CHAPTER 1

INTRODUCTION

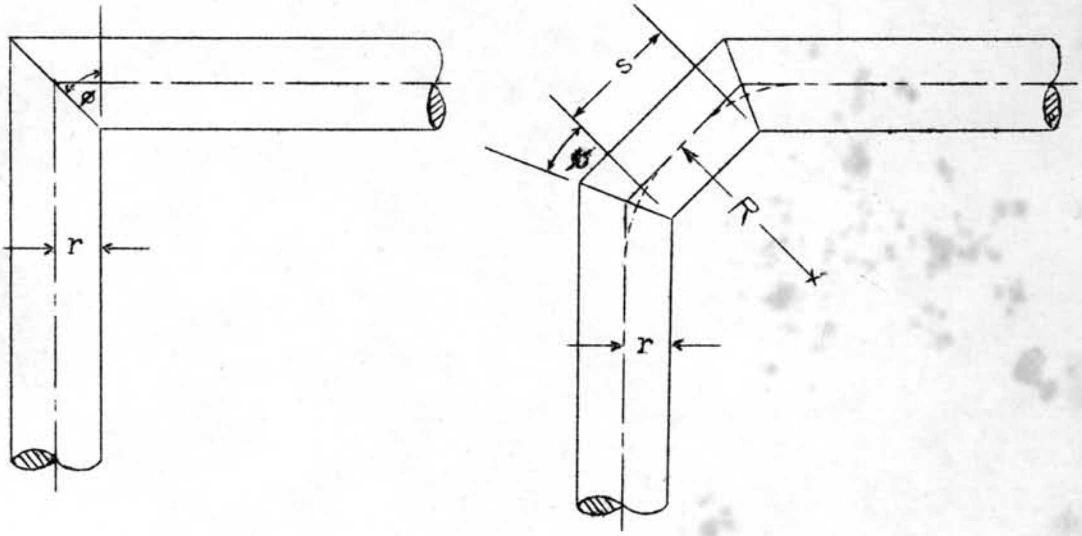
1. General Background

When pipe bend is used to carry fluid under pressure it is said to be acted upon by internal pressure. Under this type of loading circumferential and longitudinal stresses are set up. However, loading in the form of in-plane bending moments occurs due to relative dimensional changes between the pipelines and their anchorage when the pipe conveys hot fluid. These bending moments tend to reduce the angle between the legs of the pipe bends, in another word, to increase the curvature and bending stresses are set up at the outer surface of the pipe wall. Hence it is important to determine the stresses of the bend subjected to combined internal pressure and in-plane bending load to see whether the stresses acting in the bend would be the sum of those stresses acting when the bend is subjected to each form of loading separately.

If the pipeline is too rigid, thermal expansion also causes end loads which will produce too high stresses on anchor points. To prevent this, pipe bend is used to connect a long straight pipeline since it is known that a pipe bend is more flexible than a straight pipe of the same cross-section. Conversely, where relative movement is required between the two points,connected by a pipeline, pipe bend can allow the movement without requiring excessive forces. Hence the flexibility of the pipe bend is also of practical importance. It is interesting to investigate whether the flexibility of single pipe bend caused by in-plane bending moment would be diminished by the presence of internal pressure.

2. Application of Mitered Bends

A mitered bend (sometimes called an "elbow") is defined as a bend produced by welding together mitered cut pieces of circular cylinder to form a discontinuous bend. Fig. 1. shows a typical form of mitered pipe bend. The bend can contain a single mitered joint as in Fig. 1(a) , or a number of mitered joints as in Fig. 1(b). In this thesis, single mitered pipe bends with bend angle of 90° (2ϕ) are used in the experiments.



1(a) Single mitered pipe bend 1(b) Double mitered pipe bend

r = radius of the pipe
R = radius of an equivalent smooth bend
ϕ = miter angle
s = miter spacing

Fig. 1. Mitered Pipe Bends

One application of these bends is that they are frequently used in large diameter duct systems carrying coolant to and from a reactor vessel. In such a vessel, several changes in directions of the gas flow are necessary due to the layout of the main carbon dioxide gas circuits of the gas cooled nuclear power plant. Because the space is restricted in the biological shield, a coolant duct containing single mitered bends may be used.

In this experiment, two types of single mitered pipe bend are tested. They are reinforced and unreinforced pipe bend. Reinforced pipe bend has a reinforced plate at the intersection to represent cascade band and blade unit in the actual duct corner. Unreinforced pipe bend is one with no reinforcement at the welded joint. All of the pipes are tested within elastic limit.

