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Environmental impact of the tunnel construction

Влияние строительства тоннелей на окружающую среду

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Ключевые слова: транспортные тоннели; окружающая среда; уникальные природно-географические условия; негативное воздействие; мониторинг; атмосферный загрязняющие вещества

Abstract. The object of research are traffic tunnels at the combined road (motorway and railway) the city of Adler to the Alpica Servis alpine resort, which construction and operation was bound up with negative environmental impact. Analysis of the environmental impact of technological processes during the construction and operation of tunnels was carried out data-driven of field study. Scientific and methodical bases of performance mining and environmental monitoring in the unique natural and geographical conditions of the Caucasian Reserve are developed. Nomenclature of monitored indicators, points and frequency of their measurement, as well as the requirements for instrumentation are defined. The measurement result of the pollution content in the air and soil during the construction and operation of traffic tunnels are presented. The objective laws of adverse impact on various components of the environment depending on the construction phase are established.

Аннотация. Объектом исследования являются транспортные тоннели на совмещённой (автомобильной и железной) дороге Адлер – горноклиматический курорт «Альпика - Сервис», строительство и эксплуатация которых была связана с негативным воздействием на окружающую среду. Анализ влияния технологических процессов, сопровождающих строительство и эксплуатацию тоннелей на окружающую среду, был осуществлен на основе данных натурных наблюдений. Разработаны научно-методические основы проведения горно-экологического мониторинга окружающей среды в уникальных природно-географических условиях Кавказского заповедника, определяющие перечень контролируемых показателей, точки и частоту их измерения, а также требования к приборному обеспечению. Приведены результаты измерений содержания загрязняющих веществ в атмосферном воздухе и почво-грунтах в периоды строительства и эксплуатации транспортных тоннелей. Установлены закономерности, характеризующие уровни негативного воздействия на различные компоненты природной среды в зависимости от периода строительства.

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1. Introduction

At the beginning of the 21st century, the volume of traffic tunnels construction in Russia has increased manyfold. Due to the demand for traffic infrastructure construction for hosting of the 2014 Winter Olympic Games, the 2017 FIFA Confederations Cup and the 2018 FIFA World Cup, as well as for creating favourable conditions for the development of the modern sport and resort centres, the construction has moved to the regions with unique environmental and geographic conditions, above all to the Krasnodar region districts (Adler, Tuapse and Anapa) [1]. Besides the railroad tunnels construction, motorroad tunnels construction has initiated in these districts. The most typical example of this trend is the city of Adler, where 9 traffic tunnels, among them 6 railroad tunnels and 3 motorroad tunnels, were constructed for hosting the 2014 Winter Olympic Games (Figure 1).

Figure 1. Tunnel routes layout

These tunnel routes pass through the premises of The Western Caucasus nature reserve, rich in rare flora and fauna species and unique in its relief, which includes the Mzymty river flowing in the vicinity of the motorway. In accordance with the existing regulations, anthropogenic impact in this area is permissible provided that it does not incur a long-term disruption of the environment that would spread beyond the construction sites during the construction period and buffer zones during the operation period [2].

As for the peculiarities of assessing the environmental impact of tunnels under construction and of working out impact reduction measures, it should be noted that a significant difference exists between the reference admissible concentration limit concentrations in the working area air and their maximum one-time concentrations used for environmental impact assessment. These two values can be significantly different. For instance, the admissible concentration limit of sulphur dioxide for the working areas is 10 mg/m^3. The maximum one-time concentration is 0.5 mg/m^3. The difference between these reference values further increases in the atmosphere of cities with the population over 200000 people and in the resort districts, where the pollutants concentration should not exceed 80 % of the maximum one-time concentration value, considering the disperion of the pollutants.

Compared to the construction of the surface facilities, the construction and the further operation of traffic tunnels has important specific features that influence the limit and the result of the detrimental environmental impact.

The following are the specific characteristics of such impact during the construction period:

– simultaneous construction works on the ground surface and underground, which influences all the biosphere components: the atmosphere, the soil, the surface and ground water, the flora and the fauna, and the population;

– application of various technologies for the construction of tunnels and surface facilities, such as: manual mining operations, use of tunnel boring machines, roadheaders; drilling and blasting operations, digging, drilling and pile insertion works, and concrete works;

– use of a large variety of construction machines and equipment;

– considerable duration of works, which can last up to 5 years with a temporary change in the detrimental impact limits [6].

