CHAPTER 3

EXPERIMENTAL WORK

In this chapter the experimental work for flexibility and bending stresses around ninety degree mitered pipe bends was divided in to 5 parts as follow :

1. Objective
2. Test Specimens
3. Equipments
4. Calibration of Testing Machines
5. Experimental Program

3:1 OBJECTIVE

The aim of this experimental study may be listed as follow :

(1) To investigate the flexibility of ninety degree single mitered pipe bends with and without reinforced plate at weld joints.

(2) To calculate the flexibility factor of each bend at each equivalent radius using the theoretical method of Von Karman and Kellogg method.

(3) To find the most suitable equivalent radius of reinforced and unreinforced ninety degree single mitered pipe bends that yield the same flexibility as that of the smooth bend of the same size.

(4) To investigate the variations of stresses due to in-plane bending around the outer surface but at the same circular section on the pipe leg of ninety degree reinforced single mitered pipe bend. The test section was a distance position from the weld joint. An attempt has been made to measure the percentage of strain at the corresponding load by strain-gage technique.

3.2 TEST SPECIMENS

Eighteen pieces of ninety degree single mitered bends provided by the Thai Steel Pipe Company as shown in Fig. A30. to A33. were tested. Half of these different sizes are reinforced at the joints . The remainders are without reinforcement at the joints. The pipes were tested by subjected to in-plane bending moment within the elastic limit. The deflections of the end flanges were measured and plotted against loads. The largest reinforced mitered bend were tested for bending and shear stresses under in-plane bending moment by strain-gage technique.

The pipe material used was hot rolled steel that had the properties as shown in table 3-1.

TABLE 3-1. PROPERTIES OF PIPE MATERIAL

Modulus of elasticity in tension or compression	$2.1092\text{x}10^6$	ksc
Modulus of elasticity in shear or torsion	$0.8085\text{x}10^6$	ksc
Poisson's ratio	0.3	-
Yield point	2500	ksc
Maximum tensile strength	3460	ksc
Elongation, on 5 cm gage length	47	%

Chemical analysis of the pipe material in percent are as follow :

C	0.06 - 0.09
Si	0.01 - 0.03
Mn	0.25 - 0.35

P 0 - 0.03

S 0 - 0.03

The dimensions of the specimens tested are shown in table 3-2.

TABLE 3-2. DIMENSIONS OF TEST SPECIMENS

Pipe bend No.	Outside Diameter, D_o	Wall Thickness, t	Pipe Length, L	Span Length, S	Bending Angle (degrees)
1a	2.13	0.200	11.78	17.50	89.73
2a	2.68	0.235	15.15	22.25	89.70
3a	3.35	0.265	20.35	29.55	89.57
4a	4.22	0.265	25.40	36.75	89.84
5a	4.82	0.290	30.70	44.20	89.75
6a	5.99	0.290	36.35	52.15	89.70
7a	7.57	0.325	47.63	68.00	89.59
8a	8.94	0.325	56.43	80.90	90.31
9a	11.50	0.365	70.58	101.25	90.64
1b	2.13	0.200	12.40	17.45	89.44
2b	2.68	0.235	15.10	21.25	89.44
3b	3.35	0.265	20.30	28.60	89.57
4b	4.22	0.265	25.80	36.25	89.26
5b	4.82	0.290	30.80	43.35	89.45
6b	5.99	0.290	36.30	51.30	89.92
7b	7.75	0.325	47.90	67.35	89.34
8b	8.94	0.325	56.28	79.60	90.01
9b	11.50	0.365	70.63	99.75	89.84

Reinforced plate thickness 0.88 cm

Range of angles of mitered bends 90 ± 0.75 degrees

and a is reinforced pipe bend

b is unreinforced pipe bend.

