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TITLE

LONG RANGE REACTION STRESSES IN SHIP STRUCTURES

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Long Range Reaction Stresses in Ship Structures

by

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ABSTRACT

It is now recognized that in complex welded structures such as ships, long range reaction stresses develop due to assembly, fit-up, and structural restraint against the weld zone shrinkage. The long range reaction stresses are different from the short range weld residual stresses, the latter being always present in the weld zone, even if the weld is deposited on a small plate, free to move and contract.

Such stresses can be ignored in fatigue design as yield level residual stresses are usually assumed to be present. However, in fracture assessment (for initiation or crack arrest), this could lead to unsafe predictions.

Literature was, therefore, reviewed to assess the magnitude of such long range reaction stresses in ships. Early studies suggested it to be 25 to 30% of the steel's yield strength. However, due to the increasing use of higher strength steels, and the absence of any recent studies on this subject, a small investigation was undertaken to measure long range reaction stresses during the fabrication of a Super Ferry. The presentation will describe the results obtained which indicated that long range reaction stresses could exceed 75% of the yield strength.

1. Long Range Reaction Stresses?

- Different from 'short range' weld thermal residual stresses.

- Caused by assembly and fit-up requirements and by the resistance/structural restraint to weld zone contraction.

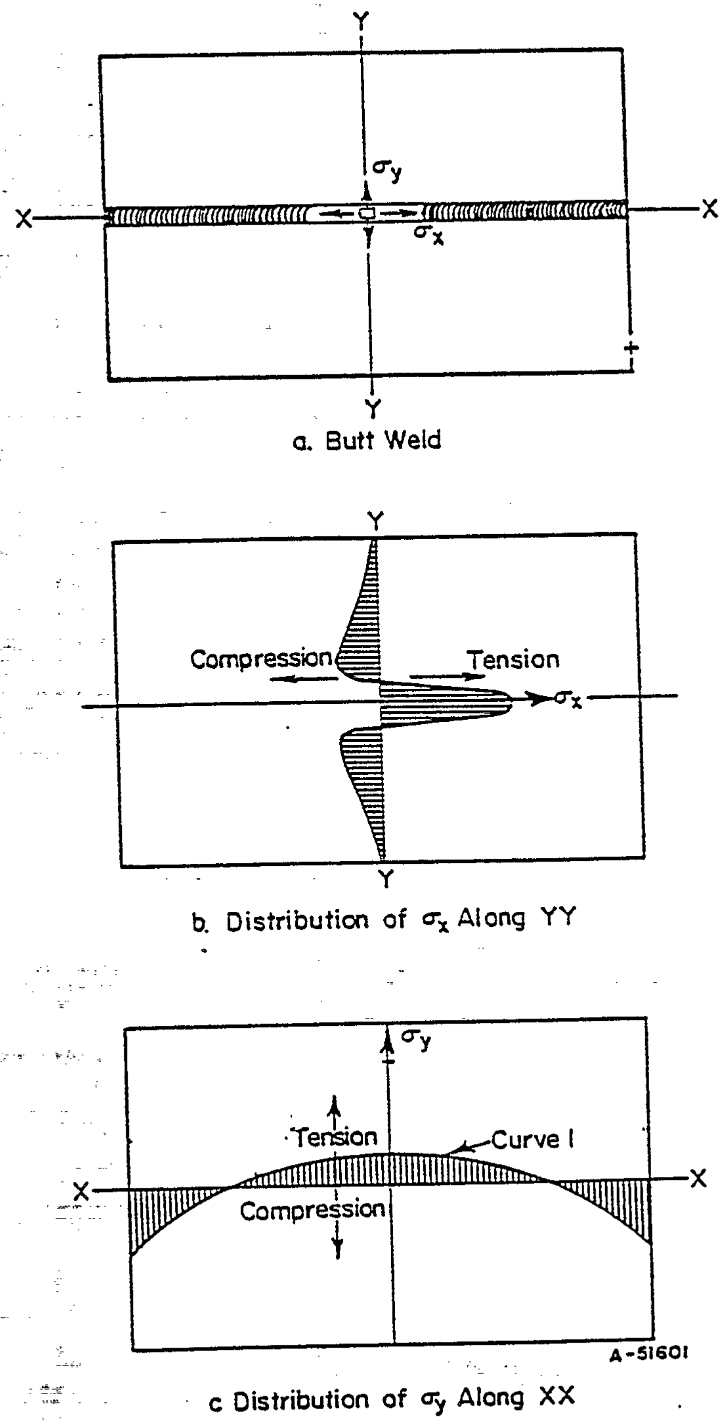


Figure 1: Typical distributions of residual stresses in butt weld

$$K = E.t/\ell$$

$$\sigma_R = m.K.$$

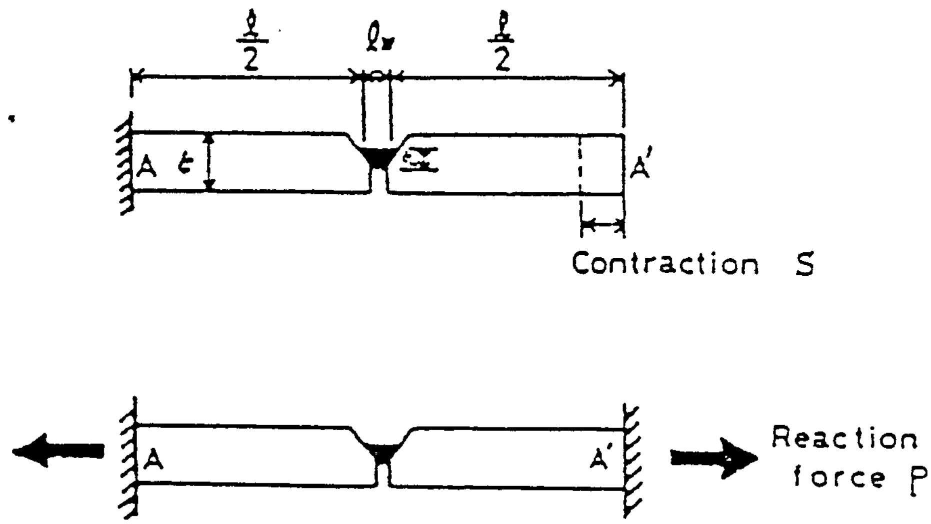


Figure 16: Simple butt joint showing concept of restraint

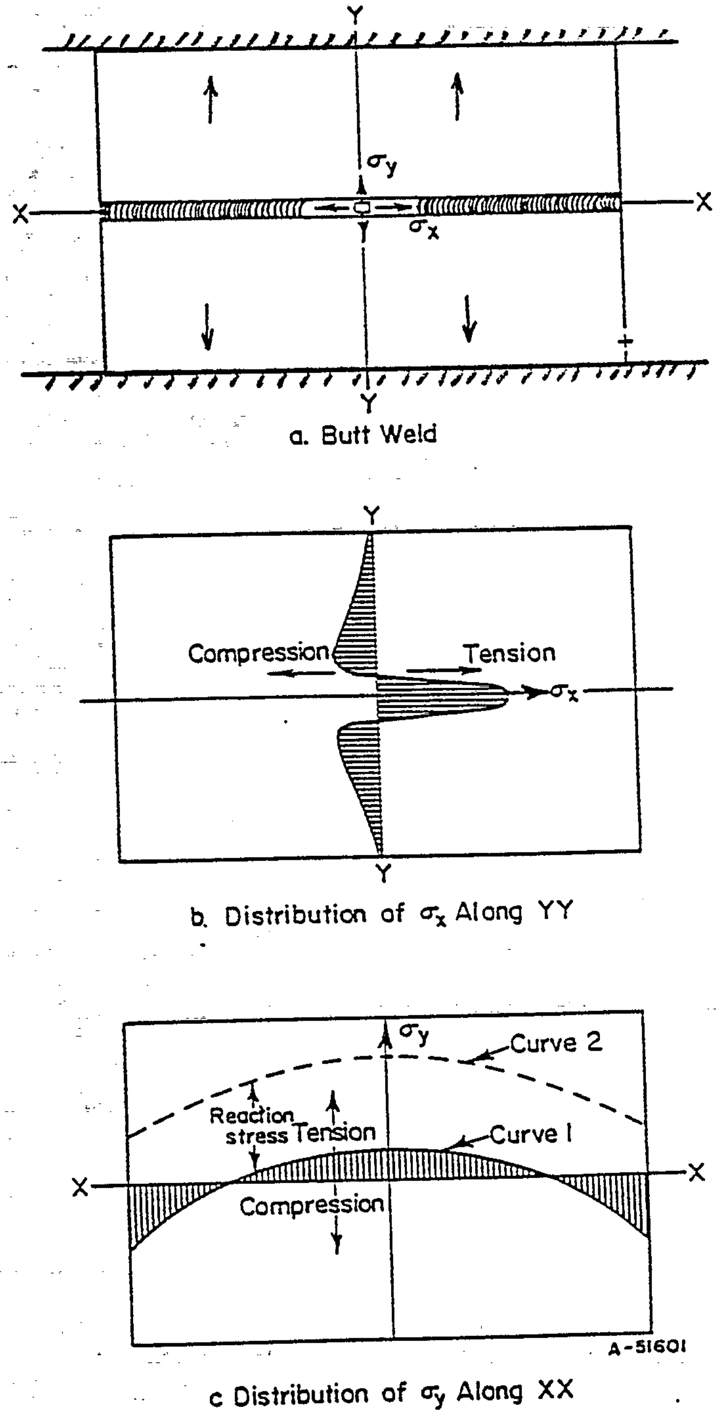


Figure 1: Typical distributions of residual stresses in butt weld

TABLE I: Measured and Calculated Restraint Intensities for Ship Structures (from Reference 14)

