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STRESS DISTRIBUTION IN THE REGION AROUND TWO NORMALLY INTERSECTING PIPES DUE TO IN-PLANE BENDING MOMENTS USING FINITE ELEMENT METHOD

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ABSTRACT

Numerically calculated stress in the region of two normally intersecting pipes due to in-plane bending moments using finite element program MECHANICA are presented in this paper. The computer results were processed and then presented in stress versus location (along several lines) diagrams. Other investigators' results for similar problem are not easy to obtain due to differences in the problem, in modelling, in finite element program used and in methods of data presentation. Lock et al (1985) and Moffat et al (1984) works were the closest for comparison purposes.

1. TABLE OF NOTATION

d_{nom}	=	branch pipe nominal diameter
d	=	branch pipe internal diameter
D_{nom}	=	main pipe nominal diameter
D	=	main pipe internal diameter
M	=	external moment
p	=	internal pressure
r	=	fillet radius
t	=	branch pipe wall thickness
T	=	main pipe wall thickness
Z	=	section modulus of pipe
α	=	angle of pipe intersection
σ	=	normal stress

2. INTRODUCTION

The problem of determining local stresses in the region of the main and branch pipe intersection caused by a variety of load types has not been completely solved. The problem variables can be categorised into (1) main and branch pipe dimensions (D, d, T, t, r, α etc.), (2) types of loading, (3) types of pipe supports, (4) methods of manufacture and (5) piping materials. The large number of variables involved in branch piping systems complicate the problem.

Many experimental, numerical as well as theoretical works on stresses distribution in the region of the main and branch pipe intersection due to internal pressure were reported in the form of stress distribution or stress concentration factors. Several of the reports were written by Corum et al (1972), Gwaltney et al (1976), Hardenberg and Zamrik (1964), Harsokoesoemo et al (1992), Hsiao and Khan (1981), Khan et al (1982), Natarajan et al (1987), Harsokoesoemo (1993a, 1993b and 1994).

Less work has been reported on stress distribution in the region of the main and branch pipe intersection due to in-plane or out-of-plane bending moment loading applied at the main and/or branch pipe ends. These include Corum et al (1972), Gwaltney et al (1975), Baldur (1980), Moffat et al (1984), Gillroy et al (1985), Lock et al (1985). Out of these, only a few were concerned with numerical computation of stress and deformation around branch pipe connection using finite element method.

Many of the results of the stress distribution around the region of two normally intersecting pipes obtained by finite element method were not directly comparable. This is due to (1) the different dimensions chosen, (2) the differences in modelling of the intersecting pipes, (3) the differences in the bending moment loads, (4) the differences in the type of pipe supports, (5) the differences in the finite element package programs used to solve the problems, and (6) the different ways of presenting the finite element results.

Many more investigations on the stress distribution around the region of two normally intersecting pipes due to bending moments, torsion and other externally applied loads are still necessary to complete the understanding of the problem. Research into the stress distribution in pipe intersection joint is a continuing activity, BS 7608 (1993, page 59).

This paper concerns with numerically calculated stress distribution around the region of two normally intersecting pipes subjected in in-plane bending moments applied at both main pipe ends.

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3. PROCEDURE

3.1. The "Physical" Model

For purposes of obtaining a general idea of the stress distribution around two normally intersecting pipes due to in-plane bending moments, only one model is used, i.e. a main pipe of 101.6 mm nominal diameter and 6 mm thickness and a branch pipe of 101.6 mm nominal diameter and 6 mm thickness. A sketch of the model is shown in Fig. 1 below

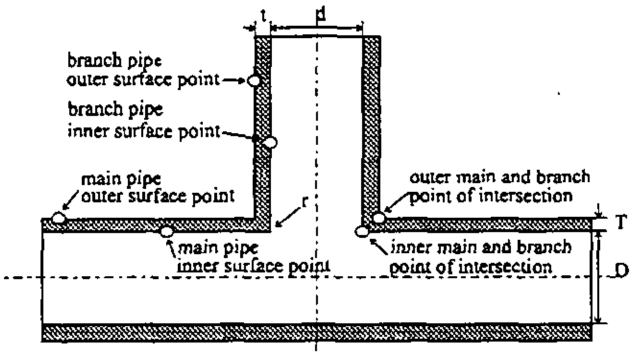

Fig. 1. Cross section of two normally intersecting pipes

The fillet radius at the intersection points of the main and branch pipe outer surfaces is assumed to be zero. The assumption will result in higher stresses around the intersection area, than when the fillet radius is not neglected.

The main and branch pipes are assumed to be of the same isotropic, homogenous, mild steel.

3.2. The Finite Element Method and Model

The finite element model is constructed in three steps. The first step is the determination of the nodal points as indicated by small circles in Fig. 2.

