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ASSESSMENT OF THE STATE OF STRESS AND DEFORMATION OF METAL CORRUGATED PIPE STRUCTURES TAKING INTO ACCOUNT ITS DIAMETER AND THICKNESSES OF THE CORRUGATED SHEET

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Abstract. The analysis of research works on the assessment of the stress-strain state of prefabricated metal corrugated structures of transport facilities was performed. It was established that the stresses and deformations of structures made of ZMGK depend on a complex of influencing factors: the amount of static and dynamic loads, the height of the backfill above the vault of the structure, the parameters of corrugation waves, etc. However, the interconnected effect of the pipe diameter and the thickness of the metal corrugated sheet on the stresses that occur in the metal pipe structures has not been established.

The object of research is metal corrugated pipe constructions. To assess the stress state of the pipe, the influence on the stress of the cross-section of the pipe and the thickness of the metal corrugated sheet of the structure are taken into account.

It was established that the geometric parameters of the cross-section of the pipe and the thickness of the metal corrugated sheet of the structure have a significant influence on the stress state of metal corrugated pipe structures. When the diameter of the pipe increases, the amount of stress that occurs in metal structures increases. However, with an increase in the thickness of the corrugated sheet, the amount of stress, with the same pipe diameter, decreases. Increasing the thickness of the sheet from 3.0 mm to 7.0 mm leads to a decrease in the stresses in the pipe metal by 50.39%. When the diameter of the pipe changes from 1.0 m to 6.0 m with a metal thickness of the corrugated sheet equal to 3.0 mm, the magnitude of the stresses increased by 7.38 times, with a sheet thickness of 4.0 mm – by 7.8 times, with a thickness of 5.0 mm sheet – 8.08 times, 6.0 mm sheet thickness – 8.28 times, and 7.0 mm corrugated pipe sheet thickness – 8.43 times.

It was established that the gradual increase in the thickness of the corrugated sheet of the structure leads to a decrease in the stress difference between the previous thickness of the sheet and the increased one. With a pipe diameter of 6.0 m, the stress difference that occurs when the thickness of the corrugated sheet is 3.0 mm and 4.0 mm is 21.35 MPa, with a thickness of 4.0 mm and 5.0 mm, the stress difference is 14.16 MPa, at 5.0 mm and 6.0 mm, the difference in stress values is 10.25 MPa, and with increased sheet thickness from 6.0 mm to 7.0 mm, the difference in stress values is 7.76 MPa.

The obtained results of the stress state of prefab metal corrugated pipe structures can have practical application in the case of acceptance of the technical and economic justification, regarding the determination of the pipe diameter and the thickness of the metal corrugated sheet of the structure. One of the limitations of the application of these research results is the assessment of the stress state of the pipe made of prefabricated metal corrugated structures with the parameters of the corrugated waves of 150×50 mm. Other parameters of corrugation waves are not taken into account in this study.

Keywords: prefabricated metal corrugated structures, pipe, tension.

Introduction. Transport constructions made of prefabricated metal corrugated structures (hereinafter referred to as PMCS) are successfully used in transport construction. There are built culverts, tunnel-type overpasses, small bridges, bio-crossings, pedestrian crossings, etc. on the communication routes made from prefabricated metal corrugated structures. The constructions of PMCS are widely used in the European Union [1-4]. Well-known manufacturers of metal corrugated structures are the Norwegian-Swedish-Finnish company ViaCon [1], the Canadian company ARMTEC [3], and the company FRACASSO [4].

In Ukraine, several PMCS constructions have been built, for example, the tunnel overpass in Kropyvnytsky [5], a culvert on the Vadul-Siret-state border section of the railway track in the shape of a horizontal ellipse with axes of 6.57 m and 6.20 m [6] (Fig. 1). The transport tunnel on 228 + 160 km of the Kyiv-Kharkiv-Dovzhansky highway, the transport tunnel on the bypass in Odessa, the transport tunnel on a bypass in Donetsk using structures SuperCor SC 86 s [7], the construction in the village of Fructove in the Autonomous Republic of Crimea, the PMC transport structure on the Kyiv-Odesa Highway at 169+292 km [8, 9] and a number of PMC structures on the other roads of Ukraine.

