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BEARING CAPACITY OF SEWERAGE PIPELINES VERSUS BEDDING CONDITIONS PART II. LABORATORY TEST

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Streszczenie: Artykuł stanowi drugą część pracy, opisującej wpływ warunków podparcia zmieniających się na długości rurociągu na jego nośność. Opierając się na normie PN-EN- 295-3, zaproponowano modyfikację sposobu podparcia rur, umożliwiającą modelowanie zmiennych warunków posadowienia rurociągu.

Abstract: This is the second part of the paper dealing with the analysis of the influence of bedding conditions varying along the pipe axis on pipe bearing capacity. On the basis of the standard PN-EN 295-3, some modification of pipe support is proposed herein in order to improve modelling of variable conditions of pipeline bedding.

Rezume:

1. INTRODUCTION

Evaluation of the influence of bedding non-linearity on pipe bearing capacity was presented in [6], [2]. Laboratory tests described in [6] were carried on on eight standard specimens, 300 mm in length and 300 mm in an inside diameter. Eight models of bedding support were applied (figure 1): in models No. 1–5 elastomeric cushions of the hardness of DIDC 55° were used, whereas in model No. 8 – the cushion of hardness of DIDC 85°. Specimens used in models No. 6 and No. 7 were supported by a steel section. The results obtained in the form of the failure forces recorded allowed us to determine the most unfavourable combinations of the non-linearity of ground support under a pipe. Comparing the pairs of models, i.e. model No. 2 with model No. 3, model No. 4 with model No. 5, model Nos. 6 with model No. 7, smaller values of failure forces were observed in models No. 2, 4 and 6. The greatest failure forces were obtained for models Nos. 1 and 8 and the ratio of the greatest failure force to the smallest failure force was 1.5 [6]. On the basis of these results, further modelling of a longitudinally variable ground support was performed with the use of models Nos. 2, 4 and 6.

