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Rail Track for Light Rail Transit Systems


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ABSTRACT

The analysis of the well-known designs and technologies for manufacture of rail tracks for light rail transit (LRT) allows to assess trends in development of this type of transportation, as well as to reveal an underestimation of public rail transport referring to the existing «tendency to eliminate tram traffic» in several Russian cities, despite the problems of urban ground passenger transport associated with a limited resource of urban space.

The prospects for development of urban ground passenger transport systems of LRT type were considered regarding adoption of new types of rolling stock, infrastructure development, reduction of costs and time of renewal of existing and construction of new tracks.

The objective of this article is to present an option of a rail track design for LRT considering its structural and technological features, as well as comparative assessment of its technical and economic indicators. The research method is based on the analysis of the current state, prospects, and trends in development of LRT in Russia, which made it possible to propose a solution to the existing problem of urban passenger transport. Research was reflected in relevant patents, in pending applications for alleged inventions, as well as in experience of manufacturing full-scale samples.

Comparative assessment referred to the known designs of sleeper and sleeperless, ballast and ballastless track used for light rail transit.

A prefabricated, two-level structure of a ballastless rail track for light rail transit is suggested. The design consists of a pile foundation with superposed longitudinal sleeper track connected by transverse braces. The design and technological features, as well as advantages of the proposed design in terms of essential indicators are shown in comparison with the known rail track designs for light rail transit.

It is shown that the proposed track design makes it possible to develop a self-sufficient, self-organising logistics system and to quickly proceed with permanent construction, processing passenger traffic and cargo flows. Since the concept of «from infrastructure to facility» is replaced by the concept of «from facility to infrastructure», it allows development of the facility to outpace development of transport infrastructure, as a costly system with a distant payback.

Keywords: light rail transit, tram lines, rapid tram transit, sleeperless foundation, ballastless foundation, self-organising logistics system.

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INTRODUCTION

Currently, there is some uncertainty in assessing the prospects for development of light rail transit. On the one hand, the problems of urban ground passenger transport associated with a limited resource of urban space are highlighted, and on the other hand, there is an underestimation of the role of public rail transport in solving this problem, along with «trends to eliminate tram traffic» [1, p. 6] in several Russian cities.

The underestimation of public rail transport is becoming more and more noticeable as the number of individual cars grows, which leads to an increase in traffic jams and a sharp (up to 7–10 km/h) decrease in the speed of the traffic flow.

Traditional and high-speed trams are commonly referred to as light rail transit (LRT). Their traffic carried out both within the general traffic flow on city streets, and within an autonomous system, on dedicated sections of the track, which, in the case of rough or hilly terrain, can be carried out on overpasses [2]. The International Association of Public Transport (UITP) understands LRT as electric rail transport, which is developing from a tram to a high-speed transport system operating on partially separated tracks (i.e., separation is not required throughout the route) [1, p. 14; 3]. At the same time, rapid tram lines include sections of tram lines with a length of at least 2 km, on which design speeds of up to 21 km/h or more are achieved during peak hours [1, p. 14]. According to Code of rules[1], the main feature of LRT is the limited permissible axle load, as well as the fact that there is no need for a completely autonomous space to organise its safe operation. This predetermines the good prospects for LRT, which is confirmed by the evolution of this type of transportation in many countries. Having a 1,5–2 times lower permissible axle load compared to the metro, LRT has a lower cost of construction per 1 km of track.

However, even such costs for cities with a population of up to 1,5–2 million and its low density are significant, which makes the issue of development of LRT in such cities debatable and requires a comprehensive justification. As an alternative solution for small towns, one should consider the construction of an LRT line of a length of only a few kilometres along a limited number of corridors, with a passenger flow of at least 1,5 thousand passengers per hour [2].

