The object of this study is a concrete pipe and a pipe whose integrity was restored using a metal clamp while filling the layer between the existing pipe and the metal clamp with self-expanding concrete mortar.

It has been established that the most common types of defects and damage to pipes on the roads are transverse and longitudinal cracks, as well as concrete chipping and spalling.

A procedure has been devised to test experimentally a new concrete pipe without reinforcement and a concrete pipe reinforced with a metal clamp under static load.

Experimental tests of the concrete pipe without reinforcement and with reinforcement with a metal clamp were carried out in the laboratory. Digital indicators, an analog-to-digital converter, and a personal computer were used to measure pipe deformations.

It was found that the maximum value of vertical deformations of a new concrete pipe before cracking was 4.75 mm, and that reinforced by a metal clamp – 4.36 mm. At the same time, the maximum deformation at which the destruction of the new pipe occurred was 6.36 mm, and that of the reinforced pipe with a metal clamp – 10.51 mm.

It was established that the reinforcement of the destroyed pipe with a metal clamp in the initial period of loading leads to detachment of the clamp from the concrete of the pipe. Further, when the clamps are included in the work, there is a stable operation of the concrete pipe and the amount of growth of pipe deformations increases smoothly.

The results of measuring vertical deformations at the top of the pipe without reinforcement and with it showed different deformation values. It was established that the complete destruction of the pipe with a reinforced metal clamp takes place during deformations 61 % higher than the deformation at which the non-reinforced new concrete pipe is destroyed.

It was found that one of the methods of restoring the bearing capacity of damaged and defective pipes in the road industry is the use of metal clamps

Keywords: concrete pipe, metal clamp, deformation diagram, three-layer structure, static load

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DETERMINING PATTERNS OF THE DEFORMED STATE OF THE TRANSPORT CONCRETE PIPE REINFORCED WITH A METAL CLAMP UNDER THE ACTION OF STATIC LOAD

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1. Introduction

On highways and railroads, a large number of water passage reinforced concrete pipes of various cross-sections are operated. Most pipes have a variety of damages and defects. The development of defects and damages in reinforced concrete pipes leads to a decrease in their durability and bearing capacity and affects the safety of movement of transport units. The timely elimination of these damages and defects in the initial stage of their development affects the reliability and failure-free-operation of the pipes [1]. In the practice of operation of transport facilities [2], there is constantly a need to solve problems of establishing modes for the further safe operation of transport structures [3].

A significant number of new domestic and foreign materials and technologies for the repair of defective structures and structures have emerged. They make it possible not only to suspend the development of defects and malfunctions of reinforced concrete structures but also to strengthen them in order to obtain the necessary performance [2]. However, the cost of repair work is high.

In addition, taking into consideration the hostilities, the number of damaged reinforced concrete pipes due to the explosion or action of a blast wave is growing every day. Therefore, in order to quickly restore the capacity of the road, the task arises of quickly restoring the bearing capacity of damaged pipes.

Thus, culverts are an integral part of the road maintenance. Therefore, to ensure reliable operation of water pipes, it is extremely necessary to introduce advanced repair technologies and structures. During the operation of the pipes, it is necessary to monitor the technical condition and analyze operational damage in order to prevent the development of defects in time and for a timely repair work.

2. Literature review and problem statement

The author of [3] describes the main damage to the culverts. The list of the most common damages and defects of reinforced concrete culverts includes the development of cracks, chipping of concrete, and leaching of concrete. In addition, there are such damages as opening of deformation joints, subsidence and roll of links and tips, violation of waterproofing, damage to the tips, and erosion of the soil in the pipe area, etc. Examples of damage to reinforced concrete pipes under operating conditions are shown in Fig. 1 [3].

a *b* *c*

Fig. 1. Damage to pipes under operating conditions: *a* — transverse cracks; *b* — longitudinal cracks; *c* — chipping of concrete [3]

It is noted that cracks develop in different elements of reinforced concrete pipes and have a different character. Longitudinal cracks, as a rule, occur in areas of action of maximum bending moments, leading to a decrease in the bearing capacity and durability of pipe elements.

Transverse cracks in the links and tips of the pipe are the result of the action of large bending moments in the vertical plane due to soil swelling, or uneven subsidence of the soil at the base of the pipe. Transverse cracks reduce the durability of the structural elements of the pipe.

In addition, during operation, pipe defects often appear in the form of concrete chipping, destruction of the protective layer, exposure of reinforcement, leaching of concrete in the elements of culverts. Leaching helps reduce the strength of concrete and the durability of pipe elements.