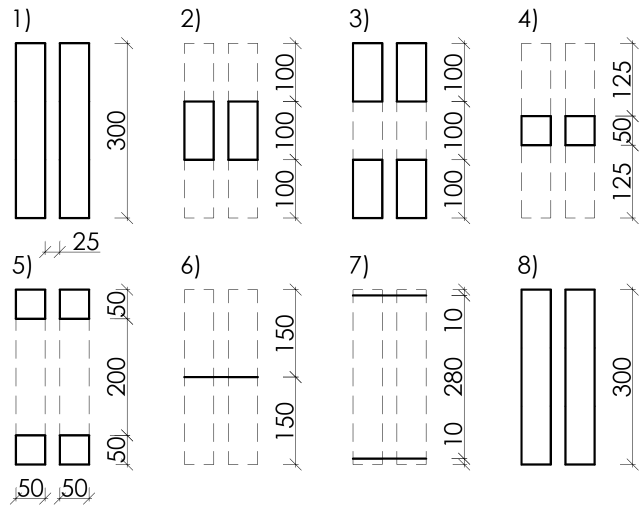


Fig. 1. Arrangements of rubber cushions under the specimens tested

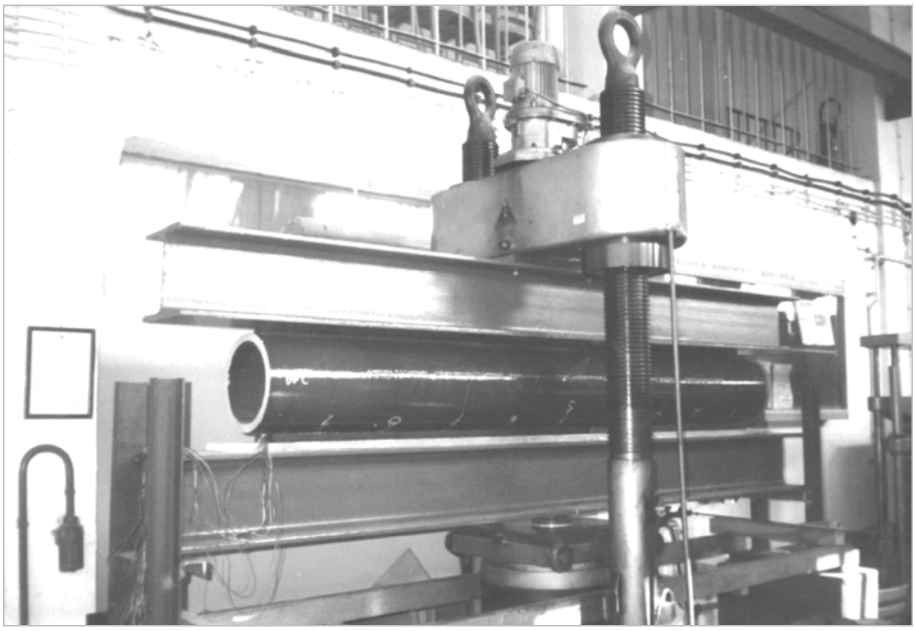
Numerical analysis of the problem was carried out based on the test results presented in [2]. In order to calculate the maximum and minimum values of flexibility of the ground base, the value of E_0 module was accepted according to the PN-81/B-03020 standard. Then, for the interval determined in such a way, the calculations were performed for the parameters of stoneware pipes available on the market. The results obtained were verified by laboratory tests conducted on pipe specimens of original size.

2. TESTING STAND

Laboratory tests were performed at Wrocław University of Technology in 2003. The WPM LIPSK, ZDM-300 press was adopted to the test (figure 2). The testing stand (figure 3) was designed in such a way as to fit the press.

A required standard PN-EN 295-3 limits the maximum length of specimens being subjected to testing strength to 300 mm. This limitation results from the necessity of keeping the load distribution uniform during the test. However, the length proposed does not allow us to identify the influence of support variations on the pipe bearing capacity. Using the supporting beams of an appropriately high stiffness (HEB 260 in figure 3) it can be assumed that the longitudinal stress will insignificantly influence the failure force. Moment of inertia of supporting beams may be calculated if we assume their maximum permissible deflection at the failure force declared by manufacturer.

a)



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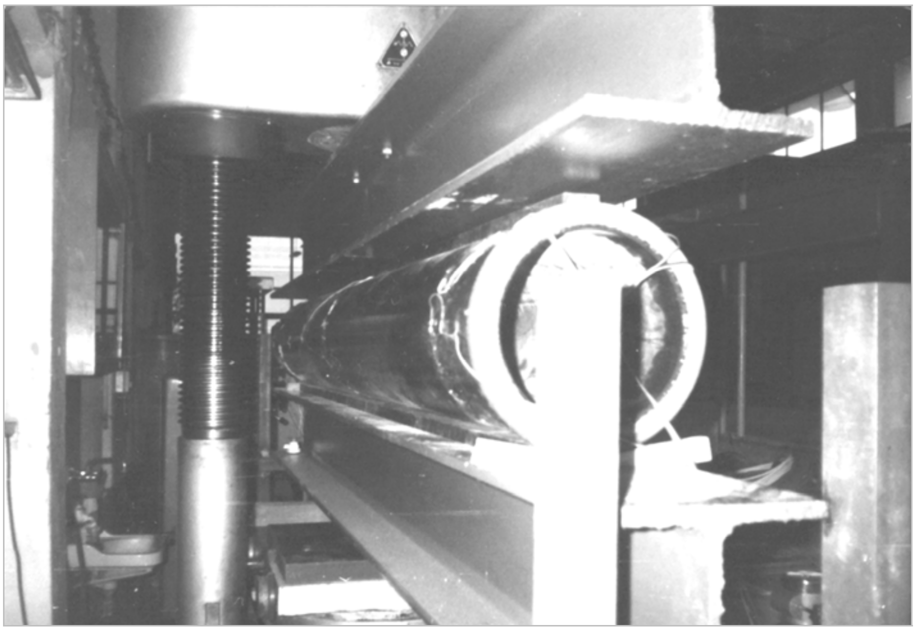

