TECHNICAL REPORT

BSW LIMITED
DESIGN & ENGINEERING

TESTING OF BALLGRAB ANCHOR CONNECTOR

REPORT NO. 2002-3263
REVISION NO. 01

DET NORSKE VERITAS

TECHNICAL REPORT

Date of first issue: 2002-07-31	Project No.: 71521012
Approved by: Elisabeth Heggelund Tørstad, Head of Section	Organisational unit: Structural Integrity and Laboratories
Client: BSW Limited, Design & Engineering	Client ref.: Ian Brown

DET NORSKE VERITAS
REGION NORGE AS

Structural Integrity and Laboratories

Veritasveien 1,
N-1322 HØVIK, Norway
Tel: +47 67 57 99 00
Fax: +47 67 57 99 11
http://www.dnv.com
Org.No: NO 959 627 606 MVA

Summary:

On commission by BSW Limited, DNV has carried out several tests of BSW's Ballgrab Anchor Connectors. The testing is part of the Type Approval Scheme (TAS) of the connectors.

This report covers the testing carried out at the DNV Structural Laboratory at Høvik:

- Function Test of 1500t MBL connector.
- Fatigue Test of 1500t MBL connector – Test 1.
- Fatigue Test of 1500t MBL connector – Test 2.
- Fatigue Test of 800t MBL connector.

Two connectors have been tested:

- 1 off 1500t MBL Ballgrab Anchor Connector.
- 1 off 800t MBL Ballgrab Anchor Connector.

A more extensive summary is presented in the report.

Report No.: **2002-3263**		Subject Group:
Report title: Testing of Ballgrab Anchor Connector		
Work carried out by: Thomas Haavi		
Work verified by: Andrzej Serednicki		
Date of this revision:	Rev. No.: 01	Number of pages: 46

Indexing terms

Ballgrab Anchor Connector

800 tonne MBL

1500 tonne MBL

Fatigue

☒ No distribution without permission from the client or responsible organisational unit, i.e. free distribution within DNV after 3 years

☐ Strictly confidential

☐ Unrestricted distribution

Table of Content *Page*

1 CONCLUSIVE SUMMARY

On commission by BSW Limited, DNV has carried out several tests of BSW's Ballgrab Anchor Connectors. The testing is part of the Type Approval Scheme (TAS) of the connectors.

This report covers the testing carried out at the DNV Structural Laboratory at Høvik:

- Function Test of 1500t MBL connector.
- Fatigue Test of 1500t MBL connector – Test 1.
- Fatigue Test of 1500t MBL connector – Test 2.
- Fatigue Test of 800t MBL connector.

Two connectors have been tested:

- 1 off 1500t MBL Ballgrab Anchor Connector (with totally 12 rows of balls).
- 1 off 800t MBL Ballgrab Anchor Connector (with totally 12 rows of balls).

The main parts of the connector are the mandrel (male) and the receptacle (female). The external loads are transferred between these two parts through a large number of balls.

1.1 Function test of 1500t MBL connector

This test was carried out to investigate the functionality of the connector, i.e. the connector was subject to a sequence of being connected, loaded and then disconnected. All the twelve rows of balls were inserted during this test.

The test sequence applied, included the following steps:

1. The mandrel and the receptacle was connected and installed in the test rig.
2. The connector was subject to 700tonne tension load.
3. The connector was unloaded.
4. After being taken out of the test rig, the connector was disconnected.

The disconnection after loading was carried out without any difficulties.

1.2 Fatigue test of 1500t MBL connector – Test 1.

This test was carried out to investigate the effect of high local cyclic loads at the interface area between the mandrel and the receptacle.

The 1500t connector has 12 rows of balls, which transfer the global loads between the mandrel and the receptacle. To be able to apply high local cyclic loads to the balls and the contact surfaces between the balls and the mandrel/receptacle, this test was carried out with only 2 rows of balls.

Assuming that the global loads are transferred evenly through the balls, the local loads in the test corresponds to a global load range of 0.5*MBL.

The test was stopped at 2.61 million load cycles, although there were no indications of failure. Magnetic particle inspection was carried out on the mandrel and the receptacle, in the area subject to contact from the two rows of balls. No cracks were found in the surfaces.

The test result is summarised in Table 1.

Table 1 Result from fatigue test of 1500t Ballgrab Anchor Connector (2 rows of balls).

Test specimen	F_{min} [tonne]	F_{max} [tonne]	R	F_{mean} [tonne]	F_{range} [tonne]	N [cycles]	Freq. [Hz]	Result from MPI
1500t MBL	63	188	0.34	125	125	**2,612,629**	2 – 3.5	No findings

1.3 Fatigue test of 1500t MBL connector – Test 2.

This test was carried out to investigate the full-scale fatigue capacity of the connector; i.e. all the twelve rows of balls were inserted during this test.

The test was stopped at 3,457,359 load cycles, although there were no indications of failure.

The test result is summarised in Table 2.

Table 2 Result from fatigue test of 1500t Ballgrab Anchor Connector.

Test specimen	F_{min} [tonne]	F_{max} [tonne]	R	F_{mean} [tonne]	F_{range} [tonne]	N [cycles]	Freq. [Hz]
1500t MBL	300	600	0.5	450	300	**3,457,359**	2

The result has been compared against relevant design S-N curves for chains, i.e. the S-N curves in DNV's Offshore Standard DNV-OS-E301 /2/.

The DNV design S-N curves are applicable for chains in seawater. For chain tests in air, the effect of seawater shall be accounted for by a reduction of the fatigue life (according to section G204 in DNV's Offshore Standard DNV-OS-E301 /2/). For stud chains, the fatigue life shall be reduced by a factor of 2. Assuming that the effect on fatigue life is less than for a stud chain, a reduction factor of 2 should be sufficient for the tested connector.

