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LABORATORY TESTS ORTHOTROPIC DECK BASCULE BRIDGE VAN BRIENENOORD

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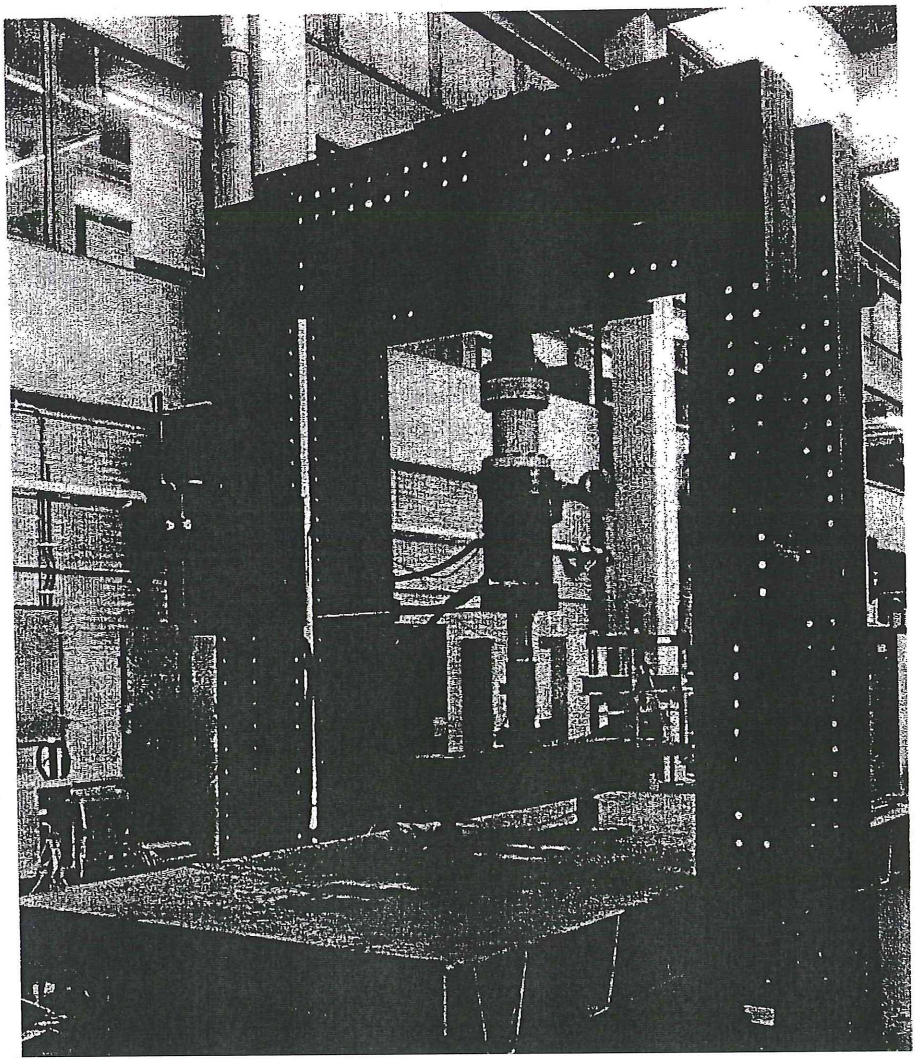

Archives
Steel Structures

Faculty of Civil Engineering and Geosciences
Stevin II Laboratory, section SH

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PRINCIPAL:

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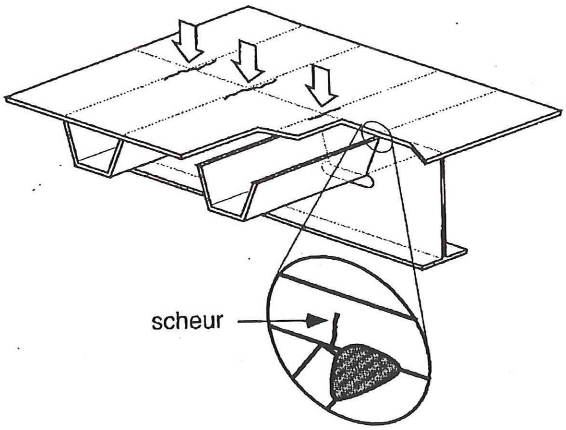
CONTENTS

SUMMARY

This laboratory report, reports full scale laboratory tests on two orthotropic bridge deck panels, carried out in charge of the Department of Steel Structures of the Ministry of Transport, Watermanagement and Public Works. The welded connection between the longitudinal trough stiffener web, cross beam web and deck plate has been the main subject of these tests.

Static tests have been carried out to obtain information about the stress distribution at the top side of the deck plate at the point of interest. The influence of different size of contact surfaces of the loaded area simulating wheel tyres has been investigated.

Fatigue tests have been carried out to obtain information about the fatigue behaviour of this welded connection, such as crack initiation point(s) and crack growth. Based on the obtained results the fatigue design strength of this particular welded detail has been defined according to the fatigue design rules of Eurocode 3 and NEN 2063.



Studied welded connection

1. INTRODUCTION

During visual examination of the condition of the surfacing of the bascule bridge Van Brienenoord several longitudinal cracks were found in the slow lane. After detailed inspection by removing the surfacing from the steel plate, more cracks appeared to be present in the steel deck as shown in Figure 1.1. The crack length varied from small indications up to 600 mm. The cracks initiated at the root of the weld connecting the continuous longitudinal trough stiffener to the deck plate at the point were also the crossbeam has been welded to the deck plate as shown in Figure 1.2. The cracks propagated through the total deck plate and surfacing and grow in longitudinal direction parallel to the stiffener to deck plate weld. Since the initiation of the crack was inside the trough no inspection from underneath was possible and they could also not be observed during regular visual inspection of the steel deck in the past. Since long adjacent parallel cracks could cause an unsafe traffic situation, preliminary repairs by grinding and filling the groove by a butt weld had to be carried out directly.

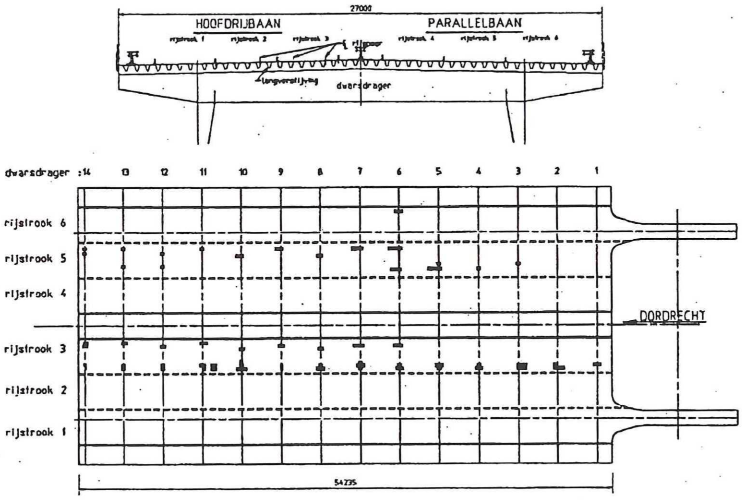


Figure 1.1 Locations of deck plate cracks

At that time it was clear that further investigations were urgently needed to obtain more information about this type of crack. Apart from a study of relevant literature, site measurements on the bridge as well as laboratory tests have been carried out to obtain information about stress spectra, stress distributions and fatigue strength of this specific detail. Finite element calculations were done to verify the experimental observations.

This laboratory report, reports the full scale laboratory tests carried out at the Stevin Laboratory of the Department of Civil Engineering and Geosciences at The Delft University of Technology in charge of the Department of Steel Structures of the Ministry of Transport, Watermanagement and Public Works.

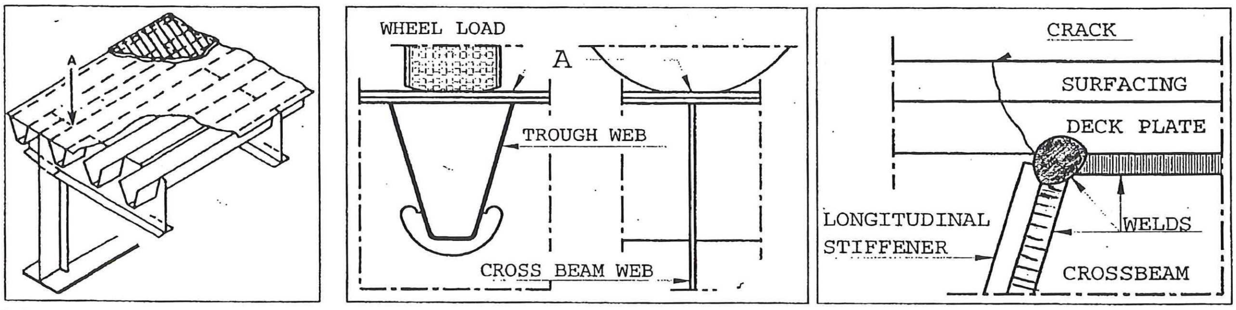


Figure 1.2 Crack initiation and crack propagation

2. TEST SET-UP AND TEST SPECIMENS

2.1 TEST ARRANGEMENT

To obtain information about the fatigue strength of the stiffener-cross beam-deck plate connection and the stress distribution of this detail at the top side of the deck plate, static as well as dynamic laboratory tests have been carried out on an orthotropic deck panel with the same dimensions as the steel deck of the Van Brienenoord bascule bridge (see Figure 2.1.a). Full scale experiments were needed to obtain realistic stress distributions. As shown in Figure 2.1.b the actuator load has been distributed over two loading areas, simulating two wheel tyres on the test specimen. Different dimensions of these areas have been used as shown in Figure 2.1.c. The load on each area has been measured using calibrated load cells. In this way the behaviour of four welded connections could be studied at the same time.

