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BEARING CAPACITY OF SEWERAGE PIPELINES VERSUS BEDDING CONDITIONS
PART III. MODIFIED LABORATORY TESTS

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Abstract: The article is the third part of the project on the influence of bedding conditions varying along a pipe axis on the bearing capacity of this pipe. Laboratory test results of the interaction between neighbouring pipes constituting a pipeline subjected to various bedding conditions were presented herein.

Streszczenie: Artykuł stanowi trzecią część pracy, podejmującej problem wpływu warunków podparcia zmieniających się na długości rurociągu na jego nośność. Przedstawiono wyniki badań laboratoryjnych, dotyczących wpływu dwóch sąsiadujących rur w ciągu rurociągu na nośność rury środkowej najniekorzystniej podpartej.

Резюме: Настоящая статья составляет третью часть работы, в которой авторы занимаются вопросом влияния изменяющихся на всей длине трубопровода условий на его несущую способность. Представлены результаты лабораторных исследований, касающихся влияния двух смежных труб в трубопроводе на несущую способность помещенной в середине и наиболее неблагоприятно укрепленной трубы.

1. INTRODUCTION

In the first part of the project [2], a static model of pipe including possible bedding non-linearities or various ground conditions in its neighborhood has been proposed. The parameters of elastic support representing the performance of bedding under load and rigid support that model the so-called stiff support points were selected according to [7].

In the second part of the project [3], laboratory test results carried out on separate specimens of DN250 stoneware pipes were presented. The mechanical press WPM LIPSK of ZDM-300 type was adapted to conduct the test at the Institute of Civil Engineering of Wrocław University of Technology. Investigation was carried out for five different support variants. The results obtained in the form of longitudinal stresses due to bending confirmed the expected drop in the pipe bearing capacity along with an increase in local bedding stiffness. In the point 2 of conclusions drawn based on this research, there is a declaration of undertaking another laboratory investigation programme, namely for three connected stoneware pipes, which definitely more precisely matches real conditions.

2. TESTING STAND

Previously constructed test stand of 3000 mm length was used for a current laboratory test (figure 1) [3].

Fig. 1. The test stand with three pipes prepared for investigation

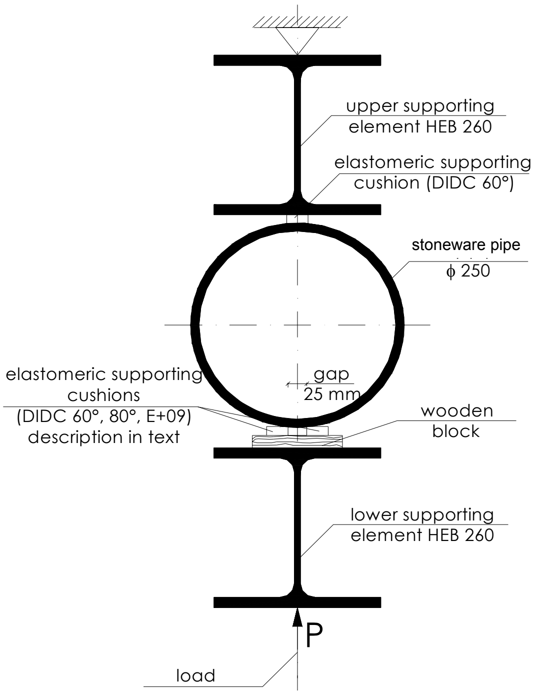

Fig. 2. Scheme of testing stand (cross-section)

The assumptions accepted and the calculation procedure for upper and lower elements are given in reference [3]. Based on these assumptions and calculations we accepted HEB 260 sections whose bending stiffness is 68 times bigger than that of DN100 pipes used for investigation.

The specimens tested were put on two elastomeric cushions of the size of 25 mm × 50 mm × 800 mm, with 25 mm spacing. Nonlinear ground support was modelled only at the bottom of pipes, whereas at the top side of pipes the load was transferred by rubber cushions of 60° Shore hardness. The cross-section of the loading/support model is shown in figure 2.

