Project related

Figure 119 - Presentation of damage numbers for the first half of the bridge before 2050 (γ_{Mf} = 1.35)

5.12 Type J: Longitudinal weld between body profile and body plate

The main beam has a longitudinal weld between the half DIN30 profile and the web plate over the entire length. This connection is made with an x-weld. The weld is at 30 locations along the length of the half bridge tested at the location of each K-bandage; see Figure 97 through Figure 99. Initially, the calculation performed for the (normative) weld at the bottom.

Figure 120 - Weld detail between ½ DIN30 profile and web [A.85367]

The detail category for the fatigue calculation of this compound is used as $\Delta\sigma_c$ =
100 N / mm ^{2} in accordance with NEN-EN 1993-1-9 Table 8.2 Detail 7. The stress calculation takes into account with the tension at the level of the weld, and not in the bottom flange.

Figure 121 - Detail category for the fatigue calculation of the connection type J (main bridge).

With a manual calculation it was also checked whether high shear stress occurs in this weld. At one tandem system LM1 (600 kN in lane 1, 400 kN in lane 2) shows the shear stress order size 10 N / mm², which does not require testing for shear stress in the weld.

Table 47 and Fi γ_{Mf} = 1.35. The test results with the other safety factors are snown in Appendix E10. The weld connection is not sufficient at two locations, in the middle of the second field. The maximum damage in 2050 is 1.6.

γ_{Mf} = 1.35	HRB west		HRB east		PRB west		PRB east	
	2018	2050	2018	2050	2018	2050	2018	2050
J1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
J2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
J3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
J4	0.1	0.3	0.0	0.0	0.1	0.2	0.0	0.0
J5	0.1	0.3	0.0	0.0	0.1	0.2	0.0	0.0
J6	0.1	0.3	0.0	0.0	0.1	0.2	0.0	0.0

J7	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
J8	0.1	0.3	0.0	0.0	0.1	0.2	0.0	0.0
J9	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
J10	0.2	0.6	0.1	0.1	0.1	0.4	0.0	0.0
J11	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
J12	0.2	0.8	0.1	0.1	0.2	0.5	0.0	0.0
J13	0.4	1.6	0.2	0.3	0.4	1.0	0.0	0.1
J14	0.3	1.2	0.1	0.2	0.3	0.7	0.0	0.1
J15	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
J16	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
J17	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
J18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
J19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
J20	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
J21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
J22	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
J23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
J24	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
J25	0.1	0.3	0.0	0.0	0.0	0.1	0.0	0.0
J26	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
J27	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
J28	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
J29	0.1	0.3	0.0	0.0	0.1	0.2	0.0	0.0
J30	0.1	0.4	0.0	0.0	0.1	0.2	0.0	0.0

Table 47 - Damage numbers of connection type J for the end of 2018 and the end of 2050 ($\gamma_{Mf} = 1.35$)

Figure 122 - Presentation of damage figures for the first half of the bridge before 2050 (γ_{Mf} = 1.35)

A comparable weld joint is also located at the top of the body and sometimes also
between parts of the web plate. Given the (significantly) lower voltage at this height in the cross-section
these will suffice.

It is concluded that only the welded joint at the bottom in the middle of field 2 over one
short length does not suffice at γ_{Mf} = 1.35.

5.13 Type K: Rivet connection between flanges in the flange package

The bottom flange of the main beam consists of a different number of plates. These are next to the welded joint also joined together with rivets along the entire length of the bridge. This one connection has been tested at 30 locations along the length of the half bridge, at the location of each K-bandage; see Figure 97 through Figure 99.

Figure 123 - Rivet connection between flanges in bottom flange flange package [A.85367]

The detail category for the fatigue calculation of this compound has been determined by TNO in the report "Fatigue IJssel bridge Rheden - non-force-absorbing rivets" section 4.2 and may are taken as $\Delta\sigma_c = 101$ N / mm^2, with $m_1 = 4.45$, $m_2 = 6.45$ and the kink point of the SN curve at $2 * 10^6$.

Project related

Figure 124 and Ta or $\gamma_{Mf} = 1.35$. The test results with the other safety factors are shown in Appendix E11. Only in the middle of field 2 do the rivets do not meet the damage requirement. The maximum loss in 2050 is 1.2 (middle two E field).

$\gamma_{Mf} = 1.35$	HRB west		HRB east		PRB west		PRB east	
	2018	2050	2018	2050	2018	2050	2018	2050
K1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
K4	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
K5	0.1	0.3	0.0	0.0	0.0	0.2	0.0	0.0
K6	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0
K7	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
K8	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
K9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K10	0.1	0.6	0.0	0.1	0.1	0.3	0.0	0.0
K11	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
K12	0.1	0.6	0.0	0.0	0.1	0.3	0.0	0.0
K13	0.3	1.2	0.1	0.2	0.2	0.7	0.0	0.0
K14	0.2	0.9	0.1	0.1	0.2	0.5	0.0	0.0
K15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

K25	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
K26	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
K27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K28	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
K29	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
K30	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0

Table 48 - Damage numbers of connection type K for the end of 2018 and the end of 2050 ($\gamma_{Mf} = 1.35$)

Figure 124 - Presentation of damage numbers for the first half of the bridge before 2050 ($\gamma_{Mf} = 1.35$)

5.14 Type N: Longitudinal weld between thickening plate and bottom flange

The bottom flange of the main beam is reinforced with a reinforcement plate at various locations. The cover plate is connected to the bottom flange of the ½ DIN profile with a fillet weld of 5 mm. The second is e opdikplaat connected to the 1 st top plate with a 5 mm corner load. The weld is at 30 locations along the length of the half bridge tested, at the location of each K-bandage; see Figure 97 through Figure 99.

Figure 125 - Weld detail between grommets and bottom flange [A.85364]

The detail category for the fatigue calculation of this compound is used as $\Delta\sigma_c$ = 100 N / mm ^{2} in accordance with NEN-EN 1993-1-9 Table 8.2 Detail 7.

Figure 126 - Detail category for the fatigue calculation of the connection type N (main bridge).

Table 49 and Fi γ $_{Mf}$ = 1.35. The test results with the other safety factors are shown in Appendix E13. In a limited number of locations, the weld joint, especially in the middle of the second field. The maximum damage in 2050 is 2.9 (middle two $_E$ field).

γ $_{Mf}$ = 1.35	HRB west		HRB east		PRB west		PRB east	
	2018	2050	2018	2050	2018	2050	2018	2050
N1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
N3	0.1	0.4	0.0	0.0	0.1	0.2	0.0	0.0
N4	0.2	0.9	0.1	0.1	0.2	0.5	0.0	0.0
N5	0.3	1.1	0.1	0.1	0.2	0.6	0.0	0.0
N6	0.2	1.0	0.1	0.1	0.2	0.6	0.0	0.0
N7	0.1	0.5	0.1	0.1	0.1	0.3	0.0	0.0
N8	0.2	0.7	0.1	0.1	0.2	0.4	0.0	0.0
N9	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
N10	0.3	1.3	0.2	0.2	0.3	0.8	0.0	0.0
N11	0.1	0.4	0.0	0.0	0.1	0.2	0.0	0.0
N12	0.5	1.8	0.2	0.3	0.5	1.1	0.0	0.0
N13	0.8	2.9	0.4	0.6	0.8	1.8	0.1	0.1
N14	0.6	2.2	0.3	0.5	0.6	1.4	0.1	0.1
N15	0.1	0.3	0.0	0.0	0.1	0.2	0.0	0.0
N16	0.1	0.3	0.0	0.0	0.0	0.2	0.0	0.0
N17	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
N18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N20	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
N21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N22	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
N23	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
N24	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
N25	0.1	0.5	0.1	0.1	0.1	0.3	0.0	0.0
N26	0.1	0.4	0.0	0.1	0.1	0.2	0.0	0.0
N27	0.1	0.3	0.0	0.0	0.0	0.2	0.0	0.0
N28	0.1	0.5	0.1	0.1	0.1	0.3	0.0	0.0
N29	0.2	0.7	0.1	0.1	0.2	0.4	0.0	0.0
N30	0.2	0.9	0.1	0.1	0.2	0.6	0.0	0.0

Table 49 - Damage numbers of connection type N for the end of 2018 and the end of 2050 (γ $_{Mf}$ = 1.35)

Figure 127 - Presentation of damage numbers for the first half of the bridge before 2050 ($\gamma_{Mf} = 1.35$)

5.15 Type O: X-seam ½ DIN profiles

In the main beam, a weld in height direction is present at a number of locations. The weld is both in the web plate as in the ½ DIN profiles of the top and bottom flange. In this section, the welded joint tested in the ½ DIN profile, the welded joint of the web plate was tested in sectio In total, there are 17 weld seams per main beam, see Figures 130 to Figure 132. Because symmetry are only tested from O1 to O9. The weld seam in the ½ DIN profiles is designed as an x-seam in the bottom flange. This can be fully welded because there is a U-shaped opening in the body was present, which was then welded closed with a K-weld.

Figure 128 - Weld connection ½ DIN profiles [Source: A.85365] Figure 129 - Detail weld connection ½ DIN profiles [Source: A.85365]

Figure 130 - Location of the connection type O in the 1 st field

Figure 131 - Location of the connection type O in the 2 nd field

Figure 132 - Location of the connection type O in the 3 rd field

For the detail category, a distinction can be made between the side of the weld that is ground-ground and the side that is not. Surface grinding of the welds is performed at the bottom, where the overlapping plates over the weld. The detail category $\Delta\sigma_c$ for the fatigue calculation of non-planar ground side follows from NEN-EN 1993-1-9 table 8.3 Detail 10 and amounts to 80 N / mm ^{2} . Because t <25 mm assumes k_s = 1.0. According to TNO, the flat-ground side of the x-seams may be used of detail category $\Delta\sigma_c$ = 112, in accordance with NEN-EN 1993-1-9 table 8.3 detail 10, see Appendix C of report [TNO draft report Risk analysis of welding imperfections in the IJsselbrug A12 (002)]. This also applies to the part of the x-seam at the top of the flange at the location of the body, because none here voltage concentration is present.

Figure 133 - Detail category for the fatigue calculation of the type O connection

The calculation is for the 9 locations (O1 to O9) for 3 different safety factors $\gamma_{Mf} = 1.35$, 1.15 and 1.00 executed. This is based on the tension at the bottom of the ½ DIN profile in the bottom flange. The test results (damage numbers) are determined in the individual main beams, namely for the main carriageway west (HRB west), the main carriageway east (HRB east), the parallel carriageway west (PRB-west) and the parallel carriageway east (PRB east).

Table 50 and Fi testing the bottom flange against the non-planar ground side witn $\gamma_{Mf} = 1.35$ and $\Delta\sigma_c = 80$. The test results with the other safety factors are in Appendix E15 shown. A number of welded joints do not appear to comply with the damage claim D <1.0 at $\gamma_{Mf} = 1.35$. The most critical connection is at O3 in the main carriageway west. The damage in 2050 is 4.0 here.