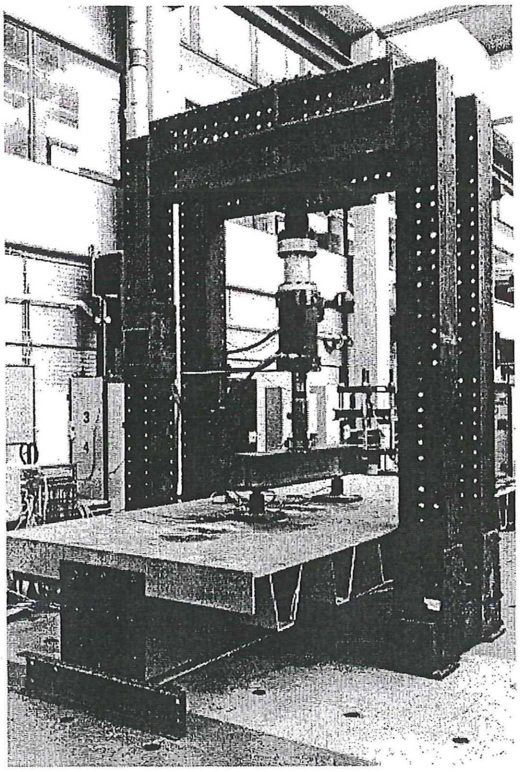


Figure 2.1a Test set-up

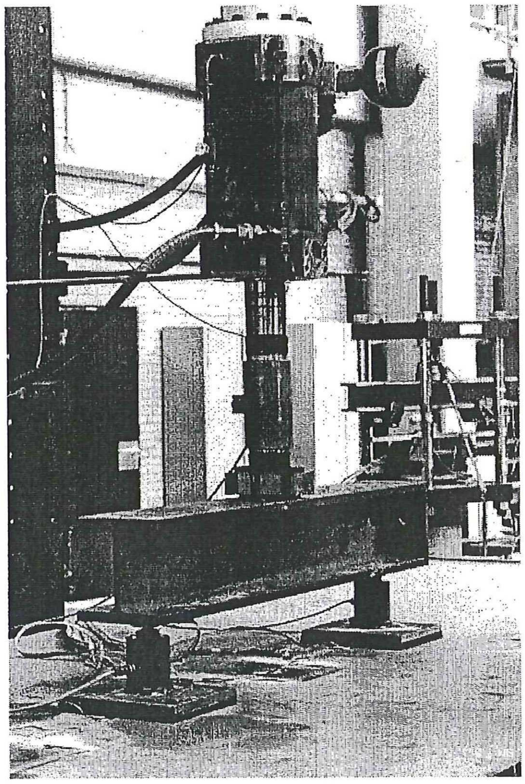


Figure 2.1.b Local wheel load

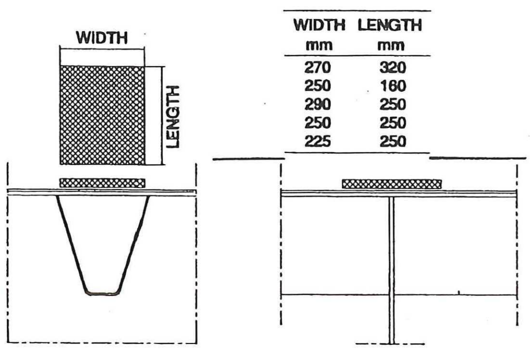


Figure 2.1c Wheel prints

2.2 TEST SPECIMENS

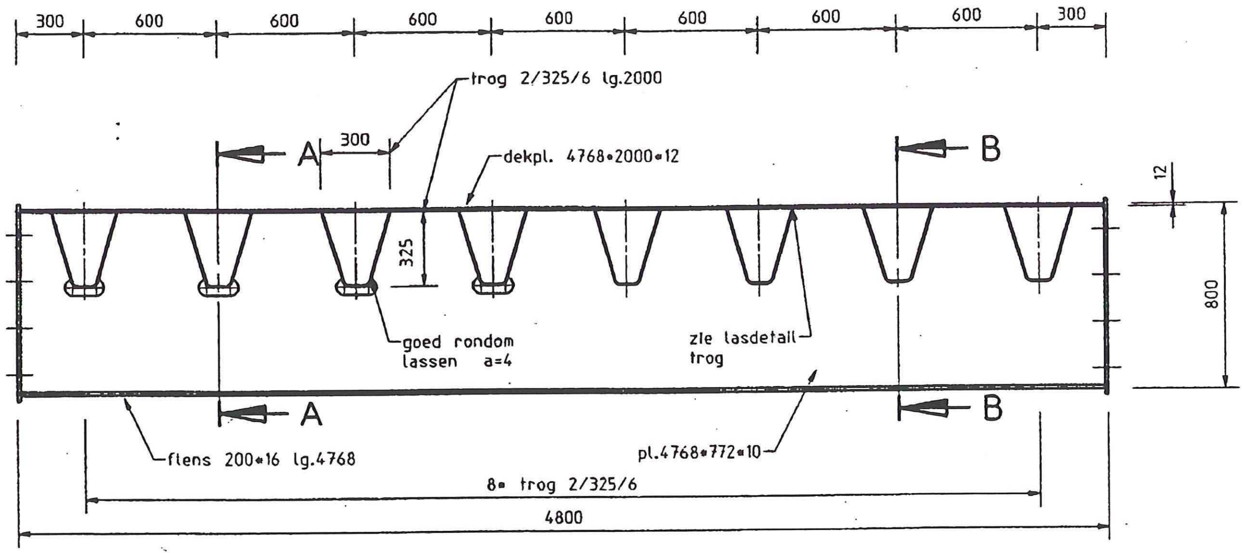


Figure 2.2.a Test panel - Front view

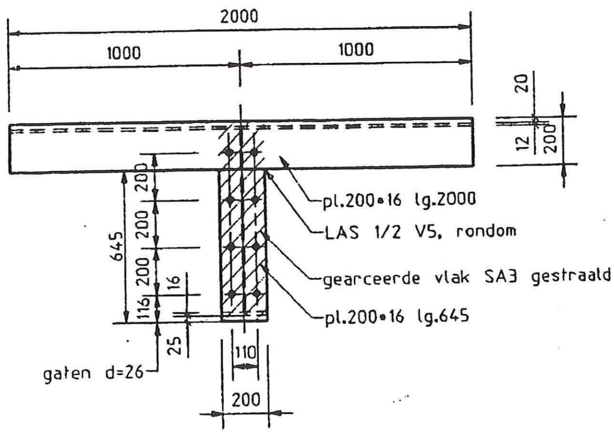


Figure 2.2.b Test panel side view

The two full scale test specimens used in this research, consists each of a cross beam with 8 longitudinal trough stiffeners. The deck plate thickness amounts 12 mm. No surfacing system has been applied on the deck plate as a 8 mm epoxy layer has no influence on the stress distribution in the deck plate. The typical dimensions of the specimens are shown in Figure 2.2.

2.2.1 BIRKHOFF TEST PANEL

The first specimen (Birkhoff Panel) had already been tested in the past [2]. During those tests, sponsored by the European Coal and Steel Community (ECSC), the attention was focussed on the fatigue strength and the stress distribution at the bottom side of the connection between the longitudinal trough stiffener and the cross beam. A total of 3.5 million load cycles of 300 kN had been applied on the specimen in that research program. Due to lack of time, the Ministry of Transport decided to test the "Birkhoff Panel" in the first place.

During the execution of the new tests on this panel RTD Quality Services performed several non-destructive testing techniques on the specimen [3]. They found cracks in the stiffener-cross beam-deck plate

connection at locations which were not directly loaded in the previous and/or current tests. Probably these cracks have been initiated by the enforced shear deformations of the crossbeam which were present in the test specimen after the previous fatigue test for a period of 3.5 million cycles. From the finite element results as shown in Figure 2.3 it can be seen that the shear deformations in the cross beam also effects the shape of the deck plate. Additional finite element calculations showed that this behaviour results also in relative high peak stresses at the stiffener-deck plate-cross beam connection [4].
So the results of the static and fatigue tests on the "Birkhoff Panel" reported in this report can be affected by the previous ECSC tests on this panel.

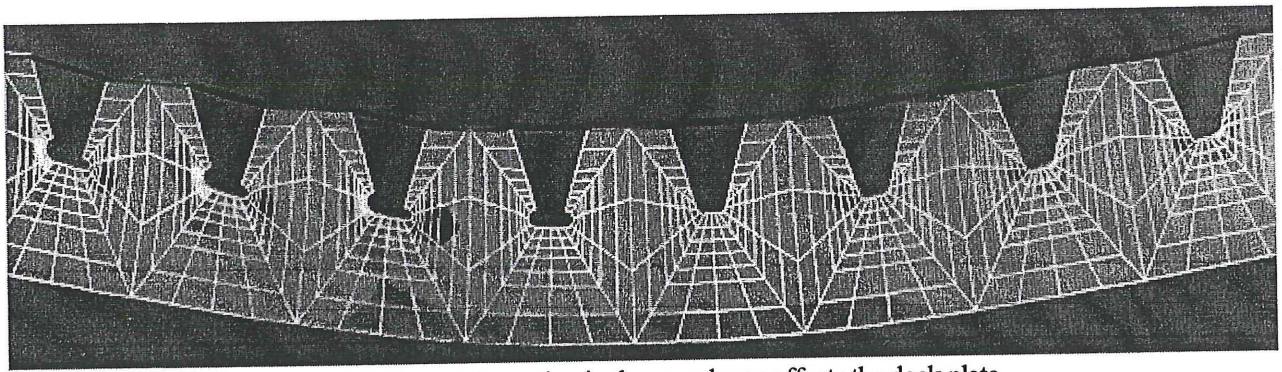


Figure 2.3 Shear deformation in the cross beam effects the deck plate

2.2.2 HOLLANDIA TEST PANEL

The second specimen (Hollandia Panel) has been tested in the "as built" situation. Before starting the laboratory tests the RTD Quality Services performed several non-destructive testing techniques on all the stiffener-cross beam-deck plate connection. No cracks or crack- like indications were found.

