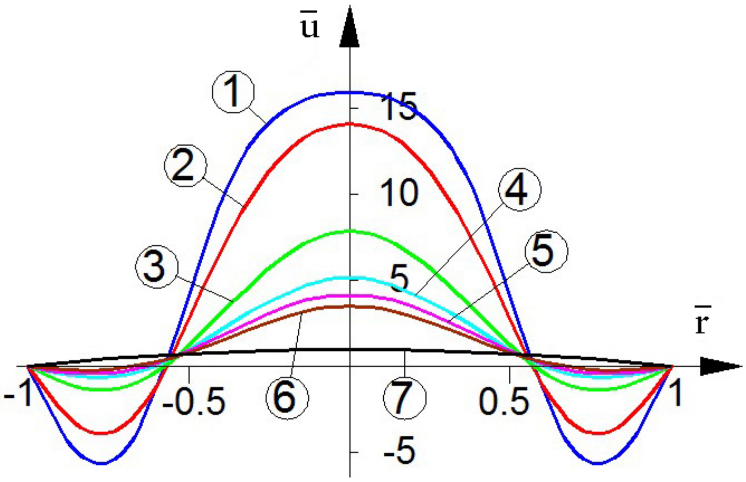

Figure 2. Superimposed graphs of lengthwise velocity change in the transitional area:
1. $\bar{z}$ = 0.02; 2. $\bar{z}$ = 0.03; 3. $\bar{z}$ = 0.04; 4. $\bar{z}$ = 0.06; 5. $\bar{z}$ = 0.08; 6. $\bar{z}$ = 0.09; 7. $\bar{z}$ = 0.2

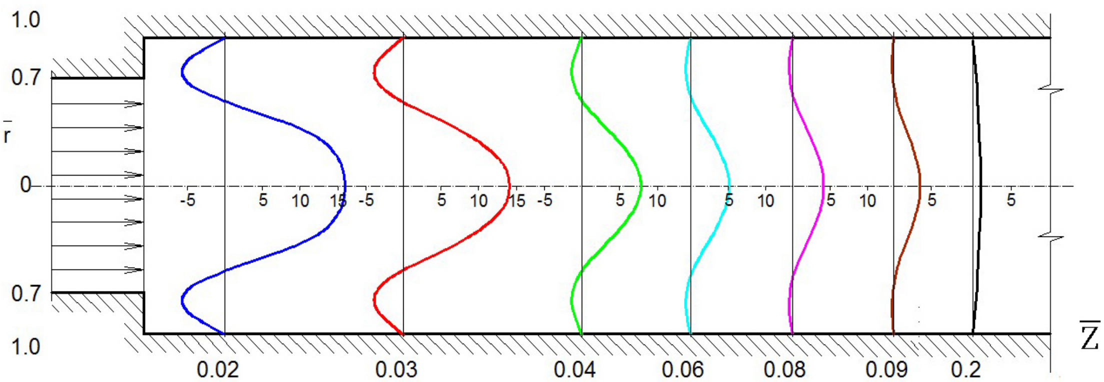

Figure 3. Graphs of lengthwise velocity change in the transitional area depending on $\bar{z}$ and $\bar{r}$ coordinates

$$\frac{P_0 - P}{\rho} = 8u_0 \sum_{k=1}^{\infty} \frac{J_1(\alpha\lambda_k)}{\lambda_k J_0^2(\lambda_k)} \left[\left[\left(\frac{\nu \operatorname{Re}}{R} - u_0 \right) J_0\left(\lambda_k \frac{r}{R}\right) + u_0 J_0(\lambda_k) \right] \left(1 - \exp\left(-\frac{\lambda_k^2}{R \cdot \operatorname{Re}} z \right) \right) \right] + \frac{8u_0 \nu}{R^2} z.$$

Case II. Let us assume that the velocity distribution of fluid entering the sudden expansion section is parabolic. Therefore,

we have $\varphi(r) = 2u_0^*\left(1 - \frac{r^2}{a^2}\right)$, $0 \le r < a$. Accordingly, the value of L_1 is defined as follows:

$$L_1 = 2u_0^* \int_0^a \left[\frac{J_0\left(\lambda_k \frac{r}{R}\right)}{J_0(\lambda_k)} - 1 \right] \left(1 - \frac{r^2}{a^2}\right) \cdot r \cdot dr = \quad (24)$$

$$2u_0^* \left[\frac{2R^2 J_2(\lambda_k \alpha)}{\lambda_k^2 J_0(\lambda_k)} - \frac{a^2}{4} \right].$$

As we substitute L_1 from Eq. (24) into Eq. (16) and take $u_0 = \frac{u_0^* a^2}{R^2}$ into account, we obtain the coefficient C_k

$$C_k = -\frac{32 u_0 J_2(\lambda_k \alpha)}{\alpha^2 \lambda_k^2 J_0^2(\lambda_k)}. \quad (25)$$

Having obtained the values of C_k coefficients, we arrive at the dimensionless patterns for the velocity change in the transitional area:

$$\overline{u} = \frac{32}{\alpha^2} \sum_{k=1}^{\infty} \frac{J_2(\lambda_k \alpha)}{\lambda_k^2 J_0(\lambda_k)} \left[\frac{J_0(\lambda_k \overline{r})}{J_0(\lambda_k)} - 1 \right] \quad (26)$$

$$\exp\left(-\lambda_k^2 \overline{z}\right) + 2\left(1 - \overline{r}^2\right).$$

To discover velocity change patterns for sudden cross-sectional expansion in the transitional area,

we have made calculations for $\alpha = 0.3; 0.5; 0.7$ cases, based on Eq. (26). On the basis of the values obtained, we have plotted diagrams representing the general behavior of velocity distribution in different cross-sections of the transitional area in Figure 5. Figure 6, in turn, shows separate diagrams according to the cross-sections ($\overline{z}$) in case $\alpha = 0.5$.

Figure 7 shows graphs $\overline{u} = f(\overline{z})$ of velocity change along the length of the pipe at $\overline{r} = 0; 0.2; 0.4; 0.8; 0.9$ points of the effective cross-section, for the $\alpha = 0.5$ case. It follows from the diagram of velocity rearrangement along the length of the pipe that in the cross-section of the sudden expansion entrance segment, the pattern of parabolic velocity distribution

$$u = 2u_0^*\left(1 - \frac{r^2}{a^2}\right),$$

becomes deformed, and velocity gets rearranged in the direction of the motion. At the end of the transitional area, the pattern of the velocity change becomes parabolic.

