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Full-Scale Tests of Pipeline Girth Welds Under Complex Cyclic Internal Pressure and Static Bending Loading Conditions

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Abstract. The critical elements of high-pressure hydrocarbon transporting pipelines are often the girth welds, which are subjected to complex loads. The aims of our research and this paper are to introduce our full-scale pipeline fatigue and burst tests applying cyclic internal pressure and superimposed external bending stress on girth welds, furthermore, attracting the importance and the applicability of the investigation results. A unique testing system was built to study the behaviour of pipeline girth welds under simultaneous loads. The tests were evaluated using video camera recordings, internal pressure vs. burst time functions and failure pressure values.

Keywords: gas transporting pipeline, full-scale test, girth weld, complex loading condition.

Introduction

Assessing the integrity of an operating structure or structural element is a complex task [1]. The content of the term already indicates this complexity: the suitability for operation at any moment of its lifetime. Understanding the practical problems and tasks requires or presupposes theoretical knowledge, structure-specific knowledge and relevant experimental work [2], [3]. Structure-specific knowledge includes design, technological and operational elements.

High pressure pipelines are used to transport different media worldwide. These piping systems contain a large number of girth welded joints which must be evaluated at the design stage to assess their fatigue resistance. The repeating operational events, the changes in the internal pressure values, furthermore the external impacts result in cyclic loads, having a characteristic effect on the lifetime of the girth welds. Unfortunately, during the construction of pipelines, it is not uncommon to encounter external influences that result in excess bending stresses in the girth welds. Defects and/or discontinuities occurring in gas pipelines, frequently in the welds, can lead to propagating cracks, and these pipeline cracks may cause catastrophic fractures.

Full-scale fatigue and burst test are the best ways of assessing the crack propagation resistance of a natural gas pipeline, especially in cases of the girth welds. Different solutions are used to test full-scale pipeline sections. An example of a four-point bending test of large diameter pipe can be seen in Figure 1, which shows a schematic of the test frame and a pipeline section after failure (local buckling) [4]. During the test, no internal pressure was applied to the pipeline section.

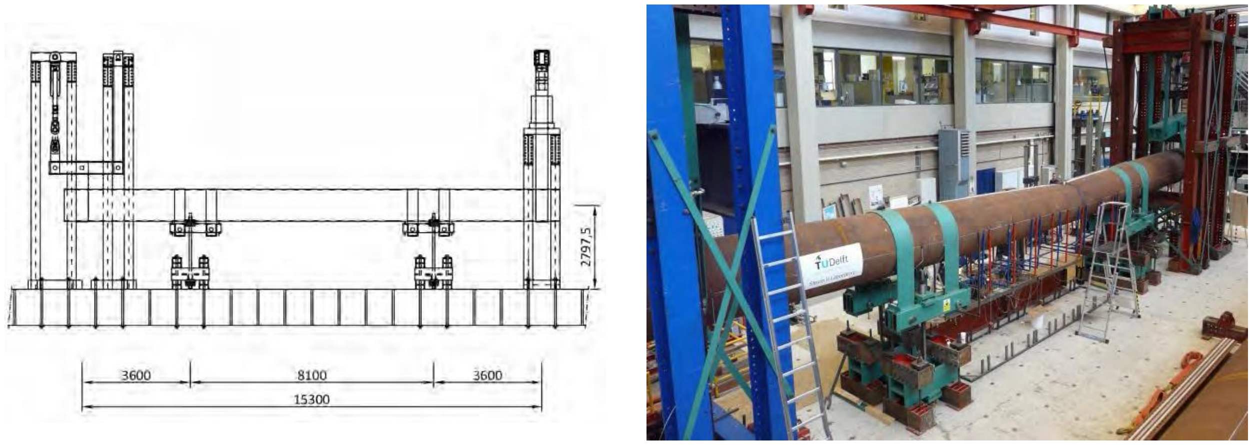

Figure 1. Sketch of test set-up (left) and test set-up after formation of a local buckle (right) [4]

An example of a similar test is shown in Figure 2, where the basic difference is that the girth weld contained an artificial notch in the root [5]. A similar test to the first example is reported in [6], while a similar test to the second example is reported in [7]. The effects of soil-transmitted loads and loads due to soil movement were investigated in [8] and [9], again without the application of internal pressure. In the case where we can superimpose external bending stress on the cyclic internal pressure, we can model the real loading conditions of the pipelines well.