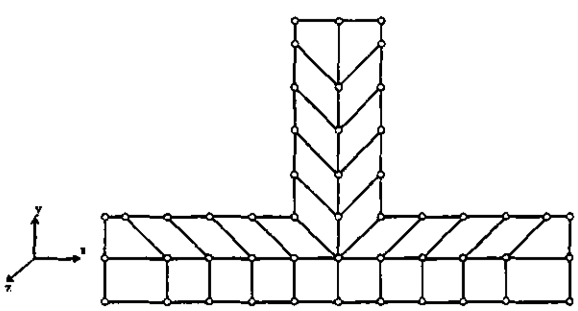

Fig. 2. First step in the Finite Element Model Construction

The number of the chosen nodal points is sixty-five and the resulting number of elements is sixty. The second step consists of refinement of the twelve elements around the pipe intersection. Each of the twelve elements is divided further into 10 elements (Fig. 3). The third step is the final refinement of each element that results from the first two steps. Ninety-six nodal points are added to each of the elements. The addition of nodal points in the third step are automatically done by MECHANICA.

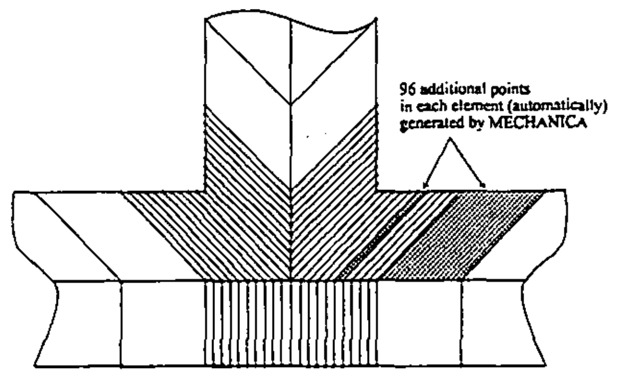

Fig. 3. The Second Step of the Finite Element Model Construction

The reason for dividing the twelve elements around the pipe intersection further is because from initial calculations it was found out that large stresses occurred there. Hence smaller element sizes in the region will locate the highest stress location more accurately. The distance between two nodal points of the smallest elements is now 1 mm.

3.3. The In-Plane Bending Moment and Intersecting Pipe Supports

The in-plane bending moments acting on both of the main pipe ends are modelled as linearly distributed forces acting on the chosen and generated forty nodal points shown in Fig. 4 below. The bending moment model represent pure in-plane bending moment more realistically than when the bending is represented by two forces acting at the top and bottom points of main pipe ends. The resultant bending moment of the linear forces acting on the nodal points of each of the pipe end is 32,540 N/mm^2.

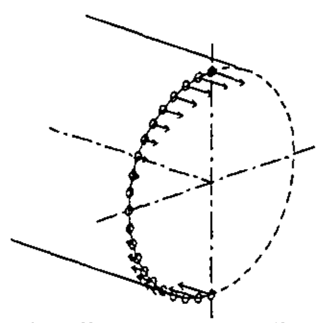

Fig. 4. In-plane bending moment loading

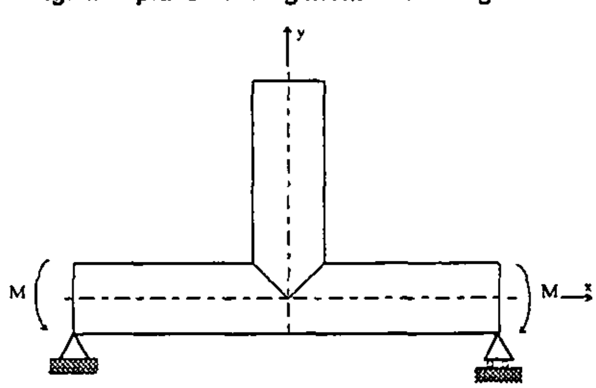

Fig. 5 Support at the main pipe's

The two normally intersecting pipes is simply supported at the main pipe ends.

3.4. The Finite Element Output

MECHANICA computes the six stress components, σ_x, σ_y, σ_z, τ_{xy}, τ_{yz} and τ_{zx}, the principal stresses σ_1, σ_2, σ_3, the displacements x, y, z and the rotations θ_1, θ_2 and θ_3 for each chosen and automatically generated nodal points.

For further processing purposes of this paper, the six component stresses at the outer main and branch pipe lines A_1-O_1-A_2, B_1-O_2-B_2 and C_1-O_3-C_2, at the inner the points at the main and branch pipe lines A_1'-O_1'-A_2', B_1'-O_2'-B_2', C_1'-O_3'-C_2', at selected nodal points are read and noted. The lines just mentioned are shown on Fig. 6 that follows. The shear stress values at all nodal points at the six lines above are practically zero, indicating that the normal stresses are principal stresses. Furthermore, one of the three principal stresses is zero, leaving the other two to be tangential and meridional/longitudinal stresses.

The stresses at selected outer and inner crotch line O_1-O_2-O_4 and O_1'-O_2'-O_4' nodal points that are read are the maximum and minimum stresses. The maximum and minimum stresses at these nodal points are, in general, neither tangential nor longitudinal stresses.

3.5. The Data Processing

The stresses, read and noted above, are then drawn on as curves in eight figures, (i.e. Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14) as functions of location.

For purposes of drawing and reading the stress vs. location diagrams, the following line and diagram definitions are described.