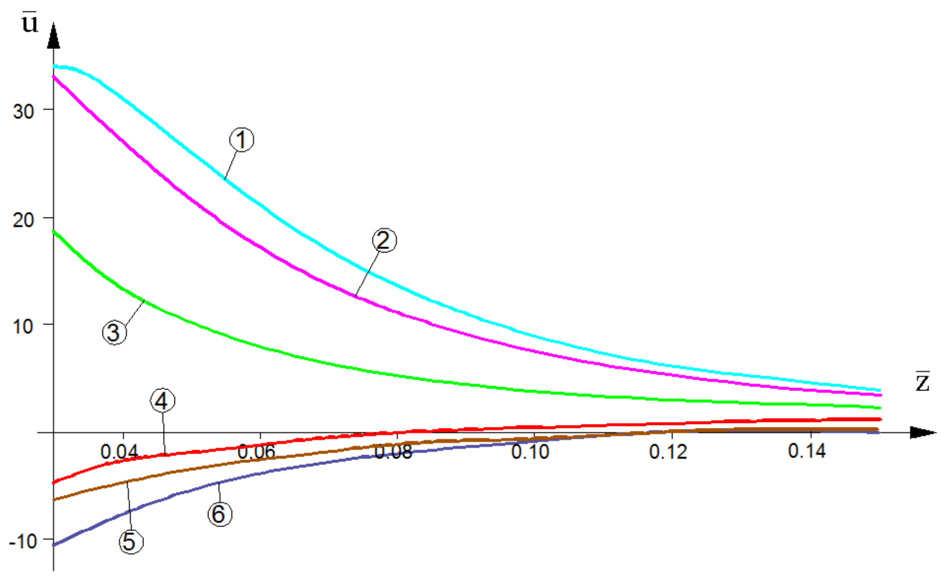

Figure 4. Velocity change in $\overline{r} = 0; 0.2; 0.4; 0.6; 0.8; 0.9$ points of the effective cross-section:

1. $\overline{r} = 0$; 2. $\overline{r} = 0.2$; 3. $\overline{r} = 0.4$: 4. $\overline{r} = 0.6$; 5. $\overline{r} = 0.8$; 6. $\overline{r} = 0.9$.

$$\frac{P_0-P}{\rho}=32\frac{u_0}{\alpha^2}\sum_{k=1}^{\infty}\frac{J_2(\alpha\lambda_k)}{\lambda_k^2J_0^2(\lambda_k)}\left[\left(\frac{\nu\,\mathrm{Re}}{R}-u_0\right)J_0\left(\lambda_k\frac{r}{R}\right)+u_0J_0(\lambda_k)\left(1-\exp\left(-\frac{\lambda_k^2}{R\cdot\mathrm{Re}}z\right)\right)\right]+\frac{8u_0\nu}{R^2}z. \quad (27)$$

According to the graphs provided in the figures above, the length of the stabilization section is obtained under the following conditions: when $\bar{r}=0$ the velocity equals , $\frac{u}{u_0}=0.99$ we obtain $\bar{z}=$ 0.163.

To obtain the pressure distribution function in the sudden expansion section, we substitute the values of C_k coefficient from Eq. (25) into Eq. (20), and arrive at the following.

Conclusion

The proposed universal method, designed for calculating velocity rearrangement in the transitional area, makes it possible to find the regular patterns in hydrodynamic parameter changes under general boundary conditions. The use of the relations that we discovered has defined the process of velocity field changes during sudden cross-sectional expansion, provided that the presence of fluid is constant and the parabolic distribution law conditions are met. This makes it possible to calculate the changes in the hydrodynamic flow parameters, as well as make generalizations. The regularities characterizing the velocity field changes in the transitional area, along with the diagrams that illustrate them, allow for correcting the design of the relevant hydromechanical equipment units.

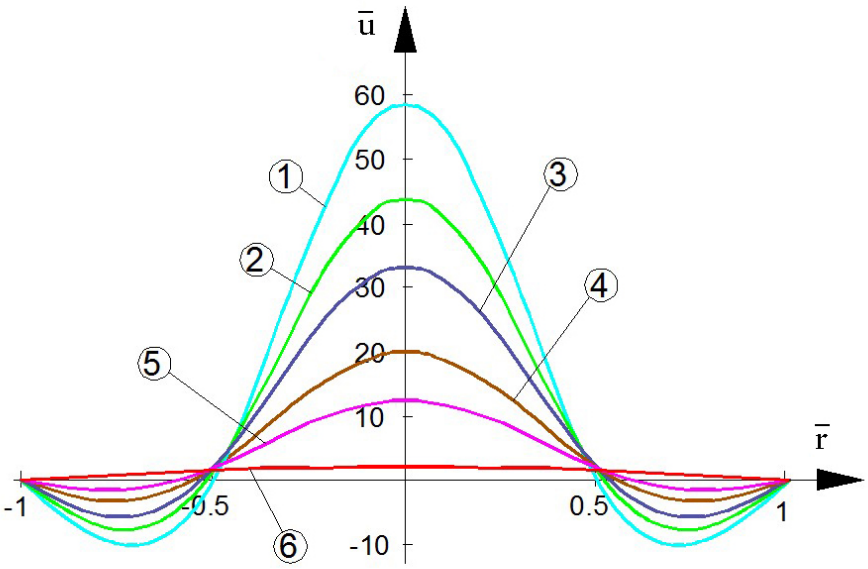

Figure 5. Superimposed graphs of lengthwise velocity change in the transitional area:
1. $\bar{z}$ = 0.04; 2. $\bar{z}$ = 0.05; 3. $\bar{z}$ = 0.06; 4. $\bar{z}$ = 0.08; 5. $\bar{z}$ = 0.1; 6. $\bar{z}$ = 0.2