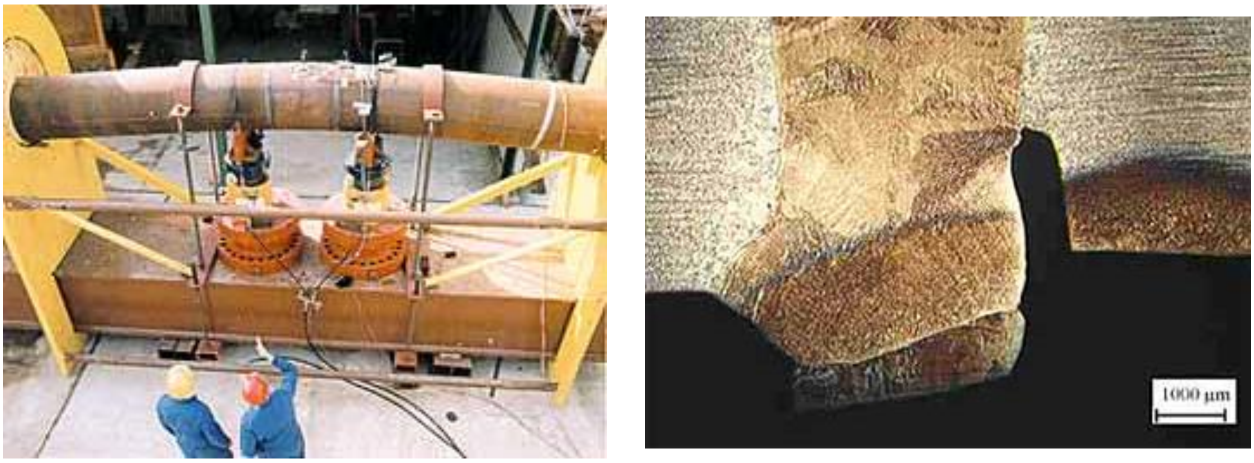

Figure 2. Four-point bending test (left) and crack tip in HAZ of weld root [5]

The aims of our research and this paper are to introduce our full-scale pipeline fatigue and burst tests applying cyclic internal pressure and superimposed external bending stress on girth welds, furthermore, attracting the importance and the applicability of the investigation results.

1. Testing circumstances

The investigated pipeline sections were made of P355NH steel with a nominal diameter of DN100 (114.3 mm) and a nominal wall thickness of 5.6 mm. The tested girth welds were made by manual metal arc welding and were inspected by visual, liquid penetrant, and radiographic tests (VT, PT, and RT, respectively). Only girth welds that have been produced to an acceptable quality level have been tested. This also means that the consistently high quality of the girth welds made it possible to investigate the impact of other influencing factors on the damage characteristics.

A unique test system has been developed for the complex loading of pipeline sections by cyclic internal pressure and external bending. In the three-point bending arrangement, the tested girth weld was positioned in the middle of a nominal 4 meters long pipeline section; the bending load was set via a load cell and checked by means of a deflection meter. The experimental setup is shown in Figure 3.

(a) Load cell and deflection meter *(b) Transfer of external load* *(c) The whole pipeline section*

Figure 3. Experimental setup for cyclic internal pressure and external bending

Five pipeline sections were tested in the first phase of the full-scale tests. The first pipeline section (Y3) was only subjected to a burst test without fatigue testing and external bending loading. The second and the third pipeline sections (Y2 and Y3) was subjected to the burst test after 100,000 cycles of internal pressure loading, both without external bending loading. The cyclic internal pressure varied between 60% and 100% of the operational pressure (64 bar). For the fourth and the fifth sections of the pipeline (Y4 and Y5), external bending loads were applied during the cyclic loading (100,000 cycles) and the burst test. The applied stress from bending was twice the axial stress from the maximum internal pressure. During the fatigue tests, where the applied frequency was 0.2 Hz, the change in the internal pressure value and the deflection value and its variation were continuously monitored. These values were recorded every 5,000-8,000 cycles, with a time interval of 50-60 cycles (250-300 s). The burst testing process was recorded from three sides with video cameras, and the change in internal pressure value was recorded every second. After the fatigue tests, the radiographic examination (RT) of the examined girth welds were performed again. During the fatigue and burst tests water was used as the internal test medium.

2. Testing results

After the burst tests were completed, the video camera recordings were reviewed, the picture-frames corresponding to the moment of failure were cut and the internal pressure vs. burst test time diagrams were plotted from the recorded internal pressure values.

