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FIRST RESULTS OF WIDE PLATE TESTING UNDER FATIGUE LOADING AT LOW TEMPERATURE

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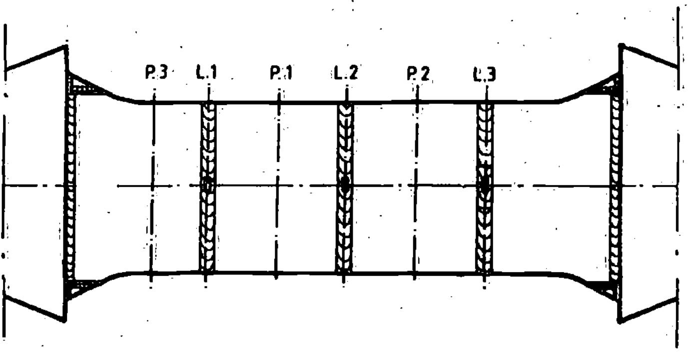

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Nomenclature

a - cracklength mm
ac - critical cracklength mm
ap - prefatigue cracklength mm
An - net-section area
B - thickness mm
CTOD - crack tip opening displacement mm
Fa - reserve factor on cracklength
FK - reserve factor of fracture toughness
FL - load factor
K - stress intensity factor MPa$\sqrt{m}$
Kc - critical stress intensity factor MPa$\sqrt{m}$
Kr - measure of proximity to LEFM failure
Lr - measure of proximity to plastic yielding
Pf - fracture load MN
Plim - limit load MN
Pnet - load at yielding in net-section MN
Ptol - tolarable load MN
Temp - test temperature degrees C
W - half width of wide plate mm

εy - yield strain %
σ - overall stress MPa
σf - flow stress ($\sigma y+\sigma uts$)/2 MPa
σnet - net-section stress MPa
σuts - ultimate tensile strength MPa
σy - yield strength MPa
$\bar{\Phi}$ - dimensionless CTOD
$\bar{\Phi}n$ - dimensionless CTOD corrected for finite plate width

1. INTRODUCTION

Testing wide plates under fatigue load conditions at low temperature is a continuation of the small scale fatigue bending tests at low temperature (fabalt-test) in the NIL fracture programme [1]. The wide plate experiments are carried out to verify if the results of the small scale tests are applicable to components of more complexity. For this purpose two wide plates are to be tested in the Ship Structure Laboratory (SSL) of the Delft University of Technology. This report presents the first results of the first wide plate that was tested.

The experiment on the first wide plate has not been completed yet. In consequence of some considerable time delay due to building-in and repairing problems, the experiments are stopped for the time being on behalf of other tests of higher priority. The experiments will be continued as soon as possible.

After presenting the test data and a short discussion of the results, the first fracture result will also be evaluated using two brittle fracture assessment methods.

2. SPECIMEN

2.1 Material

The wide plate was made of a Fe 510Nb steel which is the same steel that was used in the small scale fabalt-tests.
The welding procedure of the three welds in the wide plate is also similar to that of the small scale tests. For further details see [1] and [2].

2.2 Geometry and instrumentation

The specimen was composed cf four welded plates as shown in fig.1. This means that three welds can be tested under the same load conditions. Each weld was provided with a mechanical notch with a geometry shown in fig.2. Like the small scale specimens the notch was also situated in the center of the weld and can be considered as a flat through the thickness defect.

The instrumentation of the plate consisted of strain gauges on three plate sections and three weld sections, and COD spring gauges over the notch. The position of the strain gauges and COD spring gauges is shown in fig.3. Strain gauges nr. 1-6 were placed to record the stress distribution of the plate. The other strain gauges, in line with the notch, were placed to give an indication of the amount of crackgrowth during fatigue at low temperature. The temperature was controled by 7 thermocouples. The COD spring gauges were placed to indicate the amount of deformation at the cracktip (fig.4).

3. TEST PROCEDURE

The wide plate was tested in the 6 MN fatigue machine of the SSL. The experiment started with precracking the defects in the three welds. The amount of fatigue precracking and other test conditions are listed in table 1.

After precracking, the specimen was insulated and cooled to the test temperature by a nitrogen cooling device at the center of the plate and a supporting alcohol cooling device for both the side welds. The temperature for the center weld was selected at -80 °C. This temperature was chosen to verify fracturing during fatigue which occured in the small scale fabalt-tests. After cooling the center weld, the side welds appeared to have a temperature of -60 °C. This temperature was adapted as test temperature for the side welds.

The plate was tested at a frequency of 2 Hz and with a stress ratio of R=0.1. The test was performed by applying a constant maximum fatigue load of 4.403 MN. Adjusting the fatigue load to maintain a constant stress situation at the cracktip was not applied because of the absence of a reliable cracklength measuring method. This way of testing results in a critical region where fracture is most likely to occur. However, compared to small scale specimen this region is considerably larger, and is estimated as 30-40 mm for the present wide plate.

