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DETERMINING THE STRAINED STATE OF PREFABRICATED METAL CORRUGATED STRUCTURES OF A TUNNEL OVERPASS EXPOSED TO THE DYNAMIC LOADING FROM RAILROAD ROLLING STOCK

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This paper reports the analysis of prospects for the use of prefabricated metal corrugated structures in the body of the embankment of a railroad track in the form of a tunnel overpass in order to pass road vehicles and railroad rolling stock.

A technique of inertial dynamic tests of the deformed state of a tunnel overpass from prefabricated metal corrugated structures during the passage of railroad rolling stock is given, by measuring accelerations at the top and on the sides of overpass structures.

An algorithm is proposed for processing the acceleration signal for assessing the strained state of metal corrugated structures of a tunnel overpass under the action of dynamic load from railroad transport.

Experimental dynamic measurements of accelerations arising at the top and on the sides of a tunnel overpass during the passage of passenger and freight railroad rolling stock were carried out. The maximum value of accelerations arising at the top of a tunnel overpass during the passage of a freight train was 7.99 m/s^2, and when passing a passenger train – 6.21 m/s^2; the maximum accelerations that occur on the sides were 2.63 m/s^2 and 1.77 m/s^2.

It is established that the maximum deformations of metal corrugated structures of the top of a tunnel overpass, when passing freight and passenger trains are, respectively, 1.63 mm and 1.11 mm. The maximum strains of metal corrugated structures on the sides of an overpass are 1.07 mm and 0.48 mm.

The value of relative deformations in the vertical and horizontal dimensions of the structures of a tunnel overpass under the action of dynamic loads from the railroad rolling stock has been found. The relative vertical strains of an overpass amounted to 0.020 %; horizontal – 0.012 %.

The practical significance of this work is that with the help of the devised procedure for measuring accelerations, it is possible to assess the strained state of metal corrugated structures under the influence of dynamic loads from the railroad rolling stock

Keywords: tunnel overpass, prefabricated metal corrugated structures, railroad track, acceleration of metal structures, vertical and horizontal strains of structures

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1. Introduction

Prefabricated metal corrugated structures (MCS) used for the construction of tunnel overpasses, small bridges, and water pipes are promising designs since transport facilities from MCS are economically feasible, require minimal time and materials for their construction and operation [1]. This issue is especially relevant for the rapid restoration of the throughput and carrying capacity of damaged transport facilities as a result of hostilities on the territory of Ukraine.

Given the experience of operating a transport facility made of metal corrugated structures used on the railroad track, it was established that in the initial period of operation there was a development of residual strains of horizontal and vertical dimensions of structures [1]. This requires special attention to the high-quality implementation of construction work and the control over changes in the technical condition of metal corrugated structures at facilities. Especially during the period when structures adjust to soil backfill [2, 3]. In addition, work [4] established that the bearing capacity of metal corrugated structures at transport facilities depends on the size of the degree of compaction of the soil backfill. With normative compaction of soil filling, the design bearing capacity of structures is ensured.

The technical condition of transport facilities on a railroad line plays almost the most important role in ensuring the safe passage of railroad rolling stock. Directive 2016/797 of the European Union and technical specifications of interoperability of the subsystem «Infrastructure» TSI INF [5] state that the main criterion for the performance of transport facilities is the passage of railroad rolling stock at established speeds and ensuring traffic safety.

In 2019, a tunnel-type overpass was built from prefabricated metal corrugated structures under a railroad track. Technical parameters of the tunnel overpass are as follows: the cross-section is an ellipse; width, 9.37 m; height, 8.12 m; length, 34.63 m. The general view of the existing tunnel overpass is shown in Fig. 1.

Fig. 1. General view of the tunnel overpass made from prefabricated metal corrugated structures under a railroad track

Control over the technical condition of transport structures from prefabricated MCS in operation is possible by conducting experimental measurements of the vertical and horizontal strains of metal structures at facilities.

To assess the deformed state of the tunnel-type overpass, the task of controlling strains under the action of dynamic load from the railroad rolling stock arose. However, the accumulated experience of experimental assessment of the deformed state of facilities made of metal corrugated structures on a railroad track is almost lacking. Therefore, an important and relevant task of research is the introduction of non-destructive methods for monitoring the technical condition of such structures. These methods (measuring systems) should provide an opportunity to predict the deterioration of the technical condition of structures from MCS, which will allow timely urgent repair work in order to ensure the design bearing capacity of facilities.