3. Review of Previous Works

In 1911, Von Karman (22) derived a theoretical analysis to describe the phenomenon of ovalization and increased flexibility of curved tubes when acted upon by an in-plane bending moment.

Markl (14) had accomplished some fatigue tests of welding elbows and comparable double-mitered bends.Two types of 90 - degree elbow were tested. One was a long-radius "Tube - Turn" welding elbow with a bend radius equal to 1.5 nominal diameter. The second was a double-mitered bend with an equivalent bend radius of about 1.9 nominal diameter. He finally summarized that for double-mitered bends the stress intensification factor at the corners were 20 % greater than that for long-radius welding elbows when subjected to in-plane bending moment and 70 % greater when out-of-plane bending was applied. The stress intensification factor was defined as the ratio of the stress at failure,obtained from S-N curve, to that calculated using simple beam formula.

In another fatigue test, Markl (13) conducted an experiment to determine the stress intensification factor of a single mitered pipe bend having an outside diameter of $4\frac{1}{2}$ in. under in-plane and out-of-plane bending load. The experiment indicated that the failure of the bend occurred at the welded joint. He also pointed out that from the obtained load-deflection data, single and double-mitered bends were not so flexible as smooth bend. However, as the number of miter increased beyond three, the flexibility of the same order as smooth bend could be obtained.

Sobieszczanski (18) had analyzed single and multiple mitered bends for stress and deformation due to in-plane bending and internal pressure. The theory of cylindrical shell was used as a tool of analysis. For comparison, experiments were carried out on models fabricated by celluloid-like plastic. This plastic model had the Young's modulus of 22,000 kg/cm^2 with thickness of 2 mm. and mean radius of 50 mm. Lastly, he concluded that local bending of the pipe wall considered as a shell in the elbow vicinity raised maximum stress up to 400 percent and more of the elementary beam stress. This stress increase was so momentous that it should not be disregarded in design. However, it did not mean instant damage, but it might mean local plastic action leading eventually to a shake-down, or incremental collapse in worse cases if temperature fluctuated. Damage would occur immediately only if faulty welding caused local zones of brittleness.

Jones (9) developed the analysis which was a logical extension, or generalization, of Von Karman's original theory on curved pipe bends. It was shown, for long-radius pipe bends which had a negligible shift of the neutral axis,that the solution reduced to that of Von Karman. It was evident from the results of the analysis that the stresses in and flexibility of curved pipe bends were virtually independent of γ or r/R (even for γ approaching unity) and depended almost entirely on the simple Von Karman pipe factor h (tR/r^2). Errors arising from premature truncation of the selected power series for the radial displacement were discussed, and a guide was given to the number of terms necessary for a particular problem.

Wahl (23) had outlined methods for the computation of stresses and reactions in expansion pipe bends, in accordance with exact theory which took into account pipe cross-section distortion. Formulas were given for various types of bends.Method based on consideration of deformation of pipe elements, and Castigliano theorem method were used in the determination of maximum transverse and shearing stresses. Experiments, both deflection and distortion test, were made on small pipe bends at the Westinghouse Research Laboratory to verify the theoretical results for deflection and distortion of the pipe cross-section. In conclusion, he wrote that the method for the estimation of stresses and reactions in pipe bends had been shown to give results with good agree to the experimental results. They should therefore have been adopted in practical design due to simple method of application. However, in the case of simple bends, as considered in his paper, simple formulas might be derived by means of which stresses and reactions might be found. For more complicated cases, the same general methods of attack might have been applied.

Kasipar (11) had done pressure and in-plane bending tests on single mitered pipe bends. The content of his experiment was divided into three parts as follows:-

First, he wanted to verify Kornecki's theory for internal pressure loading and a theoretical analysis for in-plane bending load analyzed by himself. The reinforced single mitered bend of the same outside diameter but with different thickness, i.e. having different t/r ratio were tested. The results indicated that Kornecki's theory for a cylindrical shell rigidly fixed in an oblique cross-section and loaded by internal pressure satisfactorily predicted the same stresses and strains in a reinforced single mitered bend. However, the experimental results did not satisfy his theory for a cylindrical shell rigidly fixed in an oblique cross-section subjected to in-plane bending. The reason was that some ovalizations of the normal cross-section occurred even at a remote distance from the center of intersection and these distortions had not been included in his theoretical analysis.