The plates were welded in the test-rigs in as welded condition. To avoid introducing secundary stresses the plates were not stretched. Unfortunately the deflection from the load line appeared to be larger as expected, and therefore high bending stresses were introduced during fatigue testing. Because strain gauges were placed at both sides of the plate, the bending effect could be quantified and will be taken into account in the discussion of the results.

4. DISCUSSION OF THE RESULTS

4.1 Measurement data

In fig.5 the strain gauge measurements are plotted as a function of the number of cycles for the variuos sections. As can be concluded from fig.5 high bending stresses of the same magnitude as the axial tension stress have occured in the center of the plate. The bending effect at the side welds is considerably less. The sudden change in strain gauge measurement data is caused by fracture in one of the connecting welds. Because of repairing this weld and placing of additional brackets the stress distribution appeared to have changed. The stress distribution over the wide plate can be illustrated by fig.6 at three different moments during this experiment.

Fig.7 shows the COD values as a function of the number of cycles. The cracktip value was not calculated because no reliable calculation method was available for this geometry. However, the COD-values indicate fracture at low toughness values which correspond to the results of the small scale tests.

The geometry of the fracture surface, shown in fig.8, illustrates the great influence of the bending effect. The fracture surface was examined and a fracture initiation point was located as indicated in fig.8. The position of this point will be used for calculating the critical cracklength.

4.2 Failure assesment evaluation

The moment of fracture of the center weld and the current situation at the side welds have been evaluated using two failure assessment methods, the COD design curve [3] with the revision of Dawes [4], and the R6 Rev.3 method [5]. For this purpose the critical cracklength was calculated from the initiation point on the fracture surface. The applied stress was evaluated taking into account the bending effect derived from the strain gauge measurement data.

Table 2 and fig.9 presents the relevant data and calculation results for the COD design curve method. For the critical CTOD-value use was made of the average CTOD-value at that temperature (indicated as av.) and of the minimum CTOD-value (min.). As can be seen the moment of fracture on the center of the weld would have been predicted safely using this method. In contrast with the results of the static wide plates in [6], fracture would not have been predicted safely when yielding in the net-section would have been used as a criterium. Comparing critical and actual cracklength of both side welds, fracture at one of those welds was very unlikely to occur and would have meant a very bad result.

The relevant test data and calculation results for the CEGB R6 Rev.3 method are gathered in table 3 and illustrated in fig.10. The results of this calculation show similar results as the COD design curve. Fracture at the center weld is predicted safely and fracture occuring at the side welds was very unlikely. The results are however less conservative compared to those from the COD design curve.

LITERATURE

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[2] Koning, C.,"NIL-breuktaaiheidsonderzoek/Nederlands programma. Uitnameplan en type proefstukken", TNO-report 85M/35/08862/KON/REV BRE 84-11, 2 juli 1984 (in Dutch).

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[4] Dawes, M.G.,"The CTOD design curve approach: limitations, finite size and application.", The Welding Institute, July 1985.

[5] Milne, I. et al.,"Assessment of the integrity of structures containing defects", Central Electricity Generating Board, R/H/R6-Revision 3, May 1986.

[6] Rongen, H.J.M. van,"Prediction of tolarable loads, for 17 wide plate tests in the NIL-fracture program, using the design curve (CTOD) approach.", TNO-report 85M/011959/RON /SCN, BRE 85-25, 26 september 1985.

Table 1. Test particulars

Weld	test temp. °C	prefatigue cracklength ap mm	cracklength at fracture a mm	area 2BW mm^2	netto area An mm^2	load at fracture Pf MN
L1	-60	17.3	34.8	20014	18884	4.403
L2	-80	19.8	92.3	20150	14560	4.403
L3	-60	17.6	35.1	19313	18223	4.403

Table 2. CTOD design curve, with last revision of Dawes : $\bar{\Phi}_n=\bar{\Phi}(1-a/W)$

Weld	Temp °C	2BW mm²	An mm²	a mm	Pf MN	σnet MPa	σ MPa	Pnet σy*An MN	Pf/Pn	CTOD av. mm	CTOD min. mm
L1	-60	22196	19690	35	4.403	224	198	11.68	0.38	0.246	0.160
L2	-80	20150	14560	92.3	4.403	302	219	9.03	0.49	0.070	0.043
L3	-60	21328	18920	35	4.403	232	206	11.20	0.39	0.246	0.160

weld	average CTOD $\bar{\Phi}_n$	average CTOD σ/σy	average CTOD σ MPa	minimum CTOD $\bar{\Phi}_n$	minimum CTOD σ/σy	minimum CTOD σ MPA
L1	0.359	0.609	361	0.233	0.483	286
L2	0.029	0.170	105	0.018	0.134	83
L3	0.359	0.609	361	0.233	0.483	286