Fig. 2. Testing stand: a) a general view, b) pipe prepared for tests

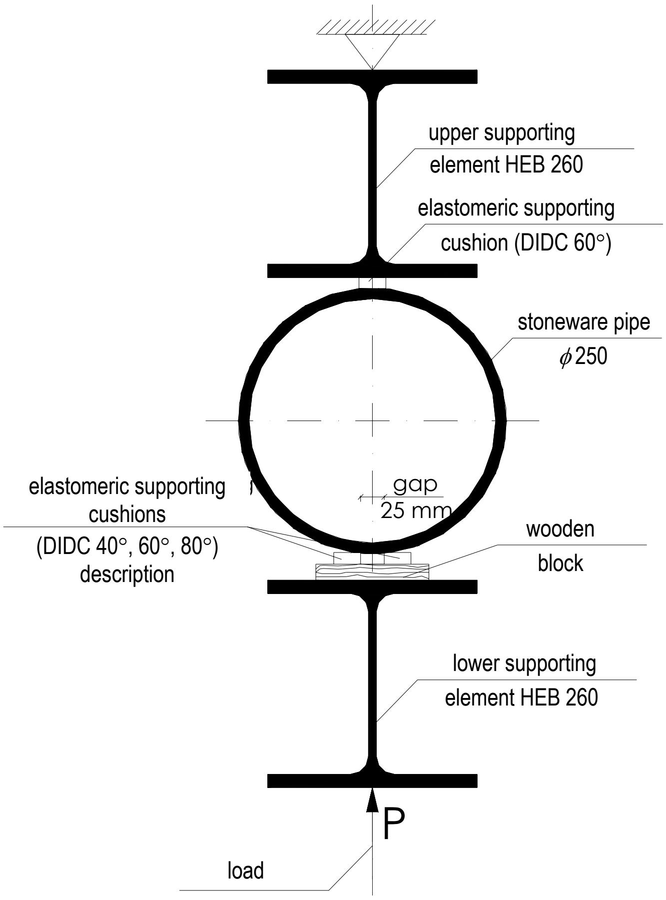

Fig. 3. Testing stand scheme

On the basis of the preliminary structural design the H-beam HEB 260 was assumed to be an upper and a lower supporting element conveying the load *p* to the pipe. This section may be vertically deflected up to U_{max} = 0.45 mm at the applied force equivalent to the pipe bearing capacity amounting to 40 kN/m.

The testing press was constructed in such a way as to reverse the configuration of the specimen loading (the force was applied upwards).

3. THE SPECIMENS TESTED

Five stoneware pipes of 250 mm diameter were tested in laboratory. Their geometrical and mechanical properties are shown in figure 4 and in table 1.

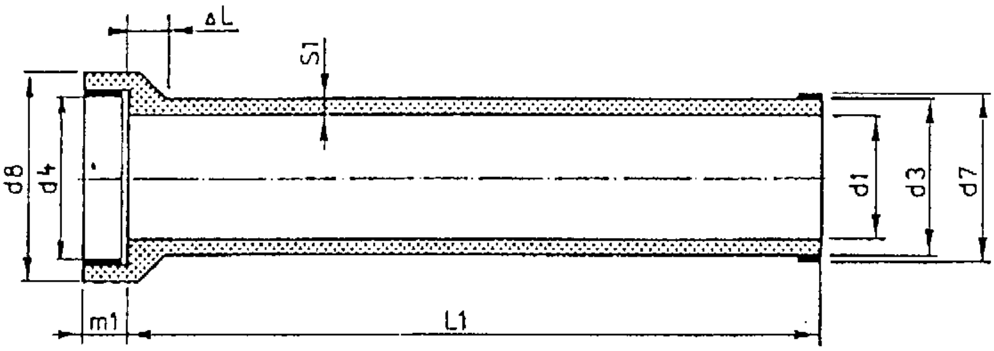

Fig. 4. Geometrical properties of pipes [3]

Table 1

Geometrical and mechanical properties of pipes after [3]

Material	clay	$d\,7\,(\pm 0.7)$ [mm]	320.6
Diameter [mm]	250	$d\,8$ max [mm]	387 ± 8
Class	160	$m1$ [mm]	74 ± 2, 70 ± 15
Strength [kN/m]	40	ΔL [mm]	60
$d1$ [mm]	250 ± 6	$d\,4\,(\pm 0.5)$ [mm]	317.5
$d3$ [mm]	299 ± 5	$L1$ [mm]	2500

The pipes were prepared for testing by cutting off their bells which was in accordance with the standard [5]. Then, the pipes were laid at the 25 mm spacing on two elastomeric supporting cushions of 25 mm × 50 mm sections.