It should also be noted that the current norms [6] provide requirements only for metal corrugated structures and methods of their installation. However, no experimental methods for monitoring the technical condition of metal corrugated structures of transport facilities during operation are given.

Thus, it is a relevant task to conduct a study into the deformed state of prefabricated metal corrugated structures for a tunnel-type overpass under the action of railroad rolling stock. Such a study will make it possible to establish the dynamic parameters of metal corrugated structures and could make it possible to assess the bearing capacity of facilities.

2. Literature review and problem statement

The current norms [6] put forward requirements for the design of transport facilities from MCS on motorways. They set out the principles of the engineering method for calculating structures under the action of static loads from vehicles. Instrumental methods of research into the deformed state of a tunnel overpass made from prefabricated metal corrugated structures are not considered.

Paper [7] provides a methodology for calculating the values of pressure forces on top of a reinforced concrete pipe, which is strengthened with metal corrugated structures. The procedure is based on determining the deformed state of the reinforced pipe during static and dynamic loads, depending on the height of the backfill above the pipe, counting from the sole of the sleeper to the top of the pipe.

In work [8], theoretical studies into the bearing capacity of metal corrugated structures of a railroad track were carried out. The calculation of equivalent forces arising from the railroad rolling stock was performed. However, the cited work does not report experimental studies into the deformed state of metal corrugated structures.

According to [9], the bearing capacity of MCS for transport facilities is ensured under the condition of performing a high-quality compaction of the soil backfill, that is, when providing the normative degree of sealing of the backfill to a coefficient of 0.97 and above. Work [10] states that in addition to the degree of compaction of the soil backfill, an important task of ensuring the long-term operation of structures made from MCS is to control the strains of the vertical and horizontal diameters of the facility from MCS. Control should be carried out within six months from the start of operation of structures from MCS. In addition, work [11] states that when operating facilities made of metal corrugated structures on railroads, it is necessary to limit the speed of trains. The speed limit is valid until the metal corrugated structures have residual strains of the vertical and horizontal size of the facility.

It should be noted that the considered works relate to topical issues regarding the need to monitor the deformed state of metal corrugated structures at facilities. However, they do not give the results of the assessment of the deformed state of facilities' structures under the action of railroad rolling stock.

Work [3] states that in the initial period of operation of structures from MCS, there are strains at facilities, which is due to an insufficient degree of compaction of the soil backfill. In addition, paper [12] notes that the technical parameters of the railroad rolling stock exert a significant impact on the forces of dynamic interaction between a railroad track and the railroad rolling stock.

Paper [13] reports the theoretical basis for determining the dynamic interaction of the track and rolling stock, taking into consideration the parameters of geometric irregularities of the track formed due to the subsidence of the ballast of the railroad track. No experimental studies into the magnitude of dynamic forces have been carried out.

However, in works [12, 13], no experimental studies into the forces of interaction between the track and rolling stock are reported.

Paper [14] gives the results of theoretical studies into the stressed-strained state of the reinforced soil bed of a railroad track with tubular drainages. It is established that the amount of strains of pipes increases with an increase in the diameter of the pipe. However, the cited paper does not provide an experimental procedure for testing the deformed state of tubular drainages.

Work [15] reports theoretical studies into the influence of the diameter of a fiberglass pipe on the deformed state of the transport structure «embankment-pipe» of a railroad track. It is established that with an increase in the diameter of the fiberglass pipe, the value of strains of the soil bed and fiberglass pipe increases. It should be noted that fiberglass pipes, which were investigated in the cited work, have a higher cylindrical rigidity than pipes made of prefabricated metal corrugated structures.

Many studies into the stress-deformed state of metal corrugated structures at transport facilities consider the development of theoretical research methods. Namely, work [16] reports a study of temperature stresses and strains of metal corrugated structures arising under the influence of climatic temperature influences of the environment. Paper [17] gives a theoretical model for assessing the strains of a water pipe made from MCS and conducts a study into their deformation depending on the density of soil backfill.

Work [18] states that visual inspections of structures are mainly used to assess the technical condition of transport facilities. In addition, in some cases, instrumental methods of surveying structures at facilities are used [19]. However, paper [20] notes that such methods of assessing the technical condition of the transport infrastructure do not ensure the establishment of a reliable technical condition of the facility. In addition, they do not make it possible to assess the dynamic parameters of the structure, which is relevant for transport facilities made from metal corrugated structures.