3. THE SPECIMENS TESTED

Twelve DN100 stoneware pipes of 1000 mm length were selected. Geometrical and mechanical properties of the pipes are shown in figure 3 and in table 1.

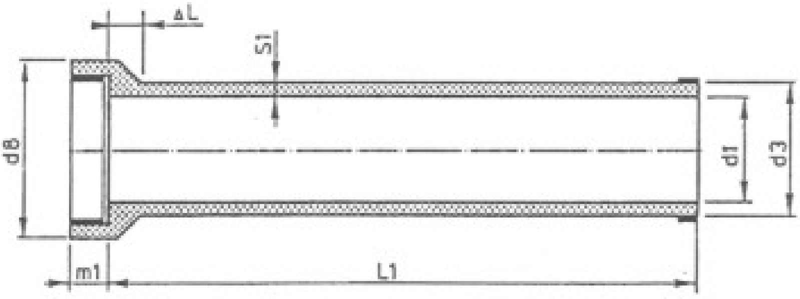

Fig. 3. Geometrical properties of pipes [4]

Table 1

Geometrical and mechanical properties of pipes according to [4]

Material	Stoneware	*d*8 max. [mm]	174±4
Strength [kN/m]	34	*m*1 [mm]	62±2, max 70
*d*1 [mm]	100±4	Δ*L* [mm]	30
*d*3 [mm]	131±1.5	*L*1 [mm]	1000

4. SIMULATION OF THE GROUND SUPPORT NONLINEARITY

Of six tests carried out three were conducted on single pipes resting on three various beddings. The first pipe (figure 4a) was put on a uniform bedding modelled with elastomeric cushions of DIDC 60° Shore hardness, according to principles proposed in

[6]. The second pipe was laid only on local support (100 mm long) in the form of cushions of DIDC 80° hardness placed in the middle of the pipe length (figure 4c). The third one was laid on a local support made of quick-setting high-strength mortar (figure 4e). Further three tests were conducted in a similar way, but two pipes were added to each pipe tested. In each case, they were laid on a bedding of elastomeric cushions of DIDC 60° hardness (figure 4b, d, f). Bedding configurations for respective tests were shown in figure 4.

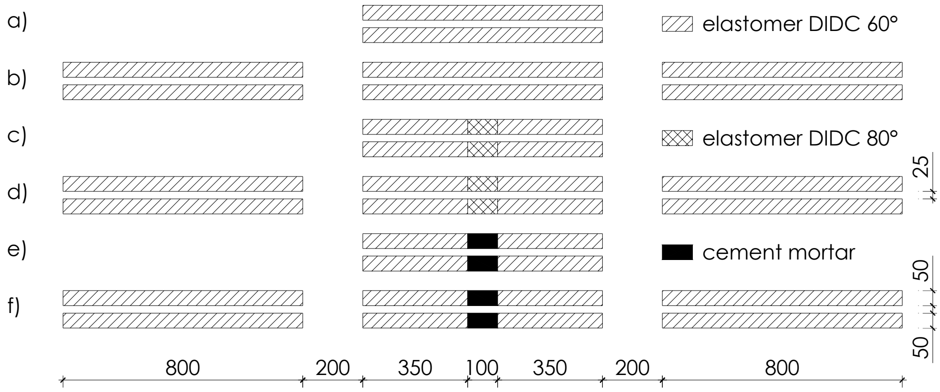

Fig. 4. Arrangement of elastomeric cushions under pipes in six tests

In order to measure stresses due to bending, foil gauges TFs-15/120 were installed on the pipes [5]. Their reference bases were set appropriately to the pipe material and amounted to 15 mm. In order to obtain accurate response pattern during the pipe bending process, gauges were positioned every 100 mm.

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

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

where:

σ – the normal stress [MPa],

ε – the strain [m^{-6}/m],

E_K – the modulus of elasticity, determined by the authors in a separate test, amounting to 45 GPa.