γ_{Mf} = 1.35	**HRB west**		**HRB east**		**PRB west**		**PRB east**	
	2018	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**

O1	0.6	2.1	0.2	0.3	0.6	1.3	0.0	0.0
O2	0.4	1.6	0.2	0.3	0.4	1.0	0.0	0.0
O3	1.2	4.0	0.5	0.7	1.2	2.6	0.0	0.1
O4	0.2	0.7	0.1	0.2	0.2	0.4	0.0	0.1
O5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O6	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
O7	0.1	0.6	0.1	0.1	0.1	0.3	0.0	0.0
O8	0.5	1.9	0.3	0.4	0.5	1.2	0.0	0.1
O9	0.6	2.2	0.3	0.4	0.6	1.4	0.0	0.1

Table 50 - Damage numbers of connection type O (x-seam ½ DIN profile DC = 80) for the end of 2018 and the end of 2050 (γ_{Mf} = 1.35)

Figure 134 - Presentation of damage figures for the first half of the bridge before 2050 (γ_{Mf} = 1.35) (½ DIN profile DC = 80)

Project related

Table 51 and Fi testing the bottom flange against the surface ground side with $\gamma_{Mf} = 1.35$ and $\Delta\sigma_c = 112$. In this detail category, all connections are sufficient.

γ_{Mf} = 1.35	HRB west		HRB east		PRB west		PRB east	
Year	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
O1	0.1	0.4	0.0	0.0	0.1	0.2	0.0	0.0
O2	0.1	0.3	0.0	0.0	0.1	0.2	0.0	0.0
O3	0.2	0.9	0.1	0.1	0.2	0.5	0.0	0.0
O4	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
O5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O7	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
O8	0.1	0.3	0.0	0.1	0.1	0.2	0.0	0.0
O9	0.1	0.4	0.0	0.1	0.1	0.2	0.0	0.0

Table 51 - Damage numbers of connection type O (x-seam ½ DIN profile DC = 112) for the end of 2018 and the end of 2050 (γ_{Mf} = 1.35)

Figure 135 - Presentation of damage numbers for the first half of the bridge before 2050 (γ_{Mf} = 1.35) (½ DIN profile DC = 112)

Given the damage numbers of the connection in the bottom flange on the non-flat ground side, the connection in the top flange checked. This appears to meet the damage requirement D <1.0 at γ_{Mf} everywhere = 1.35.

γ_{Mf} = 1.35	HRB west		HRB east		PRB west		PRB east	
	2018	2050	2018	2050	2018	2050	2018	2050
O1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
O5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O8	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
O9	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0

Table 52 - Damage numbers of connection type O (½ DIN profile top flange DC = 80) for the end of 2018 and the end of 2050 (γ_{Mf} = 1.35)

5.16 Type P: X-seam web plate main beam

As an extension of the weld in the ½ DIN profile, there is also a weld connection (x-weld) present in the web plate. In total, there are a main girder 17, x-seams present, is in the same cuts as type O, see Figure 130 t / m Figure 132. Due to symmetry, only P1 to P9 were tested.

Figure 136 - Detail weld joint body plate [Source: A.85367]

The detail category $\Delta\sigma_c$ for the fatigue calculation of this connection follows from NEN-EN 1993-1-9 table 8.3 Detail 5 and amounts to 90 N / mm ^{2} . Since the sheet thickness is 12mm, is for all calculations assuming a factor k_s equal to 1.0.

Figure 137 - Detail category for the fatigue calculation of the type P connection

The calculation is for the 9 locations (P1 to P9) for 3 different safety factors γ_{Mf} = 1.35, 1.15 and 1.00 executed. This is based on the tension at the bottom of the body plate, at the connection to the ½ DIN profile. The test results (damage numbers) are in the individual main beams determined, namely for the main carriageway west (HRB west), the main carriageway east (HRB east), the parallel carriageway west (PRB west) and parallel carriageway east (PRB east).

Table 53 and Fi γ_{Mf} = 1.35. The test results with the other safety factors are shown in Appendix E16. Only the weld connection at the location of P3 appears to be the case the HRB west at the bottom does not meet the damage requirement D <1.0 at γ_{Mf} = 1.35.

γ_{Mf} = 1.35	HRB west		HRB east		PRB west		PRB east	
	2018	2050	2018	2050	2018	2050	2018	2050
P1	0.1	0.5	0.0	0.1	0.1	0.3	0.0	0.0
P2	0.1	0.4	0.0	0.1	0.1	0.2	0.0	0.0
P3	0.4	1.4	0.1	0.2	0.3	0.8	0.0	0.0
P4	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
P5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P7	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
P8	0.1	0.5	0.1	0.1	0.1	0.3	0.0	0.0
P9	0.1	0.6	0.1	0.1	0.1	0.3	0.0	0.0

Table 53 - Damage numbers of connection type P (bottom of body plate) for the end of 2018 and the end of 2050 (γ_{Mf} = 1.35)

Figure 138 - Presentation of damage numbers for the first half of the bridge before 2050 (γ_{Mf} = 1.35) (underside of body plate)

For connection P3 in the HRB west, a search was then made for the height where the connection is sufficient. This appears to be 100 mm above the top of the ½ DIN profile in the bottom flange.

γ_{Mf} = 1.35	HRB west		HRB east		PRB west		PRB east	
	2018	2050	2018	2050	2018	2050	2018	2050
P3	0.2	1.0	0.1	0.1	0.2	0.6	0.0	0.0

Table 54 - Damage numbers of connection type P3 (100 mm above underside of body plate) for the end of 2018 and the end of 2050 (γ_{Mf} = 1.35)

The weld connection on the top flange side has not been further tested. Considering the significantly lower voltage at the top, the weld connection will suffice here.

5.17 Type S: Coupling longitudinal stiffeners

At portal C, a coupling of the longitudinal stiffener has been realized with a relatively low one detail category (cross connection). At the location of the transverse stiffeners, the horizontal plate is the through coupling of the longitudinal stiffeners provides connected by fillet welding (a = 5 mm) with the body of the transverse stiffener. In addition, local welding gates have been installed, so that the vertical welding of the cross stiffener. These welding gates will result in a voltage concentration.

Figure 139 - Welded connection body and flange crossbeam [Source: A.85378]

In contrast to the relatively unfavorable detail category and the voltage concentration through the welding gates that thickening plates are placed on the body and flange extenders are present in the bottom flange. because of this nominal voltages will be lower locally.

Root test of the weld

Because welding gates are provided in the corners of the horizontal plate, it is with the help of a room plate model of the joint, the voltage in the weld determined at the location of the stress concentration. For this, a unit voltage of -100 N / mm² is placed on the edge of the plate and the voltage is in the root of the weld determined according to the report IIW Guideline for the Assessment of Weld Root Fatigue [11]. For this, the average stress in the last 0.5 * t = 5 mm may be taken and be spread over the weld that runs all around through the welding gate.

Figure 140 - Method for determining the voltage at the end of the weld [11]

The tension in the last 5 mm is shown in the figure below, based on a nominal tension of -100 N / mm² in the plate.

Figure 141 - Tension σ $_x$ in the connection under a unit load of -100 N / mm² (3D view)

Figure 142 - Tension σ $_x$ in the joint under a unit load of -100 N / mm² (top view)

Figure 143 - Tension σ $_x$ in the connection under a unit load of -100 N / mm² (detail at the stress peak)

The greatest average stress in the last 5 mm of the plate, assuming a unit load of -
100 N / mm², is -260 N / mm² (stress concentration factor 2.6). From this follows the following voltage in the read.

$$\perp_{,,} = \frac{}{2 \cdot + _2} = \frac{-260 / _2 \cdot 5 \cdot 10}{2 \cdot 5 \cdot 10 + (5)_2} = -104 / _2$$

The (maximum) shear stress parallel to the weld can be determined in a similar way and is the same On:

$$\parallel_{,,} = \frac{}{2 \cdot + _2} = \frac{-115 / _2 \cdot 5 \cdot 10}{2 \cdot 5 \cdot 10 + (5)_2} = 46/ _2$$

A test voltage of:

$$_{,,} = \sqrt{\ _{\perp,,}{}^2 + \ _{\parallel,,}{}^2} \quad \sqrt{104} = _2 + 46 _2 = 114/ _2$$

The voltage in the weld is therefore maintained as 1.14 times the nominal voltage. The detail category for the fatigue calculation of the root of the weld is taken as $\Delta\sigma_c$ = 36 * in accordance with NEN-EN 1993-1-9 Table 8.5 Detail 3.

Figure 144 - Detail category for the fatigue calculation of the connection type S (welding root).

The fatigue calculation is shown in Appendix E18. This is based on the nominal
stresses from the beam model, whereby in the cross-sectional properties the thickening plates on the body, the flange extenders and the longitudinal stiffeners at the location of the connection are included and where

the above - mentioned surcharge has been applied to translate the nominal voltages into the voltages in the read. The following damage figures follow from the calculation.

γ_{Mf} = 1.35	HRB west		HRB east		PRB west		PRB east	
	2018	2050	2018	2050	2018	2050	2018	2050
Root	0.1	0.4	0.0	0.0	0.1	0.3	0.0	0.0

Table 55 - Damage numbers of connection type S (root of the weld) for the end of 2018 and the end of 2050 (γ_{Mf} = 1.35)

Test toe of the weld

For the testing of the toe of the weld, a hotspot method was used, in which the voltage is extrapolated linearly from the voltage at 0.4t and 1.0t from the intersection of the plates, in accordance with (a) from the figure below from IIW-Recommendations for Fatigue Design of Welded Joints and Components (2016).

Figure 145 - Extrapolation method for the determination of the hotspot voltage [10]

The voltage 0.4t and 1.0t are shown in the figure below, based on a unit voltage of -100 N / mm².

0.4t 1.0t

Figure 146 - Voltages at 0.4t and 1.0 for the determination of the hotspot voltage

This finds the next hotspot voltage, starting from a nominal voltage from -100 N / mm²:

$$_{h} = 1.67 \cdot {}_{0.4\,\cdot} - 0.67 \cdot {}_{1.0\,\cdot} = 1.67 \cdot -238.4 - 0.67 \cdot -149.3 = -298 \, / \, {}^{2}$$

A voltage concentration factor of 2,98 has been used for the calculation rated voltage. The detail category for the fatigue calculation of the toe of the weld is maintained as $\Delta\sigma_{c}$ = 90 N / mm² in accordance with table 3.3 of the IIW reccomendation IIW-2259-15 [10] for hot spot calculations.

Figure 147 - Detail category for the fatigue calculation of the connection type S (welding stone).

The fatigue calculation is shown in Appendix E18. This is based on the nominal stresses from the beam model, whereby in the cross-sectional properties the thickening plates on the body, the flange extenders and the longitudinal stiffeners at the location of the connection are included and where the above-mentioned surcharge has been applied to translate the nominal voltages to the hotspot voltages in the plate near the welding gates. The following damage numbers follow from this.

γ_{Mf} = 1.35	HRB west		HRB east		PRB west		PRB east	
	2018	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
Toe	0.1	0.5	0.1	0.1	0.1	0.3	0.0	0.0

Table 56 - Damage numbers of connection type S (toe of the weld) for the end of 2018 and the end of 2050 (γ_{Mf} = 1.35)

Project related

5.18 Type T: Welded jacking points

At the location of the intermediate bearings, a plate is welded to the lower flange above the jacking points the introduction of the auger forces. The plates above the supports themselves are not welded, but through rivets connected, making this last connection equal to type K (not force-supported rivet connection). This has therefore not been tested further. There is one for the jacking points additional tests to be carried out.