In the countries of the European Union, inertial diagnostic systems were widely used to diagnose the technical condition of the elements of a railroad track [21]. These are ESAH-M and ESAH-F. The ESAH-M system is stationary, that is, it is installed directly on the structure of a railroad track being diagnosed. Diagnostics of railroad track structures by the ESAH-F system involves the installation of a system on the railroad rolling stock (the acceleration sensor is attached to the journal of the train wheel). As a result, when the train moves, the dynamic interaction of rolling stock and railroad track is recorded [23].

The main element of the ESAH-M and ESAH-F systems are 3D acceleration sensors, which make it possible to establish acceleration. In addition, the systems include devices for collecting and digitizing measured information.

The disadvantages of the ESAH-M system include the component of manual processing of measured acceleration values and that is does not measure accelerations at high speeds of rolling stock movement. In addition, it does not have an autonomous power source [24]. The ESAH-F system requires identification of rolling stock passing places [25]. That leads to inaccuracies in establishing the coordinates of faulty sections of the track and requires the development of complex algorithms for processing the measured values of the acceleration signal.

Our review of research works [5–25] has revealed that not experimental studies into the deformed state of a tunnel-type overpass made from prefabricated metal corrugated structures under the action of railroad rolling stock were carried out.

It should be noted that due to the specific working conditions of MCSs and their negligible use on railroads, the issues of assessing their dynamic characteristics are still unresolved. Most scientific papers relate to the issues of mathematical modeling and evaluation of the stressed-strained state of structures made from MCS, without reporting experimental dynamic tests of facilities made from MCS. Therefore, it is advisable to study the deformed state of prefabricated metal corrugated structures under the action of dynamic loads, which will resolve the task of establishing dynamic parameters for a tunnel overpass under the action of railroad rolling stock.

3. The aim and objectives of the study

The purpose of this work is to determine the impact of dynamic load from the railroad rolling stock on the deformed state of prefabricated metal corrugated structures in a tunnel overpass. This will make it possible to obtain reasonable data on the deformed state of prefabricated metal corrugated structures for a tunnel overpass, depending on the type of railroad rolling stock.

To accomplish the aim, the following tasks have been set:

– to carry out experimental measurements of accelerations at the top of a tunnel overpass made from metal corrugated structures and on the side of the facility under the action of variable dynamic loads of railroad rolling stock;

– to assess the strains of the top and sides of a tunnel overpass made from metal corrugated structures under the action of railroad rolling stock.

4. The study materials and methods

4. 1. Geometric parameters of the tunnel overpass under study

Experimental measurements of the deformed state of prefabricated MCS were carried out on a tunnel-type overpass. Geometric parameters of the overpass are as follows: the cross-section of the overpass is ellipse; width, 9.23 m; height, 8.12 m; length, 34.19 m. The material of the facility is corrugated galvanized metal structures with the following corrugated size: the height of the corrugated wave is 140 mm, the distance between the vertices of corrugated waves is 380 mm, and the thickness of the corrugated sheet is 6 mm. The strength limit of corrugated sheet steel is 355 MPa.

The material of the filling of corrugated structure is a crushed stone-sand mixture of a fraction of 0–40 mm with an average sealing factor of 0.99.

A two-track electrified railroad passes over the structure (Fig. 2). The height of the embankment above the structure, when counting from the bottom of the sleeper to the top of the corrugation, is 2.91 m.

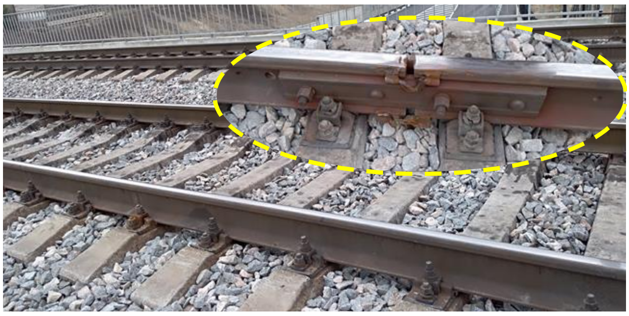


Fig. 2. Two-track railroad over a tunnel overpass made of metal corrugated structures

Above the top of the tunnel overpass is a rail joint with a gap of 32 mm. As a result of the impact of rolling stock wheels against the joint, an additional dynamic load is formed on the metal corrugated structures of the tunnel overpass.