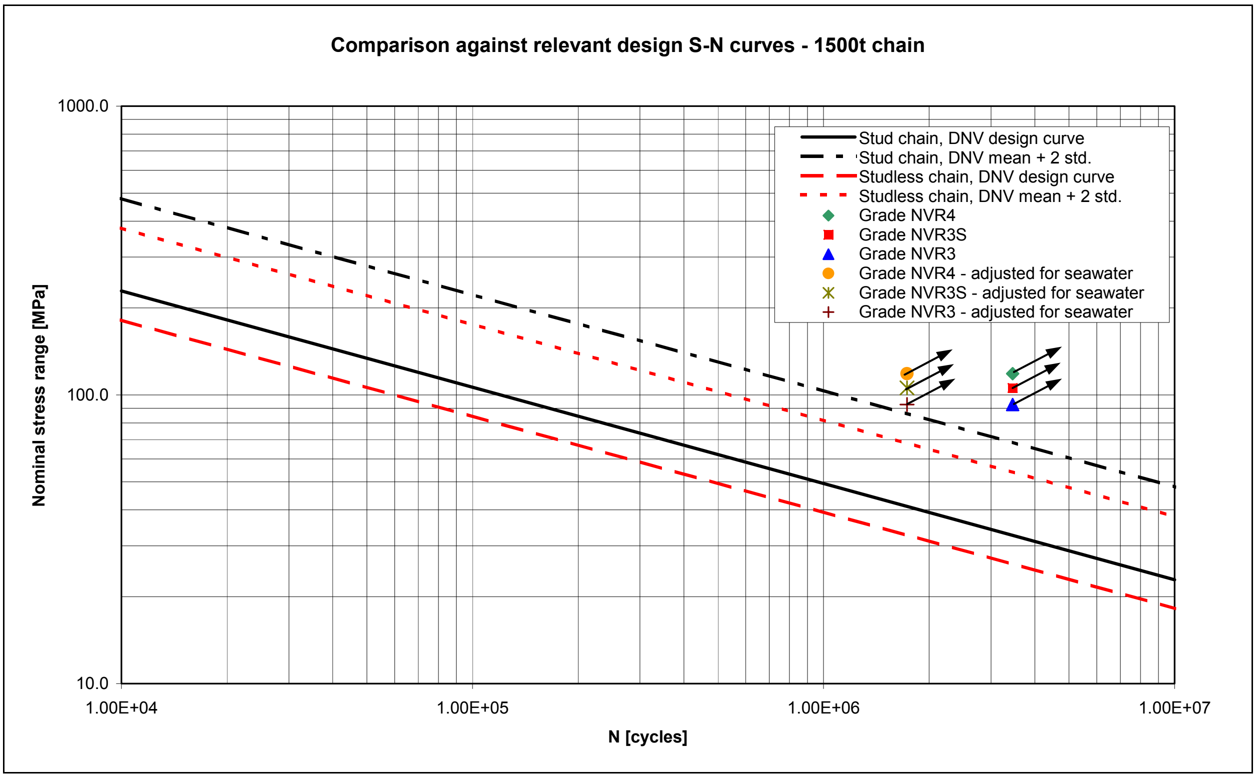

Figure 1 Corresponding chain stress ranges derived from test results.

The results in Figure 1 are presented as the stress range in a chain connected to the anchor connector, i.e. the chain and the connector are subject to the same dynamic load because they are linked together. The chain will therefore have to have a fatigue capacity as presented, to be able to withstand the same fatigue loading as the connector.

The results presented in Figure 1 shows that the corresponding stresses in the different types of chains are exceeding the design curves and also the derived upper bound curves (mean + 2 standard deviations). There were no indications of failure of the 1500t anchor connector, and the safety margins may therefore be even bigger. However, the results presented in this report should be evaluated together with the tests that are going to be carried out at DNV's structural laboratory in Bergen. A subsequent failure investigation should also form the basis for the type approval of the 1500t anchor connector.

1.4 Fatigue test of 800t MBL connector.

This test was carried out to investigate the fatigue capacity of the connector. All the twelve rows of balls were inserted during this test.

The test was stopped at 344,771 load cycles, although there were no indications of failure.

The test result is summarised in Table 3.

Table 3 Result from fatigue test of 800t Ballgrab Anchor Connector.

Test specimen	F_{min} [tonne]	F_{max} [tonne]	R	F_{mean} [tonne]	F_{range} [tonne]	N [cycles]	Freq. [Hz]
800t MBL	120	360	0.33	240	240	344,771	1.5

The result has been compared against relevant design S-N curves for chains, i.e. the S-N curves in DNV's Offshore Standard DNV-OS-E301 /2/.

The DNV design S-N curves are applicable for chains in seawater. For chain tests in air, the effect of seawater shall be accounted for by a reduction of the fatigue life (according to section G204 in DNV's Offshore Standard DNV-OS-E301 /2/). For stud chains, the fatigue life shall be reduced by a factor of 2. Assuming that the effect on fatigue life is less than for a stud chain, a reduction factor of 2 should be sufficient for the tested connector.