Second, he attempted to find the flexibility of the bend by finding an equivalent radius R supposing that the single mitered bend was replaced by a smooth bend of the same dimension. Twelve pieces of reinforced and unreinforced single mitered bends were tested to find the overall deflections. Then, the flexibility factors were determined using Gross and Ford (7) expression for smooth bend which was

$$Y = \frac{F}{12EI}\left[4C^3 + KR\left\{3\pi C^2 + 6CR(4-\pi) + 6R^2(\pi-3)\right\}\right]$$

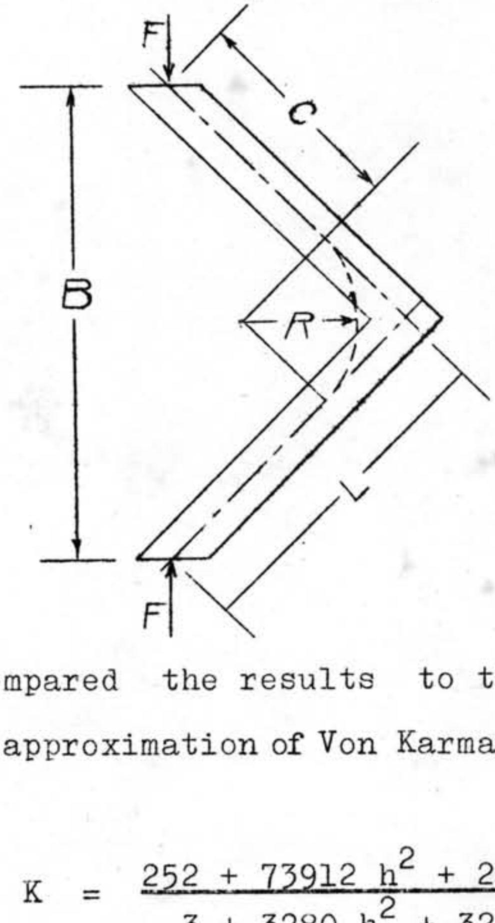


Fig. 2. Mitered pipe bend and equivalent smooth bend

and compared the results to those obtained by using the third approximation of Von Karman's analysis which expressed as

$$K = \frac{252 + 73912\,h^2 + 2446176\,h^4 + 2822400\,h^6}{3 + 3280\,h^2 + 329376\,h^4 + 2822400\,h^6}\,.$$

He finally summarized that the flexibility under in-plane bending of unreinforced single mitered bend was the same as that of smooth bend of the same dimension having an equivalent radius of four times the pipe bore mean radius. The third approximation of Von Karman's analysis could then be used to determine the flexibility factor of unreinforced mitered bend.

Third, he investigated the behaviour of the bend beyond the yield point. An attempt was made to find out the ratio of maximum load and the first yield load. The maximum strain at the intersection when the maximum load had been reached was also found. At conclusion, he commented that for the reinforced single mitered bends, the ratios of maximum load to yield load and the approximate ratios of deflection at maximum load to deflection at yield load indicated that after the point of yielding, the mitered bend could carry considerably more load without suffering undue deflection. He further remarked that due to considerable variation of bending strains at maximum loads for reinforced single mitered bend under in-plane bending beyond yield point, further tests be needed before any conclusion could be completed.

Bunditkul (2) had tested eighteen pieces of ninety degree mitered pipe bends for flexibility and bending stresses due to in-plane bending moment. In his experiment, the flexibility factor was calculated using an expression for smooth bend of Gross and Ford as well, and then the results were compared to that obtained by using the third approximation of Von Karman's analysis. He concluded that the flexibility under in-plane bending of unreinforced ninety degree single mitered bend was the same as that of smooth bend of the same dimension having an equivalent radius of five times the pipe bore mean radius. An equivalent radius of seven times the pipe bore mean radius was required for smooth bend of the same dimension to give the same flexibility as the reinforced one did under in-plane bending load. He further commented that the third approximation of Von Karman's analysis be used to determine the flexibility factor of unreinforced and reinforced ninety degree single mitered bend. The plot of deflection against load showed that the unreinforced mitered bend was more flexible than the reinforced one of the same dimension.

In finding the stresses around ninety degree single mitered bends subjected to in-plane bending load by the use of strain-gage technique, the test section was 40.48 cm. on neutral line from the welded joint. The outside diameter of the tested pipe bend was 11.50 cm. with thickness of 3.65 mm. The experiment showed that the practical value of longitudinal stress on pipe was approximately 1.4 time of the value from bending stress theory. He suggested that in practical design the minimum value of safety factor used should not be less than 1.8 based on longitudinal stress.