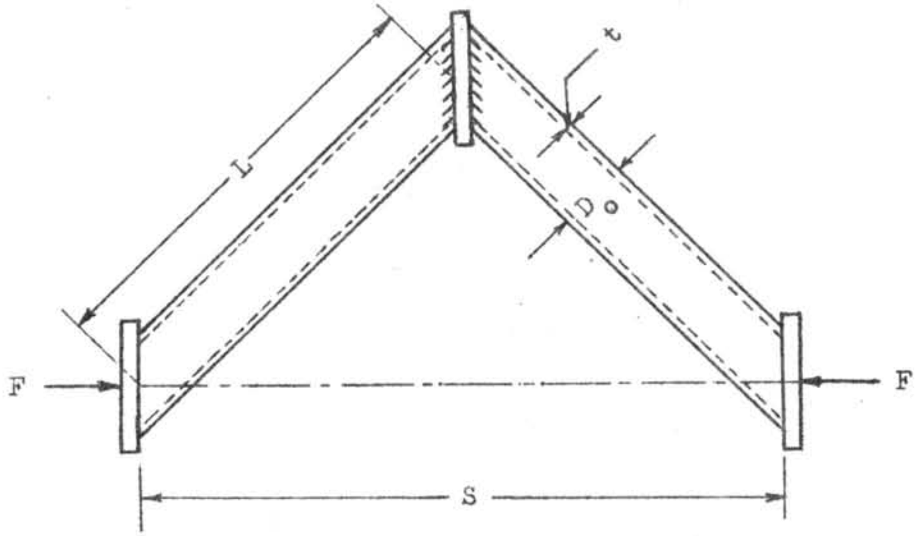

Fig. 3-1. REINFORCED MITERED PIPE BEND.

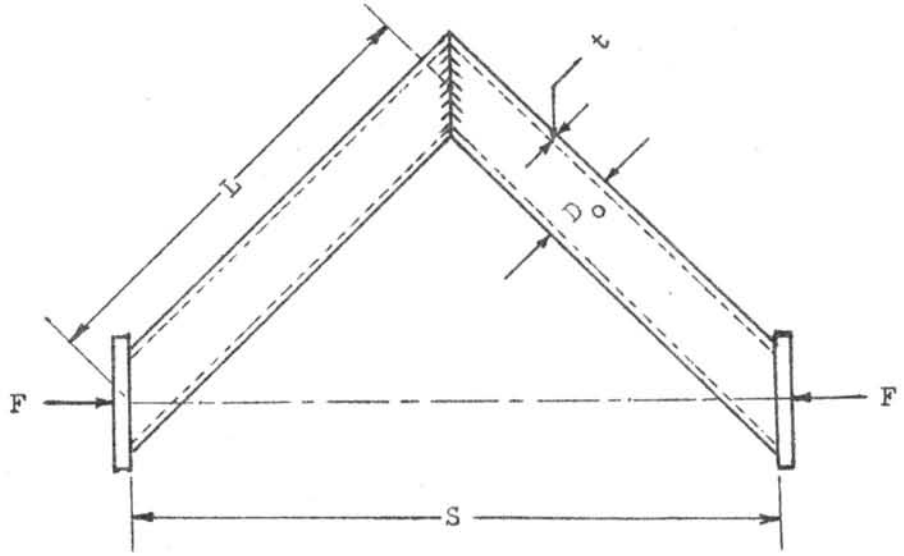

Fig. 3-2. UNREINFORCED MITERED PIPE BEND.

3.3 EQUIPMENTS

The equipments used in this experimental study are :

(1) Testing Machines Three types of testing machine were employed.

(a) AVERY Universal Testing Machine This machine has capacity of 15000 lb, type 7108 DCN, serial no.E 66110 with 1.5 hp. 380 line volts, 380 coil volts, 2.9 amperes, 50 c.p.s. There are six load ranges available namely, 0 to 300, 600, 1500, 3000, 6000 and 15000 lb with 1, 2, 5, 10, 20, and 50 lb divisions respectively. To change the unit to kg a conversion factor of 2.207 lb = 1 kg is used. Thus the range 0 to 3000 lb becomes 0 to 1359.52 kg and this range is used in the experiment. This machine is capable of compressing the specimen with length between 0 to 430 mm. Using for tension, 25 to 450 mm long specimen can be accommodated. Specimens no. 1a, 1b, 2a, 2b, 3a, 3b, 4a, and 4b were tested by this machine. This machine is shown in Fig. A27. and A34.