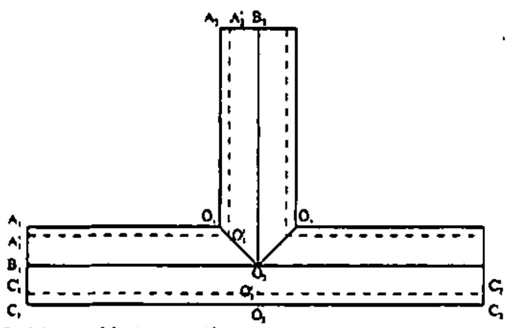

Fig. 6. Line of intersection

- A_1-O_1-A_2 : Line of intersection of main and branch pipes outer surface and the plane passing through the main and branch pipe axes (first plane).
- A_1'-O_1'-A_2' : Line of intersection of main and branch pipes inner surface and the plane passing through the main and branch pipe axes (first plane).
- B_1-O_2 : Line of intersection of the main pipe outer surface and the plane perpendicular to the first plane and passing through the main pipe axis.
- O_2-B_2 : Line of intersection of the branch pipe outer surface and the plane perpendicular to the first plane and passing through the branch pipe axis.
- B_1'-O_2' : Line of intersection of the main pipe inner surface and the plane perpendicular to the first plane and passing through the main pipe axis.
- O_2'-B_2' : Line of intersection of the branch pipe inner surface and the plane perpendicular to the first plane and passing through the branch pipe axis.
- C_1-O_3-C_2 : Line of intersection of the main pipe outer surface and the first plane.
- C_1'-O_3'-C_2' : Line of intersection of the main pipe inner surface and the first plane.
- O_1-O_2-O_4 : Line of intersection of the main and branch pipes outer surface and the first plane.
- O_1'-O_2'-O_4' : Line of intersection of the main and branch pipes inner surface and the first plane.

Location of points on the line of intersection are measured from either point $O_1(O_1')$, point $O_2(O_2')$ or point $O_3(O_3')$. Positive number indicates distances of points on the branch pipe (diagram I and diagram II). Positive number indicates distances of points on the main pipe line O_3-C_2 (diagram III). Positive number indicates distances of points on the intersection line O_2-O_4 (diagram IV). Negative number indicates distances of points on the main pipe (diagram I and diagram II). Negative number indicates distances of points on the main pipeline C_1-O_3 (diagram III). Negative number indicates distances of points on the intersection line O_1-O_2 (diagram IV).

3.6. Data Presentation

The stresses vs. locations for points on various intersection lines are then drawn on eight diagrams described below:

- Figure 7: Tangensial stress on pipes outer surface points at intersection line A_1-O_1-A_2 vs. location and on pipes inner surface points at intersection line A_1'-O_1'-A_2' vs. location.
- Figure 8: Meridional stress on pipes outer surface points at intersection line A_1-O_1-A_2 vs. location and on pipes inner surface points at intersection line A_1'-O_1'-A_2' vs. location.
- Figure 9: Tangensial stress on pipes outer surface points at intersection line B_1-O_2-B_2 vs. location and on pipes inner surface points at intersection line B_1'-O_2'-B_2' vs. location.
- Figure 10: Meridional stress on pipes outer surface points at intersection line B_1-O_2-B_2 vs. location and on pipes inner surface points at intersection line B_1'-O_2'-B_2' vs. location.
- Figure 11: Tangensial stress on pipes outer surface points at intersection line C_1-O_3-C_2 vs. location and on pipes inner surface points at intersection line C_1'-O_3'-C_2' vs. location.
- Figure 12: Meridional stress on pipes outer surface points at intersection line C_1-O_3-C_2 vs. location and on pipes inner surface points at intersection line C_1'-O_3'-C_2' vs. location.
- Figure 13: Maximum stress on main and branch pipes lines of intersection vs. location.
- Figure 14: Minimum stress on main and branch pipes lines of intersection vs. location.

4. RESULTS, DISCUSSION AND CONCLUSION

The stress distribution around the region of two normally intersecting pipes are described along six lines, three on the main and branch pipe outer surfaces and three on the main and branch pipe inner surfaces (Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 13 and Fig. 14). Two lines on the outer and inner surfaces of main pipe are also used to describe the stress distribution (Fig. 11and Fig. 12).

The purpose of the investigation is to find the maximum stress and its location in the region of the pipe intersection. The ultimate purpose is to calculate stress concentrations on the main and branch pipe.

The investigation stopped for a moment when study on the stress distribution revealed that maximum stress did not occur at the point of pipe intersection line. It occurred at the inner surface of the branch pipe off the line of pipe intersection. In the case of stress distribution around two normally intersecting pipes due to internal pressure, for example, it is agreed by almost all investigators that the most severely stressed point is the upper corner point of intersection of the main and branch pipe outer surface.

There are not too many data on stress distribution in the region around two normally intersecting pipes due to in-plane bending moment available for comparison purposes. Those that may be used for comparison purposes are the two following papers. However the two normally intersecting pipes studied in those papers were welded pipes. This was not case in this paper.

Lock et al (1985) and Moffat et al (1984) reported stress distribution of two normally intersecting pipes due to in-plane bending moment around the junction of branch pipe (adjacent to the weld), the crotch line and the run pipe (adjacent to the weld). They did not report stress distribution away from the pipe intersecting line, on the main pipe or on the branch pipe surfaces.

The curve shape of the stress distribution along the pipe intersection lines of this paper and that of Lock (1985) looked almost the same.