At portal B (pillar G / K) a plate of 250x250 mm has been applied, which is welded all around with fillet weld a = 4 mm, see Figure 148 .

Figure 148 - Connection between jack point plate and bottom flange at portal B

At portal C (pillar H / J) a plate of 200x500 mm has been applied, which is welded all around with fillet weld a = 5 mm, see Figure 149 .

Figure 149 - Connection between jack point plate and bottom flange at portal C

The fatigue test was carried out on the basis of the voltage change in the lower flange of the main girder. Flange spacers in the relevant cross section are located at portal C present, but not at portal B (just). These are only for the jacking points at portal C. included in the determination of the voltage change. The detail category of this connection is not given in the standard, but complied with [10], Table 3.1, detail 513, $\Delta\sigma_c = 63$ N / mm ^{2} , assuming L = 250 mm and L = 200 mm.

Figure 150 - Detail category for connection type 18 according to [10].

The calculation was performed at the location of intermediate supports, for 3 different safety factors $\gamma_{Mf} = 1.35$, 1.15 and 1.00. The numbering of the locations is the same as type H, so T2 for the jacking points at portal B and T3 for the jacking points at portal C. The test results are for different main girders for $\gamma_{Mf} = 1.35$ are shown in Table 57 and Figure 151. The connectio do not meet the damage requirement $D \leq 1.0$ at $\gamma_{Mf} = 1.35$ everywhere . The test results with the other safety factors are summarized in Appendix E19.

$\gamma_{Mf} = 1.35$	HRB west		HRB east		PRB west		PRB east	
Year	2018	2050	2018	2050	2018	2050	2018	2050
T-2	2.6	8.6	1.5	2.1	2.6	5.6	0.2	0.5
T-3	0.3	1.1	0.1	0.1	0.3	0.7	0.0	0.0

Table 57 - Damage figures for connection type T for the end of 2018 and the end of 2050.

Figure 151 - Presentation of damage numbers for the first half of the bridge of type T connection before the end of 2050.

5.19 Crossbars

5.19.1 Introduction

For testing the fatigue of the cross beam connections on the main beam / cross stiffener used a combination of measurements and calculations to reduce fatigue damage determine. Following the first calculations at the cross beam connections with the main girder and the observations on the bridge, in consultation with Rijkswaterstaat, it was decided to install a set up a measurement program. The purpose of these measurements is to measure the actual voltage fluctuations determine locally several critical details, because it was suspected that the calculation model was too high gave peak voltages at the locations of discontinuities and connections.

TNO carries out stretch measurements on behalf of Rijkswaterstaat and in consultation with Royal HaskoningDHV performed at a number of locations of the main bridge. The measurement program is described in the TNO reports TNO-2019-R11393 [6] and TNO-2020-R10226 [9]. The measurements were carried out on:

- A cross beam without K-bandage (DD-zK)
- A crossbeam with K-bandage at a ½ INP30 cross stiffener in the main bridge (DD-K30)
- A crossbeam with K-bandage with a ½ INP24 cross stiffener in the main bridge (DD-K24)
- A cross beam at portal A (DD-STPA)
- A cross beam at portal B (DD-STPB)
- A cross beam at portal C (DD-STPC)

a
P
T
-S -K24
DD DD
PB
T
-zK -S
DD DD
-K30
DD
C
P
T
-S
DD

Figure 152 - Location of tested cross beams

On the basis of the measurements, hotspot voltages were determined by TNO, with both continuous measurements
The racks are continuously measured under normal conditions for a period of 24 hours
traffic load and ballast tests in which stretches are measured during a number of passages of a single
vehicle of known weight. The purpose of the continuous measurements is to determine the traffic spectrum
and compare it with the traffic spectrum according to the standard. The purpose of the ballast test is to test the
influence line of the voltage per measuring location and compare it with the calculated influence line. In
this report mainly made use of the results of the ballast measurements.

5.19.2 Ballast measurements

During the ballast measurements is with a truck with known (measured) axle weights and axle distances drove over the bridge. During the ballast measurements, the bridge was kept free from other traffic. On base the influence lines of the measurements can be determined for the different measured positions and can a comparison with the calculated influence lines is made.

5.19.2.1 Processing and filtering the measurement data

The raw measurement data has been processed and filtered by TNO, such that the measurement noise is filtered out and the offset of the measurement data is equal to zero just before the passage of the vehicle. In addition, the measurement data (racks plotted against time) converted to stresses plotted against distance traveled, by the multiply stretch by the modulus of elasticity (E = 210000 N / mm²) and translate the time into distance traveled based on vehicle speed. The location of the peaks in the measurements are shifted to occur at the same distance traveled as in the calculation.

Where relevant, the measurements are extrapolated to the hot spot voltage at the toe of the weld. A linear extrapolation is usually used from the measured values at 0.4t and 1.0t, according to the extrapolation method “type a” according to “IIW Recommendations for Fatigue Design of Welded Joints and Components ”[10].

Figure 153 - Hotspot extrapolation type a and b [10]

For a number of cases the voltage is (also) determined by means of a quadratic extrapolation from the measurement results at 4 mm, 8 mm and 12 mm from the toe of the weld. This is referred to as type b in “IIW Recommendations for Fatigue Design of Welded Joints and Components” [10]. Type a is normally used for the hot spot voltage at the toe of the weld on it plate surface, type b for the toe of the weld on the plate edge.

Figure 154 - Hotspot type [10]

5.19.2.2 Influence of undercut weld

During the measurements it was found that at a number of locations the welds are back compared to the surface of the plate. In this report this is referred to as the “undercut”. For illustrative purposes, it is in the figure below shows a cross section of a comparable welded joint with a large undercut of one other bridge (not being the IJssel Bridge) shown.

Figure 155 - Undercut for a welded joint (NB. Photo is not of the IJssel bridge)

The influence of the undercut on the stresses at 0.4t and 1.0t has been investigated using a DIANA model based on plain strain elements. In the figure below, the voltage is σ_y shown in vertical direction of a model with 2.0 mm undercut.

Figure 156 - Vertical stresses in plain strain model with 2.0 mm undercut

Due to the undercut, the stresses on the plate surface in the vicinity of the undercut will decrease, because the stresses from the undercut are again evenly distributed over the entire section. The full calculation of the influence of different sizes of the undercut The voltages at 0.4t and 1.0t are shown in Appendix H of this report. From this follow the subsequent reductions on the stresses, relative to a cross-section without an undercut.

	0.4 t		1.0 t	
Undercut [mm]	Voltage [N / mm²]	Percentage	Tension [N / mm²]	Percentage
0	48.9	100%	49.2	100%
0.5	44.1	90%	49.4	101%
1.0	36.7	75%	49.4	101%
2.0	22.5	46%	49.5	101%

Table 58 - Relationship between the depth of the undercut and the measured stresses

It can be seen that the influence on 0.4 t is considerable. The influence is hardly more at 1.0 t present. TNO has therefore corrected the measurements to 0.4 t when determining the hotspot voltage, by measuring the depth of the undercut and correcting the measured tension accordingly, by divide it by the percentage above. With this corrected voltage is then one hotspot extrapolation, so that a hotspot voltage is obtained as if there were no undercut present.

5.19.3 Comparison of calculation and measurement

In the following chapters a comparison will be made for the various measurement locations between the hotspot or nominal voltages as determined from the measurement results by TNO and the hotspot or nominal voltages that follow from the finite element model. One becomes in each chapter the crossbeam, giving an overview of the location of the relevant crossbeam and of the various tested details within the connection, even where measurements have not been taken. For the details where measurements were taken, a comparison between model and measurements is made of the (average) voltage change at 1.0t and at the hotspot location. For the locations where only one nominal voltage is measured, a comparison is made with the nominal voltage in the model.

During the ballast tests, two speeds were driven, 80 km / h and 20 km / h. For both speeds an average has been determined and displayed separately. Below each graph a "model factor" is given, which corresponds to the ratio of the voltage change from the measurement divided by the voltage change that follows from the model. In most cases this is done based on the change of the rear axis or of the entire influence line.

Based on the model factor at 20 km / h, the voltage of the unit load from the FEM model is back scaled and a fatigue analysis was performed with the corrected influence line. There has been chosen for the tensions at 20 km / h because they are least affected by dynamic effects. The effect Namely, this has already been included in the fatigue calculation as a dynamic enlargement factor of 1.1, and an additional factor of 1.15 at the joint transition. The measurements show that the tensions at 80 km / h sometimes higher and sometimes lower compared to the tensions at 20 km / h. When several measurements have been taken at one location (e.g. north and south side of a plate), then the side with the largest change in the measurement is used for the model factor for the fatigue analysis.

In locations where no measurements have been taken, the damage calculation is based on the voltage change from the fashion model.

5.19.4 Eccentricity of knee bulkhead - cross stiffener body

Many crossbars have an eccentricity between knee bulkhead and cross stiffener. Hollandia has measured the eccentricity **Error! Reference source not found.** . This will work with especially affect the stresses at the area of the weld between the knee bulkhead and the horizontal flange longitudinal stiffener and of the weld between web transverse stiffener and horizontal flange longitudinal stiffener.

Figure 157 - Eccentricity in the cross beam between knee bulkhead and cross stiffener body.

Figure 158 - Measured eccentricity in the intermediate crossbars without K-bandage

Figure 159 - Measured eccentricity in the crossbar with K-bandage

Figure 160 - Measured eccentricity in the cross beam at the portals

In the following chapters, the damage was calculated based on measurements. So there are already effects here of any eccentricity present, but that is not necessarily the maximum eccentricity. Because the welded joints with the horizontal flange of the longitudinal stiffener over it generally not satisfactory, no further looked at other crossbars with a higher one eccentricity. This effect will be further investigated and included in the gain calculations in the gain design.

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Project related

5.20 Type DD-zK: Main beam - intermediate cross member connection

The intermediate cross members are connected to the web of the main beams by the body and the lower flange by means of a head plate with rivets and a bulkhead under the bottom flange. The top flange of the cross beam (= cover plate) is connected to the top flange of the main beam and the cantilever part of the deck outside the main girders by means of a rivet connection. The cover plate is in fact interrupted at the location of the main beam.

Figure 161 - Overview of the connection Type DD-zK

5.20.1 Location of tested crossbeam

The tested and measured cross beam corresponds to the 1st cross beam north of pillar G. De voltage fluctuations in the connection have been determined with the hybrid model B, in which over a length of two K-relations before and after portal B the calculation model is constructed with plate elements.

Figure 162 - Location of tested intermediate crossbeam

5.20.2 Tested details

In the connection between cross beam and main beam there are various details that are critical regarding fatigue. For each part it will be explained how the test voltage is determined, where the normative cut and which detail category applies.

