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Maximisation of Buckling Resistance in Structural Members Made of Circular Hollow Sections

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This paper deals with the optimisation of the joint for thin-walled compressed elements that have circular hollow sections (CHS). A steel pipe is studied that has 3 m length, 52.3 mm diameter and 3 mm thick wall. Few examples of joint shapes are proposed. The first of them uses two extra plates that are perpendicular to the circular section. They are both in the shape of an isosceles triangle with 100 mm long and 3 mm thick sides. The second option uses four of those triangle plates. The next step is to provide perforation only in the joint area as well as along the whole element. The last option is to use a short smaller pipe inside the base pipe. Results have been compared to each other and conclusions are summarised.

Keywords: thin-walled pipe, steel pipe, CHS joint.

1. Introduction

Nowadays, demands made by a civil engineering industry are simple. Everyone wants to build cheap, comfortably, and especially quick. Light steel structures are more and more popular [3], as they meet all these demands. One of the options is to use thin-walled profiles, but one needes to be aware of the hazards associated with their use. First of all, it is extremely important to analyse the possibility of stability loss when these elements are compressed [4, 11]. The second thing is to figure out joints in a proper way and analyse how stiffening can change buckling resistance [9]. In this paper, it has been shown that the results of adding extra elements are not so obvious as it may seem. Additionaly, regarding [10], the influence of perforation has been considered. An attempt was made to optimise elements made of a circular hollow section [5].

2. Base pipe

A circular hollow section element, named pipe in the text for simplicity's sak, is cocidered as a base. Its length is 3 metres, and it is made of steel (S235JR) (Fig. 1). The load is compressive axial force of 30 kN. The pipe has two pinned supports, and there is a possibility of horizontal movement on one side (Fig. 3). Solid finite elements TET 4 have been used and nonlinear buckling analysis has been conducted. As a result, solid von Misses stress and deformations were observed [8]. In addition, yield strength of 235 MPa was used as strength limit criterion. All numerical calculations were made in Autodesk Nastran In-CAD software. The objective function was to increase critical load P_{cr} depending on slenderness λ and geometric changes G:

find G,

to maximise $P_{cr}(G, \lambda)$,

subjected to $\sigma \leq 235$ MPa,

where design variables G represent element perforation, modifications in joint area, e.g., usage of extra plates, use of cuts on the ends, and enlargement of section.

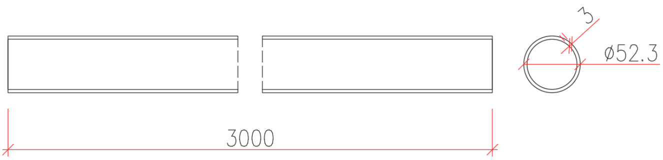

Fig. 1. The geometry of the base pipe.

The way of choosing the section size shows trivially why it is necessary to take into accound the possibility of stability loss. Let us begin by looking for the section that meets the rule of maximum compressive stress only. This would be

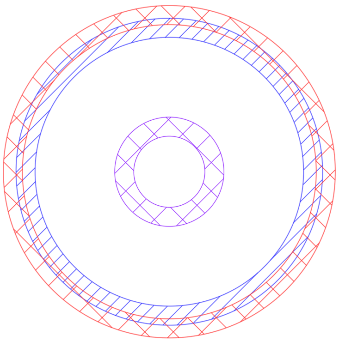

Fig. 2. Draft of CHS profile – description in the text.

extremely tiny profile of CHS 17.2 × 3 mm, marked in purple in Fig. 2. Therefore, it is better to find some rules in the literature about maximum slenderness λ. For example, in Russian standard SP16.13330.2011 [1] λ, stands as 210 for elements not precisely specified, which means that there are not columns, chords, T-sections, etc. Regarding this standard, the base pipe should have a CHS profile of 48.3 × 3 mm, marked in blue in Fig. 2. This result is better but to obtain the best result we use a quick and simple solution and determine Euler's critical load [11]. In this way, the final dimension obtained for a CHS is 52.3 × 3 mm. It is marked in red in Fig. 2, where the difference is shown between this correct profile and the other two profiles that are too small to be used.