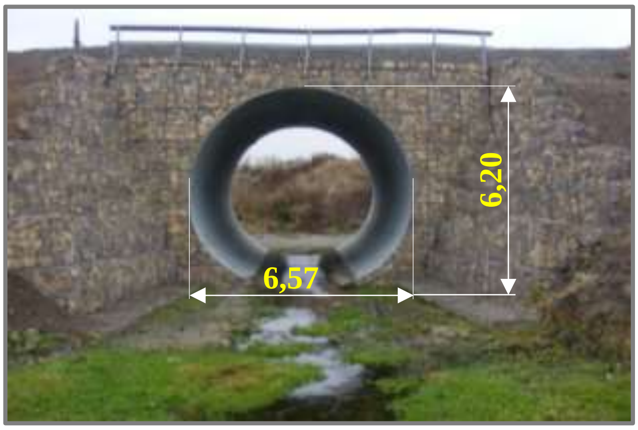

Fig. 1. A pipe made of metal corrugated structures

A PMC tunnel-type overpass built in Kropyvnytsky is of a large cross-section size. The construction is 9.23 m wide and 8.12 m high. The length of the overpass under the railway track is 34.19 m. At the same time, the width of the highway in the overpass is 5.5 m.

The problem and its relevance. On operating the constructions made of prefabricated metal corrugated structures, they are exposed to a variety of influences. As a result, the constructions suffer a variety of damages. In addition, the durability of constructions made of PMCS depends on compliance with the technological conditions of the ground compaction backfill device and ensuring anti-corrosion protection of metal structures.

It should be noted that in the practice of constructing PMC structures, there are cases that residual deformations of vertical and horizontal axes that occurred during the initial service life [6]. Therefore, to ensure the load-bearing capacity of structures, multivariate calculations should be carried out regarding to the influence of a complex of factors on the load-bearing capacity of constructions made of prefabricated metal corrugated structures. The transverse rigidity of individual PMCS elements is provided due to the thickness of the elements and their wavy corrugated shape. This study presents the results of estimating the stresses that occur in metal structures, taking into account the pipe diameter and thickness of the metal corrugated sheet.

Analysis of recent research and publications. Today, there are a number of scientific papers on studies of the stress-strain state of PMC structures [10-16]**.** In scientific works [10, 11], it is indicated that constructions made of metal corrugated structures have high reliability. Since experimental tests of constructions have shown that PMC structures are able to withstand loads 2.5 times higher than the calculated ones. Also, the results of experimental studies of the stress-strain state of PMC structures are given in the works [13, 14].

In [12], it is indicated that it is difficult to estimate the actual stresses and deformations of metal structures during the construction of structures, especially when compacting the ground backfill of structures.

In [15, 16], the results of estimating the stress-strain state of PMC structures are presented, taking into account the influence of the degree of compaction of ground backfill. It is established that only with the standard degree of compaction, the load-bearing capacity and durability of such structures are ensured. In the case of an insufficient degree of compaction in the metal of the structures, stresses may develop that exceed the allowable stresses.

From the analysis of research, it was found that PMC structures have advantages over concrete and reinforced concrete constructions. Most scientific works are related to studying PMC structures, taking into account the impact of loads from vehicles and taking into account the physical and mechanical parameters of the sealing backfill. The problems of estimating the stress-strain state of PMC structures, taking into account the geometric parameters of structures, have not been sufficiently developed. This would give practical results regarding the feasibility of using the structures of a certain cross-section size. Therefore, the work conducts a study on the influence of the cross-section of a PMC pipe and the thickness of a corrugated metal sheet on the stress-strain state of structures.

The research purpose is an assessment of the stress-strain state of metal corrugated structures of the construction, depending on the size of the cross-section of the pipe and the thickness of the metal corrugated sheet.

Materials and methods of the research. To study the stress-strain state of a PMC pipe, we consider the geometric model shown in Fig. 2. To study the features of the stress-strain state of a pipe made of metal corrugated structures, a study of stresses that occur in metal structures depending on the diameter of the structure and the thickness of the metal corrugated sheet of the structure was conducted. A corrugated pipe with 150×50 mm corrugation wave parameters was taken in the study. In this case, the thickness of the corrugated sheet is assumed to be from 3.0 mm to 7.0 mm. The backfill height above the metal pipe arch is 2.0 m. The maximum pipe diameter is assumed 6.0 m, and the minimum is 1.0 m.

