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COMPARISON OF EXPERIMENTAL STUDIES AND NUMERICAL MODELING RESULTS OF CONCRETE FILLED TUBULAR ELEMENTS WITH DEMOUNTABLE JOINTS

The article presents the results of experimental tests of compressed tubular elements with demountable joints investigated on the central and noncentral compression (with eccentricities 0, 0,25 and 0.5 from the diameter of the sample) and numerical simulation by the finite element method. The obtained results were compared for similar samples and their models. For which using numerical simulation in the Femap software system a stress-strain state was investigated and graphical representations of principal stresses were presented. For comparison the tensions that arose when the shell's steel pipe was reached the yield strength were selected. The mean square deviation and the coefficient of variation of the data obtained varied in the range of 5 – 7%, which indicates the correspondence of the results and allows further research of partial replacement of experimental tests with numerical simulation.

***Keywords:** concrete filled tubular structure, demountable joints, experimental research, numerical modeling.*

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ПОРІВНЯННЯ РЕЗУЛЬТАТІВ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ ТА ЧИСЕЛЬНОГО МОДЕЛЮВАННЯ ТРУБОБЕТОННИХ ЕЛЕМЕНТІВ ІЗ РОЗ'ЄМНИМИ СТИКАМИ

Наведено результати експериментальних випробувань стиснутих трубобетонних елементів із роз'ємними стиками, досліджених на центральний і позацентровий стиск (з ексцентриситетами 0, 0,25 та 0,5 від діаметра зразка) та чисельного моделювання методом скінченних елементів. Виконано порівняння отриманих результатів для аналогічних зразків і їх моделей, для яких за допомогою чисельного моделювання у програмному комплексі Femap досліджено напружено-деформований стан та наведено графічні зображення головних напружень. Для порівняння обрано напруження, що виникають при досягненні текучості сталевої труби оболонки. Середньоквадратичне відхилення та коефіцієнт варіації отриманих даних коливались у межах 5 – 7%, що свідчило про відповідність результатів, це дозволяє у подальших дослідження часткову заміну експериментальних випробувань чисельним моделюванням.

***Ключові слова:** трубобетон, роз'ємні стики, експериментальні дослідження, чисельне моделювання.*

Introduction. Concrete filled tubular structures are effective combination of steel and concrete that allows to fully implement the features of such materials. For example, saving of metal and cement, reduce the size of cross section of concrete filled tube elements and as a consequence reduce the weight of the structure and transportation costs [1]. It should be noted that the joints are an important structure element of concrete filled tubular designs. One of the main features of concrete filled tube elements is thing that during design we should provide the cooperation of a steel pipe-shell and concrete core.

Over the past two decades with the significant development of computer availability and capabilities, researchers have almost unlimited prospects for calculating and modeling structures with the help of CAD (Automated Design Systems). Abroad, the terms CAD/CAE/CAM are usually used, where CAD (computer-aided design) – the use of computer technology for design. CAM (computer-aided manufacturing) – under this term is understood as the actual process of computerized production preparation and the software systems that are used in this process as well as CAE (computer-aided engineering) are the common name of software systems designed to solve various engineering tasks. For example, calculation, analysis and modeling of physical processes the most well-known among them is ABAQUS, ANSYS, ESAComp, Femap, CAE Fidesys, HyperWorks, Moldex3D, NX Nastran and many others. Calculations in these programs are carried out by solving differential equations by numerical methods (finite volume method, finite difference, finite element, etc.)

