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# EXPERIMENTAL RESEARCH OF THE STRESS-STRAIN STATE OF THE RAILWAY TRACK METAL CORRUGATED STRUCTURES

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***Summary.*** *In the paper the scientific principles of a new device for the measurement and evaluation of the stress-strain state of transportation facilities under changing temperatures and loads have been developed. The technical problem solved by this paper deals with the making evidence-based decisions on the need for renewal of the element, control of the gradual reduction of the bearing capacity of the structural elements, determination of their real technical condition and residual life according to the transport facilities monitoring.*

*In the heart of the new device is measuring of strain using analog-to-digital converter (ADC) and analog measuring bridge - tenzometer. The advantage of the proposed device is that the accuracy of measurements made by it does not depend on the length of the connecting conductors and supply voltage. The deformations caused by the temperature effects on transport facilities can be estimated and taken into account too.*

*The problems of adapting of foreign regulations on the design of metal corrugated structures at the Ukraine railways and motor roads were analyzed. The results of experimental and theoretical calculations of bearing capacity of metal corrugated structures were presented.*

*During dynamic experimental testing it was found: maximum relative vertical deformation of the pipe was registered for a freight train and equals 2.74 mm. In this case, residual deformation was 0.21 mm; relative horizontal deformation for a freight train equals 0.77 mm, here residual deformation being 0.038 mm. The maximum fibre stresses under the dynamic loading at the top of the pipe in specified points equal 10.7 MPa.*

***Key words:*** *device, residual deformations, designing, plastic hinge, rolling stock of railways, soil fill stabilization.*

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**Introduction.** The problem of creation and improvement of the calculation methods for metal corrugated structures (MCS) in the soil environment started to be developed simultaneously with their application in construction engineering. While designing the metal corrugated structures the designers face the problem of choosing the analytical model for estimation of the MCS bearing capacity taking into account the fact, that the designers of Ukraine have not experienced the construction of the metal corrugated structures "construction-soil". That is why the paper is in great need and up to time.

The increase of the automobile and railways broaching, great number of the defect transporting facilities require the application of more improved and effective transporting interrelations, which would provide easy operation, balanced architectural solutions, long life-time and strength of the structure itself simultaneously. Among them are the metal corrugated structures (MCS), which can be used in transport engineering, bridges, water pipelines, etc., in particular.

The metal corrugated structures are one of the most reasonable and promising types of the transporting facilities, construction of which takes the minimum time and material consumptions, which contribute to the unsufficient economic expenditures. Many countries

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have experienced already the application of the large-span structures made of the corrugated elements, USA, Canada, Japan, France, Italy, Scandinavian countries in particular.

The MCS construction has been known in Ukraine since the 90-ies. Such structures were used while constructing transport facilities and pipelines in the Crimea, at the highway Kyiv-Odessa, Kharkiv-Simferopol, at the area Vadul-Siret-Stateboarder of the Lviv railway.

**The Objective.** To develop the device for the evaluation of the bearing capacity of the metal corrugated structures interrelated with the soil fill caused by the railway freight movement loadings as well as to carry out experimental investigations of the stress-strain state of the metal corrugated pipe being in operation at the railways of Ukraine.

**Analysis of the available investigations and publications.** The world experience in the design and operation of the metal corrugated structures shows, that the sufficient impact on the MCS stress-strain state is that of the soil fill stabilization [1 – 3]. The proposed stabilization is to be of 0,95 – 0,97 level. Besides, in the paper [1] it was noted, that the decrease of the soil stabilization from 0,95 to 0,8 can cause the decrease of the soil deformation modulus in four times which, in its turn, can contribute to the sufficient increase of stress and strain in the structure walls.

Long-term monitoring of over 900 corrugated pipe facilities built during 1951 – 1965 in the Ohio state (USA) made possible to conclude: in all cases for the structures being not damaged the sufficient deformations were of 22 – 34%, for the structures being damaged such deformations were of 45 – 55%. There investigations testified, that the sufficient deformations were caused by the lack of the soil stabilization or application of the unproper material for the soil stabilization. According to [6, 8], if the deformations are within 15 – 20% and the layer height over the pipe is greater than 1,8, the structure does not need any additional means for its strengthening.

Broadening of the MCS application field is not provided by any scientific or standard regulations. Available standard regulations [3, 9, 10] deal only with the round pipes of up to 3m diameter and are based on the calculation analysis of the pipes deformations under the simple hypothesis on the soil pressure on the pipe.