The opening of deformation seams contributes to the mutual displacement of sections, watering of the body of the embankment, the formation of voids in the seam zone, the separation of the tip from the pipe body, the appearance and development of cracks in the links and tips.

This type of damage greatly disrupts the operational regime of the pipes and it is classified as the most dangerous, requiring repair and restoration work.

These damages require expensive restoration work. As a rule, they are registered and studied in order to prevent the possibility of occurrence in the future.

It is noted in works [4, 5] that the service life of defective reinforced concrete structures can be increased with the help of metal corrugated pipes using the "sleeve" method of repair. Namely, in work [4], an assessment of the stressed-strained state of the reinforced concrete pipe reinforced by metal corrugated structures was carried out, under the influence of variable climatic influences of the environment. It was established that a jump in temperature stresses occurs at the contact of the reinforced pipe and metal corrugated structures, which can lead to the premature decommissioning of the mentioned structures. However, in [4, 5] only analytical calculations of the stressed-strained state of reinforced concrete pipes were carried out, which are not confirmed by experimental studies.

In [5], the calculation of the thermal stress state of the strengthened reinforced concrete pipe by the method of finite elements was carried out. It was established that as a result of calculating the temperature field, the temperature is distributed unevenly in the transverse direction of the pipe. The temperature difference between the metal and reinforced concrete shells is up to +10 °C. It has been established that at the point of contact of a metal pipe with reinforced concrete there is a jump in temperature stresses. The maximum stress values were 302.44 kPa. However, no experimental studies of strengthened reinforced concrete pipe have been carried out in the cited work.

In [6–8], a study of the deformed state of corrugated metal structures in the FEMAP with MSC NASTRAN software package was carried out. The results have not been confirmed by experimental studies.

In [9], the results of the assessment of the bearing capacity and stressed-strained state of metal corrugated structures are reported. It is noted that such structures can be effectively used to reinforce defective small bridges and culverts. However, the results have not been confirmed by experimental studies.

In [10], in the study of the strength of metal corrugated structures, it was established that their bearing capacity is enabled, under the action of the rolling stock of railroads, provided that the standard degree of compaction of the soil backfill is ensured.

In [11], it is noted that the largest number of pipes in operation are made of concrete. Also intensively used in road construction are pipes made of prefabricated metal corrugated structures [5]. They are used in the form of small bridges [12] and tunnel overpasses [13]. However, in those works there are no studies of the features of deformation of pipes under static loads.

In [14], it was established that with poor-quality compaction of the soil backfill, the bearing capacity of structures made of corrugated metal structures is not provided. This is due to the fact that prefabricated metal corrugated sheets and soil sealing backfill work together [15]. To assess the effectiveness of the use of corrugated metal structures in the repair of defective structures, additional studies of the deformed state of the pipes under static loads are required.

Study [12] has established that the bearing capacity of pipes is influenced by operational factors such as static and dynamic loads from motor transport units [16]. In addition, the transverse dimensions of the structure, which is built of prefabricated metal corrugated sheets, have a significant impact [17]. However, in those works, the peculiarities of deformation of pipes under the influence of static loads have not been assessed.

In the case of irregularities on the railroad track, the growth of the dynamic load on the pipes increases [18]. The cited study has justification only at the analytical level.

In [19], an assessment of the deformed state of the metal structures of the tunnel overpass under the action of a dynamic load from the rolling stock of railroads was carried out. It has been established that the metal structures of the structure bend under load and at the exit of the rolling stock from the structure, the metal structures of the pipe return to their original position. The results of studies of the deformed state of pipes give an idea of the operation of structures under operating conditions. However, the deformation of such structures, when used as repair of defective pipes, was not carried out.

More rigid are fiberglass pipes. In [20], it was found that the embankment of the soil bed, and not the body of the pipe itself, undergoes greater deformations. However, studies of the deformed state of fiberglass pipes, when used to repair defective reinforced concrete pipes, have not been conducted.

Corrugated polyethylene pipes have become widely used for the repair of defective reinforced concrete pipes [21]. Experimental tests given in work [22] made it possible to establish that polyethylene pipes with a profiled wall are stronger in performance than "smooth" pipes made of rigid materials. In the analyzed works [21, 22] the issues of assessing the deformed state of polyethylene pipes under the action of vehicles have not been resolved.

In [23], it was proved that an important factor influencing the bearing capacity of the pipes is the height of the embankment above the top of the pipe. Studies have established that it should be in the range from 0.9 m to 1.2 m.