Note that the two results cannot be compared directly, since the intersecting pipe dimensions are different, the pipe support and model of the bending moment load, the finite element package programs used to solve the problems, the ways of data presentations are all different.

As has been mentioned in subsection 3.1, the fillet radius at the intersection points of the main and branch pipe outer surfaces in this paper is assumed to be zero. Using the term in the BS 7608 (1993), the stress distribution due to in-plane bending moment in this case is called the geometric stress distribution. The presence of weld in a welded pipe intersection causes additional local stresses to the geometric stresses. In fatigue design, the stress range to be used is the "hot spot" stress range.

The hot spot stress is defined as the greatest value of the direct stress around the main and branch pipe intersection of the extrapolation to the weld toe of the geometric stress distribution near the weld toe. This hot spot stress incorporates the effects of overall joint geometry, i.e. the relative sizes of main and branch pipe, but omits the stress concentrating influence of the weld itself, which results in a local stress distribution.

One of the methods to calculate the hot spot stress is by finite element method. When finite element calculations do not allow for any effect of weld geometry, the hot spot stress at the weld toe can be estimated from the value obtained at the main and branch pipe intersection, BS 7608 (1993, page 30). The maximum stress at the main and branch pipe calculated in this paper can be taken as hot spot stress.

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REFERENCES

Boldur, R. and Sabourin, M., 1980, "Finite Element Analysis of Cylindrical Intersections Loaded by Moments," *Century 2nd Conference on Pressure Vessels and Piping*, San Fransisco.

British Standard, 1995, "BS 7608: 1993, Code of practice for Fatigue design and assessment of steel structures."

Corum, J. M., Bolt, S. E., Greenstreet, W. L., and Gwaltney, R. C., 1972, "Theoritical and Experimental Stress Analysis of ORNL Their Shell Cylinder to Cylinder Model I," ORNL-4533.

Gwaltney, R. C., Corum, J. M., Bolt, S. E., and Bryson, J. W., 1976, "Experimental Stress Analysis of Cylinder to Cylinder Shell Model and Comparison with Theoretical Predictions," ASME *Journal of Pressure Vessel Technology*, pp. 283-290.

Gwaltney, R. C., Bolt, S. E., and Bryson, J. W., 1975, "Theoretical and Experimental Stress Analysis of ORNL Thin-Shell Cylinder-to-Cylinder Model No. 2," Oak Ridge Natn. Lab. Rep. No. ORNL-5021.

Gilroy, J. E., Clark, J. S. and Tosh, P. A., 1985, "Finite Element Stress Analysis of Extruded Outlet Tee Junctions," *Pipework Design and Operation, IMechE Conf.* (Mechanical Engineering Publication, London).

Hardenberg, D. E. and Zamrik, S. Y., 1964, "Effect of External Loading on Large Outlet in a Cylinder Pressure Vessel," Welding Research Council Bulletin 96.

Harsokoesoemo, D. et. al., 1992, "Research on Several Aspects of Piping Systems," Progress Report, Research Founded by The Directorate for Research, Ministry of Education and Culture of The Republic Indonesia.

Harsokoesoemo, D. et. al., 1993a, "Stress Distribution Around 90^0 Branch Pipe Connection Due to Internal Pressure," *Proceedings, Pressure Vessel and Piping Technology Seminar*, Singapore.

Harsokoesoemo, D. et.al., 1993b, "Stress Distribution Around 90^0 Branch Pipe Connection Due to External Loads," *The Third International Offshore and Polar Engineering Conference*, Singapore.

Harsokoesoemo, D. and Santoso, G., 1994, "The Influence of Diameter Ratio on the Stress Distribution Around 90^0 Branch Pipe Connection Due to Internal Pressure," *Proceedings, the Fourth International Offshore and Polar Engineering Conference*, Osaka.

Harsokoesoemo, D. and Santoso, G., 1996, "Numerically Calculated Stress Concentration Factors for Two Normally Intersecting Cylinder Due to Internal Pressure," *Proceeding of the 8th International Conference on Pressure Vessel Technology*, Montreal.

Hsiao, C. and Khan, A. S., 1981, "Stress Intensification Effect in Unreinforced Oblique Branch Intersections Due to External Moments," *ASME Proceedings, the Fourth International Conference of the Pressure Vessel and Piping, Materials, Nuclear Engineering and Solar Engineering Division*, PVP-Vol. 50.

Khan, A. S., et. al., 1982, "A Comparative Study of the Stress Field Around a Reinforced Normally Intersection Cylindrical Shell," ASME Paper No. 82 PVP-9.

Lock, J. D., Carmichael, G. D. T., and Moffat, D. G., 1985, "Finite Element Stress Analysis of An Equal Diameter Branch pipe Intersection Subjected to Internal pressure and In-Plane Moments Loadings," *Pipework Design and Operation, IMechE Conf* (Mechanical Engineering Publications, London).

MECHANICA, 1994, "Model Reference: Structure and Thermal Release 7," Rasna Corporation, San Jose, California.

Moffat, D. G. and Mistry, J., 1984, "Interaction of External Moment Loads With Internal Pressure on An Equal Diameter Branch Pipe Intersection," *Fifth Int. Conf. On Pressure Vessel Technology*, San Fransisco.