Structure	Weld joint	Plate thickness (mm)	Restraint intensity (kg/mm.mm)	Restraint coeff. (kg/mm^2.mm)	Estimation method	Remarks
Ship	Deck longi.	25-30	av. 400	16	measurement & calculation	weld deferment Δ = 200mm
	Trans. web	16	av. 500	31	measurement	
	Collar plate at the slot	20	av. 500	25	〃	
	Butt joint (trans. bulkhead)	16	av. 1638	102	〃	after tack weld* (its pitch 80mm)
	(longi. bulkhead)	13.5	av. 1258	93	〃	
	(side shell)	20	av. 886	44	〃	
	(bottom shell)	28	av. 784	28	〃	
	(upper deck)	32	av. 1277	40	〃	
		32	av. 1222	38	〃	
Ship	Bottom longi.face	32	av. 573	18	calculation	
	Bottom trans.face	30	av. 158	5	〃	
	Strut face	25	av. 85	3	〃	
	Side longi. web	12.5	av. 118	9	〃	
	Butt joint (upper deck)	22.5	av. 158	7	measurement	
	(lower deck)	22.5	av. 131	6	〃	

2. Reason For The Study

- Fracture toughness requirements implicitly assume:
    - a peak service stress;
    - a 'critical' flaw size.

- For small flaws in the weld region, yield level residual stresses also assumed.

- For larger flaws, with flaw tips outside the zone of short range weld residual stresses, these can be ignored.

But What About Long Range Reaction Stresses in Ships?

Sumpter (1980's):

Reaction stresses can be ignored for long cracks (meter long).

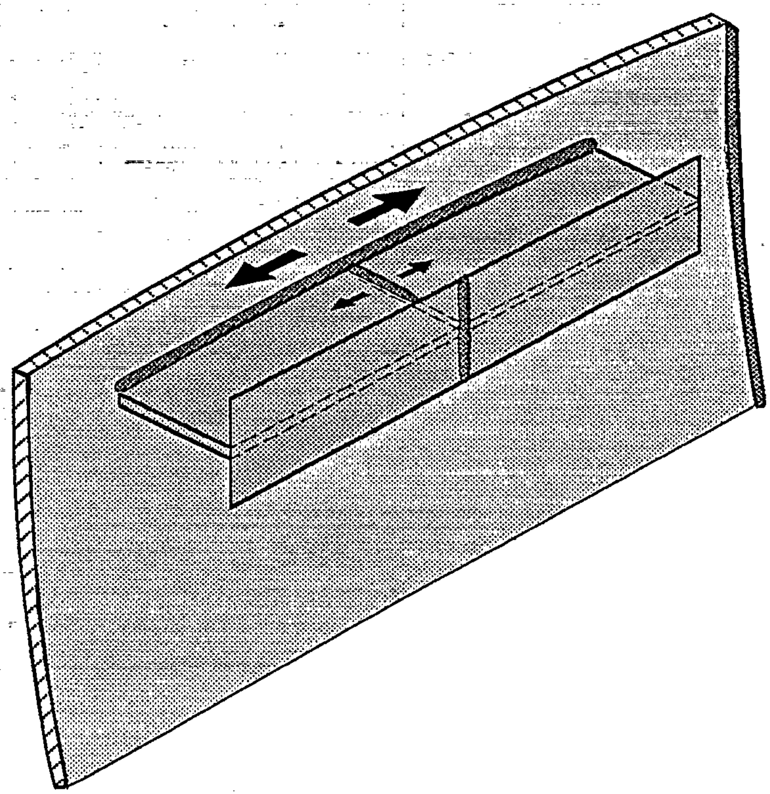
Pellini (1970's):

Tensile reaction stresses about 50% of yield strength in new ships; 20% in in-service ships.
(20% also assumed in CASPPR)

Ignoring long range reaction stress may be nonconservative since fracture toughness requirements, to prevent crack initiation, would increase.

$$K_{app} = y \cdot \sigma \sqrt{a}$$

Also, the crack arrest performance of the steel would be adversely affected.



Therefore, it is considered important to assess the magnitude of the long range reaction stresses in ships.

Literature Search:

- Leide (1977)
- DeGarmo (1946)
- Ffield (1946)

Leide (1977)

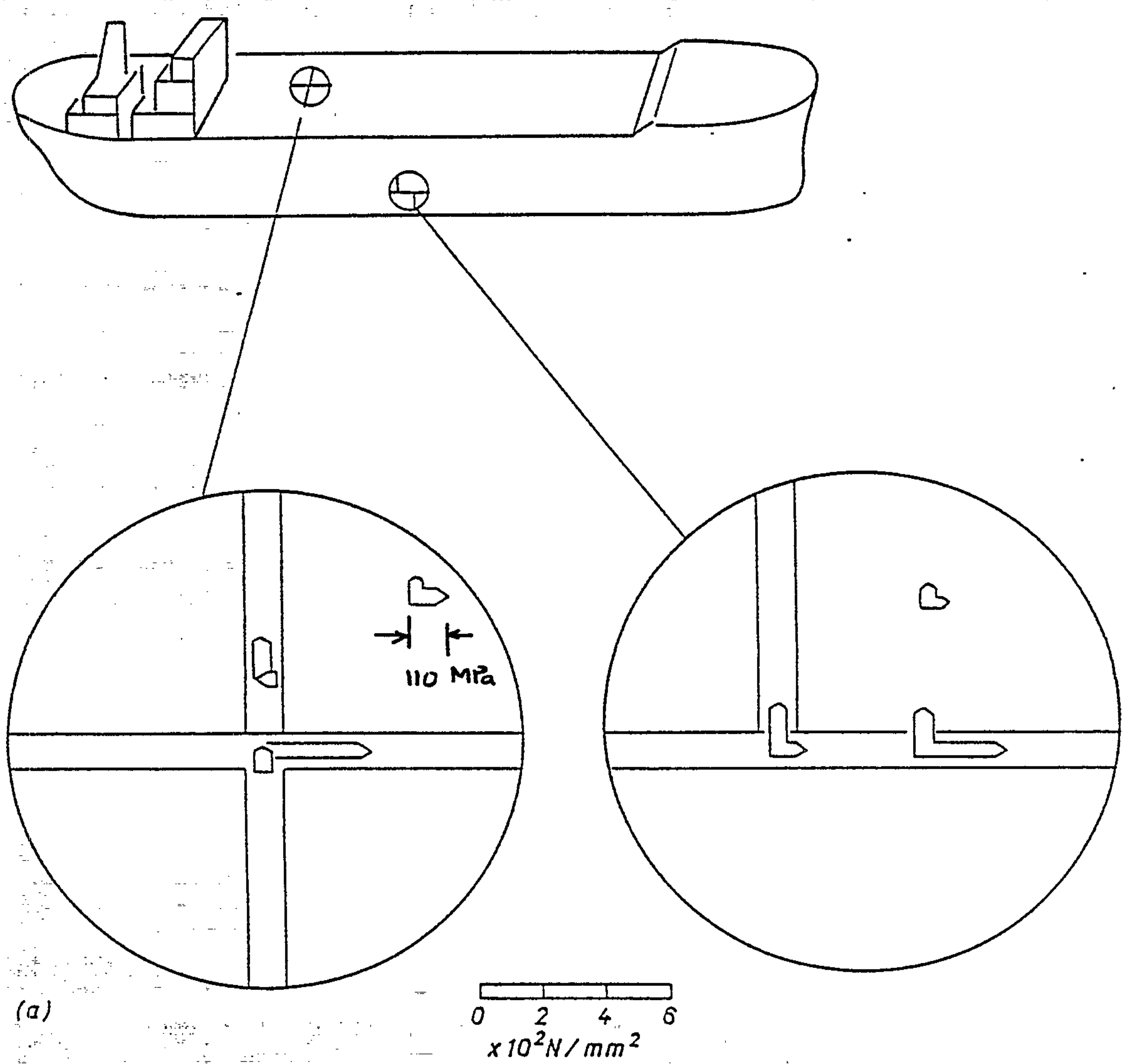
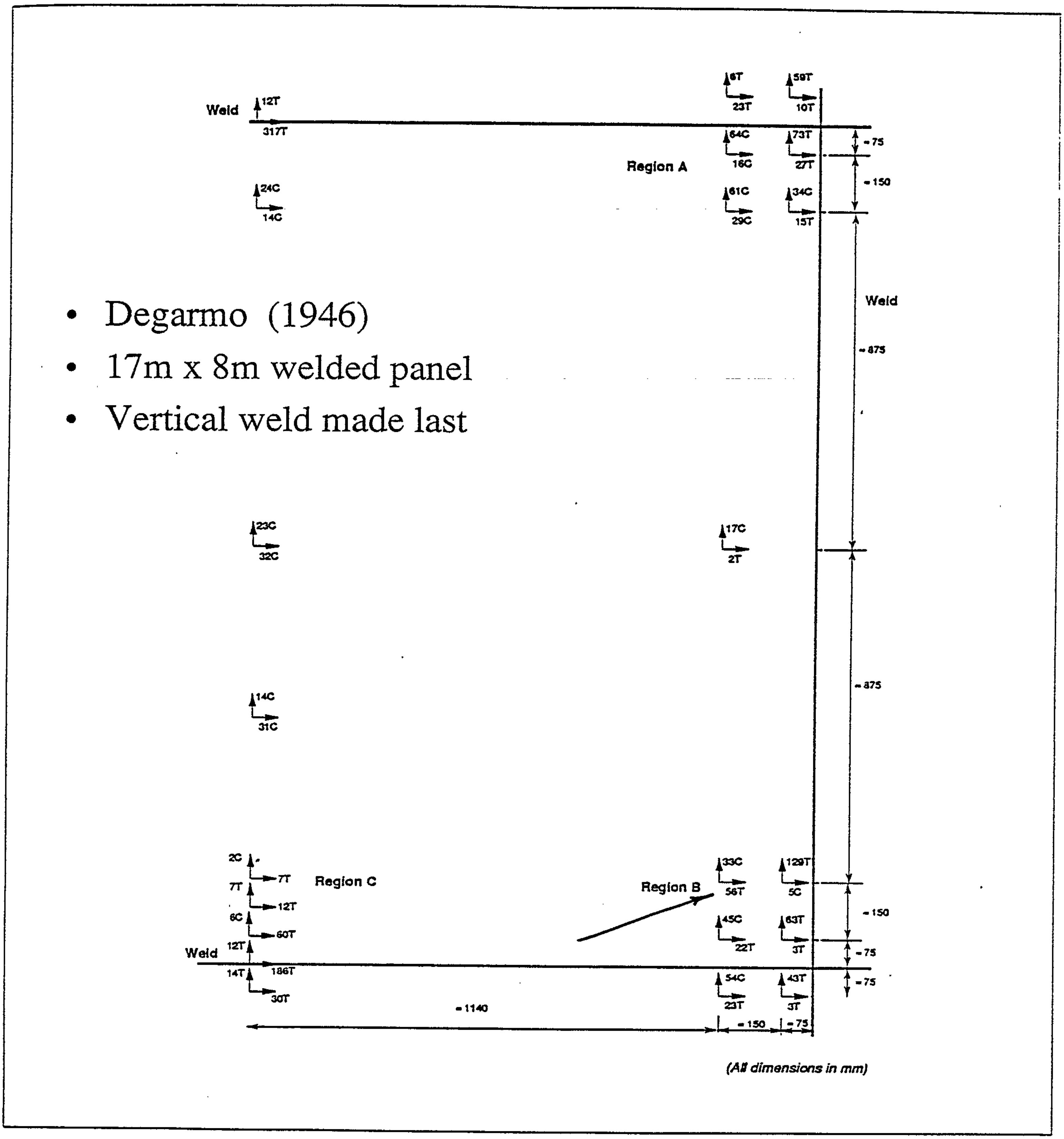