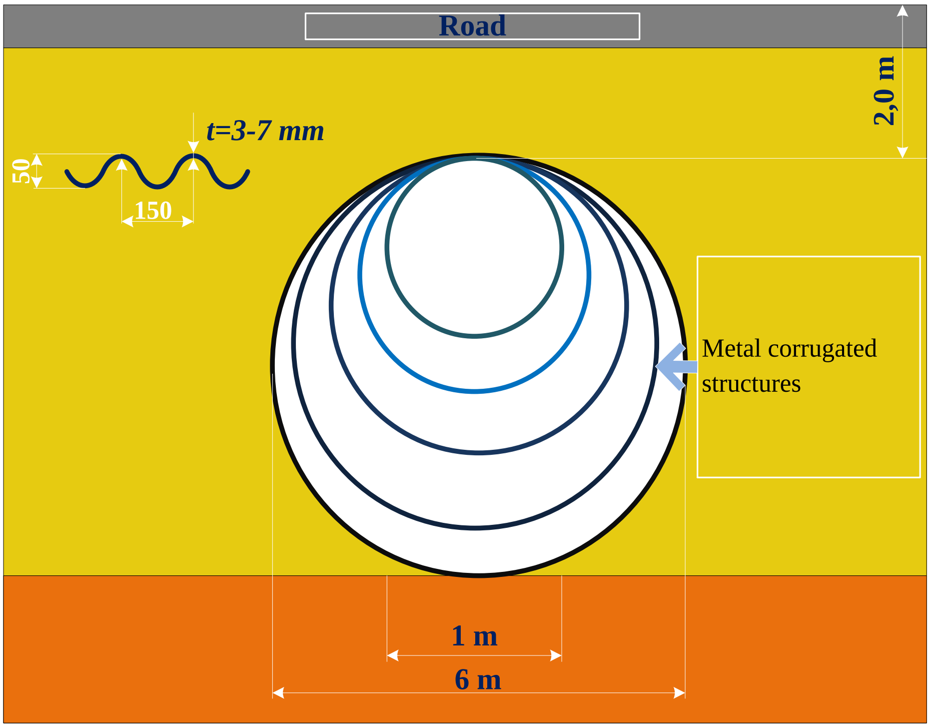

Fig. 2. Calculation scheme for assessing the stress-strain state of a pipe made of metal corrugated structures

Geometric and physical and mechanical parameters of metal corrugated structures and ground compacting backfill are given in Table 1.

Table 1 – Geometric and physical and mechanical parameters of the PMC pipe used in the calculation

No	Parameter name	Dimension	Parameter value
Data on prefabricated metal corrugated structures			
1	Pipe diameter	m	From 1.0 m to 6.0 m, in 0.5 m increments
2	Geometric parameters of wave corrugation of metal pipe structures	mm	150×50
3	PMC thickness	mm	3.0; 4.0; 5.0; 6.0; 7.0
4	Elastic modulus of steel	MPa	2.1×10^5
5	Poisson's ratio of construction material	-	0.25
6	Specific gravity of the PMC material	kN/m^3	78
Data on soil compaction backfill			
7	Specific gravity of backfill soil	kN/m^3	21
8	Backfill soil deformation modulus	MPa	82
9	Distance from the top of the pipe to the bottom of the road surface	m	1.8
Load data			
10	Equivalent load	kN/ m	182
11	Overload coefficients	-	n=1.3; n_1=1.1

It should be noted that the thickness of the corrugated sheet of the structure also depends on the area of the corrugation wave, which is taken from reference data according to [17].