5. LABORATORY TEST RESULTS

The set of measured failure forces for the respective bedding models is presented in figure 4, and nominal failure forces are given in table 2.

Table 2

Failure forces $F_{\max}$ obtained in six laboratory tests

Test No.	Number of pipes	Type of bedding*	Failure force measured [kN]	Failure force per single pipe ($K4$:$K2$) [kN]	Failure force according to [3] [kN]	Actual/ nominal failure force ratio ($K5$:$K6$) [%]	Disturbance rate $\frac{(W1 \div W6)}{W1}$ [%]
1	2	3	4	5	6	7	8
1	1	uniform	45.00	45.00	34	132.35	100.00
2	1	nonuniform	40.00	40.00	34	117.65	88.89
3	1	rigid	28.00	28.00	34	82.35	62.22
4	3	uniform	116.00	38.67	34	113.74	85.93
5	3	nonuniform	89.00	29.67	34	87.27	65.93
6	3	rigid	54.00	18.00	34	52.94	40.00

*The test with uniformly elastic bedding corresponds to pipes laid on elastomeric cushions of DIDC 60° hardness. The test with nonuniformly elastic bedding corresponds to the case of local elastomeric support of DIDC 80° hardness placed in the middle of pipe length. Rigid bedding corresponds to the case of rigid local bedding made of quick-setting cement mortar.

The magnitudes of bending stress along pipes under load from the range of 10–110 kN, the latter being transferred to pipes in six consecutive tests, were presented in table 3. Stress magnitudes were measured with the mechanical meter for every 10 kN load rise at the load increment of 1 kN/s.

Table 3

Bending stress rise in pipe walls for consecutive load steps

Test No.	Maximum stress [MPa] in the middle of the specimen length for the load imposed [kN]											$F_{\max}$
	10	20	30	40	50	60	70	80	90	100	110	kN
1	1.80	2.84	3.60	4.37	–	–	–	–	–	–	–	45
2	–2.84	–4.59	–6.03	–8.01	–	–	–	–	–	–	–	40
3	–7.79	–17.9	–	–	–	–	–	–	–	–	–	28
4	3.69	4.41	4.68	4.91	5.04	5.18	5.31	5.49	5.67	6.30	5.99	116
5	–5.72	–7.65	–8.87	–9.95	–10.9	–11.7	–12.5	–13.3	–	–	–	89
6	–0.99	–	–8.42	–12.2	–17.1	–	–	–	–	–	–	54

Diagrams of stress along pipes in six laboratory tests were show in figures 5 to 10.