The assessment of detrimental environmental impact in the period of construction was performed in 2009–2013 as regular quarterly observations during the construction of traffic tunnels at the combined road (motorroad and railraod) connecting Adler and the Alpika-Servis alpine resort. In the course of observations, simultaneous measurements of the thermodynamic and chemical parameters of the air in the tunnel excavations and at the construction sites were made, as well as the analyses of the chemical composition of the drainage and the waste water, and of the soil in the part of the road that are adjacent to the tunnel portals [7].

During the operation period, the number of factors that determine the environmental impact of the traffic tunnels decreases [8]. Besides, while during the construction period the environmental impact is almost similar for railroad and motorroad tunnel construction, provided that similar tunneling techniques are applied, during the operation of motorroad tunnels the main detrimental factor is the polluting vehicle exhausts that increase the pollutants concentration in the tunnel air and in the atmosphere and, consequently, in the soils in the portal areas [9]. Railroad tunnels have minimal impact on the atmosphere, however, the noise impact of the train in the portal areas is significant [10].

In 2014–2017, the assessment of the traffic tunnels detrimental environmental impact was completed with the instrumental measurements of the pollutants concentration in the atmosphere and the soil during the operation period.

The study reveals that national and foreign literature does not cover environmental issues enough as to traffic tunnels [11]. The absence of scientifically based data challenges evaluation and choice of environmentally safe construction technology [12]. Given the unique nature and geography, this may wreak significant social and economic damage [13].

The field study performed was marked by a large number of measurement tools used in a limited construction space of nine traffic tunnels (six railway tunnels and three road tunnels) from 128 to 4572 m long, as well as by unique nature and geography of the construction area. The results of the study will serve as a basis for the development of environmentally friendly construction of traffic tunnels under similar conditions.

2. Methods

2.1. Monitoring during tunnels construction

When providing monitoring during tunnels construction, the emphasis was made on measuring the pollutants concentration in the atmosphere [14]. The monitoring technique was tested and adjusted during the tunnels construction for the first tunnel ensemble consisting of relatively parallel motorroad and railroad tunnels and a service adit located between the tunnels. The tunnels and the adit were linked by a breakthrough connection. The railroad tunnel measured 2535 metres long, and the motorroad tunnel — 2298 metres long.

The tunnels were created by mined tunneling. Thus, the first railroad tunnel was built with the use of the Voest Alpine Miner AM75 roadheaders that allow to do machine mining of soils with various rock strength of the tunnel bearing rocks; the motorroad tunnel was built in a similar way. The sources of environmental impacts were identical: motor transport and excavation equipment, which produce a considerable share of pollutants while functioning.

The ecological monitoring during tunnels construction was done every quarter between 2009 and 2013. The monitoring activities included the assessment of construction impact on the atmosphere, on the water, and on the soil of the near-portal sites.

The assessment of the impact on the atmosphere consisted in determining the concentration of the suspended substances, of carbon oxide (CO), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) in the air. The measurement were made at various sites in the excavation (face, middle of the tunnel, portal and construction site). Following portable hardware were used:

– portable gas analyzer PGA-200 (CO, SO_2, NO_2). Original equipment manufacturer – Russia; limit percentage error is 25 %;

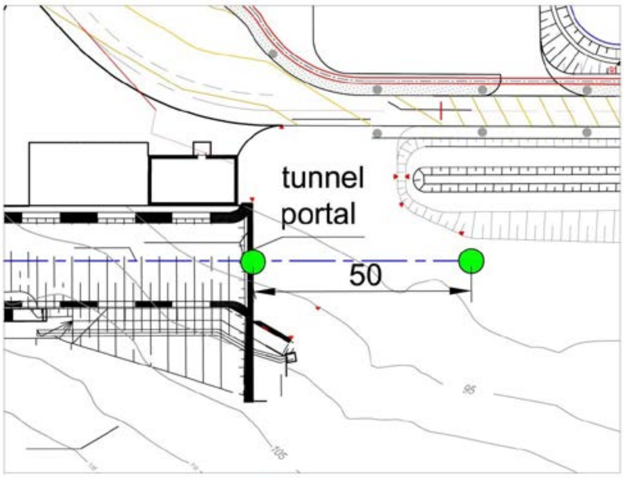
– dust meter ICP-4 (suspended substances). Original equipment manufacturer – Russia; limit percentage error is 25 %.