Figure 2: Weld residual and reaction stresses in a newly constructed 25,500 ton tanker (from Reference 3)



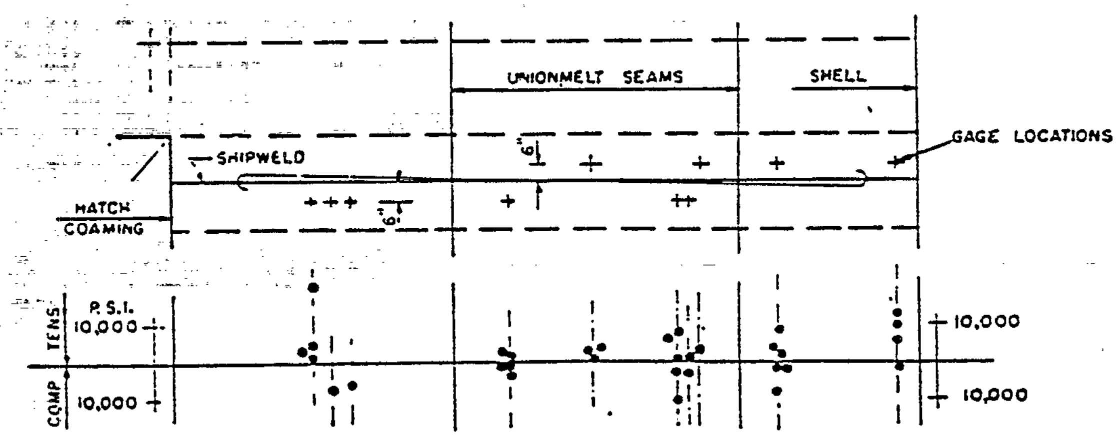
- Degarmo (1946)
- 17m x 8m welded panel
- Vertical weld made last

Figure 5(b): 'Reaction stresses (MPa) at some of the locations in Figure 5(a)

Ffield (1946)

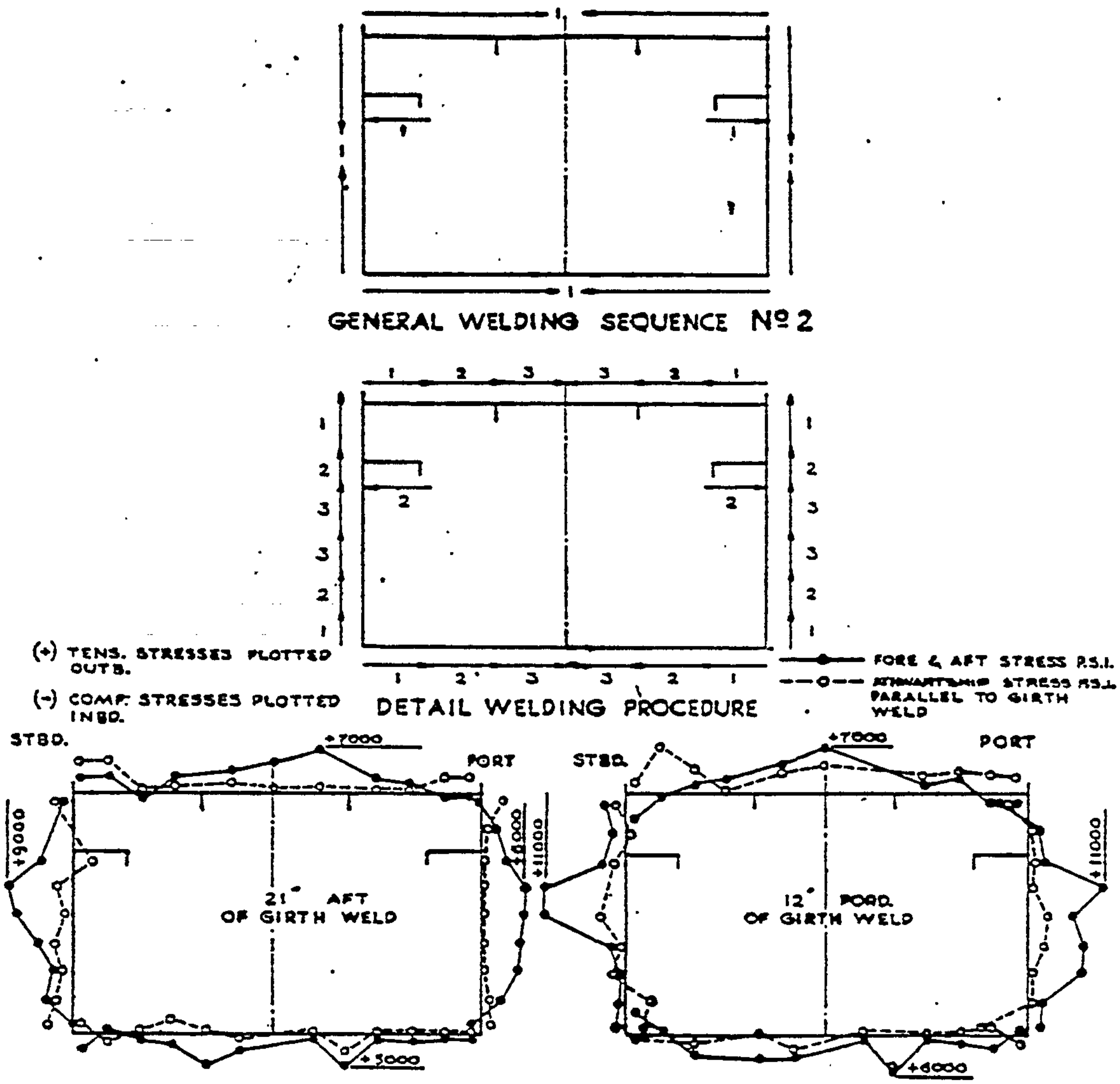
- Reaction stress up to 10 ksi tensile
- One value as high as 15 ksi

