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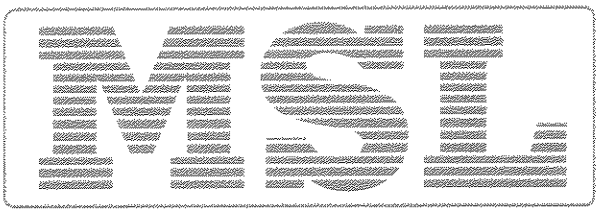

JOINT INDUSTRY PROJECT

DEVELOPMENT OF GROUTED TUBULAR JOINT TECHNOLOGY FOR OFFSHORE STRENGTHENING AND REPAIR

STRAIN GAUGING OF TEST SPECIMENS

DOC REF C14100R014 Rev 0 DECEMBER 1994

MSL Engineering Limited

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STRAIN GAUGING OF TEST SPECIMENS

CONTENTS

1. INTRODUCTION

The prime objective of the grouted joints testing programme is to measure Strain Concentration Factors (SNCFs) for both ungrouted and grouted T and DT tubular joints of various geometries.

There are three aspects which need consideration to enable the correct measurement of strains. These are as follows:

- adequate number of strain gauges and correct positioning to enable extrapolation of strain to the weld toe.
- adequate number of strain gauges around the circumferential chord/brace intersect to enable interpolation to the hot spot location.
- rosette gauges may be required to enable measurement of principal strains when the principal stress direction is not orthogonal to the chord/brace intersect.

These aspects are addressed in Section 2 which also details current guidance for gauge positions to enable measurement of strains and extrapolation to the weld toe. The proposed strain gauge instrumentation for test specimens in this project is contained in Section 3.

2. BACKGROUND

Determination of SNCFs at the weld toe can be carried out using either linear or non-linear extrapolation of strain measurements. Either method should not be influenced by the stress concentrating effect of the weld. With the exception of K and Y joints (ungrouted), determination of SNCFs in tubular joints can generally be carried out using linear extrapolation. Due to the variation in gauge locations between each method, it is therefore important to either predict which type of extrapolation is required or make provision for both.

Very little test data exist for SNCF measurements on grouted tubular joints. The type of extrapolation to be used is not known and therefore it is necessary to bound the possibility of either linear or non-linear extrapolation.

Table 2.1 presents recommended strain gauge positions for the test matrix based on the following guidance:

- HSE, Reference 1 and ECSC give essentially the same guidance for strain gauge locations to enable linear extrapolation to the weld toe.

- DnV, Reference 2, recommends the first strip gauge location to be 0.25T (where T is the thickness of the tubular) from the weld toe with four subsequent strip gauges at 2 mm centres, for linear extrapolation.

- R S Puthli et al, Reference 3, give guidance for gauge locations to enable either linear or non-linear extrapolation, see Figure 2.1.

All the above state that the first strip gauge should be located a minimum 4 mm from the weld toe in order to avoid the concentrating effect of the weld. The guides attempt to position the gauges in the region of stress linearity, between the region effected by the weld and where the stress becomes equal to the nominal stress.

Puthli et al go one step further by giving guidance for the location of gauges to enable non-linear extrapolation, ie. quadratic extrapolation.

For any of the above methods, extrapolation is made from several strain gauge measurements. This, therefore, will also influence the number of gauges required to enable either linear or non-linear extrapolation.

It is expected that for all specimens within the test matrix for this project, with exception of the X joint, the principal stress direction will be orthogonal (or very close) to the chord/brace intersect. The variation in principal strain is expected to be small and therefore the requirement for rosette gauges is not justified. Since the initial tests are planned for T and DT joints, strain gauging of the X or Y joint will be addressed at a later stage, during the course of the project.

3. PROPOSED GAUGING

Figures 3.1 and 3.2 (a) and (b) present the proposed strip gauge positions to enable either linear or non-linear extrapolation. The gauge region, ie. between the first and last gauges, is sufficient to adequately bound the variation and increase in stress towards the chord/brace intersect. The number of gauges will enable a sufficient number of intermediate readings on the brace and chord side of the intersection.

It is proposed that the first, third or fourth and, depending on the tubular thickness, the fifth or sixth gauges (see Figure 3.1) will be connected in order to enable either linear or non-linear extrapolation. The unused gauges from each strip will act as contingency, should one of the nominated gauges fail to function. Figure 3.1 gives examples of gauge locations based on nominal tubular thickness.