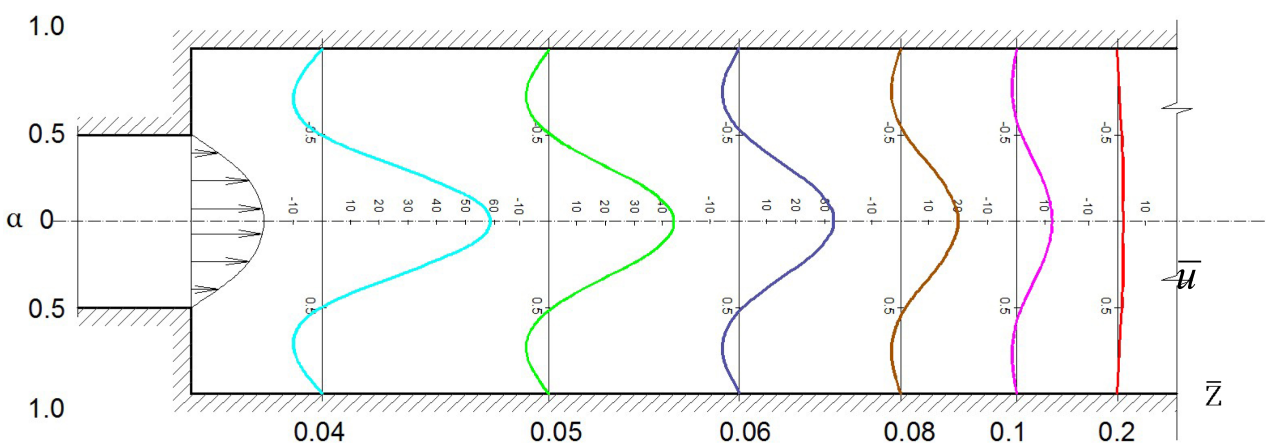

Figure 6. Curves of lengthwise velocity change in the transitional area depending on $\bar{z}$ and $\bar{r}$ coordinates

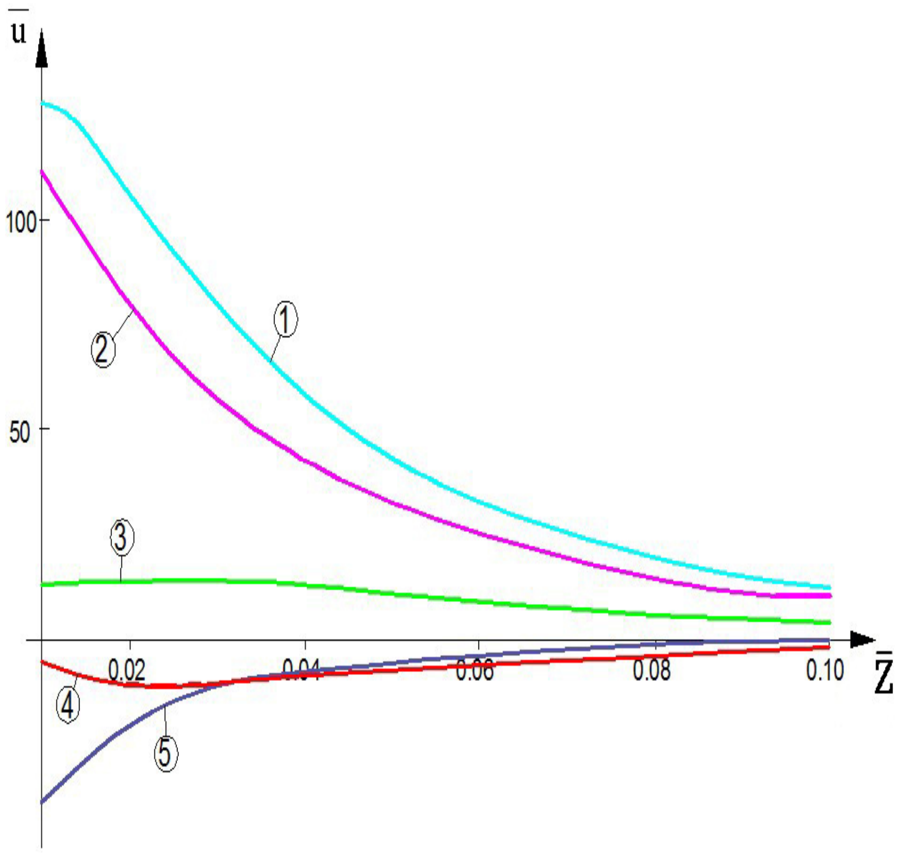

Figure 7. Velocity change in $\overline{r} = 0; 0.4; 0.8; 0.9$ points of the effective cross-section:
1. $\overline{r} = 0$; 2. $\overline{r} = 0.2$; 3. $\overline{r} = 0.4$; 4. $\overline{r} = 0.8$; 5. $\overline{r} = 0.9$

References

Belyaev, L. A., Zaitsev, A. S., Kondakov, A. A., Shevelev, S. A., Valkov, E. P. and Matveeva, A. A. (2015). Numerical analysis of fluid particles motion in curved ducts. *MATEC Web of Conferences,* Vol. 37, 01007. DOI: 10.1051/matecconf/20153701007.

Boussinesq, J. (1891). *Comptes rendus hebdomadaires des séances de l'Académie des sciences*, Vol. CXII (1), pp. 9–14, 49–51.

Chen, R.-Y. (1973). Flow in the entrance region at low Reynolds numbers. *Journal of Fluids Engineering*, Vol. 95, Issue 1, pp. 153–158. DOI: 10.1115/1.3446948.

Durst, F., Ray, S., Ünsal, B. and Bayoumi, O. A. (2005). The development lengths of laminar pipe and channel flows. *Journal of Fluids Engineering,* Vol. 127, Issue 6, pp. 1154–1160. DOI: 10.1115/1.2063088.

Fester, V., Mbiya, B. and Slatter, P. (2008). Energy losses of non-Newtonian fluids in sudden pipe contractions. *Chemical Engineering Journal*, Vol. 145, Issue 1, pp. 57–63. DOI: 10.1016/j.cej.2008.03.003.

Gücüyen, E., Erdem, R. T. and Gökkuş, Ü. (2019). Numerical modelling of sudden contraction in pipe flow. *Sigma: Journal of Engineering and Natural Sciences,* Vol. 37, No. 3, pp. 903–916.

Hava, T. and Rusak, Z. (2000). Viscous flow in a slightly asymmetric channel with a sudden expansion. *Physics of Fluids,* Vol. 12, Issue 9, pp. 2257–2267. DOI: 10.1063/1.1287610.

Hornbeck, R. W. (1964). Laminar flow in the entrance region of a pipe. *Applied Scientific Research, Section A*, Vol. 13, pp. 224–232. DOI: 10.1007/BF00382049.

Letelier, S. M. F. and Leutheusser, H. J. (1983). Unified approach to the solution of problems of unsteady flow in long pipes. *Journal of Applied Mechanics,* Vol. 50, Issue 1, pp. 8–12. DOI: 10.1115/1.3167023.

Loitsyansky, L.G. (1973). *Fluid and gas mechanics. 4th edition.* Moscow: Nauka, 847 p.

Mohanty, A. K. and Asthana, S. B. L. (1979). Laminar flow in the entrance region of a smooth pipe. *Journal of Fluid Mechanics*, Vol. 90, Issue 3, pp. 433–447. DOI: 10.1017/S0022112079002330.