} *6" from weld*



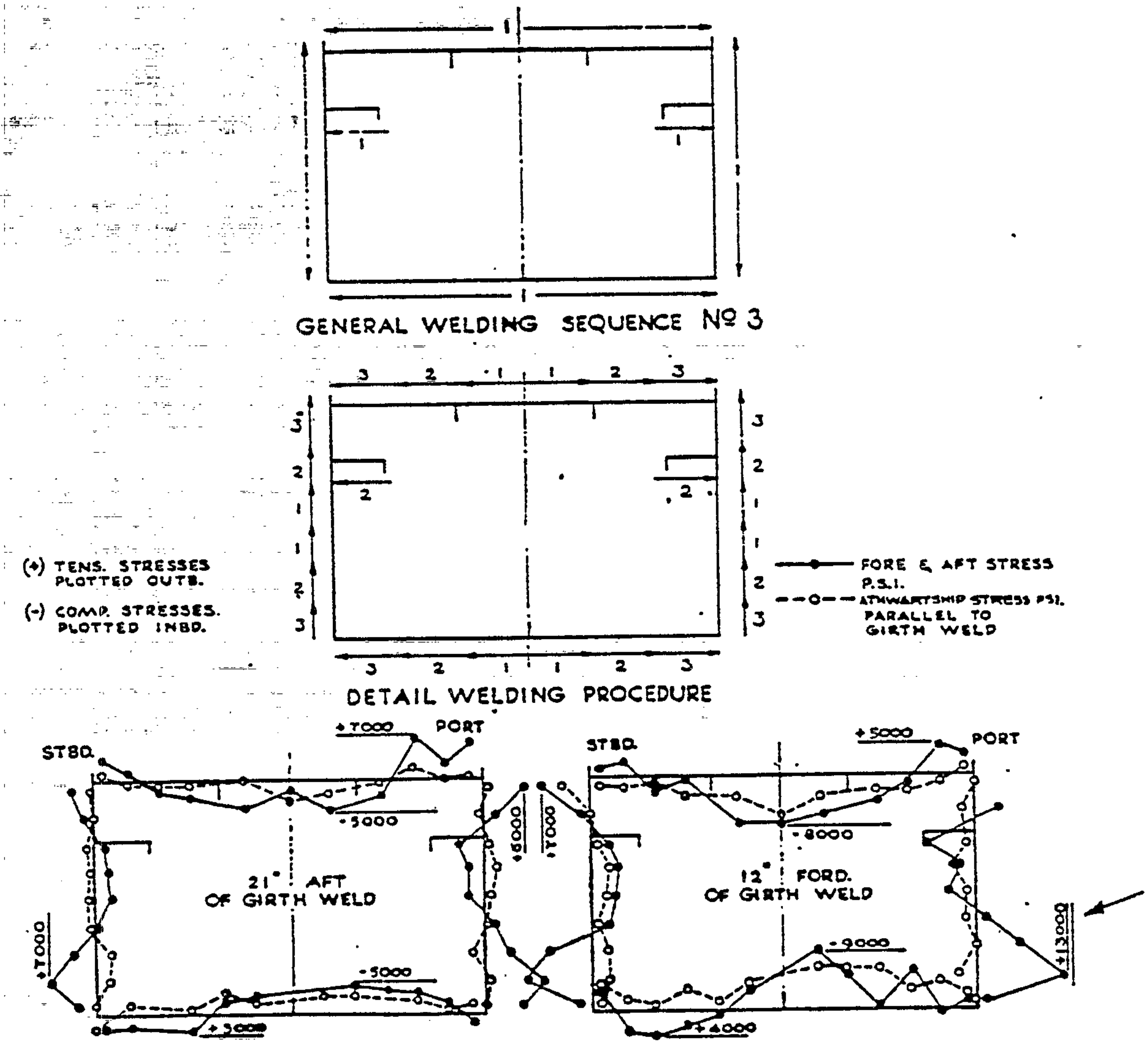
Fore and aft welding stresses ≈ 150mm from welded butts in upper deck of 7 Beth Fairfield Liberty Ships (from reference 10).

Ffield (1946)



- Girth weld between 10m x 3.5m x 2.28m boxes
- Frames at 0.6m spacing
- 9.6mm thick plate
- Peak stress 11 ksi (77 MPa) 12" from weld
  9 ksi (63 MPa) 21" from weld
- Peak stress at neutral axis.

Ffield (1946)



- Peak stress 13 ksi (91 MPa) 12" from weld
  7 ksi (49 MPa) 21" from weld

- Peak stress at corners.

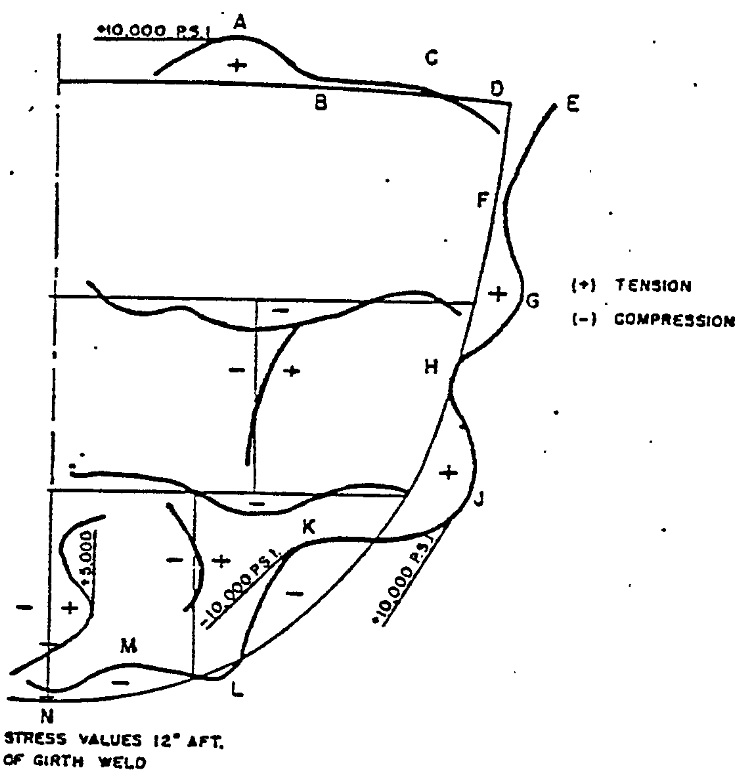


Figure 15: Fore and aft stress plot (ksi) on DE girth weld,
Sum of Steps 1, 2 and 3 (from Reference 10)

- Peak stress at completion of fabrication:
  10 ksi (70 MPa) 12" from weld.

Summary – Literature Search

Tensile Reaction Stress (MPa)	Location	Distance From Weld	Reference
120	Deck; Weld Intersection	≈5 weld widths (100 to 125mm)	3
17	Laboratory Size Plate	100mm	9
56	Ship Subassembly	225mm	9
70 to 105	Liberty Ships	150mm	10
77 to 91	Girth Weld Model	305mm	10
70	Destroyer Escort Girth Weld (Deck & Hull Plating)	305mm	10

- Reaction stress at locations 300mm (12") from the weld can be as high as 91 MPa (13 ksi) It could be higher at locations closer (say 150mm away) to the weld; and conversely lower at locations further away from the weld.

4. Reaction Stress Measurements in a Super Ferry

Objective: Strain gauge two plates and monitor the changes in strain as they are welded into the structure.
(The plates were identically located, one on the port side and one on the starboard side).