There are some available methods for the calculation. The conventional methods of evalution of the pipes bearing capacity is that of the pipes and soil interrelation proposed by Duncan and Drawsky [11]. It takes into account both the effect of the compression forces and the bending moments on the structure walls, and the non-linear soil stresses and deformations. It is shown, that the increase of the soil compactness ( modulus of deformation ) decreases the effect of the bending moment of the structure stress-strain state.

The Vaslestada method [12] was proposed for the large cross-section structures. According to it the bearing capacity of the pipe walls on the compression and deformation of the structure upper side while their laying and the fill stabilization can be evaluated as well as the effect of the soil friction on the compression force value. This method describes the phenomenon of the structure bursting occurring while being subjected to the soil upper layer over the pipe. But it takes into account only the axis forces, the most loadings are assumed to be obtained by the soil.

The Ontario Highway Bridge Design Code (OHBDC) method and the Canadian Highway Bridge Design Code (CHBDC) method [13] are developed basing on the American and Canadian standards of the bridge design. The axis forces are assumed to be of the prime importance in the pipe walls here.

The American Association of State Highway and Transportation Officials (AASHTO) method [14]. The American method has been developed according to the design standards for bridges of the American Association of the highway and transport officials. It makes possible to investigate the frame cross-section type structure and to take into account the dynamic coefficient for the case of the variable loadings.

One of the latest methods is the Sundquista – Petterson method [15, 16]. It takes into account the axis force and the bending moment, the angle of the fill inner friction and the dynamic loading caused by the moving facilities for the estimation of the transportation bearing capacity. It is known to be the versatile enough and takes into account the metal corrugated structures yeilding.

The carried out analysis of the available references shows, that the evaluation of the bearing capacity of the metal corrugated structures deals only with the small-diameter pipes (up to 6m). The great diameter pipes under ultimate loading caused by the railway freight transporting stress-strain state have not been investigated. The method of the experimental investigation of their bearing capacity has not been presented in these papers either.

**Importance of investigations.** The experience in the MCS pipes operation testifies, that their reliability and lifetime are not good enough. It is caused by the fact, that for a long time the constructors underestimated the factor of the soil fill in the MCS operation while their designing. Only lately there appeared the possibilities for the correct analysis of the MCS and dynamic loadings.

During the operation there occur the residual strains of the metal corrulated pipes, which exceed the permissible deformations.

The problem of deformation of the stress-strain state caused by the variable loadings and temperatures in the metal corrugated structures is of the complex nature and comprises scientific, engineering and professional components. To carry out complicated design activity, which is of non-standard nature, it is necessary to perform a great deal of scientific investigations. The scientific developments must be implemented in the engineering facilities, the basis of which is the certain software, which comprises both theoretical models and the experimental data. Taking advantage of it the design of the bridge structures spans will be performed.

**Method of investigations. Development of the device for the MCS stress-strain state diagnosis.** To evaluate the stress-strain state (SSS) of the metal corrugated pipes the monitoring device has been developed [17 – 19]. The measurement are performed according to the following scheme (Fig. 1):the signal from the tensometer 1 comes to the АЦП 2, where the parameters of the measured signal are determined and taking advantage of the software 5 are shown on the screen 3 in order to be used and processed and stored in the memory 4. To provide the operation of the measuring scheme and АЦП the power supply 6 is used.