(b) AMSLER Universal Testing Machine This machine, as shown in Fig. A28., A35. and A36. has capacity of 20 tons, type 20 ZBDA 357 serial no. 060355 AK. There are four load ranges available namely, 0 to 2, 5, 10 and 20 tons with 5, 10, 10 and 50 kg divisions respectively. The load range of 0 to 2 tons were used in this experiment. At present this machine is available for compression of the specimen solely of length about 0 to 750 mm, although the maximum distance between compression plates is 1250 mm. Specimens no. 5a, 5b, 6a, 6b, 7a and 7b were tested by this machine. Other specification are as follow :

Distance between the gripping head exclusive of ram stroke 0 - 1150 mm

Clearance between vertical columns 50 mm

Maximum test speed 180 mm per min.

Ram stroke 30 mm.

Electric motor for pump 1½ HP.

Net weight 1030 kg.

Maximum height of machine 3400 mm

(c) SIGURD STENHØJ Testing Machine This machine as shown in Fig. A37. and A44. has capacity of 100 tons, serial no. 27456106, AR 1968, made by BARRIT - DANMARK. It is available for compression of the specimen having a length 0 to 116.5 mm. The piston diameter is 200 mm. Specimens no. 8a, 8b, 9a and 9b were tested by this machine.

(d) Pressure Gage The gage no. 422209T with range 0 to 60 psi was used with the SIGURD STENHØJ testing machine.

(e) BUDENBERG Dead-Weight Pressure Tester. The BUDENBERG "Ranger" Patented Dual Range Dead-Weight pressure gage tester complete with accessories, serial no. 3677 as shown in Fig. A29. was used for the calibration of pressure gage. The specification are as follow :

Piston areas : $\frac{1}{8}$ in.^{2} and $\frac{1}{80}$ in.^{2}

Pressure range : 10 to 800 psi (1 to 55 ksc) on $\frac{1}{8}$ in.^{2} piston.

100 to 8000 psi (10-550 ksc) on $\frac{1}{80}$ in.^{2} piston.

Oil specification : General use : SAE 10 W mineral oil or a medium viscosity hydraulic oil.

Low pressures : Light Hydraulic or Spindle Oil SAE 5 W.

Weights : The smallest increments that can be measured with the standard set of weights supplied with the tester are : 5 psi (0.5 ksc) on the $\frac{1}{8}$ in.^{2} piston, or 50 psi (5 ksc) on the $\frac{1}{80}$ in.^{2} piston.

Pressure datum : At the gage inlet.

(f) <u>Proving Ring</u> To calibrate the AVERY and AMSLER Testing Machine, the OLSEN proving ring as shown in Fig. A26. was used. This ring has capacity of 10 tons, serial no. 56180, produced by TINIUS OLSEN TESTING MACHINE CO., WILLOW GROVE PA, USA.

(g) Dial Gage with Magnetic Holder. To measure the values of deflection of the bends accurately, dial gage with magnetic holder as shown in Fig. A38. were placed at the suitable position on testing machine. In this experiment FEDERAL dial gage of range about 0 to 26.23 mm type Q6IS-R1 with 0.01 mm division were used with ERICK MAGNA holder which could be fitted either on flat or curve surface.

(h) Harden Steel Balls Two balls of diameter 12.6 mm were used. The load applied to the bend was transmitted through these balls to avoid unwanted end fixed moment and to take up the movement of the bend in the direction perpendicular to the line of action of the load.