G1
C
G2
J
A1 B
G3
D
H
G1

G2
I
J
A2
A1 / B
C →
G3
G4
E D
F
H

Figure 163 - Tested details of crossbeam connection (Type DD-zK)

I
B A1
A2
A2
A1 B
G3
G3
G4
G4
D
E
E
D

North side *South side*

Figure 164 - Overview details in bulkhead cross beam DD-zK

The following table describes the details that have been tested and / or where a measurement is executed.

Detail	Description	Fatigue test	Measured
A1	Fillet weld bulkhead - bottom flange (type a)	X	X
A2	Fillet weld bulkhead - bottom flange (type a)	X	
B	Fillet weld bulkhead - bottom flange (type b)	X	X
C	Nominal voltage lower flange		X
D	Fillet weld bulkhead - horizontal flange longitudinal stiffener	X	X
E	Fillet weld bulkhead - horizontal flange longitudinal stiffener	X	X
F	Fillet weld transverse stiffener - horizontal flange longitudinal stiffener	X	X
G1 / G2	Fillet weld crossbeam body - headboard	X	X
G3 / G4	Fillet weld bulkhead	X	X
H	Weld web transverse stiffener - vertical flange longitudinal stiffener	X	X
I	Lower flange crossbeam - headboard	X	
J	Lower flange crossbeam at bulkhead	[1]	

[1] Not normative

Table 59 - Overview of test and measurement locations intermediate cross member (DD-zK)

For the connection in the top flange of the cross beam it applies that it is driven directly by a wheel print. From the voltage fluctuations from the local model it follows that local bending of the deck / top flange main beam in the direction perpendicular to the body of the main beam determines the voltage change and so the fatigue calculation. However, testing the deck construction falls outside the scope of the assignment and has therefore not been tested further. The fatigue calculations are shown in Appendix E20.

5.20.3 Detail A1 / B - Connection bulkhead - lower flange crossbeam

Detail A1 / B concerns the connection at the top, at the end of the bulkhead with the bottom flange of the crossbeam. A voltage concentration is present at this location. Measurements were taken at the front and back (detail A1) and on the front side (detail B).

A1 / B

A1 / B

Figure 165 - Tensions at the location of detail A1 / B bulkhead - lower flange crossbeam

In Appendix G the comparison of the measured voltages and the calculated voltages is given for detail A1 (north and south side) and detail B. The highest average hotspot voltage change measured occurs in detail B.

Figure 166 - Voltage change in hotspot voltages DD-zK detail B

Detail A1 / B - Toe of the weld

Based on the ratio of the voltage range from the measurements and from the model when passing the heaviest axis is a model factor (56%). This is based on the largest measured voltage change at 20 km / h (detail B). The voltages due to the unit load are for the fatigue calculation of the toe of the weld multiplied by this model factor, after which one fatigue calculation has been performed. This is based on a hotspot analysis with a detail category DC = 90, in accordance with table 3.3, detail 6 of IIW report “Recommendations for Fatigue Design of Welded Joints and Components ”[10].

Figure 167 - Detail category for detail A1 - toe of the weld [10]

It follows from this calculation that no damage has yet occurred at the location of detail A1.

	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 60 - Damage figures for late 2018 and late 2050 for detail A1 - weld toe

Project related

Detail A1 / B - root of the weld

Because there is a strong voltage gradient at the tip of the bulkhead, the voltage change determined in accordance with “IIW Guideline for the Assessment of Weld Root Fatigue” [11] paragraph 3.3.2. It describes a method for determining the voltage fluctuations for fillet welds at the ends of a plate, where the force over the last becomes t / 2 (= 5 mm) spread over the fillet welds on both sides of the plate and the weld on the front side, see it shaded area in the figure below.

Figure 168 - Geometry and load at the end of a connection [11]

The mean voltage was determined using SCIA by averaging over the last 5 mm request tension in the record.

Figure 169 - Average stress in the last 5 mm of the plate (σ y +) due to the unit load (2x50 kN)

The voltage change in the weld must be determined for testing. In accordance with the above method, the (maximum) normal voltage in the weld (a = 4 mm) as a result of the unit load (2x50 kN) can be determined as follows.

$$\perp_{,,} = \frac{}{2 \cdot + {}_2} = \frac{\cdot 5 \cdot 10}{2 \cdot 4 \cdot 10 + (4)\ {}_2} = 0.52 \cdot$$

The (maximum) shear stress parallel to the weld can be determined in a similar way and is the same On:

$$\parallel_{,,} = \frac{}{2 \cdot + {}_2} = \frac{\cdot 5 \cdot 10}{2 \cdot 4 \cdot 10 + (4)\ {}_2} = 0.52 \cdot$$

A test voltage of:

$$_{,,} = \sqrt{\perp_{,,}{}^2 + \parallel_{,,}{}^2}$$

In accordance with TNO Note 100315818 / ALL, the connection may be calculated with detail category 40, taking into account the available compressive stress. So this is slightly more beneficial if detail category 36 * in accordance with the Eurocode.

Figure 170 - Method for testing fillet and cross welds in accordance with [2]

Contrary to the method according to IIW [11], where a comparison voltage is used, must now a distinction is made between the normal stress and the shear stresses. The normal voltage perpendicular to the longitudinal axis of the weld ($\sigma_{\perp, w, loc}$) is tested for detail category 40, taking into account the (pressure) stress present, in accordance with the above TNO method, the shear stress is parallel the longitudinal axis of the weld ($\tau_{II, w, loc}$) is tested for detail category 80, in accordance with NEN-1993-1-9. The damage from both calculations must be added together.

The tables below show the test results for the normal voltage, including testing is according to the method from the TNO memorandum, both for type 1 (contact between the plates) and type 2 2 (no contact between the plates). The normative of the two assessments must be adhered to and added to the shear stress damage parallel to the longitudinal axis of the weld.

Type 1	**HRB west**		**HRB east**		**PRB west**		**PRB east**	
γ_{Mf}	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
1.35	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 61 - Damage figures for the end of 2018 and the end of 2050 for detail A1 - root of the weld (DC = 40, type 1)

Type 2	**HRB west**		**HRB east**		**PRB west**		**PRB east**	
γ_{Mf}	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
1.35	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0

1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 62 - Damage figures for the end of 2018 and the end of 2050 for detail A1 - root of the weld (DC = 40, type 2)

The shear stress change is so low that it does not cause any damage.

5.20.4 Detail A2 - Bulkhead connection - crossbar bottom flange

Detail A2 is located at the welding gate close to the main beam, in the connection bulkhead with the bottom flange of the cross beam. No measurements have been made on this detail. This detail is comparable to detail A1 and has been tested in a similar way, based on the calculated influence lines.

Detail A2 - toe of the weld

For detail A2, the calculated hotspot voltage is higher than for detail A1. The damage calculation therefore location A2 has also been calculated.

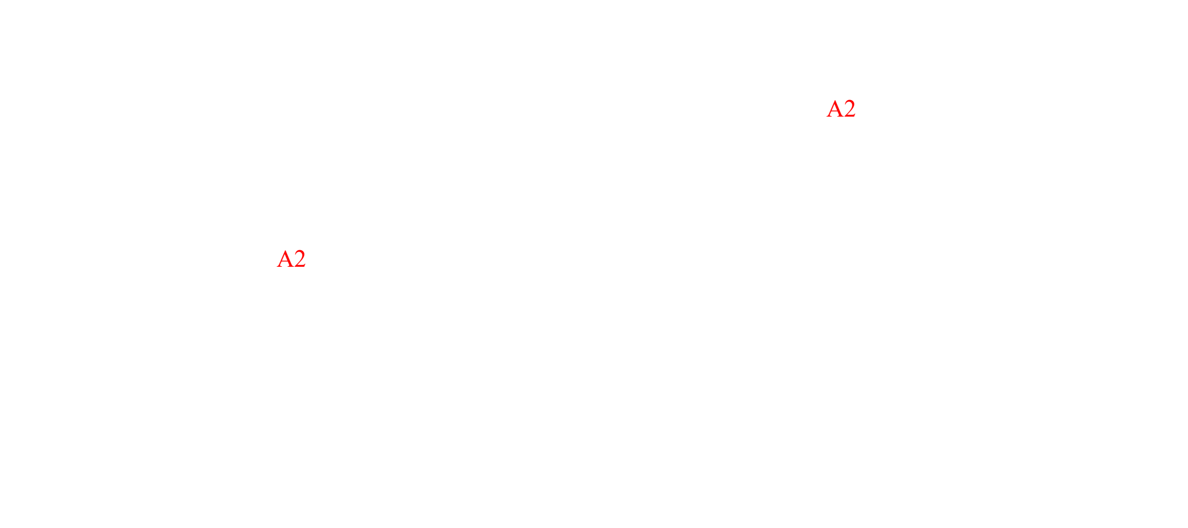

Figure 171 - Tensions at location A2, connection bulkhead - bottom flange crossbeam

The damage category is equal to location A1, if DC = 90, based on a hotspot analysis.

	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 63 - Damage figures for the end of 2018 and the end of 2050 for location A2

Location A2 - root of the weld

The damage calculation of the root of the weld was performed in the same way as for location A1. Also here the shear stress change is so low that it will not cause any damage.

Type 1	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.1	0.3	0.0	0.0	0.1	0.2	0.0	0.0
1.15	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 64 - Damage numbers for the end of 2018 and the end of 2050 for location A2 - root of the weld (DC = 40, type 1)

Type 2	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 65 - Damage numbers for the end of 2018 and the end of 2050 for location A2 - root of the weld (DC = 40, type 2)

5.20.5 Detail C - Bottom flange cross member (nominal)

A measurement was carried out at location C to compare the nominal voltages
to be able to perform the calculation model and measurements. This was measured at 1.75 m from the edge of the shot.

1750

Figure 172 - Overview DD-zK location C

Figure 173 - Voltage change (nominal) DD-zK location C.

The voltages correspond well between model and measurement. Because location C has a nominal voltage and not a fatigue-sensitive detail, there is no fatigue calculation for this location executed.

5.20.6 Detail D - Connection bulkhead - horizontal flange longitudinal stiffener

Detail D is located at the bottom of the bulkhead, at the junction with the horizontal flange of the longitudinal stiffener. For this detail measurements were taken in two places, D1 is as much as possible on the angle, D2 at 10 mm inwards.

D1 D2

Figure 174 - Detail photos DD-zK detail D1 and D2 north

Detail D - toe of the weld

The tension at the toe of the weld is determined by determining the hot spot voltage location of the stress peak at the end of the bulkhead, by extrapolating the stresses at 0.4t and 1.0t.

D

E F

Figure 175 - Voltage at the location of the bulkhead connection - horizontal flange longitudinal stiffener - transverse stiffener body (σ_{y+}) due to the unit load (2x50 kN)

Contrary to the other details, this location was chosen to allow comparison between measurement and calculations based on the stretches, in order to filter out the effects of cross contraction. Attached G compares the calculated hotspot racks and the measured hotspot racks on site of D1 and D2, both for the north and south sides.

Based on the ratio of the strain range from the measurements and from the model at the passage of the heaviest axis, a model factor has been determined. This is based on the largest measured strain change at 20 km / h (from DD-zK detail D1, north side) and equals 75%.