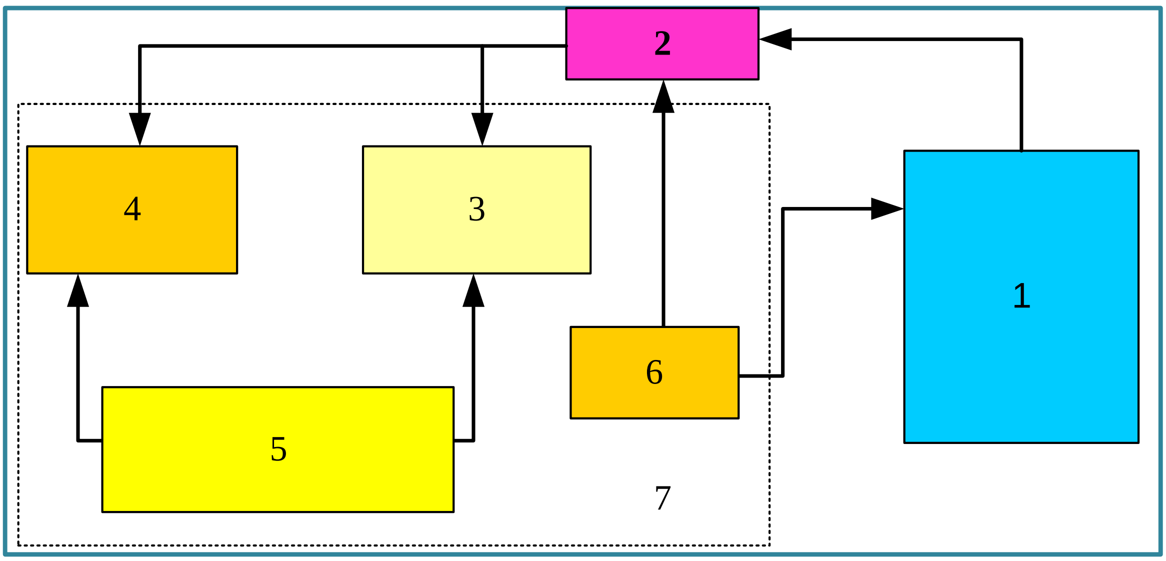


**Figure 1.** Generalized structural scheme of measurements

The real scheme of the measuring is presented in Fig. 2.

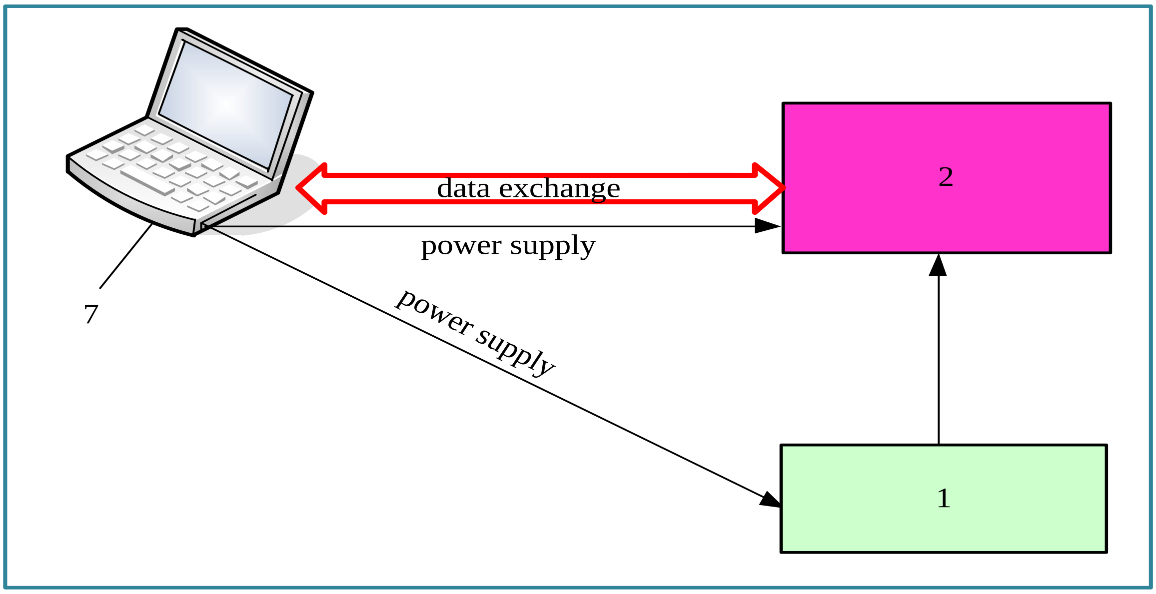


**Figure 2.** Real scheme of measurements

The scheme consists of the PC 7 supplying the АЦП 2, and from it – to the PC 7, which in this case acts as the information screen 3, accumulation of information 4 and software 5.

The PC used for the measuring does not need yo have any special characteristics. The only requirement for it the hard disk possessing memory enough to store the great amount of the measured information. The PC is worth being portable.

The PC software must provide the storage and reservation of the obtained data, possibility being processed and visually retrieved.

Then let us analyse the characteristics of the bridge schemes under the resistance change in one of the bridge arms or in some arms of the measured bridge and present the method of the parameters calculation of such schemes with the tensormeters.

The bridge scheme equilibrium condition is determined according to the relation

$$\frac{R_1}{R_2} = \frac{R_4}{R_3}, \tag{1}$$

or

$$R_1 R_3 = R_2 R_4. \tag{2}$$

The dependence of the input stress on the parameters of the scheme resistance looks like

$$U_v = U_0 \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_2)(R_3 + R_4)}, \tag{3}$$

where $U_0 = E_0 - IR_{vn}$ – bridge supply voltage

While measuring small deformations caused by the temperature effect it is worth using the bridge scheme, when the sensors are used in four bridge arms. Such switching scheme is reasonable here, because the pipe metal thickness is very small as compared with the deformation and its opposite sides are in different temperature conditions.

