The influence of transport vibrations on the condition of Russian cultural heritage objects

I Dyachkova*, M Skachkova, V Kovyazin
Department of Engineering Geodesy, Saint Petersburg Mining University, 2, 21st Line, St. Petersburg 199106, Russian Federation

*Corresponding email: irinad95@mail.ru

Abstract. This article is devoted to the negative impact of transport vibrations on the condition of historical and cultural monuments. The causes of the occurrence of transport fluctuations and the consequences of their impact were considered. The authors proposed a classification of the negative impact of transport on monuments, ways to reduce the negative impact were given, as well as the regions of Russian Federation that are the most susceptible to such impact were analyzed.

1. Introduction
Russia has a rich cultural and historical heritage. In 2019 the UNESCO World Heritage List includes 29 objects which located in Russia, and they are 2.6% of the total (1 121 objects in 2019 in total). There are 268 127 real historical and cultural monuments on the Russian territory in 2018 (figure 1) [1].

![Figure 1. The total amount of Russian cultural heritage objects.](image)
Despite the obvious high importance of the cultural heritage objects, reality shows disappointing facts: according to the All-Russian Society of the Protection of the History and Culture Monuments (RSPHCM) more than 2.5 thousand historical and cultural monuments have died in the Russian Federation over the last 10 years, and the annual loss is about 150–200 monuments, which is approximately 1.4% of the total number of historical and cultural monuments for 2017 [1].

The reasons of the loss and destruction of cultural heritage objects in Russia are legal instability, abandonment, vandalism, legislative imperfections in the fields of protection of valuable objects, as well as anthropogenic and natural environmental problems [2]. According to RSPHCM, there are about 2.3 thousand cultural heritage objects that are threatened due to the impact of anthropogenic factors.

The most common causes of the anthropogenic physical destruction and loss of cultural heritage objects are disturbances of the geological environment as a result of economic activity during the active development of the adjacent territory, air pollution from industrial emissions, vehicles and public utilities, chemical pollution of soils and earth, visual disturbance of landscapes and unregulated building, as well as noise, vibration and other disturbances of natural physical parameters of the environment, including the movement of various modes of transport: rail, road, tram communications, subways, etc. [3, 4].

The development of transport infrastructure in the cities ensures the social and economic well-being of the population. Modern cities are permeated by a network of transport routes that ensure the movement of passengers and goods, communication between individual segments of urban space. Every year transport infrastructure is actively developing and expanding in connection with the increasing economic needs of society and population growth ([table 1] [5, 6].

**Table 1.** The length of transport routes, thousand km.

| Type of transport / Years | 2005 | 2010 | 2015 | 2016 | 2017 |
|--------------------------|------|------|------|------|------|
| Railways                 | 85   | 86   | 86   | 86   | 87   |
| Car roads                | 858  | 1004 | 1642 | 1658 | 1666 |
| Tram rails               | 2.8  | 2.6  | 2.5  | 2.5  | 2.5  |
| Trolleybus lines         | 4.9  | 4.9  | 5.3  | 5.3  | 5.2  |
| Subway ways              | 0.436| 0.475| 0.517| 0.532| 0.542|

According to the Federal State Statistics Service, population growth, the development of cities and transport links result in an increase of the number of cars (in 2017 there was an increase of almost 1.74 times compared with 2005) and the number of metro stations (in 2017 there was an increase of 1.22 times since 2005), passenger turnover and the number of passenger traffic are growing too (figure 2) [5].
In connection with the development of transport infrastructure, an increase of passenger traffic, and, consequently, an increase of the physical load of transport infrastructure on adjacent objects, which is especially acute in the historical centers of cities, the problem of the negative impact of transport vibrations on the physical condition of historical and cultural monuments located near transport routes arises.

The aim of this work is to identify and classify the main negative effects of transport vibrations on the condition of historical and cultural monuments.

2. Methods and Materials
Research methods are analysis, comparison, classification. The problem of the influence of transport vibration on historical and cultural monuments was investigated by such Russian scientists as S G Alimov, A V Lukin, M E Krogius, E K Borisov, A G Usov, I R Machine, Yu A Koryazhmina, E N Sychkina [2, 3, 7], and foreign scientists: I Roselli, V Fioriti, I Bellagamba, M Mongelli, A Tati, M Barbera, M M Cianetti, G de Canio, X Gao, L Zhang, G Liu, Z Ba [7, 8] and others.

2.1. Research of transport vibrations
All modes of transport transmit vibrational energy to buildings and structures located near transport routes. The resulting vibration negatively affects the technical condition of the buildings and the sanitary and hygienic conditions of use.

If we consider the structure from a physical point of view, then it will be a consumer of vibrational energy. And this energy is transmitted to the structure depending on its nature, the feature of the contact with the energy-bearing medium and the physical and mechanical characteristics of this medium.

Vibrations are the mechanical vibrations which are characterized by a certain repeatability in time, amplitude and frequency. Types of mechanical vibrations are presented in figure 3 [9].

![Figure 2. Passenger transportation index and passenger turnover index by types of public transport (as a percentage of the previous year).](image-url)
According to the specificity of the transfer of vibrational energy to the structure, in all cases transport vibration is a kinematic disturbance of the protected object (self-oscillation).

When the natural frequencies of building structures oscillations coincide with the frequency of external influences, resonance phenomena occur. And it leads to complex destruction of the building or its parts, violation of the external appearance, and cracks [3].

In the historical part of any large city there are narrow streets laid during its initial construction, which eventually turned into noisy highways [3]. A large flow creates a vibrational load on a valuable historical building. State standard RF 52892-2007 “Vibration and shock. Vibration of buildings. Measurement of vibration and assessment of its impact on the structure” says that vibration is capable of changing the properties of the soils where the building is located [10]. For example, local compaction of the soil occurs. Due to uneven settlement of the soil base, it can lead to serious structural damage. Soil compaction can occur even with a low level of vibration, if it is long-term.