In order to simulate a "uniform ground support", the first pipe of the length L_{R1} equal to 2440 mm was put on elastomeric cushions of the DIDC 60 hardness. According to point 4.3.1 of the standard PN-EN 295-3, the cushions were shorter than the pipe, since their length L_{P1} was 100 mm. In order to assess accurately the influence of upper and lower supporting element deflection on the stress, the foil gauges of TFs-15/120 type [4] were installed on the pipe. Their reference bases were fitted for the pipe material and amounted to 15 mm. Gauges were positioned in three places on the pipe circumference every 40 degrees. The most distant gauge sets were installed at the distance of about 200 mm from the pipe ends. In addition, in order to obtain an accurate response pattern during the pipe bending process, gauges were positioned every 250 mm.

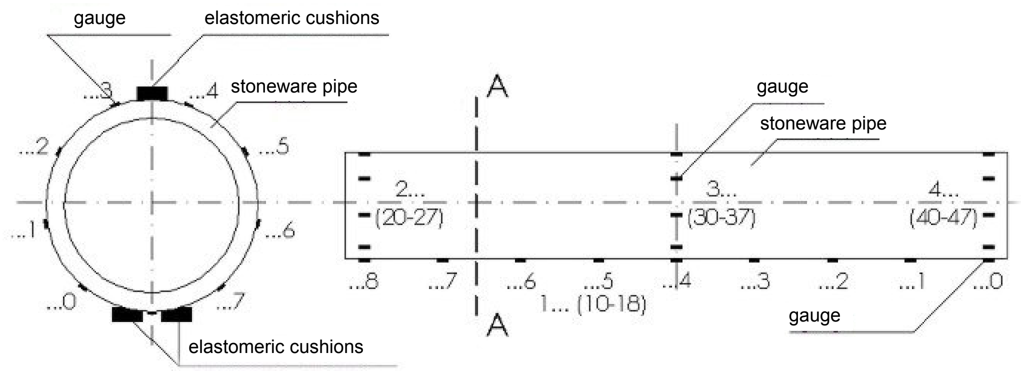

Fig. 5. Gauges arrangement on pipe No. 1

The gauges numeration is shown in figure 5. The stress measurement for pipe No. 1 was performed with 9 gauges of numbers from 10 to 18. The stress measurement on pipe circumference was carried out with 3 sets of gauges (20–27, 30–37, 40–47). There were nine gauges installed on pipes Nos. 2, 3, 4, 5 numbered respectively: 50–58, 60–68, 70–78, 80–88. Such a numeration pattern was applied in order to make it universal, thus applicable to all the test cases.

The strain magnitudes ε obtained were multiplied by the material modulus of elasticity according to Hook's law [1]:

$$\sigma = \varepsilon E_K , \tag{1}$$

where:

σ – normal stress [MPa],

ε – strain [10^{-6}],

E_K – modulus of elasticity for stoneware; according to [3] it ranges from 40 to 50 GPa and we assume it to be 45 GPa.

4. SIMULATION OF GROUND SUPPORT NON-LINEARITY

The patterns of local non-linearity of pipe support simulated by means of elastomeric cushions of various flexibility are shown in figure 6.

The cushions of DIDC 60, DIDC 40 and DIDC 80 hardness were applied in the test. In an extremely unfavourable case, the equivalent of complete loss of ground support was simulated by no support at pipe ends and the support provided for its central part, i.e. a randomly assumed length of 170 mm. The pattern of supporting cushions arranged according to the standard PN-EN 295-3 was represented by continuous bold line in figure 6. Deviations from this standard allowing us to simulate variations of ground support are marked by a dashed line.

