CHAPTER 2

EXPERIMENTAL INVESTIGATION

According to the experimental work accomplished by many other authors as previously described in chapter one, this chapter dealt solely with the experiment to investigate the behaviour of single mitered pipe bend under combined internal pressure and in-plane bending load. As for Kasipar's work, a number of pipe bends were tested under internal pressure alone to find the circumferential and longitudinal stresses. Aside from this, pipe bends were also tested to find the flexibilities under pure in-plane bending moment. However, in practical work, where piping systems were most widely used in chemical plants, industrial plants and power stations, pipe bends were frequently subjected to both internal pressure and in-plane bending load simultaneously. It was therefore necessary to investigate the behaviour of such a pipe fittings under this type of combined loading in order that a more accurate solution and a better design be accomplished.

It was obvious that this experiment differed entirely from Kasipar's work. In this experiment, the specimens were tested by being subjected to combined loading of internal pressure and in-plane bending moment, while in Kasipar's work the specimens were tested under separate loading of internal pressure and in-plane bending moment. The contents of the experiment could be divided into 5 categories as follows:

1. Objectives
2. Test Specimens
3. Apparatus and Measuring Equipments
4. Calibration of Pressure Gages and Testing Machines
5. Experimental Work

1. Objectives

The purpose of the experiment in this thesis was divided into 5 categories as fóllow :-

1.1 To find the flexibility factor of the single mitered pipe bend under in-plane bending load alone.

1.2 To investigate the flexibility of single mitered pipe bend, both reinforced and unreinforced, under combined pressure and in-plane bending load.

1.3 To find out whether the flexibility of the single mitered pipe bend under in-plane bending moment will be diminished by the presence of internal pressure. Meanwhile, the flexibility factors due to these combined effects are determined as well.

1.4 To observe the variation of longitudinal and circumferential stresses of the single mitered pipe bend subjected to combined pressure and in-plane bending load.

1.5 To prove whether the stresses in the bend due to these combined load are equal to the sum of those when the bend is subjected to in-plane bending and internal pressure separately.

2. Test Specimens

Twelve pieces of single mitered pipe bend as shown in Fig. A14. were tested in this experiment. They were supplied by the Thai Steel Pipe Industry Company Limited. Half of them were reinforced and the rest unreinforced. The drawings and dimensions of these samples were tabulated as shown below :-

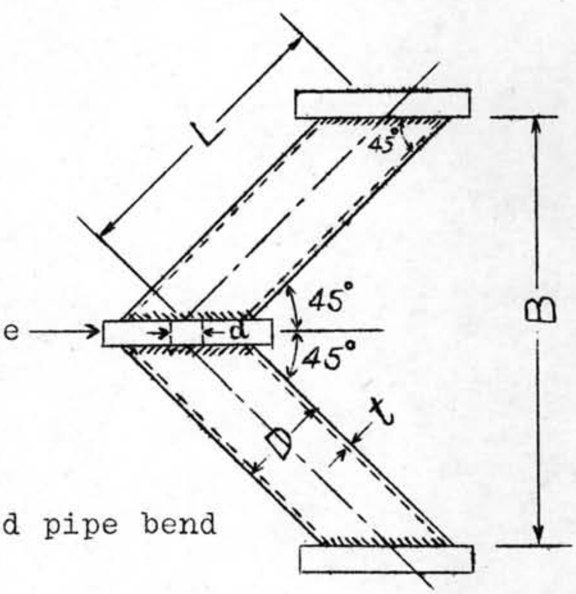

Fig. 3.

Reinforced single mitered pipe bend

Pipe bend No.	Outside diam. D, mm.	Thickness t, mm.	B mm.	L mm.	d mm.
1a	33.5	2.3	360	250	3
2a	48.4	3.2	360	250	3
3a	60.3	3.6	430	300	5
4a	75.6	3.05	430	300	5
5a	88.8	3.95	504	350	8
6a	114.1	4.4	574	400	10

