CHAPTER 4

DISCUSSION

This chapter associates the discussion of the results from this experiment. It is divided into three parts corresponding to the test. Part (1.) concerns with flexibility factor of the single mitered pipe bend under pure in-plane bending. Part (2.) is dealt with flexibility factor under combined pressure and in-plane bending load. Part (3.) involves the discussion of the stresses in the bend due to combined loading

1. Flexibility Factor of The Single Mitered Pipe Bend under Pure In-plane Bending

The aim of this test is to find the flexibility factor at various equivalent radius using the expression from Gross and Ford. The calculated flexibility factors are then compared to those of von Karman's third approximation, American Standard Code and Kellogg's formula. The American Standard Code for flexibility factor is $K = 1.65/h$ while for Kellogg's formula is $K = 1.52/h^{5/6}$. Table 3.2 demonstrates the comparison among these factors from $R = r$ through $R = 8r$. It is noted that Karman's formula and American Standard Code yield nearly the same flexibility factor, so the comparison is rather based on both of them than on Kellogg's formula.

It is evident that the most suitable value of equivalent radius for reinforced pipe bend is R = 6r. At this value, the calculated flexibility factors areapproximately closed to those of von Karman's and American Standard Code. For unreinforced pipe bend, the equivalent radius of R = 7r seems to give an appreciable comparison between calculated and Karman's or American's flexibility factor.

According to the obtained equivalent radius from the experiment, it is of interest to investigate the range of the pipe characteristic which is $h = tR/r^2$. For reinforced pipe bend these values lie between 0.48 ~ 0.88 using R = 6r. Likewise, for unreinforced pipe bend these values lie between 0.56 ~ 1.03 using R = 7r. It is noticeable that the flexibility factors for unreinforced pipe bend are higher than those for reinforced pipe bend when subjected to simply in-plane bending.

2. Flexibility Factor of The Single Mitered Pipe Bend under Combined Pressure and In-plane Bending Load

The object of this experiment is to compare the flexibility factor with internal pressure between theoretical development and experimental results. The experimental flexibility factors with internal pressure are estimated from Gross and Ford formula using the obtained experimental values from Table 3.1 when p = 10, 20 and 25 ksc respectively. The theoretical flexibility factors are determined from the theory developed by Rodabaugh and George in Appendix I. The desired flexibility factor, K, for reinforced pipe bend is obtained from Table 3.2 at the bend equivalent radius of R = 6r. Likewise, for unreinforced pipe bend, the desired flexibility factor is obtained from Table 3.2 at the bend equivalent radius of R = 7r.

Table 3.3 illustrates the comparison between experimental and theoretical flexibility factors with internal pressure. It is apparent that for both the reinforced and unreinforced the experimental values are approximately the same as that of the theoretical ones. According to theoretical formula, the theoretical flexibility factors decrease as the internal pressure increases. For unreinforced pipe bend, the experimental values seem to give the same trend as the theory does. However, reinforced pipe bend shows the experimental figures of discrepancy except for pipe bend No. 6a. This is due to the fact that reinforced pipe bend is more stiff than unreinforced one, and the effect of internal pressure can not play any important role to the pipe bend of rather small inside diameter and short pipe length. As for pipe bend No. 6a, the inside diameter is large enough for the internal pressure to show the noticeable effect. Nevertheless, it is inferred that this theory for flexibility factor with internal pressure can be adopted in engineering practice for single mitered pipe bend of various sizes.

3. Stresses in The Bend due to Combined Loading

The purpose of this experiment is to observe the variation of longitudinal and circumferential stresses around the pipe cross - section under combined loading. Furthermore, it is desirable to compare the validity of theoretical and experimental stress-intensification factor.

Table 3.4 and table 3.5 show the results of the experimental strains and stresses around the pipe cross-section under in-plane bending and internal pressure respectively. Table 3.6 illustrates the variation of longitudinal and circumferential strains and stresses under combined internal pressure and in-plane bending load. Table 3.7 is the comparison between theoretical and experimental stress-intensification factor. The theoretical stress - intensification factor with internal pressure is calculated from the theoretical formula developed by Rodabaugh and George in Appendix I.

The stress - intensification factor, i, is simply obtained by dividing experimental bending stresses from table 3.4 by stress from ordinary beam theory which is Mr/I. The experimental stress-intensification factor with internal pressure is obtained by dividing experimental stresses from table 3.6 by stresses from beam theory as well.

The results from table 3.7 is shown graphically in Fig.A1 through Fig.A4. Fig.A1 and Fig.A2. demonstrates the theoretical and experimental stress - intensification factor with internal pressure around the pipe cross-section in longitudinal and circumferential direction. It is obvious that both theoretical and experimental longitudinal stress - intensification factor give the curve pattern of sine wave. The stresses at the upper half of the pipe are tensile while at the lower half they are compressive. The maximum value of experimental longitudinal stress - intensification factor is somewhat higher than the theoretical one at the upper half while at the lower half they are nearly equal.

For circumferential direction, the theoretical and experimental curve show an identity of variation. The maximum stress occurrs at the lower side of the pipe and is tensile stress.The maximum experimental circumferential stress-intensification factor is also somewhat higher than the theoretical one. The factor for the circumferential is higher than that for the longitudinal.

Fig.A2. shows the comparison between theoretical and experimental longitudinal and circumferential stress - intensification factor similar to Fig.A1. except that the bending moment is one time greater. The curve lines for theoretical and experimental longitudinal stress - intensification factor are nearly identical. The peak values for the longitudinals are a little higher than those in FigA1., however, the peak values for the circumferentials appear to be equal.

Fig.A3. and Fig.A4. show the variation of longitudinal and circumferential stress-intensification factor with 20 ksc internal pressure. The bending moment applied to the pipe in Fig.A4. is also one time greater. It is constructive to notice that as the in-plane bending moment increases, the compressive stresses will increase in the region defined by $0^\circ < \phi < 135^\circ$ and $270^\circ < \phi < 360^\circ$. The comparison between Fig.A1. and Fig.A3. with the same in-plane bending load but different internal pressure indicates that the variation of stresses does not be affected by this incremental value of pressure increase. The reason is that the pipe thickness is rather large compared to its mean radius, so internal pressure increase of 10 ksc can not give any effect to the change in stress.

The variation of longitudinal and circumferential stress under various types of load are shown in Fig.A5. The longitudinal stresses created by internal pressure do not distribute uniformly around the cross-section as defined by pressure vessel formula. One reason may be that the pipe thickness is not uniform. Another reason is that the pressure created by hand pump is not constant. The circumferential stresses from in-plane bending and combined load seem to go along with each other. The experimental circumferential stresses are not constant around the cross-section, instead fluctuating up and down due to the same reason as previously described. Moreover, its values are greater than pr/t computed from pressure vessel theory.

The variation of longitudinal and circumferential stress around the pipe cross-section with greater load are shown in Fig.A6. The combined loads create higher longitudinal stress than in-plane bending. Likewise, the same is true for circumferential stress. It is obvious that the peak values of circumferential stress on compressive side grow bigger as the bending moment increases. The reason is that pipe length is long enough for in-plane bending to cause some ovalization at the cross-section.

Fig.A7. displays the stress variations which are similar to those shown in Fig.A5. except that the applied internal pressure increases one time. It can be deduced from the comparison that the internal pressure increase of 10 ksc is too small to create any visible effect on stress changes because the pipe wall thickness is rather large compared to its mean radius. Again, the longitudinal and circumferential stress variation in Fig.A8. is compared to those shown in Fig.A6. The comparison seems to show an identical result that small internal pressure increase causes no significant effect in stress for the same reason as previously described.