In order to assess the tunnels construction impact on the near-portal sites soil, samples of the surface layer at the depth of 0.0–0.2 m were analysed. The analysis looked for oil products and heavy metals [15]. The soil type is chernozem with stony inclusions.

This interval allowed determining the areas and periods of works that have the highest or the lowest environmental impact [16]. As well as allowed discovering the correlation between the exhausts and the pollutants dispersion in the atmosphere and establishing the dynamics of the pollutants accumulation and wash-out from the soil.

2.2. Monitoring during tunnels operation

The methodology of the study at that period of time implied the measurement of physical, chemical and thermodynamic characteristics of ambient air and chemical analysis of soils. Since the main contamination source is motor vehicles, most measurements were focused on road tunnels [17]. Since contaminated air is emitted into the atmosphere through tunnel portals, measurement points were arranged directly at the portals and around right-of-way areas adjacent to the highway at a 50 m distance from the portals. The choice of measurement points and tools met the requirements of the construction period [18].



Notation conventions: ● - sampling points

Figure 2. Sampling points chart

3. Results and Discussion

At the initial stage of construction, the pollutants concentration at the tunnel portal is around 0–0.2 mg/m^3. As the length of the tunnel increased, an increase in the pollutants concentration was observed (up to 5.0 mg/m^3), which may be explained by the increase in the amount of mining and conveyor equipment operating in the tunnel simultaneously. The drop in the pollutants concentration occurred after the creation of a breakthrough in the tunnel (February 2011) and after the completion of the main excavation works, as the result of the change in the ventilation system (Figure 3).

Before the creation of the breakthrough, the railroad and the motorroad tunnels were aired through plenum ventilation system. After the breakthrough connection was created between the tunnel sections with opposed egresses, in the central part of the tunnels airway stoppings were built, divings thus the tunnels into two separate parts, each of them aired through plenum ventilation. In the period of equipping of the mined excavations they were aired with a ventilator installed at the airway stopping and supplying air depending on the direction of the natural draught towards the northern or the southern portal.

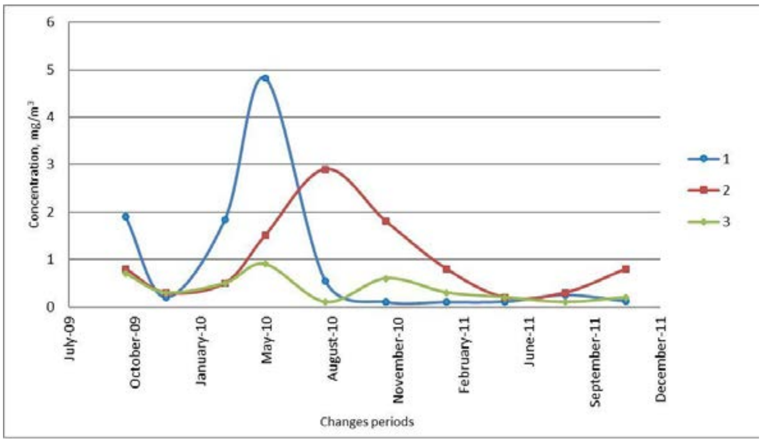


Figure 3. Pollutants concentrations at the tunnel portal, where 1 – suspended substances concentration; 2 – carbon oxide concentration; 3 – sulphur dioxide concentration

During the motorroad tunnel construction results similar to those of the railroad tunnel were obtained. During the initial construction stage, a stronger environmental impact was observed. After the creation of a breakthrough and the completion of the main tunnel excavation works, the impact decreased.

The described atmosphere environmental load dynamics may be explained by the increase in the amount of the load-haul-dump units as the length of the mined tunnel section grew and, consequently, the pollutants dumping into the tunnel air intensified.