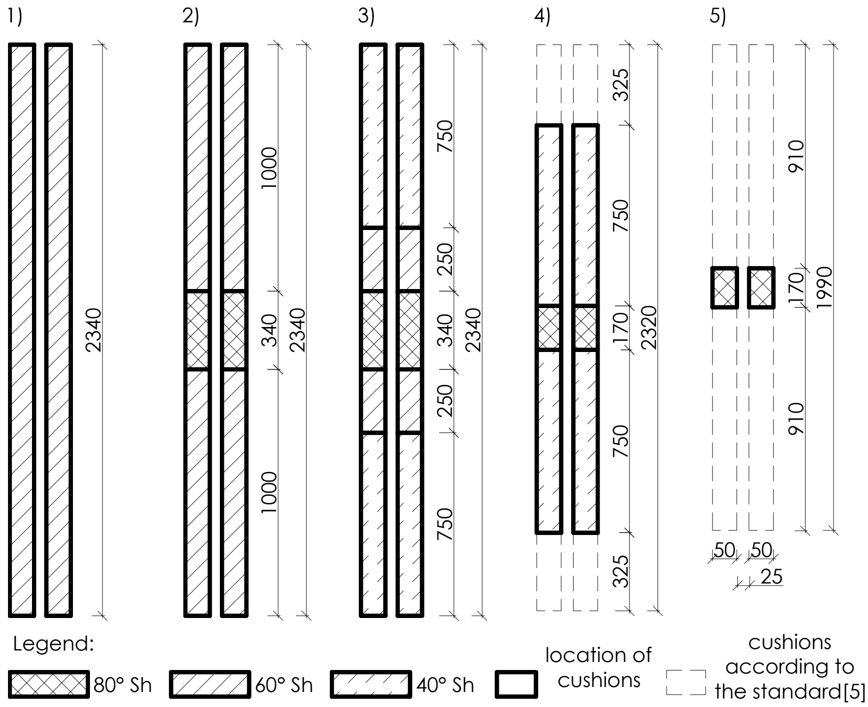

Fig. 6. Arrangement of elastomeric cushions under pipes

5. LABORATORY TEST RESULTS

The failure forces obtained for respective support models and nominal bearing capacity of pipes are presented in table 2.

Table 2

Failure forces and bearing capacity of the specimens tested

Specimen No.	Failure force [kN]	Specimen length [m]	Actual failure force per 1 m of pipe length [kN/m]	Nominal failure force declared by manufacturer [kN/m]	Nominal/actual failure force ratio [%]
1	131.00	2.44	53.70	40.00	74.50
2	102.00	2.44	41.80	40.00	95.70
3	61.00	2.44	25.00	40.00	**160.00**
4	53.00	2.44	21.70	40.00	**184.30**
5	108.00	2.09*	51.70	40.00	77.40

* The pipe was shortened due to a damage to its spigot.

The values of stress in pipes at loading ranging from 10 to 120 kN are given in table 3. Pipe No. 1 fractured at the force of 131 kN, but the respective stress values were not recorded due to failure of the measuring system. Stress values were measured with the mechanical meter for every 10 kN load increment at a rate of 1 kN/sec.

Table 3

Stress recorded in pipe walls at various loads

Pipe No.	Maximum stress in [MPa] at the mid-point of the specimen length for respective load magnitude in [kN]											
	10	20	30	40	50	60	70	80	90	100	110	120
1	0.86	1.04	1.08	2.52	1.44	1.44	1.49	1.49	1.98	1.935	1.53	1.58
2	3.06	4.77	6.03	6.93	7.65	8.42	9.09	9.68	10.26	11.60	–	–
3	0.14	0.72	1.17	1.58	1.98	2.43	–	–	–	–	–	–
4	3.96	7.02	10.3	13.4	16.5	–	–	–	–	–	–	–
5	0.95	1.80	2.57	3.24	3.96	4.68	5.45	6.17	6.84	7.65	–	–

In pipes Nos. 2, 3, 4 and 5, in which the support stiffness in the mid-zone was higher than the stiffness at pipe ends, the stress increase was non-linear (for pipe No. 2 this was illustrated in figure 7). This resulted from the fact that for elastomers the relationship $\sigma/\varepsilon = \text{const}$ is not valid.