- Plate thickness: 15mm
- Yield strength: 350 MPa
- $\sigma_1 = [E/(1 - \nu^2)] (\varepsilon_1 + \nu \varepsilon_2)$

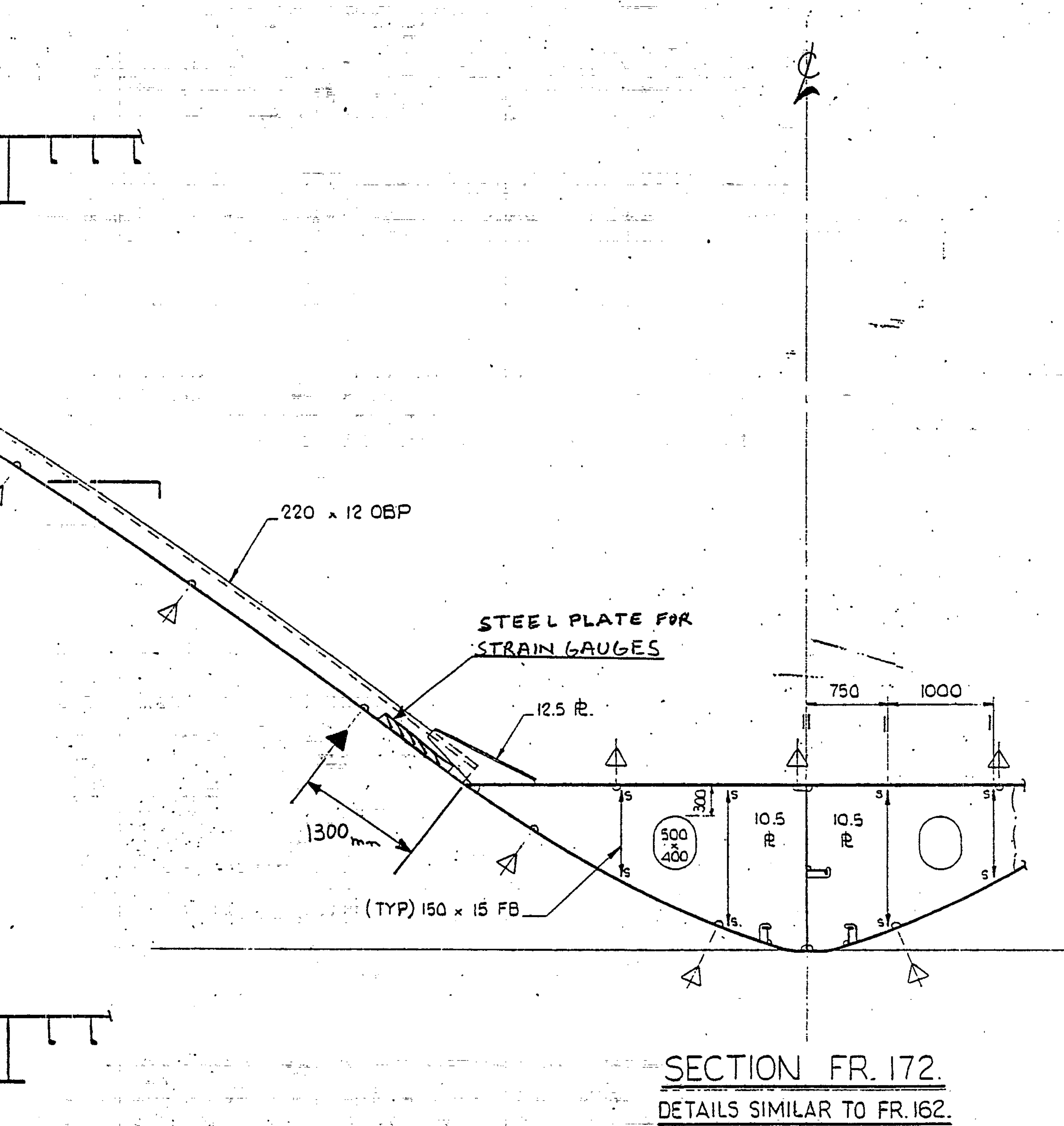


Figure 3 **Location of Steel Plates for Instrumentation: Section View Frame 172**

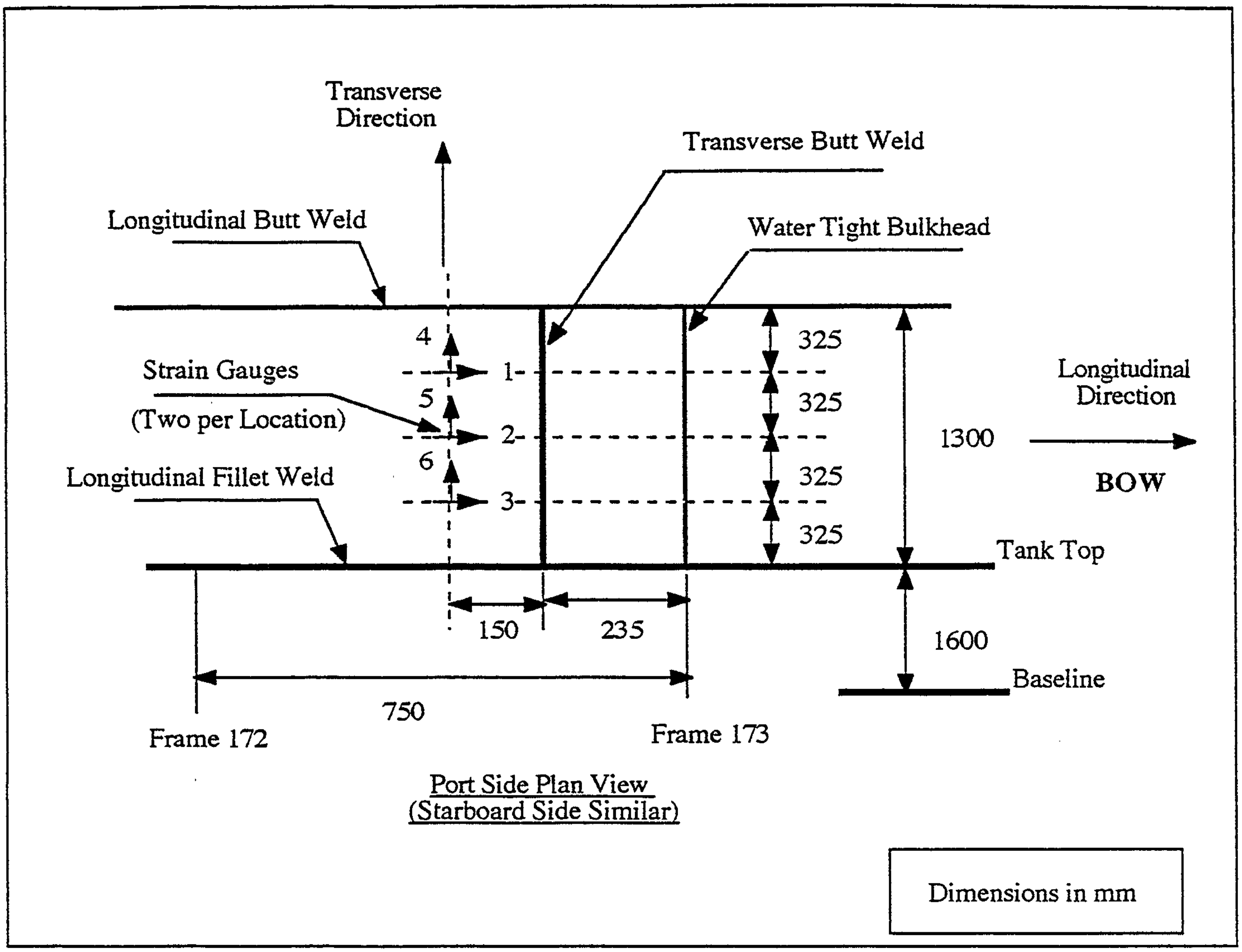
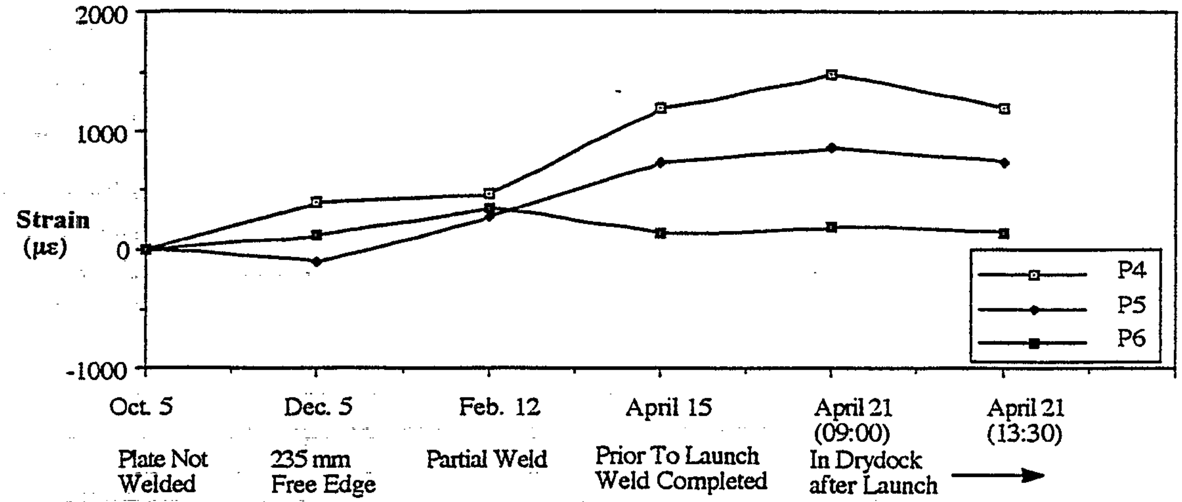