Weld material properties

Temp °C	σy MPA	σf MPa	σuts MPa	εy %
-60	592	639	686	0.2766
-80	620	666	711	0.2884

Weld	σ test MPa	σ/σy test	Pf MN	average CTOD Ptol MN	average CTOD Pf/Pt	average CTOD a crit mm	average CTOD a/ac	minimum CTOD Pt MN	minimum CTOD Pf/Pt	minimum CTOD ac mm	minimum CTOD a/ac
L1	198	0.334	4.403	8.01	0.55	90.0	0.39	6.35	0.69	62.2	0.56
L2	219	0.353	4.403	2.12	2.08	28.2	3.27	1.67	2.64	17.9	5.16
L3	206	0.348	4.403	7.70	0.57	84.9	0.41	6.10	0.72	61.0	0.57

Table 3. Failure assesment method CEGB R6 - Revision 3.

Weld	Temp. °C	Pf MN	B mm	W mm	a mm	Kc MPa√m	σy MPa	Pnet MN	Lr	σ MPa	K MPa√m	Kr
L1	-60	4.403	35.8	310	35	178.1	592	11.68	0.377	223	74.4	0.418
L2	-80	4.403	32.5	310	92.3	101.1	620	9.03	0.488	285.2	161.8	1.60
L3	-60	4.403	34.4	310	35	178	592	11.20	0.394	233	77.8	0.447

Weld	Limit condition				Reserve factors		
	Lr	K	Plim MN	a mm	FK	FL	Fa
L1	0.488	0.961	5.70	97.5	0.43	0.77	0.36
L2	0.305	0.987	2.75	38.6	1.62	1.60	2.39
L3	0.499	0.958	5.58	93.0	0.47	0.79	0.38

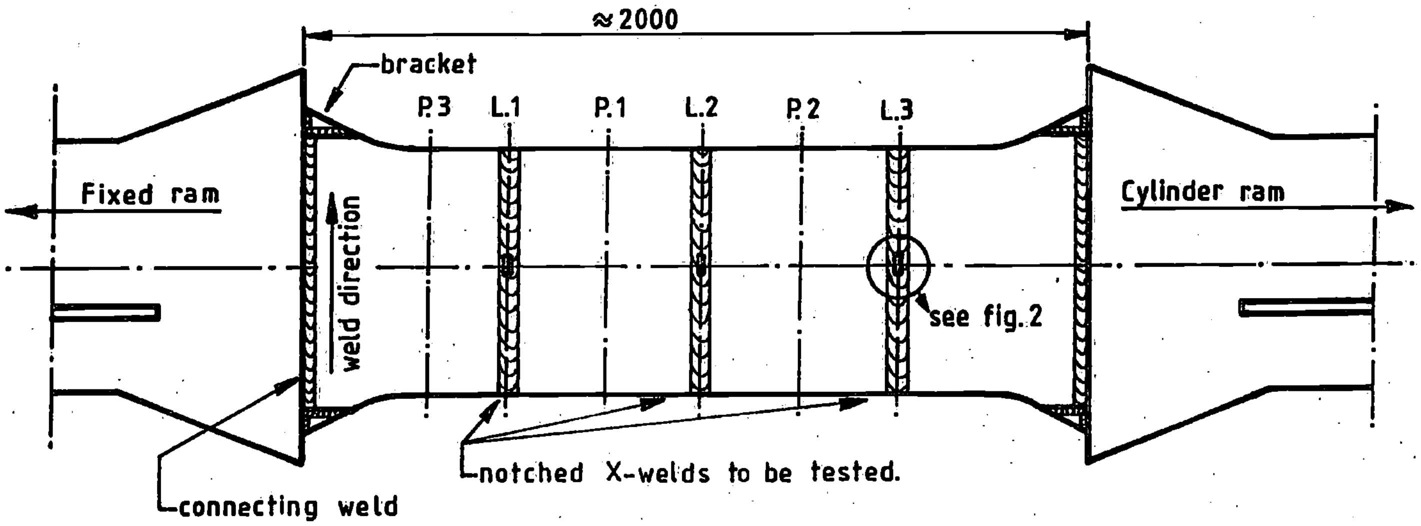


Fig.1 General view of plate between loading clambs.