4. 2. Procedure for the experimental measurements of tunnel overpass accelerations

Experimental measurements of accelerations in the tunnel overpass were carried out according to two schemes for placing measuring acceleration sensors. The first scheme involved the arrangement of acceleration sensors under the axis of the even track, and the second scheme – the arrangement of acceleration sensors under the axis of the odd track.

The layout of acceleration sensors on metal corrugated structures of the tunnel overpass is shown in Fig. 3.

In each scheme, one acceleration sensor was placed on top of the tunnel overpass (the largest vertical overpass size), and two sensors on the sides of the overpass (the largest horizontal overpass size).

The measurement of accelerations was carried out during the passage of railroad rolling stock on even and odd tracks. Experimental measurements of accelerations under the axis of the even track were carried out during the passage of a passenger train and under the axis of the odd track when passing two freight trains and one passenger train.

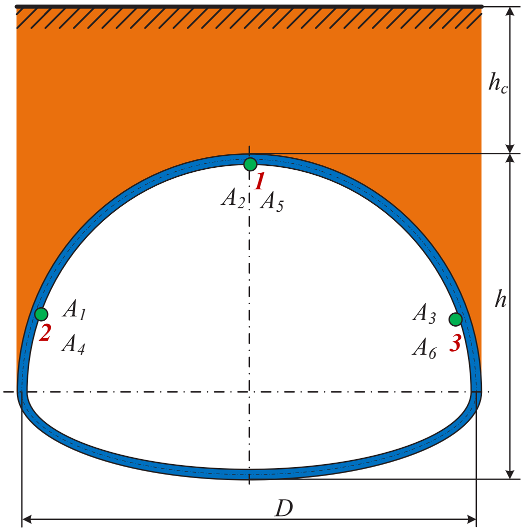


Fig. 3. The layout of measuring sensors on metal corrugated structures during testing: A1–A3 – measuring acceleration sensors are placed under the axis of the paired track A4–A6 acceleration sensors are placed under the axis of the odd track

The general view of our inertial experimental tests of the tunnel overpass made from prefabricated metal corrugated structures is shown in Fig. 4.

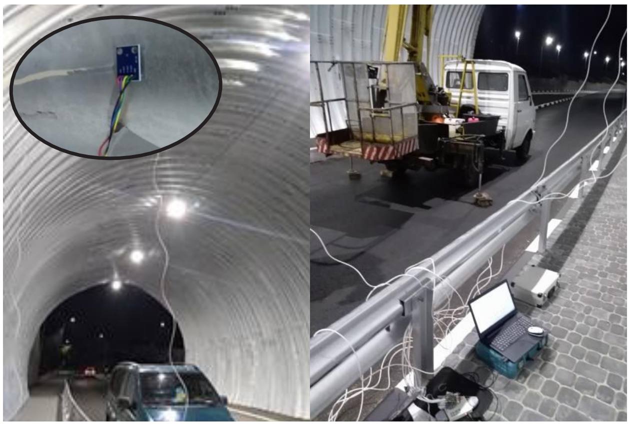


Fig. 4. Inertial experimental tests of the tunnel overpass made from prefabricated metal corrugated structures

To record dynamic oscillations, the high-frequency three-axial acceleration sensor ADXL335 with low power consumption and low noise was used. The sensor has a full range of sensitivity for measuring accelerations within ±3g. It can measure static acceleration caused by tilt-sensitive gravity, as well as dynamic acceleration caused by movement, impact, or vibration, which is characteristic when exposed to dynamic loads from rail transport.

The acceleration sensors were attached to the metal structures using high-strength two-component glue. As a result, good contact of the sensor with the structure of the overpass was ensured, which is a prerequisite for inertial tests of transport facilities.

4. 3. Procedure for processing measured signals of accelerations

As a result of the passage of railroad rolling stock, an inertial measurement system was used to record the values of accelerations at the top and on the sides of the tunnel overpass made from metal corrugated structures.

The mathematical algorithm of the programmed system involves the elimination of high-frequency signals. At the same time, the signal drift is eliminated by smoothing the acceleration signal with splines on characteristic areas of the acceleration recording line. For this purpose, digital processing of the acceleration signal was used, in accordance with the recommendations given in [26–29].