Figure 4 illustrates the internal pressure vs. burst test time diagrams of the investigated pipeline sections without external bending (Y3, Y1 and Y2), where the arrows indicate the burst points (burst pressures). The pressure drop parts of the diagrams demonstrate the volume expansions of the pipeline sections. During the time with decreasing pressure, the test system took water from the external water network. Figure 5 shows the investigated pipeline sections without external bending at the moment of failure, where the water burst with huge force through the split area.

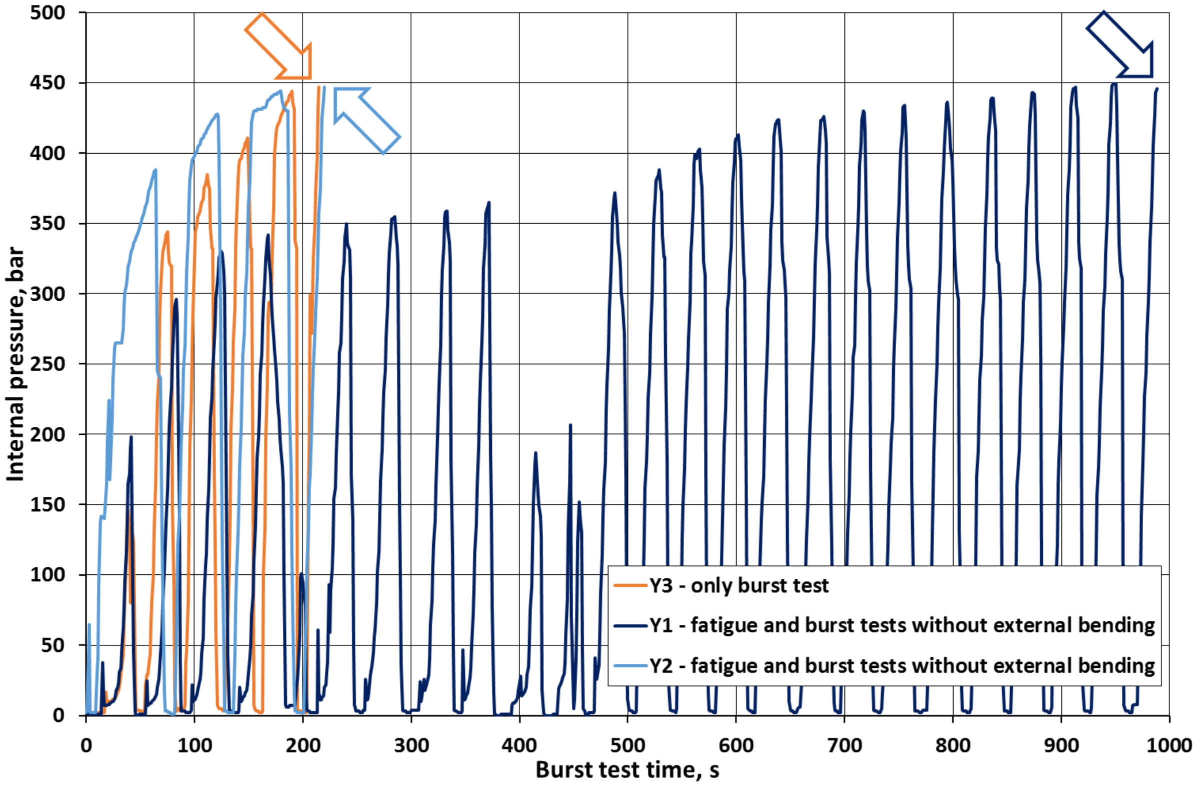

Figure 4. Internal pressure vs. burst test time diagrams of the investigated pipeline sections (Y3, Y1 and Y2) without external bending

(a) Y3 pipeline section *(b) Y1 pipeline section* *(c) Y2 pipeline section*

Figure 5. The investigated pipeline sections without bending at the moment of their failures

Figure 6 illustrates the internal pressure vs. burst test time diagrams of the investigated pipeline sections with external bending (Y4 and Y5), furthermore, these sections can be seen in Figure 7 at the moment of failure. The features shown in Figures 6 and 7 are the same as those shown in Figures 4 and 5, respectively. Table 1 summarizes the main characteristics of the investigated pipeline sections.