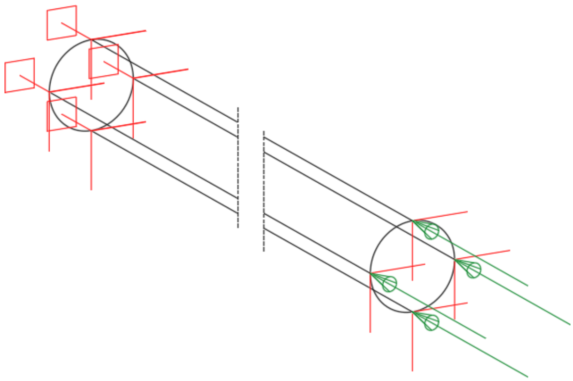

Fig. 3. Boundary conditions.

For the base pipe, the diagram showing the dependence between displacement and load increase (Fig. 4) has been prepared. The blue line regards resultant displacement and the green one is for displacement perpendicular to the longitudinal axis of the pipe. By using the latter one, it is easier to identify the moment when the pipe except reducing length is relocating to follow stability loss form.

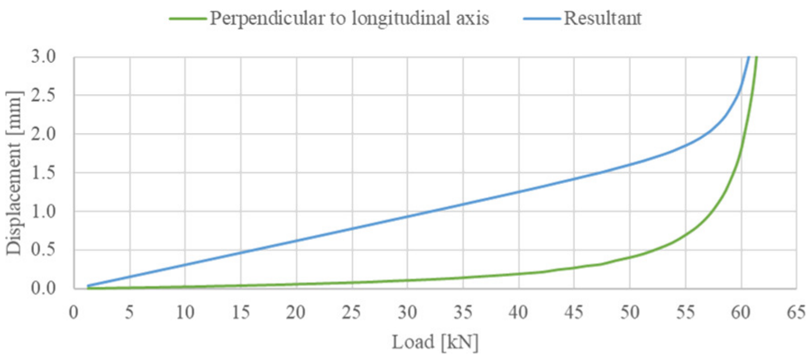

Fig. 4. Dependence of displacement on load – base pipe 1.

3. Strengthening solutions

3.1. Extra plates

The idea of the pipe strengthening is quite obvious: we add extra stiffened plates at the ends of the element (Fig. 5). In the first step, two extra plates are provided on each end, and this is "pipe 2". Plates are isosceles triangles, with sides 100 mm long. The thickness of the plates is the same as the pipe, so it is 3 mm. The idea of strengthening by plates was considered in the variant with four plates as well, and this model is "pipe 3" (Fig. 6). The expected result is that the buckling length will decrease, so the critical force will be larger. Effectively, the critical force declines. The reason for this effect is shown in Fig. 7. In the case where the thin-walled element is used, plates damage the perpendicular thin wall of the pipe. The circular shape of the element 'wants' to transform to ellipse because of compressive force by the plates, and the critical point appears where there is a concentration of stress.

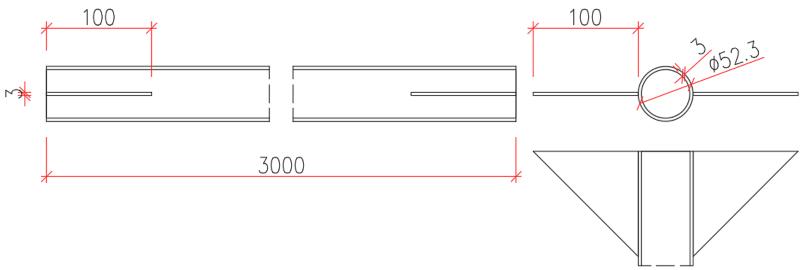

Fig. 5. Two extra plates – geometry.