Then let us analyse the principle of the SSS determination of the pipe components under variable loadings and temperatures, which deals with the simultaneous measurement of the facility deformation and its temperature ( and compensation of the temperature effect on the tensorresistors .) The developed approach makes possible to determine SSS in sufficiently small enough threshold of any point of the facility surface. It is based on the dependence of the tensorresistors ( sensor ) resistance on the temperature and deformation. As the result we will obtain the value of the facility deformation, which is transformed into the stress according to the formula:

$$\sigma_{t^\circ} = \varepsilon \frac{\nu E + (1-2\nu)E}{(1+\nu)(1-2\nu)}$$

Thus, the values of deformations and stresses are obtained under the certain temperature and loading.

To determine the real MCS components stress state in order to evaluate their bearing capacity the static and dynamic testings have been carried out. The fibre stresses in the pipe corrugated walls have been measured. The locomotive ЧМЭ 3 was used for the testing loading under the static testings, the locomotive 2M62 – for the dynamic testings.

**Experimental testings of the bearing capacity of the metal corrulated structures while interrelating with the soil fill.**

**Static testings.** Under the static testing the following loading schemes of the MCS by the railway freight movement have been used (Fig. 3):

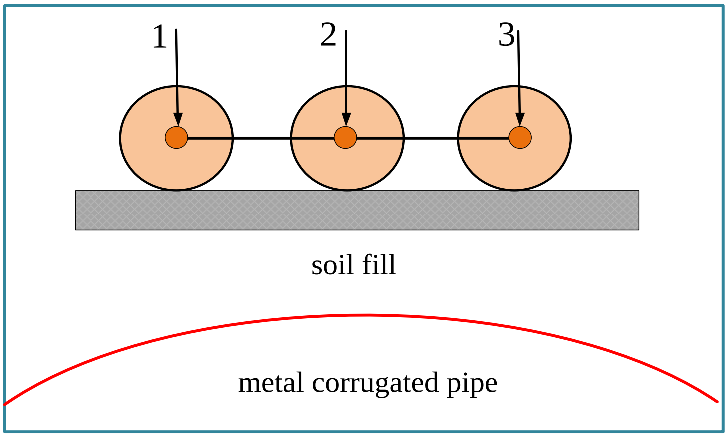


**Figure 3.** Schemes of loading of a metal corrugated pipe

Scheme 1 – the first locomotive axis was mounted over the pipe axis.

Scheme 2 – the second locomotive axis was mounted over the pipe axis to create the maximal bending moment.

Scheme 3 – the third locomotive axis was mounted over the pipe top.

The results of experimental investigations of the fibre stresses of the metal corrugated pipe on the static loadings are presented in Fig. 4.

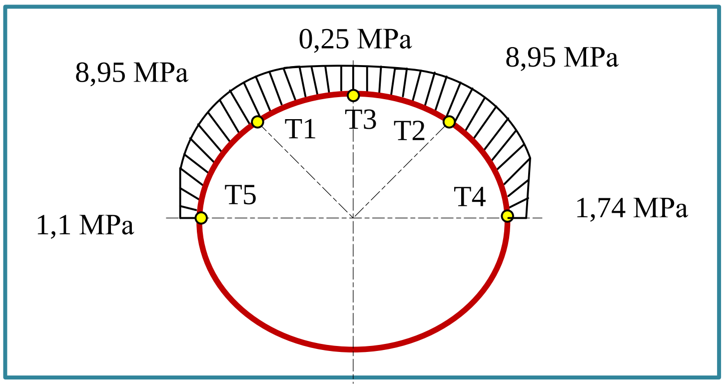


**Figure 4.** Diagram of stresses on the metal corrugated pipe under the static loading while the locomotive ЧМЕ-3 movement

During static testings of the pipe it was determined that the vertical relative deformation (sagging) in the middle part of the pipe is 2,05mm under the loading according to thescheme 2. The maximal fibre stresses in the upper points were 8,95 MPa, which do not exceed the permissible stresses. Thus, the pipe metal operates in the elastic state without being transformed into plastic one.

**Dynamic testings.** Commutation trains with the steam locomotive 2M62 for the passengers and cargo transporting moving with the speed of 25 km/hr were used for the dynamic testings.

The results of the experimental investigations of the fibre stresses of the metal corrugated pipe on the dynamic loadings are presented in Fig. 5.