Natarajan, R., Widera, G. E. O., and Afshari, P., 1987, "A Finite Element Model to Analyze Cylinder to Cylinder Intersection," *Journal of Pressure Vessel Technology*, Vol. 109.

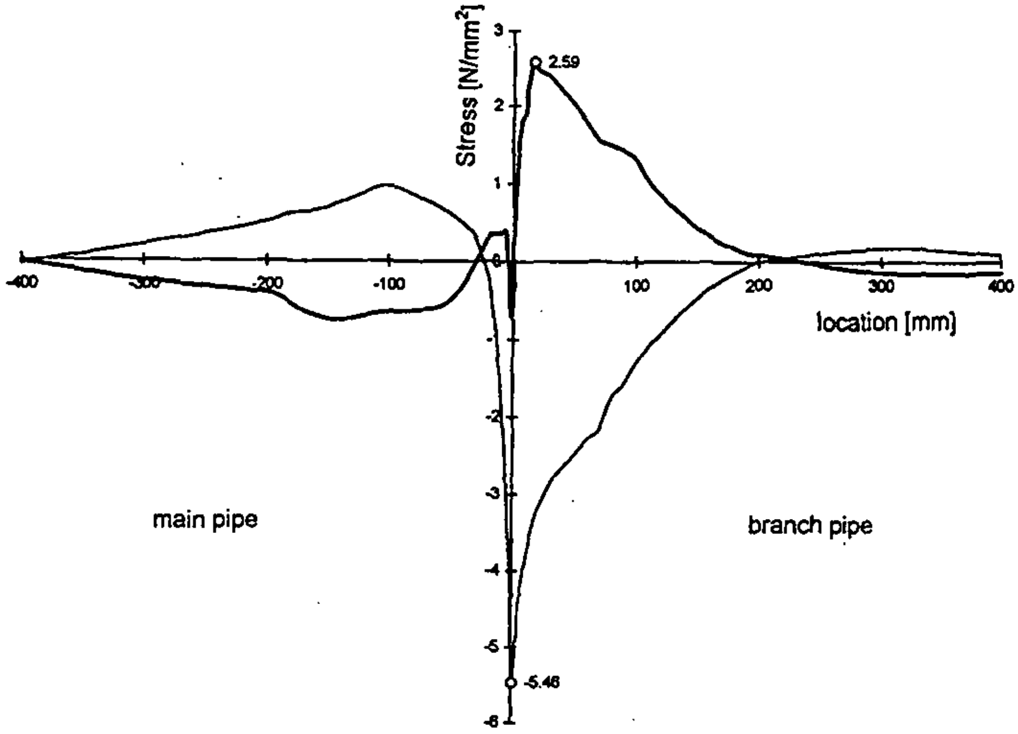

Fig. 7 Tangensial stress on intersection line A_1-O_1-A_2 vs. location (bold line)
Tangensial stress on intersection line A_1'-O_1'-A_2' vs. location (thin line)

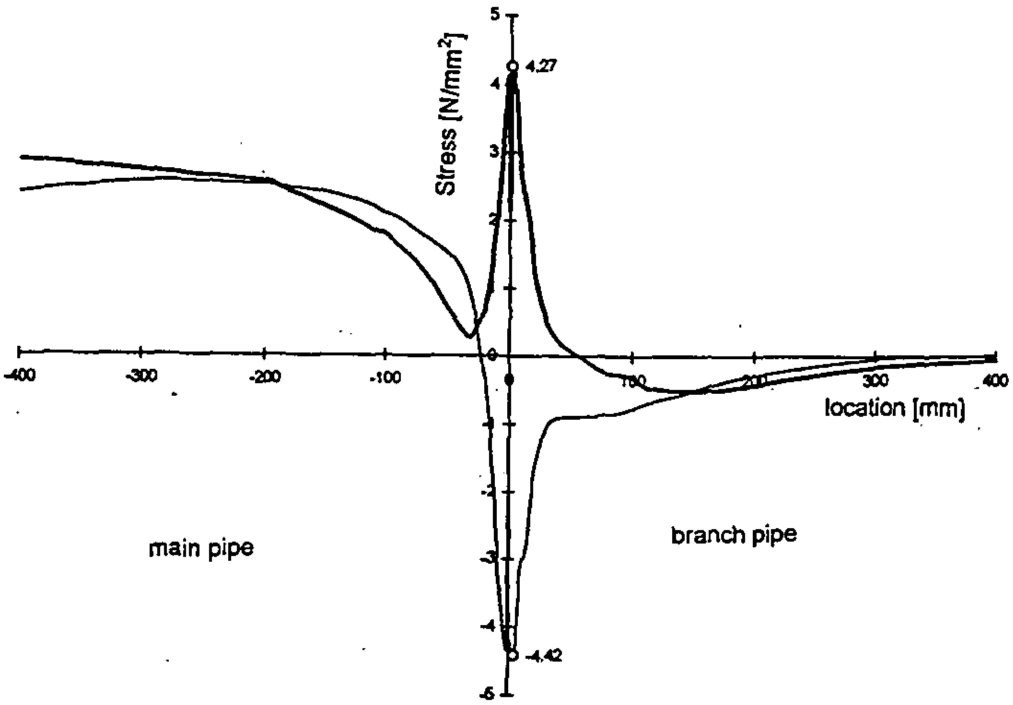

Fig. 8 Meridional stress on intersection line A_1-O_1-A_2 vs. location (bold line)
Meridional stress on intersection line A_1'-O_1'-A_2' vs. location (thin line)