Mullin, T., Seddon, J. R. T., Mantle, M. D. and Sederman, A.J. (2009). Bifurcation phenomena in the flow through a sudden expansion in a circular pipe. *Physics of Fluids,* Vol. 21, Issue 1, 014110. DOI: 10.1063/1.3065482.

Rocha, G. N., Poole, R. J. and Oliveira, P. J. (2007) Bifurcation phenomena in viscoelastic flows through a symmetric 1:4 expansion. *Journal of Non-Newtonian Fluid Mechanics*, Vol. 141, Issue 1, pp. 1–17, DOI: 10.1016/j.jnnfm.2006.08.008.

Sarukhanyan, A., Vartanyan, A., Vermishyan, G. and Tokmajyan, V. (2020). The study of hydrodynamic processes occurring on transition of sudden expanding of hydraulic section of plane – parallel full pipe flow. *TEM Journal*, Vol. 9, Issue 4, pp. 1494–1501. DOI: 10.18421/TEM94-23.

Schiller, L. (1936). *Fluid flow in pipes*. Moscow – Leningrad: Joint Scientific and Technical Publishing House (ONTI).

Schlichting, H. (1934). Laminare Kanaleinlauf Strömung. *ZAMM*, No. 14, pp. 368–373.

Schlichting, H. (1974). *Theory of boundary layer*. Moscow: Nauka, 711 p.

Slyozkin, N. A. (1955). *Dynamics of viscous incompressible fluid*. Moscow: Gostekhizdat, 520 p.

Sparrow, E. M., Lin, S. H. and Lundgren, T. S. (2004). Flow development in the hydrodynamic entrance region of tubes and ducts. *The Physics of Fluids,* Vol. 7, Issue 3, 338. DOI: 10.1063/1.1711204.

Targ, S. M. (1951). *Fundamental problems of the theory of laminar flow*. Moscow: Gostekhizdat, 420 p.

Yemtsev, B. T. (1978). *Technical hydrodynamics*. Moscow: Mashinostroyeniye, 463 p.

Young, F. J. (2016). The entrance region of circular pipes revisited. *Open Access Library Journal*, Vol. 3, No. 7, pp. 1–7. DOI: 10.4236/oalib.1102675.

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DISTRIBUTION OF THE NORMAL REACTIONS ON THE QUANTOMOBILE WHEELS

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Abstract
Introduction: The progress of science has made it possible to create new quantum engines (QEs) powered by physical vacuum energy. A QE will generate a vector-based propulsive force, or thrust, applicable to the vehicle body directly, with no transmission required. Traditional cars will be upgraded with QEs and thus converted into quantomobiles. QE thrust application at the point of the vehicle body, hovering above the bearing surface, introduces changes in the traditional diagram of forces acting on the vehicle. Therefore, it is necessary to assess the influence of thrust on the longitudinal stability of the quantomobile. **Methods:** In the course of the study, we upgraded the diagram of forces acting on the traditional vehicle, by introducing QE thrust (bearing in mind vehicle hovering above the bearing surface). We also developed a corresponding mathematical model for the distribution of the normal reactions on the wheels, taking into account QE placement. **Results:** Among the developed calculation complexes to perform a qualitative analysis of the influence of force factors on the quantomobile chassis load, a complex representing the longitudinal thrust and the thrust height was distinguished. **Discussion:** These complexes may serve as the basis of calculation units for more detailed programming, analysis, and synthesis of the design of vehicles with QEs, assessment of the longitudinal stability of the vehicle, optimization of QE placement in the quantomobile body. **Example:** The method developed is presented using a quantomobile similar to a KamAZ-4326 automobile. **Conclusion:** The considered diagram of forces acting on a quantomobile, including QE thrust above the bearing surface, shall become generic for force diagrams of quantomobiles with additional thrusters intended to increase the longitudinal stability of the vehicle.

Keywords
Quantum engine, quantomobile, force balance, wheel normal reactions, longitudinal stability

Introduction

The progress of science has created prerequisites for the emergence of entirely new propulsion systems – quantum engines (QEs). The implementation of advanced ideas – e.g., Leonov's quantum engine (Leonov, 2002, 2010) – will make it possible to extract energy from the physical vacuum, by using vehicle power units. A new generation of vehicles with quantum engines – quantomobiles – will replace automobiles (Kotikov, 2018c).

A QE will generate a vector-based propulsive force, or thrust, applicable to the vehicle body directly, with no transmission required (Kotikov, 2018a, 2018c; Leonov, 2010). The wheeled chassis will lose its function as a propulsion unit but will remain a support in the ground movement of the quantomobile (Kotikov, 2019a, 2019b, 2019d, 2019e, 2020). All wheels will become driven.

QE thrust application at the point of the vehicle body, hovering above the bearing surface, introduces changes in the traditional diagram of forces acting on the vehicle. The points of thrust emergence (application) in the wheel contact patches within traditional kinematic diagrams will move towards the points of QE (thruster) thrust vector application to the vehicle body. The vehicle body may have several thrusters.

On the threshold of QE introduction, it is required to develop corresponding kinematic diagrams, which will be quite useful at the early stages of designing quantomobiles and their structural subclasses. The paper addresses the generic scheme of quantomobile movement along the inclined bearing surface where the QE generates longitudinal thrust only. We focus on methodological developments regarding the assessment of the overturning moment caused by QE thrust and assurance of the longitudinal stability of the quantomobile.

Analysis of the normal reactions on the quantomobile wheels

By using the diagram for the determination of the normal reactions R_z on the automobile wheels, presented by Volkov (2018), but in Selifonov's notation (Selifonov et al., 2007), we will consider its transformation for the quantomobile. Figure 1 shows the following: V_q – the velocity vector when moving along a section of the bearing surface (at an angle α to the horizon); C_g – the vehicle center of gravity (CoG); G_q and G_q' – the gravity force and its projection onto the vertical axis of the vehicle; F_{Tx}, F_w, F_j, F_α, F_{f1}, and F_{f2} – the QE longitudinal thrust, wind resistance, reduced vehicle inertia force, climbing force, resistance against the rolling of the front and rear wheels, respectively; T_{f1} and T_{f2} – the rolling resistance moments; h_w, h_{FTx}, h_g – the distance of the vectors of the corresponding forces F_w, F_{Tx}, F_j, and F_α from the bearing surface; L, L_1, and L_2 – the wheelbase and the distance from the wheel axles to the CoG projection onto the bearing surface; A and B – the central points of the contact patches; R_{z1} and R_{z2} – the normal reactions to be determined; Q – the point of QE thrust application to the vehicle body.