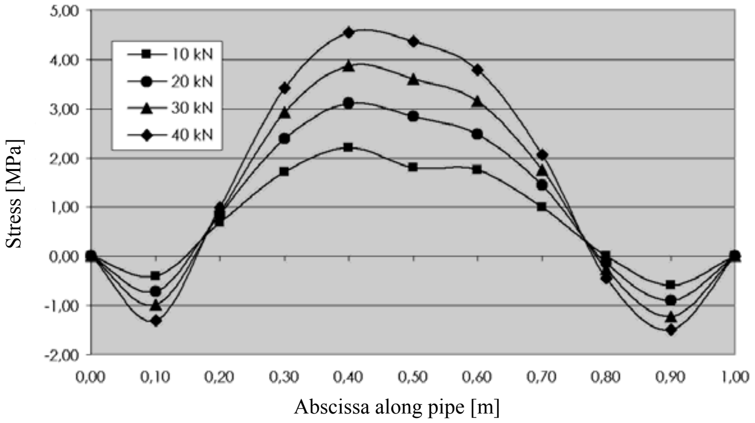

Fig. 5. Stress diagram for uniformly elastic pipe bedding

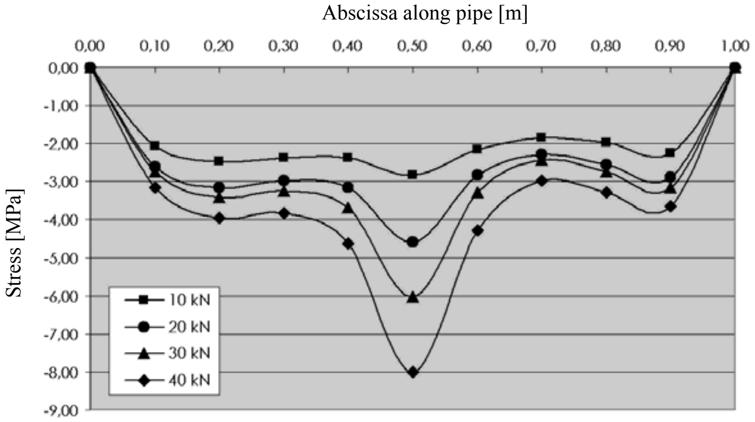

Fig. 6. Stress diagram for nonuniformly elastic pipe bedding

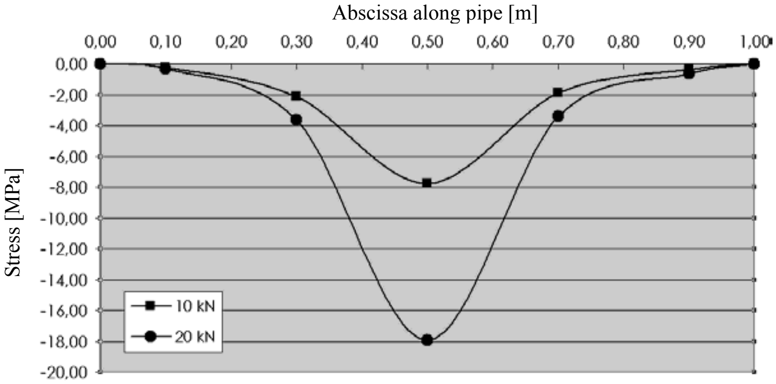

Fig. 7. Stress diagram for rigid pipe bedding

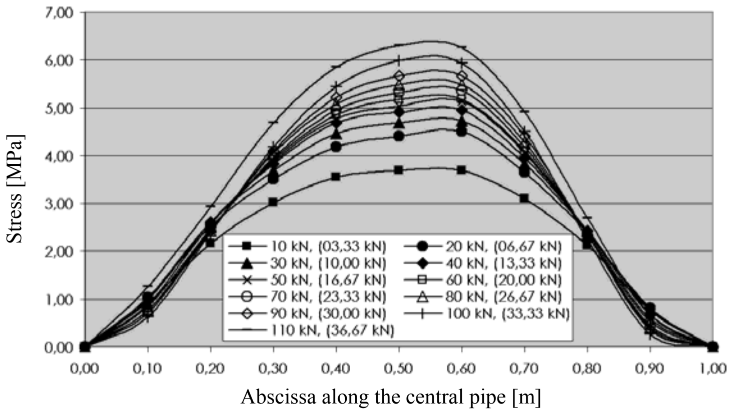

Fig. 8. Stress diagram for uniformly elastic pipe bedding (central pipe)

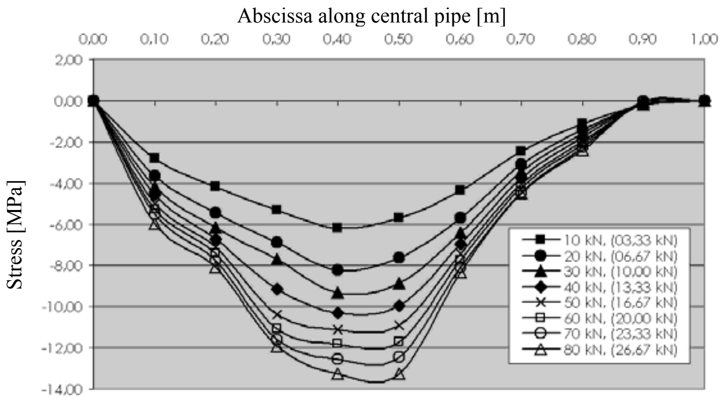

Fig. 9. Stress diagram for nonuniformly elastic pipe bedding (central pipe)