Additional strain gauges are provided on the brace(s) to enable measurement of nominal axial strains and brace bending strains. Depending on joint type, gauges will be placed, as follows:

T joints

Saddle and crown locations on both the chord and brace as shown in Figure 3.2(a). Additionally for $\beta = 1.0$ test specimens, two diagonally opposite quadrants will have a further two sets of gauges, at equal spacing, on both the chord and brace.

DT joints

Saddle and crown locations on both the chord and brace as shown in Figure 3.2(b). Additionally for $\beta = 1.0$ test specimens, one quadrant on each brace will have a further two sets of gauges, at equal spacing, on both the chord and brace.

Table 3.1 presents the proposed strip gauge positions for the first and last gauges for each of the specimens. These are based on formulations by Puthli, which bound the gauge positions from the other formulations.

REFERENCES

1. "Background to new fatigue design guidance for steel welded joints in offshore structures."
   Report of the Dept. of Energy, Guidance Notes Revision Drafting Panel - 1984.

2. Det norske Veritas "Rules for Classification of Fixed Offshore Installations", Oslo, Norway, July 1993.

3. "Numerical and experimental determination of strain (stress) concentration factors of welded joints between square hollow sections".
   Puthli, R.S., Wardenier, J., Koning, C.H.M de., Wingerde, A. M. van., and Doren, F.J. van.
   Heron, Volume 33, 1988, Number 2.

Specimen Ident.	Geometry				Chord Crown						Chord Saddle						Brace Crown						Brace Saddle					
	D	T	d	t	1st			Last			1st			Last			1st			Last			1st			Last		
	(mm)	(mm)	(mm)	(mm)	HSE	DnV	Puthli	HSE	DnV	Puthli	HSE	DnV	Puthli	HSE	DnV	Puthli	HSE	DnV	Puthli	HSE	DnV	Puthli	HSE	DnV	Puthli	HSE	DnV	Puthli
T1	406.4	16	168.30	16.0	7.3	4.0	6.4	18.3	12.0	16.0	7.3	4.0	6.4	17.7	12.0	16.0	7.3	4.0	6.4	23.9	12.0	16.0	7.3	4.0	6.4	23.9	12.0	16.0
T3	406.4	16	406.40	16.0	11.4	4.0	6.4	22.8	12.0	16.0	11.4	4.0	6.4	17.7	12.0	16.0	11.4	4.0	6.4	37.1	12.0	16.0	11.4	4.0	6.4	37.1	12.0	16.0
T5	406.4	9.5	273.00	10.0	7.4	4.0	4.0	16.1	12.0	9.7	7.4	4.0	4.0	17.7	12.0	9.7	7.4	4.0	4.0	24.0	12.0	9.7	7.4	4.0	4.0	24.0	12.0	9.7
T7	406.4	7.9	168.30	8.0	5.2	4.0	4.0	12.9	12.0	8.7	5.2	4.0	4.0	17.7	12.0	8.7	5.2	4.0	4.0	16.9	12.0	8.7	5.2	4.0	4.0	16.9	12.0	8.7
T9	406.4	7.9	406.40	7.9	8.0	4.0	4.0	16.0	12.0	8.7	8.0	4.0	4.0	17.7	12.0	8.7	8.0	4.0	4.0	26.0	12.0	8.7	8.0	4.0	4.0	26.0	12.0	8.7
DT2	406.4	16	273.00	16.0	9.3	4.0	6.4	20.6	12.0	16.0	9.3	4.0	6.4	17.7	12.0	16.0	9.3	4.0	6.4	30.4	12.0	16.0	9.3	4.0	6.4	30.4	12.0	16.0
DT3	406.4	16	406.40	16.0	11.4	4.0	6.4	22.8	12.0	16.0	11.4	4.0	6.4	17.7	12.0	16.0	11.4	4.0	6.4	37.1	12.0	16.0	11.4	4.0	6.4	37.1	12.0	16.0
DT4	406.4	9.5	168.30	10.0	5.8	4.0	4.0	14.3	12.0	9.7	5.8	4.0	4.0	17.7	12.0	9.7	5.8	4.0	4.0	18.9	12.0	9.7	5.8	4.0	4.0	18.9	12.0	9.7
DT5	406.4	9.5	273.00	10.0	7.4	4.0	4.0	16.1	12.0	9.7	7.4	4.0	4.0	17.7	12.0	9.7	7.4	4.0	4.0	24.0	12.0	9.7	7.4	4.0	4.0	24.0	12.0	9.7
DT6	406.4	9.5	406.40	9.5	8.8	4.0	4.0	17.6	12.0	9.7	8.8	4.0	4.0	17.7	12.0	9.7	8.8	4.0	4.0	28.6	12.0	9.7	8.8	4.0	4.0	28.6	12.0	9.7
DT8	406.4	7.9	273.00	7.8	6.5	4.0	4.0	14.5	12.0	8.7	6.5	4.0	4.0	17.7	12.0	8.7	6.5	4.0	4.0	21.2	12.0	8.7	6.5	4.0	4.0	21.2	12.0	8.7
DT9	406.4	7.9	406.40	7.9	8.0	4.0	4.0	16.0	12.0	8.7	8.0	4.0	4.0	17.7	12.0	8.7	8.0	4.0	4.0	26.0	12.0	8.7	8.0	4.0	4.0	26.0	12.0	8.7