The *objective* of this article is, based on the research: to present an option of the design of rail track for LRT with a consideration of its structural and technological features followed by comparative assessment of its technical and economic indicators; based on the proposed option of LRT track design and the relevant patents and applications for alleged inventions, as well as on the experience in manufacturing full-scale samples of the proposed LRT track, to consider a possible concept for its development, providing a solution to existing and potential problems of urban passenger and industrial transport.

An analysis of the current state of LRT in Russia used as a research *method* made it possible to identify the prospects for and trends in development of this type of transportation considering the diversity of conditions for development of transport infrastructure in different cities.

RESULTS

Problems and Prospects for LRT Development

The advantages of light rail «over other types of urban ground passenger transport, include in particular: increase in the speed of traffic and reduced average time of access to transportation in urban agglomerations, environmental friendliness, vehicle unit capacity, low costs for transportation per passenger (40 % lower than in a bus), durability (life cycle is up to 35 years)» [1, p. 5]. A very important advantage of LRT is the most efficient use of a limited resource of urban space [1; 6].

However, despite the «advantages of LRT over other types of urban ground passenger transportation, today in Russia, the number of cities with tram systems is decreasing and the tendency to eliminate tram traffic prevails. According to 2018 data, tram traffic existed in 61 cities in Russia, while tram traffic was suspended: in 2007 – in Astrakhan; in 2008 – in Ivanovo; in 2009 – in Voronezh; in 2010 – in Ryazan; in 2013 – in Noginsk (Moscow region); in 2015 – in Dzerzhinsk (Nizhny Novgorod region); in 2018 – in Tver and Komsomolsk-on-Amur (Khabarovsk region)» [1, p. 6].

Despite the noted negative trend towards the degradation of the tram system up to its complete closure, there are also elements showing

[1] SP 84.13330.2016. Code of rules. Tram tracks. Updated version of SNiP III-39-76. In force from 2017–06–17. Federal Agency for Technical Regulation, 36 p. [Electronic resource]: https://docs.cntd.ru/document/456054203. Last accessed 16.08.2022.

a positive trend that are manifested in development of projects for creation of new rail transport systems (in particular, using the existing infrastructure), including projects aimed at modernising and developing rail transport in a number of cities of the Russian Federation: Kaliningrad, Samara, Vladivostok, St. Petersburg [4]. Work is underway on a project for a rapid tram line that will connect the east of the capital city with Balashikha near Moscow [5].

In addition, within the framework of the research work «Development of a transport strategy for Novosibirsk region until 2030», «urban rail transport is singled out as a separate subsection, similar to a separate subparagraph in the Transport strategy of the Russian Federation»[2], which provides for «development of urban rail transport in the core of *public passenger transport* in Novosibirsk agglomeration»[3]. In particular, «The tram development strategy provides for development of a Sectoral model for integrated development of rapid and conventional tram systems with separate stages of construction and of a feasibility study; reconstruction of the existing tram network with separation of track sections»[3].

A possible shift in distribution of total passenger traffic between different types of transport in favour of rail transport can be facilitated by its large carrying capacity, a high level of comfort, environmental friendliness, and aesthetics.

Besides, promising can be the application of the concept, called tram-train, which provides for the connection of the urban rail transport network with the suburban railway network. Through it, the use of dual-system cars ensures their circulation both on tram lines and on electrified lines of suburban railways. So, tram rolling stock, leaving a city, follows the suburban railway line to reach another one, and within the city limits it circulates along tram lines [1; 6].

To a large extent, the negative trends associated with functioning of tram systems are due to the problem of underfunding, «the solution to which can be facilitated by the implementation of projects for development of LRT networks with involvement of extrabudgetary sources on the terms of public-private partnership» [1, p. 3].

Known Track Construction Design and Technologies for LRT

According to mentioned SP[1], the main parts of the tram track structure that absorb the load from wheels of the tram car and transfer them to the roadbed include rails, under-rail base (sleepers or a solid reinforced concrete base designed to absorb loads from rails and transfer them to the ballast layer or roadbed). At the same time, the well-known tram track structures can be divided into two large groups: I – with foundations with sleepers; II – sleeperless ones. Tracks without sleepers can be divided into two subgroups: II, a – with ballast; II, b – without ballast. The requirements imposed on their design are the same as for the railway track, besides, there are requirements imposed due to the movement of non-rail transport along tram tracks.