In work [24], methods of strengthening engineering structures and buildings using the extension of working reinforcement of defective structures are given. Also proposed is a method of using clamps to strengthen engineering structures.

To restore the bearing capacity of engineering structures today, polymeric materials have been widely used [25], which are characterized by high tensile strength, crack resistance, water resistance, and corrosion resistance, etc. [26]. However, in works [25, 26] no assessment of the features of deformation of polyethylene pipes under static loads was carried out.

In [27], it is noted that in systems modified with liquid resins and monomers, the addition of water stimulates the hydration of cement and the polymerization of liquid resins or monomers. As a result, a strong conglomerate is formed, which contributes to the strengthening of defective structures. However, studies of deformed restored structures have not been conducted.

In [28], it is proved that polymer concrete can be reinforced in the same way as concrete on a cement binder. However, the properties of polymer concrete depend on the polymer used filler, the ratio between them, etc. [29], which requires experimental studies of reinforced structures.

In [30], a theoretical study of the conditions of structural compatibility of materials of old and new concrete during the repair of transport structures was carried out. For research, the method of finite elemental analysis of ANSYS software was used to solve issues related to the structural compatibility of the materials of the base of the structure – old concrete and repair material – new concrete. However, experimental studies of reinforced transport facilities have not been conducted.

In [31], studies of three-layer concrete models with different physical and mechanical properties were carried out. It was established that in order to optimize the properties of the repair material for structural compatibility, it is necessary that the modulus of elasticity of the new concrete be smaller or equal to the modulus of elasticity of the old concrete.

In [32], the method of strengthening the supports of bridges by applying a reinforced concrete cage around defective crossbars is given. It has been proven that the most rational form of the clamp is bi-trapezoidal.

It should be noted that the reviewed works [4–32] report studies into the deformed and stressed states by analytical calculation methods. Experimental research into the features of deformation of reinforced defective pipes with a metal clamp under static loads remained unresolved.

3. The aim and objectives of the study

The aim of this work is to determine the features of deformation of a new concrete pipe and a pipe reinforced by a metal frame under the action of static load. This will make it possible to assess the effectiveness of reinforcing defective concrete pipes with metal frames.

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

– to conduct experimental tests of concrete pipe without reinforcement;

– to conduct experimental tests of reinforced concrete pipe with a metal clamp;

– to compare the deformed state of the pipes before and after amplification.

4. The study materials and methods

4. 1. Defect pipe reinforcement procedure

The object of the study is a concrete pipe and a pipe whose integrity was restored with the help of the proposed technology of strengthening (restoring) the bearing capacity of defective and damaged pipes. The essence of the technology is that a metal clamp is inserted into the existing defective concrete pipe, and then the space between the concrete pipe and the metal clamp is filled with concrete mortar (Fig. 2).

Fig. 2. Defective concrete pipe reinforcement scheme: 1 — existing defective concrete pipe; 2 — metal pipe (clamp); 3 — a layer of mortar between the existing concrete pipe and the new metal pipe

As a result of such repair, we obtain a three-layer structure, the elements of which differ significantly from each other in physical and mechanical characteristics.

It should be noted that this technology makes it possible to perform a complete and effective filling of the internal space and, in addition, to repair the defective structure without stopping the movement of transport units and eliminates the need for its disassembly.

4. 2. Procedure for testing a pipe experimentally

To study the effect of reinforcement on the deformed state of the concrete pipe, a concrete pipe was tested without reinforcement and the reinforced pipe was tested with a metal clamp (Fig. 3). The concrete pipe was tested on the P-250 hydraulic test press, which makes it possible to set a static load.

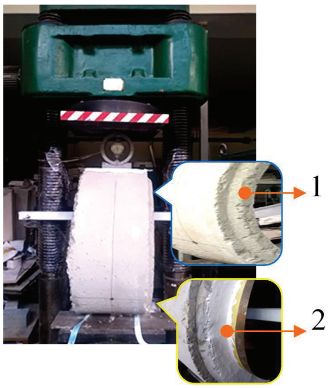

Fig. 3. General view of pipes under study: 1 — pipe without reinforcement; 2 — the pipe is reinforced with a metal clamp

To determine the deformations of the concrete pipe, digital indicators with a division price of 0.01 mm were used. From digital indicators, the results of pipe deflection measurements were transmitted to a computer using a special programmed microcontroller.