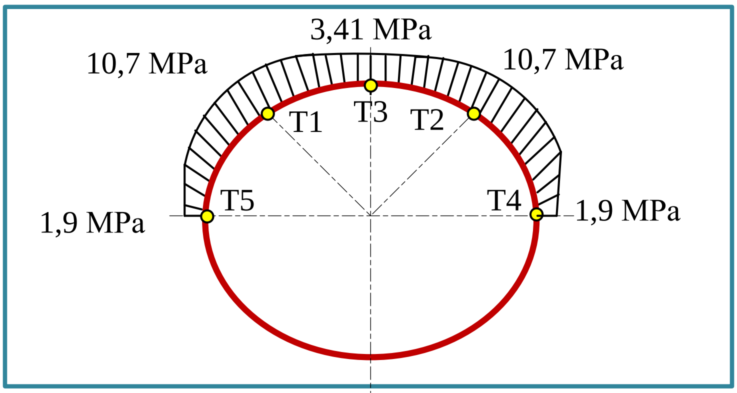


**Figure 5.** Diagram of stresses on the metal corrugated pipe under the dynamic loading while the steam locomotive 2M62 movement

Such results are registered under the dynamic testings:

– the maximum vertical relative deformation of the pipe was registered while the cargo train movement and equals 2,74mm, here the residual strain being 0,21mm.
– the horisontal relative deformation while the cargo train movement equals 0,77mm, here the residual strain being 0,038mm.

The maximum fibre stresses caused by the dynamic loading in the upper part of the pipe in the definite points equals 10,7 MPa.

**Conclusions and prospect for the further investigations.** 1. The developed device for the measuring of the stress-strain state characteristics of the metal corrugated structures under variable temperature and loadings can be used for the continuous favourable monitoring of their operational condition. To create the monitoring system for the stress-strain state of these structures it is worth using the tenzors as the measuring deformation transformers. According to the results of such monitoring the metal pipe top deformation can be predicted under the variable loadings caused by the railway trains movement.

2. It was determined during the static experimental testings, that the vertical relative deformation (sagging) in the middle part of the pipe equals 2,05mm. The maximum fibre stresses in the upper points of the pipe were 8,95 MPa, which does not exceed the permissible stresses.

3. It was determined during the dynamic experimental testings, that the vertical relative deformation of the pipe was registered while the cargo train moving and equals 2,74 mm, here the residual strain being 0,21mm, horizontal relative deformation – 077mm, here residual strain being 0,038mm. The maximum fibre stresses caused by the dynamic loading in the upper part of the pipe in the definite points equals 10,7 MPa.

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# ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ МЕТАЛЕВИХ ГОФРОВАНИХ КОНСТРУКЦІЙ ЗАЛІЗНИЧНОЇ КОЛІЇ

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***Резюме.*** *Розроблено наукові засади нового пристрою для вимірювання та оцінювання напружено-деформованого стану транспортних споруд при змінних температурах та навантаженнях. Технічна задача полягає у прийнятті за результатами моніторингу транспортних споруд науково-обгрунтованих рішень щодо потреби у відновлювальному ремонті того чи іншого елемента, контролю поступового зниження несучої спроможності цих елементів конструкції, встановленні їх фактичного технічного стану та залишкового ресурсу.*

*В основі нового пристрою лежить вимірювання деформацій за допомогою аналого-цифрового перетворювача (АЦП) та аналогового вимірювального моста – тензометра. Перевагою пропонованого пристрою є те, що точність вимірювань, виконаних за його допомогою, не залежить від довжини з'єднувальних провідників та напруги джерела живлення. За його допомогою можна оцінювати та враховувати деформації, спричинені також і температурними впливами на транспортні споруди.*

*Проаналізовано проблеми адаптації закордонних нормативних документів щодо проектування металевих гофрованих конструкцій на залізничних та автомобільних дорогах України. Наведено результати експериментальних і теоретичних розрахунків несучої здатності металевих гофрованих конструкцій.*

*При динамічних експериментальних випробуваннях встановлено, що максимальна вертикальна відносна деформація труби зафіксована при проходженні вантажного поїзда і становить 2,74 мм. При цьому залишкова деформація становила 0,21 мм; горизонтальна відносна деформація при проходженні вантажного поїзда – 0,77 мм. При цьому залишкова деформація становила 0,038 мм. Максимальні фіброві напруження від дії динамічного навантаження у верхній частині труби у визначених точках становили 10,7 МПа.*

***Ключові слова:*** *пристрій, залишкові деформації, проектування, пластичний шарнір, рухомий склад залізниць, щільність грунтової засипки.*

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