Strip Gauge Locations (in mm) from weld toe defining regions of strain linearity

Formulation :-

Location	Gauge Position	HSE / ECSC	DnV	Puthli	
				Linear	Quadratic
Chord Crown	1st	$0.2(rt)^{0.5}$	0.25T	0.4T	0.4T
	Last	$0.4(rtRT)^{0.25}$	0.25T + 8mm	1.0T	1.4T
Chord Saddle	1st	$0.2(rt)^{0.5}$	0.25T	0.4T	0.4T
	Last	$(5/360)2\pi R$	0.25T + 8mm	1.0T	1.4T
Brace Crown	1st	$0.2(rt)^{0.5}$	0.25t	0.4t	0.4t
	Last	$0.65(rt)^{0.5}$	0.25t + 8mm	1.0t	1.4t
Brace Saddle	1st	$0.2(rt)^{0.5}$	0.25t	0.4t	0.4t
	Last	$0.65(rt)^{0.5}$	0.25t + 8mm	1.0t	1.4t

Note :-

For all , 1st point , 4mm minimum from weld toe

For Puthli :- Linear extrapolation for (T or t) < 10mm Last position = 4mm + 0.6 x (T or t)

Quadratic extrapolation for (T or t) < 10mm Last position = 4mm + 1.0 x (T or t)

For quadratic extrapolation, sufficient number of data points are required between 1st and last

The above dimensions are based on nominal tubular thickness. Gauge positions based on actual tubular thickness may vary.

Table 2.1 Guidance for location of strain gauges to enable extrapolation of stresses to chord/brace wall intersect

MSL

Specimen Ident.	Geometry				Proposed strip gauge locations *							
	D	T	d	t	Chord Crown		Chord Saddle		Brace Crown		Brace Saddle	
	(mm)	(mm)	(mm)	(mm)	1st	Last	1st	Last	1st	Last	1st	Last
T1	406.4	16	168.3	16.0	6.4	22.4	6.4	22.4	6.4	22.4	6.4	22.4
T3	406.4	16	406.4	16.0	6.4	22.4	6.4	22.4	6.4	22.4	6.4	22.4
T5	406.4	9.5	273.0	10.0	4.0	13.5	4.0	13.5	4.0	14.0	4.0	14.0
T7	406.4	7.9	168.3	8.0	4.0	11.9	4.0	11.9	4.0	12.0	4.0	12.0
T9	406.4	7.9	406.4	7.9	4.0	11.9	4.0	11.9	4.0	11.9	4.0	11.9
DT2	406.4	16	273.0	16.0	6.4	22.4	6.4	22.4	6.4	22.4	6.4	22.4
DT3	406.4	16	406.4	16.0	6.4	22.4	6.4	22.4	6.4	22.4	6.4	22.4
DT4	406.4	9.5	168.3	10.0	4.0	13.5	4.0	13.5	4.0	14.0	4.0	14.0
DT5	406.4	9.5	273.0	10.0	4.0	13.5	4.0	13.5	4.0	14.0	4.0	14.0
DT6	406.4	9.5	406.4	9.5	4.0	13.5	4.0	13.5	4.0	13.5	4.0	13.5
DT8	406.4	7.9	273.0	7.8	4.0	11.9	4.0	11.9	4.0	11.8	4.0	11.8
DT9	406.4	7.9	406.4	7.9	4.0	11.9	4.0	11.9	4.0	11.9	4.0	11.9

* 1st & last gauge position based on Puthli Quadratic formulation
The above dimensions are based on nominal tubular thickness. Gauge positions based on actual tubular thickness may vary.