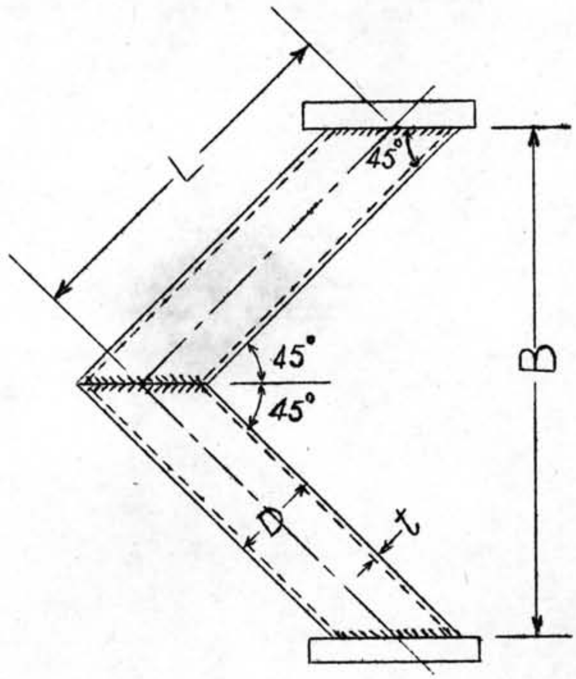

Fig. 4.

Unreinforced single mitered pipe bend

Pipe bend No.	Outside diam. D, mm.	Thickness t, mm.	B mm.	L mm.
1b	33.5	2.3	354	250
2b	48.4	3.2	354	250
3b	60.3	3.6	424	300
4b	75.6	3.05	424	300
5b	88.8	3.95	495	350
6b	114.1	4.4	565	400

Mechanical properties of the specimens.

Some important pipe characteristics were supplied by the producer to enable the tester a limitation or range of bending load and internal pressure to be applied in the test. The material used to fabricate the pipe was hot-rolled steel. The mechanical properties of the specimens were shown below:

Modulus of elasticity in tension or compression	2.1092×10^6	ksc
Modulus of elasticity in shear or torsion	0.808×10^6	ksc
Poisson's ratio	0.3	-
Yield point	2,500	ksc
Maximum tensile strength	3,500	ksc
Elongation, on 5 cm. gage length	47	%

Chemical properties of the specimens.

The chemical analysis of the specimens were conducted by manufacturer to yield the percentage of each component existing in the pipe material. They were listed as follow:

Carbon	0.06 ~ 0.09
Silicon	0.01 ~ 0.03
Manganese	0.25 ~ 0.35
Phosphorus	0.01 ~ 0.03
Sulphur	0.01 ~ 0.03

3. Apparatus and Measuring Equipments

The apparatus and measuring equipments used in this experiment were described as follow:-

3.1 Amsler Universal Testing Machine This machine, having capacity of 20 tons, type 20 ZBDA 357, serial no. 060355 AK, was shown in Fig. A15. Four load ranges were available namely, 0 to 2, 5, 10 and 20 tons with 5, 10, 20 and 50 kg. divisions respectively. This machine was capable of compressing the specimen of length between 0 ~ 750 mm., although the maximum distance between compression plates was 1,250 mm. Other specifications of this machine were as follow:-

Distance between the gripping head exclusive of ram stroke	0 ~ 1,150 mm.
Clearance between vertical columns	50 mm.
Maximum test speed	180 mm./min
Ram stroke	30 mm.
Electric motor for pump	1.5 hp
Net weight	1,030 kg.
Maximum height of machine	3,400 mm.

3.2 Hand Pump Simple hand pump was used to supply internal pressure for the mitered pipe bend. It was composed of a cylindrical container, a pumping element, and a hand lever. This equipment was shown in Fig.A16.

3.3 Reducers Since the diameter of the hand pump outlet was fairly large, a reducer was needed to reduce the cross-section to a proper size corresponding to the inside diameter of the flexible pipe. A number of reducers used in this test were shown in Fig. A18.

3.4 Flexible Pipe Rubber pipe of 10 mm. inside diameter with thickness of 7 mm., shown in Fig. A18., was used to connect the pump outlet and the mitered pipe bend inlet. It was desirable to use a rather thick pipe to withstand internal pressure. The reason to use this flexible pipe instead of a rigid pipe was that it was convenient to alter or move the hand pump to any other position when necessary. A clamp was needed between the two ends of this rubber pipe to prevent the leakage of internal pressure through atmosphere.