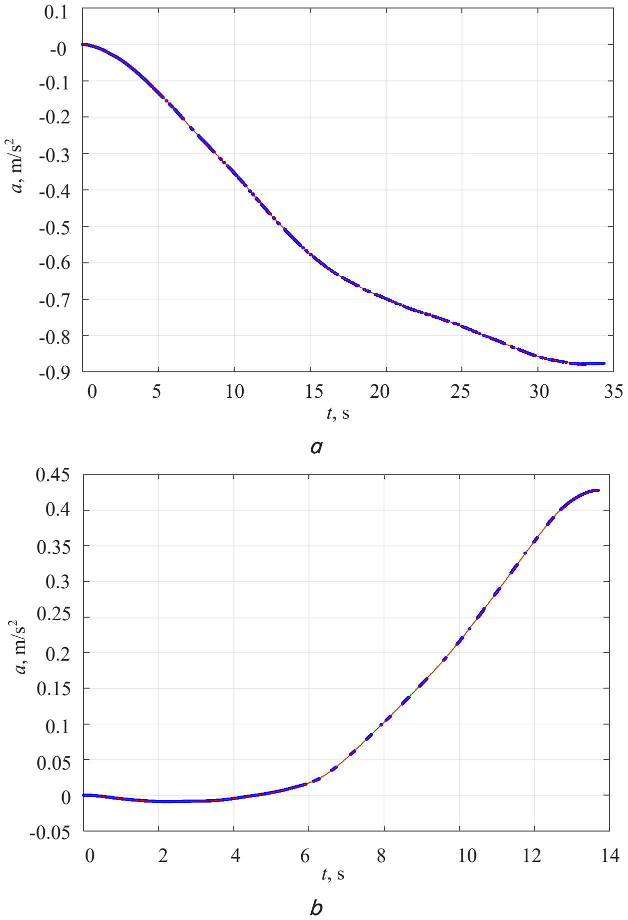
The results of processing the input signal of accelerations by smoothing in separate areas with splines are shown in Fig. 5. Separately given are the results of signal processing at rolling stock speeds of up to 50 km/h (Fig. 5, *a*) and at a rolling stock speed exceeding 100 km/h (Fig. 5, *b*).

After processing the acceleration signal by double integration by trapezoidal approximation, the strains of the top and sides of the tunnel overpass were determined.

The first integration of the acceleration signal a_x and a_y by trapezoidal approximation [29–36] makes it possible to establish the speed determined from the formulas:

$$V_x = \sum_{i=1}^{n} \left[\frac{\left(a_{x_{i-1}} + a_{x_i}\right)}{2} \cdot \Delta t \right], \quad V_y = \sum_{i=1}^{n} \left[\frac{\left(a_{y_{i-1}} + a_{y_i}\right)}{2} \cdot \Delta t \right], \qquad (1)$$

where Δt is the time interval between the measured acceleration values. It depends on the frequency of discreteness of recording the acceleration signal.



a

b

Fig. 5. The results of filtration of the acceleration signal depending on the movement speed of railroad rolling stock: *a* – at speeds of up to 50 km/h; *b* – at speeds exceeding 100 km/h

The following integration of V_x and V_y velocity values makes it possible to establish the strains determined from the formulas:

$$S_x = \sum_{i=1}^{n}\left[\frac{\left(V_{x_{i-1}} + V_{x_i}\right)}{2}\cdot\Delta t\right],\quad S_y = \sum_{i=1}^{n}\left[\frac{\left(V_{y_{i-1}} + V_{y_i}\right)}{2}\cdot\Delta t\right], \qquad (2)$$

Thus, as a result of double integration of the filtered acceleration values, we determine the deformation of metal corrugated structures of the tunnel overpass.

5. Results of studying the deformed state of the tunnel overpass made from prefabricated metal corrugated structures

5. 1. Results of studying the acceleration of the tunnel overpass made from prefabricated metal corrugated structures

Experimental measurements of the accelerations of the tunnel overpass made from MCS were carried out at the top of the overpass and on the sides. Records of accelerations were obtained when passing one train along an even railroad track and from the passage of two freight and one passenger train along an odd track.

The acceleration recording line that occurs at the top of the tunnel overpass made from MCS, when passing a freight train, is shown in Fig. 6. The recording of the accelerations from a passenger train is shown in Fig. 7.