The rail track, with a sleeper base made in the form of a track grid, is the most common. This predetermines one of its main operational advantages, since for its construction and maintenance, e.g., track facilities divisions of JSC Russian Railways can use various track machines that move along the railway track [7]. At the same time, along with them, when building an LRT track in an urban environment, it is advisable to use dual mode, road-rail track machines, providing the necessary quality of track alignment [8; 9]. Other advantages of the «sleeper track design are low capital costs; ease of maintenance and upgrade; sufficiently long service life» [10, p. 18].

«However, along with the advantages, the base made of crushed stone ballast also has a significant drawback. So, …the presence of voids distributed between its particles ranging in size from 20 to 60 mm, with dynamic compression of the ballast, under the impact of rolling stock, leads to its sedimentation, and displacement and abrasion of crushed stone particles lead to its destruction. It is possible to optimise the superstructure of the ballast track by increasing the area of contact between the reinforced concrete sleepers and the ballast» [10, pp. 18, 21].

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[2] Transport strategy of the Russian Federation until 2030 with a forecast for the period until 2035. Decree of the Government of the Russian Federation No. 3363–3 dated November 27, 2021 [Electronic resource]: http://publication.pravo.gov.ru/Document/View/0001202112030006. Last accessed 16.08.2022.

[3] Research work «Development of a transport strategy for Novosibirsk region until 2030», pp. 42–43 [Electronic resource]: http://vseon.com/analitika/programmy/transportnaya-strategiya-nso-do-2030-goda. Last accessed 16.08.2022.

«Reducing the pressure on the ballast can be achieved by abandoning the transverse sleepers and replacing them with longitudinal sleeper track, the greater bending stiffness of which ensures a more uniform distribution of loads on the ballast» [10, p. 22]. «The simple design of the longitudinal sleepers ensures their easy installation and allows you to place the lawn inside the railway track, which has a beneficial effect on the environment» [10, p. 22]. «The experience of using longitudinal sleepers for tram tracks is known in Poland, and in Russia there is the experience in using longitudinal sleepers namely in the tunnels of the Moscow Metro, where the tracks are embedded in concrete, which does not require transverse elements to maintain the gauge» [10, p. 22]. Known are monolithic design of longitudinal sleepers and a design of a longitudinal sleeper track developed by the authors, consisting of longitudinal sleeper slabs, with rail fasteners installed in them, connected by cross braces made in the form of a prefabricated structure [12]. Thus, a prefabricated, closed, single frame element of the rail track is formed, which is profile-coupled with the longitudinal sleeper slab, and which ensures the formation of straight, transitional, and circular sections of the rail longitudinal sleeper track with the possibility of its alignment in the profile and plan, as well as with the possibility of their element-by-element dismantling.

However, a significant factor hindering widespread introduction of the ballast longitudinal sleeper track is associated with missing of track machines in track divisions that can provide a necessary level of mechanisation of works during track construction and maintenance.

Balastless track design is an alternative to a ballast track, when building large transport facilities within the city [13], the advantages of balastless design include track geometry stability, low cost of its current maintenance. At the same time, «high initial investment in construction pays off due to the lower cost of ongoing maintenance. In addition, important is one of the traditional areas of application of a ballastless track which is a an elevated track» [13, p. 133], which is especially in demand for complex terrain.

«There is a well-known track design consisting of a sleeperless, ballastless NFF (Neue Feste Fahrbahn) foundation of Gleistechnik GmbH of the ThyssenKrupp concern» [10, p. 47], and of the track superstructure of the track, consisting of two longitudinal sleepers connected by rigid crossbars, forming a supporting rail grid.