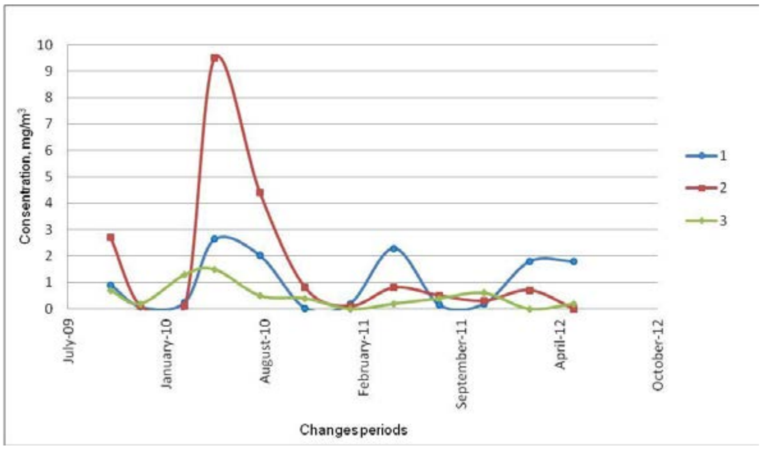


Figure 4 — Pollutants concentrations at the tunnel portal, where 1 – suspended substances concentration; 2 – carbon oxide concentration; 3 – sulphur dioxide concentration

Accordingly, the analysis of the monitoring results obtained during the construction period demonstrated that in the course of traffic tunnels construction the environmental load, in particular that of the atmosphere, is not uniform. The environmental load is minimal at the initial construction period and increases as the mined tunnel sections grow in length and the mining works intensify. After the completion of the main construction stage, during the tunnel equipping, the environmental load drops again.

3.1. The results of the pollutants concentration measurement in the atmosphere during operation

The results of the measurements demonstrated that in the course of the railroad tunnels operation at the section connecting Adler and Alpika-Servis alpine resort, no sources of atmosphere impact were detected, while the impact on the drainage industrial water evacuated from the tunnel is minimal.

In the course of motorroad tunnels operation the main source of detrimental impact on the atmosphere were the pollutants exhausts of the motor transport. The final pollutants concentration in the air flow exiting the tunnel depends on the motor vehicles traffic, which changes throughout the day: maximal during the "rush hour" and minimal at night; it also depends on the amount of air moving along the tunnels.

The measurements were made at different moments of the day in different air flow density conditions. Thus, the "rush hour" was set from 10.00 till 12.00. The regular traffic period was defined as 22.00 to 00.00.

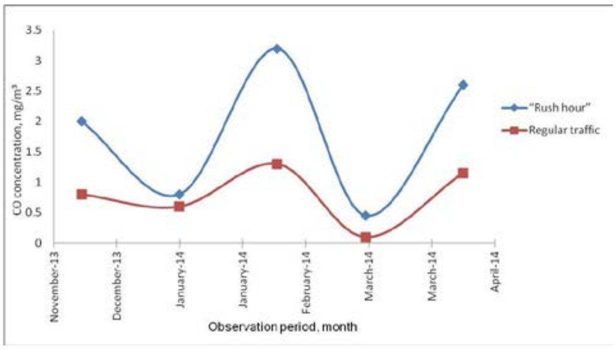


Figure 5. CO concentration at the southern portal of motorroad tunnel No. 1 during operation

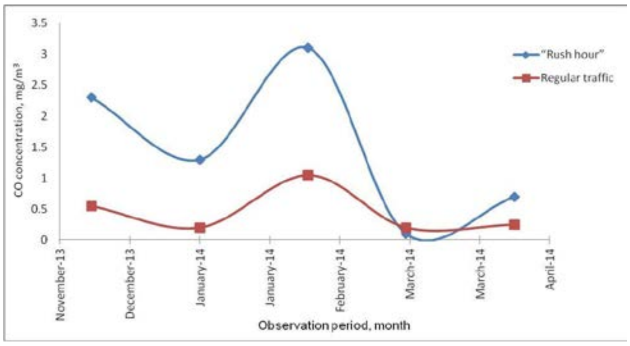


Figure 6. CO concentration at the northern portal of motorroad tunnel no. 1 during operation

The increase in the traffic causes a certain degradation of the environmental conditions. However, even in the periods of busy traffic typical for the "rush hour", the CO concentration in the atmosphere at the tunnel portals and near-portal sites does not exceed the recommended values stipulated by Hygienic Regulations GN 2.1.6.1338-03 " Admissible concentration limits Concentrations in the Atmosphere of Inhabited Areas". In the periods of decreased traffic (regular period) the pollutants concentrations drop even lower than the "rush hour" values (Fig. 5 and 6).