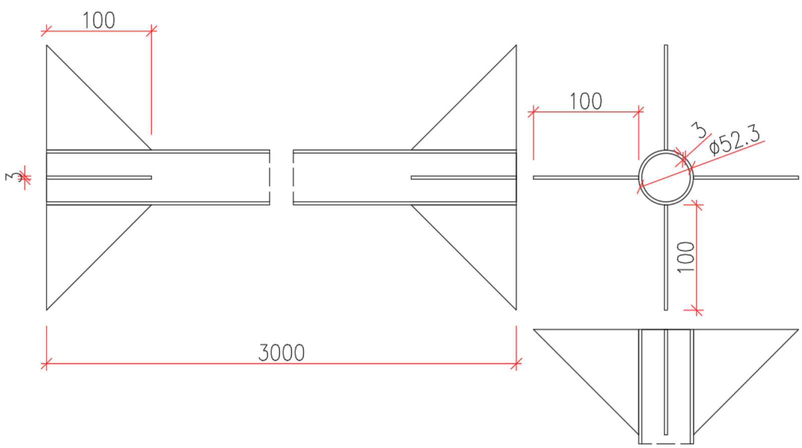

Fig. 6. Four extra plates – geometry.

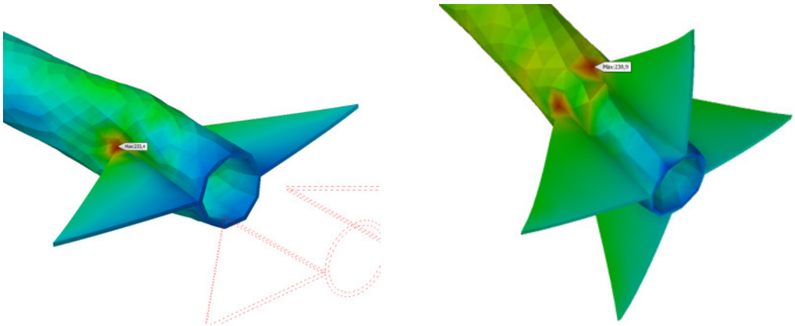

Fig. 7. Stress map and 3D displacement of pipes 2 and 3.

The diagram (Fig. 8) presents forms of displacement increase for pipes with extra plates. It can be noted that the critical force for the purlin with two plates is close to 15 kN, and with four plates it is around 10 kN.

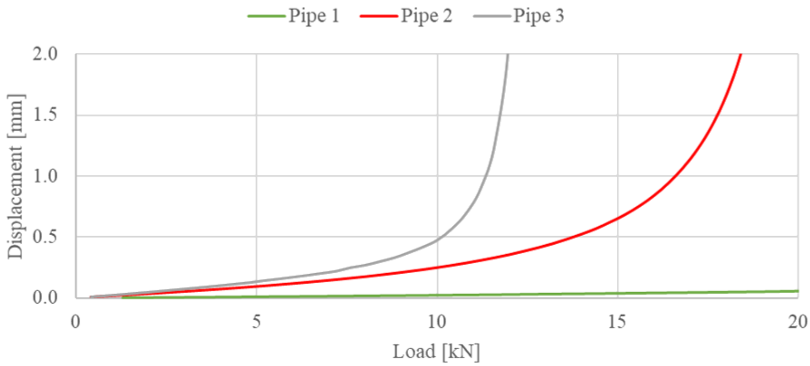

Fig. 8. Dependence of displacement on load – (2) two extra plates, (3) four extra plates.

3.2. Pipe end perforation

The second case is perforation. Two elements have been analysed, one with two cuts per end (pipe 3, Fig. 9) and another with four cuts per end (pipe 4, Fig. 10). The shape of the ends deformation is presented in Fig. 11.