3. TEST MONITORING

3.1 STRAIN MEASUREMENTS

The test specimens have been instrumented with a number of strain gauges before testing. A review of the used strain gauge locations and numbers is given in Figure 3.1. During the endurance test strain measurements were carried dynamically to check the applied stress range on the test specimen. Furthermore, strain measurements were envisaged 24 hours a day to obtain information about moment and location of starting a crack.

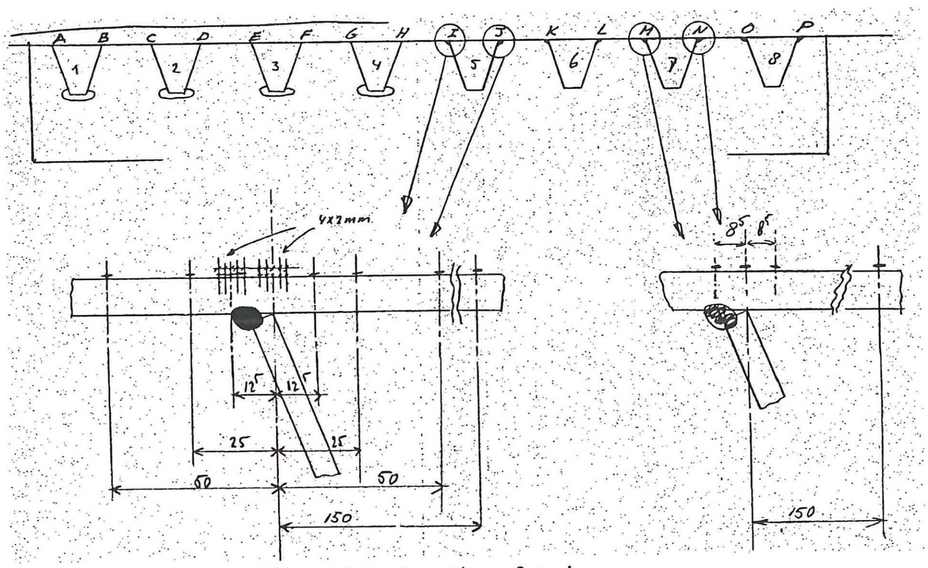


Figure 3.1.a Location of strain gauges

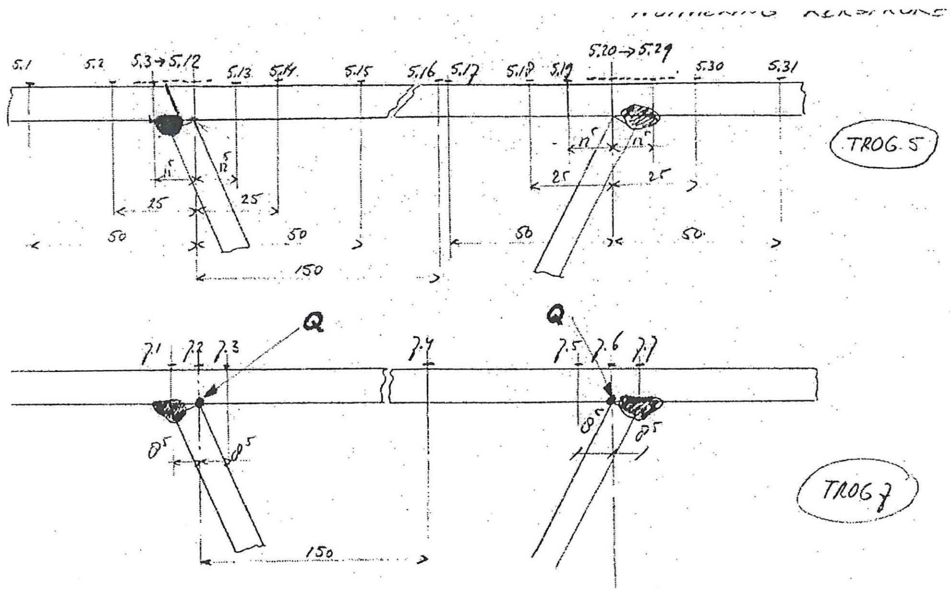


Figure 3.1.b Strain gauge numbers

The location of the marks Q at the point where the web of the troughs touches the deck plate have been pointed out from the outer ends of the specimen. So the exact location of the land mark Q at the location of the cross beam web was difficult to control. It is possible that there exists some deviation from the drawings in Figure 3.1.

3.2 CRACK GROWTH MONITORING

Measurements of crack growth were carried out by more or less periodic visual inspection with a magnifying glass. It was only possible to measure crack length at the surface of the specimens

3.3 STAGES IN FATIGUE FAILURE

As far as possible the normally used following four stages in fatigue failure expressed in number of cycles are used:

N1: Moment of crack initiation given by 10% strain fall off measured in the strain gauge nearest to the crack.

N2: Moment of visual crack initiation.

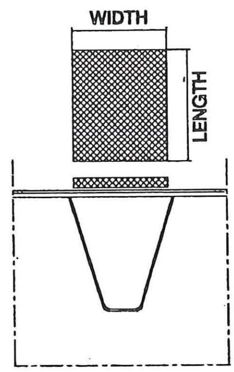
N3: The number of cycles indicating a surface crack at the top side of the deck plate with a length of 50 mm is reached.

N4: For this test the moment that the end of the cracks disappeared under the "wheel prints".

To obtain more information about the crack development in the deck plate, besides stage N1, as far as possible, three other stages of change in strain level have been defined (+10%, -25% and -50%).

4. TEST PROGRAMME

The static tests have been carried out using five different sizes of the loading area simulating different wheel types as shown in Figure 4.1. The fatigue tests have been carried out using loading area with a width of 270 mm and length of 320 mm representing a "super single wheel tyre". In all tests centre line of the load has been positioned above the cross beam respectively a longitudinal trough (see Figure 4.1.)



WIDTH mm	LENGTH mm	LOAD kN	LOAD N/mm²
270	320	70.4	0.82
250	160	30.2	0.76
290	250	65.9	0.90
250	250	50.2	0.80
225	250	50.4	0.90

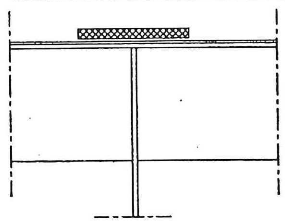


Figure 4.1 Contact surfaces

4.1 BIRKHOFF PANEL

A review of the tests (test number 1-8) carried out on the Birkhoff Panel is shown in Table 1.

Table 1. Test programme Birkhoff Panel

STATIC TESTS									
Test nr	Trough 5				Trough 7				Test Results
	Fmax kN		Width mm	Length mm	Fmax kN		Width mm	Length mm	APPENDIX
1	- 35.4		270	320	- 35.7		270	320	A
2	- 14.1		250	160	- 14.3		250	160	B
3	- 32.8		290	250	- 31.7		290	250	C
4	- 24.3		250	250	- 24.4		250	250	D
5	- 24.1		225	250	- 25.6		225	250	E
6	- 113.7		270	320					F
FATIGUE TESTS									
Test nr	Trough 5				Trough 7				Test Results
	Fmax kN	Fmin kN	ΔF kN		Fmax kN	Fmin kN	ΔF kN		APPENDIX
7	- 85.0	- 4.8	80.2		- 87.8	- 7.0	80.9		G
	Trough 4				Trough 6				
8	- 61.5	- 3.7	57.8		- 62.7	- 4.1	58.6		F

4.2 HOLLANDIA PANEL

A review of the tests (test number 9-16) carried out on the Hollandia Panel is shown in the following table:

Table 2. Test programme Hollandia Panel

STATIC TESTS									
Test nr	Trough 5				Trough 7				Test Results
	Fmax kN		Width mm	Length mm	Fmax kN		Width mm	Length mm	APPENDIX
9	-200 ?		270	320	-200 ?		270	320	-
10	- 70.4		270	320	- 69.2		270	320	I
11	- 30.2		250	160	- 29.4		250	160	J
12	- 65.9		290	250	- 64.9		290	250	K
13	- 50.2		250	250	- 49.0		250	250	L
14	- 50.4		225	250	- 49.2		225	250	M
FATIGUE TESTS									
Test nr	Trough 5				Trough 7				Test Results
	Fmax kN	Fmin kN	ΔF kN		Fmax kN	Fmin kN	ΔF kN		APPENDIX
15	- 88.0	- 8.0	80.0		- 86.3	- 7.8	78.5		N
	Trough 4				Trough 6				
16			80.1				79.7		-
17			-				80.0		P

In all Tests except Test 17 two troughs have been loaded at the same time. Test 9 was an uncontrolled overloading of the test specimen

5. TEST RESULTS

5.1 STATIC TESTS

All results of the strain gauge measurements carried out are plotted in graphs which presents on the horizontal axis the testing period and on the vertical axis the stress at a particular point (see Figure 5.1). These graphs have been gathered in several Appendices (see Table 1 and 2).