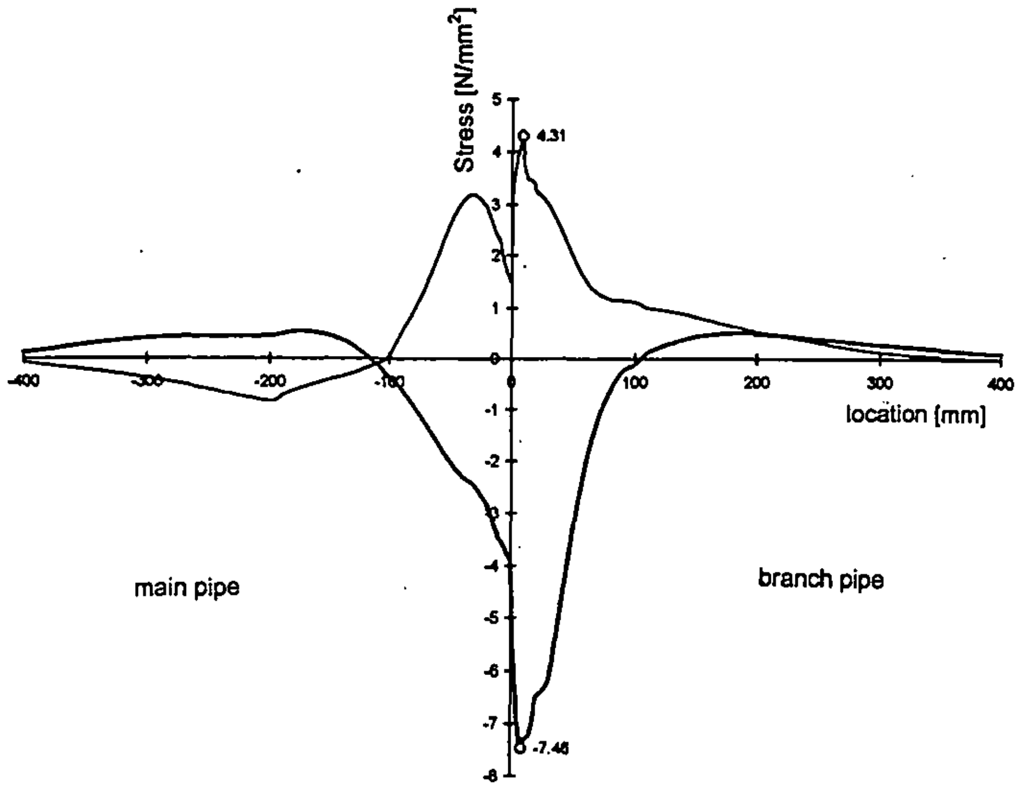

Fig. 9 Tangensial stress on intersection line B_1-O_2-B_2 vs. location (bold line)
Tangensial stress on intersection line B_1'-O_2'-B_2' vs. location (thin line)

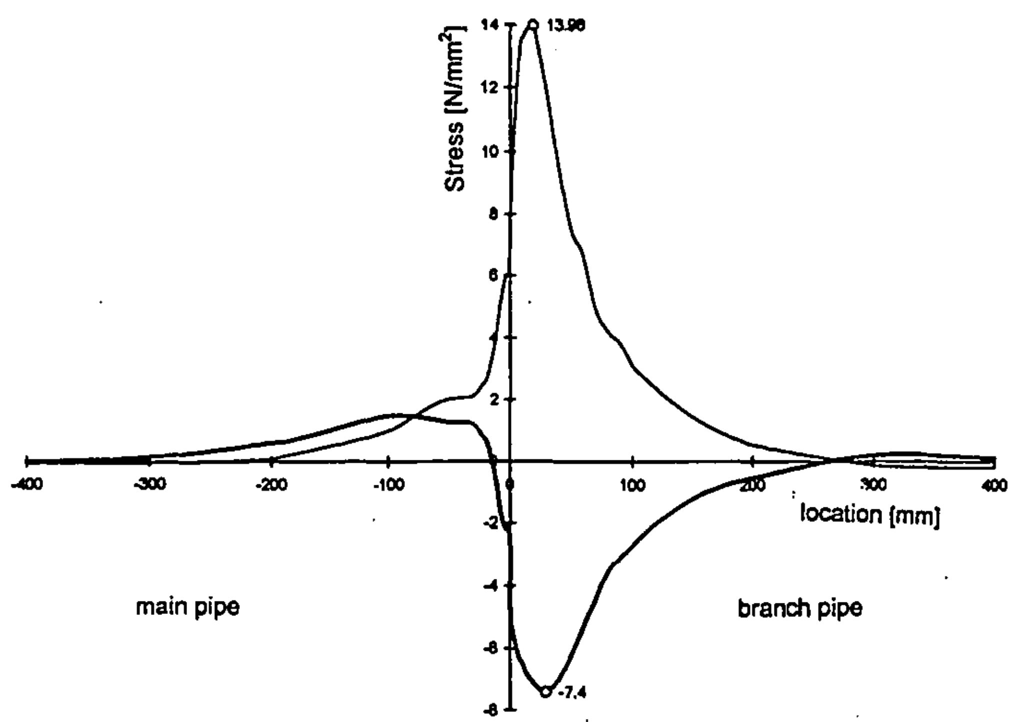

Fig. 10 Meridional stress on intersection line B_1-O_2-B_2 vs. location (bold line)
Meridional stress on intersection line B_1'-O_2'-B_2' vs. location (thin line)