3.2. Results of measurements of pollutants concentration in the soil at near-portal sites during construction

According to the results of the measurements, the pollutants concentration in the air depends on the amount of motor transport and construction equipment operating in the tunnel and at the construction site at the time of measurement. Due to this, the concentration value may be significantly different for different periods. For more detailed assessment of the environmental impact, the oil products and heavy metals concentrations in the surface soil layers in the near-portal tunnel areas were measured; these areas may over time accumulate part of the pollutants settling down on their surface after exiting the tunnel in the tunnel air flow [19]. The pollutants accumulation in the soil has wavelike character (with peaks of concentration). The periods of accumulation are succeeded by periods of pollutants wash-out from the soil [20].

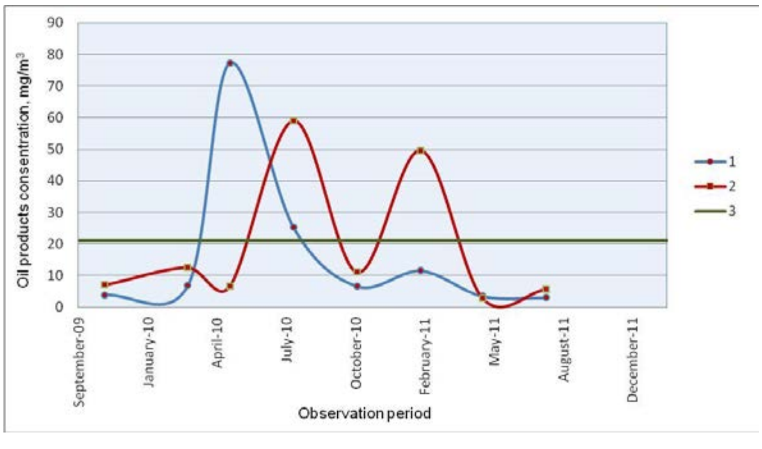


Figure 7. Oil products concentration in the soils at the near-portal areas of the railroad tunnel no. 1. 1 – southern portal; 2 – northern portal; 3 – background concentration

In order to determine the extent of the surface soil layer chemical pollution the overall pollution indicator (Z_c) was used (1).

$$Z_c = K_{c_1} + ... + K_{c_i} + ...K_{c_n} - (n-1) \tag{1}$$

where n – quantity of analytes;

C_i – concentration of the i-th pollutant component.

Z_c is a sum of the concentration coefficients K_c (2) of the toxic substances (pollutants) of the I, II and III class of toxicologic hazard (mostly metals) divided by the background values.

$$K_c = \frac{C_i}{C_{NBC}} \qquad (2)$$

where C_{NBC} – natural background concentration.

The changes in the Z_c values with time determine the dynamics of change in the heavy metals concentrations in the soil compared to the background concentration. As well as can identify the periods of metals accumulation and migration in the soil.