Figure 176 - Hotspot racks DD-zK detail D, north side

The stresses for the unit load are multiplied by this for the fatigue calculation model factor (75%), after which a fatigue calculation of the toe of the weld was performed. Hereby is based on Detail category $\Delta\sigma_c = 90$ N/mm² based on IIW report "Recommendations for Fatigue Design of Welded Joints and Components" [10], table 3.3, detail 6, comparable for detail A1.

Weld toe fatigue analysis was performed for three partial safety factors, where
the damage was determined at the end of 2018 and at the end of 2050. The results are summarized in the table below.

γ_{Mf}	HRB west		HRB east		PRB west		PRB east	
	2018	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
1.35	18.5	48.3	14.6	27.7	15.8	30.6	6.9	13.4
1.15	10.9	28.7	8.6	16.3	9.3	18.2	3.9	7.8
1	6.7	17.9	5.2	9.9	5.8	11.3	2.4	4.7

Table 66 - Damage figures for the end of 2018 and the end of 2050 for DD-zK detail D.

Detail D - Root of the weld

The root has been tested in the same way as for details A1 and A2. For this, the average voltage in the last t / 2 = 5 mm read and translated into a tension in the weld.

Figure 177 - Average stress in the last 5 mm of the plate (σ_{y}) due to the unit load (2x50 kN) at detail D

Project related

The result of the damage calculation for the normal voltage in the weld is shown below ($\sigma_{\perp, w, loc}$), where testing is done on detail category 40, taking into account the (pressure) stress present by its own weight (see detail A1 for the description of this method). There is no account account for the lower measured voltage, because it is difficult for the root to clearly determine the reduction to determine and any size violations have already been found for the toe of the weld.

Type 1	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 67 - Damage figures for the end of 2018 and the end of 2050 for detail D - root of the weld (DC = 40, type 1)

Type 2	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	21.7	56.0	17.1	32.1	18.3	35.5	7.8	15.3
1.15	13.1	34.0	10.3	19.3	11.1	21.5	4.7	9.2
1	8.4	21.9	6.6	12.4	7.1	13.8	3.0	5.9

Table 68 - Damage figures for the end of 2018 and the end of 2050 for detail D - root of the weld (DC = 40, type 2)

It can be seen that in type 1, where contact between the plates is assumed, no damage occurs. This is because there is a relatively high voltage due to the permanent load, which the self-tensions largely offsets. This means that virtually the entire change in pressure is included method 1 must be multiplied by $\alpha = 0.00$. With type 2 there is a (size) damage found, because here the voltage change in pressure must be included with $\alpha = 0.63$.
In view of the exceedance, the damage due to the shear stress is no longer determined, since the connection is already insufficient. The damage caused by the shear stress actually has to be added to damage mentioned above.

It is concluded that at location D both the toe and the root of the weld are not sufficient.

Project related

5.20.7 Detail E - Connection bulkhead - horizontal flange longitudinal stiffener

Detail E is located at the bottom of the bulkhead, at the junction with the horizontal flange of the longitudinal stiffener, on the side close to the main beam body. There is a welding gate here.

E

Figure 178 - Detail photo DD-zK detail E

Relatively low voltages were found here in the model. During the measurement it appeared that the measured tensions were significantly higher. Appendix G gives the comparison between the measurements and the calculated hotspot voltages. The highest stresses were found on the north side, where the measurement ratio to calculated hotspot voltage change equals 292%.

Figure 179 - Hotspot voltage DD-zK detail E, north side

Detail E - Toe of the weld

Based on the ratio of the voltage range from the measurements and from the model when passing the heaviest axis is a model factor determined. This is based on the largest measured voltage change at 20 km / h (from DD-zK, detail E, north side) and equals 292%. The tensions for the fatigue calculation, the unit load has been multiplied by this model factor, after which a fatigue calculation of the toe of the weld has been performed. This is based on Detail category $C\sigma_c$ = 90 N / mm², based on IIW report "Recommendations for Fatigue Design of Welded Joints and Components "[10], table 3.3, detail 6.

Weld toe fatigue analysis was performed for three partial safety factors, where the damage was determined at the end of 2018 and at the end of 2050. The results are summarized in the table below.

γ_{Mf}	HRB west		HRB east		PRB west		PRB east	
	2018	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
1.35	0.6	1.9	0.4	0.5	0.6	1.2	0.0	0.1
1.15	0.2	0.7	0.1	0.2	0.2	0.5	0.0	0.0
1	0.1	0.3	0.1	0.1	0.1	0.2	0.0	0.0

Table 69 - Damage figures for the end of 2018 and the end of 2050 for DD-zK detail E

Detail E - Root of the weld

The root of the weld at location E has not yet been tested, given the exceedances at location D and in the toe of the weld. The starting point is that there must be a reinforcement for the entire welded joint (detail D and E).

5.20.8 Detail F - Connection horizontal flange longitudinal stiffener - transverse stiffener

Detail F is located on the body of the transverse stiffener, just below the horizontal flange of the longitudinal stiffener, on the side close to the vertical flange of the longitudinal stiffener. Here is one welding gate.

Figure 180 - Detail photo DD-zK detail F

Appendix G provides the comparison between the measurements and the calculated hotspot voltages. The highest voltages were found on the south side, where the ratio measurement to computed

hot spot voltage change equals 100%.

Figure 181 - Hotspot voltage DD-zK detail F, south side

Detail F - Toe of the weld

Based on the ratio of the voltage range from the measurements and from the model when passing the heaviest axis is a model factor determined. This is based on the largest measured voltage change at 20 km / h (from DD-zK, detail F, south side). This is based on a type a extrapolation. The stresses due to the unit load have been multiplied for the fatigue calculation with this model factor, after which a fatigue calculation of the toe of the weld was performed. Hereby is based on Detail category $\Delta\sigma_c$ = 90 N / mm², based on IIW report “Recommendations for Fatigue Design of Welded Joints and Components ”[10], Table 3.3, Detail 6.

Weld toe fatigue analysis was performed for three partial safety factors, where the damage was determined at the end of 2018 and at the end of 2050. The results are summarized in the table below.

γ_{Mf}	HRB west		HRB east		PRB west		PRB east	
	2018	2050	2018	2050	2018	2050	2018	2050
1.35	7.3	19.4	5.5	10.4	6.2	12.2	2.4	4.8
1.15	4.1	11.0	3.0	5.8	3.4	6.9	1.3	2.7
1	2.3	6.4	1.7	3.3	2.0	4.0	0.7	1.5

Table 70 - Damage figures for the end of 2018 and the end of 2050 for DD-zK detail F

Detail F - Root of the weld

The square root of detail F has been tested in the same way as for detail D. The average is for this voltage in the last t / 2 = 5.4 mm read and translated into a voltage in the weld.

The result of the damage calculation for the normal voltage in the weld is shown below ($\sigma_{\perp, w, loc}$), where testing is done on detail category 40, taking into account the (pressure) stress present by its own weight (see detail A1 for the description of this method). There is no account account for the lower measured voltage, because it is difficult for the root to clearly determine the reduction to determine and any size violations have already been found for the toe of the weld.

Type 1	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.1	0.1	0.3	1.0	0.0	0.0	0.2	0.6
1.15	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 71 - Damage figures for the end of 2018 and the end of 2050 for detail F - root of the weld (DC = 40, type 1)

Type 2	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	5.6	14.6	4.2	8.0	4.7	9.2	1.8	3.7
1.15	3.2	8.5	2.4	4.5	2.7	5.3	1.0	2.1
1	1.9	5.1	1.4	2.7	1.6	3.2	0.6	1.2

Table 72 - Damage figures for the end of 2018 and the end of 2050 for detail F - root of the weld (DC = 40, type 2)

The calculation is based on type 2, which assumes no contact between the plates.
In view of the exceedance, the damage due to the shear stress is no longer determined, since the connection is already insufficient. The damage caused by the shear stress actually has to be added to damage mentioned above.

It is concluded that at location F both the toe and the root of the weld are not sufficient.

Project related

5.20.9 Detail G - Connection body / bulkhead crossbeam - headboard on main beam body

The stresses at the location of the welded connection between the body of the cross beam and the headboard and between the bulkhead under the cross beam and the head bulkhead is shown in the figures below. It the headboard, in turn, is connected to the body of the main beam with rivets. Especially with the welding gates occur voltage concentrations.

G1 G2 G4

G3

Figure 182 - Tensions at the point of connection of cross beam body / bulkhead - bulkhead on main beam body, DD-zk, Detail G

During the measurement it emerged that the welding gate appears to be absent at G2. There is therefore decided to perform measurements at G1 and G3. Measurements were only taken on the south side. Appendix G gives the comparison between the measurements and the calculated hotspot voltages.

Figure 183 - Detailed photos DD-zK location G1 and G3

It was not possible to determine one factor for location G1 for the ratio between measurement and calculation, but a distinction is made between a scaling for global behavior and a another factor for the scaling for the local behavior. This is further explained in Appendix G. When This corrected influence line is used to calculate the voltage change that is calculated (shown in yellow) corresponds to the measured voltage change at 20 km / h (shown in gray). The scaling of the influence line is done in such a way that the largest change in terms of size also corresponds.

Figure 184 - Hotspot voltage DD-zK detail G1, south side

It can be seen for location G3 that the measured voltage change is almost zero. Probably this will come because G3 is almost in the neutral line of the connection. In the calculation was made a significant greater tension found. This will, among other things, be due to the fact that there are slightly different factors in the calculation model stiffnesses between the different parts will occur as in reality, for example due to the play in the rivet connection.

The measured voltages at G3 are so low that no further calculations have been made fatigue.

Figure 185 - Hotspot voltage DD-zK detail G3, south side

Detail G - Toe of the weld

The highest voltage change occurs at detail G1. The test of the toe of the weld is therefore executed for detail G1. This takes into account the corrected influence line of the hot spot voltage. Because the voltage has been determined using the hotspot method, it has been assumed detail category 90. The damage appears to be just not satisfactory at γ_{Mf} = 1.35.

	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.4	1.4	0.2	0.2	0.4	0.9	0.0	0.0
1.25	0.3	0.9	0.1	0.1	0.9	0.0	0.0	0.0
1.15	0.2	0.5	0.1	0.1	0.2	0.3	0.0	0.0
1	0.1	0.2	0.0	0.0	0.1	0.2	0.0	0.0

Table 73 - Damage figures for the end of 2018 and the end of 2050 for location G1 - toe of the weld

However, there is some conservatism in the calculation. In accordance with TNO report TNO-2019-R11394 “Diverse advice fatigue life crossbeam connections IJsselbrug ”is allowed for the fatigue calculation of the cross bars is assumed from γ_{Mf} = 1.25. With this factor the connection. In addition, the actual traffic spectrum has not yet been taken into account is lower if the observed traffic spectrum in accordance with NEN 8701.

Detail G - Root of the weld

The square root at detail G1 has been tested in the same way as for detail F. Because detail G1 is on the way there is no difference between the testing for type 1 and type 2. Here too, use has been made a corrected influence line, but now based on the difference in influence lines between measurement and calculation at 1.0t (see Appendix G). This location was chosen because it corresponds better to the rated voltage. It is expected that the scaling of the voltage in the last 0.5 t of the plate, which is used for testing the root is more related to the nominal voltage than to the hotspot voltage.