3.5 Strain Gage and Cement The strains of the single mitered pipe bend under combined pressure and in-plane bending load were measured by means of strain gage equipped with strainometer. Tinsley Telcon strain gage type W8/120/G/K/2, shown in Fig. A17., were used in this test. Durofix adhesive was used as cement for the attachment of the strain gage around the outer surface of the bend. Both strain gages and cement were manufactured by Tinsley Telcon Limited VAT NO. 2182 340 80 Werndee Hall, South Norwood, London SE 25

3.6 Strain Gage Bridge The Tinsley portable strain gage bridge, type 5580 was used. It was a ruggedly built instrument which was neatly fitted and weighed only 5.5 kg. The bridge was designed for the measurement of strain in all types of machines and structures using strain gages range 50 to 2,000 ohms. It was fully transistorized and suitable for single gage, 2 gage and 4 gage bridges. The bridge supply was obtained from a self contained 1,000 cps square wave oscillator working at approximately 3 volts. The use of a square wave oscillator eliminated the effect of the lead capacitance and also the parasitic emf's which usually arised in D.C. circuits according to temperature difference. The bridge output was amplified in a three-stage amplifier and a manual balance obtained on a center zero pointer type detector. Supplies for the oscillator and amplifier were obtained from an internal battery which could be charged in situ when not in use. A separate mains operated circuit was provided for this purpose. This instrument equipped with selector switch was depicted in Fig. A19. and A20.

The equipment specification:

Dimensions: 292 x 216 x 152 mm.

Weight: 5.5 kg.

External circuits: Suitable for single active gage with dummy gage, 2 active gage and 4 active gage bridge

Gage factor range:	2 dials, 1.8 to 4.5 in steps of 0.01
Limit of error:	± 0.5 % of reading or 5 units of microstrain whichever is the greater
Output:	Jack plug provided to enable examination of output with an oscilloscope
Power supplies:	(1) Internal DEAC 13.5 volt battery for oscillator and amplifier (2) 240 volts 50 cycles for charging battery in situ, when not in use.
Ranges:	Indicated on a digitised 10 turn counter × 1 ± 10,000 units of microstrain in steps of 10 units × 0.1 ± 1,000 units of microstrain in steps of 1 unit.
Reactive effect:	Lead capacitance up to 0.5 μF will not affect the balance or sensitivity of the bridge.
Sensitivity:	Detector sensitivity sufficient to balance to 1 unit of microstrain using 100 ohm gage.
Strain gages:	Gages with resistance ranging between 50 to 2,000 ohms and gage factor 1.8 to 4.5 could be used.

3.7 Pressure Gage ' Bourdon-tube pressure gage, range 0 ~ 40 ksc, serial no. 74004439, as shown in Fig. A17. , was attached to the reducer to read the internal pressure supplied by the hand pump. It was desirable to connect the pressure gage normally to the reducer to eliminate inherent error. Before using the gage, it must have been calibrated in order that the correct reading was obtained.

3.8 Proving Ring In the calibration of Amsler Universal Testing Machine, Olsen proving ring no. 56180 was used in this calibration. The proving ring was a circular ring provided with projection lugs and was widely used as a calibration standard for either large tensile or compressive testing machines with static load.

3.9 Dial Gage with Magnetic Holder The values of the bend deflections were measured accurately by the use of dial gage with magnetic holder. Fig. A21. showed Federal dial gage of range 0~26.23 mm. type Q 6IS-R1 with 0.01 mm. division together with Erick Magna holder which could be fitted either on flat or curved surface.

3.10 Transparent Pipe A suitable length of transparent plastic pipe was used in this experiment. One end of the pipe was fitted on the air vent of the specimens and the other end was immersed in the hand pump container. The use of this pipe was to lead the water overflow from the specimens back to the container.

3.11 Steel Balls   Two steel balls of 10 mm. diameter were placed at the drilled hole on both rectangular steel plates welded on pipe ends. The load applied to the bend was transmitted through these balls. The need for these balls was to get rid of end fixed moment that might occur and allowed the bend to move freely when the load was applied.

3.12 Vaseline   After the gages were attached on the bend, thin coat of vaseline was required to prevent them from moisture.

4. Calibration of Pressure Gage and Testing Machine

4.1 Pressure Gage Calibration Bourdon-tube pressure gage used to measure the internal pressure of the specimens created by hand pump was calibrated by Budenberg Dead Weight Pressure Tester serial no. 3677. The dead weight tester was an equipment used to balance fluid pressure by a known weight. Generally, it was seldom employed for an actual pressure measurement since it was used only for static calibration of pressure gage. The calibration of this pressure gage was shown in Fig. A22.