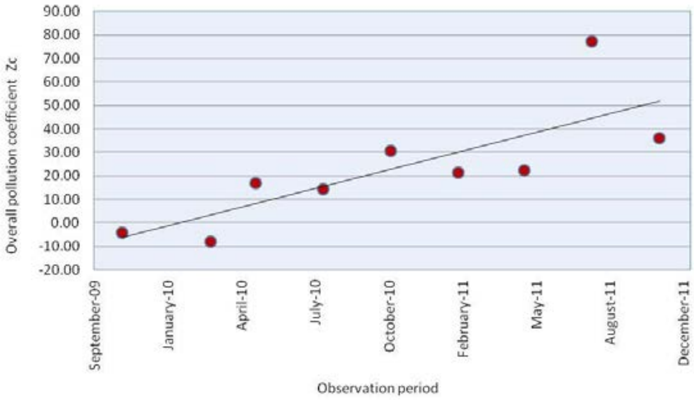


Figure 8. Changes in Zc during railroad tunnel construction

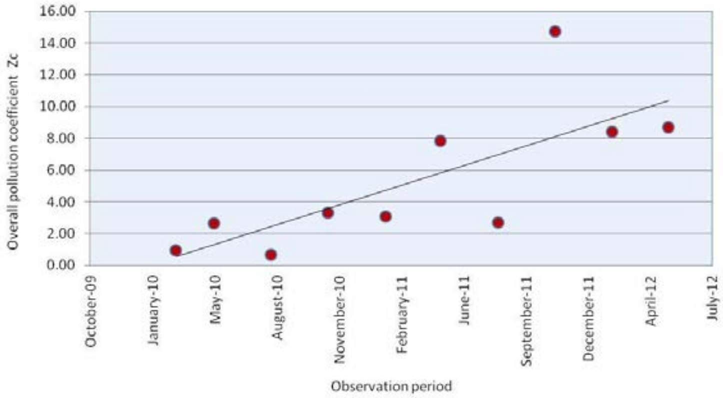


Figure 9. Changes in Zc during motorroad tunnel construction

As demonstrated by the preceding diagrams, depending on the samples collection period, the metals concentration in soil tends to increase. This trend is confirmed by the linear correlation between the Zc coefficients and the time of impact. The linear correlation coefficients for the railroad and the motorroad tunnels were 0.79 and 0.75 respectively.

However, as it turns out, the oil products and the heavy metals soil concentrations dynamics is influenced not only by the technological processes related to tunnel construction, but also by the environmental factors related to the alternation of the dry and rainy seasons.

3.3. Results of measurements of pollutants concentration in the soil at near-portal sites during operation

In order to determine the concentration of pollutants that settle down on and accumulate in the daylight surface of the right-of-way area of the tunnels, surface soil layer samples were collected. The samples were analysed to determine the presense of heavy metals (Table 1).

Table 1. Comparative of heavy metals concentration in the surface soil layer of the near-portal areas of the motorroad and the railroad tunnels

Indicator	Concentration, mg/kg	
	Railroad tunnel	Motorroad tunnel
1	2	3
Copper, Cu	14.1	34.2
Zink, Zn	43.7	77.1
Lead, Pb	9.6	19.3
Cadmium, Cd	0.69	1.01
Mercury, Hg	0.05	0.05
Arsenic, As	2.22	8.12
Nickel, Ni	22.5	74.4
Manganese, Mn	1211	2730
Cobalt, Co	8.1	30.5

The comparison of heavy metals concentrations in the soil allows making a conclusion regarding the environmental situation during the operation of motorroad and railroad tunnels.

Thus, based on Table 1, the heavy metals concentration in the soils of areas adjacent to the motorroad tunnel are considerably higher than those of the areas near the railroad tunnel.

The data obtain confirms the higher level of detrimental impact during operation of motorroad tunnels than during the operation of the railroad tunnels.

4. Conclusion

1. Evaluation of the negative impact of tunnel construction and operation of transportation tunnels and the designing measures to reduce it should be carried out on the basis of data from mining and environmental monitoring including periodic observations of all the environmental conditions both at construction sites and in the adjacent territory.

2. Mining and environmental monitoring revealed that the level of anthropogenic impact on environment in case of tunnel construction depends on the technology of tunnel digging, construction stages and mining, conveying and tunneling equipment.

3. The analysis of measurements of the content of pollutants in the atmospheric air at the tunnel portals and around them made during construction period showed that the environmental impact on was unbalanced. Being minimal at the initial construction stage, it increased together with the length of the tunnel dug and the intensity of tunneling works. After the completion of the main construction, environmental impact decreased while tunnels were being finished.

4. The dynamics of pollutant concentration in soil and ground in areas adjacent to the excavation sites on the day surface is wavelike, what is associated with the accumulation of pollutants during the dry period and with their washing and transfer into the Mzymta river during by rains;

5. A distinctive feature of the environmental impact from the operation of road tunnels in comparison with railway tunnels is the increased concentration of pollutants in the ambient air near the portals that depends on the traffic intensity, and higher concentrations of heavy metals in soil and ground.

6. The correlations revealed make it easier to forecast the negative environmental impact during the construction and operation of transportation tunnels depending on their type, construction technology and the specifics of their usage at different periods.

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