(i) Strain Gages and Cement KYOWA Japanese strain gage type KC-70-A1-11 with strain gage cement 20 gm type BC-11 as shown in Fig. A39. were used. These were produced by KYOWA ELECTRONIC INSTRUMENTS CO., LTD. TOKYO JAPAN. The gage has gage length of 67 mm, resistance 120.0 ± 0.3 ohms with gage factor 2.10 ± 0.8%

(j) Strain Gage Bridge The TINSLEY portable strain gage Bridge Type 5580 as shown in Fig. A40. has been designed for the "on site" measurement of strain and stress in all types of structures and machines using strain gages range 50 to 2000 ohms.

The instrument is ruggedly built, compact and weighsonly 12 lbs. It is fully transistorised and suitable for single gage, 2 gage and 4 gage bridges. The bridge supply is obtained from a self contained 1000 c/s square wave oscillator operating at approximately 3 volts. The output from the bridge is amplified in a three-stage amplifier and a manual balance obtained on a center zero pointer type detector. The use of a square wave oscillator elimates the effect of the lead capacitance and also the parasitic e.m.f.'s which generally arise in D.C. circuits due to differences in temperature. Supplies for the oscillator and amplifier are obtained from an internal battery which can be charged in situ when not in use. A seperate mains operated circuit is provided for this purpose.

Specification :

Ranges : Indicated on a digitised 10 turn counter
X1 ± 10000 units of microstrain in steps of 10 units.
X0.1 ± 1000 units of microstrain in steps of 1 unit.

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.

Sensitivity : Detector Sensitivity sufficient to balance to 1 unit of microstrain using 100 ohm gages.

Strain gages : Gages with any resistance between 50 to 2000 ohms and gage factor 1.8 to 4.5 may be used.

Reactive effect : Lead capacitance up to $0.5\mu F$ will not effect the balance or sensitivity of the bridge.

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

Output : Jack plug provided to enable examination of the output with an oscilloscope.

Power supplies : (1) Internal DEAC 13.5 volt battery for oscillator and amplifier

(2) 240 volt 50 cycles for charging battery in situ, when not in use.

Dimensions : $11\frac{1}{2}$ x $8\frac{1}{2}$ x 6 in (292 x 216 x 152 mm).
Weight 12 lb (5.5 kg)

(k) <u>Selector Switch and Apex Units</u> The apex units as shown in Fig. A41. consist of a bank of 1.2 ohm variable potentiometers, known as apex resistors, together with a thermo-free selector switch which selects each apex resistor in turn. One side of each of the active and compensating gages is connected to each apex resistor which is used for initial balance of the gage circuit. When fitted with 1.2 ohm resistors, the apex units are suitable for use with gages having resistances between 50 and 200 ohms. If it is desirable to use high resistance gages, the apex resistor should be adjusted to 1% of the gage resistance. However, it is usual to use only 100 ohm gages in multi-point work. Each apex unit has a common terminal for the switch and special sockets for making the connections to the active and dummy gages.

The TINSLEY selector switch and apex units type 4907J was used in this experiment. It has 25-point manual, with 26-position selector switch. Two plugs and sockets for each resistor connection. Dimension 18 x 12 x $5\frac{1}{2}$ in. (460 x 305 x 140 mm). Net weight 15 lb (6.8 kg). The apex units are mounted in hardwood cases with bakelite insulating panels upon which the apex resistors and selector switches are mounted.

(1) Vasaline To prevent moisture at the strain gages in this experiment, a thin coat of Vasaline was applied.

3.4 CALIBRATION OF MEASURING EQUIPMENTS

3.4.1 Testing Machines Calibration.

Three methods commonly used for calibration of the testing machines are :

1. the use of weights alone
2. the use of levers and weights (proving levers)
3. the use of elastic calibration devices

The testing machines which used in this experiment were calibrated by the third method because it is the simplest and most common method of calibrating large capacity machines. This method consists of an elastic metal member or members combined with a mechanism for indicating the magnitude of deformation under load. Two forms of this device are

(1) a steel bar together with an attached strainometer, and

(2) a "calibration ring" or "proving ring" which is a steel ring or loop combined with some type of deflection indicator.