The sum of the moments with respect to point B of the rear wheels is as follows:

$$\sum T_B = R_{z1} \cdot L + G_q \cdot \sin\alpha \cdot h_g + m' \cdot \alpha \cdot h_g + 0.5 \cdot c_x \cdot \rho \cdot S_{front} \cdot V_q^{\,2} \cdot h_w - G_q \cdot \cos\alpha \cdot L_2 + T_{f1} + T_{f2} - F_{Tx} \cdot h_{FTx} = 0, \tag{1}$$

where:

c_x – the wind shape coefficient;

ρ – the air density, kg/m^3;

S_{front} – the frontage area of the quantomobile, m^2;

m' – the reduced vehicle mass (with account for the rotational inertia of the wheels), kg;

a – the acceleration of the quantomobile, m/s^2.

For the reduced vehicle mass, the following is true: $m' = m \cdot \delta_{ric} = (G_q/g) \cdot \delta_{ric}$, where δ_{ric} – the rotational inertia coefficient of the wheels. In the case of quantomobiles, this coefficient takes into account only the rotation of the carrying wheels since there are no rotating power drive parts (an ICE with a flywheel, a clutch coupling, a gearbox, a final drive).

Let us take into account that $T_{f1} + T_{f2} = f R_{z1} r_d + f R_{z2} r_d = (R_{z1} + R_{z2}) f r_d = G_q \cos\alpha\, f r_d$, where r_d – the dynamic radius of the wheel. In this section, we will not reveal the structure of the coefficient of resistance to the rolling of the wheels f, bearing in mind that it represents the velocity function.

Based on the sum of the moments (1), R_{z1} can be expressed as follows:

$$R_{z1} = \frac{G_q \cdot L_2}{L} \left(\begin{array}{l} (\cos\alpha - \frac{h_g}{L_2} \cdot \sin\alpha) - (\frac{c_x \cdot \rho \cdot S_{front} \cdot V_q^{\,2}}{2 \cdot G_q \cdot L_2} \cdot h_w) \\ -(\frac{a}{g} \cdot \frac{h_g}{L_2} \cdot \delta_{ric}) - (\cos\alpha \cdot f \cdot \frac{r_{\ddot{a}}}{L_2}) + (\frac{F_{Tx} \cdot h_{FTx}}{G_q \cdot L_2}) \end{array} \right). \tag{2}$$

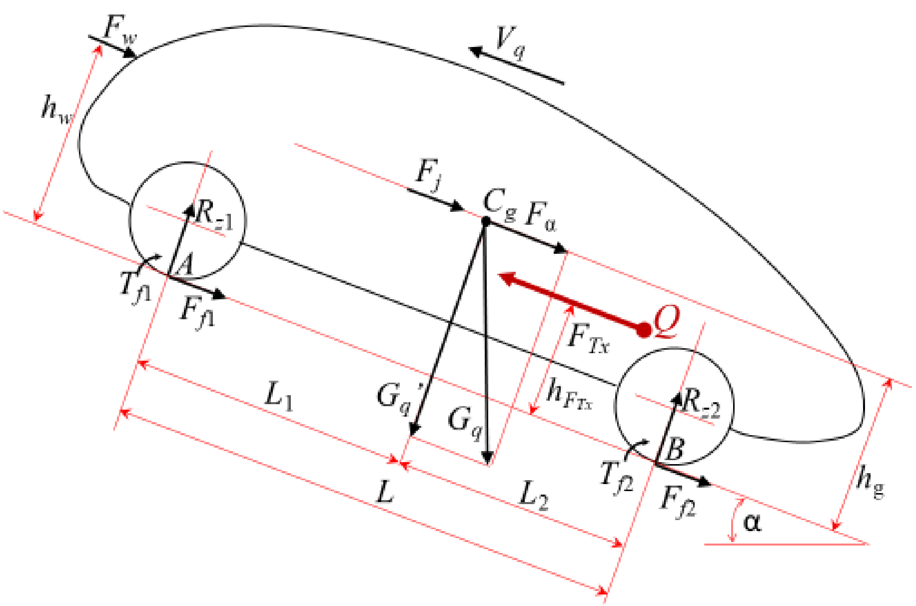

Figure 1. A computational model for the normal reactions on the quantomobile wheels

It seems that the following form will be more convenient in the analysis of the quantomobile configuration:

$$R_{z1} = \frac{G_q}{L}\begin{pmatrix} (\cos\alpha(L_2 - f \cdot r_{\ddot{a}}) - h_g \cdot \sin\alpha) - \\ (\frac{c_x \cdot \rho \cdot S_{front} \cdot V_q^2}{2 \cdot G_q} \cdot h_w) - \\ (\frac{a}{g} \cdot h_g \cdot \delta_{ric}) + (\frac{F_{Tx} \cdot h_{FTx}}{G_q}) \end{pmatrix} = \quad (3)$$

$$= \frac{G_q}{L}(k_{\varphi n2} - k_{wn} - k_{jn} + k_{FTxn}).$$

Here, we introduce notations (that differ significantly from Selifonov's notation (Selifonov et al., 2007) for the complexes having the length dimension, each of which represents a share in the shift of the center of dynamic equilibrium in the normal reactions of the vehicle axles.

$k_{\psi n2} = (\cos\alpha(L_2 - f \cdot r_{\ddot{a}}) - h_g \cdot \sin\alpha)$ – the complex of values, describing the interaction between the wheels and the bearing surface. In the case of a horizontal bearing surface, it is reduced to the following: $k_{\psi n2} = (L_2 - f \cdot r_{\ddot{a}})$, where $f \cdot r_d$ represents the shift of the point of dynamic equilibrium from the GoG projection on the bearing surface (due to the presence of the rolling resistance moments T_{f1} and T_{f2}).

$k_{wn} = (\frac{c_x \cdot \rho \cdot S_{front} \cdot V_q^2}{2 \cdot G_q} \cdot h_w)$ – the complex taking into account the influence of wind resistance on the normal reactions;

$k_{jn} = (\frac{a}{g} \cdot h_g \cdot \delta_{ric})$ – the complex taking into account the influence of the longitudinal acceleration of the vehicle on the normal reactions;

$k_{FTxn} = (\frac{F_{Tx} \cdot h_{FTx}}{G_q})$ — the complex taking into account the value of the QE longitudinal thrust and its height relative to the bearing surface.