«Sleeperless bases include structures of a vibration-protective track, consisting of reinforced concrete longitudinal sleepers attached to the rail sole, each of which is placed in a trough-shaped rubber cover, embedded in track concrete. This design provides reduction in vibration and noise, reduction in material consumption for rail fastening parts, increase in labour productivity while manufacturing under-rail base parts, as well as during current maintenance of the track with replacement of the under-rail base» [11, p. 52]. This track design can also be used for industrial transport tracks [13; 14, SP[4]].

Proposed Design and Construction Technology for LRT Track

The design of LRT track proposed below, which is the rational implementation of the ballastless elevated track [1; 10; 13, SP[1]], consists of longitudinal sleeper slabs, with rail fastenings installed in them, and connected by cross braces, made in the form of a prefabricated, two-level structures (Pics. 1–3).

Pics. 1, 2 show a frontal view and a top view of the proposed LRT track, consisting of a monolithic pile support *1*, an element of which is a transverse beam *3*, and a prefabricated frame structure of longitudinal sleeper track *2* installed on them.

The elements of the prefabricated frame structure of the longitudinal sleeper track *2* include support beam *4* of the upper-level transverse connection; elastic elements *5* which according to GOST[5] are made with a surface bevelled at a certain angle and matching with an inclined side surface of the beam *3*; longitudinal sleeper slabs *6*; spacer beam *7*; screw coupling *8*.

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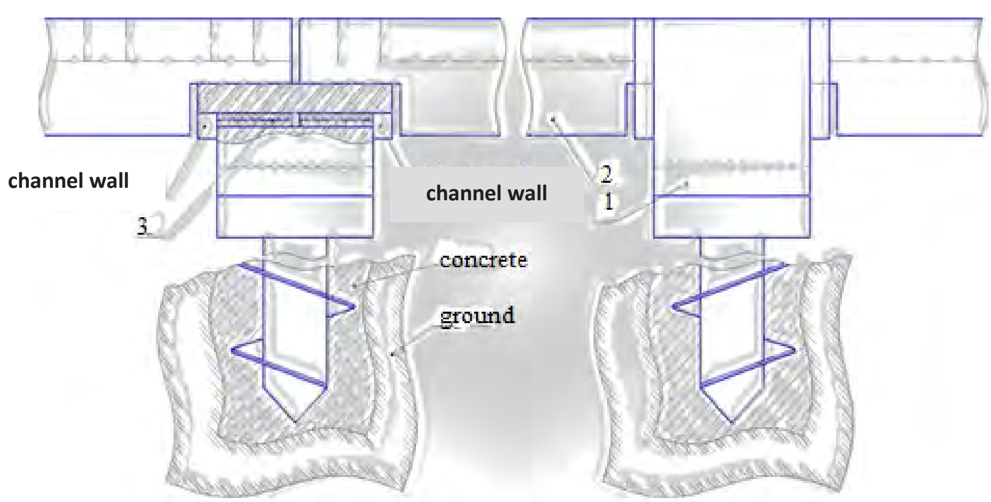
[4] SP 37.13330.2012. Code of rules. Industrial transport. Updated edition of SNiP2.05.07–91. In force from 2013–01–01. [Electronic resource]: https://hseblog.ru/kb/document/2996/files/11810/СП%2037.13330.2012 %20 Промышленный%20транспорт.%20Актуализированная%20редакция%20СНиП%202.05.07–91%20 %28с%20 Изменениями…_Текст.pdf. Last accessed 16.08.2022.

[5] GOST [State standard] 32020 2012. The rubber supporting parts for bridge construction. Technical specifications (EN 1337–1:2000, NEQ) (EN 1337–3:2005, NEQ) (EN 1337–11:1997, NEQ). [Electronic resource]: https://docs.yandex.ru/docs/view?tm=1663591807&tld=ru&lang=ru&name=4293781960.pdf&text=.%20ГОСТ%2032020&url=https%3A%2F%2Ffiles.stroyinf.ru%2FData2%2F1%. Last accessed 16.08.2022.