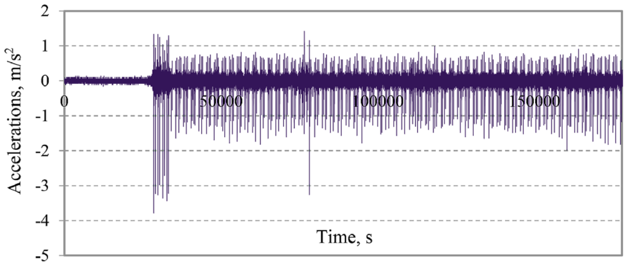


Fig. 6. The plot of accelerations arising at the top of the metal corrugated overpass structure when passing a freight train

Along the line of recording accelerations (Fig. 6) there are sections of accelerations arising from the action of traction rolling stock and freight cars. The accelerations arising from traction rolling stock are larger than the values of accelerations arising from freight cars. The maximum acceleration value from traction rolling stock was 3.77 m/s^2, and from freight cars – 1.98 m/s^2.

It should also be noted that when passing freight cars, the plot demonstrates a sharp change in accelerations from one of the freight cars, which are 3.24 m/s^2. This is due to a malfunction of the chassis of rolling stock. A significant impact on increasing the dynamic effect of rolling stock on the tunnel overpass is exerted by the technical condition of rolling stock wheels. With excessive wear of the wheels, or sliding, an additional dynamic load on the tunnel overpass occurs.

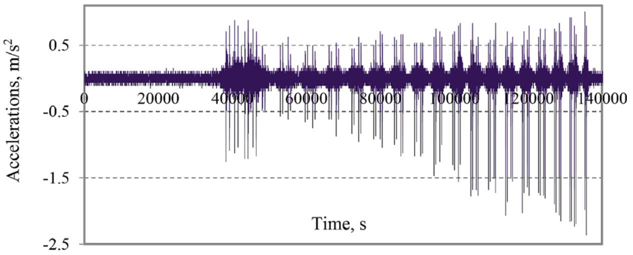


Fig. 7. The plot of accelerations arising at the top of the metal corrugated overpass structure when passing a passenger train

With an increase in the speed of the passenger train, accelerations at the top of the overpass increase. Moreover, the acceleration from the first to the last passenger car increases linearly. From the first passenger car, the maximum acceleration value was 0.62 m/s^2, and from the last – 2.42 m/s^2. This is explained, first, by an increase in the speed of rolling stock when dispatched from the station, and, second, by a significant fluctuation in the last passenger car.

The results of recording the maximum accelerations obtained during the passage of railroad rolling stock along even and odd tracks are given in Table 1. The accelerations occurring at the top of the overpass (this is point 1, Fig. 3) and on the sides of the overpass (these are points 2 and 3, Fig. 3) are given.

Our experimental measurements of accelerations (Table 1) established that the maximum value of the overpass accelerations was 7.99 m/s^2 when passing a freight train. When passing a passenger train, the acceleration value was 6.21 m/s^2.

Table 1

Results of maximum accelerations arising in the tunnel overpass made from MCS when passing the railroad rolling stock

Railroad rolling stock type	Left side of the overpass (point 2)		The top of the overpass (point 1)		Right side of the overpass (point 3)	
	A1	A4	A2	A5	A3	A6
Passenger train	0.40	–	2.36	–	0.42	–
Freight train	0.88	–	3.77	–	0.71	–
Freight train	2.63	–	7.99	–	2.35	–
Passenger train	–	1.96	-	6.21	–	1.77

The maximum accelerations that occur on the sides of the tunnel overpass when passing a freight car are 2.63 m/s^2, and when passing a passenger train – 1.77 m/s^2.

5. 2. Results of studying the strains of metal corrugated structures of the tunnel overpass made from prefabricated MCS under the action of railroad rolling stock

Based on the known values of accelerations arising at the top and on the sides of the tunnel overpass, the strains of the metal structures of the overpass were established by double-integrating the acceleration signal according to formulas (1) and (2).

The line of recording strains arising at the top of the tunnel overpass during the passage of a freight train is shown in Fig. 8, and when passing a passenger train – Fig. 9.

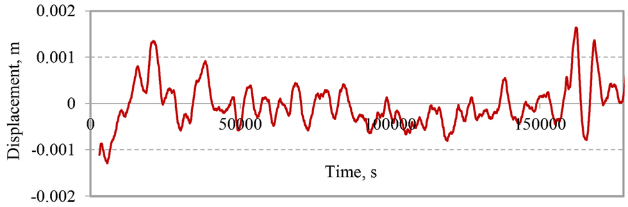


Fig. 8. Deformation of the top of the tunnel overpass during the passage of freight railroad rolling stock