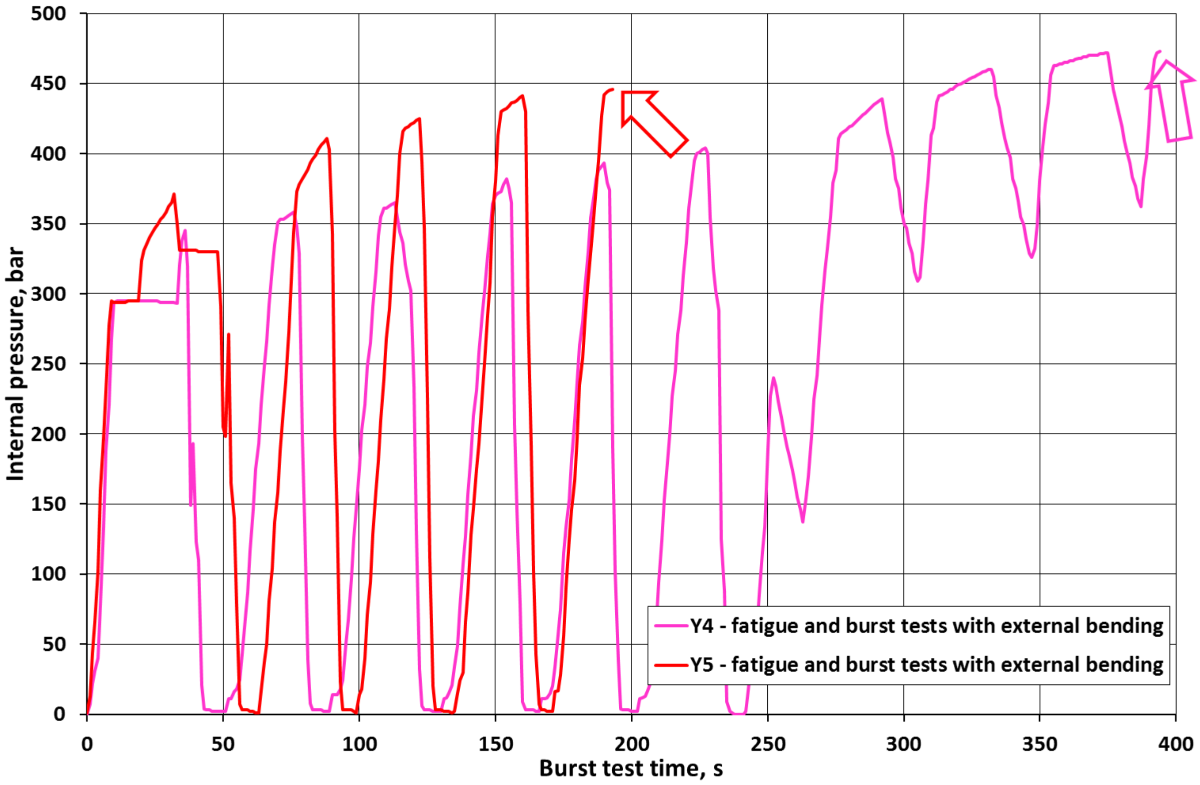

Figure 6. Internal pressure vs. burst test time diagrams of the investigated pipeline sections (Y4 and Y5) with external bending

(a) Y4 pipeline sectio *(b) Y5 pipeline section*

Figure 7. The investigated pipeline sections with bending at the moment of their failures

Pipeline section	Fatigue	External bending	Burst pressure	Failure location
Y3	N/A	N/A	446	pipe surface
Y1	applied	N/A	447	pipe surface
Y2	applied	N/A	447	pipe surface
Y4	applied	applied	473	pipe surface
Y5	applied	applied	446	pipe surface

Table 1. Main characteristics of the investigated pipeline sections

3. Summary and conclusions

Based on the investigations and their results the following conclusions can be drawn.

- The test system developed is suitable for testing pipeline sections subjected to cyclic internal pressure and external bending simultaneously.
- The full-scale tests have confirmed the high load-bearing capacity of the girth welds produced to the required quality.
- The failure of the tested pipeline sections occurred similarly, but in none of the cases in a girth weld, with failure pressures significantly higher than the operating pressure.
- Neither the cyclic loading nor the cyclic loading and applied external bending load (in this magnitude) significantly affect the pipeline sections' failure (Y2 and Y3 vs. Y4 and Y5).
- However, further full-scale tests are needed in the near future; both under higher axial stresses from the external bending and using artificial girth weld defects on the tensile bending stress side of the pipeline section.
- Because of the mixing of hydrogen into the natural gas transmission system [10], similar tests need to be carried out in the medium term.

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