The scheme of the process of conducting studies of the deformed state of the concrete pipe is shown in Fig. 4.

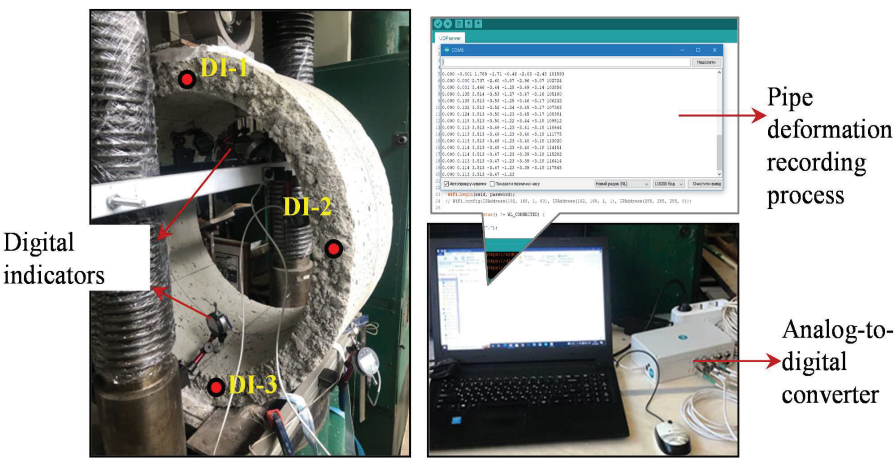

Fig. 4. Experimental scheme of measurements of deflections of reinforced concrete pipe on a hydraulic test press P-250

Deformations of the concrete pipe were measured at three points. In Fig. 4, they are indicated by the numbers DI-1, DI-2 and DI-3. It is assumed that the pipe is deformed symmetrically, so experimental measurements of pipe deformations have been made only on one side.

The deformations of the new concrete pipe and pipe of the restored metal clamp were measured continuously. The results of pipe deformations at the time of cracking and at the time of complete destruction of the pipe are given.

After testing the new concrete pipe, up to complete destruction, the concrete pipe was restored using a metal clamp and mortar that was placed between the layer of the existing pipe and the metal clamp.

5. Results of experimental tests of the pipe

5. 1. Results of experimental tests of non-reinforced concrete pipe

When experimental studies of the deformed state of the pipe were performed, the pipe was tested until complete destruction. The criterion for assessing the deformed state of the pipe was the moment of nucleation of surface cracks in the pipe and the complete destruction of the pipe. The results of the assessment of the deformed state of the new concrete pipe at the time of the nucleation of cracks are shown in Fig. 5, and at the moment of complete destruction – in Fig. 6.

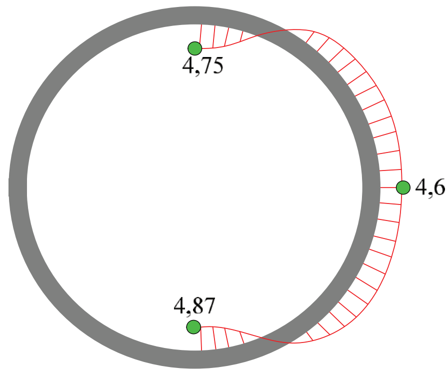

Fig. 5. Deformation distribution diagram in the concrete pipe at the time of cracking

Fig. 5 shows that the pipe receives maximum deformations in the vertical direction. The maximum amount of vertical deformation of the concrete pipe at its top at the time of the start of cracking was 6.12 mm. At the same time, on the side horizontal side – 4.62 mm. At the base of the pipe, the deformation was 4.87 mm.

The maximum amount of vertical deformation of the concrete pipe during destruction (Fig. 6) was 7.31 mm at the base of the pipe, while at the top of the pipe the vertical deformation was 6.36 mm. On the side horizontal side, the deformation was 6.34 mm.

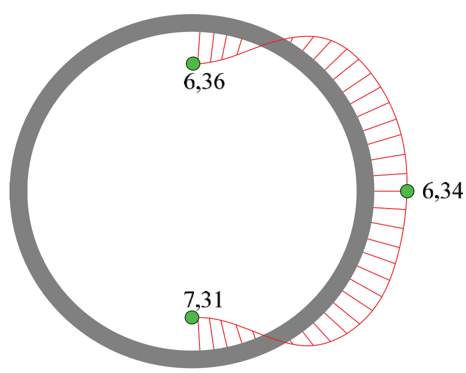

Fig. 6. Deformation distribution diagram in the concrete pipe at the time of destruction

5. 2. Results of experimental tests of reinforced defective concrete pipe with a metal clamp

After restoring the integrity of the destroyed concrete pipe, its experimental tests were carried out until complete destruction. The results of the assessment of deformations in the concrete pipe, which is reinforced by a metal clamp at the time of the occurrence of cracks, are shown in Fig. 7, and at the moment of complete destruction – in Fig. 8.