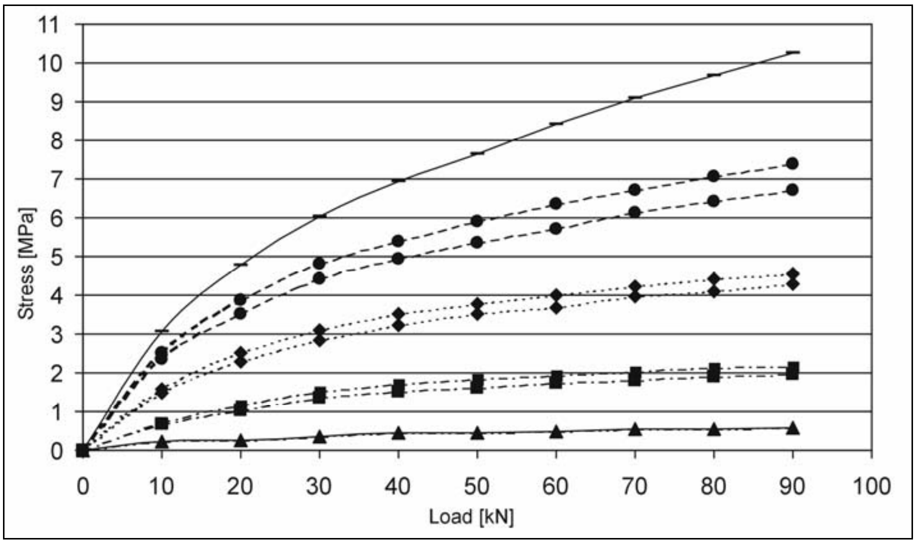

Fig. 7. Stress vs. load for pipe No. 2 (symbol description in the text)

The couples of lines presented refer to the points laying symmetrically along the longitudinal axis of the pipe. The solid line represents the records of gauge No. 54 mounted on the pipe No. 2 in its half-length section.

The other types of lines represent the records for couples of gauges placed on the pipe from the centre towards its ends, respectively: 53–55 (●), 52–56 (◆), 51–57 (■), 50–58 (▲). Numeration of gauges according to figure 5.

A little influence of elastomeric supporting cushions on the $\sigma - \varepsilon$ relationship shape was established for pipe No. 5 which was supported in its centre part along the 170 mm section and not supported at its ends. The form of stress vs. load relationship is approximately linear (figure 8).

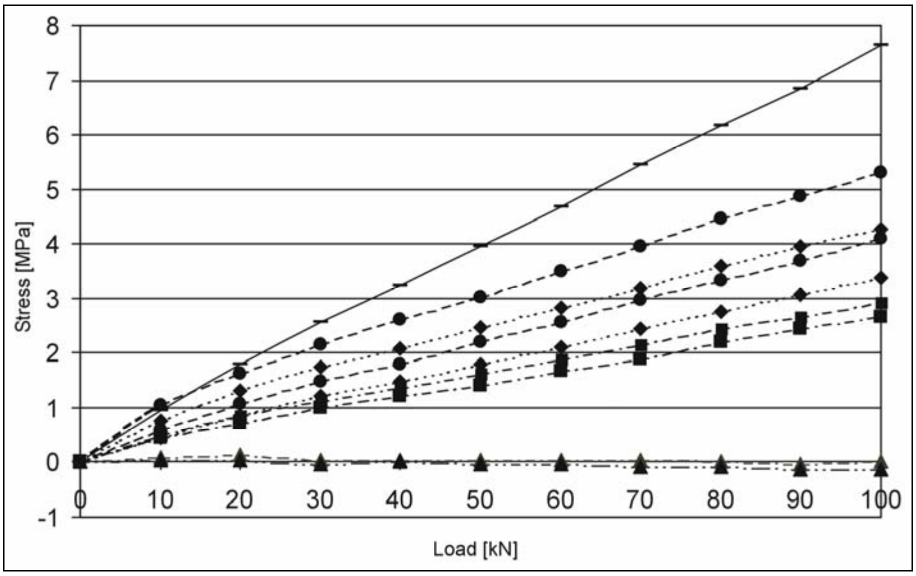

Fig. 8. Stress vs. load relationship for pipe No. 5 (symbol description in the text)