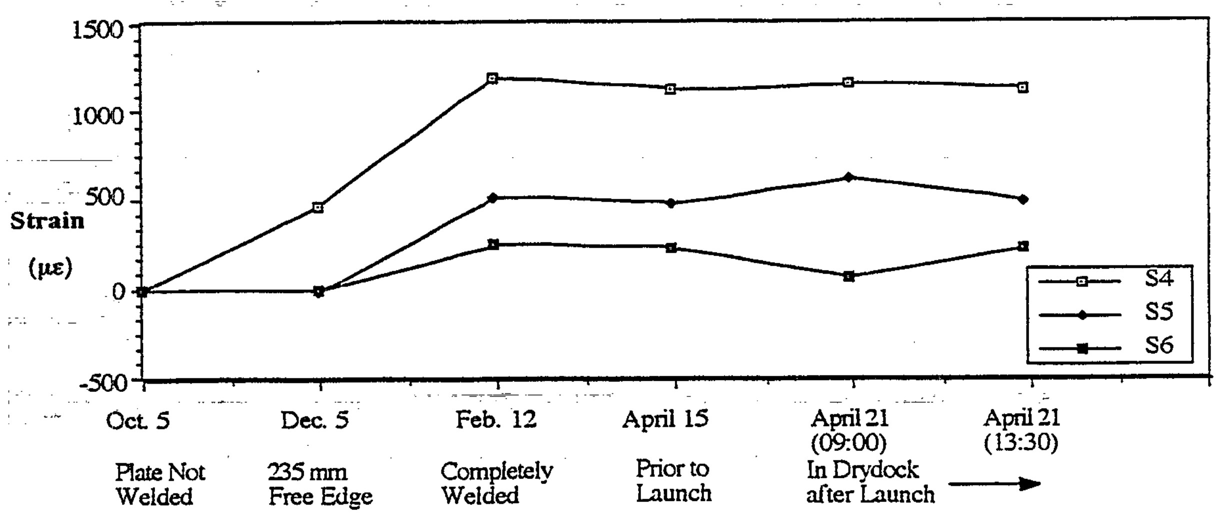
Figure 4: Location of Strain Gauges

Figure 11 Measured Strain Change on Port Side Plate - Transverse Direction

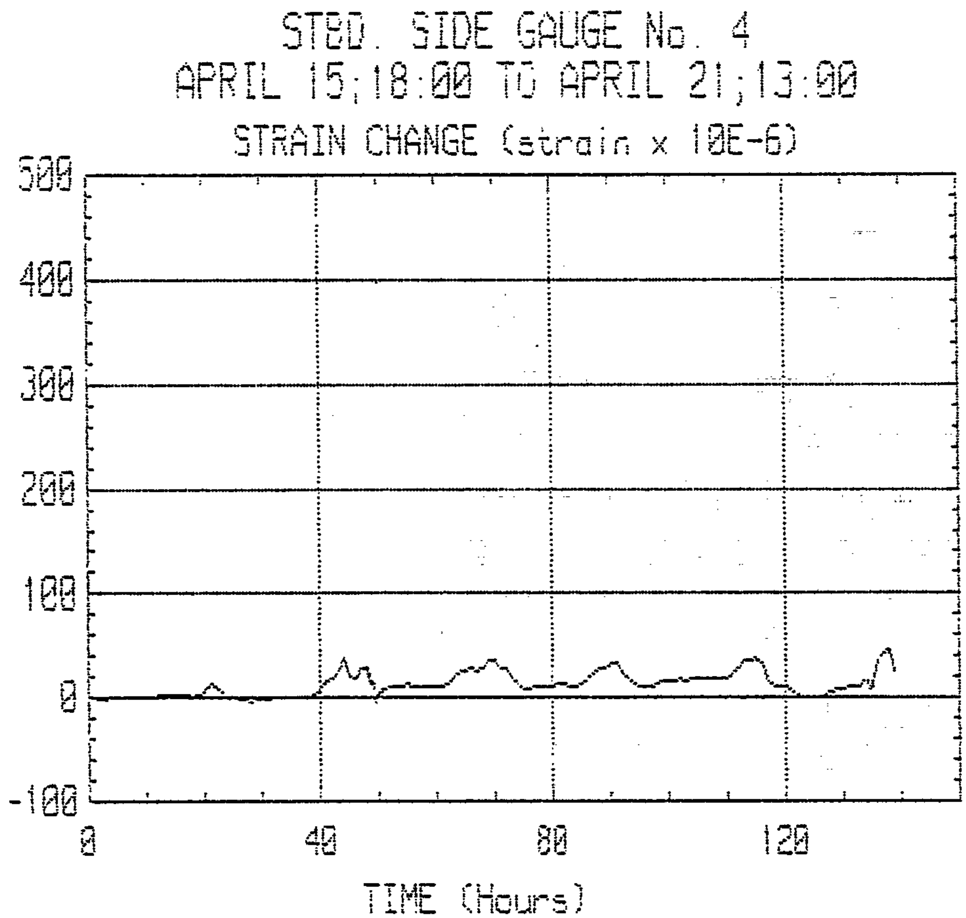


Measurement Date and Construction Phase

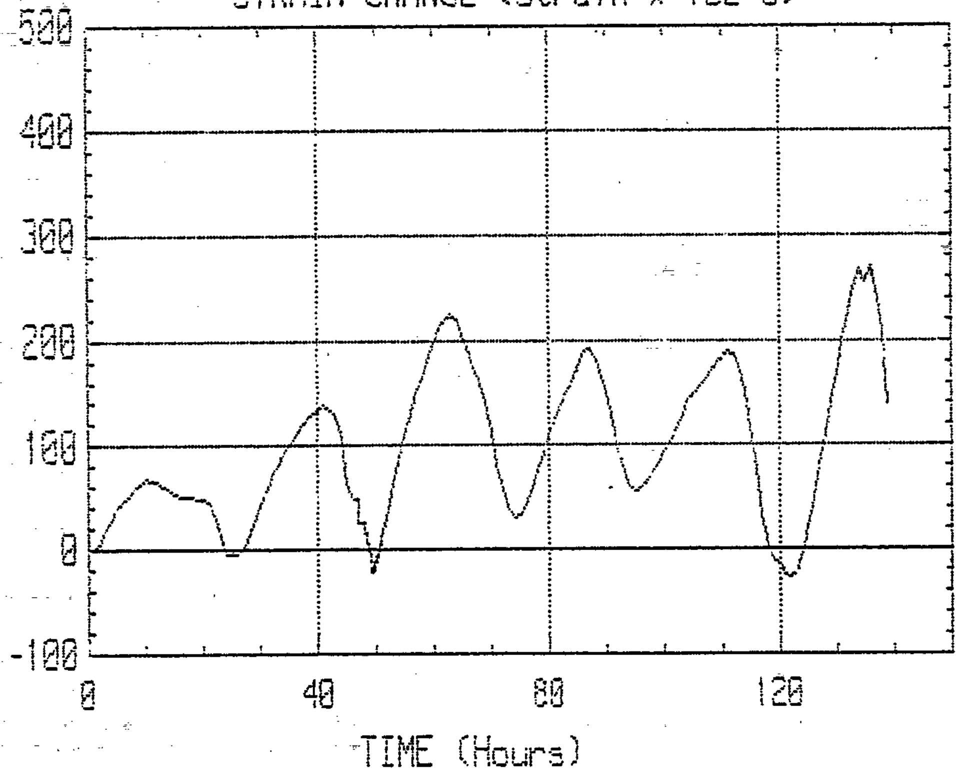
Figure 10 Measured Strain Change on Starboard Plate - Transverse Direction



Measurement Date and Construction Phase


STBD. SIDE GAUGE No. 4
APRIL 15;18:00 TO APRIL 21;13:00
STRAIN CHANGE (strain x 10E-6)
500
400
300
200
100
0
-100
0
40
80
120
TIME (Hours)

PORT SIDE GAUGE No. 4
APRIL 15;18.00 TO APRIL 21;13:00
STRAIN CHANGE (strain x 10E-6)