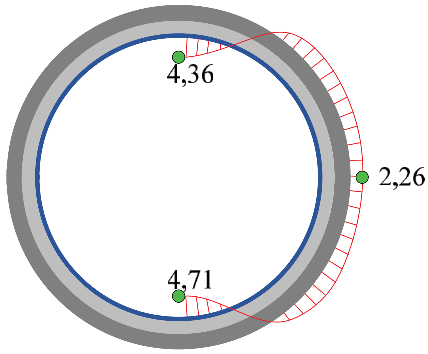

Fig. 7. Deformation distribution diagram in a concrete pipe reinforced by a metal clamp at the time of cracking

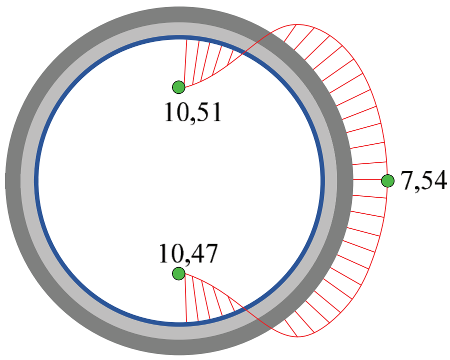

Fig. 8. Deformation distribution diagram in a concrete pipe reinforced by a metal clamp at the time of destruction

Fig. 7 demonstrates that the pipe receives maximum deformations in the vertical direction. The magnitude of the vertical deformation of the concrete pipe at its top at the time of the beginning of the cracking was 4.36 mm. At the same time, on the side horizontal side – 2.26 mm. At the base of the pipe, the deformation was 4.71 mm.

The maximum amount of vertical deformation of the concrete pipe during destruction (Fig. 8) was 10.51 mm at the top of the pipe, while at the base of the pipe the vertical deformation was 10.47 mm. On the side horizontal side, the deformation was 7.54 mm.

From the tests of the reinforced defect pipe, one can see that the maximum deformations of the concrete pipe, both during the formation of cracks and with the complete destruction of the pipe, occur in the vertical direction of the pipe.

5. 3. Comparative assessment of the deformed state of the pipes before and after reinforcement

The results of comparing the deformations that occur at the top of the pipes when testing a new pipe and pipe with a restored metal clamp are shown in Fig. 9.

The results of comparing the deformed state of the pipes at the top (Fig. 9) demonstrated that at the moment of crack emergence in the pipe reinforced by the metal clamp, lower deformation values were observed than in the new pipe. This is explained by the fact that when the restored pipe is loaded, only a layer of concrete mortar was included in work, filling the space between the pipe and the metal clamp, and not the body of the reinforced pipe itself. Further, after the appearance of cracks, the metal clamp was included in work, and with the complete destruction of the reinforced pipe, higher values of deformations were obtained, in which the pipe collapsed than the deformations that arose during the complete destruction of the new concrete pipe.

The results of deformation of the concrete pipe are given in Table 1.

Table 1

Results of determining the deformation of the pipe

Point No.	Pipe deformation, mm	
	Without reinforcement	Reinforced with metal clamp
Moment of crack appearance		
1	4.75	4.36
2	4.60	2.26
3	4.87	4.71
Moment of destruction		
1	6.36	10.51
2	6.34	7.54
3	7.31	10.47

From the experimental tests of the concrete pipe without reinforcement (Table 1) at the time of the nucleation of cracks in the concrete of the pipe, the maximum vertical deformation at the top of the pipe was 4.75 mm, at the base of the pipe – 4.97 mm. On the sides of the horizontal sides, the deformation of the pipe was 4.60 mm. When testing a concrete pipe reinforced with a metal clamp, the maximum vertical deformation at the top of the pipe was 4.36 mm, at the base of the pipe – 4.71 mm. On the side horizontal side, the deformation of the pipe was 2.26 mm.