The steel bar is suitable principally for use in tension, although some bars are used in compression. The proving ring is a ring transducer or loop device, which is widely used as a calibration standard for either large tensile or compressive testing machines with static load. A compressive load shortens the vertical diameter and this deflection is measured by the sensitive micrometer as shown in Fig. 3-3. This micrometer has threads about 40 to 60 micrometer threads per inch. To obtain a precise measurement, one edge of the micrometer is mounted on a vibrating reed device which is plucked to obtain a vibratory motion. The micrometer contact is then moved forward until a noticeable damping of the vibration is observed or contact is indicated by the marked damping of the vibration. Deflection measurements may be made to one-or two-hundred thousandths of an inch with this method. From these measurements and the calibration results of the ring, the applied load can be determined. Calibration rings of this sort are available in capacities range from 300 to 300,000 lb, but compression bars having capacities up to 3,000,000 lb are equipped with electronic strain gages. Also, for calibrating very large machines in compression, several calibration rings or bars can be used in parallel.

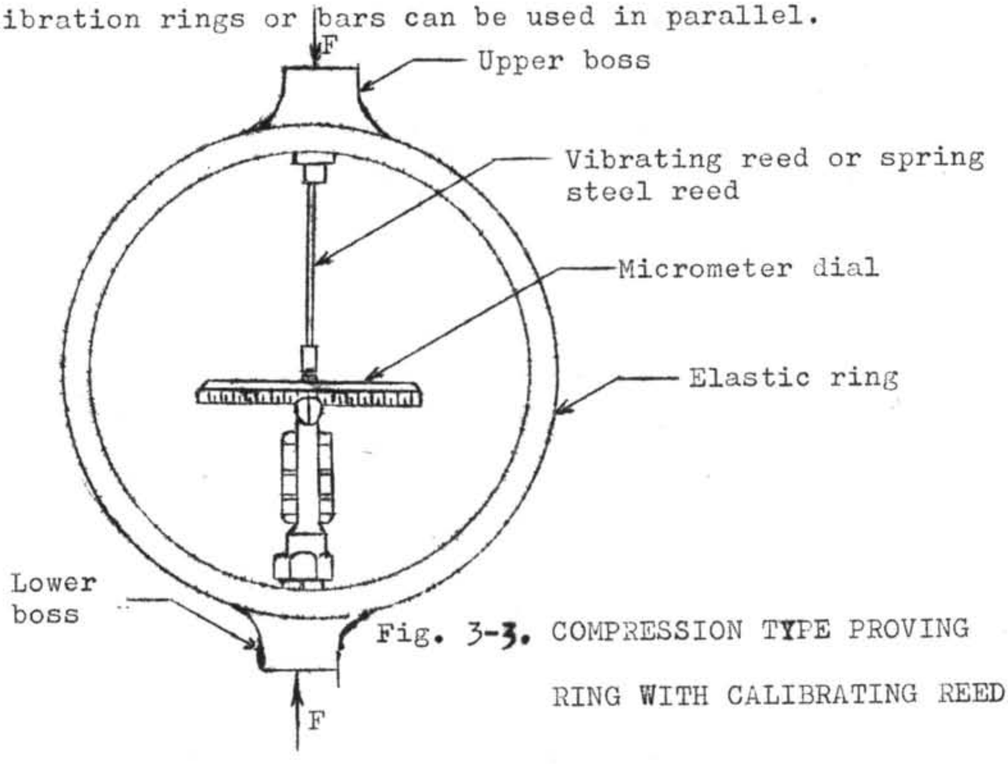

Fig. 3-3. COMPRESSION TYPE PROVING RING WITH CALIBRATING REED.

The followings are three important requirements of an elastic calibration device (proving ring)

(1) It should be so constructed that its accuracy is not impaired by handling and shipping and that parts subject to damage or removal can be replaced without impairing the accuracy of the device.

(2) It should be provided with shackles or bearing blocks so constructed that the accuracy of the device in use is not impaired by imperfections in the shackles or blocks.