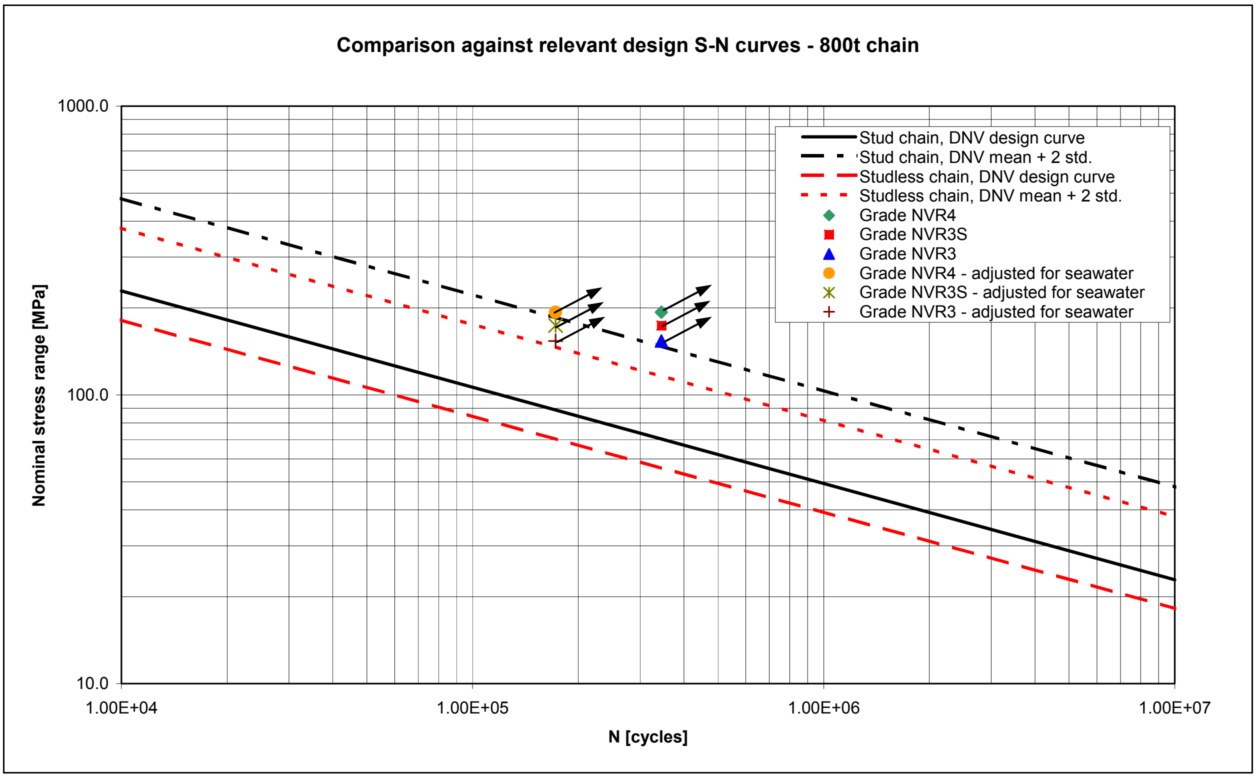

Figure 2 Corresponding chain stress ranges derived from test results.

The results in Figure 2 are presented as the stress range in a chain connected to the anchor connector, i.e. the chain and the connector are subject to the same dynamic load because they are linked together. The chain will therefore have to have a fatigue capacity as presented, to be able to withstand the same fatigue loading as the connector.

The results presented in Figure 2 shows that the corresponding stresses in the different types of chains are exceeding the two design curves and the derived upper bound curve for studless chain. The upper bound curve for stud chain is not exceeded for the corresponding chain stress ranges that are adjusted for seawater. It should be noted that there were no indications of failure of the 800t anchor connector, and the capacity of the connector may therefore be larger.

2 INTRODUCTION

On commission by BSW Limited, DNV has carried out several tests of BSW's Ballgrab Anchor Connectors. The testing is part of the Type Approval Scheme (TAS) of the connectors.

This report covers the testing carried out at the DNV Structural Laboratory at Høvik:

- Function Test of 1500t MBL connector.
- Fatigue Test of 1500t MBL connector – Test 1.
- Fatigue Test of 1500t MBL connector – Test 2.
- Fatigue Test of 800t MBL connector.

Further tests will be carried out at DNV's laboratory in Bergen.

3 TEST SPECIMENS

Two connectors have been tested:

- 1 off 1500t MBL Ballgrab Anchor Connector, shown in Figure 3.
- 1 off 800t MBL Ballgrab Anchor Connector.

The main parts of the connector are the mandrel (male) and the receptacle (female), as shown in Figure 3. The mandrel on both test specimens had 12 rows of balls.

**Figure 3 To the left: 1500t MBL Ballgrab Anchor Connector being connected.
To the right: 1500t MBL Ballgrab Anchor Connector after connection.**

Figure 4 is showing the anchor connector and its internals. The load carrying parts are the mandrel, the receptacle and the numerous balls that are creating the interface between the mandrel and the receptacle. The external tension applied to each end of the connector is transferred through the balls. The mandrel has tapered surfaces that interact with the balls. Due to these tapered surfaces, the grip between the mandrel and the receptacle increases when the external tension is increased.

The ball cage is keeping the balls in place and is part of the releasing mechanism.