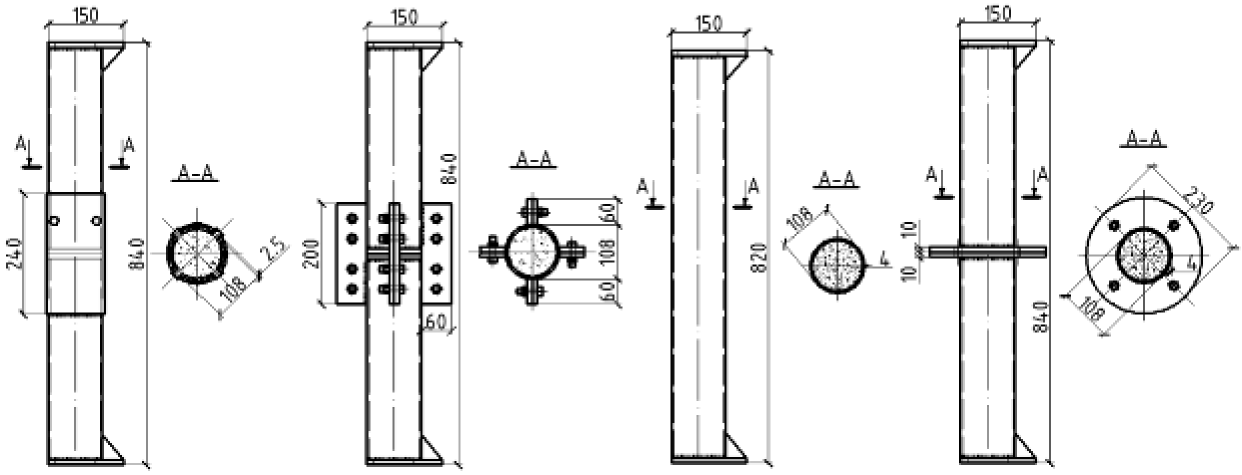
Analysis of recent research. Concrete filled tubular structures are especially actively investigated worldwide in the last 30-40 years, which was reflected in the works of: L.I. Storozhenko – research of concrete filled tubular structures [1], A.E. Lopatto – investigation of stress-strain state concrete in CFT structure [2], A. Fan – CFT elements subjected to axial compression and lateral cyclic loads [3], S. Morino – research of concrete filled tubular elements in Japan [5], Q.Q. Liang – nonlinear analysis of axially loaded CFT columns [6], S.P. Schneider – reviews of CFT frames design [7], X.L. Zhao – cold-formed tubular members and connections [8]. Specifics of numerical modeling in general and pipe structures in particular are the works of S.P. Rychkov [9].

Selection of previously unsettled parts of the general problem. Unfortunately, today the lack of data about modeling of demountable joints CFT elements. The article is devoted to comparison of experimental test results and the modeling of concrete filled tubular elements with demountable joints by numerical methods.

Problem statement. The purpose of this work was to compare the data obtained by the numerical method with the results of experimental studies of concrete filled tubular elements with demountable joints.

Main material and results. Experimental tests of concrete filled tubular elements with demountable joints were conducted. For laboratory tests joints with longitudinal ribs (TBR series) and steel couplings (TBC series) were selected as the most promising. Also for the comparison the standard flange joint (ТБF series), non-jointed concrete tubes (TB series) and 1 sample without concrete filling (T series) were investigated. Drawings and photo samples are shown in Figures 1 and 2. The common for all samples was the height of the pipe-type element – 800 mm, the diameter of the pipe (D) – 108 mm, and its thickness – 4 mm, the diameter of the bolts – 12 mm, the seam leg – 4 mm.

During the test concrete filled tubular elements with splice joints on compression, two criteria were selected for the carrying capacity of the concrete filled tubular element. The first criterion was the state of the samples, in which the deformation of the steel pipe corresponds to deformations of steel, which reached the yield strength (N1). The second is the state in which a significant deformation development occurs in a concrete filled tubular element with a constant or insignificant increase in loads, for example – in fact, this state corresponds to the destruction of the concrete filled tubular element (N2). The criterion of the bearing capacity for the joint was chosen to reach the limit of steel flux of one of its elements.



a) b)

c) d)

Figure 1 – Design of prototype samples:
a) TBC series; b) TBR series; c) TB and T series; d) TBF series

Figure 2 – Photo of samples before the test

Comparing the bearing capacity of the elements with joints in the TB series, we saw that the bearing capacity of N1 was approximately equal to all experimental samples (the difference was less than 10%), analyzing the onset of destruction (N2): with central compression, samples of the TBR and TBC series had some higher bearing capacity (up to 5%); during noncentral tests difference in bearing capacity was significantly increased and amounted to 35% for samples of TBR and TBF series and up to 53% for TBC series samples.

The TBC series (from 5% to center compression up to 53% for noncentral) were the best samples of central and centripetal compression, in comparison with reference and better efficiency (from 4 to 12%), which testifies to the rationality of the construction of this type of connection at minor tensile moments in the joint (at eccentricities to 0.5 D). Table 1 shows the values of bearing capacity based on the results of experimental experiments.