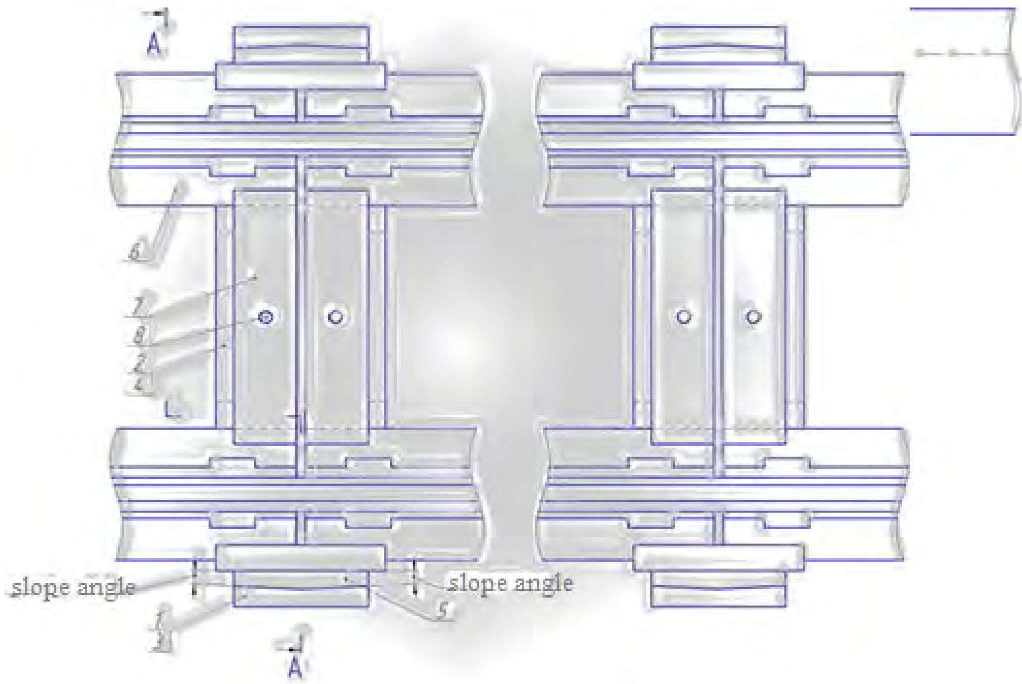
http://www.rzd-expo.ru/innovation/infrastructure/way_and_structures/

Pic. 3 shows the A-A cross-section of the proposed LRT track, which shows the elements of a monolithic pile support *1* and a prefabricated frame structure of the longitudinal sleeper track *2*. The elements of a monolithic pile support *1* include pile supports *9* of a known screw, bored or bored injection design, fixing mounting blocks *10* located on the sides of the transverse beam *3* and formed inside the holes *11*, using the lower metal formwork *12*. At the same time, the ends of the reinforcement of the transverse beam *3* are brought inside the holes *11*, which are preferably conical in shape.