2nd BRIDGEPANEL -VAN BRIENENOORD-
STATIC LOADING: Fmax 70.4 kN
LOADED AREA: Width 270mm Length 320mm
SURFACE STRESS: 0.815 N/mm2

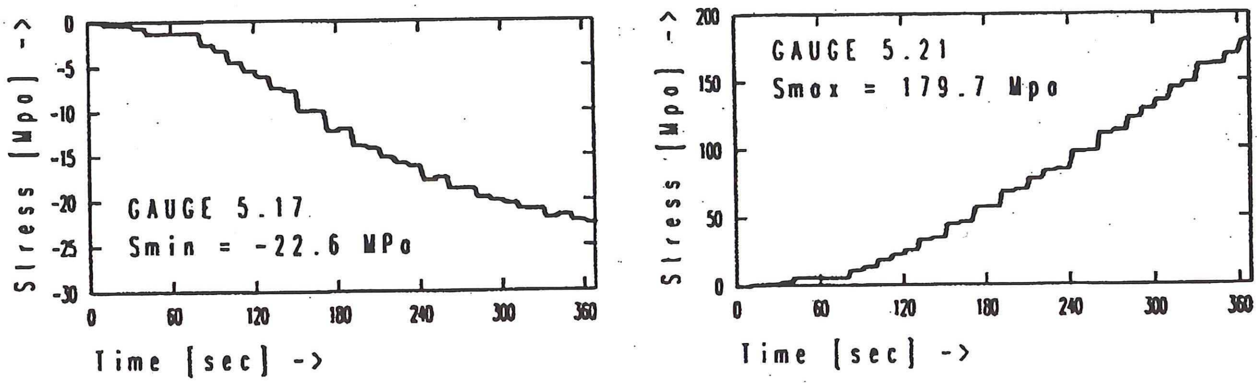


Figure 5.1 Results strain measurements during static tests

5.1.1 STRESS DISTRIBUTIONS

The position of the different strain gauges are presented with respect to location Q as pointed out in Figure 5.2.

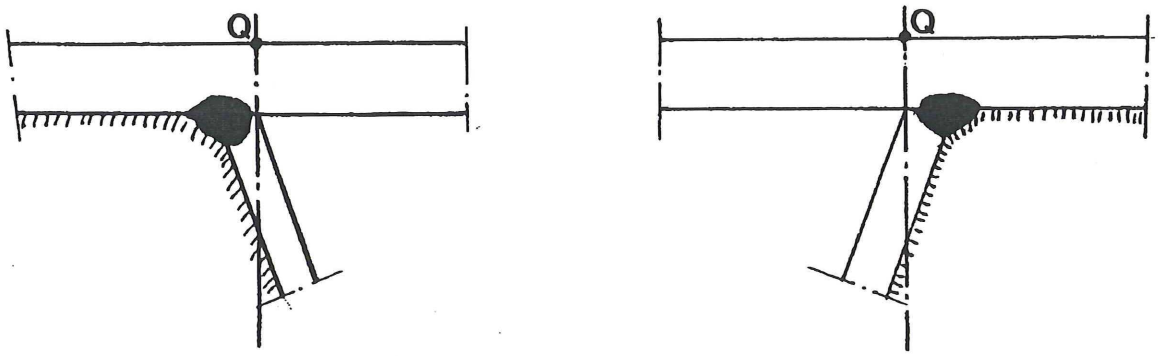


Figure 5.2 Location Q

The measured stress distributions at the two stiffener-deck plate-cross beam connection of Through 5 of the "Hollandia Panel" are shown in Figure 5.3.
The different tests include different loaded area and/or load level. The surface stress for Test-10, 12, 13 and 14 varies 0.815 - 0.9 N/mm^2. For Test 11 the surface stress amounts 0.755 N/mm^2.

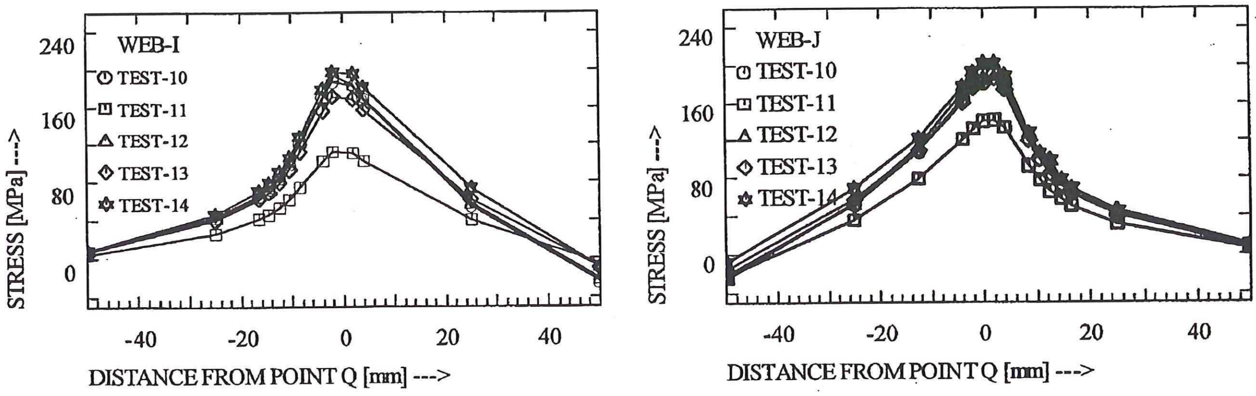


Figure 5.3 Measured stress distribution on the Hollandia Panel

In Figure 5.4 the surface stress for tests has been normalized for 1.0 N/mm2. It can be seen that the Test 11 with a relative short length of the loaded area (160 mm against 250 and/or 320 mm) results in the lowest stresses.

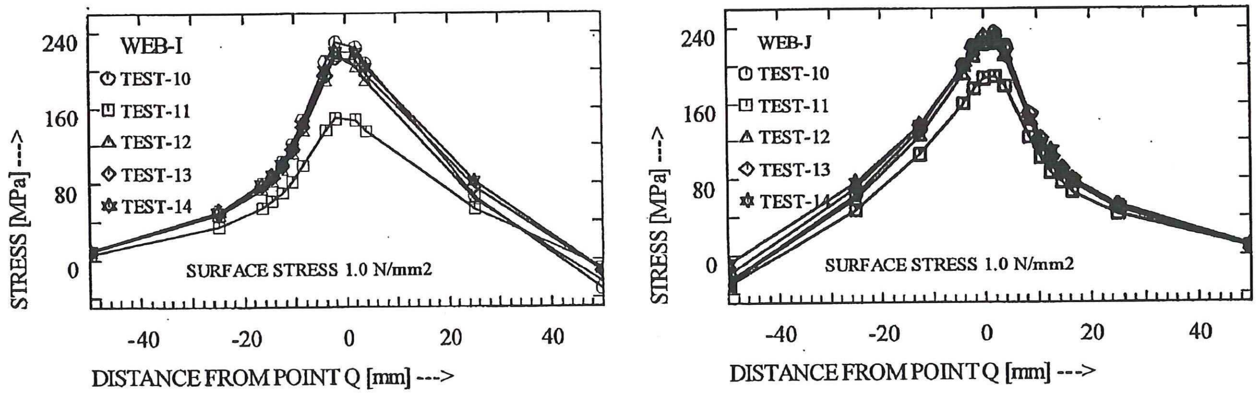


Figure 5.4 Normalized stress distribution for the Hollandia Panel

In Figure 5.5 the measured stress distributions of the "Hollandia Panel" and the "Birkhoff Panel" have been compared. The loads have been normalized for the load level as given in the different graphs so that the stress distributions as measured on both panels are comparable. In most loading situations the peak stresses in the Birkhoff Panel are greater. This is probably the effect of the overloading of the Hollandia Panel at the start of the static tests, which resulted in a plastic deformation of the deck plate between WEB-I and WEB-J and of the end of the trough webs. It is not clear why the location of the peak stress differs on both test panels.