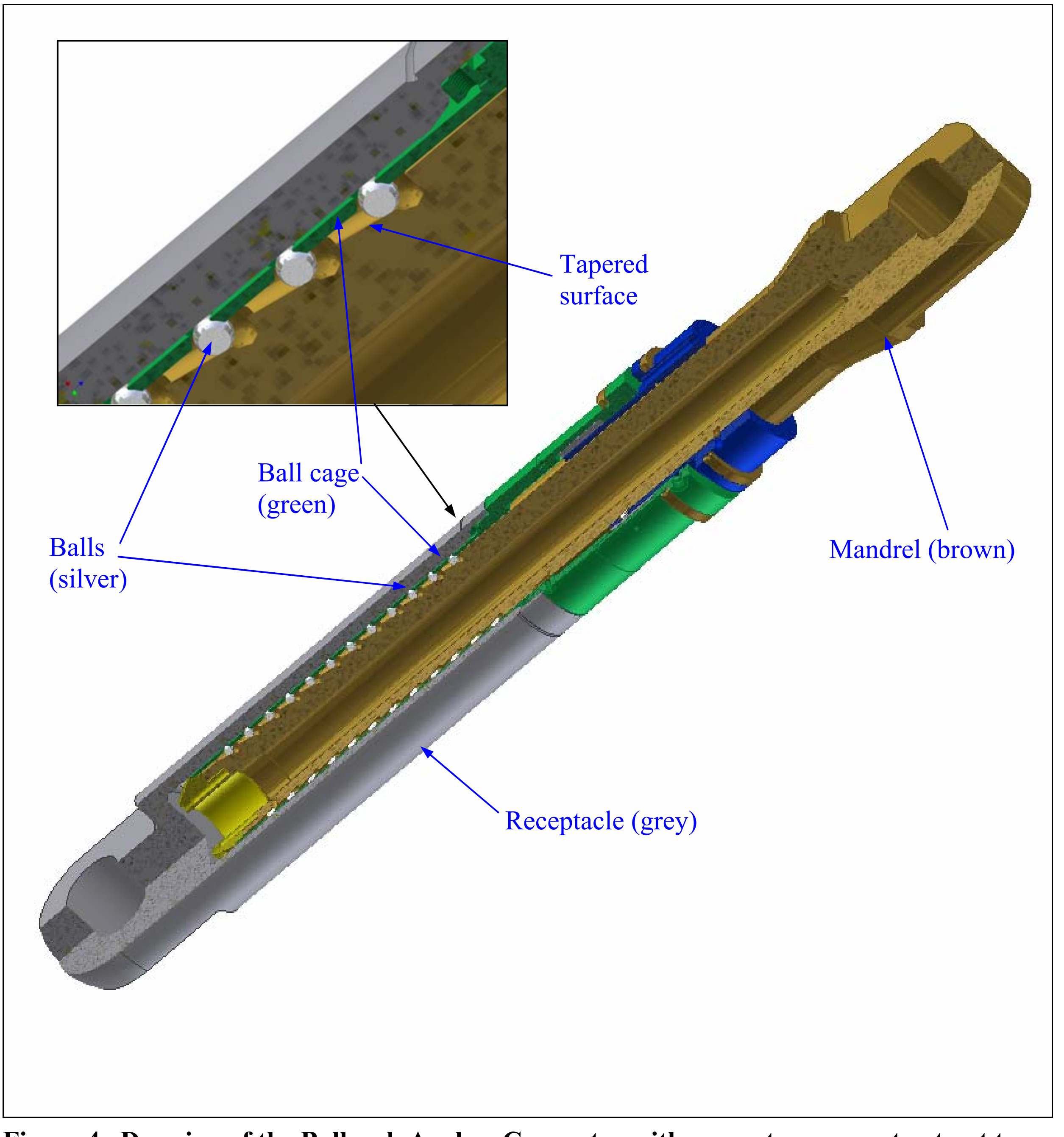

Figure 4 Drawing of the Ballgrab Anchor Connector with a quarter segment cut out to show the internals.

4 TEST SET-UP

The tests were carried out in DNV's 750t dynamic test rig, which has a servohydraulic 7.5 MN Schenck actuator and an Instron 8500 Plus control panel. The test set-up for the 1500t connector is shown in Figure 5 and Figure 6.

The actuator load and the actuator displacement were measured during testing.

In addition, the test specimens were instrumented with displacement gauges and strain gauges as follows (see Figure 5):

- Two displacement gauges were mounted between the mandrel and the receptacle. The displacement gauges were located 180 degrees apart, and were measuring the relative displacement between the mandrel and the receptacle.
- Two cross strain gauges were mounted on the mandrel. The strain gauges were located 180 degrees apart, and were measuring strains in the axial direction and the circumferential direction.
- Two cross strain gauges were mounted on the receptacle. The strain gauges were located 180 degrees apart, and were measuring strains in the axial direction and the circumferential direction.

The measurements were mainly carried out to monitor the tests, i.e. to be able to reveal any uneven load distribution or other irregularities during testing.

The measurement record is not included in the report, but are stored with the project file.