Before settling the calibration, the spirit level must be placed on the weight platform to set the level by adjusting the levelling screws. To set this tester for pressure gage calibration, turn the capstan handle of screw press fully in, i.e. clockwise, then unscrew the priming pump to full extend, remove sight plug, pull out handle and pour in oil until nearly full and then open the valve. Replace handle in priming pump and screw down until oil comes from gage connection. Screw on gage, wind screw press fully out (anti-clockwise) whilst continuing to screw down priming pump fully anti-clockwise and top up with oil. The tester is now ready for use, the pressure exerted on the fluid by the piston is now transmitted to the gage. Then screw down the priming pump until 5 ~ 10% of the gage range is obtained.

This tester was well suited for general testing of gages within the range of 1 to 550 ksc. Pressure was applied by screw press until the piston rised and the piston head skirt floated within the balancing band, then the corrected value of pressure at the corresponding indicated value of pressure gage was obtained.

The results of the pressure gage calibration was shown in the table below.

Tester reading, ksc	Gage reading, ksc						Error	
	1	2	3	4	5	mean	ksc	percent
5	5.2	5.3	5.3	5.3	5.3	5.28	0.28	5.31
10	10.2	10.2	10.5	10.0	10.1	10.20	0.20	1.96
15	15.2	15.0	15.1	14.8	14.9	15.00	0.00	0
20	19.5	19.8	19.9	20.1	20.2	19.90	-0.10	-0.503
25	24.8	25.2	24.9	25.4	25.0	25.06	0.06	0.239
30	29.5	29.5	29.2	29.4	29.6	29.44	-0.56	-1.902

Type of gage	Bourdon-tube pressure gage
Number of gage	74004439
Range of gage	0 ~ 40 ksc
Method of calibration	Budenberg Dead Weight Pressure Tester serial no. 3677

4.2 The Calibration of Amsler Universal Testing Machine

This testing machine was calibrated by the Olsen Proving Ring No. 56180 having capacity of 10,000 kg. The proving ring was a circular ring provided with projection lugs for compressive loading and equipped with a micrometer device for measuring the diametral deformation. It was a standard device for calibrating large material - testing machine and also obtaining accurate measurement of large