Table 3.1 Proposed strip gauge locations (in mm) for 1st and last gauges

FIGURES

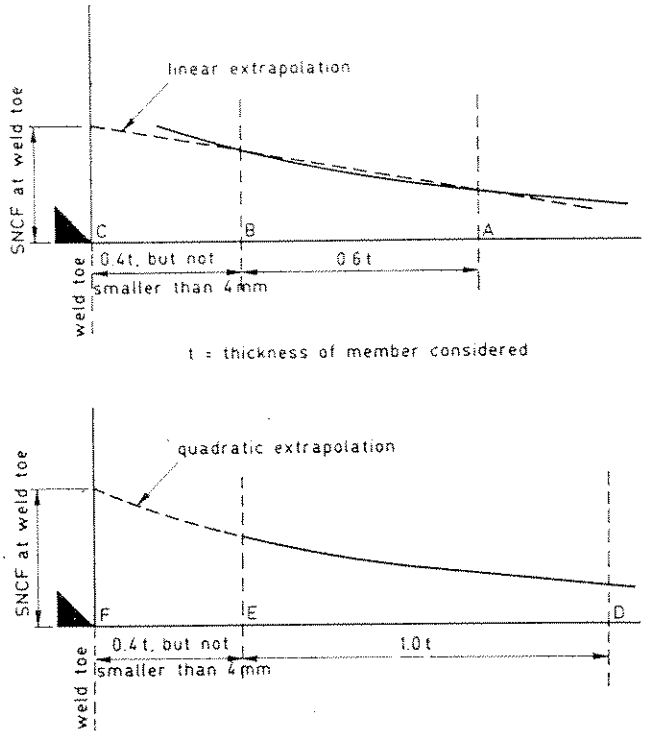

Figure 2.1
Methods of Extrapolation

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MSL Project No. C141	Sheet 1 of 1	Rev. 0	
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Checked by [signature]	Date 30th '94		

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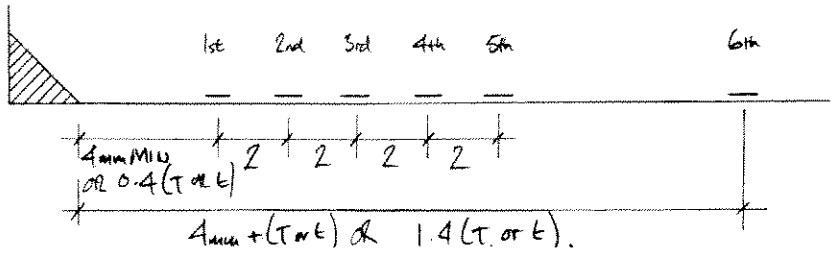
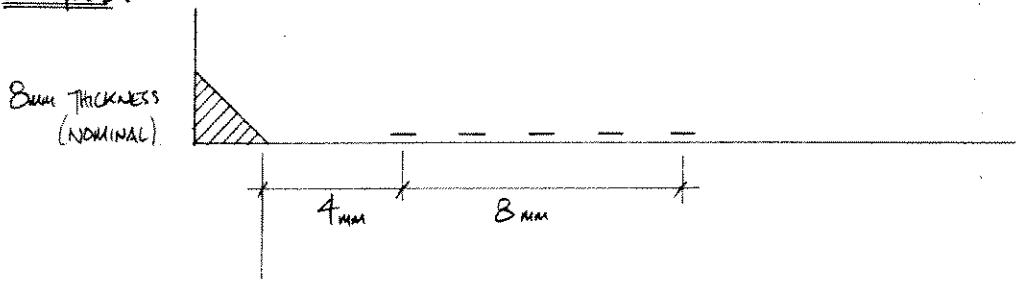
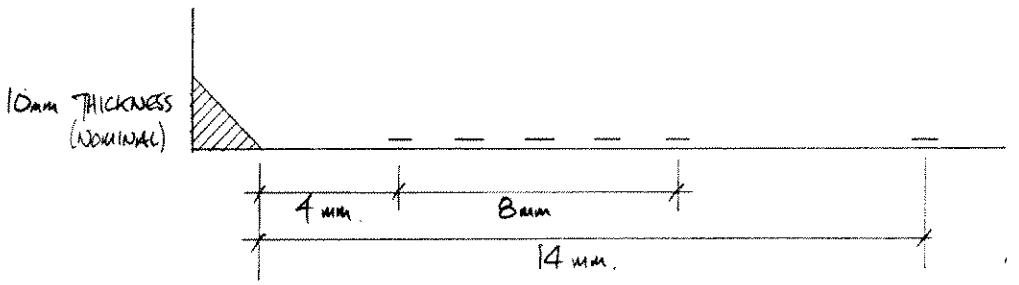
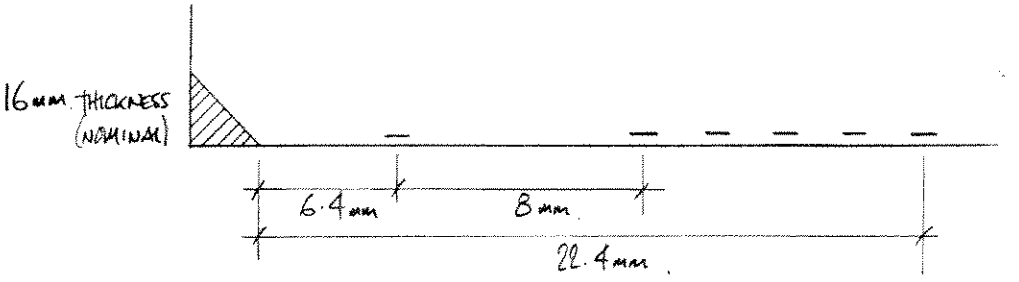