(3) It should be calibrated in conjunction with the strainometer to be used with it, and the strainometer should be used in the same range as that covered by the calibration.

Care must be taken to minimize any temperature changes during the use of proving ring. Furthermore, the actual temperature at time of use and at time of its own calibration must be known, since the elastic properties of the device change with temperature. In general, the reading of a ring-type device changes by about 0.015 percent for each degree Fahrenheit change in temperature from the standard.

In all ordinary calibration work, the calibration load should be applied so that the resultant load acts as nearly as possible along the axis of the weighing head. In special instances, calibrations may be achieved with the load applied at known eccentricities.

Care should be taken in obtaining the initial micrometer reading which is the reading at no deflection of the proving ring. This in fact is the micrometer-reading at no load. Since the actual deflections are given by the subsequent readings less the initial value, these figures will not be the true ones unless the initial deflection is read correctly. It can be seen from the graph of the proving ring that the calibration factors will also be affected by this initial reading.

The deflection equation and deflection constant are derived for circular rings with the assumption that the radial thickness of the ring is small compared with the radius, these equations are :

deflection equation :

$$Y = \frac{1}{16}\left(\frac{\pi}{2} - \frac{4}{\pi}\right)\frac{FD^3}{EI} \quad \text{(from Ref.(13) pp. 316-319)}$$

deflection constant (force per unit length)

$$K = \frac{16EI}{\left(\frac{\pi}{2} - \frac{4}{\pi}\right) \cdot D^3}$$

where F = Applied load

D = Diameter of ring

E = Young's modulus

I = Moment of inertia of section about centroidal axis of bending section.

But most proving rings are made of section with appreciable radial thickness. However, the use of thin-ring rather than thick-ring relations introduces errors of only about 4% for a ratio of section thickness to radius of $\frac{1}{2}$. Increased stiffness in the order of 25% is introduced by the effects of integral bosses. It is, therefore, apparent that use of the simpler thin-ring equation is normally justified.

Stress may be calculated from the bending moments, M determined by the relation.

$$M = \frac{FR}{2}\left(\cos\gamma - \frac{2}{\pi}\right) \qquad \text{Ref.(2)}$$

(Symbols correspond to those shown in Fig. 3-4.)

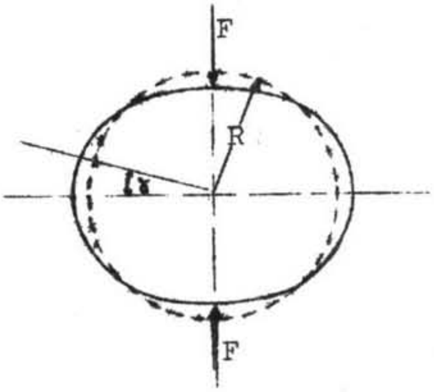

Fig. 3-4. PROVING RING SUBJECTED TO LOAD.

TABLE 3-3. THE CALIBRATION OF "AVERY" TESTING MACHINE CAPACITY 15000 LB,
LOAD RANGE 0-3000 LB AGAINST STANDARD PROVING RING NO. 56180.

Load Increased					Load Decreased				
Indicated Load lb	Indicated Load kg	Deflection of Proving Ring division	Calibration Factor kg/div.	Corrected Load kg	Indicated Load lb	Indicated Load kg	Deflection of Proving Ring division	Calibration Factor kg/div.	Corrected Load kg
0	0	0	32.000	0	5	2.27	0.1	31.999	3.20
266	120.54	5.8	31.990	185.54	250	113.29	4.4	31.994	140.77
495	224.32	10.2	31.985	326.25	500	226.59	10.4	31.985	332.64
770	348.94	14.1	31.980	450.92	750	339.88	14.2	31.980	454.12
1000	453.17	18.0	31.974	575.53	1000	453.17	18.3	31.973	585.11
1250	566.47	21.8	31.969	696.92	1250	566.47	21.5	31.970	687.36
1500	679.76	25.2	31.964	805.49	1500	679.76	24.8	31.965	792.73
1750	793.05	28.0	31.960	894.88	1750	793.05	28.3	31.959	904.44
2000	906.34	31.2	31.955	997.00	2000	906.34	31.7	31.955	1012.97
2250	1019.64	34.0	31.952	1086.37	2250	1019.64	34.2	31.952	1092.76
2500	1132.93	35.7	31.949	1140.58	2500	1132.93	37.2	31.948	1188.47
2750	1246.22	40.4	31.941	1290.42	2750	1246.22	40.4	31.941	1290.42
3000	1359.52	43.9	31.937	1402.03	3000	1359.52	43.9	31.937	1402.03