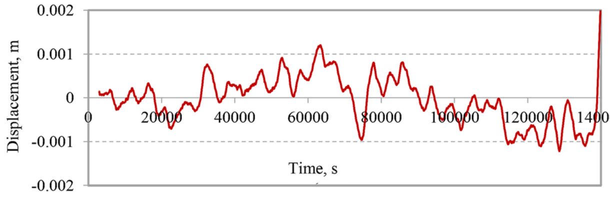


Fig. 9. Deformation of the top of the tunnel overpass during the passage of passenger railroad rolling stock

When passing a freight train, the plot of the strains of the metal corrugated structures of the tunnel overpass demonstrates a deflection of the overpass. As a result of the approach of the train to the overpass, the top of the overpass rises by 0.71 mm to the top and, when moving over the overpass, there is a deflection of the overpass structures. The maximum bending value of the top of the overpass was 1.63 mm.

When passing passenger rolling stock, the value of the maximum strains of metal corrugated structures of the tunnel overpass was 1.11 mm.

At the end of the recording of the deformation line of the top of the overpass (Fig. 9), a jump in strains is observed. As a result, the strains amounted to more than 2 mm. This is due to the flexibility of prefabricated metal structures. When exiting the overpass, the metal structures return to their original position.

The results of recording the maximum strains obtained during the passage of railroad rolling stock on even and odd tracks are given in Table 2.

Table 2

The results of recording the maximum strains arising in the tunnel overpass made from the prefabricated MCS during the passage of railroad rolling stock

Railroad rolling stock type	Left side of the overpass (point 2)		The top of the overpass (point 1)		Right side of the overpass (point 3)	
	A1	A4	A2	A5	A3	A6
Passenger train	0.41	–	1.02	–	0.63	–
Freight train	1.07	–	1.54	–	0.91	–
Freight train	0.51	–	1.63	–	0.65	–
Passenger train	–	0.39	–	1.11	–	0.48

Table 2 shows that the maximum strains of metal corrugated structures at the top of the tunnel overpass, when passing a freight car, amounted to 1.63 mm, and when passing a passenger train – 1.11 mm.

The maximum strains that occur on the sides of the tunnel overpass during the passage of a freight car are 1.07 mm, and when a passenger train passes – 0.48 mm.

6. Discussion of results of the dynamic tests of the tunnel overpass made from prefabricated metal corrugated structures

Inertial dynamic tests of the tunnel overpass made from prefabricated MCS, operated in the body of the embankment of the railroad track, were carried out. As a result, the lines of recording accelerations and strains arising at the top of the overpass and on its side during the passage of freight and passenger trains were obtained.

Fig. 6 demonstrates that the maximum acceleration value from traction rolling stock was 3.77 m/s^2, and from freight cars acceleration – it reached the values of 1.98 m/s^2. The maximum value of accelerations during the passage of a passenger train (Fig. 7) was 2.42 m/s^2.

In addition, the plot of recording accelerations (Fig. 6, 7), arising during the passage of freight and passenger trains, clearly demonstrates the sections of passage of the traction rolling stock and cars. When passing a freight train, greater acceleration values arise from the traction rolling stock, and less – from freight cars (Fig. 6). However, when a passenger train moves, higher values were obtained from the last passenger car, which is explained by the side vibrations of the last passenger car. This is also due to an increase in the speed of the passenger train when dispatched from the station.

The recording of accelerations arising in metal corrugated structures makes it possible to see sections of significant jumps in the accelerations arising from cars. This, in turn, indicates a malfunction of the chassis of the cars and makes it possible to identify specifically the number of the car that has technical malfunctions. Since the significant wear, rolling, or sliding of the wheel of rolling stock increase the dynamic addition of forces to the track, which also increases the load on the tunnel overpass.

As a result of recording accelerations from freight and passenger trains, it was established that the maximum acceleration value at the top of the overpass when passing a freight train was 7.99 m/s^2, and when passing a passenger train – 6.21 m/s^2 (Table 1). At the same time, the maximum accelerations that occur on the sides of the tunnel overpass during the passage of a freight car are 2.63 m/s^2, and, when a passenger train passes, 1.77 m/s^2.

The results of the recording of strains in the prefabricated metal corrugated structures of the tunnel overpass showed that the structure of the overpass bends under the influence of the load, and then, when the train exits the overpass, the structures return to their original position (Fig. 8). This is due to the flexibility of metal corrugated structures and the redistribution of bending moments.

In addition, when the train approaches the overpass, its top rises by 0.71 mm to the top, and when hitting the overpass, its structures bend. The maximum strains of the metal corrugated structures of the top of the tunnel overpass, when passing a freight car, amounted to 1.63 mm, and when passing a passenger train – 1.11 mm (Table 2).