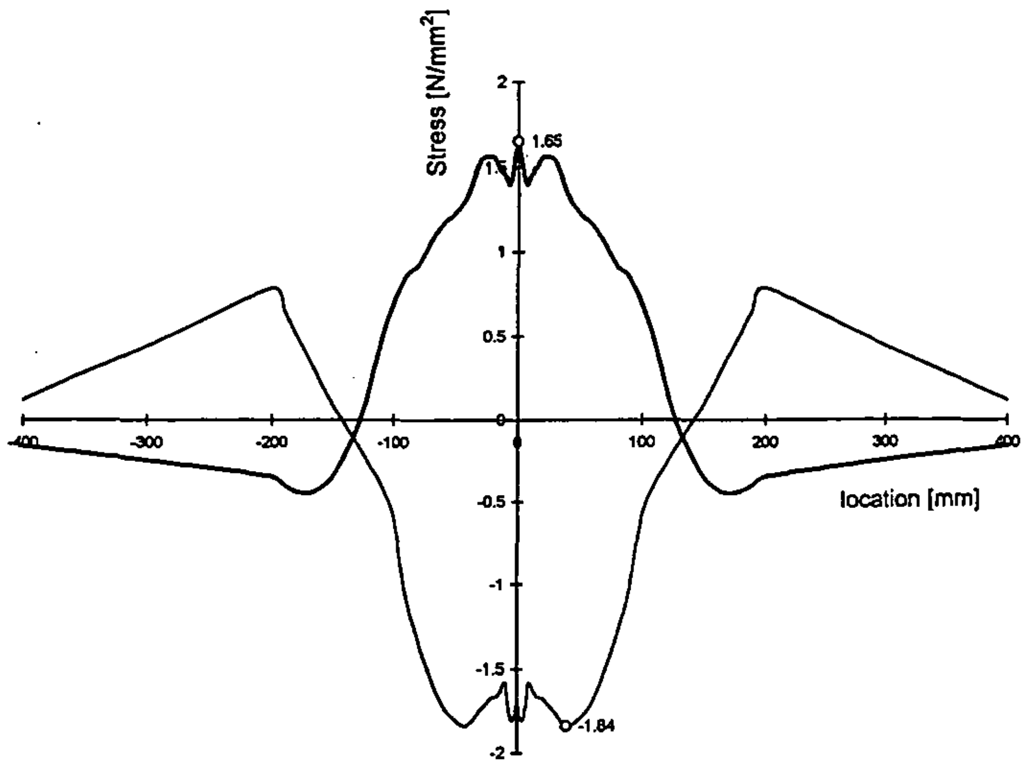

Fig. 11 Tangensial stress on intersection line C_1-O_3-C_2 vs. location (bold line)
Tangensial stress on intersection line C_1'-O_3'-C_2' vs. location (thin line)

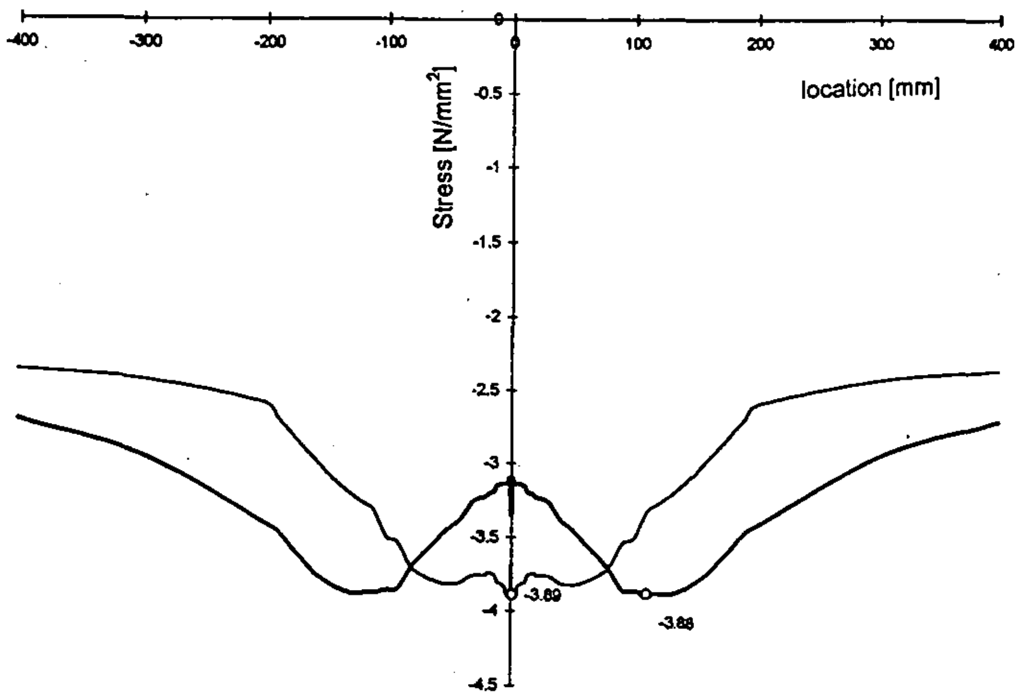

Fig. 12 Meridional stress on intersection line C_1-O_3-C_2 vs. location (bold line)
Meridional stress on intersection line C_1'-O_3'-C_2' vs. location (thin line)