To check the load-bearing capacity of a pipe made of prefabricated metal corrugated structures, the method given in [17] was used. The load-bearing capacity of metal corrugated structures is checked by the formula:

$$\frac{\mathrm{N}}{\mathrm{A}} \le R_y m, \tag{1}$$

where is the normal (tangential) force N in a corrugated structure from the design loads per length λ one corrugation is determined by the formula:

$$\mathrm{N} = \frac{\gamma \cdot \mathrm{n} \cdot D \cdot \left(\mathrm{h_{eq}} + h + \frac{D}{2}\right) \cdot \lambda}{2 + \frac{E_0}{E} \cdot \frac{D}{\delta} \cdot \left(1 - \nu^2\right)} + \frac{\gamma_{sh} n_1 \delta \frac{D}{2} \lambda}{1 + \frac{\delta^2}{3D^2}}. \tag{2}$$

An explanation of the values given in formulas (1) and (2) is given in [17].

Presentation of the main research material. The results of assessing the stress state of metal structures depending on the diameter of the PMC pipe and the thickness of the metal sheet of structures are given in Table 2.

From the calculation results performed (Table 2) it is established that the values of stresses that occur in metal corrugated structures depend on the pipe diameter. Thus, with a metal sheet thickness of 3 mm and a pipe diameter of 1.0 m, the stress value is 14.61 MPa, with a diameter of 2.0 m – 30.86 MPa, with a diameter of 4 m – 67.33 MPa, with a diameter of 5 m – 87.17 MPa and with a diameter of 6 m – 107.89 MPa.

The value of stresses increases with increasing the diameter of the PMC pipe. When changing the pipe diameter from 1.0 m to 6.0 m with a metal thickness of the corrugated sheet equal to 3.0 mm, the stress value increased by 7.38 times, with a sheet thickness of 4 mm – by 7.8 times, with a sheet thickness of 5 mm – by 8.08 times, with a sheet thickness of 6 mm – by 8.28 times and with a corrugated sheet thickness of 7 mm – by 8.43 times.

Table 2 – The studies' results of the stress state of metal corrugated pipe structures

Structure diameter, m	Thickness of metal corrugated sheet structures with parameters of corrugation waves 150×50 mm				
	3	**4**	**5**	**6**	**7**
	Voltage, MPa				
1.0	14.61	11.09	8.96	7.51	6.45
1.5	22.55	17.24	13.98	11.75	10.12
2.0	30.86	23.75	19.33	16.29	14.06
2.5	39.52	30.59	25.01	21.12	18.26
3.0	48.5	37.76	30.98	26.23	22.72
3.5	57.78	45.23	37.23	31.6	27.43
4.0	67.33	52.99	43.77	37.24	32.37
4.5	77.13	61.01	50.56	43.11	37.55
5.0	87.17	69.28	57.59	49.23	42.94
5.5	97.42	77.79	64.88	55.57	48.55
6.0	107.89	86.54	72.38	62.13	54.37

In addition, the amount of stress is also affected by the thickness of the metal corrugated sheet of the pipe. Let us analyze the stress value for the smallest and largest pipe diameters. And so with a pipe diameter of 1.0 m and a corrugated sheet thickness of 3 mm, the stress value is 14.61 MPa, with a sheet thickness of 4 mm – 11.09 MPa, with a sheet thickness of 5 mm – 8.96 MPa, with a sheet thickness of 6 mm – 7.51 MPa and with a corrugated pipe sheet thickness of 7 mm, the stress value is 6.45 MPa.

With the maximum diameter of a pipe made of prefabricated metal corrugated structures, equal to 6.0 m, which is taken in the calculations, with a thickness of a corrugated sheet of 3 mm, the stress value is 107.89 MPa, with a sheet thickness of 4 mm – 86.54 MPa, with a sheet thickness of 5 mm – 72.38 MPa, with a sheet thickness of 6 mm – 62.13 MPa and with a thickness of a corrugated pipe sheet of 7 mm, the stress value is 54.37 MPa.

Fig. 3 shows the graphical dependence of stresses on the diameter of a construction made of prefabricated metal corrugated structures and the thickness of a metal corrugated sheet of the structure.