The maximum strains of the metal corrugated structures on the sides of the overpass (Table 2), when passing a freight car, amounted to 1.07 mm, and when passing a passenger train – 0.48 mm.

A comparison of the results of studying the vertical strains of metal corrugated structures shows that maximum strains occur at the top of facilities, both when freight and passenger trains move. In work [1], in the dynamic experimental tests of a water pipe with a diameter of 6.57 m made from MCS, it was established that the maximum, vertical relative deformation of the pipe was 2.74 mm when passing a freight train and 0.77 mm when passing a passenger train. In our study, when passing a freight car, the vertical deformation of the top of the overpass of the metal corrugated structures was 1.63 mm, and when passing a passenger train – 1.11 mm.

It should be noted that the difference in the values of strains is due, first of all, to the conditions of loads, as well as the amount of backfill from the sole of the sleeper to the top of the metal structure of the structure.

It should be noted that most scientific works [5–25] relate to the issues of mathematical modeling and evaluation of the stress-strained state of structures made from MCS, without reporting any experimental dynamic tests of structures made from MCS. Therefore, the proposed algorithm for conducting experimental inertial measurements of accelerations at the top of the tunnel overpass made from metal corrugated structures and on the side of the facility under the action of variable dynamic loads of railroad rolling stock makes it possible to solve the problem of experimental studies of the deformed state of metal corrugated structures of transport facilities under the action of dynamic loads of railroad transport. In addition, taking into consideration the specific working conditions of MCS and their minor use on railroads, this work allows engineering and scientific specialists in the railroad industry to monitor the technical condition of the tunnel-type overpass made from metal corrugated structures.

As a result of our dynamic inertial tests of the tunnel overpass, it was established that the value of relative strains of the vertical size of the structure was 0.020 % of the vertical size of the facility. The value of the relative strains of the horizontal size of the overpass structure was 0.012 % of the horizontal size of the facility. These values are less than the permissible value of relative strains of 5 %, regulated by the norms [5, 6]. Therefore, the bearing capacity of the overpass made from metal corrugated structures, which is operated under the railroad track and undergoes dynamic loads from the railroad rolling stock, is ensured.

The practical significance of our results is the possibility of using the inertial method by engineering and scientific specialists to assess the deformed state of metal corrugated structures of transport facilities under the influence of dynamic loads from railroad transport.

One of the limitations of the current research is determining only the strains in the prefabricated MCS in a tunnel overpass, arising from the dynamic action of freight and passenger trains. In addition, the values of stresses arising in the metal structures of the overpass were not established. Therefore, further continuation of our research is the development of experimental methods for assessing the stress-strained state of prefabricated metal corrugated structures under the action of static and dynamic loads from moving vehicles.

7. Conclusions

1. The maximum value of accelerations arising at the top of the tunnel overpass when passing a freight train was 7.99 m/s^2, and when passing a passenger train – 6.21 m/s^2.

The accelerations arising from traction rolling stock are larger than the accelerations arising from freight cars. The maximum acceleration value from traction rolling stock was 3.77 m/s^2, and from freight cars – 1.98 m/s^2.

The maximum accelerations that occur on the sides of the tunnel overpass during the passage of a freight car are 2.63 m/s^2, and when passing a passenger train – 1.77 m/s^2.

The established parameters of accelerations arising in the metal corrugated structures of the tunnel overpass can be further used to monitor its technical condition under operating conditions.

2. The value of the maximum deformation of the metal corrugated structures of the top of the tunnel overpass during the passage of a freight car was 1.63 mm, and when passing a passenger train – 1.11 mm. At the same time, the maximum strains of the metal corrugated structures on the sides of the overpass during the passage of a freight car amounted to 1.07 mm, and when passing a passenger train – 0.48 mm.

It is established that the value of the maximum relative strains of the vertical and horizontal transverse dimensions of the tunnel overpass of the metal corrugated structure, under the action of railroad rolling stocks, is 0.020 % of the vertical size of the facility. At the same time, the value of relative strains of the horizontal size of the overpass structure was 0.012 % of the horizontal size of the facility. They are less than the permissible value of relative strains of 5 %, so the bearing capacity of the metal corrugated structures of the tunnel overpass is provided.

The inertial method makes it possible to determine the deformed state of the metal corrugated structures of the tunnel overpass, therefore, it is proposed for practical use.

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