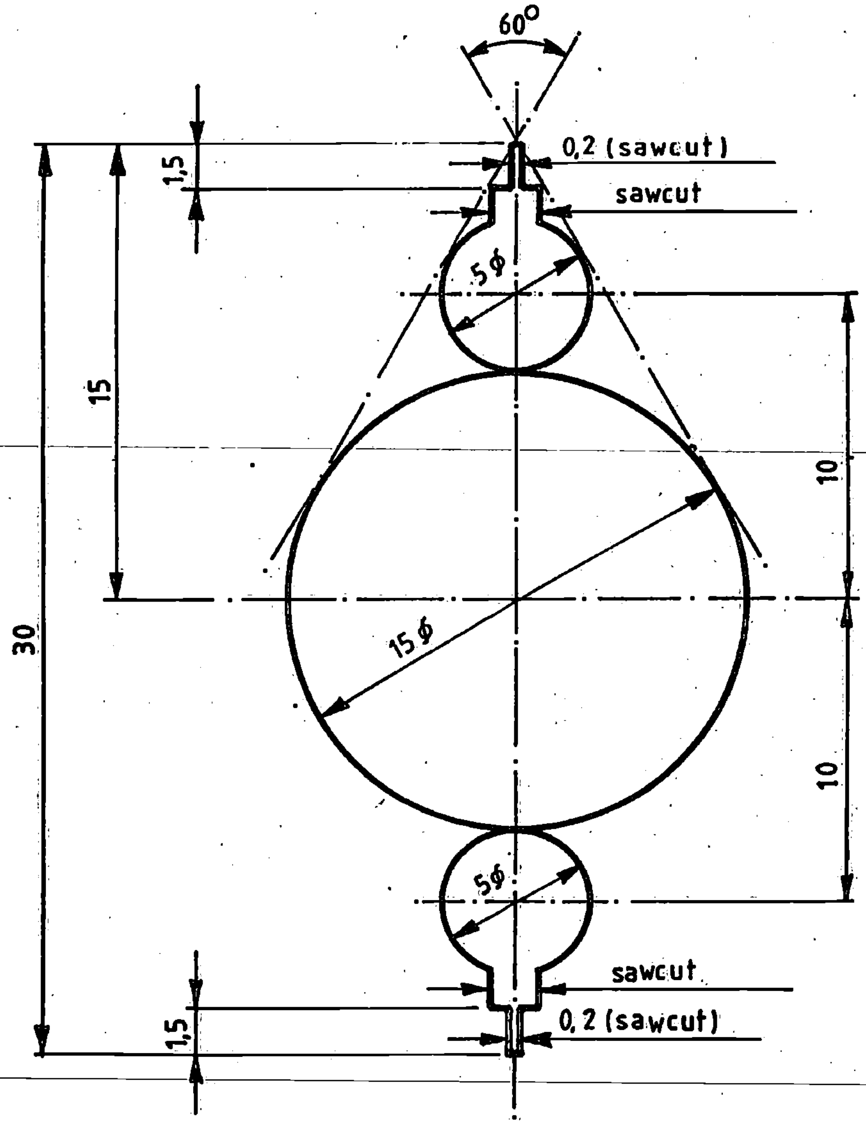


Fig.2 Detail of notches

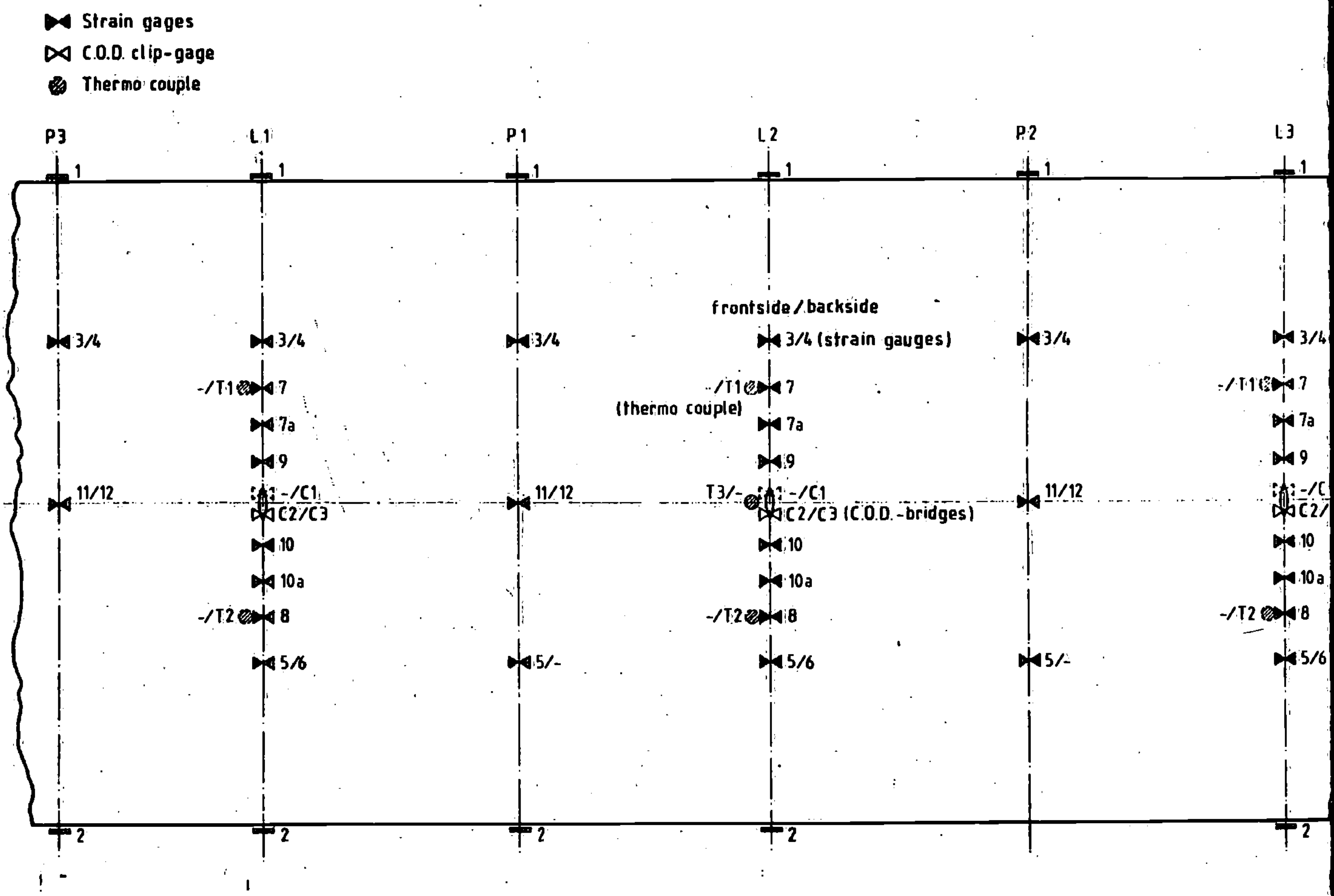


fig.3. Instrumentation of the wide plate.