A numerical simulation of 13 samples was performed for pipes without concrete, CFT samples without joints, CFT specimens with a demountable flange joint, with a joint made with the help of longitudinal ribs and a joint made using a steel sleeve. The cases of central compression and noncentral with eccentricities of applying a load equal to 0.25 and 0.5 from the diameter of the sample were considered.

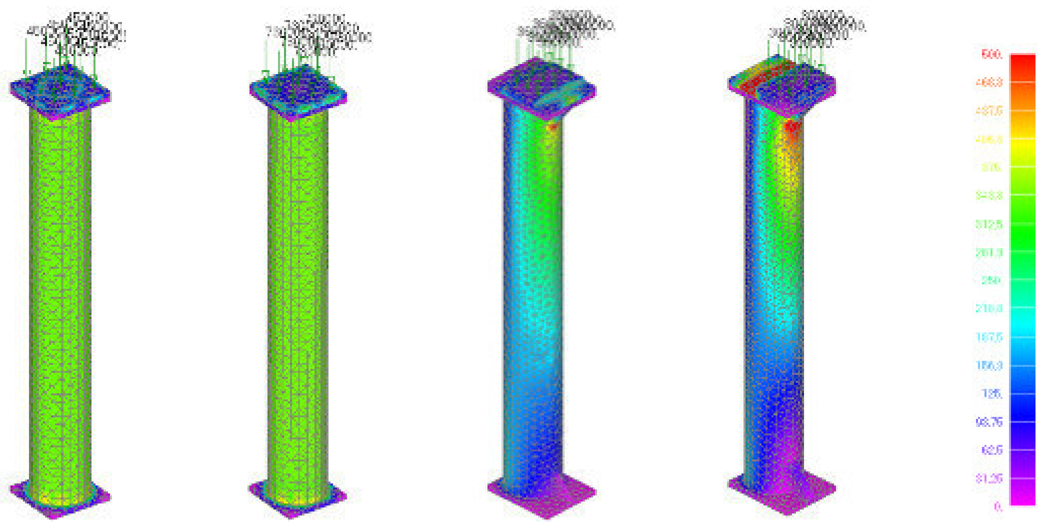
Table 1 – The value of the bearing capacity of experimental samples

№ of Sample	Eccentricity of load, mm	Bearing capacity, kN		N_2/N_1	The coefficients of efficiency of samples		
		N_1	N_2		m_1	m_2	η
T-1	0	450	580	1,29	-	-	-
TB-1	0	730	950	1,30	1,15	1,49	1,98
TB-2	27	360	465	1,29	-	-	-
TB-3	54	300	326	1,09	-	-	-
TBR-1	0	690	980	1,42	1,08	1,54	2,14
TBR-2	27	410	580	1,41	-	-	-
TBR-3	54	320	440	1,38	-	-	-
TBC-1	0	725	996	1,37	1,14	1.56	2.23
TBC-2	27	400	620	1,55	-	-	-
TBC-3	54	280	500	1,79	-	-	-
TBF-1	0	725	900	1,29	1.10	1.41	1.71
TBF-2	27	400	610	1,53	-	-	-
TBF-3	54	280	440	1,57	-	-	-

Numerical simulation of concrete filled tubular T and TB series samples.

Modeling of samples by the finite element method confirmed the typical case of destruction, as can be seen from Fig. 3 where the main stresses obtained from numerical simulation are depicted. For samples with a random (central) loading application, the values of stresses were same for almost all body of the studied element, with growth near the heads, which led to the formation of corrugations that were observed during experimental tests.

For noncentral compressed concrete filled tubular elements TB-2 and TB-3, as can be seen from Fig. 3 were characterized by uneven distribution of stresses, with a gradual increase in the approach to the upper steel head, which is confirmed by experimental data.