The solid line represents the records from gauge No. 84 (-) for pipe No. 5 placed in its half-length section. Subsequent couples of lines refer to couples of gauges placed symmetrically along the longitudinal pipe axis from pipe centre towards pipe ends, respectively: 83–85 (●), 82–86 (◆), 81–87 (■), 80–88 (▲).

Deformations of supporting elements, which lessen the vertical load on pipe ends, were observed during test No. 1. The specimen was laid on a uniformly linear support in order to assess the influence of lower and upper supporting elements on the uniformity of the load being transferred. The values of stress measured in pipe walls at the load of 120 kN were presented in table 4. Lines of the table represent the stresses measured on the same level of the pipe cross-section for the half-length section (3...) and for pipe ends (2..., 4...).

Table 4

Hoop stress values for pipe No. 1 (gauge numeration in figure 5)

Gauge location on the pipe circumference	Stress in pipe wall (MPa) with respect to the gauge location for 120 kN load		
	2...	3...	4...
...0	–0.36	–0.68	–0.39
...1	6.12	8.01	6.30
...2	4.41	5.58	4.86
...3	–4.77	–6.66	–5.27
...4	–5.45	–7.88	–6.93
...5	4.19	5.31	4.05
...6	6.53	8.42	6.80
...7	–0.36	–0.41	–0.36

6. SUMMARY

1. Variations in continuity and uniformity of pipe support modelled by elastomeric cushions of various hardness affect significantly the reduction in pipe bearing capacity. In practice, this may result in pipe failure if this factor is not taken into account in structural design of the pipe, and uniform support is not achieved during pipe construction.

2. Individual pipe specimens were tested in laboratory. Real pipeline in ground takes the form of a kinematic chain consisting of pipes connected with hinge joints by bells and spigots. As a result the neighbouring pipes have also a significant influence on pipe bearing capacity. This problem will be the subject of further analysis.

3. The difference in stress distributions along pipes at the moment of failure proves that the nonuniformity of the pipe support has a significant impact on pipe bearing capacity. For cases Nos. 3 and 4 failure forces were smaller than nominal failure forces declared by manufacturer by respectively 37.50% and 45.75% (table 2).

4. The difference in hoop stress of up to 12% was observed in the results obtained (table 4). Maximum longitudinal stress, which amounted to 1.58 MPa, occurred at the load of 131 kN and the nominal maximum tension stress ranging from 10 to 20 MPa according to [3]. This difference may be caused by:

- Imperfections of pipe geometry (lack of rectilinearity). Maximum dimensional tolerance of pipe axis declared by manufacturer amounted to 5 mm/m [3].
- Imperfections of geometry and arrangement of elastomeric cushions on supporting elements (figure 3).
- Non-axially conveyed load as well as non-hinged connection of upper supporting element and the press.
- Deformations of supporting elements. However, this factor seems to be the least significant since pre-calculated deflection of HEB260 section for model No. 5 reaches

only 0.45 mm. Such a deviation is by one order of magnitude smaller than dimensional tolerance for stoneware pipe manufacturing.

5. Material properties of cushions affect the stress–strain relationship for pipes Nos. 1–4. A non-linear increase in wall stress in pipes Nos. 1–4 was due to non-linear vertical deformation of elastomeric cushions (figure 7). The influence of cushion material properties on $\sigma-\varepsilon$ relationship was small for pipe No. 5 supported along its short section whose randomly assumed length reached 170 mm (figure 8). The relationship obtained in this case was almost linear.

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