HOLLANDIA & BIRKHOFF PANEL -VAN BRIENENOORD-
STATIC DATA TROUGH 5

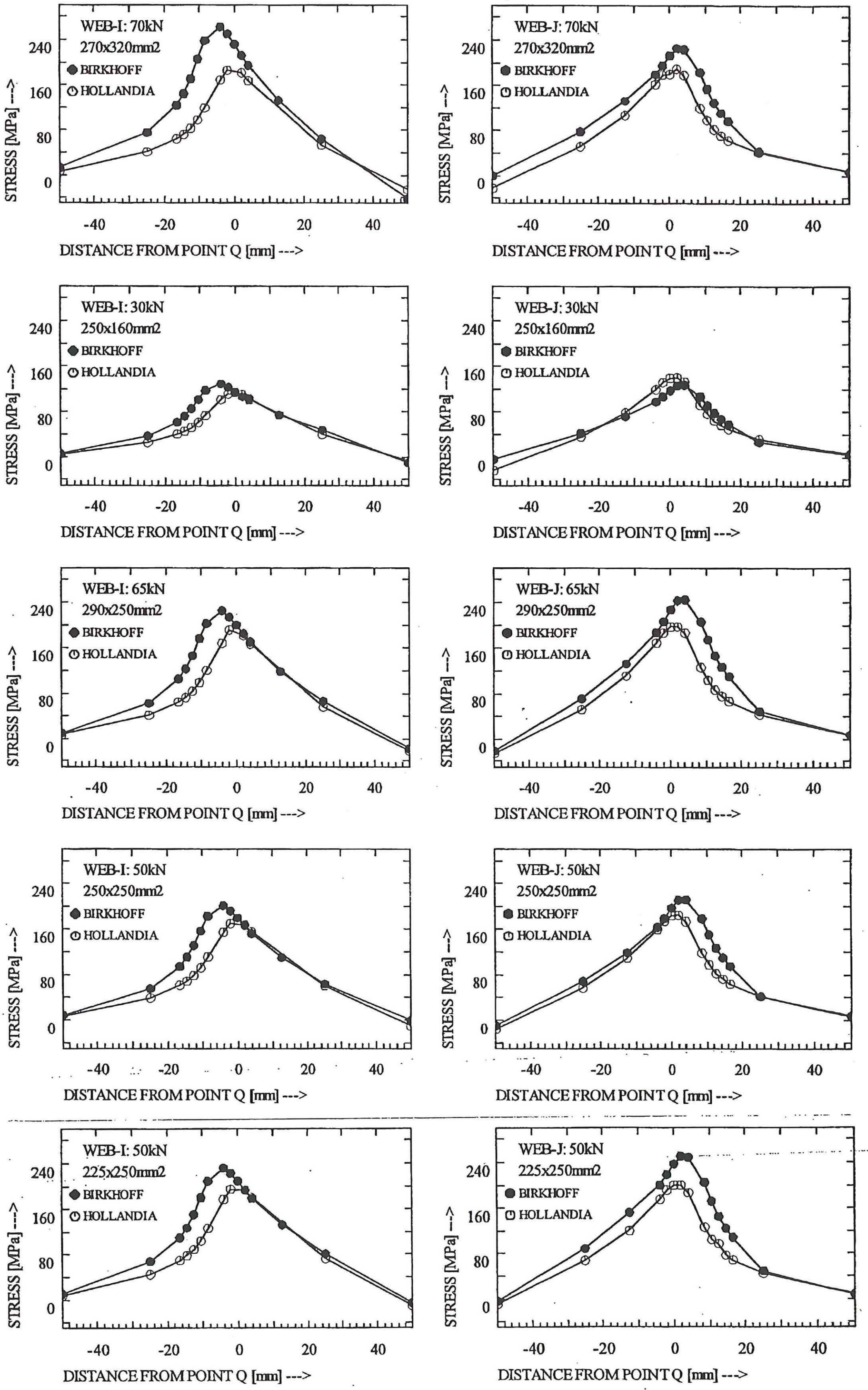


Figure 5.5 Comparison "Hollandia & Birkhoff Panel

5.1.2 STRESS RANGE FACTOR

The laboratory tests had to be integrated with the in situ measurements on the Van Brienenoord bridge. Therefore a so called Stress Range Factor (SRF) has been calculated using the measured stress distributions on the laboratory specimens. In the analysis the Stress Range Factor has been defined as the quotient of measured maximum stress and the measured stresses 25 mm from the location where the web of the trough meets the deck plate (see Figure 5.6). The position of 25 mm has been chosen as on the existing bridge deck of the Van Brienenoord stress spectra have been measured at this location.
The SRF values for the different tests have been gathered in Table 3 and Figure 5.7.

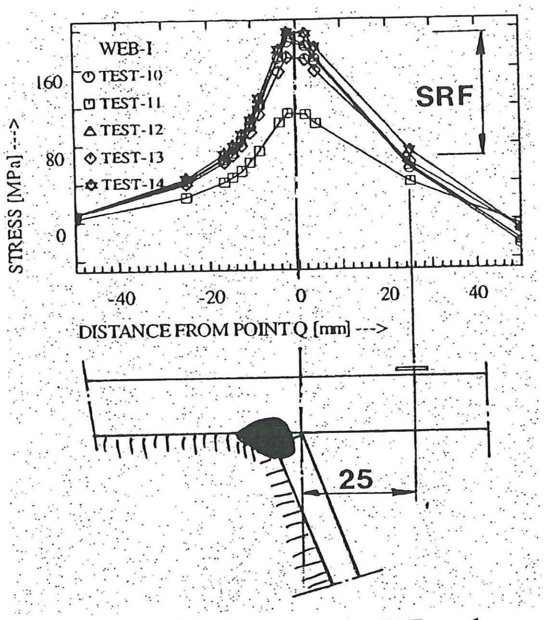


Figure 5.6 Definition of the SRF used

Table 3. Stress Range Factors

Web	Test :	BIRKHOFF BRIDGE PANEL							HOLLANDIA BRIDGE PANEL					
		1	2	3	4	5	6	7	10	11	12	13	14	15
		ST	ST	ST	ST	ST	OL	FAT	ST	ST	ST	ST	ST	FAT
I :	SRF :	4.07	2.70	3.39	3.15	2.87	3.74	3.57	3.45	2.80	3.41	2.80	2.70	3.12
J :	SRF :	2.90	3.00	3.45	3.12	2.81	3.29	3.26	3.69	3.95	3.78	3.27	2.95	3.48

ST: STATIC LOADING, OL: STATIC OVERLOADING, FAT: FATIGUE LOADING
SRF: STRESS RANGE FACTOR = PEAK STRESS / STRESS 25 MM FROM WELD ROOT

The highlighted boxes are the SRF-valuesas measured using the wheel print with a width of 270 mm and a length of 320 mm. The mean SRF-value of all available data amounts 3.26. In Figure 5.7 the SRF-values have been plotted as a function of the width of the wheel print. The SRF-value tends to be linear with the width of the wheel print.

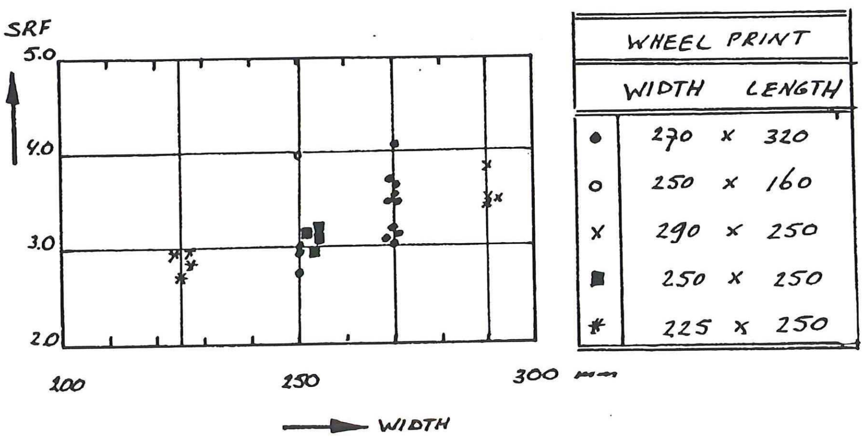


Figure5.7 SRF related to the width of the wheel prints

5.2 FATIGUE TESTS

A review of the fatigue test results is shown in Table 4. This table includes the total of load cycles (N4) on the test specimens during the different tests and the locations were cracks have been found. For some cracks also the moment of the first visual observation (N2) has been given.

Table 4: Review fatigue test results

TEST NR	TEST SPECIMEN	LOADED TROUGH	LOAD RANGE	NUMBER OF CYCLES	OBSERVATIONS
7	BIRKHOFF PANEL ¹)	5 7	80.2 80.9	N4 = 1.007.228	SMALL CRACKS *BOTTOM SIDE DECK PLATE* TROUGH 4, 5 & 6 WERE THREE WELDS MEET (see Figure 5.8)
8		4 6	57.8 58.6	N4 = 2.397.612	
15	HOLLANDIA PANEL	5 7	80.0 78.5	N4 = 6.260.378	CRACKS *BOTTOM SIDE DECK PLATE* TROUGH 5 & 7 AT WELD TOE OF TROUGH/DECK PLATE WELD (see Figure 5.9)
16		4 6	80.1 79.7	N2 = 1.362.500 N4 = 3.264.809	TWO CRACKS *TOPSIDE DECK PLATE*: WEB-G & H (see Figure 5.10)
17		6 ²)	80.0	N2 = 1.072.190 N4 = 5.412.392	ONE CRACK *TOPSIDE DECK PLATE*: WEB-K (see Figure 5.10)

¹) ECSC Program 3.565.000 CYC
²) Total number of cycles on Trough 6 amounts 8.677.201

At the bottom side of the deck plate of the "Birkhoff Panel" small cracks were found at the point where the cross beam and trough-web are connected to the deck plate. These cracks located in the weld (see Figure 5.8) as well as at the weld toe (see Figure 5.9) did not grow after they had been observed.

On the "Hollandia Panel" cracks have been found in the deck plate at a similar location as observed on the Van Brienenoord Bridge [1] (see also Figure 5.10). These cracks initiated at the root of the weld at the bottom side of the deck plate at the point where the cross beam and trough-web are welded to the deck plate. They grow through the deck plate and developed along the deck plate weld at both sides of the cross beam.