Tested for detail category DC = 40, based on the TNO method, as described in detail A1. The following damage figures follow from the assessment with the corrected influence line.

Type 1	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.3	0.9	0.1	0.1	0.3	0.6	0.0	0.0
1.15	0.1	0.4	0.0	0.1	0.1	0.2	0.0	0.0
1.00	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0

Table 74 - Damage figures for the end of 2018 and the end of 2050 for location G1 - root of the weld (DC = 40)

The shear stresses are very low in both cases and will not result in additional damage. Also here, there is still some conservatism in the calculation.

5.20.10 Detail H - Connection transverse stiffener body - vertical flange longitudinal stiffener

Detail H is located at the connection between the body of the transverse stiffener and the vertical flange of the longitudinal stiffener. At the end of the welded joint between the vertical flange of the longitudinal stiffener and the body of the transverse stiffener a stress concentration occurs. There are details for this no measurements taken. Therefore, the calculated hotspot voltage for the fatigue testing.

H

Figure 186 - Stresses at the location of the transverse stiffener body connection - vertical flange longitudinal stiffener, DD-zK, Detail H

The testing of the toe of the weld of this detail has been carried out on the basis of the hot spot voltage is determined by a non-linear extrapolation of the results at 4 mm, 8 mm and 12 mm from the toe of the weld (type b extrapolation in accordance with IIW). This is based on a detail category DC = 100, in accordance with table 3.3, detail 6 of IIW report “Recommendations for Fatigue Design of Welded Joints and Components ”[10].

Figure 187 - Detail category for detail H - toe of the weld [10]

The following damage figures follow from the fatigue analysis.

γ_{Mf}	HRB west 2018	HRB west 2050	HRB east 2018	HRB east 2050	PRB west 2018	PRB west 2050	PRB east 2018	PRB east 2050
1.35	7.9	21.1	5.9	11.2	6.9	13.5	2.7	5.3
1.15	4.5	12.1	3.3	6.2	3.9	7.7	1.5	2.9
1	2.6	7.0	1.8	3.5	2.3	4.5	0.8	1.6

Table 75 - Damage figures for the end of 2018 and the end of 2050 for location H - toe of the weld (DC = 100)

5.20.11 Detail I - Connecting the lower flange crossbeam - headboard

Detail I - Toe of the weld

The bottom flange has a narrowing at the connection to the head plate from 250 mm to 200 mm. Voltage peaks also occur here, although they are considerably lower than the previous peaks.

I1

I2

Figure 188 - Tension σ x- in the bottom flange (longitudinal tension) at details I1 and I2.

Detail I2 is decisive for the assessment. The toe of the fillet weld is based on the hot spot voltage tested for fatigue, based on detail category 90, comparable to detail A1. Follow from this the following results.

	HRB west	HRB east	PRB west	PRB east

γ Mf	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 76 - Damage figures for late 2018 and late 2050 for location I2 - toe of the weld (DC = 90)

Detail I - Root of the weld

The root has been tested in a similar way as for detail A1. The voltage in the weld is determined by the determine the force in the outer 12/2 = 6 mm of the bottom flange and distribute it over the cross-section of the fillet weld, including end face. The test was performed conservatively on class 40, with the break point at 10^7, without taking into account the available compressive stress. It follows from the calculation that the weld connection is sufficient.

	HRB west		HRB east		PRB west		PRB east	
γ Mf	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 77 - Damage figures for the end of 2018 and the end of 2050 for location I2 - root of the weld (DC = 40)

5.20.12 Detail J - Lower flange crossbeam at the end of the bulkhead

For the bottom flange of the cross beam, it must be tested for detail category 56, in accordance with NEN -EN 1993-1-9 Table 8.4 Detail 1 (L> 100 mm), based on the nominal voltage in the bottom flange.

Figure 189 - Detail category for the fatigue calculation of the DD-zK compound, detail J

It follows from the calculation that the nominal longitudinal voltages in the lower flange at the location of the connection practically zero.

Lower flange at the end of the bulkhead (J)

Figure 190 - Voltage in lower flange due to unit load on the intermediate cross member

The voltage change is so low that no damage will occur here. This cut is therefore not further tested.

5.21 Type DD-K30: Main beam - cross beam with K-bandage connection with 1/2 INP30 cross stiffener

The crossbars with K-bandages are connected to the body and the lower flange to the body of the main girders by means of a head plate with rivets and a bulkhead below the lower flange. The top flange of the cross beam (= cover plate) is connected to the top flange of the main beam and the cantilevered part of the deck outside the main girders by means of a rivet connection. The cover plate is interrupted at the location of the main beam.

Figure 191 - Overview of the connection Type DD-K30

This chapter describes the testing of the crossbeam with K-band at the location of the cross stiffeners tested with a ½ INP30 cross stiffener. The cross bars with ½ INP24 cross stiffeners are used Chapter 5.22 tested.

5.21.1 Location of tested crossbeam

The tested and measured cross beam corresponds to the 2nd cross beam after the 2nd riveted section division in the 2nd field (axis 12 on the original design drawings). The voltage fluctuations the compounds have been determined with the hybrid model D, which includes lengths of 4 k-bonds (cross beam 11 to 14 on the original design drawings) the calculation model is constructed with plate elements. At the location of this cross beam, the body of the main beam is ½ INP30 cross stiffeners supported.

Figure 192 - Location of tested crossbeam with K bandage, DD-K30.

5.21.2 Tested details

In the connection between cross beam and main beam there are various details that are critical regarding fatigue. For each part it will be explained how the test voltage is determined, where the normative cut and which detail category applies.

G1

C

G2

J

A1-B

G3

D

H

G1

G2

I

J

A2

A1 / B

C →

G3

G4

E

D

F

H

Figure 193 - Tested crossbeam connection details (Type DD-K30)

J I
B A1
A2 A2 A1 B
G3 G3
G4
G4 E
E
H
H

North side *South side*

Figure 194 - Overview of details in bulkhead cross beam DD-K30

The following table describes the details that have been tested and / or where a measurement is executed.

Detail	Description	Fatigue test	Measured
A1	Fillet weld bulkhead - bottom flange (type a)	X	X
A2	Fillet weld bulkhead - bottom flange (type a)	X	
B	Fillet weld bulkhead - bottom flange (type b)	X	X
C	Nominal voltage lower flange		X
D	Fillet weld bulkhead - horizontal flange longitudinal stiffener	X	X
E	Fillet weld bulkhead - horizontal flange longitudinal stiffener	X	X
F	Fillet weld transverse stiffener - horizontal flange longitudinal stiffener	X	X
G1 / G2	Fillet weld transverse stiffener - headboard	X	X
G3 / G4	Fillet weld bulkhead	X	X

H	Weld web transverse stiffener - vertical flange longitudinal stiffener	X	X
I	Lower flange crossbeam - headboard	X	
J	Lower flange crossbeam at bulkhead	X	

Table 78 - Overview of test and measurement locations for cross bars with K-bandages (DD-K30)

For the connection in the top flange of the cross beam it applies that it is driven directly by a wheel print. From the voltage fluctuations from the local model it follows that local bending of the deck / top flange main beam in the direction perpendicular to the body of the main beam determines the voltage change and so the fatigue calculation. However, testing the deck construction falls outside the scope of the assignment and is therefore not tested further here. The fatigue calculations are shown in Appendix E12.

5.21.3 Detail A1 / B - Connection bulkhead - lower flange crossbeam

Detail A1 / B concerns the connection at the top, at the end of the bulkhead with the bottom flange of the crossbeam. A voltage concentration is present at this location. Measurements were taken at the front and back (detail A1) and on the front side (detail B).

A1 B

A1 B

Figure 195 - Tensions at the location of detail A1 / B bulkhead - lower flange crossbeam

In Appendix G the comparison of the measured voltages and the calculated voltages is given for detail A1 (north and south side) and detail B. The highest average hotspot voltage change measured occurs in detail B.

Figure 196 - Voltage change hotspot voltages DD-K detail B

Detail A1 / B - Toe of the weld

Based on the ratio of the voltage range from the measurements and from the model when passing the heaviest axis is a model factor (64%). This is based on the largest measured voltage change at 20 km / h (detail B). The voltages due to the unit load are for the fatigue calculation of the toe of the weld multiplied by this model factor, after which one fatigue calculation has been performed. This is based on a hotspot analysis with a detail category DC = 90, in accordance with table 3.3, detail 6 of IIW report "Recommendations for Fatigue Design of Welded Joints and Components "[10].

Figure 197 - Detail category for detail A1 - toe of the weld [10]

From this calculation follows the following damage numbers at the location of detail A1.

	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
1.35	0.2	0.6	0.1	0.3	0.2	0.4	0.0	0.1
1.15	0.1	0.3	0.0	0.1	0.1	0.2	0.0	0.0

1.00	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Table 79 - Damage figures for the end of 2018 and the end of 2050 for detail A1 - toe of the weld

Detail A1 / B - root of the weld

Because there is a strong voltage gradient at the tip of the bulkhead, the voltage change determined in accordance with “IIW Guideline for the Assessment of Weld Root Fatigue” [10] paragraph 3.3.2. The application of this method is described in chapter 5.20.3 .

The mean voltage was determined using SCIA by averaging over the last 5 mm to request tension in the bulkhead with a thickness of 10 mm.

Figure 198 - Average stress in the last 5 mm of the knee bulkhead (σ_{y+}) due to the unit load (2x50 kN).

The voltage change in the weld must be determined for testing. In accordance with the above method, the (maximum) normal voltage in the weld (a = 4 mm) as a result of the unit load (2x50 kN) can be determined as follows. Determining the stresses in the weld is described in chapter 5.20.3 therefore it is not discussed here again.

In accordance with TNO Note 100315818 / ALL [2], the connection may be calculated with detail category 40, taking into account the available compressive stress and the residual stresses due to the weld process. This is therefore slightly more favorable as a detail category 36 * in accordance with the Eurocode.

Figure 199 - Method for testing fillet and cross welds in accordance with [2]

Contrary to the method according to IIW [11], where a comparison voltage is used, must now a distinction is made between the normal stress and the shear stresses. The normal voltage perpendicular to the longitudinal axis of the weld ($\sigma_{\perp, w, loc}$) is tested for detail category 40, taking into account the (pressure) stress present, in accordance with the above TNO method, the shear stress is parallel the longitudinal axis of the weld ($\tau_{II, w, loc}$) is tested for detail category 80 with slope m = 5, in accordance with NEN 1993-1-9. The damage from both calculations must be added together.

The tables below show the test results for the normal voltage, including testing is according to the method from the TNO memorandum, both for type 1 (contact between the plates) and type 2 2 (no contact between the plates). The normative of the two assessments must be adhered to and added to the shear stress damage parallel to the longitudinal axis of the weld.