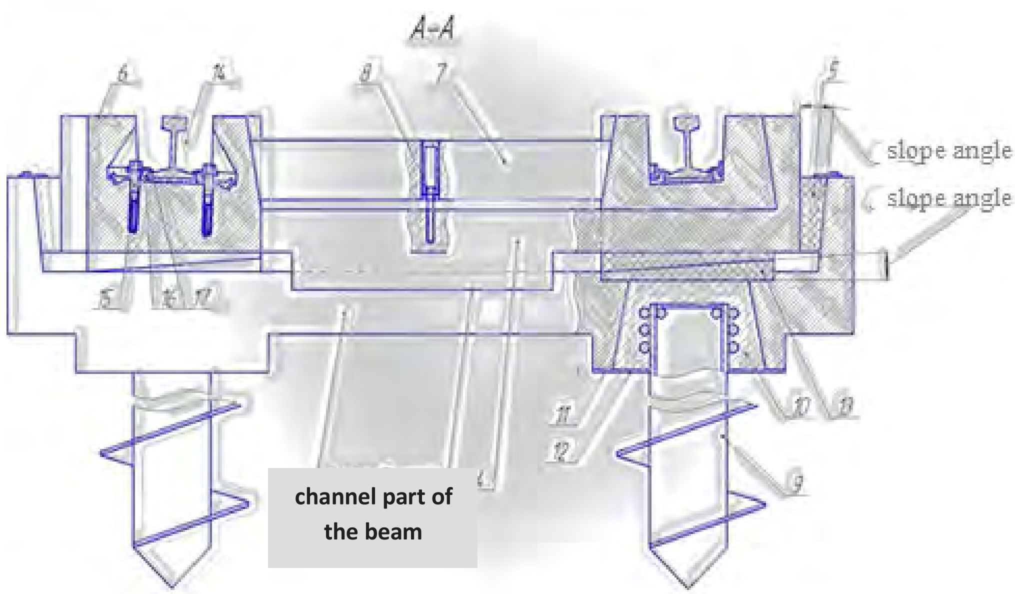
The elements of the prefabricated frame structure of the longitudinal sleeper track *2* include support beam *4*, elastic elements *5* which



Pic. 1. Front view of the proposed LRT track: 1 – monolithic pile support, 2 – prefabricated frame structure of longitudinal sleeper slab, 3 – twin elastic support elements [performed by the authors].



Pic. 2. Top view of the proposed LRT track: 1 – monolithic pile support, 2 – prefabricated frame structure of longitudinal sleeper track, 3 – crossbeam, 4 – support beam, 6 – longitudinal sleeper slab, 7 – spacer beam, 8 – screw coupling [performed by the authors].



Pic. 3. Section A–A of the proposed LRT track: 3 – transverse beam, 4 – support beam, 5 – elastic elements, 6 – longitudinal sleeper slab, 7 – spacer beam, 8 – screw coupling, 9 – pile supports, 10, 11 – fixing mounting blocks in the holes, 12 – metal formwork, 13 – twin elastic support elements, 14 – channels of slabs, 15, 16, 17 – rail track fasteners [performed by the authors].

are made with a surface bevelled at a certain angle, matching with the inclined side surface of the beam *3*, paired elastic support elements *13* with matching surfaces bevelled at a certain angle, longitudinal sleeper slabs *6*, spacer beam *7*, screw coupling *8*. Niches in channels *14* of the longitudinal sleeper slabs *6* are made to install rail track fasteners *15*, *16*, *17*, of a known design.

The matching inner surface of the longitudinal sleeper slabs *6* and the end surfaces of the spacer beam *7* are made with a slope, which ensures their wedging, within the limits of the side surfaces of the support beam *4*, by the expansion force achieved by installing a screw coupling *8* between the support beam *7* and the spacer beam *4*.

To develop the LRT track, pile supports, made in accordance with SP[6], are installed at the design points of the track in the profile and plan. Then industrially manufactured transverse beams *3* are installed. After a possible adjustment of the position of the transverse beam *3* in the profile and plan, concrete is poured into the space limited by the surface of the holes in the transverse beam *3* and pre-installed lower metal formwork *12*. This ensures formation of fixing mounting blocks *10* and, as consequence, formation of a monolithic pile support *1*.

On the formed monolithic pile base *1*, a prefabricated frame structure *2* of the longitudinal sleeper slab is installed, while a transverse support beam *4* is installed on the transverse beam *3* of the monolithic pile support *1*. Elastic elements *5*, *13* are installed between the supporting and side surfaces of the beams *3*, *4*. The elastic elements provide adjustment and fixation of the position of the beams *3*, *4* relative to each other. The elastic elements *13* are made twinned with matching surfaces bevelled at some angle.