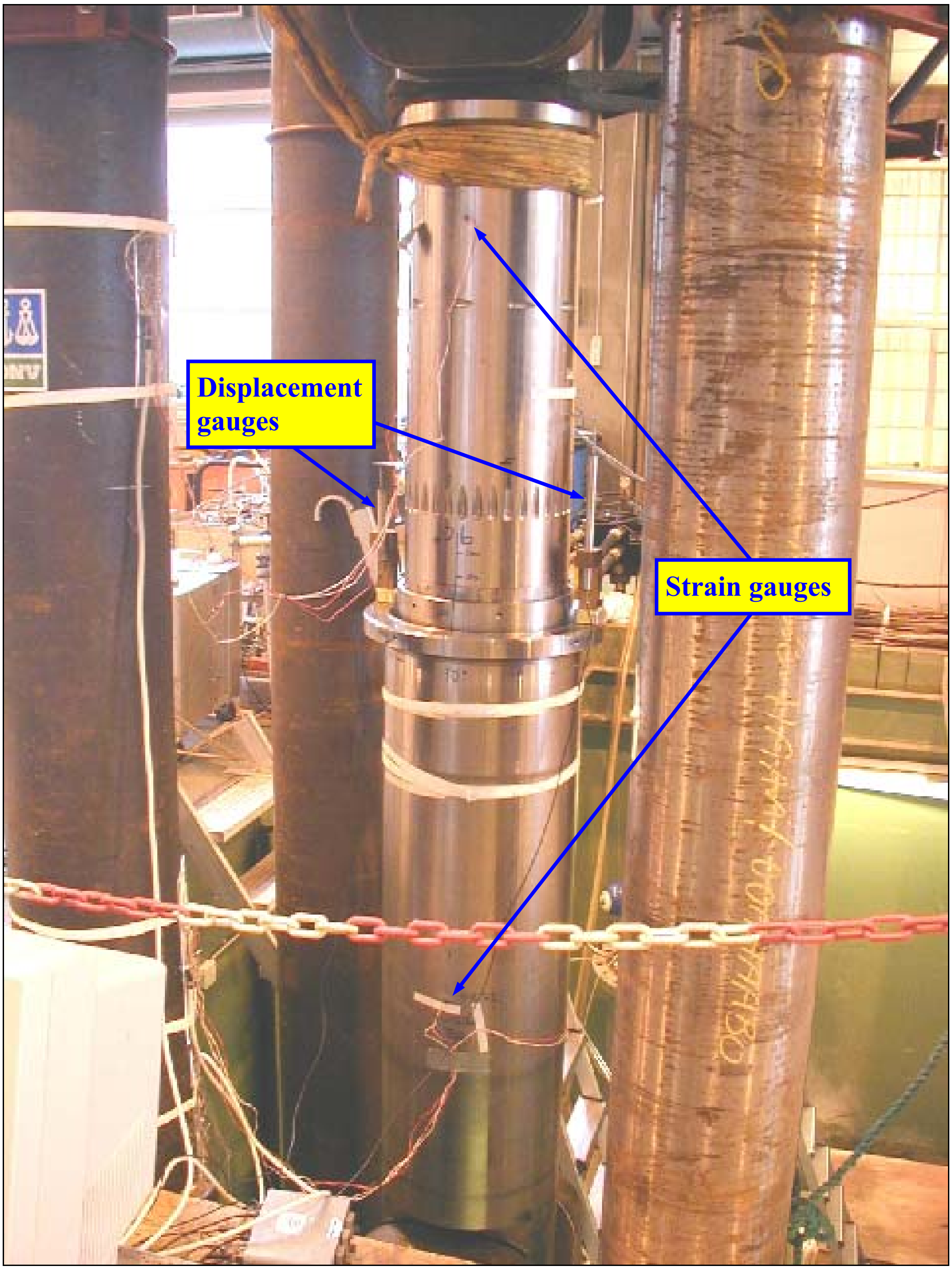

Figure 5 Fatigue testing of 1500t MBL Ballgrab Anchor Connector.

Figure 6   Fatigue testing of 1500t MBL Ballgrab Anchor Connector.

5 CALCULATIONS

The results from the fatigue tests have been compared against relevant design S-N curves for chains, i.e. the S-N curves in DNV's Offshore Standard DNV-OS-E301 /2/.

The following calculations are based on the assumption that a chain is not stronger than the weakest link. The anchor connector is assumed to have sufficient strength as long as it is stronger than the chain it is connected to, i.e. the chain itself is the weakest link. The results in chapter 6.3 and 6.4 is therefore presented as the stress range in a chain connected to the anchor connector, i.e. the chain and the connector are subject to the same dynamic load because they are linked together. The chain will therefore have to have a fatigue capacity as presented, to be able to withstand the same fatigue loading as the connector.

The comparison is based on the load range applied to the connector and the required dimensions for chains of grade NV R3, NV R3S and NV R4. The corresponding nominal stress ranges for the chains were found by dividing the load range with the calculated cross-sectional area of the chains:

$$S_{range} = \frac{F_{range}}{A_{chain}} = \frac{F_{range}}{\frac{\pi \cdot d^2}{4} \cdot 2}$$

where

S_{range}	=	The corresponding stress range of a chain with the same MBL as the connector.
F_{range}	=	Load range applied to the connector.
A_{chain}	=	Cross-sectional area of a chain with the same MBL as the connector.
d	=	Chain diameter of a chain with the same MBL as the connector.

The chain diameters were found by using the MBL of the connector and the formulas in Table 10-3 in DNV's Certification Note No. 2.6 /1/. The effect of any corrosion allowance has not been considered.

The design S-N curves in DNV's Offshore Standard DNV-OS-E301 /2/ is given by the formula:

$$\log N = \log a_D - m \cdot \log S$$

where

N	=	Number of cycles.
S	=	Stress range.
a_D	=	The intercept parameter of the S-N curve.
m	=	Slope of the S-N curve.

The fatigue curve parameters for stud chain and studless chain are given in Table 4.

Table 4 S-N fatigue curve parameters for design curve.

	a_D	m
Stud chain	$1.2 \cdot 10^{11}$	3.0
Studless chain	$6.0 \cdot 10^{10}$	3.0

The test results that the S-N curve is based on is assumed to have a scattering that is normal distributed. The design S-N curves are associated with a 98% probability of survival, which in this case means that the fatigue capacity of the chain is likely to exceed the design value with a probability of 98%. Design S-N curves are typically derived by reducing the mean S-N curve with approximately two standard deviations (depending on the number of test results). By increasing the mean S-N curve with two standard deviations, an upper bound S-N curve can be derived. The chain has a 98% probability of being weaker than the upper bound S-N curve, and this curve was therefore considered to be a relevant measure for the fatigue capacity of the anchor connector.
The DNV design curves are based on results presented in DNV report no. 98-3110; "DEEPMOOR – Design Methods for Deep Water Mooring Systems. Calibration of a Fatigue Limit State." /3/. By using the mean S-N curve and the recommended standard deviation presented in this report, fatigue curve parameters for the upper bound S-N curves have been derived. The parameters are presented in Table 5.