EXAMPLES.







STRAIN GAUGE POSITIONS FOR LINEAR / QUADRATIC EXTRAPOLATION.

FIGURE 3.1.

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Client —	Report No. C141OOR014		
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Checked by	Date OCT. '94		

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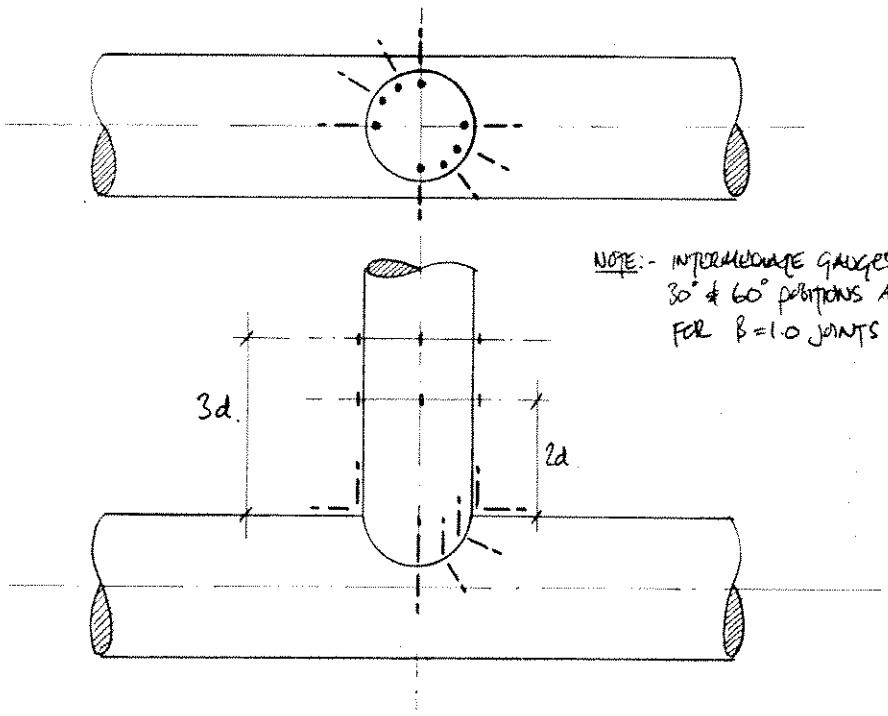

NOTE:- INTERMEDIATE GAUGES @ 30° & 60° POSITIONS ARE FOR β=1.0 JOINTS

KEY :-

— STRIP GAUGE, CONSISTING OF 5 STRAIN GAUGES, 3 OF WHICH ARE USED.

- SINGLE STRAIN GAUGE.

Nº OF GAUGES REQUIRED PER SPECIMEN.