The same holds for R_{z2} reaction but using the sum of the moments with respect to point *A*. Thus, we will obtain the following for R_{z2}:

$$R_{z2} = \frac{G_q}{L}\begin{pmatrix} (\cos\alpha(L_1 + f \cdot r_{\ddot{a}}) + h_g \cdot \sin\alpha) \\ +(\frac{c_x \cdot \rho \cdot S_{front} \cdot V_q^2}{2 \cdot G_q} \cdot h_w) + \\ (\frac{a}{g} \cdot h_g \cdot \delta_{ric}) - (\frac{F_{Tx} \cdot h_{FTx}}{G_q}) \end{pmatrix} = \quad (4)$$

$$= \frac{G_q}{L}(k_{\varphi n1} + k_{wn} + k_{jn} - k_{FTxn}).$$

Let us note that the representation of the result of the interaction between the second axle wheels and an inclined bearing surface differs from the previous one:

$$k_{\psi n1} = (\cos\alpha(L_1 + f \cdot r_{\ddot{a}}) + h_g \cdot \sin\alpha).$$

Discussion

The $k_{\psi n1}$, $k_{\psi n2}$, k_{wn}, k_{jn}, k_{FTxn} coefficients represent convenient complexes for qualitative analysis of the influence of force factors on the quantomobile chassis load. These complexes have the length dimension (m) and represent the shift of the point of dynamic equilibrium of the normal reactions along the wheelbase L (let us call them linear complexes). They may serve as the basis of calculation units for more detailed programming, analysis, and synthesis of the design of vehicles with QEs, assessment of the overturning moment, optimization of QE placement in the quantomobile body.

The $k_{FTxn} = (\frac{F_{Tx} \cdot h_{FTx}}{G_q})$ complex in Eqs. (3) and (4) is of particular interest since it describes the force leading to the vehicle nosedive (emergence of the longitudinal overturning moment of forces), which is directly proportional to QE thrust and its height. If we remove the parentheses in Eq. (3) and analyze the $R_{s1} = \ldots + \frac{F_{Tx} \cdot h_{FTx}}{L}$ fragment, we will see that the share of QE thrust action in the vehicle nosedive is inversely proportional to the wheelbase of the wheeled chassis of the quantomobile.

As for thrust, it loads the front wheels to the same extent as it unloads the rear wheels (see the signs of the last terms in Eqs. (3) and (4)).

With an increase in the vehicle weight, the nosedive effect is reduced: the increasing total weight G_q in the denominator of the k_{FTxn} complex reduces the value of this complex. However, in this case, we need to bear in mind that the vehicle load shifts the CoG height h_g, thus changing the values of the $k_{\psi n1}$, $k_{\psi n2}$ and k_{jn} complexes. It is obvious that lower values of the CoG height are required.

The issue of the longitudinal stability (neutralization of the overturning moment) of the quantomobile (as compared with the traditional vehicle) is becoming more acute. In automobiles, even the significant overturning moment is reflected (taken up) by the bearing surface (if there is a pressing force of the vehicle weight). In quantomobiles, thrust above the bearing surface creates a significant overturning impulse. Besides, quantomobile hovering (and even its breakoff from the bearing surface (Kotikov, 2019a, 2020)) requires assessment of this moment in order to neutralize negative angles of attack and eliminate the possibility of overturning.

Example. Let us consider a quantitative example of applying the introduced complexes when studying the longitudinal stability of the quantomobile and determining the value of the additional thruster to neutralize the overturning moment. We will examine a quantomobile with specifications similar to those of a KamAZ-4326 race truck considered in the previous studies (Kotikov, 2018a, 2018b, 2018c).

Let us restrict ourselves with a horizontal bearing surface. We will present calculations for the normal loads on the wheels of the front axle, bearing in mind that the load on the wheels of the rear axle at the perceived longitudinal overturning moment (with no vehicle hovering above the bearing surface) will be approximately equal to the difference between the total vehicle weight and the load on the wheels of the front axle. We will also neglect complex aerodynamics (shape of the vehicle body, air flows under the vehicle body, etc.) and use only the generalized aerodynamic coefficient.

To represent resistance against the rolling of the wheels, the following relationship was chosen: $f = f_{wh.0}(1 + f_{wh.V}{\cdot}V_q^2)$, where $f_{wh.0}$ – the coefficient of rolling resistance at the velocity close to zero (during starting), and $f_{wh.v}$ – the velocity coefficient of rolling resistance. Since the height of movement and air density are constant, the model of aerodynamic properties can be simplified: $c_x{\cdot}\rho/2 = k_{w.x}$.

Necessary data on the vehicle:

To perform a qualitative analysis, we chose a hypothetical quantomobile with the specifications of a similar KamAz-4326 automobile with a QE, under extremely severe conditions of motion: $G_q = 88$ kN; $f_{wh.0} = 0.3$; $f_{wh.V} = 4{\times}10^{-4}$ s²/m²; $k_{w.x} = 0.5$ N×s²/m⁴; $S_{front} = 7$ m²; $\delta_{ric} = 0.04$ (Kotikov, 2019c).

Wheelbase L = 4,250 m; wheelbase components: L_1 = 2,100 m; L_2 = 2,150 m.

Height of force application (Figure 1): h_g = 1.3 m; h_w = 1.6 m; h_{FTx} = 1.0 m.

Maximum (implemented in the example in the entire velocity range) QE thrust value: 90 kN.

Let us use the graphic representation that was taken earlier for the quantomobile force balance analysis (Figure 2) (Kotikov, 2019a):

We used the following force balance equation for steady motion along a horizontal bearing surface:

$$P_x = \begin{pmatrix} f_{wh.0}\left(1 + f_{wh.v}\cdot V_q^2\right)\right)\cdot \\ G_q + k_{w.x}\cdot S_{front}\cdot V_x^2 \end{pmatrix}. \qquad (5)$$

The remainder of the force $F_{Tx} - P_x = P_a$ was used as the acceleration margin; at $F_{Tx.max} = G_q$, the corresponding area is highlighted in light green in Figure 2, and acceleration at $F_{Tx.max}$ is represented by the green *AB* line.

For $f_{wh.0}$ = 0.3, three zones are highlighted in Figure 2: wind resistance (blue), resistance of the bearing surface (yellow), vehicle acceleration margin (green). Figure 2 also shows the acceleration curve *AB* upon complete depletion of the thrust margin highlighted in green. It is possible to alter the zones for different values of $f_{wh.0}$ in a similar way.

Table 1 shows the results of calculating the complexes described above and presented in *Eq*. (3) for six velocity cross-sections of the quantomobile (Figure 2) at thrust F_{Tx} = 90 kN, accelerating from 0 to 67.2 m/s, which is the maximum velocity for this thrust value.