Their relative longitudinal displacement provides adjustment of the relative vertical position of the beams *3*, *4* and thereby corrects the position of the track slab in the profile. The elastic elements *5* are made with a surface bevelled at some angle, matching with the inclined side surface of the beam *3*. The vertical displacement of the elastic elements *5* on both sides of the beam *3* provides adjustment and fixation of the position of the beams *3*, *4*, which is transverse relative to the axis of the track, and thereby correcting position of the track in plan. After the support beams *4* of the longitudinal sleeper track are installed, the end parts of the longitudinal sleeper slabs *6* are placed on them, fixing themselves with their outer side surfaces along their inner side surfaces, after which spacer beams *7* are installed between the inner surfaces of the longitudinal sleeper slabs *6*, fixing their end surfaces along the inclined inner side surfaces of the longitudinal sleeper slabs. The combination of these matchings forms two three-element profile connections, the execution of which has the property of self-fixing under the action of the own weight of the spacer beam *7*. If necessary, additional fixation of such a connection can be provided by tightening the support and spacer beams using a coupler *8*. The sequence of the above operations ensures formation of a prefabricated, closed, single element of the frame longitudinal sleeper track with a possibility of its dismantling. After the rail is installed, rail fasteners *15*, *16*, *17* of known design are installed.

When developing new territories where there is no road infrastructure, it is advisable to build the LRT track through two stages. At the first stage, the construction of the LRT track is carried out in an intermediate, technological version. In this case, concrete is not poured into the space limited by the surface of the holes in the transverse beam *3* and pre-installed lower metal or reinforced concrete formworks *12*. This ensures formation of the support of the fixing mounting blocks *10*, movable in the transverse direction and fixed in the vertical direction. The technological track formed in this case allows the use of technological track machines, which ensure the construction of the LRT track in the forward direction, from the starting point to the end points, according to the «lay-and-drive» scheme. When moving in the opposite direction, process include injections of the concrete into the pile supports, possible adjustment of the position of the transverse beam *3* in the profile and plan, pouring concrete into the space limited by the surface of the holes in the transverse beam *3* and formwork *12*, all this ensuring the formation of a monolithic pile support 1.

There is particularly important to provide LRT tracks with a large traffic load with due routine maintenance and repairs [15]. Speaking

[6] SP 24.13330.2021. Set of rules. Pile foundations. Updated edition of SNiP 2.02.03-85. Introduction date 2011–05–20. [Electronic resource]: https://docs.yandex.ru/docs/view?tm=1663826580&tld=ru&lang=ru&name=SP_24.13330.2011. Last accessed 16.08.2022.

Table 1

Comparative costs of the ballast track (based on ZhelDorSpetsProekt* data) and the proposed ballastless LRT track [compiled by the authors]

No.		Cost,	
	Name	mln rub./km	mln rub./km
		known ballast LRT track[6]	proposed ballastless LRT track
1	Roadbed	3,1	0
2	Track superstructure		
2.1	Track laying with separate elements	9,8	2,5
2.2	Track ballasting	1,7	0
2.3	Straightening and tamping machine	4,2	0
3.	Materials		
3.1	Rails of R65 type	10,4	10,4
3.2	Sleepers	5,7	0
3.3	2R-65 joint bars and elements	1,1	0
3.4	Sand, loam, gravel (total 14000 m^3)	8,3	0
	Concrete,20 m^3	0	0,12
3.5	Other	4,9	4,9
4	Loading and transporting material	4,2	0,42
5	Pile foundation, 990 pcs/km	0	10,5
6	Support beam (grillage), 330 pcs/km	0	1
7	Strut beam, 330 pcs/km	0	0,66
8	Longitudinal sleeper slabs, 660 pcs/km	0	6,6
	Total	53,4	37,1

* Cost of construction of 1 km of railway. ZhelDorSpetsProekt design and construction company. [Electronic resource]: https://желдорспецпроект.рф/calculate. Last accessed 16.08.2022.

about urban transport systems, it is worth highlighting among the most important problems those of current maintenance that is conducted under the conditions of dense urban development, and the problems of frequency of repairs, as well as the provision of traffic intervals for maintenance works. The design and high industrial readiness of track elements of the proposed design supposes repair of the track by replacing its elements, and alignment of the track can be carried out at reference points above the pile foundation. This significantly reduces the cost and duration of the works.