Table 5 S-N fatigue curve parameters for upper bound curve (mean + 2 std.).

	$a_{D\ mean+2std.}$	m
Stud chain	$1.1 \cdot 10^{12}$	3.0
Studless chain	$5.4 \cdot 10^{11}$	3.0

6 RESULTS

6.1 Function test of 1500t MBL connector.

This test was carried out to investigate the functionality of the connector, i.e. the connector was subject to a sequence of being connected, loaded and then disconnected. All the twelve rows of balls were inserted during this test. The connector had not been subject to any previous testing, so there were no indents in the mandrel or the receptacle prior to the test.

The test sequence applied, included the following steps:

5. The mandrel and the receptacle was connected and installed in the test rig.
6. The connector was subject to 700tonne tension load.
7. The connector was unloaded.
8. After being taken out of the test rig, the connector was disconnected.

The disconnection after loading was carried out without any difficulties.

Photographs from the function test can be found in Appendix A.

6.2 Fatigue test of 1500t MBL connector – Test 1.

This test was carried out to investigate the effect of high local cyclic loads at the interface area between the mandrel and the receptacle. The connector had already been subject to functionality testing, so there were one set of indents in the mandrel and the receptacle prior to this test.

The 1500t connector has 12 rows of balls, which transfer the global loads between the mandrel and the receptacle. To be able to apply high local cyclic loads to the balls and the contact surfaces between the balls and the mandrel/receptacle, this test was carried out with only 2 rows of balls. Balls were only inserted in row 6 and row 7, i.e. the two centre rows.

The loads applied in this test were:

$$F_{mean} = 0.5 \cdot MBL \cdot \frac{2\ rows\ of\ balls}{12\ rows\ of\ balls} = 125t = 1226kN$$

$$F_{range} = 0.5 \cdot MBL \cdot \frac{2\ rows\ of\ balls}{12\ rows\ of\ balls} = 125t = 1226kN$$

$$F_{\max} = F_{mean} + \frac{F_{range}}{2} = 188t = 1844kN$$

$$F_{\min} = F_{mean} - \frac{F_{range}}{2} = 63t = 618kN$$

Assuming that the global loads are transferred evenly through the balls, the local loads in the test corresponds to a global load range of 0.5*MBL.

The test was stopped at 2.61 million load cycles, although there were no indications of failure. Magnetic particle inspection was carried out on the mandrel and the receptacle, in the area subject to contact from the two rows of balls. No cracks were found in the surfaces (see Appendix C).

The test result is summarised in Table 6.

Table 6 Result from fatigue test of 1500t Ballgrab Anchor Connector (2 rows of balls).

Test specimen	F_{min} [tonne]	F_{max} [tonne]	R	F_{mean} [tonne]	F_{range} [tonne]	N [cycles]	Freq. [Hz]	Result from MPI
1500t MBL	63	188	0.34	125	125	**2,612,629**	2 – 3.5	No findings

Photographs from this fatigue test can be found in Appendix B.

6.3 Fatigue test of 1500t MBL connector – Test 2.

This test was carried out to investigate the full-scale fatigue capacity of the connector; i.e. all the twelve rows of balls were inserted during this test. The connector had already been subject to functionality testing and the fatigue test with two rows of balls inserted. Due to a failure in the test rig fixtures, the test specimen was also subject to 87000 load cycles, taken out of the test rig and disassembled prior to this final fatigue test. Therefore, there were three sets of indents in the mandrel and the receptacle prior to this test. This also means that after this test, the 1500t anchor connector had been connected, loaded and disconnected four times.

Note: None of the previous load cycles are included in the test results presented in this chapter, i.e. neither the above mentioned 87000 load cycles nor the load cycles from test 1.

The loads applied in this test were:

$$F_{mean} = 0.3 \cdot MBL = 450t = 4414.5kN$$

$$F_{range} = 0.2 \cdot MBL = 300t = 2943.0kN$$

$$F_{\max} = F_{mean} + \frac{F_{range}}{2} = 600t = 5886.0kN$$

$$F_{\min} = F_{mean} - \frac{F_{range}}{2} = 300t = 2943.0kN$$

The test was stopped at 3,457,359 load cycles, although there were no indications of failure.

The test result is summarised in Table 7.

Table 7 Result from fatigue test of 1500t Ballgrab Anchor Connector.

Test specimen	F_{min} [tonne]	F_{max} [tonne]	R	F_{mean} [tonne]	F_{range} [tonne]	N [cycles]	Freq. [Hz]
1500t MBL	300	600	0.5	450	300	**3,457,359**	2

The result has been compared against relevant design S-N curves for chains, i.e. the S-N curves in DNV's Offshore Standard DNV-OS-E301 /2/. The procedure for deriving the stress ranges is described in chapter 5.

The derived stress ranges for different chain qualities are summarised in Table 8. Together with the number of load cycles from the test, these stress ranges have been compared against the corresponding values of the DNV design S-N curve for stud chain. These results are also found in Table 8.

Table 8 Test result compared to design S-N curve for stud chain.