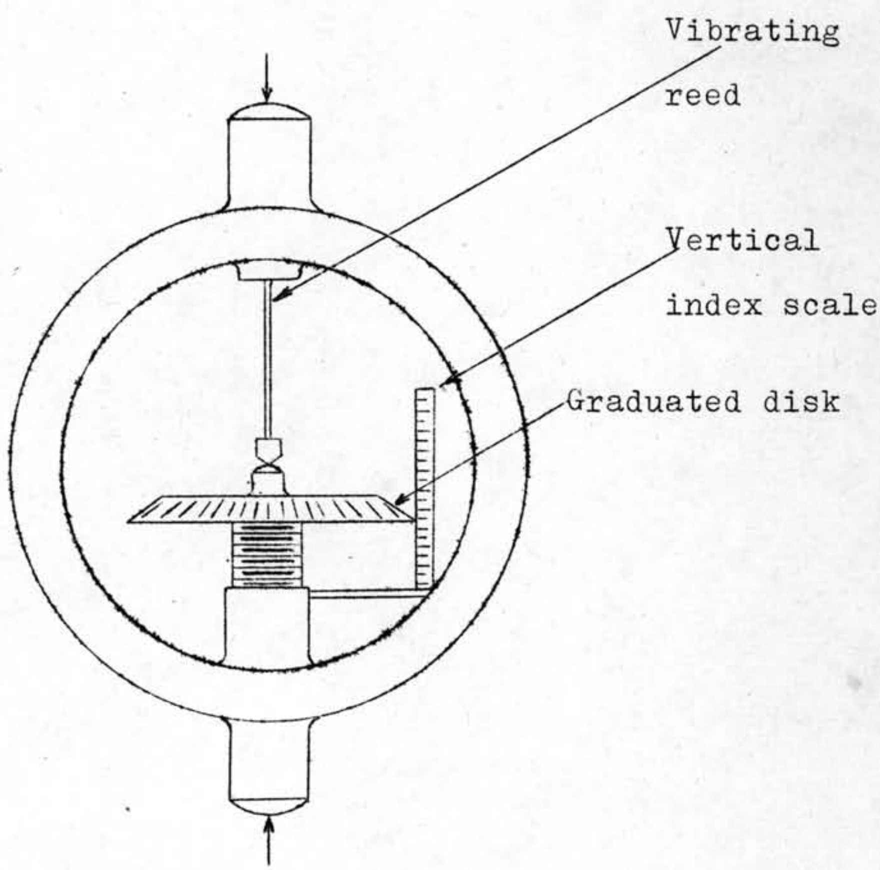

Fig. 5. Proving Ring

static loads. This type of instrument could be used to measure the load ranging from 150 to 150,000 kg. The figure above illustrated the construction of this compression-type ring. The micrometer contact screw was fitted with a large-diameter graduated disk. The vertical index scale was provided with graduations to count the revolutions. A vibrating reed formed the contacting feeler for the micrometer tip. The deflection of the proving ring, measured by means of a precision graduated disk, was used as the measurement of the applied load. In use, the reed was plucked, and the micrometer disk was advanced until contact was indicated by the marked damping of the vibration. With 40 to 64 micrometer threads per inch, the deflection readings could be made to one- or two- hundred thousandths of an inch. From the measurements of the proving ring deflection together with the calibration results of the ring in Fig. A9. the corrected applied load could be determined. The calibration curve of Amsler Universal Testing Machine was also shown in Fig. A10.

5. Experimental Work

The experiment was conducted on single mitered pipe bend, both reinforced and unreinforced, in order to compare the experimental results to the theoretical ones. Prior to being tested, all specimens were drilled two holes one on each leg of the bend. The pipe inlet was welded on one of the hole for the connection between the flexible pipe from the pump and the specimens. The air vent was then brazed over the other hole to allow the air flow out as the water was pumped into the pipe. The experimental procedure in this topic could be divided into three parts, viz:-

Part 1. Pure in-plane bending

Single mitered pipe bends were tested to find the flexibility factor under in-plane bending alone. Twelve pieces of the specimens were applied by pure in-plane bending moment using Amsler Universal Testing Machine. The load was transmitted through the test piece by means of two steel balls placing in the hemispherical hole one on the upper and the other on the lower rectangular plate. The use of the two steel balls was to get relieved of any end fixing moment and also allowed the pipe bend to move freely when the load was applied. The deflection of the line joining both end plates corresponding to each bending load value was measured by the use of dial gage attaching magnetically to the testing machine frame. The deflection-load curve was thereafter plotted to find the flexibilities for each pipe bend. The experiment in this part was depicted in Fig. A23.

Part 2. Combined pressure and in-plane bending load

Flexibility factors of single mitered pipe bends under combined pressure and in-plane bending load were obtained by this experiment. The specimen was equipped in the same way as explained in the preceding part. Before in-plane bending load was applied, the flexible pipe must have been put on the pipe inlet and then tightly clamped by screw-driven iron belt to get rid of any pressure leakage. A suitable length of transparent plastic pipe was fitted from the air vent to the hand pump receiver for the purpose of water overflow. The air vent was opened to let the air flow out as the water was pumped into the pipe bend by hand pump till it was full. The overflow was conveyed back into the hand pump receiver by way of transparent pipe. It was constructive to go on pumping until there was no bubble indicating that air was completely vented out. The air vent was then tightly closed to raise the internal pressure. The pressure started from 10 ksc and increased by an increment of 10 ksc. Bourdon tube pressure gage was attached to the reducer to measure the internal pressure. At each value of internal pressure, the specimen was loaded by in-plane bending moment and the deflection was measured the same way as in part one. The maximum pressure in this part of the experiment was 25 ksc. When the experiment was accomplished, the air vent was opened to release the internal pressure down to zero after which the specimen was taken off and replaced with another one. All specimens were tested under this simultaneous load and experimental flexibilities could be found. Fig.A24. illustrated the equipment together with test piece under combined loading.

Part 3. Stresses in the bend due to combined loading

Pipe bend No. 6a was tested in this part of the experiment. The cross-section of the pipe bend at which the strain gages were attached was 20 cm. from the welded joint measured along the neutral axis. Sixteen pieces of strain gage was used. They were attached around this cross-section with 45° apart. At each position, two pieces of strain gage were attached, one longitudinally and the other circumferentially. These strain gages were used to measure the variation of longitudinal and circumferential strains around the pipe cross-section. Fig.A25. showed the specimen fixed with series of strain gage around the cross-section.

In the experiment, the bend was first loaded by in-plane bending alone and the strains were measured. Later, the bend was supplied by internal pressure only to measure the longitudinal and circumferential strains. Finally, the bend was loaded by combined load to measure the strains from these combined effects. The strains were measured by the use of strain gage bridge equipped with selector switch. The strain gage technique was explained in detail in Appendix II. The experiment in this part was shown in Fig.A26. and A27.