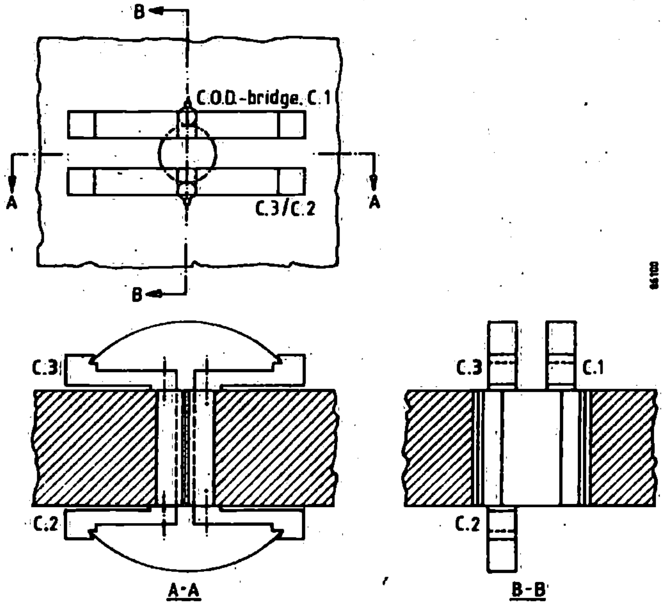


fig.4. Detail of COD spring gauge instrumentation instrumentation

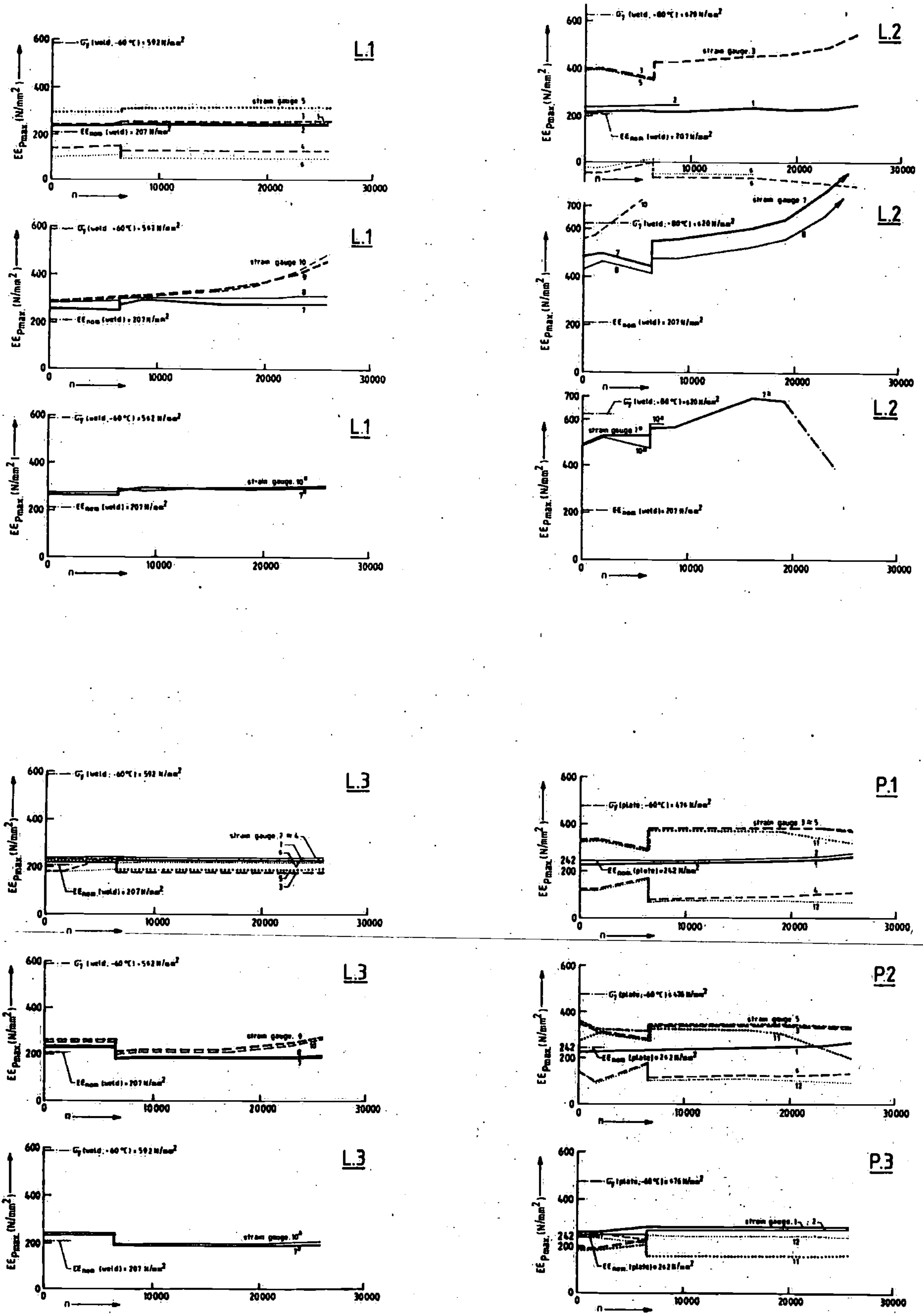


fig.5. Plots of strain gauge measurement data at weld and plate sections.