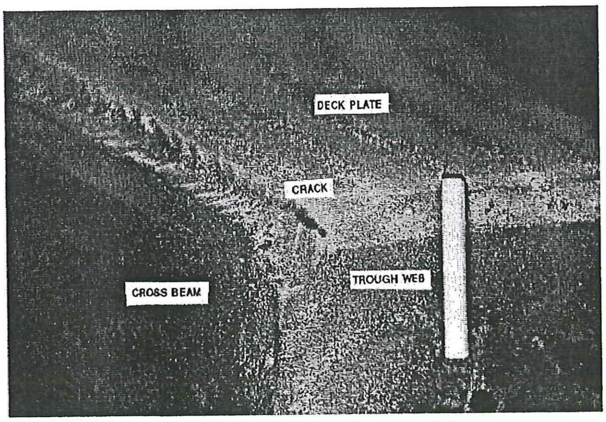


Figure 5.8 Cracks were three welds meet

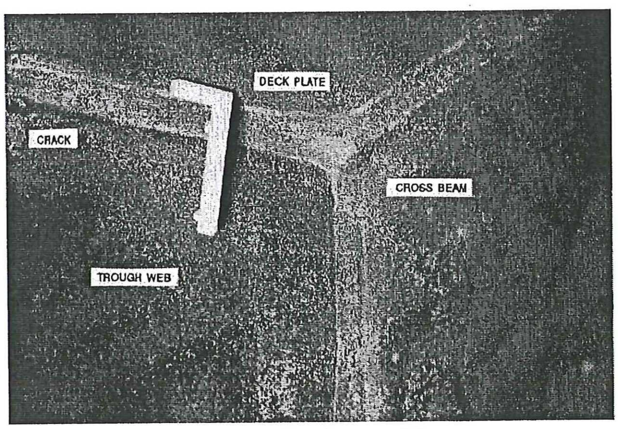


Figure 5.9 Crack at weld toe

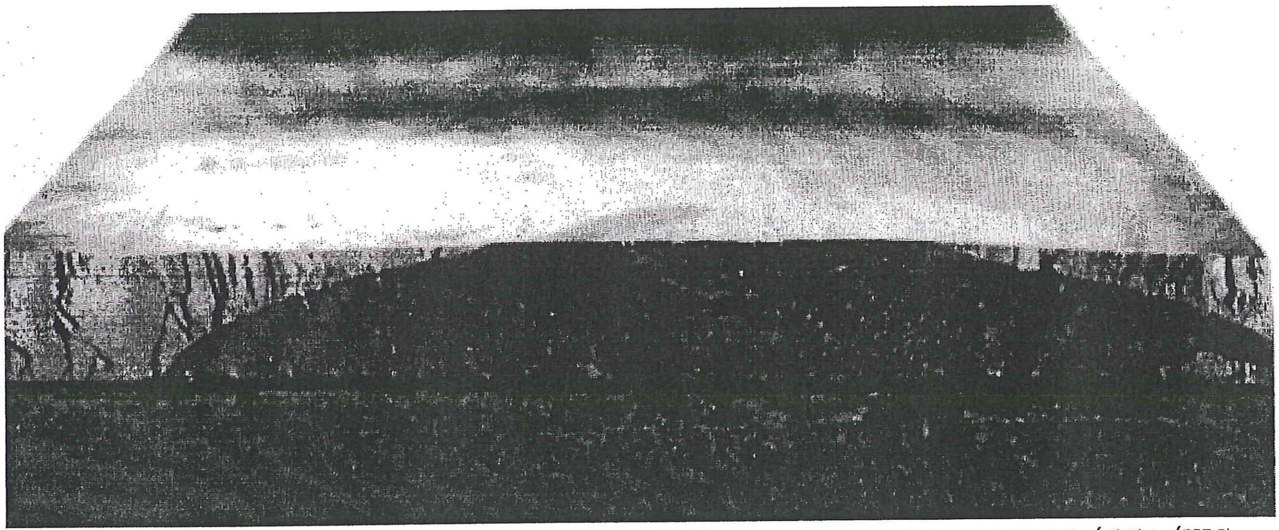


Figure 5.10 Deck plate crack (see TNO rapport 97MI-00990/SCA/VIS

5.2.1. CRACK DEVELOPMENT

The crack growth of the cracks as found in the bottom side of the deck plate of the "Birkhoff Panel" (see Figure 5.8 and 5.9) during the fatigue test was neglectable. The crack growth of the cracks as found at the topside of the "Hollandia Panel" (see Figure 5.10) amounts about 1 mm/14.000 cycles. Typical data of these cracks is shown in the following table:

Table 5. Crack growth data of the deck plate cracks in the "Holandia Panel".

CRACK GROWTH HOLLANDIA PANEL							
TEST 16: TROUGH 4					TEST 16 & 17 TROUGH 6		
NUMBER OF CYCLES (cyc)	WEB-G		WEB-H		NUMBER OF CYCLES (cyc)	WEB-K	
	LENGTH (mm)	SPEED (1 mm/cyc)	LENGTH (mm)	SPEED (1 mm/cyc)		LENGTH (mm)	SPEED (1 mm/cyc)
1.362.500	43	-	16	-	4.336.999	7	-
1.520.000	52	17.500	19	52.500	4.650.436	24	43.953
1.676.500	52	-	29	15.650	4.940.309	43	15.257
1.843.000	64	16.375	41	13.875	5.417.218	65	21.678
1.976.000	71	19.000	50	14.778	6.023.159	85	30.115
2.441.732	103	14.554	82	14.554	6.508.856	90	97.139
2.715.620	118	18.259	104	12.450	7.654.909	100	114.605
2.903.184	129	17.051	116	15.630	8.477.650	121	39.178
3.247.800	-	-	148	10.769	8.677.201	-	-
3.264.809	-	-	-	-			

5.2.2. WELD CLASSIFICATION: S-N CURVES

In this paragraph only the results for the deck plate cracks as observed for the "Hollandia Panel" have been considered. The results of the "Birkhoff Panel" are not included as the cracks developed here in an other way.

For the fatigue strength classification the stress as well as the number of cycles to be used have to be defined. First the available data have been grouped in Table 6 using the stress, measured at about 9 mm from point Q "inside the trough" (see Figure 5.2). With respect to the number of cycles several stages have been considered as this type of crack initiates inside the connection and will grow for a while until it will be discovered visually. Four different stages in change of measured strain have been considered and three stages with respect to the length of the crack (see Table 6).

Table 6. Different stages in fatigue failure (9 mm from point Q)

HOLLANDIA PANEL										
LOCATION 9 mm point Q "INSIDE TROUGH"		STRESS RANGE (MPa)		NUMBER OF CYCLES (cyc)						
				STRAIN CHANGE (%)				FIRST VISUAL CRACK	CRACK LENGTH ~50 mm	MAXIMUM OBSERVED CRACK LENGTH
		START	MAX	+10	-10	-25	-50			
TROUGH 4 (TEST 16) ΔF=80.1 kN	WEB-G Gauge 4.1	154	174 ($2,0.10^{5}$ cyc)	$1,3.10^{5}$	$4,1.10^{5}$	$9,9.10^{5}$	$1,1.10^{6}$	$1,4.10^{6}$ (43 mm)	$1,5.10^{6}$ (52 mm)	$2,9.10^{6}$ (129 mm)
	WEB-H Gauge 4.2	138	165 ($2,2.10^{5}$cyc)	$1,1.10^{5}$	$5,5.10^{5}$	$1,3.10^{6}$	$1,5.10^{6}$	$1,4.10^{6}$ (16 mm)	$2,0.10^{6}$ (50 mm)	$3,3.10^{6}$ (148 mm)
TROUGH 6 *1st TEST* (TEST 16) ΔF=80.1 kN	WEB-K Gauge 6.1	154	184 ($2,5.10^{5}$ cyc)	$7,7.10^{4}$	$4,8.10^{5}$	$9,8.10^{5}$	-	-	-	-
	WEB-L Gauge 6.2	168	173 ($4,2.10^{5}$ cyc)	-	$7,5.10^{5}$	$1,2.10^{6}$	-	-	-	-
TROUGH 6 *2nd TEST* (TEST 17) ΔF=80.0 kN	WEB-K Gauge 6.1	149	-	-	$1,1.10^{6}$	$1,2.10^{6}$	$1,3.10^{6}$	$1,1.10^{6}$ (7 mm)	$2,2.10^{6}$ (65 mm)	$5,2.10^{6}$ (121 mm)
	WEB-L Gauge 6.2	149	-	-	-	-	-	-	-	-
TROUGH 7 (TEST 15) ΔF=78.5 kN	WEB-M Gauge 7.1	167	385 ($6,3.10^{6}$ cyc)	$2,8.10^{4}$	-	-	-	-	-	-
	WEB-N Gauge 7.2	183	352 ($7,0.10^{5}$ cyc)	$1,3.10^{4}$	$1,2.10^{6}$	$2,0.10^{6}$	-	-	-	-
TROUGH 5 (TEST 15) ΔF=80.0 kN	WEB-I Gauge 5.7	150	defect	$1,2.10^{6}$	-	-	-	-	-	-
	WEB-J Gauge 5.25	153	342 ($5,5.10^{5}$ cyc)	$1,1.10^{6}$	-	-	-	-	-	-

Table 7 reviews these data for the different strain gauge locations as measured on Trough 5 in Test 15. From the data it can be concluded that the measured stresses at -9mm from point Q (gauge 5.7 or 5.25) is a factor 2 higher than the stresses measured at +25mm (gauge 5.14 or 5.18). The maximum measured stresses are as mentioned before in Table 3 a factor of ~ 3.0 higher than those measured at +25mm from the weld root.
For the definition of the stresses as used in the S-N diagram the measured stresses as given in Table 6 have been multiplied by a factor 1.5. The stresses obtained in this way are comparable to the extrapolated stress at the weld root using measured stresses at a distance of 0.4 times and 1.4 times the thickness of the deck plate (see Figure 5.11). A review of the data as used for the fatigue classification of the detail is given in Table 8.

Table 7. Different stages in change of measured strain ranges (different strain gauge locations)

HOLLANDIA PANEL									
			STRESS RANGE (MPa)		NUMBER OF CYCLES (cyc)				
	STRAIN GAUGE				STRAIN CHANGE (%)				REMARKS
	NUMBER	mm FROM WELD ROOT	START	MAX	+10	-10	-25	-50	
TROUGH 5 WEB-I (TEST 15) ΔF=80.0 kN	5.4	-15	93	141	-	$5,6.10^5$	$1,1.10^6$	-	**1. END OF TEST: $6,3.10^6$ cycles** **2. TEST: NO VISUAL CRACKS** **3. RTD: CRACK INDICATION**
	5.5	-13	107	197	-	$6,7.10^5$	$1,3.10^6$	-	
	5.6	-11	124	277	-	$1,0.10^6$	-	-	
	5.7	-9	150	defect	-	$1,2.10^6$	-	-	
	5.8	-4	210	270	-	$4,6.10^5$	$1,3.10^6$	-	
	5.9	-2	231	256	-	$2,0.10^5$	$6,0.10^5$	$4,9.10^6$	
	5.10	0	defect	-	-	-	-	-	
	5.11	+2	230	-	-	$6,8.10^4$	$1,6.10^5$	$7,5.10^5$	
	5.12	+4	208	-	-	$5,7.10^4$	$1,6.10^5$	$9,1.10^5$	
	5.13	+13	defect	-	-	-	-		
	5.14	+25	74	78	-	$1,9.10^5$	$6,8.10^5$		
TROUGH 5 WEB-J (TEST 15) ΔF=80.0 kN	**5.18**	**+25**	**69**	**74**	-	**$1,1.10^5$**	**$4,6.10^5$**	**$2,6.10^6$**	1. END OF TEST: $6,3.10^6$ cycles 2. TEST: NO VISUAL CRACKS 3. RTD: CRACK INDICATION
	5.19	**+13**	**138**	**144**	-	**$4,5.10^5$**	**$1,5.10^5$**	**$1,4.10^6$**	
	5.20	**+4**	**207**	-	-	**$4,0.10^4$**	**$8,3.10^4$**	**$5,7.10^5$**	
	5.21	**+2**	**225**	-	-	**$5,1.10^4$**	**$1,0.10^5$**	-	
	5.22	**0**	**237**	-	-	**$8,9.10^4$**	**$1,7.10^5$**	**$3,4.10^5$**	
	5.23	**-2**	**240**	**270**	-	**$1,5.10^5$**	**$2,9.10^5$**	**$1,8.10^6$**	
	5.24	**-4**	**226**	**306**	-	**$2,6.10^5$**	**$1,4.10^6$**	-	
	5.25	**-9**	**153**	**342**	-	**$1,1.10^6$**	-	-	
	5.26	**-11**	**126**	**234**	-	**$6,6.10^5$**	**$1,2.10^6$**	-	
	5.27	**-13**	**106**	**150**	-	**$5,9.10^5$**	**$1,0.10^6$**	-	
	5.28	**-15**	**92**	**105**	-	**$5,6.10^5$**	**$1,4.10^6$**	-	
	5.29	**-17**	**81**	**86**		**$4,1.10^5$**	**$1,4.10^6$**	-	