TABLE 3-4. THE CALIBRATION OF "AMSLER" TESTING MACHINE CAPACITY 20 TONS, LOAD RANGE 0-2 TONS AGAINST STANDARD PROVING RING NO. 56180.

Load Increased				Load Decreased			
Indicated Load kg	Deflection of Proving Ring division	Calibration Factor kg/div.	Corrected Load kg	Indicated Load kg	Deflection of Proving Ring division	Calibration Factor kg/div.	Corrected Load kg
0	0	32.000	0	0	0	32.000	0
65	2.3	31.996	73.59	50	1.4	31.997	44.80
108	4.1	31.995	131.18	100	3.3	31.995	105.58
155	5.7	31.991	182.35	150	5.0	31.992	159.96
210	7.6	31.989	243.12	200	7.2	31.990	230.33
250	9.4	31.986	300.67	250	9.3	31.986	297.47
300	12.5	31.982	399.78	300	12.0	31.983	383.80
350	14.2	31.980	454.12	350	13.9	31.980	444.52
400	15.9	31.979	508.47	400	15.8	31.978	505.25
450	17.9	31.974	572.33	450	17.8	31.975	569.16
500	19.5	31.972	623.45	500	19.4	31.972	620.26
550	21.4	31.970	684.16	550	21.3	31.970	680.96
600	23.8	31.966	760.79	600	23.0	31.967	735.24
650	25.4	31.964	811.89	650	24.7	31.965	789.54
700	27.2	31.961	869.34	700	26.6	31.962	850.19

3.4.2 Pressure Gage Calibration

The pressure gage which was used with SIGURD STENHØJ Testing Machine in the experiment was calibrated by Budenberg Dead Weight Pressure Tester serial no. 3677 as shown in Fig. A22. and A29. The dead weight tester is a device used for balancing a fluid pressure with a known weight. Typically, it is a device which is used for static calibration of pressure gages and is seldom employed for an actual pressure measurement.

The level must be set before test by placing the spirit level provided on the weight platform and adjusting the levelling screws. To set this tester for pressure gage calibration, wind 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 is well suited for general testing of gages within the range of 10 to 8000 psi. Pressure is applied by screw press until the piston rises and the piston head skirt floats within the balancing band, then the corrected value of pressure at the corresponding indicated value of pressure gage is obtained.

The accuracies of dead-weight testers are limited by two factors :

(1) the friction between the cylinder and the piston.

(2) the uncertainly in the area of the piston.

The friction is reduced by rotation of the piston and use of long enough surfaces to ensure negligible flow of oil through the annular space between the piston and the cylinder. The area upon which the weight force acts is not the area of the piston nor the area of the cylinder; it is some effective area between these two which depends on the clearance spacing and the viscosity of the oil. The smaller the clearance, the more closely the effective area will approximate the cross-sectional area of the piston. It can be shown that the percentage error due to the clearance varies according to

$$\text{Percent error} \sim \frac{(\rho \Delta p)^{1/2} b^3}{\mu D L} \quad \text{(from Ref.(13) pp. 32-39)}$$

where

ρ = Density of the oil.

Δp = Pressure differential on the cylinder.

b = Clearance spacing

D = Piston diameter

μ = Viscosity

L = Piston length

At high pressures there can be an elastic deformation of the cylinder which increases the clearance sqacing and thereby increases the error of the tester.