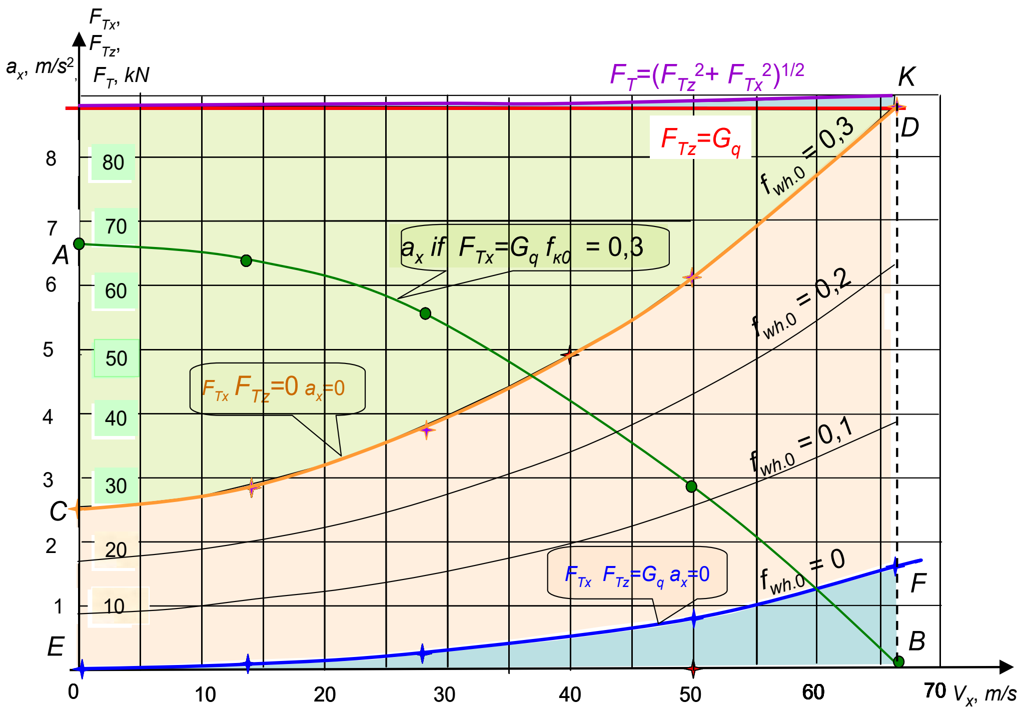

Figure 2. Quantomobile force balance when moving along the bearing surface with fwh.0 = 0.3 (fwh.0 = 0.1 and 0.2 — additionally)

Table 1. Calculated values of the linear complexes for different quantomobile acceleration points

State, velocity	Acceleration, m/s^2	Complex $k_{\psi n1}$ components		Complexes, m				Location of the point of dynamic equilibrium
		L_2	$f{\cdot}r_d$	$k_{\psi n1}$	k_{wn}	k_{jn}	k_{FTxn}	$\sum k_i$, m
1. Standstill condition	0	2.15	0	2.15	0	0	0	2.15
2. Starting	6.7	2.15	–0.15	2.00	0	–0.923	1.023	2.10
3. 13.9 m/s	6.35	2.15	–0.17	1.98	–0.012	–0.876	1.023	2.115
4. 27.8 m/s	5.55	2.15	–0.20	1.95	–0.049	–0.765	1.023	2.159
5. 50.0 m/s	2.9	2.15	–0.31	1.84	–0.159	–0.400	1.023	2.304
6. 67.2 m/s	0	2.15	–0.43	1.72	–0.287	0	1.023	2.456

Table 1 shows that, for instance, at the maximum velocity, the point of dynamic equilibrium shifts at a distance of 2.456 – 2.15 = 0.306 m as compared with the position in the standstill condition.

If we shift to load units, the analysis may be just as informative. Let us transform Eq. (3) as follows:

The four obtained complexes have the force dimension and represent the share of each of them in the formation of the total normal load on the wheels of the same axle (let us call these force complexes). Table 2 shows the result of calculating these complexes for the same six vehicle states during acceleration.

$$\frac{G_q}{L}(k_{\psi n2} - k_{wn} - k_{jn} + k_{FTxn}) = R_{z\_\psi} - R_{z\_w} - R_{z\_j} + R_{z\_FTx}. \quad (6)$$

Table 2. Calculated values of the force complexes for different quantomobile acceleration points

State, velocity, m/s	Accel-era-tion, m/s2	Load on the front axle in the stand-still con-dition, kN	Share of the load from rolling resist-ance, kN	Contribution of the complexes in the normal load on the front wheels during longitudinal motion, kN				Load on the front wheels in mo-tion, kN	Load on the rear wheels in mo-tion, kN	Differ-ence be-tween the normal loads on the axles, kN	Over-turning mo-ment, kNm
		$R_{z1.st}$	$\frac{f{\cdot}r_d}{G_q/L}$	R_{z_ψ}	R_{z_w}	R_{z_j}	$R_{z\_}F_{Tx}$	R_{z1}	R_{z2}	R_{z1}-R_{z2}	T_y
Standstill condition	0	44.5	0	0	0	0	0	44.5	43.5	1.0	4.25
Starting	6.7	44.5	–3.17	41.33	0	–19.1	21.19	43.42	44.58	–1.16	–4.93
13.9	6.35	44.5	–3.42	41.08	–0.25	–18.1	21.19	43.92	44.08	–0.16	–0.68
27.8	5.55	44.5	–4.14	40.36	–1.02	–15.8	21.19	44.73	43.27	1.46	6.20
50.0	2.9	44.5	–6.34	38.16	–3.29	–8.29	21.19	47.77	40.23	7.54	32.04
67.2	0	44.5	–8.88	35.62	–5.94	0	21.19	50.87	37.13	13.74	58.40

Table 2 shows that, with the velocity increase, the influence of rolling resistance $(f{\cdot}r_d)$ and wind resistance (R_{z_w}) on the formation of the normal loads on the wheels increases as well. The portion of the load on the wheels, caused by the inertial forces of the vehicle, decreases with the velocity increase (due to the acceleration decrease, see Figure 2).

The thrust of 90 kN, acting longitudinally on the vehicle body at a height h = 1 m (Figure 1), results in an increase in the normal reaction of the front wheels (R_{z_FTx} = 21.19 kN).

The load on the rear wheels R_{z2} can be calculated by using Eq. (4), but in the case of a horizontal bearing surface, the difference $R_{z2} = G_q - R_{z1}$ can be used.