	Grade NVR3	Grade NVR3S	Grade NVR4	Comment
F_{range} [tonne]	300			Load range applied to connector
F_{range} [kN]	2943			
d [mm]	142	133	126	Calculated chain diameter
A_{chain} [mm^2]	31773	27834	24858	Calculated chain cross-section area
S_{test} [MPa]	93	106	118	Corresponding stress range for chains. Based on F_{range}.
N_{test} [cycles]	3457359			No. of load cycles from test
S_{design} [MPa]	33			Stress range calculated from design curve for stud chains. Based on N_{test}.
N_{design} [cycles]	151008	101516	72312	No. of load cycles calculated from design curve for stud chains. Based on S_{test}.
Safety factor on stress	*2.8*	*3.2*	*3.6*	*Safety factor calculated as S_{test} / S_{design}*
Safety factor on life	*22.9*	*34.1*	*47.8*	*Safety factor calculated as N_{test} / N_{design}*

The DNV design S-N curves are applicable for chains in seawater. For chain tests in air, the effect of seawater shall be accounted for by a reduction of the fatigue life (according to section G204 in DNV's Offshore Standard DNV-OS-E301 /2/). For stud chains, the fatigue life shall be reduced by a factor of 2. Assuming that the effect on fatigue life is less than for a stud chain, a reduction factor of 2 should be sufficient for the tested connector. The effect of applying a reduction factor of 2 to the test result is summarised in Table 9.

In Figure 7, all results are plotted together with the DNV design S-N curves and the derived upper bound curves (see chapter 5).

Table 9 Test result compared to design S-N curve for stud chain.
Fatigue life adjusted to account for the effect of sea water (due to testing in air).

	Grade NVR3	Grade NVR3S	Grade NVR4	Comment
F_{range} [tonne]	300			Load range applied to connector
F_{range} [kN]	2943			
d [mm]	142	133	126	Calculated chain diameter
A_{chain} [mm^2]	31773	27834	24858	Calculated chain cross-section area
S_{test} [MPa]	93	106	118	Corresponding stress range for chains. Based on F_{range}.
N_{test} [cycles]	3457359			No. of load cycles from test
Reduction factor	2			To account for the effect of sea water for tests in air
$N_{test\ adjusted}$ [cycles]	1728680			No. of load cycles from test when the effect of sea water is accounted for.
$S_{design\ adjusted}$ [MPa]	41			Stress range calculated from design curve for stud chains. Based on $N_{test\ adjusted}$.
N_{design} [cycles]	151008	101516	72312	No. of load cycles calculated from design curve for stud chains. Based on S_{test}.
Safety factor on stress	*2.3*	*2.6*	*2.9*	*Safety factor calculated as $S_{test} / S_{design\ adjusted}$*
Safety factor on life	*11.4*	*17.0*	*23.9*	*Safety factor calculated as $N_{test\ adjusted} / N_{design}$*

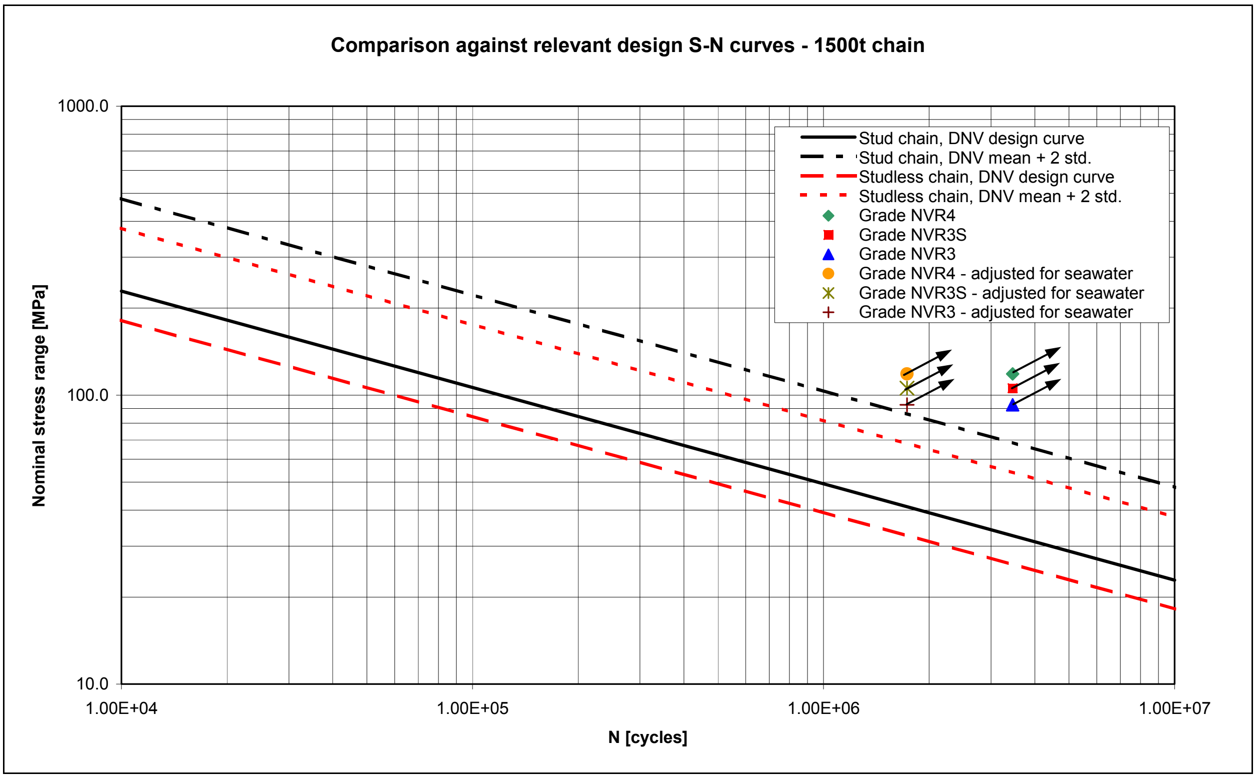

Figure 7 Corresponding chain stress ranges derived from test results.