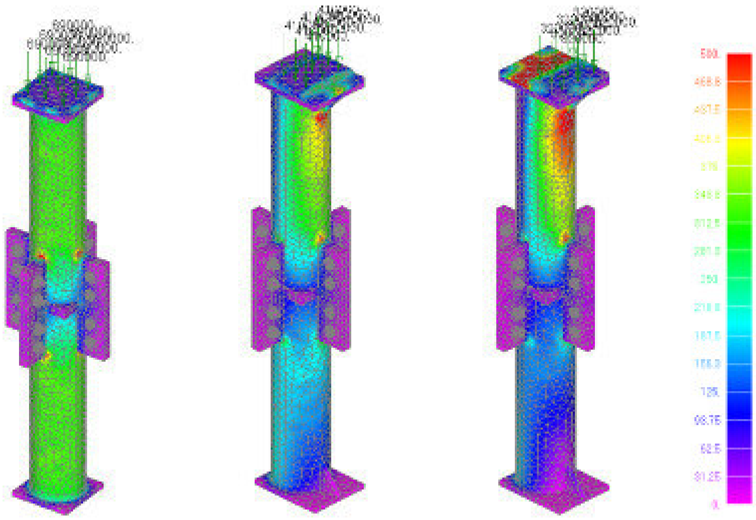


T-1 TB-1 TB-2 TB-3

Figure 3 – Graphical representation of main stresses in numerical simulation for the studied samples of T and TB series

Numerical simulation of concrete filled tubular TBR series samples

Piping elements were investigated for central and noncentral compression. At central compression, in fact, two rigidly connected with the longitudinal edges of concrete filled tubular elements of the analogous sample TB-1 were tested resulting in uniform distribution of stresses with an increase near the upper steel head which led to the formation in this place of corrugations. However, the test compound area was reinforced by ribs, which led to a decrease in stresses in this area. This was confirmed both by mathematical modeling and by the nature of the deformations fixed in the experiment (Fig. 4).



TBR-1 TBR-2 TBR-3

Figure 4 – Graphical representation of main stresses in numerical simulation for the investigated samples of the TBR series

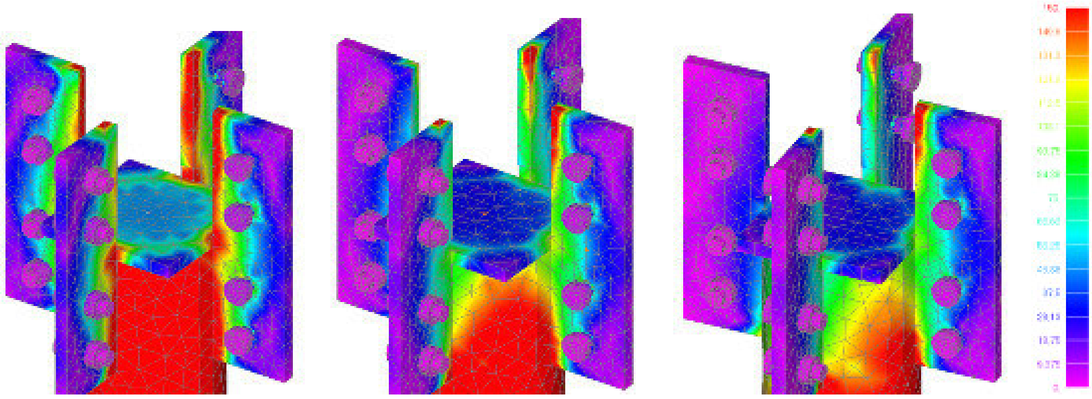
For noncentral compressed TBR-2 and TBP-3 samples, in addition to the characteristic of all concrete filled tubular elements with a similar application of the load, a significant increase in stresses near the upper steel flange attention was drawn to the reduction of stresses in the lower CFT element with magnitude of eccentricity. Also, for all samples of this series the fact that there was neither a bolt cut nor a deformation of the steel longitudinal flanges, the proof of which is both mathematical modeling and experimental data, is common.

In the places of the connection of longitudinal ribs with concrete filled tubular elements there were places of concentration of stresses.

In Fig. 5, the detail of the concrete filled tubular element is shown in more detail. It should be noted that at the central compression of the stress in the joint were larger than at the noncentral. For the given structure the impact of the size of the load which acted like a little more influence than the eccentricity of the application of the load. This corresponds to the experimental data according to which the deformations of the ribs under central compression were higher than in the noncentral.