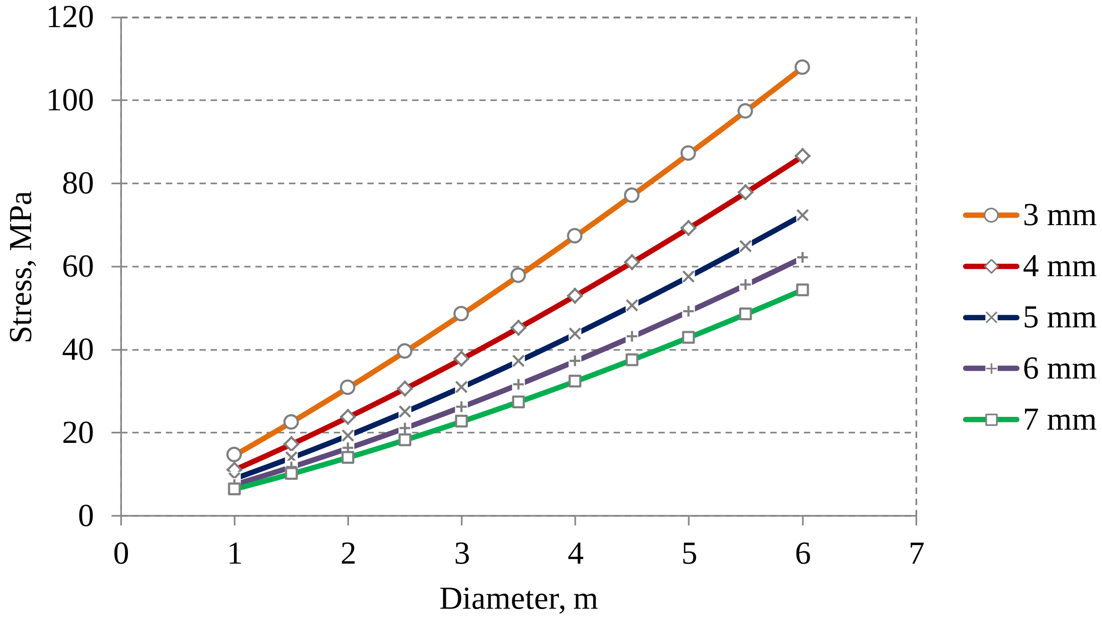

Fig. 3. Graph of stress dependence in metal corrugated structures on the diameter of the construction and the thickness of the metal corrugated sheet

From Fig. 3 it can be seen that with an increase in the thickness of the corrugated sheet of the structure, with the same pipe diameter, the value of stresses changes. Increasing the thickness of the corrugated sheet leads to a decrease in stresses in the pipe metal. It was found when the sheet thickness increased from 3 mm to 7 mm, the stress value decreased by 50.39 %.

However, it should be noted that if we analyze the stress values, for example, with a pipe diameter of 6.0 m and different values of the thickness of the corrugated sheet, we can see in Fig. 3, that the stress difference when changing the thickness of the corrugated sheet from 3.0 mm to 4.0 mm is higher than when changing from 4.0 mm to 5.0 mm and so on. That is, a gradual increase in the thickness of the corrugated sheet of the structure leads to a decrease in the stress difference between the previous thickness and the increased one. And so when the sheet thickness was increased from 3.0 mm to 4.0 mm, the stress value decreased by 21.35 MPa, from 4.0 mm to 5.0 mm, the stress value decreased by 14.16 MPa, from 5.0 mm to 6.0 mm, the stress value decreased by 10.25 MPa, and when the sheet thickness was increased from 6.0 mm to 7.0 mm, the stress value decreased by 7.76 MPa.

Conclusions. As a result of calculations of stresses that occur in metal pipe structures, taking into account the cross-section of the pipe and the thickness of the metal corrugated sheet, the following conclusions are obtained:

1. It is established that the magnitude of stresses that occur in metal corrugated pipe structures depends on the size of the pipe diameter and the thickness of the metal corrugated sheet of the structure. With a metal sheet thickness of 3.0 mm and a pipe diameter of 1.0 m, the stress value is 14.61 MPa, with a diameter of 2.0 m – 30.86 MPa, with a diameter of 4.0 m – 67.33 MPa, with a diameter of 5.0 m – 87.17 MPa and with a diameter of 6.0 m – 107.89 MPa.