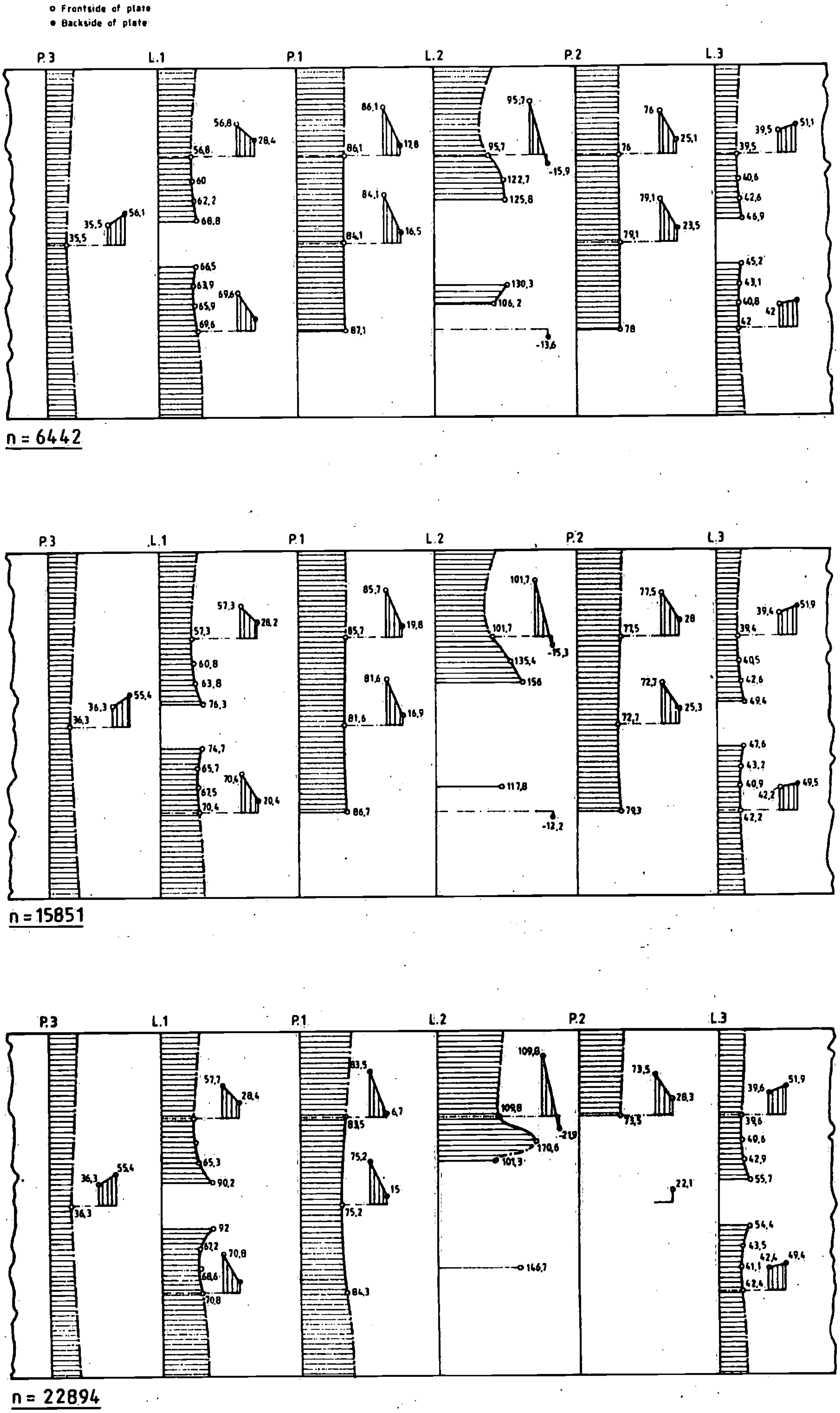
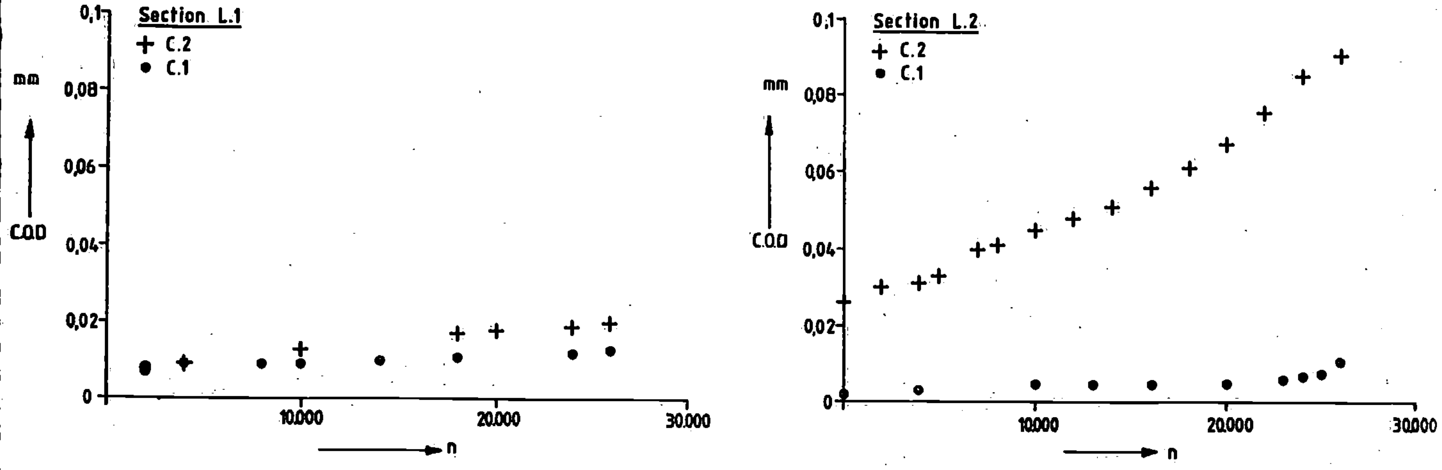


fig.6. Stress distribution over the wide plate at three different stages during the experiment. Numbers refer to eε/1000 kN values.



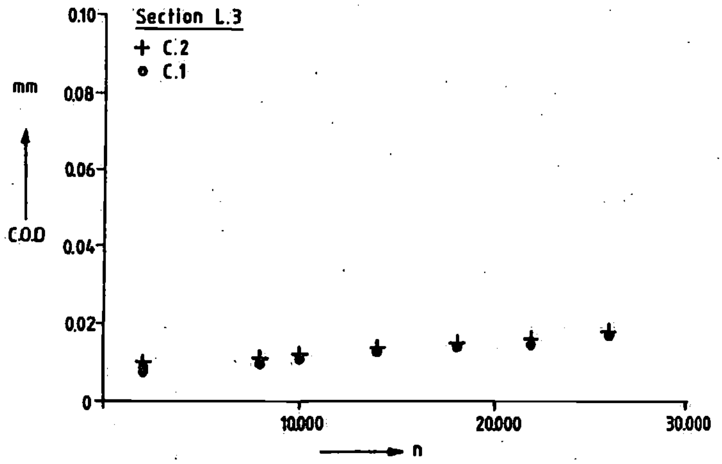


fig.7. COD measurements at welded sections.