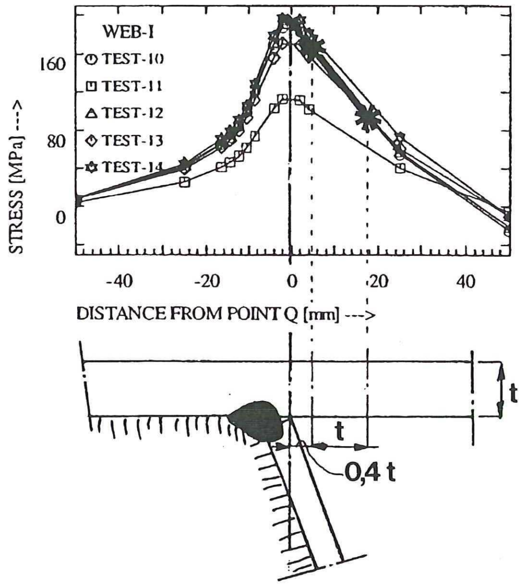


Figure 5.11 Extrapolated stress

Table 8: Fatigue test results for the S-N analysis

HOLLANDIA PANEL									
STRAIN GAUGE		EXTRAPOLATED STRESS (MPa)	NUMBER OF CYCLES (cyc)						
			STRAIN FALL (%)			FIRST VISUAL CRACK	CRACK LENGTH ~ 50 mm	END OF TEST
TROUGH	WEB		-10	-25	-50			
4	G	231	4,1.10^5	9,9.10^5	1,1.10^6	1,4.10^6	1,5.10^6	3,3.10^6
4	H	207	5,5.10^5	1,3.10^6	1,3.10^6	1,4.10^6	2,0.10^6	3,3.10^6
5	I	225	-	-	-	-	-	6,3.10^6
5	J	184	1,1.10^6	1,3.10^6	-	-	-	6,3.10^6
6	K-1*)	231	4,8.10^5	9,8.10^5	-	-	-	3,3.10^6
6	K-2	224	4,4.10^6	4,5.10^6	4,6.10^6	4,4.10^6	5,5.10^6	8,7.10^6
6	L-1	252	7,5.10^5	1,2.10^6	-	-	-	3,3.10^6
6	L-2	224	-	-	-	-	-	8,7.10^6
7	M	251	-	-	-	-	-	6,3.10^6
7	N	275	1,2.10^6	2,0.10^6	-	-	-	6,3.10^6

*) 1: 1st test (TEST 16); 2: 2nd test (TEST 17).
Number of cycles of the 1st test included in those of the 2nd test.

The fatigue results of the constant amplitude tests as discussed before are presented in Figure 5.12, as a S-N relation, on a double-log scale. In Figure 5.12.a-d, also the Eurocode fatigue design curves have been plotted. The fatigue design curves according to NEN 2063 are included in Figure 5.12.e-h. Depending on the number of cycles, the data has been grouped and a regression analyses using a fixed slope of -3 has been applied on the data. The results are also presented in Figure 5.12 showing the mean-line, the mean-line minus or plus two times the standard deviation. The fatigue classifications as shown in Table 9 are based on the mean-line minus two times the standard deviation (S_i - 2sd). Also the fatigue strength according to the Eurocode at 2.10^6 and the NEN2063 at 1.10^7 are given (S_i). As the number of test results is small the fatigue classifications are also given for the mean-line divided by a factor 1.45 (S_i / 1.45) which is the scatter band if enough reliable data is available.

Table 9: Fatigue classification according to Eurocode 3 and NEN 2063

HOLLANDIA PANEL (12 mm deck plate)							
FAILURE MODE	REGRESSION ANALYSIS*)	FATIGUE CLASSIFICATION					
		S_i -2sd		S_i / 1.45		S_i	
		EC 3	NEN 2063	EC 3	NEN 2063	EC 3	NEN 2063
STRAIN FALL OF 10% (7 results)	$S_i=21630N_i^{-0.33}$ $S_i -2sd=15595N_i^{-0.33}$	EC 130	K 76	EC 124	K 73	EC 180	K 73
STRAIN FALL OF 25% (7 results)	$S_i=25663N_i^{-0.33}$ $S_i -2sd=21681N_i^{-0.33}$	EC 181	K 106	EC 148	K 87	EC 214	K 87
FIRST VISUAL CRACK (3 results)	$S_i=26661N_i^{-0.33}$ $S_i -2sd=20603N_i^{-0.33}$	EC 172	K 101	EC 153	K 90	EC222	K 90
CRACK LENGTH ~ 50mm (3 results)	$S_i=28634N_i^{-0.33}$ $S_i -2sd=20518N_i^{-0.33}$	EC 171	K 101	EC 165	K 97	EC239	K 97

*) Stress range : extrapolated stress top side deck plate at the cross section of the weld root (0.4t and t), S_i=Mean line of the test results, 2sd= 2 times the standard deviation

The definition of stress as used in Table 9 and Figure 5.12 is the linear extrapolated stress at the weld root using the measured or calculated stress at 0.4t mm and t mm from point Q (see Figure 5.11). Based on this definition of the stress range considering the number of test results, the type of crack and inspection possibilities a fatigue design stress range of 73 MPa at 1.10^7 is recommended.