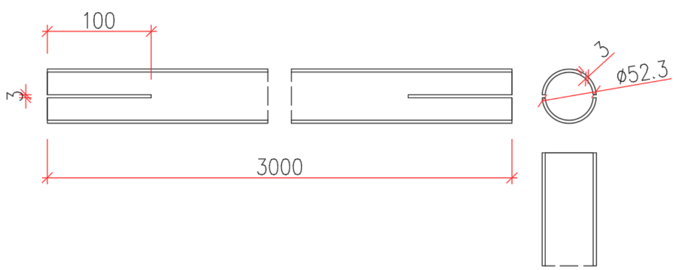

Fig. 9. Two cuts on each end – geometry.

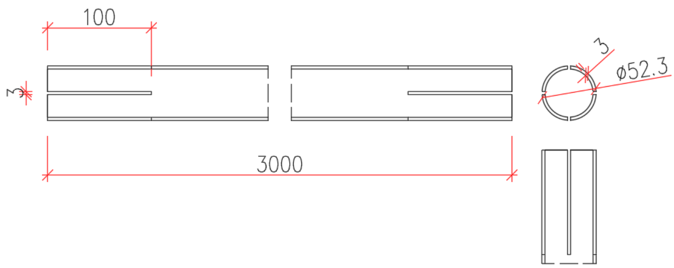

Fig. 10. Four cuts on each end – geometry.

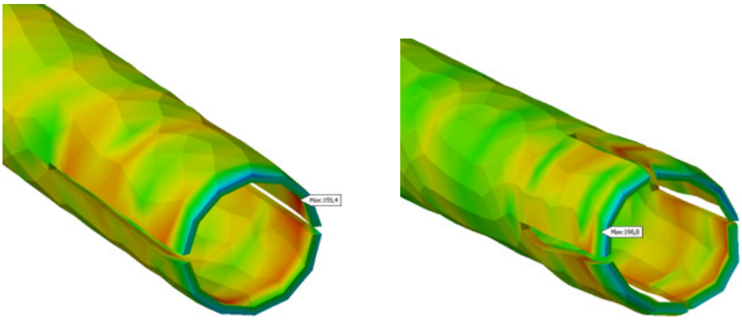

Fig. 11. Stress map and 3D displacement of pipes 4 and 5.

Figure 12 is a diagram in which it is presented that two cuts give critical force around 25 kN that is a bigger load than in the case with extra plates. Four cuts are a worse option, as the critical load is around 10 kN.

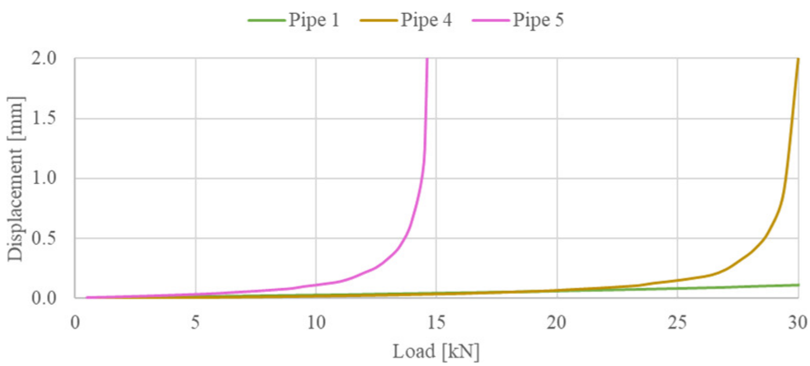

Fig. 12. Dependence of displacement on load -– (4) two cuts, (5) four cuts.