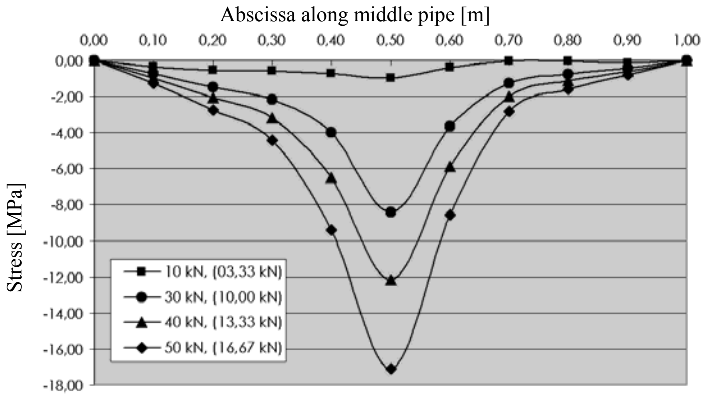

Fig. 10. Stress diagram for rigid pipe bedding (central pipe)

In order to maintain the invariability of load transferred from the mechanical press to the pipe specimen in test No. 1, some additional gauges were installed along the pipe circumference, at the pipe bottom and at springings. Stress magnitudes measured in these places on pipe walls under the load of 40 kN were shown in table 4.

Table 4

Circumferential stress in test No.1

Location of gauges along the pipe circumference	Stress in pipe wall [MPa] in various places along the pipe under 40 kN load		
	Bell	Middle	Spigot
Left springing	5.81	9.45	7.79
Bottom	11.88	14.00	13.28
Right springing	5.90	9.63	7.70

If a decrease in stress near the bell in comparison with the stress in the spigot zone results from a higher value of the moment of inertia of the pipe cross-section, an increase in the stress in the middle zone cannot be explained by this phenomenon. Cross-sections of the central pipe zone and spigot zone seemed to be identical and despite this fact circumferential stress in the middle zone was higher: at the bottom by 5.4% and at the springings by 25.1%. This shows that an increase in maximum stress in the middle zone of the pipe should be attributed to slightly bending conditions despite applying a uniformly elastic bedding.

6. CONCLUSION

1. The current test results show a significant decrease in bearing capacity of pipe specimens in the case of an increase in the bedding stiffness under the pipe middle zone. If a pipe is laid on a uniformly elastic bedding with elastomeric cushions of DIDC 60° hardness, the measured failure force amounts to 45 kN, which is a magnitude by 32.35% higher than the nominal pipe failure force. 45 kN was considered to be a reference value to which other values were compared. Application of only local bedding conditions and elastomeric cushions of DIDC 80° hardness in the pipe middle zone resulted in 11.11% drop in a pipe bearing capacity. Rigid bedding under a pipe middle zone caused a decrease in pipe bearing capacity by 37.78%. It must be highlighted here that the above mentioned cases (tests Nos. 1, 3, 5) concerned separate pipes.

Tests Nos. 2, 4, 6, carried out for the sets of three pipes showed a negative influence of neighbouring pipes on the bearing capacity of a central pipe being tested. Despite applying a uniformly elastic support in test No. 2, a 14.07% decrease in the bearing capacity of a central pipe was observed. In test No. 4, bedding with DIDC 80° hardness cushions was responsible for a decrease in bearing capacity by 34.07%, whereas in test No. 6 dealing with a rigid pipe support, a drop of 60.00% was obtained. Comparing the values of stress obtained in two tests for the same bedding type, namely 1–2, 3–4, 5–6, the rise of stress (a decrease in bearing capacity) was observed in the case of three-pipe models. In test No. 2, the bearing capacity fell by 14.07% in comparison with its magnitude in the test No. 1. In test No. 4, the bearing capacity fell by 25.83% in comparison with its magnitude in test No. 3. Then, in test No. 6 the bearing capacity fell as much as by 35.71% in comparison with its magnitude in test No. 5.

