Scientific Research and Studybehavior of Curved Pipes Under Loads

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Annotation: *This article discusses the issues of coverage of the works in the field of study behavior of curved pipes under different types of loads.*

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The behavior of curved pipes under load was extensively studied in the early 20th century with intense theoretical and experimental research. In 1910, Bantlin [1] experimentally determined that curved pipes behave more elastically under bending than conventional pipes of the same cross-section. Later von Karman [2] gave a theoretical explanation for this behavior. In short, when the pipe is bent, the section tends to flatten due to the constant reversal of the stress direction parallel to the pipe axis and balancing the applied moment. When a pipe is bending, any applied force is a source of shearing forces. In bending, flattening forces of two kinds arise: direct ones from the pressure of the working bodies and those generated by the stresses of the bending fibers of the pipe. The former act during the entire bending period, while the latter develop when the pipe is bending. The forces arising during bending of the pipe flatten it (one of the main axes of the cross-section in the bending plane decreases) and increase the size of the cross-section in the direction perpendicular to the plane of bending (the second main axis of the oval is lengthened).During flattening, the elongation of the outermost fibers, corresponding to a given curvature of the centerline of the tube, is less than it would be in the absence of flattening. Consequently, less bending moment is required to achieve a given change in curvature. Since the stiffness of a pipe is defined as the ratio of the bending moment to the change in curvature, it can be seen that flattening the section reduces the stiffness of the pipe.This basic information constitutes von Karman's analysis of round and thick-walled pipes with regular cross-sections. The analysis also laid the foundation for a version of the potential energy minimum principle of the Rayleigh-Ritz theory of elasticity. An approximate solution to the problem is given in the Rayleigh-Ritz expression, and the accuracy of the results is determined by comparing successive approaches.

In 1912, Lorenz [3] presented another method of analysis as an alternative to solving the problem of bending in curved pipes using Castigliano's principle of least work instead of the principle of minimum

potential energy. Lorenz tried to prove that his numerical results were closer to the experimental result than von Karman's numerical results. However, a few years later, Clark and Reissner [4] theoretically proved that von Karman's conclusion was the most correct.

In 1923 Timoshenko [5] took up the problem of a rectangular pipe e and reached approximate results using the principle of minimum potential energy.

While investigating the problem of bending of curved thin-walled circular pipes, Karl [6] used the principle of minimum potential energy and the principle of least work together, taking into account the work of K. Weber. Thus, he easily determined the upper and lower limits of the pipe stiffness.

Beskin [7] gave numerical solutions for stiffness and stresses corresponding to values for a wide range of geometric parameters using the principle of least work (the energy method with trigonometric polynomials). As a result of the analysis, in this work it is proposed to use an infinite trigonometric series, which gives the correct result for the bending state acting along the plane of the pipe centerline and perpendicular to this plane. Theoretically, the analysis is applicable only for cases where the ratio of the radius of curvature to the radius of the pipe is large.

Huber [8] solved the problem by the method of minimum potential energy with the difference that the cross section of the tube is elliptical. In this analysis, assuming that the non-deforming elliptical section corresponds to another deforming elliptical section, approximate results are obtained regarding the pipe stiffness of the elliptical section.

Clarke and Reissner [4] solved the problem of a curved tube with a circular cross-section and uniform thickness, subject to bending, using the trigonometric series method in the theory of thin shells. The use of trigonometric series made it possible to achieve the results obtained by applying to the problem the principles of minimum potential energy and minimum work.

For the first time in this work, the method of asymptotic integration was used for the problem of bending of curved tubes of circular cross-section and uniform thickness. This method can also give accurate results for non-circular and curved pipes of varying thickness.

In this study, a solution to the problem of a curved pipe with a uniform elliptical section subject to bending is also included in the methods mentioned above.

While investigating the effect of internal pressure in tubes, Reissner [9] presented a study by von Karman [2] and Thuolup [10] on the linear problem of curved pipes subjected to pure bending, as well as the nonlinear Brazier problem [11] for a smooth tube under the same load. In the course of the study, these two problems were combined and the following results were obtained:

1. It is assumed that the results of Brazier [11] and Wood [12] on the expansion of smooth tubes under loading should be taken into account only as a first approach to solving this problem.

2. The results of the linear theory of curvilinear pipes are supplemented with nonlinear corrections of the first order and the area of application of the linear theory is expanded.

3. Taking into account that the initial curvature of smooth pipes is as important as the critical curvature, the first approximation of the nonlinear theory is found for a small value of the initial curvature in smooth pipes.

Bathe and Almeida [13], using a displacement finite element method, explained the interaction of a pipe element between a rigid flange and a straight pipe. Later, as a continuation of this, they presented a study that included the impact of interaction on the problem (Bathe and Almeida [14]). Interaction effects are handled in the analysis very simply but efficiently using the formulation of the penalty function

method.However, the general formulation of the elements in this study is based on numerous considerations and requires further detailed research to determine the range over which the elements can be used. The study uses different analysis patterns for a pipe element using an interaction effect.

In 1982, Lang [15] solved the problem of bending of a toroidal annular sector with an elliptical cross section, given by the equation $b^2x^2+a^2y^2=a^2b^2$ under the action of a torque. In this study, the stresses were obtained by applying Göhner's method for five different values of the b/a ratio and presented in the form of a table (where a and b are the lengths of the main axes of the ellipse). The analysis is completed by adding first order approximations to the initial stress state in an elliptical annular sector subject to bending. The analysis is fairly straightforward as no elliptical coordinates are used here.

This study is especially interesting as it concerns an elliptical section, since in the case of a pipe with a circular section, the throat can take an elliptical shape during bending. However, some of the results turned out to be incorrect (Pala [16]).

Hübner[17] studied the effect on flanges, which is of great importance mainly in industrial and technological skills in finding the general characteristics of curved pipes subjected to bending. In practice, the semi-membrane theory is considered, that is, the full stress state in the tangential direction is taken into account, and the deformed state of the membrane in the direction of the pipe. The flanges are assumed to retain their original circular cross-section and the resulting partial differential equations are solved by expanding them using a Fourier series. The results show that there is a loss of elasticity compared to the pipe considered as a curved bar.

The solution for a thin-shell pipe element with a symmetrical non-circular cross-section, subject to bending and internal pressure, at which end effects are not taken into account, was investigated by Whatham [18]. The study builds on the scientific work of Clark et al. [19] on elliptical tubes subject to bending and internal pressure.The distribution of environmental stress showed that the pressure acts in the same way as a bending moment and tries to straighten the pipe. The results for pressure and bending moment overlap. The results showed that the flexibility of a tube is inversely proportional to the bend radius (radius of the side surface) surrounding each chamber in thin-walled tubes.

In 1996, Pala [16] theoretically obtained the distribution of internal stresses, considering the problem of pure bending of a toroidal annular sector, the cross section of which consists of confocal ellipses. Using Göhner's method, which is based on a different approach to analysis, the problem of pure bending of a solid elliptical annular sector in Lang's work [15] was transformed into the problem of pure bending of a hollow elliptical annular sector. The difficulty of setting the boundary conditions made it possible to give solutions only in confocal ellipses.The analysis was discontinued with second-order corrections due to analytical computational difficulties. The results show that the circumferential stress varies with the ratio of the radius of curvature R to the axial length of the elliptical section (R/a), rather than the dimensions of the cross section. Research has shown that although the basic equations given by Lang [15] are correct, there are some errors in the stress results.

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