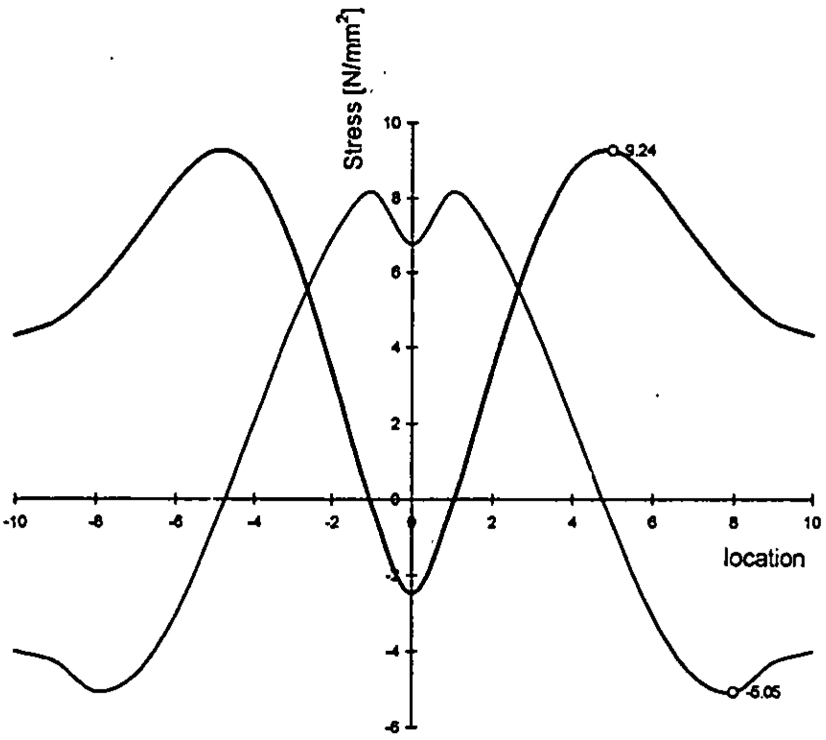

Fig 13 Maximum stress on outer surface on main and branch pipe lines of intersection vs. Location (bold line)
Maximum stress on inner surface on main and branch pipe lines of intersection vs. Location (thin line)

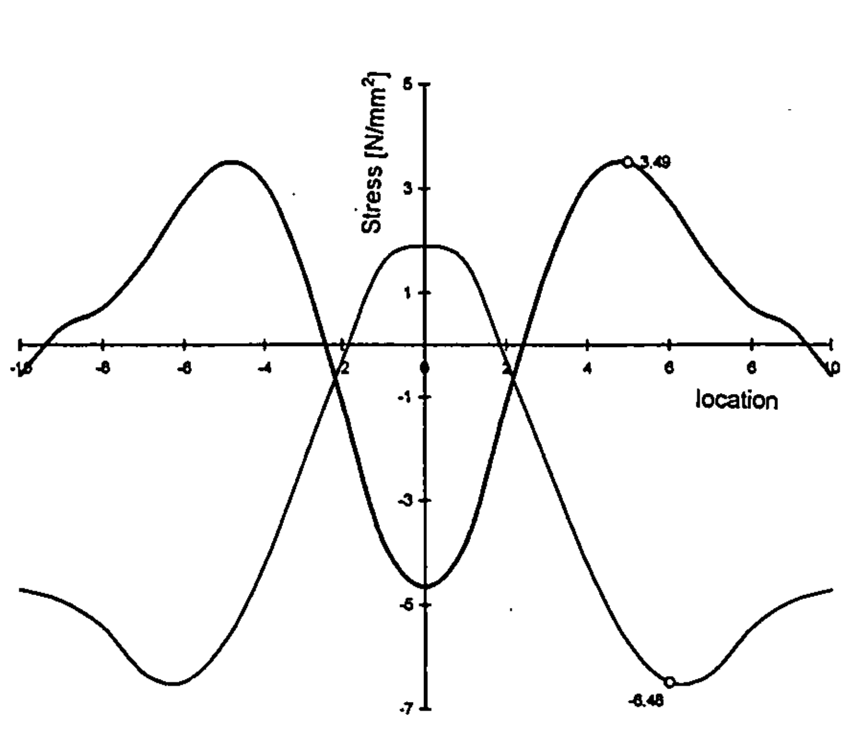

Fig 14 Minimum stress on outer surface on main and branch pipe lines of intersection vs. Location (bold line)
Minimum stress on inner surface on main and branch pipe lines of intersection vs. Location (thin line)