LOCATION.	β = 0.41 & 0.67		β = 1.0	
	STRIP GAUGES	SINGLE GAUGE	STRIP GAUGES	SINGLE GAUGE
BRACE	4	12	8	16
CHORD.	4	4	8	8
TOTAL.	8	16	16	24

NOTE: FOR TEST SPECIMENS OF THICKNESS LESS THAN 10mm, THERE IS NOT A REQUIREMENT FOR SINGLE GAUGES AT THE CHORD/BRACE INTERSECT.

FIGURE 3.2(a)

STRAIN GAUGE POSITIONS FOR T JOINTS.

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Client —	Report No. C141/DR/04		
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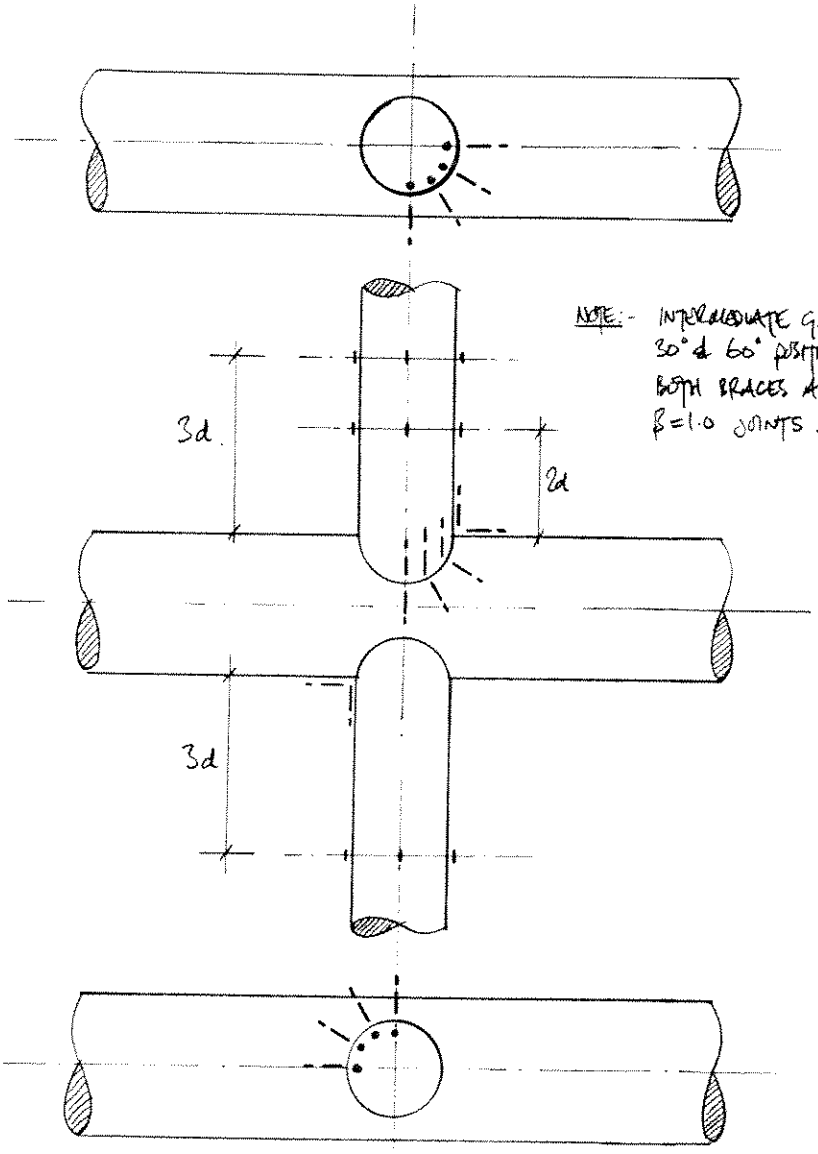

NOTE:- INTERMEDIATE GAUGES @ 30° & 60° POSITIONS ON BOTH BRACES ARE FOR β=1.0 JOINTS.

Nº OF GAUGES REQUIRED FOR SPECIMEN.

LOCATION	β = 0.4 & 0.6		β = 1.0	
	STRIP GAUGES	SINGLE GAUGES	STRIP GAUGES	SINGLE GAUGES
BRACES	4	16	8	20
CHORD	4	4	8	8
TOTAL	8	20	16	28

NOTE: SEE FIGURE 3.2(a).

FIGURE 3.2 (b).

STRAIN GAUGE POSITIONS FOR DT JOINTS.