3.3. Full perforation

The next option is an extended idea of perforation. Here, two cuts at each end and extra brakes along the element are provided. In all instances, there are

10 holes, each 3 mm wide. In pipe 6, holes are 100 mm long, in pipe 7 holes are 50 mm long, in pipe 8 holes are 25 mm long, and pipe 9 has holes with the length of 10 mm Fig. 13. Figure 14 shows how stress concentrates around cuts. The pattern of the stress map for all perforated pipes is similar. As it is visible in the diagram (Fig. 15), the best result has been obtained for pipe 8 with 25 mm long holes. Smaller holes gave worse output but similar to pipe 4, which is the case without perforation, only with cuts at both ends.

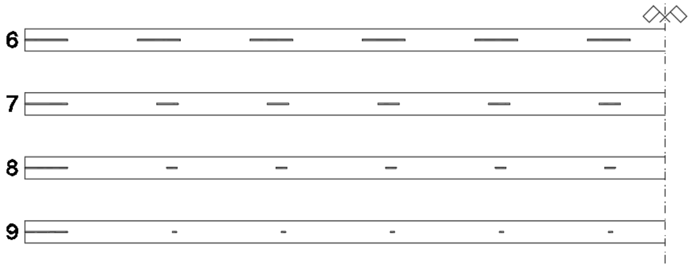

Fig. 13. Perforation of pipes – geometry.

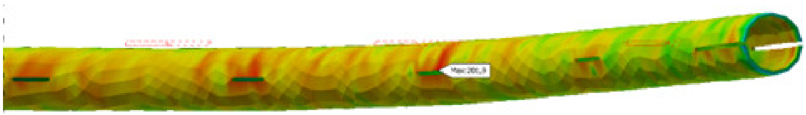

Fig. 14. Stress map and 3D displacement of pipes 6, 7, 8, 9.

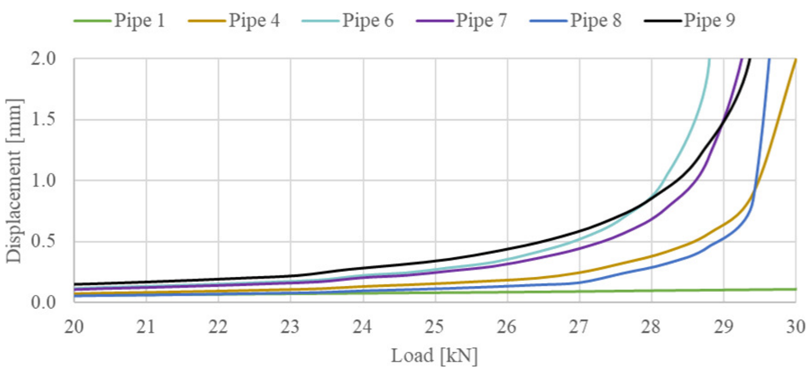

Fig. 15. Dependence of displacement on load – (4) two cuts, pipes with perforation: (6) 10 × 10 mm, (7) 10 × 50 mm, (8) 10 × 25 mm, (9) 10 × 10 mm.

3.4. Extra width on ends

The last instance is pipe 10 that has ends strengthened by smaller pipes inside. These stiffeners are 100 mm long and have a 3 mm thick wall, so the final width of the wall on the end is 6 mm. The shape of deformation and distribution of stress is similar to the base pipe (Fig. 16). The difference is the reduction of stress in ends area. Moreover, this effect allowed us to obtain the best solution for the pipe. In diagram presented in Fig. 17 we see that the deformation in the direction perpendicular to the longitudinal axis of element started to perform later than for the base pipe.

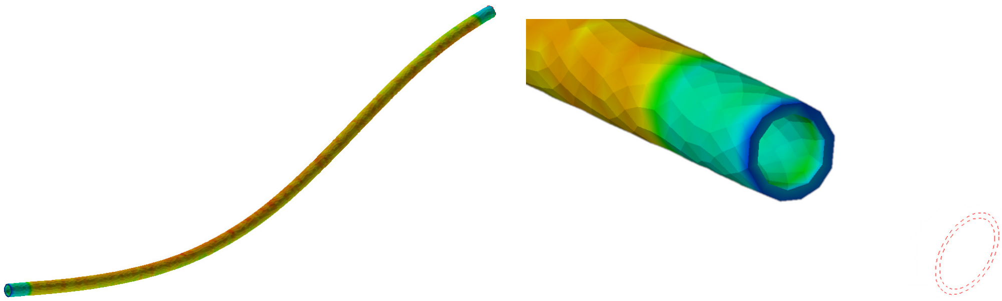

Fig. 16. Stress map and 3D displacement of pipe 10.