2. The results of the research have shown that the magnitude of stresses increases with increasing the diameter of pipes made of precast metal corrugated structures. When changing the pipe diameter from 1.0 m to 6.0 m with a metal thickness of the corrugated sheet equal to 3.0 mm, the stress value increased by 7.38 times, with a sheet thickness of 4.0 mm – by 7.8 times, with a sheet thickness of 5.0 mm – by 8.08 times, with a sheet thickness of 6.0 mm – by 8.28 times and with a corrugated sheet thickness of 7.0 mm – by 8.43 times.

3. It is established that the value of stresses decreases with increasing the thickness of the metal corrugated pipe sheet. With a pipe diameter of 1.0 m and a corrugated sheet thickness of 3.0 mm, the stress value is 14.61 MPa, with 4.0 mm – 11.09 MPa, with 5.0 mm – 8.96 MPa, with 6.0 mm – 7.51 MPa and with a corrugated pipe sheet thickness of 7.0 mm, the stress value was 6.45 MPa.

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ОЦІНЮВАННЯ НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ МЕТАЛЕВИХ ГОФРОВАНИХ КОНСТРУКЦІЙ ТРУБИ ІЗ ВРАХУВАННЯМ ЇЇ ДІАМЕТРУ ТА ТОВЩИНИ ГОФРОВАНОГО ЛИСТА

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Анотація. Виконано аналіз науково-дослідних робіт із оцінки напружено-деформованого стану збірних металевих гофрованих конструкцій транспортних споруд. Встановлено, що напруження та деформації споруд із збірних металевих гофрованих конструкцій залежать від комплексу факторів впливу: величини статичних та динамічних навантажень, висоти засипки над склепінням конструкції, параметрів хвиль гофр тощо. Однак не встановлено взаємопов’язаного впливу величини діаметру труби і товщини металевого гофрованого листа на напруження, які виникають у металевих конструкціях труби.

Об’єктом досліджень є металеві гофровані конструкції труби. Для оцінки напруженого стану труби враховано вплив на напруження величини поперечного перетину труби та товщину металевого гофрованого листа конструкції.

Встановлено, що значний вплив на напружений стан металевих гофрованих конструкцій труби мають геометричні параметри поперечного перетину труби та товщина металевого гофрованого листа конструкції. При збільшенні діаметру труби величина напружень, які виникають у металевих конструкціях, зростає. Однак, при збільшенні товщини гофрованого листа, величина напружень, при одному і тому ж діаметрі труби, знижується. Збільшення товщини листа від 3,0 мм до 7,0 мм призводить до зменшення напружень у металі труби на 50,39 %. При зміні діаметру труби від 1,0 м до 6,0 м при товщині металу гофрованого листа рівній 3,0 мм, величина напружень збільшилася у 7,38 рази, при товщині листа 4,0 мм – у 7,8 рази, при товщині листа 5,0 мм – у 8,08 рази, при товщині листа 6,0 мм – у 8,28 рази та при товщині гофрованого листа труби 7,0 мм – у 8,43 рази.

Встановлено, що поступове підвищення товщини гофрованого листа конструкції призводить до зменшення різниці напружень між попередньою товщиною листа і збільшеною. При діаметрі труби 6,0 м різниця напружень, яка виникає при товщині гофрованого листа 3,0 мм і 4,0 мм складає 21,35 МПа, при товщині 4,0 мм та 5,0 мм різниця величин напружень складає 14,16 МПа, при 5,0 мм та 6,0 мм різниця величин напружень складає 10,25 МПа та при підвищені товщини листа від 6,0 мм до 7,0 мм різниця величин напружень складає 7,76 МПа.

Отримані результати напруженого стану збірних металевих гофрованих конструкцій труби можуть мати практичне застосування у випадку прийняття техніко-економічного обґрунтування, щодо призначення діаметру труби та товщини металевого гофрованого листа конструкції. Одним із обмежень застосування даних результатів досліджень є оцінка напруженого стану труби виготовленої із збірних металевих гофрованих конструкцій із параметрами хвиль гофр 150×50 мм. Інші параметри хвиль гофр у даному дослідженні не враховано.

Ключові слова: збірні металеві гофровані конструкції, труба, напруження.

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