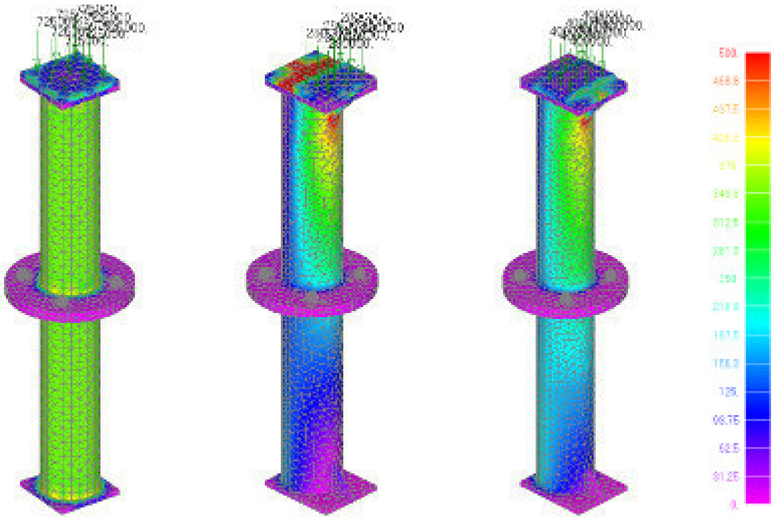
Numerical simulation of concrete filled tubular TBF series samples

The samples of the TBF series were similar to other prototype designs of the concrete filled tubular element and differed by the method of the demountable connection, this joint was carried out using steel round flanges with a milled surface welded to the upper or lower element and connected by bolts. The load was applied centrally and with eccentricities equal to 0.25 and 0.5 from the diameter of the pipe. For the boundary conditions, fixing was adopted similar to that which was during the experiment (Fig. 6).



TBR-1 TBR-2 TBR-3

Figure 5 – Graphic representation of main stresses in the lower part of the joint with longitudinal ribs



TBF-1 TBF-2 TBF-3

Figure 6 – Graphical representation of main stresses in numerical simulation for the investigated samples of the TBF series

In mathematical modeling, the fact that the presence of a joint at central compression had virtually no effect on the bearing capacity of the structure, the onset N_1 when simulations occurred at a load similar to the experimental one, which testifies to the reliability of numerical simulation.

The peculiarity of noncentral compressed samples is that the stresses in the steel flanges compared to the stresses in the concrete filled tubes are very small, even with the growth of the eccentricity of the load. It is also characteristic that the stresses and deformation, respectively in the upper concrete filled tubular elements were significantly higher than the lower ones. For the existing joint is actually an enhancement of the entire structure all specimens with joints when applying the load with the eccentricity 0,5 of diameter had a carrying capacity higher than a solid sample of more than 30%.

Numerical simulation of concrete filled tubular TBC series samples

Considering the case of central compression of the TBC-1 sample, it is noteworthy that due to somewhat more load compared with other samples of tension in the upper concrete cell were 10–15% more prominent than the lower ones, which are uncharacteristic for centrally loaded samples of other series in this experiment. and is explained by the influence of the steel coupling. Also very interesting is that the greatest stresses were in the steel coupling exactly when the central compression because in other cases the concrete element lost load bearing capacity at the upper part at significantly lower loads (Fig. 7).

Considering the stress-strain state of the steel coupling, it should be noted the emergence of small stress concentrators near the bolt holes. Similarly, the junction with the longitudinal ribs of stress was slightly larger at the central compression, especially in the lower part of the coupling (Fig. 8).

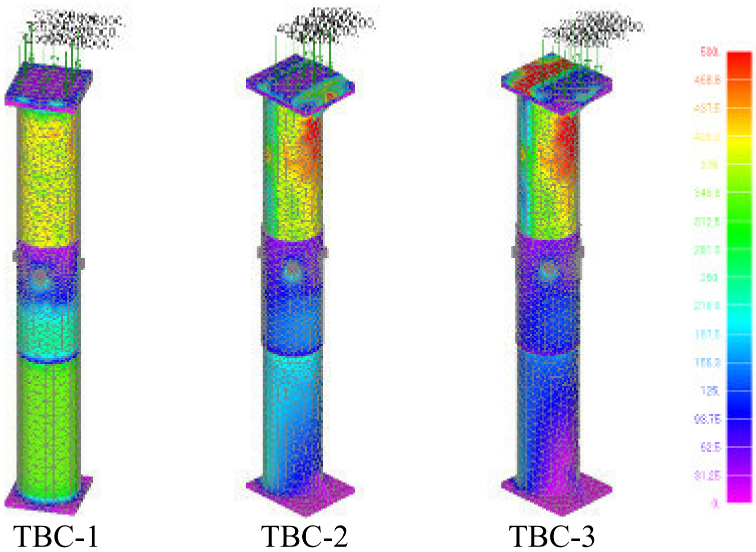


Figure 7 – Graphic representation of main stresses in numerical simulation for the studied samples of the TBC series