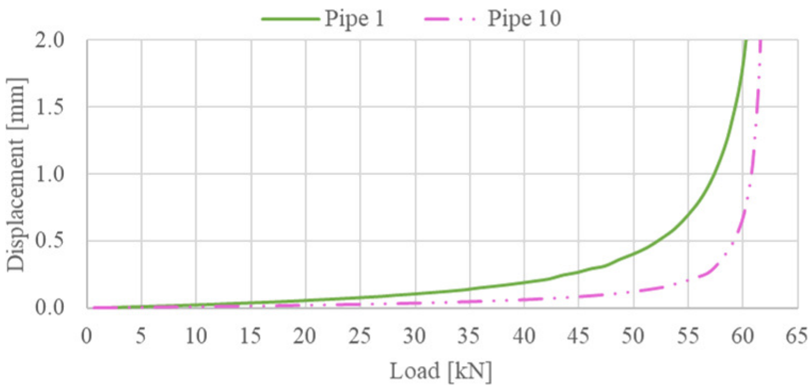

Fig. 17. Dependence of displacement on load – (10) extra pipe pieces.

4. Summary and conclusions

To sum up, thin-walled circular hollowed sections can be considered as structure elements because they are cheap and effective. Nevertheless, the phenomenon of buckling is really important to study. These long elements with relatively small sections are extremely responsive to loss of stability [6, 7].

The authors analysed a few alternatives for the strengthening of thin-walled pipes. In Fig. 18, the set of results for all cases is shown. Pipe 1 is the base one without any extra elements or changes. First, extra plates were added, two plates for pipe 2 and four plates for pipe 3. As a result, the strengthening was

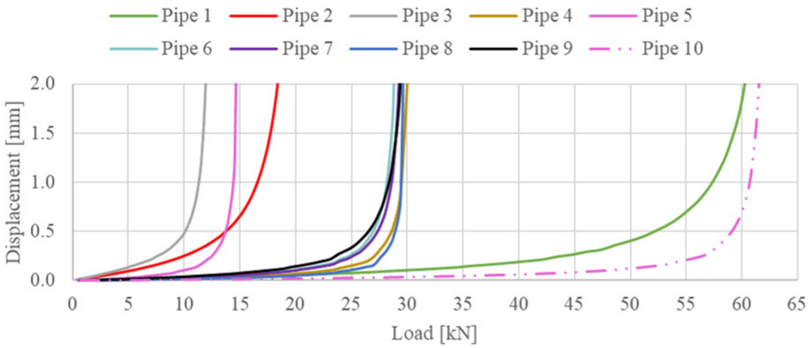

Fig. 18. Dependence of displacement on load – all cases.

expected, but in fac, pipes were weakened. To reverse this outcome, the attempt was made to provide perforation in pipes. Pipe 4 had two cuts on each end, and pipe 5 had four of them. Next, pipes 6, 7, 8, and 9 had perforations along the whole element with a different dimension of holes. It appears that the outcome for pipes with perforations in two rows was better than for pipes with extra plates. Only pipe 5 with four extra cuts deformed for the similar load as pipes with plates. This shows that for the analysed pipe, the better scenario was to make the element lighter than to add extra material such as plates. The solution that gave the best results was obtained by using extra pipes 100 mm long inside ends of the element. The strengthening was not spectacular, but it showed the best way to resolve elements like this.

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