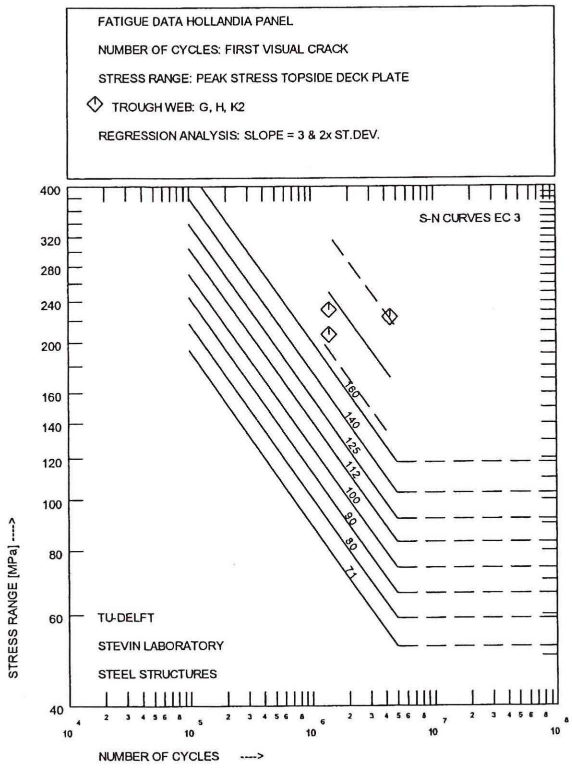


Figure 5.12.a

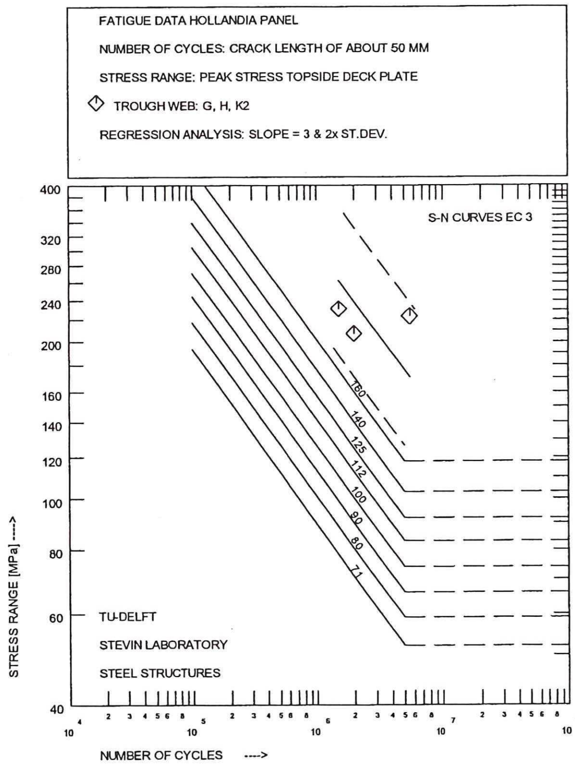


Figure 5.12.b

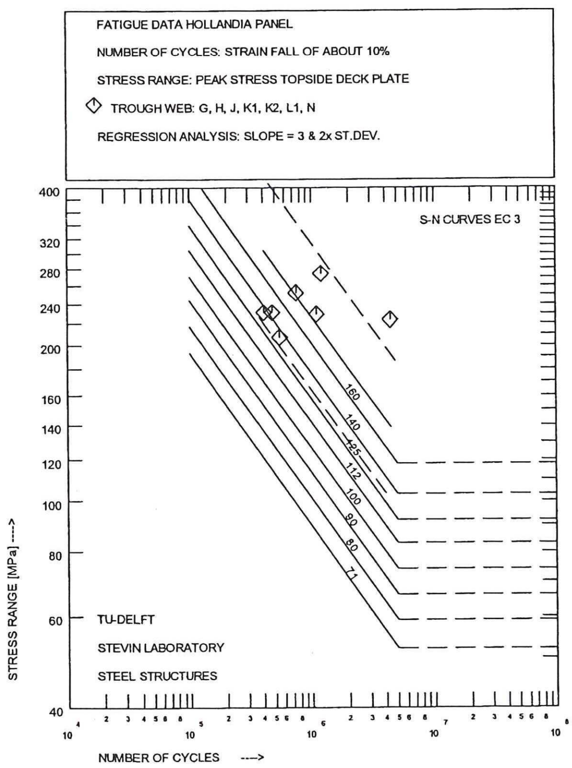


Figure 5.12.c

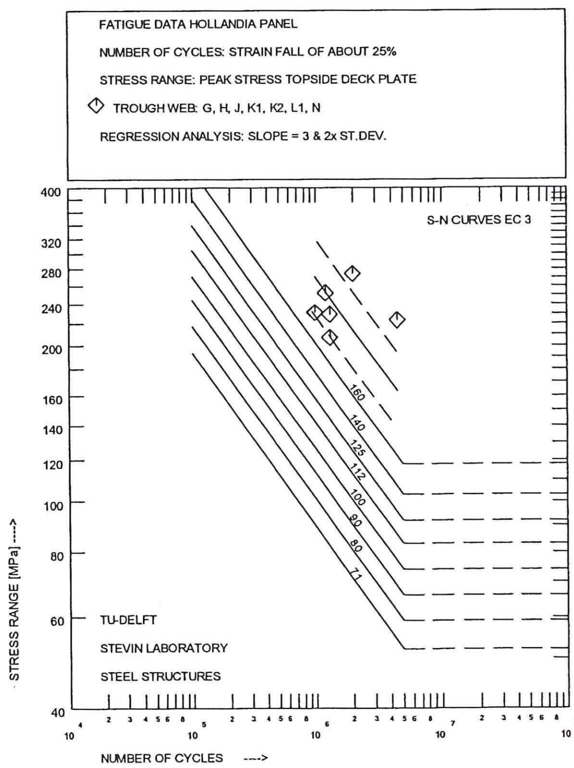


Figure 5.12.d

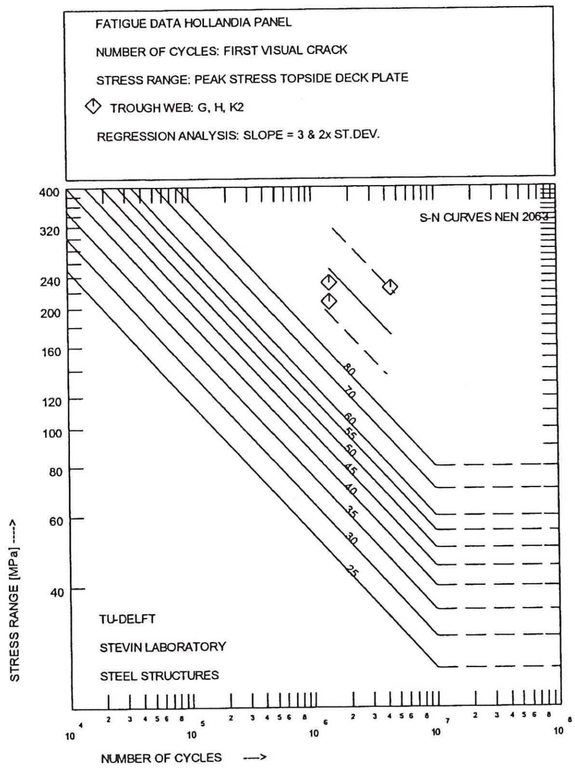


Figure 5.12.e

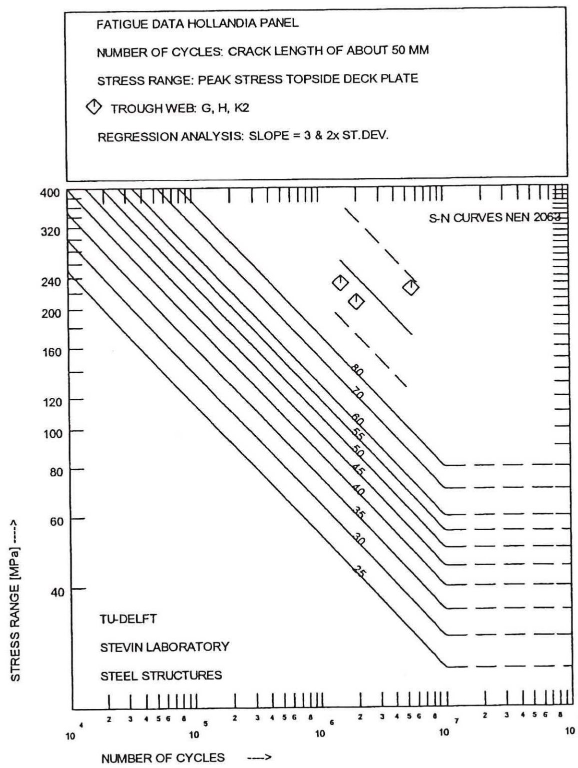


Figure 5.12.f

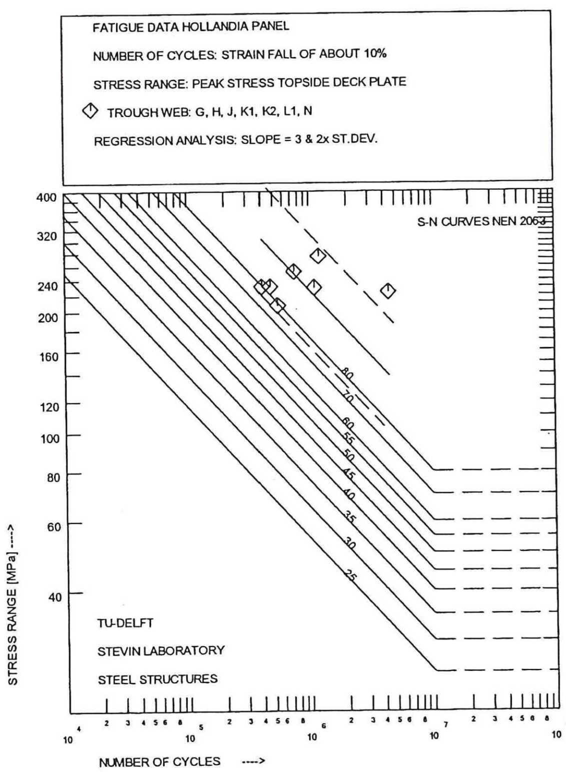


Figure 5.12.g

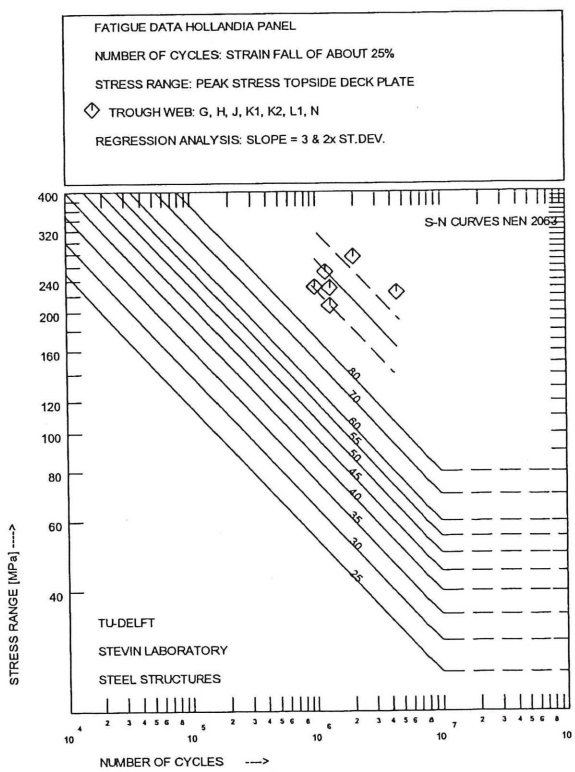


Figure 5.12.h

6. CONCLUSIONS

Static tests with realistic loaded areas on a full size orthotropic steel bridge deck showed:

- The stress distribution at the top side of the deck plate at the point where the trough web, cross beam web and deck plate meet is not much influenced by the width of the contact surface. The length of the contact surface for the same contact pressure seemed to be much more important.
- The maximum measured stress at above mentioned location is about a factor 3 (+/- 25%) higher than the value measured 25 mm from the location where the web of the trough meets the deck plate inside the trough.

Fatigue tests using a "super single" contact surface resulted in cracks at the following locations:

- Small cracks at the bottom side of the deck plate at the point where the weld between the trough web and the deck plate, the cross beam web and the deck plate and the trough web and cross beam meet. No crack growth has been observed for this type of crack.
- Small cracks at the bottom side of the deck plate at the weld toe of the weld connecting the trough web and the deck plate. No crack growth has been observed for this type of crack.
- Cracks in the deck plate, initiating at the point where the trough web, cross beam web and deck plate meet. This type of crack is simular to those as found on the bascule bridge Van Brienenoord. The crack growth of this crack amounts about 1mm every 14.000 load cycles.

The fatigue strength of the deck plate as described above is based on a peak stress at the top side of the deck plate. This measured peak stress is comparable to the linear extrapolated stresses using a stress 0.4t mm and 1.4t mm of the location where the web of the trough meets the deck plate (t=12mm, thickness of the deck plate). The number of cycles corresponds to the fatigue failure criterion based a 10% strain fall of the measured stress. The design fatigue strength according to the Eurocode at 2 million cycles amounts 124 MPa and 73 MPa at 10 million cycles using the NEN2063.

The number of test results for a statistical analysis is relative small. Additional tests to obtain more fatigue data points is recommended.

7. REFERENCES

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