IN-PLANE AND OUT-OF-PLANE BENDING TESTS ON CARBON STEEL PIPE BENDS

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The objectives of these tests were to obtain experimental results on bends behaviour in elastic and plastic regime by in plane and out of plane bending.

Results were used to improve the computer model, for large distorsion of bends, to be used in a simplified beam type computer code for piping calculations.

Tests were made on type ANSI B 169 DN 5" bends in ASTM A 106 Grade B carbon steel.

The installed instrumentation gave :
- deflection forces
- overall displacements (deflection and ovalization)
- angular rotations of pipes
- local elongations of external and internal surface on the maximal elongation point which is determined by calculation.

These tests made it possible to measure, for identical bends, in elastic regime, the flexibility factors and, in plastic regime, the total evolution in opening, in closing and out of plane.

Flexibility factors of 180° bend without flanges are approximately the same in opening and in closing. The end effect due to flanges is not very significant, but it is important for 90° bends.

In plastic regime, collapse loads or collapse moments of bends depends also of both the end effects and the angle bend.

The end effects and the angle bend are more sensitive in opening than in closing.

The interest of these tests is to procure some precise evolution curves of identical bends well characterized in geometry and metal strength, deflected in large distorsions.
1. Introduction

The objectives of these tests were to obtain experimental results on bends behaviour in elastic and elastic-plastic regimes. These results have been used to improve the computer code model, for large distorsion of bends, to be used in a simplified beam type computer code for piping calculations [1], [2].

Tests were designed in order to obtain the evolution of several parameters. Within this paper, we can give a brief idea only of the entire program.

2. Program

Tested bends were made of carbon steel ASTM A 106 grade B (ANSI B 169 DN 5" type).

Dimensions were
- inside diameter 125 millimeters
- thickness 7.1 millimeters
- bend radius 190 millimeters

Tests were performed at room temperature, without pressure inside the bends.

Charging modes (in plane opening and closing, out of plane deflection) were applied monotonously with imposed displacement. Two geometries were explored (90° and 180°) with two end conditions : with and without flanges (Figures 1 and 2) :

- Welding fitting on API 5 L Carbon steel pipes having the same nominal dimensions that those of bends.

- Welding fitting on thick rings whose rigidity is equivalent to those of flanges.

There was not out-of-plane bending test on 90° bend.

The dimensions of bends were accurately measured before and after the tests, in particular diameters and thicknesses along the cross section corresponding to the maximum value of the bending moments. Concerned steels were characterized by tensile tests on specimens taken from bends (figure 3).
These verifications were very useful. They showed for example that the average thickness varies of about 10% from one bend to another.

The thickness variation along cross sections is of the same value too.

3. Measurements

Measures were made continuously during the deflection tests of bends. They concerned:

- deflection forces
- deflection of the ends of the pipes
- deflection of the ends of the bends (junction bends-pipes or bends-flanges)
- angular rotations of pipes (by accelerometers)
- local elongations of inner and outer surfaces at the maximal elongation point, determined by calculations.

Measures of the maximum bending moment cross section were made manually during short interruption of the tests.

Figures 4 to 7 show the instrumented bends.

4. Obtained results

This test program gave the evolution curves of the different measured parameters versus forces or moments applied, from the original state to the maximum deflection state allowed by the geometries of models.

Figures 8 to 12 gave examples of typical results. It is possible to verify that in the plastic field, the behaviour of bends in opening and in closing is quite different (figure 13). It is also possible to verify the reinforcement due to flanges at the end of bends.

In elastic regime

The 180° bends flexibility coefficients are nearly the same in opening and in closing. The flange effect is nevertheless significant.

For 90° bends which are lesser flexible, the flange effect is more important (see Table I).
The flexibility coefficient calculated after the ASME 3 code is 5.34 for that bend.

In elastic-plastic regime

The collapse moments of bends depend also of the end effects and angle bends.

For in plane bending test we obtained following results (see Table II).

For a better comparison between these values, it is preferable to take the collapse moment of the 180° bend without flanges as reference. Table III below gives the ratio between the different collapse moments and the reference moment (collapse moments in opening and in closing without flanges are about the same).

The end effect and the angle bend are marked significant in opening than in closing.

For out-of-plane deflection tests on 180° bends, the collapse moments of bends are equal to:
- 1881 meter x da Newton without flanges
- 2515 meter x da Newton with flanges

That is to say, there is a ratio of 1.33 between the two.

5. Conclusions

The bends tests we carried out, confirmed results known previously, such as the different behaviour of bends in opening and in closing for large in-plane deflections [3].

The interest of this program has been to provide some precise experimental results on the evolution of a well defined, similar group of bends.

The knowledge of accurate geometries and characteristics of steel, will make it possible to improve the behaviour of bend models, used in simplified beam type method for piping inelastic analysis, by qualification calculations.
### TABLE I

<table>
<thead>
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<th>Flexibility coefficients</th>
<th>Without flanges</th>
<th>With flanges</th>
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<tbody>
<tr>
<td></td>
<td>Opening</td>
<td>Closing</td>
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<tr>
<td>180°</td>
<td>4.4</td>
<td>5.1</td>
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<tr>
<td>90°</td>
<td>3</td>
<td>2</td>
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### TABLE II

<table>
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<th>Collapse moments (m da N)</th>
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<tbody>
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<td>1445</td>
</tr>
<tr>
<td>90°</td>
<td>2000</td>
<td>1656</td>
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### TABLE III

Collapse moments with reference to the collapse moment of 180° bends without flanges

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<td>Closing</td>
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</tr>
<tr>
<td>90°</td>
<td>1.39</td>
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**Tested bends code**

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<td>B</td>
</tr>
<tr>
<td>90°</td>
<td>G</td>
<td>H</td>
</tr>
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References


[2] ROCHE R. "Modèle simple pour le calcul plastique d'une tuyauterie" Note CEA N 1872 SACLAY 1975


Fig. 1 Models characteristics for in plane bending tests
Fig. 2 Models characteristics for out of plane bending tests

Fig. 3 Stress/strain curve of bends steel

Fig. 4 Out of plane bending, before test

Fig. 5 Out of plane bending, after test
Fig. 6  90° bend with flanges after closing test

Fig. 7  90° bend without flanges after closing test

Fig. 8  180° bends in plane bending. Force/deflection curves

Fig. 9  90° bends in plane bending. Force/deflection curves
Fig. 10  180° bends out of plane bending. Force/deflection curves

Fig. 11  90° bends, variation of the maximum bending moment cross section deformation

Fig. 12  90° bends, variation of the elongation measured by transverse strain gauges on external surface

Fig. 13  90° bends with flanges. Comparison of cross section shapes in opening and in closing after tests.