The experimental tests of the concrete pipe without reinforcement at the time of destruction of the concrete pipe show that the maximum vertical deformation at the top of the pipe was 6.36 mm, at the base of the pipe – 7.31 mm. On the side horizontal side, the deformation of the pipe was 6.34 mm. When testing a concrete pipe reinforced with a metal clamp, the maximum vertical deformation at the top of the pipe was 10.51 mm, at the base of the pipe – 10.47 mm. On the side horizontal side, the deformation of the pipe was 7.54 mm.

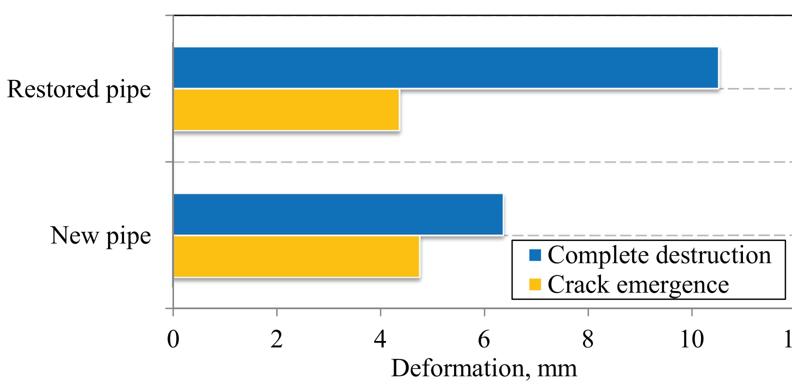

Fig. 9. Results of comparison of the deformed state of pipes at the top of the pipe

6. Discussion of results of investigating deformations in static tests of concrete pipe

The procedure of experimental static testing of a new concrete pipe and pipe with a restored metal clamp has been devised.

Static tests of concrete pipe without reinforcement and concrete defect pipe reinforced with a metal clamp were carried out.

It should be noted that the reinforced concrete pipe was previously destroyed and further restored with the help of a metal clamp. The space between the destroyed ring of concrete pipe and the metal clamp was filled with concrete mortar. Therefore, on the diagrams of the deformed state at the time of the appearance of cracks in the pipe reinforced by the metal clamp, lower deformation values were obtained than in the new pipe (Fig. 9). However, the complete destruction of the restored pipe occurs under higher deformations than the new one (Fig. 9), which is explained by the inclusion of a metal clamp in work.

Comparison of the results of vertical deformations at the top of the pipe without reinforcement and with reinforcement showed different values of pipe deformations. It was established that the complete destruction of the pipe with a reinforced metal clamp takes place during deformations 61 % higher than the deformations in which the new concrete pipe is destroyed.

The results of the tests of the concrete pipe, reinforced by a metal clamp, made it possible to establish the deformed state of the concrete pipe under static loads. This complements the studies that are reported in the reviewed papers [4–32]. Our results obtained make it possible to reasonably choose methods for reinforcing damaged pipes under operating conditions. The practical significance of the obtained results of concrete pipe deformations lies in the possibility of using the results of experimental research by engineers and researchers when choosing a method for strengthening defective pipes under operating conditions.

The disadvantages of the study into the deformed state of concrete pipes are due to determining deformations on only one symmetrical side of the pipe. It is believed that the other side of the pipe is deformed similarly.

One of the limitations of our research is to determine only the deformations of concrete pipes arising from static loads. Therefore, a continuation of research is the development of experimental methods for assessing the stressed-strained state of concrete pipes under the action of dynamic loads.

7. Conclusions

1. The results of our experimental studies showed that at the time of the emergence of cracks in the new concrete pipe, the maximum vertical deformation at the top of the pipe was 4.75 mm, at the base of the pipe – 4.87 mm, and on the side horizontal side – 4.60 mm. At the time of destruction of the new concrete pipe, the maximum vertical deformation at the top of the pipe was 6.36 mm, at the base of the pipe – 7.31 mm, and on the side horizontal side – 6.34 mm.

2. When testing a concrete pipe restored with a metal clamp, the maximum vertical deformation at the time of cracking at the top of the pipe was 4.36 mm, at the base of the pipe – 4.71 mm, and on the side horizontal side – 2.26 mm. At the time of destruction of the concrete pipe with the restored metal clamp, the maximum vertical deformation at the top of the pipe was 10.51 mm, at the base of the pipe – 10.47 mm, and on the side horizontal side – 7.54 mm.

3. The results of comparison of vertical deformations arising at the top of a new pipe and pipe restored by a metal clamp showed that the complete destruction of the pipe reinforced by the metal clamp takes place during deformations by 61 % higher than the deformations during which a new concrete pipe is destroyed.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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