Type 1	**HRB west**		**HRB east**		**PRB west**		**PRB east**	
γ_{Mf}	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
1.35	2.4	6.3	1.9	3.8	1.9	3.9	1.0	1.9
1.15	1.1	3.1	0.8	1.8	0.9	1.9	0.4	0.9
1	0.5	1.4	0.4	0.8	0.4	0.8	0.2	0.4

Table 80 - Damage figures for the end of 2018 and the end of 2050 for detail A1 - root of the weld (DC = 40, type 1)

Type 2	**HRB west**		**HRB east**		**PRB west**		**PRB east**	
γ_{Mf}	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
1.35	0.7	2.0	0.5	0.9	0.6	1.2	0.2	0.4
1.15	0.2	0.8	0.2	0.4	0.2	0.5	0.1	0.1
1	0.1	0.3	0.1	0.1	0.1	0.2	0.0	0.0

Table 81 - Damage figures for the end of 2018 and the end of 2050 for detail A1 - root of the weld (DC = 40, type 2)

In view of the exceedance, the damage due to the shear stress is no longer determined, since the connection is already insufficient. The damage caused by the shear stress actually has to be added to damage mentioned above

5.21.4 Detail A2 - Bulkhead connection - crossbeam bottom flange

Detail A2 is located at the welding gate close to the main beam, in the connection bulkhead with the bottom flange of the cross beam. This detail is comparable to detail A1 and has been tested in a similar manner.

Detail A2 - toe of the weld

The welding gate produces a peak voltage at the location A2. Therefore, the fatigue calculation for this location also performed.

A2

A2

Figure 200 - Tensions at location A2, connection bulkhead - bottom flange crossbeam

The detail category is equal to location A1 maintained as DC = 90, based on a hotspot analysis.

γ_{Mf}	HRB west		HRB east		PRB west		PRB east	
	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 82 - Damage figures for the end of 2018 and the end of 2050 for location A2 - toe of the weld

Location A2 - root of the weld

The damage calculation of the root of the weld was performed in the same way as for location A1. Also here the shear stress change is so low that it will not cause any damage.

Type 1	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 83 - Damage figures for the end of 2018 and the end of 2050 for location A2 - root of the weld (DC = 40, type 1)

Type 2	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 84 - Damage figures for the end of 2018 and the end of 2050 for location A2 - root of the weld (DC = 40, type 2)

5.21.5 Detail C - Bottom flange cross member (nominal)

A measurement was carried out at location C to compare the nominal voltages to be able to perform the calculation model and measurements. This was measured at 1.75 m from the edge of the shot.

1750

Figure 201 - Overview DD-K30 location C

Figure 202 - Voltage change (nominal) DD-zK location C.

The voltages correspond well between model and measurement. Because location C has a nominal voltage and not a fatigue-sensitive detail, there is no fatigue calculation for this location executed.

5.21.6 Detail D - Connection bulkhead - horizontal flange longitudinal stiffener

Detail D is located at the bottom of the knee bulkhead, at the connection with the horizontal flange of the longitudinal stiffener. For this detail measurements were taken in two places, D1 is as much as possible on the angle, D2 at 10 mm inwards.

D1 D2

Figure 203 - Detail photos DD-K30 detail D1 and D2 south and north.

Project related

Detail D - toe of the weld

The stress at the toe of the weld is determined by determining the hot spot voltage at the spot of the voltage peak at the end of the bulkhead, by extrapolation of the stresses at 0.4t and 1.0t.

E

D

F

Figure 204 - Voltage at the location of the bulkhead connection - horizontal flange longitudinal stiffener - transverse stiffener body (σ_{y+}) due to the unit load (2x50 kN)

Appendix G compares the calculated hotspot voltage and the measured hotspot voltages at D1 and D2, both for the north and south sides.

Based on the ratio of the voltage range from the measurements and from the model when passing the heaviest axis is a model factor determined. This is based on the largest measured voltage change at 20 km / h (from DD-K30 detail D2, north side) and equals 36%.

Figure 205 - Hotspot voltage DD-K30 detail D, north side

The stresses for the unit load are multiplied by this for the fatigue calculation model factor (36%), after which a fatigue calculation of the toe of the weld was performed. Hereby is based on Detail category $\Delta\sigma_c$ = 90 N / mm², based on IIW report “Recommendations for Fatigue Design of Welded Joints and Components ”[10], table 3.3, detail 6, comparable for detail A1.

Weld toe fatigue analysis was performed for three partial safety factors, where the damage was determined at the end of 2018 and at the end of 2050. The results are summarized in the table below.

	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	1.2	3.4	0.8	1.4	1.1	2.2	0.3	0.6
1.15	0.5	1.6	0.4	0.6	0.5	1.0	0.1	0.3
1	0.2	0.7	0.1	0.3	0.2	0.4	0.0	0.1

Table 85 - Damage figures for the end of 2018 and the end of 2050 for DD-K30 detail D.

Detail D - Root of the weld

The root has been tested in the same way as for details A1 and A2. For this, the average voltage in the last t / 2 = 5 mm read and translated into a tension in the weld.

Figure 206 - Average stress in the last 5 mm of the plate (σ_{y-}) due to the unit load (2x50 kN) at detail D

The result of the damage calculation for the normal voltage in the weld is shown below ($\sigma_{\perp, w, loc}$), where testing is done on detail category 40, taking into account the (pressure) stress present by its own weight (see detail A1 for the description of this method). There is no account account for the lower measured voltage, because it is difficult for the root to clearly determine the reduction to determine if exceedances have already been found for the toe of the weld.

Type 1	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.2	0.5	0.2	0.6	0.1	0.3	0.1	0.3
1.15	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 86 - Damage figures for the end of 2018 and the end of 2050 for detail D - root of the weld (DC = 40, type 1)

Type 1	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	12.1	31.1	9.5	17.7	10.2	19.7	4.3	8.4
1.15	7.2	18.6	5.6	10.5	6.1	11.8	2.5	5.0
1	4.5	11.6	3.5	6.5	3.8	7.4	1.5	3.0

Table 87 - Damage figures for the end of 2018 and the end of 2050 for detail D - root of the weld (DC = 40, type 2)

It can be seen that in type 1, where contact between the plates is assumed, no damage occurs. This is because there is a relatively high voltage due to the permanent load, which the self-tensions largely offsets. This means that virtually the entire change in pressure is included method 1 must be multiplied by α = 0.00. With type 2 there is a (size) damage found, because here the voltage change in pressure must be included with α = 0.63.

In view of the exceedance, the damage due to the shear stress is no longer determined, since the connection is already insufficient. The damage caused by the shear stress actually has to be added to damage mentioned above.

It is concluded that at location D both the toe and the root of the weld are not sufficient.

5.21.7 Detail E - Connection bulkhead - horizontal flange longitudinal stiffener

Detail E is located at the bottom of the bulkhead, at the junction with the horizontal flange of the longitudinal stiffener, on the side close to the main beam body. There is a welding gate here.

E

Figure 207 - Detail photo DD-K30 detail E

Relatively low voltages were found here in the model. During the measurement it appeared that the measured tensions were significantly higher. Appendix G gives the comparison between the measurements and the calculated hotspot voltages. The highest stresses were found on the north side, where the measurement ratio to calculated hotspot voltage change equals 141%.

Figure 208 - Hotspot voltage DD-K30 detail E, north side

Detail E - Toe of the weld

Based on the ratio of the voltage range from the measurements and from the model when passing the heaviest axis is a model factor determined. This is based on the largest measured voltage change at 20 km / h (from DD-kL, detail E, north side) and is equal to 141%. The tensions for the fatigue calculation, the unit load has been multiplied by this model factor, after which a fatigue calculation of the toe of the weld has been performed. This is based on Detail category $C\sigma_c$ = 90 N / mm², based on IIW report “Recommendations for Fatigue Design of Welded Joints and Components ”[10], table 3.3, detail 6.

Weld toe fatigue analysis was performed for three partial safety factors, where the damage was determined at the end of 2018 and at the end of 2050. The results are summarized in the table below.

	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 88 - Damage figures for the end of 2018 and the end of 2050 for DD-K30 detail E

Detail E - Root of the weld

The root of the weld at location E has not yet been tested, given the exceedances at location D and in the toe of the weld. The starting point is that there must be a reinforcement for the entire welded joint (detail D and E).

5.21.8 Detail F - Connection horizontal flange longitudinal stiffener - transverse stiffener

Detail F is located on the body of the transverse stiffener, just below the horizontal flange of the longitudinal stiffener, on the side close to the vertical flange of the longitudinal stiffener. Here is one welding gate.

Figure 209 - Detail photo DD-K30 detail F

Appendix G provides the comparison between the measurements and the calculated hotspot voltages. The highest voltages were found on the south side, where the ratio measurement to computed hot spot voltage change equals 51%.

Figure 210 - Hotspot voltage DD-K30 detail F, south side

Detail F - Toe of the weld

Based on the ratio of the voltage range from the measurements and from the model when passing the heaviest axis is a model factor determined. This is based on the largest measured voltage change at 20 km / h (from DD-k30, detail F, south side). This is based on a type a extrapolation. The stresses due to the unit load have been multiplied for the fatigue calculation with this model factor, after which a fatigue calculation of the toe of the weld was performed. Hereby is based on Detail category $\Delta\sigma_c$ = 90 N / mm², based on IIW report "Recommendations for Fatigue Design of Welded Joints and Components "[10], Table 3.3, Detail 6.

Weld toe fatigue analysis was performed for three partial safety factors, where the damage was determined at the end of 2018 and at the end of 2050. The results are summarized in the table below.

	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.8	2.3	0.5	0.9	0.7	1.5	0.2	0.3
1.15	0.3	1.0	0.2	0.4	0.3	0.6	0.1	0.1
1	0.1	0.4	0.1	0.1	0.1	0.3	0.0	0.0

Table 89 - Damage figures for the end of 2018 and the end of 2050 for DD-K30 detail F

Detail F - Root of the weld

The square root of detail F has been tested in the same way as for detail D. The average is for this voltage in the last t / 2 = 5.4 mm read and translated into a voltage in the weld.

The result of the damage calculation for the normal voltage in the weld is shown below ($\sigma_{\perp, w, loc}$), where testing is done on detail category 40, taking into account the (pressure) stress present by its own weight (see detail A1 for the description of this method). There is no account account for the lower measured voltage, because it is difficult for the root to clearly determine the reduction to determine and any size violations have already been found for the toe of the weld.

Type 1	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	1.9	5.0	1.5	3.4	1.5	3.0	0.8	1.8
1.15	0.8	2.1	0.6	1.4	0.6	1.3	0.4	0.8
1	0.2	0.9	0.2	0.6	0.2	0.5	0.1	0.3

Table 90 - Damage figures for the end of 2018 and the end of 2050 for detail F - root of the weld (DC = 40, type 1)

Type 2	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	5.2	14.1	3.9	7.0	4.6	9.1	1.6	3.1
1.15	3.0	8.1	2.2	3.9	2.6	5.2	0.9	1.7
1	1.7	4.8	1.3	2.3	1.6	3.1	0.4	1.0

Table 91 - Damage figures for the end of 2018 and the end of 2050 for detail F - root of the weld (DC = 40, type 2)

The calculation is based on type 2, which assumes no contact between the plates.
In view of the exceedance, the damage due to the shear stress is no longer determined, since the connection is already insufficient. The damage caused by the shear stress actually has to be added to damage mentioned above.