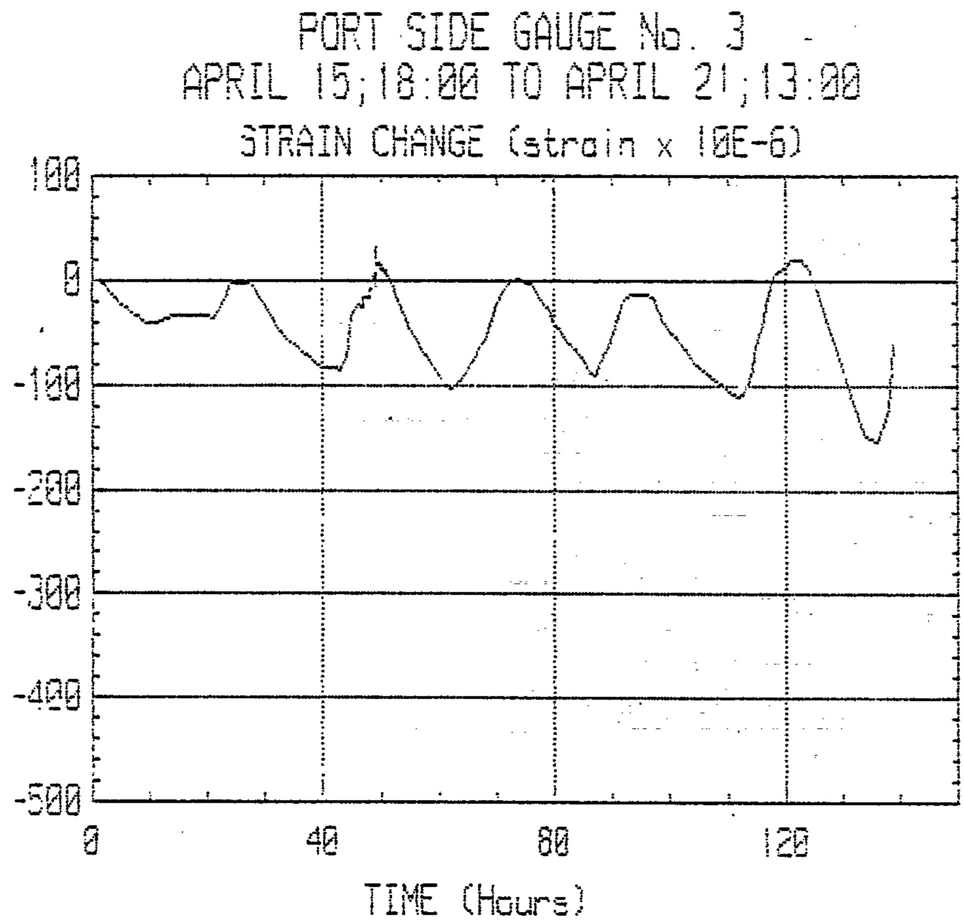
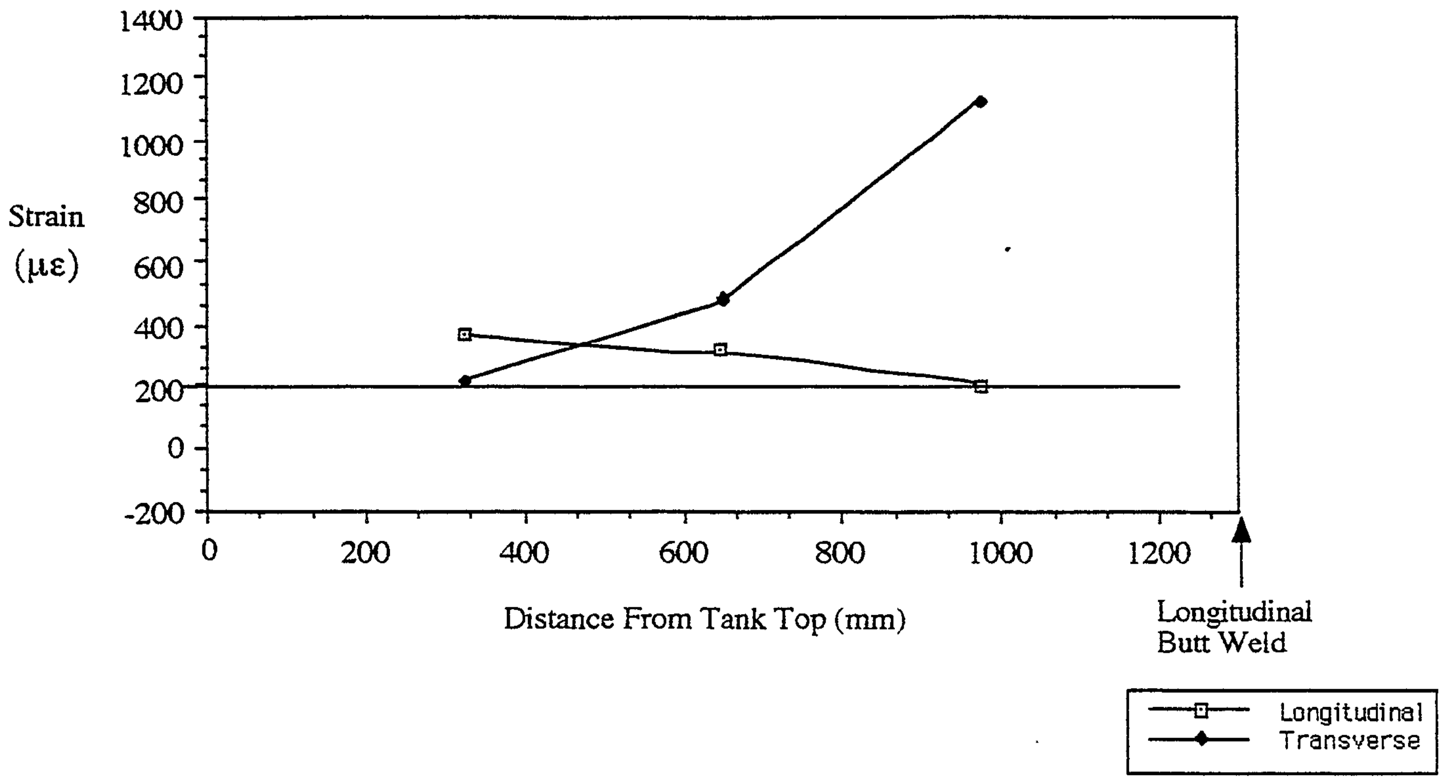

PORT SIDE GAUGE No. 3
APRIL 15;18:00 TO APRIL 21;13:00
STRAIN CHANGE (strain x 10E-6)
100
0
-100
-200
-300
-400
-500
0
40
80
120
TIME (Hours)

Table 3 Maximum Change in Measured Strain Levels From April 15 to April 21: Launching/Towing/Dry Docking

Gauge #	Strain (με) L	Strain (με) T	Stress (MPa) L	Stress (MPa) T
Port				
1	120		46	
4		270		70
2	-190		-34	
5		130		17
3	-150		-30	
6		60		3
Stbd.				
1	-30		-4	
4		43		8
2	130		39	
5		140		41
3	-40		-20	
6		-160		-39

Notes
L - Longitudinal Direction
T - Transverse Direction
Base Line Strain Level Defined on April 15: 18:00

The changes in the strain during the April 15 - April 21 time span are periodic in nature, the period being exactly 24 hours. This suggests that periodicity is related to exposure to sun and that the resulting changes in stress can be as high as 70MPa.