The overturning moment is determined as follows: $T_y = (R_{z1} - R_{z2}) \cdot L$.

The maximum overturning moment T_y = 58.4 kNm occurs at a velocity of 67.2 m/s; this value is quite significant and should be neutralized. The simplest solution is to move the additional thruster having a vertical structure forward at a distance of 2.5 m from the point of dynamic equilibrium (see $\sum k_i$ = 2.456 in Table 1). To ensure stabilization, a force of 58.4 kNm / 2.5 m = 23.4 kN (one fourth of the force of the main thruster) will be required. Without stabilization, such imbalance will result in overturning when moving along a microprofile bearing surface. In the mode of partial or full hovering (Kotikov, 2020), the out-of-limit negative angle of attack will occur.

In the case of changes in the h_w, h_{FTx}, h_g heights (Figure 1) and their combinations, the nature of the contribution of the corresponding forces (and even their signs) in the formation of the normal loads will change as well. In this paper, we have just numerically demonstrated the methodical approach.

The fact that the example provided used the imperfect KamAZ-4326 body shape shows that it is possible to improve significantly the quantomobile aerodynamics and configure the vehicle in the shape of a flying wing (Stepanov, 1963). Then, at high speeds, due to emerging buoyancy, the normal reactions will be distributed in another way, with a decrease in the longitudinal overturning moment (or even its elimination). Nevertheless, the method developed can serve as the basis for further studies, quantomobile configuration design and implementation.

Conclusion

In this paper, we considered the diagram of forces acting on the quantomobile, including thrust generated by a QE (thruster) hovering above the bearing surface. A quantomobile shall have at least three thrusters to ensure not only the longitudinal motion in the pitch plane but roll and yaw control as well (Kotikov, 2018c). The diagram considered shall underlie the formation of multi-thruster diagrams for quantomobile motion and control.

References

Kotikov, Ju. (2018a). Comparative analysis of energy consumption by modern cars and future quantomobiles. *Architecture and Engineering,* Vol. 3, Issue 4, pp. 24–30. DOI: 10.23968/2500–0055–2018–3–4–24–30.

Kotikov, Ju. G. (2018b). Quantomobile: research of formation and imposition of thrust. Bulletin of Civil Engineers, No. 4 (69), pp. 189–198. DOI: 10.23968/1999–5571–2018–15–4–189–198.

Kotikov, Ju. G. (2018c). *Transport energetics: monograph.* Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering, 206 p.

Kotikov, Ju. (2019a). Actualization of the quantomobile force balance in the pitch plane. *Architecture and Engineering,* Vol. 4, Issue 2, pp. 53–60. DOI: 10.23968/2500–0055–2019–4–2–53–60.

Kotikov, Ju. G. (2019b). Calculation research of the quantomobile power balance. *Bulletin of Civil Engineers,* No. 2 (73), pp. 147–152. DOI: 10.23968/1999–5571–2019–16–2–147–152.

Kotikov, Ju. (2019c). Graphical-and-analytical basis for quantomobile near-ground motion studies. *Architecture and Engineering,* Vol. 4, Issue 3, pp. 55–64. DOI: 10.23968/2500–0055–2019–4–3–55–64.

Kotikov, Ju. (2019d). Specifics of the quantomobile force balance. *Architecture and Engineering,* Vol. 4, Issue 1, pp. 3–10. DOI: 10.23968/2500–0055–2019–4–1–3–10.

Kotikov, Ju. G. (2019e). Traction-speed properties of the quantomobile. *Bulletin of Civil Engineers,* No. 1 (72), pp. 168–176. DOI: 10.23968/1999–5571–2019–16–1–168–176.

Kotikov, Ju. (2020). The rise of the quantomobile theory. *Architecture and Engineering,* Vol. 5, Issue 4, pp. 74–81. DOI: 10.23968/2500–0055–2020–5–4–74–81.

Leonov, V. S. (2002). *Method of creating thrust in vacuum and field engine for spacecraft (versions).* Patent No. RU2185526C1.

Leonov, V. S. (2010). *Quantum energetics. Vol. 1. Theory of Superunification.* Cambridge: Cambridge International Science Publishing, 745 p.

Selifonov, V. V., Khusainov, A. Sh. and Lomakin, V. V. (2007). *Automobile theory: study guide.* Moscow: Moscow State Technical University “MAMI”, 102 p.

Stepanov, G. Yu. (1963). *Hydrodynamic theory of air-cushion vehicles.* Moscow: Mashgiz, 94 p.

Volkov, Ye. V. (2018). *Car motion theory: monograph.* Khabarovsk: Publishing House of Pacific National University, 204 p.

РАСПРЕДЕЛЕНИЕ НОРМАЛЬНЫХ РЕАКЦИЙ НА КОЛЕСАХ КВАНТОМОБИЛЯ

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Аннотация
Продвижение научно-технической мысли обозначило возможность создания квантовых двигателей (КвД), использующих энергию физического вакуума. КвД будет создавать векторную тяговую силу (траст), которую можно непосредственно, исключая трансмиссию, прикладывать к корпусу экипажа для его движения. Классический автомобиль при установке на нем КвД трансформируется в квантомобиль. Приложение силы тяги КвД (траста) в вывешенной над опорной поверхностью точке корпуса экипажа меняет традиционную схему сил, действующих на экипаж. Возникает необходимость оценки влияния действия траста на продольную устойчивость квантомобиля. **Методы:** Применен метод модернизации схемы сил, действующих на классический автомобиль, путем введения траста КвД, вывешенного над опорной поверхностью. Построена соответствующая математическая модель распределения нормальных реакций на колесах, учитывающая размещение КвД. **Результаты:** Среди сформированных расчетных комплексов для качественного анализа влияния силовых факторов на загрузку шасси квантомобиля выделен комплекс, представляющий продольную силу тяги и высоту расположения траста КвД. **Обсуждение:** Комплексы могут явиться основой расчетных блоков для более детализированного программирования, анализа и синтеза конструкции экипажа с КвД, оценки продольной устойчивости экипажа, оптимизации размещения КвД в корпусе квантомобиля. **Пример:** Демонстрация методики осуществлена на примере квантомобиля-аналога КамАЗ-4326. **Заключение:** Рассмотренная схема сил, действующих на квантомобиль, включающая тяговую силу КвД (траст), реализуемую над опорной поверхностью, должна стать родовой (generic) для формирования силовых схем квантомобилей с дополнительными трастерами для повышения продольной устойчивости экипажа.

Ключевые слова
Квантовый двигатель, квантомобиль, силовой баланс, нормальные реакции на колеса, продольная устойчивость.

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