Consideration of the known and proposed design of the LRT track allows comparing them in terms of the main quality indicators.

Design: prefabricated modular structure combining load-bearing elements and rail track elements with high industrial readiness is made with separately mounted elements fastened with profile connections and does not involve the use of inter-rail fastenings; it is effective on straight and curved sections of the track of a small radius; in combination with a slab base, it provides formation of curved track sections with a small radius.

Table 2

Comparative indicators of quality of rail tracks [compiled by the authors]

Quality indicators	Ballast track	Non-ballast track	Proposed track design
Capital construction costs	average (1)	high (0)	low (2)
Maintenance costs	high (0)	low (2)	low (2)
Possibility of straightening the track	high (2)	low (0)	average (1)
Possibility of renewal	high (2)	average (1)	average (1)
Noise and vibration dampening	high (2)	average (1)	average (1)
Unification of track elements	high (2)	average (1)	average (1)
Generalised indicator	9	5	8

Technology: high industrial readiness; a high degree of mobility and mechanisation during modernisation, construction and operation of the rail track using dual-mode machines with attached standard and specialised equipment.

Operation: modular design reduces repair and maintenance time; ensures effective maintenance of the necessary positioning of the track in profile and plan.

Scope: modernisation of old and construction of new tram tracks; construction of rapid tram tracks; construction of rail tracks for light transport of industrial enterprises; construction of rail tracks as a primary transport infrastructure while developing new territories of industrial zones.

It should be especially noted that historically the track was used as a road structure in undeveloped territories. The proposed LRT design makes it possible to practically implement this possibility, as it is a self-reliable and self-organising logistics system that allows quickly organising permanent construction, processing passenger traffic and cargo flows. Considering organisational, logistical and infrastructural benefits, this significantly reduces the time for development of remote and hard-to-reach territories.

In this case, the concept «from infrastructure to facility» is replaced by the concept «from facility to infrastructure». In this case, development of the facility may outpace development of transport infrastructure, as a costly system with a distant payback.

Dual-mode rail-road rolling stock (vehicles) can be used for construction and maintenance of the LRT track [9].

A comparative analysis of costs according to the 2022 data of design and construction company ZhelDorSpetsProekt and CJSC KPM Service, shown in Table 1, demonstrates that the savings in the cost of manufacturing the proposed balastless LRT track, compared to the cost of manufacturing a ballast LRT track, are about 30 %.

Comparative indicators of quality of the rail track, considering the work [11] and the data of CJSC KPM Service, determined by the expert method and shown in Table 2, allow arguing that the proposed design of the LRT ballastless track is superior in terms of the main indicators (lines 1, 2) and in terms of the generalised indicator it is not inferior to the quality indicators of the ballast track.

CONCLUSIONS

Prospects for development of urban ground passenger transport, which belongs to the LRT category, are associated with the adoption of new types of rolling stock, infrastructure development, reduction in cost and time of modernisation of existing and construction of new tracks. Social and economic effects of implementation of LRT projects have been studied in many research sources referring to practices of the United States, Japan, Indonesia, Malaysia [16–19] as well as to comparative evaluation of urban LRT systems and urban mass transit systems focused mainly on bus operations [20].

The authors' study has made it possible to present an option of the LRT track and, upon considering its design and technological features, as well as relative technical and economic indicators, to determine its viability. Besides, the proposed version of the LRT track allows developing LRT concept based on «from facility to infrastructure» principle instead of «from infrastructure to object», in which development of a facility can outstrip development of transport infrastructure, as a costly system with a distant payback.

The results obtained allow us to suppose that the proposed LRT design along with the technology of its manufacture is a possible option for solving the problem of modernisation of existing and building new light rail transit passenger and industrial tracks.

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