It is concluded that at location F both the toe and the root of the weld are not sufficient.

Project related

5.21.9 Detail G - Connection body / bulkhead cross beam - headboard on main beam body

The stresses at the location of the welded connection between the body of the cross beam and the headboard and between the bulkhead under the cross beam and the head bulkhead is shown in the figures below. It the headboard, in turn, is connected to the body of the main beam with rivets. Especially with the welding gates occur voltage concentrations.

G4

G2

G3

G1

G2

Figure 211 - Tensions at the location of crossbeam / bulkhead connection - headboard on main beam body, DD-K30, Detail G.

Project related

During the measurement it emerged that the welding gate appears to be absent at G2. There is therefore decided to perform measurements at G1 and G3. Measurements were only taken on the south side. Appendix G gives the comparison between the measurements and the calculated hotspot voltages.

Figure 212 - Detailed photos DD-K30 location G1 and G3

Project related

It was not possible to determine one factor for location G1 for the ratio between measurement (shown in gray) and FEM calculation (shown in red). Therefore, a distinction has been made between a scaling for the global behavior and another factor for the scaling for the local behavior.
This is further explained in Appendix G. When this corrected influence line is taken into account, this will be the case the calculated corrected voltage change (shown in yellow) corresponds well with the measured voltage change at 20 km / h (shown in gray).

Figure 213 - Hotspot voltage DD-K30 detail G1, south side

For location G3 it can be seen that the voltage change is almost zero and even opposite in sign. This is because G3 is almost in the neutral line of the connection crossbeam - main beam. From the measurement therefore shows that G3 is still on the tensile side of the neutral line, in the calculation G3 is on the pressure side. This difference can be explained by the fact that the modeled stiffnesses will deviate from the actual stiffness, for example due to the play in rivets. Both the calculated voltage and the measured voltages are very low.

Figure 214 - Hotspot voltage DD-K30 detail G3, south side

Detail G - Toe of the weld

The highest voltage change occurs at detail G1. The test of the toe of the weld is therefore executed for detail G1. This takes into account the corrected influence line of the hot spot voltage. The damage appears to be just not sufficient at $\gamma_{Mf} = 1.35$.

HRB west	HRB east	PRB west	PRB east

γ Mf	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.4	1.3	0.2	0.2	0.4	0.8	0.0	0.0
1.15	0.2	0.5	0.1	0.1	0.1	0.3	0.0	0.0
1	0.1	0.2	0.0	0.0	0.1	0.1	0.0	0.0

Table 92 - Damage figures for the end of 2018 and the end of 2050 for location G1 - toe of the weld

Detail G - Root of the weld

The square root at detail G1 has been tested in the same way as for detail F. Because detail G1 is on the way there is no difference between the testing for type 1 and type 2. Here too, use has been made a corrected influence line, but now based on the difference in influence lines between measurement and calculation at 1.0t (see Appendix G). This location was chosen because it corresponds better to the rated voltage. It is expected that the scaling of the voltage in the last 0.5 t of the plate, which is required for testing the root is more related to the nominal voltage than to the hotspot voltage.

The following damage figures follow from the assessment with the corrected influence line.

Type 1	HRB west		HRB east		PRB west		PRB east	
γ Mf	2018	2050	2018	2050	2018	2050	2018	2050
1.35	1.2	3.7	0.6	0.8	1.2	2.4	0.1	0.1
1.15	0.6	2.0	0.3	0.4	0.6	1.3	0.0	0.1
1	0.3	1.1	0.1	0.2	0.3	0.7	0.0	0.0

Table 93 - Damage figures for the end of 2018 and the end of 2050 for location G1 - root of the weld (DC = 40)

The shear stresses are very low in both cases and will not result in additional damage.

It is concluded that the testing of the root is not sufficient.

5.21.10 Detail H - Connection transverse stiffener body - vertical flange longitudinal stiffener

Detail H is located at the connection between the body of the transverse stiffener and the vertical flange of the longitudinal stiffener.

H

Figure 215 - Detail photo DD-K30 detail H

At the end of the weld connection between the vertical flange of the longitudinal stiffener and the web a tension concentration of the transverse stiffener occurs.

H

Figure 216 - Tensions at the location of transverse stiffener body connection - vertical flange longitudinal stiffener, DD-K30, Detail H

Stretch measurements were also carried out for this location, see Appendix G. Both in the measurement and in the calculation the hot spot voltage is determined by a non-linear extrapolation of the results at 4 mm, 8 mm and 12 mm from the toe of the weld (type b extrapolation according to IIW).

Figure 217 - Hotspot voltage DD-K30 detail H

From the comparison between measurement and calculation it follows that the measured hotspot voltage change at 20 km / h is 73% of the calculated hotspot voltage change. For fatigue testing, the calculated influence line therefore scales with this factor. This is based on a DC detail category = 100, in accordance with table 3.3, detail 8 of IIW report “Recommendations for Fatigue Design of Welded Joints and Components ”[10].

Figure 218 - Detail category for detail H - toe of the weld [10]

	HRB west		HRB east		PRB west		PRB east	
γ Mf	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**	**2018**	**2050**
1.35	4.8	12.9	3.6	6.4	4.2	8.3	1.4	2.9
1.15	4.4	12.6	1.9	3.4	2.3	4.5	0.7	1.5
1	1.4	4.1	1.0	1.7	1.3	2.6	0.3	0.7

Table 94 - Damage figures for the end of 2018 and the end of 2050 for location H - toe of the weld (DC = 100)

It is concluded that the weld connection is not sufficient.

5.21.11 Detail I - Connecting the lower flange crossbeam - bulkhead

Detail I - Toe of the weld

The bottom flange has a narrowing at the connection to the head plate from 250 mm to 200 mm. Voltage peaks also occur here, although they are considerably lower than the previous peaks.

I1

I2

Figure 219 - Tension σ $_{x+}$ in the bottom flange (longitudinal tension) at details I1 and I2.

Detail I2 is decisive for the assessment. The toe of the fillet weld is based on the hot spot voltage tested for fatigue, based on detail category 90, comparable to detail A1. Follow from this the following results.

	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 95 - Damage figures for late 2018 and late 2050 for location I2 - toe of the weld (DC = 90)

Detail I - Root of the weld

The root has been tested in a similar way as for detail A1. The voltage in the weld is determined by the determine the force in the outer 12/2 = 6 mm of the bottom flange and distribute it over the cross-section of the fillet weld, including end face. The test was performed conservatively on class 40, with the break point at 10^7, without taking into account the available compressive stress. It follows from the calculation that the weld connection is sufficient.

	HRB west		HRB east		PRB west		PRB east	
γ_{Mf}	2018	2050	2018	2050	2018	2050	2018	2050
1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 96 - Damage figures for the end of 2018 and the end of 2050 for location I2 - root of the weld (DC = 40)

5.21.12 Detail J - Lower flange crossbeam at the end of the bulkhead

For the bottom flange of the cross beam, it must be tested for detail category 56, in accordance with NEN -EN 1993-1-9 Table 8.4 Detail 1 (L> 100 mm), based on the nominal voltage in the bottom flange.

Figure 220 - Detail category for the fatigue calculation of the DD-zK compound, detail J

The peak voltages occur at the location of the knee joint connection with the lower flange of the crossbeam. However, the nominal voltages are so low that no damage will occur.

Lower flange at the end of the bulkhead (J)

Figure 221 - Stress in lower flange due to unit load on the cross member with K-bandage

5.22 Type DD-K24: Main beam - cross beam with K-bandage connection with 1/2 INP24 cross stiffener

The crossbars with K-bandages at the location of the ½ INP24 cross stiffeners are similar connected to the main beam as at the location of the ½ INP 30 cross stiffeners. Main difference between the two connections is the connection of the longitudinal stiffener to the transverse stiffener. That is how it is the ½ INP24 transverse stiffeners are not connected to the vertical flange of the longitudinal stiffener, while this is ½ INP30 cross stiffeners is.

Figure 222 - Overview of the connection Type DD-K24

5.22.1 Location of tested crossbeam

The tested and measured cross bar corresponds to the 1st cross bar with k-bandage in the 1st field.
The voltage fluctuations in the connection are determined with the hybrid model A, which is over a length the calculation model of the cross beam 1 to 3 is constructed with plate elements. Spot this cross beam, the body of the main beam is stiffened with a ½ INP24 cross stiffener.

Figure 223 - Location of tested crossbeam with K-bandage, DD-K24.

Project related

5.22.2 Tested details

In the connection between cross beam and main beam there are various details that are critical regarding fatigue. For each part it will be explained how the test voltage is determined, where the normative cut and which detail category applies.

AB

D

AB

E D

F

Figure 224 - Tested crossbeam connection details (Type DD-K24)

AB

AB

D E

F

North side *South side*

Figure 225 - Overview details in bulkhead cross beam DD-K24

Given the similarities and differences with DD-K30, only detail D, E and F is one fatigue calculation performed. For the other details, it is assumed that here a similar one voltage, and thus damage, occurs as with DD-K30. For detail A1 / B, a comparison has been made between the both locations to check this. The following table describes the details that are tested and / or where a measurement was taken. The fatigue calculations are shown in Appendix E13.

Detail	Description	Fatigue test	Measured
A1	Fillet weld bulkhead - bottom flange (type a)	**	
A2	Fillet weld bulkhead - bottom flange (type a)	**	
B	Fillet weld bulkhead - bottom flange (type b)	**	
C	Nominal voltage lower flange	**	

D	Fillet weld bulkhead - horizontal flange longitudinal stiffener	X	X
E	Fillet weld bulkhead - horizontal flange longitudinal stiffener	X	X
F	Fillet weld transverse stiffener - horizontal flange longitudinal stiffener	X	X
G1 / G2	Fillet weld transverse stiffener - headboard	**	
G3 / G4	Fillet weld bulkhead	**	
H	Weld web transverse stiffener - vertical flange longitudinal stiffener	**	
I	Lower flange crossbeam - headboard	**	
J	Lower flange crossbeam at bulkhead	**	

*** Geometry and stresses correspond to K30 (see section 5.22.3). Reference is made to the assessment of this location paragraph 5.21*

Table 97 - Overview of test and measurement locations for crossbeam with K bandage (DD-K24)

5.22.3 Detail A1 / B - Connection bulkhead - lower flange crossbeam

Detail A1 / B concerns the connection at the top, at the end of the bulkhead with the bottom flange of the crossbeam. A voltage concentration is present at this location. There are no measurements performed at this location.

Figure 226 - Tensions at the location of detail A1 / B bulkhead - lower flange crossbeam

The geometry, loads, and detail category of location A and B at DD-K24 correspond to DD-K30. In the figure below shows the influence lines without reduction of DD-K30 and DD-K24. Such as the voltages are expected to correspond fairly well, for DD-K24 about 10% higher voltages will be found it. Given the slight difference, it can therefore be assumed for location A that the fatigue analysis of DD-K30 is also representative of DD-K24. For the measurement data and the fatigue calculation of location A is therefore referred to section 5.21.

South

rd
O
No.

DD-K30 DD-K24

Figure 227 - Influence lines unit load without reduction (DD-K30 + DD-K24)