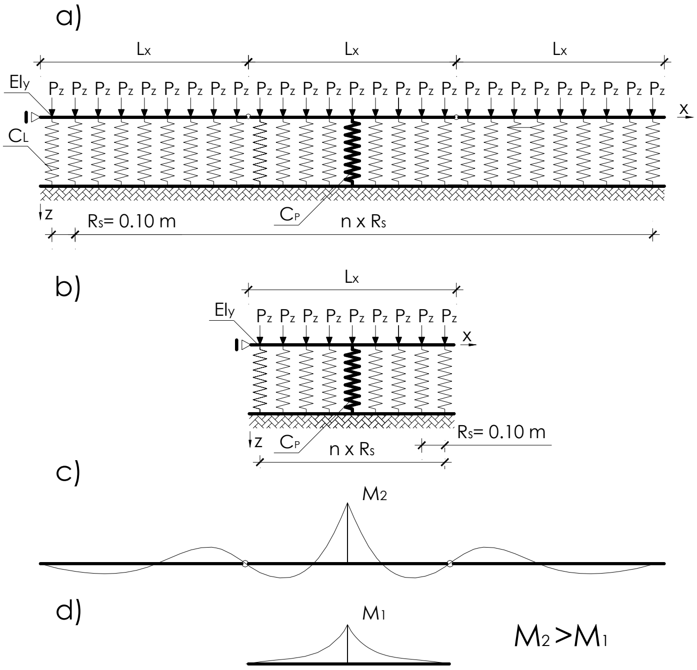

Fig. 11. Test models a), b) and bending moment diagrams c), d) for a set of three pipes and a separate pipe, respectively

These results confirm the results of numerical analysis carried out earlier for the sets of three connected pipes laid on various beddings of a central pipe [2] as well as the calculation results for separate pipes. The values of bending moments in the middle of a central pipe in the set of three pipes were higher than these for a separate pipe model. The difference, depending on the stiffness of support elements, ranged from 0 to 30%. The magnitudes compared were obtained in the same load q = 10 kN/m and the same bedding conditions. Models and diagrams representing bending moments were shown in figure 11.

2. Investigation conducted for three-pipe models reflects better actual performance of sewerage pipes because they allow taking into account the influence of hinges in bell-and-spigot pipe connections on pipe bearing capacity. In the case of careful site installation, i.e., after removing all elements which may cause local rigid bedding under pipes (foundation remainder, big stones), and after making properly compacted bedding in all zones the nominal bearing capacity of pipes seems sufficient for further failure-free exploitation of pipeline. However, where some zones of higher compressibility exist under pipes, there is a risk of 60% reduction of the pipe bearing capacity to the value of 18 kN at the nominal bearing capacity of 34 kN.

3. Modelling with the use of elastomeric cushions of various hardness, disturbances of uniformity and continuity of pipe bedding affected significantly the pipe performance.

4. On the basis of the results obtained for specimen No. 1 the differences in circumferential stresses in pipe walls were observed under the 40 kN load; their values were higher by 5.4% at the bottom and by 25.1% at springings (table 4). This phenomenon may be caused by:

- Geometrical imperfections of pipes (lack of rectilinearity). A manufacturer declares the tolerance of 6 mm/m for the pipe DN100 [4].
- Geometrical imperfections of elastomeric cushions applied to supporting elements.
- Non-axial load transfer and non-hinged connection of the upper supporting element to the mechanical press.
- Deflection of supporting elements. This factor seems to be of a minor importance due to the ratio of HEB260 section stiffness to the stiffness of the pipe tested amounting to 30586 kNm^2 / 450 kNm^2, i.e., (68:1).

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