Port Side Shell Plate

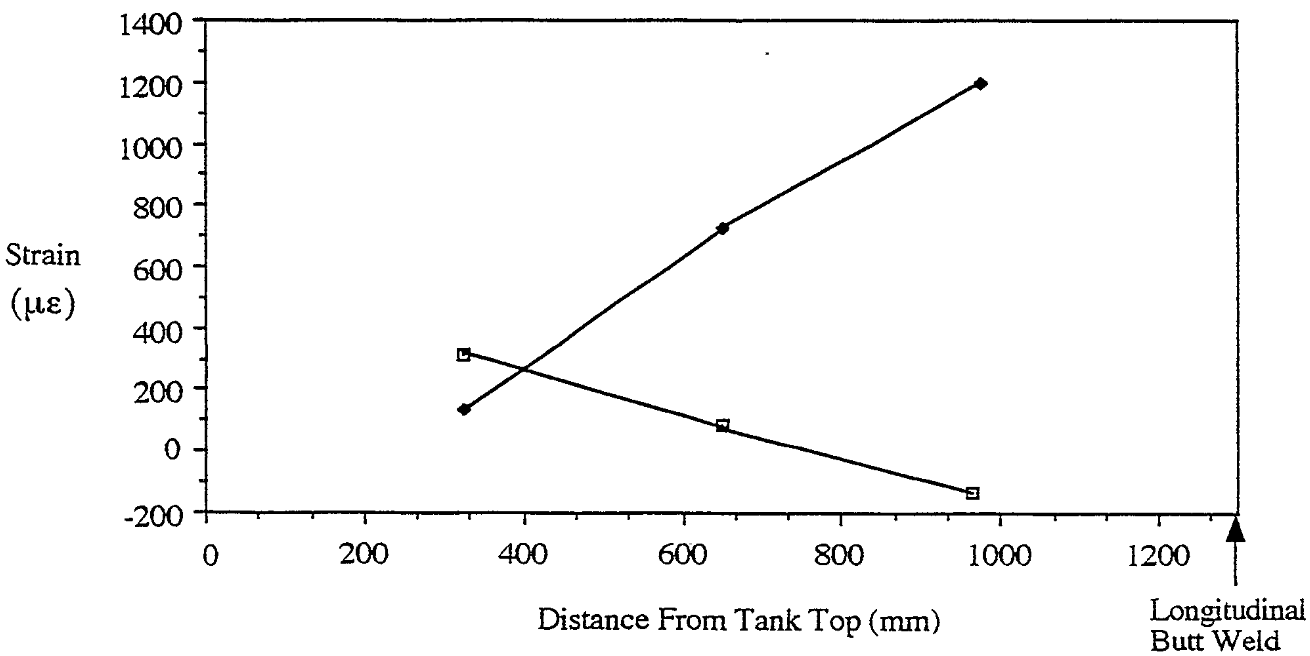


Figure 6 Reaction Strain Distributions on Welded Plate: April 21

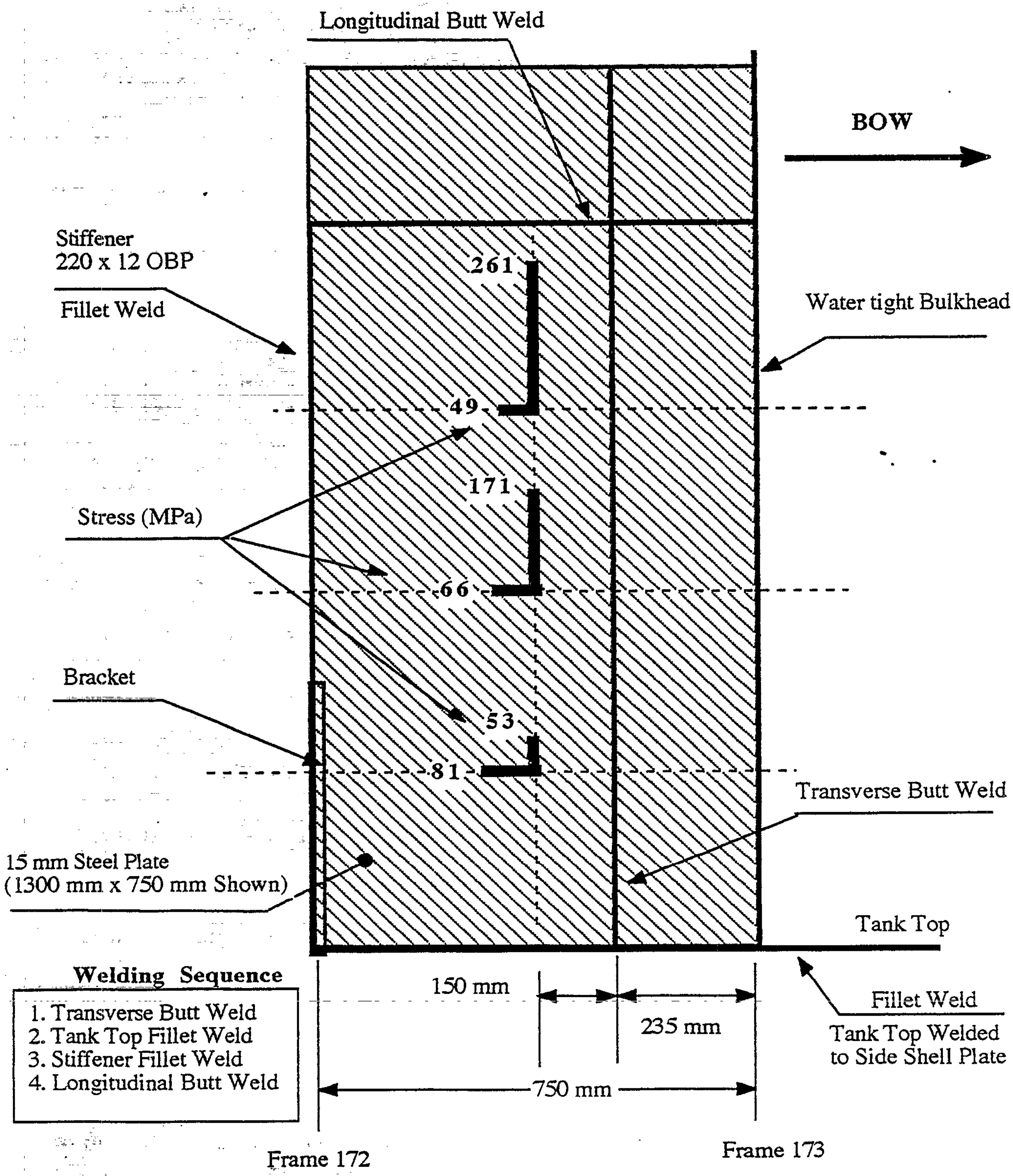


Figure 8 Reaction Stress Distribution on Port Side Shell Plate: April 21

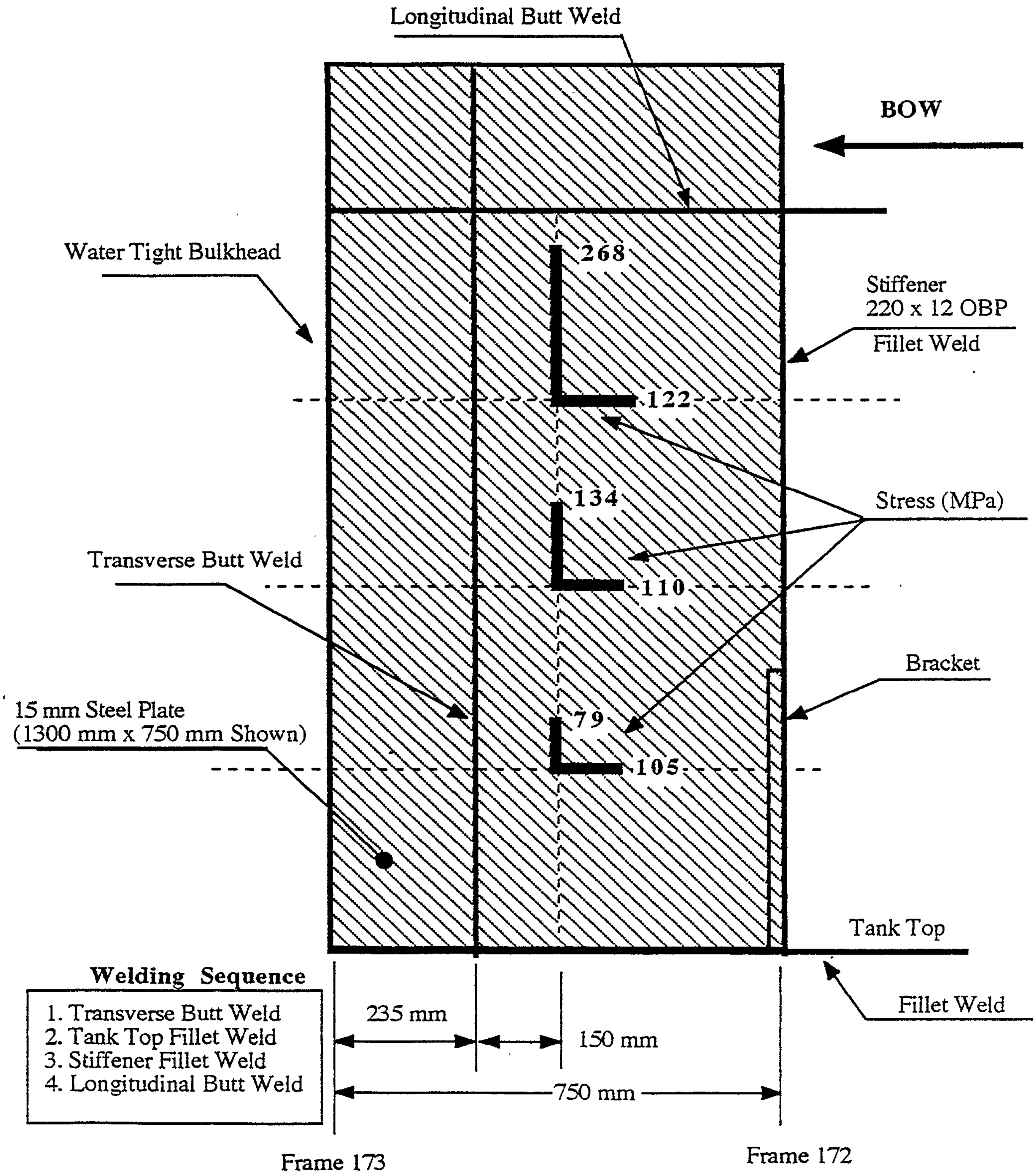


Figure 7 Reaction Stress Distribution on Starboard Side Shell Plate: April 21

Conclusions

1. Based on experimental data in literature, the long range tensile reaction stresses, perpendicular to the weld and at locations ≈ 300 mm (12") from it, can be as high as 91 MPa (13 ksi). At locations closer to the weld, they are expected to be higher.

2. In measurements made during the construction of a large ferry, the reaction stress perpendicular to a longitudinal butt weld, at a location 325 mm (13") from the weld was 268 MPa (≈ 38 ksi), though the transient reaction stress reached 330 MPa (47 ksi), about 95% of the steels yield strength.

Conclusions

3. Parallel to the hull girder longitudinal bending stresses, the peak reaction stress, 150 mm (6") from the transverse weld was 122 MPa (18 ksi), and the peak transient value was 149 MPa (21 ksi)

4. Reaction stresses should not be ignored in developing material specifications for fracture toughness or in fitness for purpose evaluation.

5. Further work is needed to quantify the magnitude of the reaction stresses, and their possible'shakedown' in service.