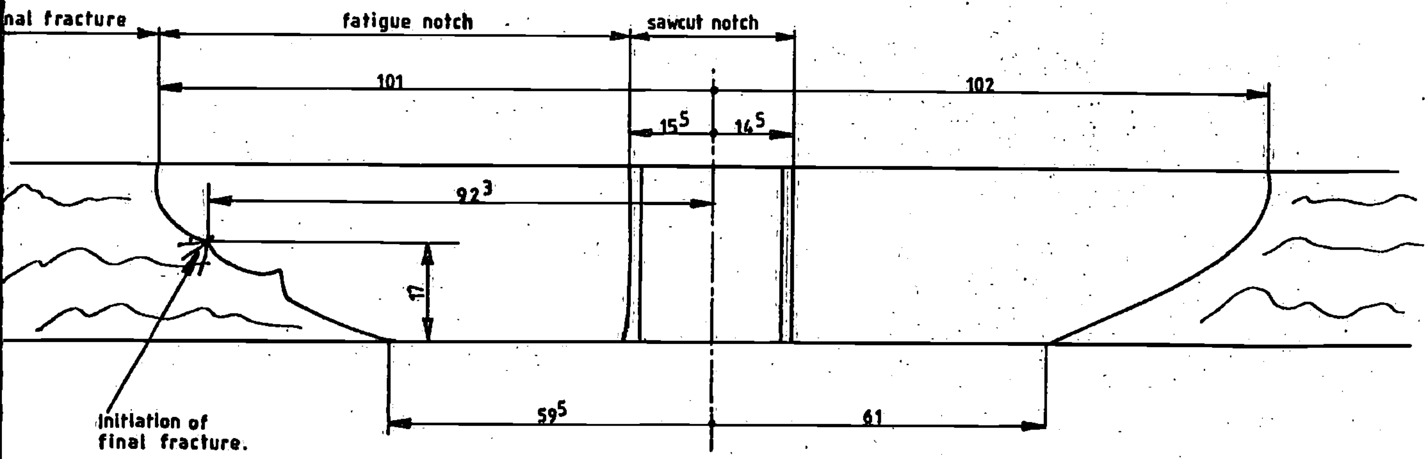


fig.8. Fracture surface of welded section L2.

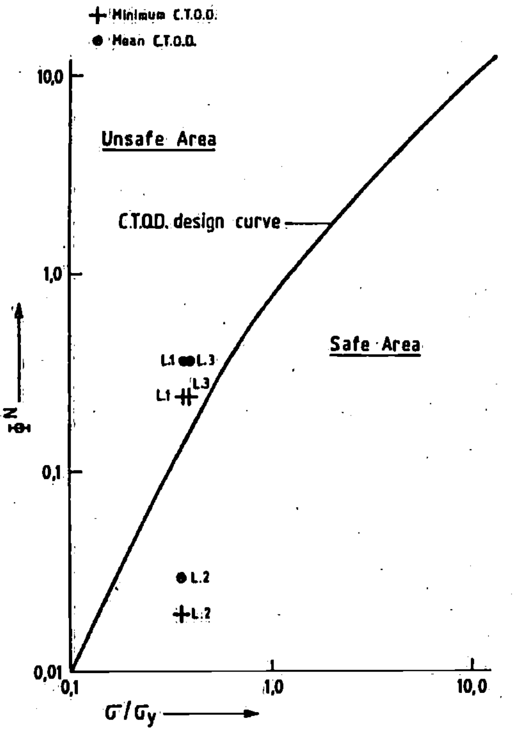


fig.9. COD design curve diagram.

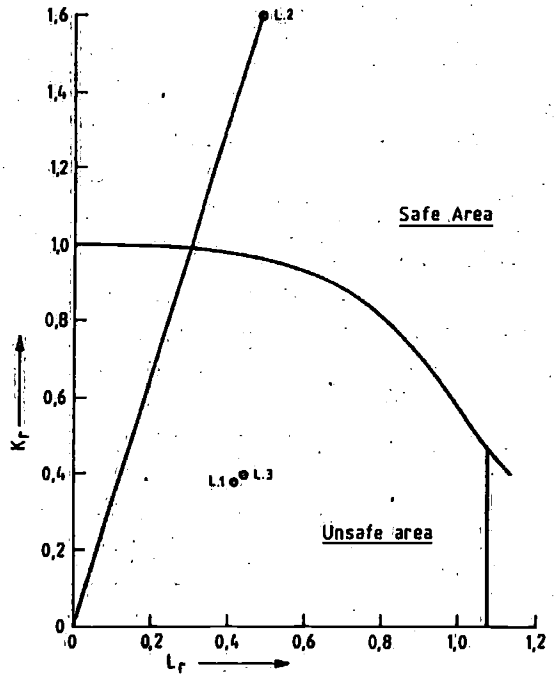


fig.10. Failure route R6 - rev.3 diagram.