TABLE 3-5. THE CALIBRATION OF PRESSURE GAGE.

Type of Gage :	Boudon-Tube Pressure Gage
Number of Gage :	422209T
Range of Gage :	0-60 psi
Method of Calibration :	Dead Weight Tester.

Tester Reading psi	Gage Reading, psi			Error	
	Increased	Decreased	Mean	psi	Percent
10.00	10.00	10.00	10.000	0	0
17.11	17.15	17.00	17.075	-0.035	-0.2046
24.22	24.20	24.20	24.200	-0.020	-0.0826
31.33	31.30	31.35	31.325	-0.005	-0.0160
38.44	38.45	38.45	38.450	+0.010	+0.0260
45.55	45.60	45.50	45.550	0	0
52.66	53.10	52.70	52.900	+0.240	+0.4558
59.77	60.00	60.00	60.000	+0.230	+0.3848

3.5 EXPERIMENTAL PROGRAM

The experimental program was broadly divided into 2 parts.

Part 1

To find the flexibility of ninety degree single mitered pipe bends. Eighteen pieces of the bends were tested. One half of these were reinforced mitered bends and the remainders were unreinforced. The accurate dimensions of each bend were measured first and the average values were found. All of these bends were tested below their yield points. Pipe bends no. 1 to no. 4 were loaded by AVERY Testing Machine whereas no. 5 to no. 7 by AMSLER Testing Machine and no. 8 and 9 by SIGURD STENHØJ Testing Machine respectively. The first two machines were calibrated by the use of proving ring. The last testing machine was used with pressure gage. The gage was calibrated by BUDENBERG Dead Weight Pressure Tester.

The load applied to the mitered bend was transmitted through the steel balls that were placed at the hole on the plates at the free ends of the bend to avoid unwanted end fixed moment and took up the movement of the bend in the direction perpendicular to the line of action of the load.

Dial gage with magnetic holder was fitted to the testing machine to measure the deflections of the bend at each load. The deflection are then plotted against corresponding load values. The flexibility, Z obtained from slope of the deflection versus load curve. As described in the theory, the calculated flexibility factor and the Karman flexibility factor at the corresponding equivalent radius R (R = r , 2r , 3r , 4r , 5r , 6r , and 7r) are obtained. From these value we can determined the most suitable equivalent radius of unreinforced and reinforced pipe bends that made the same flexibility as of the smooth bend of same size.

Part 2

To find the stresses around ninety degree single mitered bends by the use of strain-gage technique. Sixteen pieces of strain gage were used. The gages were attached on the circular section on the surface of the reinforced ninety degree mitered pipe bend. This section is 404.8 mm on neutral line from the welded joint and at this section the gage were attached on the longitudinal position on one side of symmetrical half of the pipe, 30 degrees apart. If the highest point of the section was taken as the position +90 degrees and lowest point -90 degrees, then the gages were attached at the position +90, +60, +30, 0, -30, -60 and -90 degrees respectively. For the circumferential direction the gages were attached as nearly as possible to the longitudinal gages at the corresponding positions. The last two gages were attached at zero degree position near the zero degree longitudinal gage, perpendicular to each other and made an angle 45 degrees with the pipe axis to determine principal strain at 0 degree position on z-θ plane. The gages were wired to the selector switch and apex units and then to the strain gage bridge as shown in Fig. A-24. and A-25. The gage factor unit on strain gage bridge was then set to the value of gage factor of strain gage used. The apex units for every gage must be set to obtain zero reading of galvanometer at zero load and zero percent strain. When load was applied on the bend through steel balls, the values of percent strain would be varied until the galvanometer pointer pointed zero only then the strain at the tested point which corresponded to the point that selector switch indicated would be obtained. Strains at other points were measured in the same way. By using Hooke's law for an isotropic material(19), Mohr's circle, the assumptions that illustrated in theory and equation 3 to 8 in chapter 2, bending and shear stresses at each point could be determined.