Another example of changing soil properties is soil liquefaction. It is more dangerous, because under vibration exposure the liquefied soil loses its bearing capacity. This phenomenon is more evident in water-saturated soils and is indirect evidence of the effect of vibration on buildings and structures. Therefore, it is necessary to obtain a comprehensive assessment of the impact of vibration and the involvement of specialists - geotechnicians [3, 11].

Thus, transport vibrations affecting cultural heritage objects can be classified as follows:
1) by source of vibration:
   - car,
   - tram,
   - trolleybus,
   - rail,
   - subway;
2) by the nature of the impact:
   - immediate (causing cracks, destruction of individual parts of the building, etc.);
   - indirect (causing deformation of soils and surrounding objects);
3) by period of exposure:
   - long-term;
   - short-term.

In St. Petersburg Petropavlovsky Cathedral was covered by through cracks and a result was subway vibration, Isaakievsy Cathedral tilted 25 cm from the vertical, construction work of the vestibule of the Teatralnaya metro station led to a serious upsetting of the oldest Mariinsky Theater. Reality knows a lot of such examples, therefore it is necessary to look for methods to reduce the influence of transport vibrations [3], as well as to do the monitoring of the technical condition of valuable real estate objects [4].

According to RSPHCM, the following regions and cities of Russia are affected by transport vibration: St. Petersburg, Orenburg, Udmurtia, Ingushetia, the Altai Republic and Altai Region, Mordovia, Krasnodar and Khabarovsk Regions, Arkhangelsk, Bryansk, Kostroma, Samara, Voronezh, Orel and Kaliningrad region, Kaluga, Smolensk, Tomsk. The examples are the House of the merchant

![Figure 3. Types of mechanical vibrations.](image-url)
Ogloblin in Izhevsk, the House of Ovchinnikov and the House of Grakhov in Votkinsk (Udmurtia), the unsatisfactory condition of more than 40 objects of monumental art in Orenburg (Orenburg region) [12].

2.2. Ways to reduce the effects of transport vibrations
Among the existing methods of reducing the negative consequences which transport vibrations influence on the physical condition of historical and cultural monuments, two directions can be distinguished (figure 4) [13].

There are many examples of the application of these methods. In Vyborg, a ring road was built in the historical center to reduce the flow of cars. In Astrakhan the tram was almost completely eliminated to reduce the vibration of rail vehicles. The use of various types of insulators is actively practiced in England (Croydon) [14].

3. Results and Discussion
Transport fluctuations are divided into several groups according to the source of vibrations, the nature of the effects and the frequency. Methods to reduce the negative effects which transport vibrations have on the physical condition of historical and cultural monuments can be divided into two directions: reducing the existing transport vibrational impact and preventing such impacts.

4. Conclusion
The problem of the influence of transport vibrations on buildings and structures is currently very acute. The primary task in the process of solving this problem is the preservation of valuable historical objects. Reducing the negative impact of an aggressive environment, such as transport vibrations on cultural heritage object, in the global sense lies in the development of the concept of “smart” cities and using of advanced technologies.
Figure 4. Decrease of the influence of transport vibrations on monument buildings.

References
[1] All-Russian Society for the Preservation of Historical and Cultural Monuments. The state of historical and cultural heritage, available at: http://www.voopik.ru/our-heritage/status-cultural-heritage/
[2] Ecology and cultural heritage, available at: http://ohrana-bgd.ru/okrsrd/okrsrd3_18.html
[3] Alimov S G 2006 Assessment of the effect of transport vibration on the construction of buildings-monuments of architecture: the example of Vladivostok, PhD thesis, Far Eastern State Technological University
[4] Skachkova M E, Lepihina O Y and Ignatova V V 2018 Journal of Physics: Conference Series Information support of monitoring of technical condition of buildings in construction risk area 1015 42056–42056
[5] Statistical collection Transport in Russia 2018 (Federal State Statistics Service) pp 9-79
[6] Bykova E and Gerasimova I 2019 Land Land plot selection rationale for the location of linear facilities 8(4) 1-17
[7] Roselli I, Fioriti V, Bellagamba I, Mongelli M, Tati A, Barbera M, Cianetti M M and G de Canio WIT Transactions on Ecology and the Environment Urban transport vibrations and cultural heritage sites in Rome: the cases of the Temple of Minerva Medica and of the Catacomb of Priscilla ed C A Brebbia, Wessex Institute, J J Sendra (Boston: WIT Press) pp 335-345
[8] Gao X, Zhang L, Liu G and Ba Z 2017 The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences Monitoring of vibrations for the conservation of cultural heritage : the case of the summer palace in Beijing pp 253-257
[9] Machine I R, Koryazhmina Yu A and Sychkina E N 2015 Construction and architecture. Experience and modern technologies Effect of transport vibration on buildings and structures 4 1-4

[10] GOST RF 52892-2007 Vibration and shock. Vibration of buildings. Measurement of vibration and assessment of its impact on the structure 2007 (Standartinform, Moscow)

[11] Heldak M and Bykowa E 2017 Journal of Ecological Engineering Construction of public roads at the meeting point of different legislation systems 18(6) 86-94

[12] Typology of the destruction of cultural monuments, available at: https://design.wikireading.ru/12939

[13] Transport and the Historic Environment, available at: https://historicengland.org.uk/advice/planning/infrastructure/planning-and-transport/

[14] Ovsyannikova T Yu, Skuridina Yu B and Kotova O V 2009 Bulletin of Tomsk State University. Economics Risk assessment of loss of immovable objects of cultural heritage of a company 3(7) 61-70