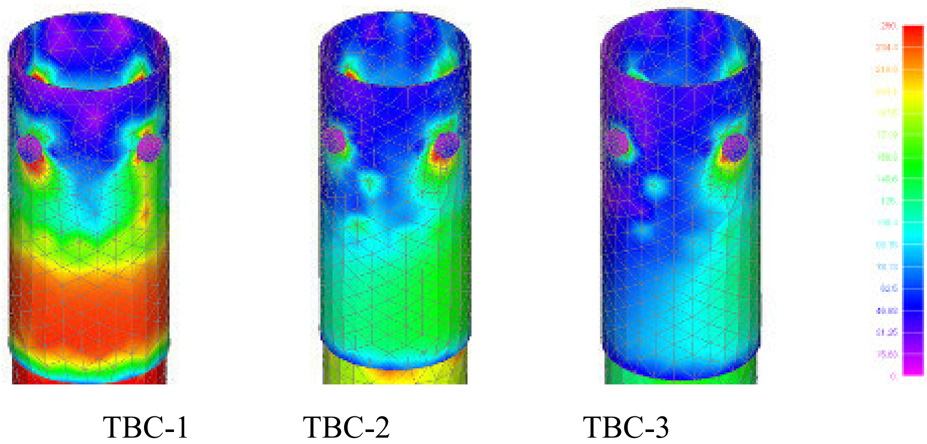


Figure 8 – Graphical representation of main stresses in the lower part of the coupling with a steel coupling

Table 2 presents a comparison of the results obtained during the experimental studies of concrete filled tubular elements and numerical simulation. The value of theoretical stresses was obtained from the software complex Femap. The mean square deviation of stresses in the compressed zone was 6.7%, the coefficient of variation was 6.8%; in a stretched mean square deviation of 4.96%, the coefficient of variation is 5.02%. Based on the above values, it can be said that the difference in the results is insignificant and varies within the variability of the materials, which confirms the objectivity and realism of the mathematical modeling of compressed concrete filled tubular samples in the software package Femap.

Table 2 – Comparison of experimental and theoretical stresses

№of Sample	e, mm	Bear. cap. N_1, kN	$\sigma_{exp.com}$ MPa	$\sigma_{mod.com}$ MPa	$\sigma_{i,\ com.}$	$\sigma_{std\ com.}$	$\sigma_{exp.ten}$ MPa	$\sigma_{mod.ten}$ MPa	$\sigma_{i,\ ten.}$	$\sigma_{std\ ten.}$
T-1	0	450	327	343	0,9534	0,00166	327	343	0,9534	0,00123
TB-1	0	730	336	345	0,9739	0,00040	336	345	0,9739	0,00021
TB-2	27	360	273	253	1,0791	0,00723	147	142	1,0352	0,00219
TB-3	54	300	332	293	1,1331	0,01934	72	78	0,9231	0,00427
TBR-1	0	690	368	334	1,1018	0,01161	368	334	1,1018	0,01285
TBR-2	27	410	340	347	0,9798	0,00020	42	40	1,0500	0,00379
TBR-3	54	320	316	341	0,9267	0,00454	120	122	0,9836	0,00002
TBC-1	0	700	310	334	0,9281	0,00434	310	334	0,9281	0,00363
TBC-2	27	400	331	340	0,9735	0,00042	48	51	0,9412	0,00223
TBC-3	54	280	326	345	0,9449	0,00241	119	117	1,0171	0,00082
TBF-1	0	725	331	334	0,9910	0,00001	331	334	0,9910	0,00001
TBF-2	27	400	349	342	1,0205	0,00070	76	79	0,9620	0,00070
TBF-3	54	280	330	360	0,9167	0,00599	183	185	0,9892	0,00000

Conclusions. After performing numerical simulation of concrete filled tubular elements with demountable joints, the following conclusions can be made:

For all investigated samples that were tested experimentally, identical real mathematical models were created. The stress-strain state was investigated using numerical simulation in the Femap software system and graphical representations of the main stresses were presented that allow estimating the stress at any point of the sample, stress concentration areas, etc.

The stresses in the compressed and stretched zone of the concrete filled tubular element were compared in accordance with the experimental data and, consequently, the results of numerical simulation. The mean square deviation and the coefficient of variation of the data obtained fluctuated within the range of 5-7%, which is admissible and suggests that the modeling results correspond to the experiment.

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