The results in Table 8, Table 9 and Figure 7 are presented as the stress range in a chain connected to the anchor connector, i.e. the chain and the connector are subject to the same dynamic load because they are linked together. The chain will therefore have to have a fatigue capacity as presented, to be able to withstand the same fatigue loading as the connector.

The results presented in Figure 7 shows that the corresponding stresses in the different types of chains are exceeding the design curves and also the derived upper bound curves (mean + 2 standard deviations). There were no indications of failure of the 1500t anchor connector, and the safety margins may therefore be even bigger. However, the results presented in this report should be evaluated together with the tests that are going to be carried out at DNV's structural laboratories in Bergen. A subsequent failure investigation should also form the basis for the type approval of the 1500t anchor connector.

Photographs from this fatigue test can be found in Appendix D.

6.4 Fatigue test of 800t MBL connector.

This test was carried out to investigate the fatigue capacity of the connector. All the twelve rows of balls were inserted during this test. The connector had been subject testing prior to arrival at DNV's laboratories, so there were one set of indents in the mandrel and the receptacle prior to this test.

The loads applied in this test were:

$$F_{mean} = 0.3 \cdot MBL = 240t = 2354kN$$

$$F_{range} = 0.3 \cdot MBL = 240t = 2354kN$$

$$F_{\max} = F_{mean} + \frac{F_{range}}{2} = 360t = 3532kN$$

$$F_{\min} = F_{mean} - \frac{F_{range}}{2} = 120t = 1177kN$$

The test was stopped at 344,771 load cycles, although there were no indications of failure.

The test result is summarised in Table 10.

Table 10 Result from fatigue test of 800t Ballgrab Anchor Connector.

Test specimen	F_{min} [tonne]	F_{max} [tonne]	R	F_{mean} [tonne]	F_{range} [tonne]	N [cycles]	Freq. [Hz]
800t MBL	120	360	0.33	240	240	344,771	1.5

The result has been compared against relevant design S-N curves for chains, i.e. the S-N curves in DNV's Offshore Standard DNV-OS-E301 /2/. The procedure for deriving the stress ranges is described in chapter 5.

The derived stress ranges for different chain qualities are summarised in Table 11. Together with the number of load cycles from the test, these stress ranges have been compared against the corresponding values of the DNV design S-N curve for stud chain. These results are also found in Table 11.

Table 11 Test result compared to design S-N curve for stud chain.

	Grade NVR3	Grade NVR3S	Grade NVR4	Comment
F_{range} [tonne]	240			Load range applied to connector
F_{range} [kN]	2354			
d [mm]	99	93	88	Calculated chain diameter
A_{chain} [mm^2]	15313	13537	12174	Calculated chain cross-section area
S_{test} [MPa]	154	174	193	Corresponding stress range for chains. Based on F_{range}
N_{test} [cycles]	344771			No. of load cycles from test
S_{design} [MPa]	70			Stress range calculated from design curve for stud chains. Based on N_{test}.
N_{design} [cycles]	33014	22808	16589	No. of load cycles calculated from design curve for stud chains. Based on S_{test}.
Safety factor on stress	*2.2*	*2.5*	*2.7*	*Safety factor calculated as* S_{test} / S_{design}
Safety factor on life	*10.4*	*15.1*	*20.8*	*Safety factor calculated as* N_{test} / N_{design}

The DNV design S-N curves are applicable for chains in seawater. For chain tests in air, the effect of seawater shall be accounted for by a reduction of the fatigue life (according to section G204 in DNV's Offshore Standard DNV-OS-E301 /2/). For stud chains, the fatigue life shall be reduced by a factor of 2. Assuming that the effect on fatigue life is less than for a stud chain, a reduction factor of 2 should be sufficient for the tested connector. The effect of applying a reduction factor of 2 to the test result is summarised in Table 12.

In Figure 8, all results are plotted together with the DNV design S-N curves and the derived upper bound curves (see chapter 5).

Table 12 Test result compared to design S-N curve for stud chain.
Fatigue life adjusted to account for the effect of sea water (due to testing in air).

	Grade NVR3	Grade NVR3S	Grade NVR4	Comment
F_{range} [tonne]	240			Load range applied to connector
F_{range} [kN]	2354			
d [mm]	99	93	88	Calculated chain diameter
A_{chain} [mm^2]	15313	13537	12174	Calculated chain cross-section area
S_{test} [MPa]	154	174	193	Corresponding stress range for chains. Based on F_{range}
N_{test} [cycles]	344771			No. of load cycles from test
Reduction factor	2			To account for the effect of sea water for tests in air
$N_{test\ adjusted}$ [cycles]	172386			No. of load cycles from test when the effect of sea water is accounted for.
$S_{design\ adjusted}$ [MPa]	89			Stress range calculated from design curve for stud chains. Based on $N_{test\ adjusted}$.
N_{design} [cycles]	33014	22808	16589	No. of load cycles calculated from design curve for stud chains. Based on S_{test}.
Safety factor on stress	*1.7*	*2.0*	*2.2*	*Safety factor calculated as* $S_{test} / S_{design\ adjusted}$
Safety factor on life	*5.2*	*7.6*	*10.4*	*Safety factor calculated as* $N_{test\ adjusted} / N_{design}$

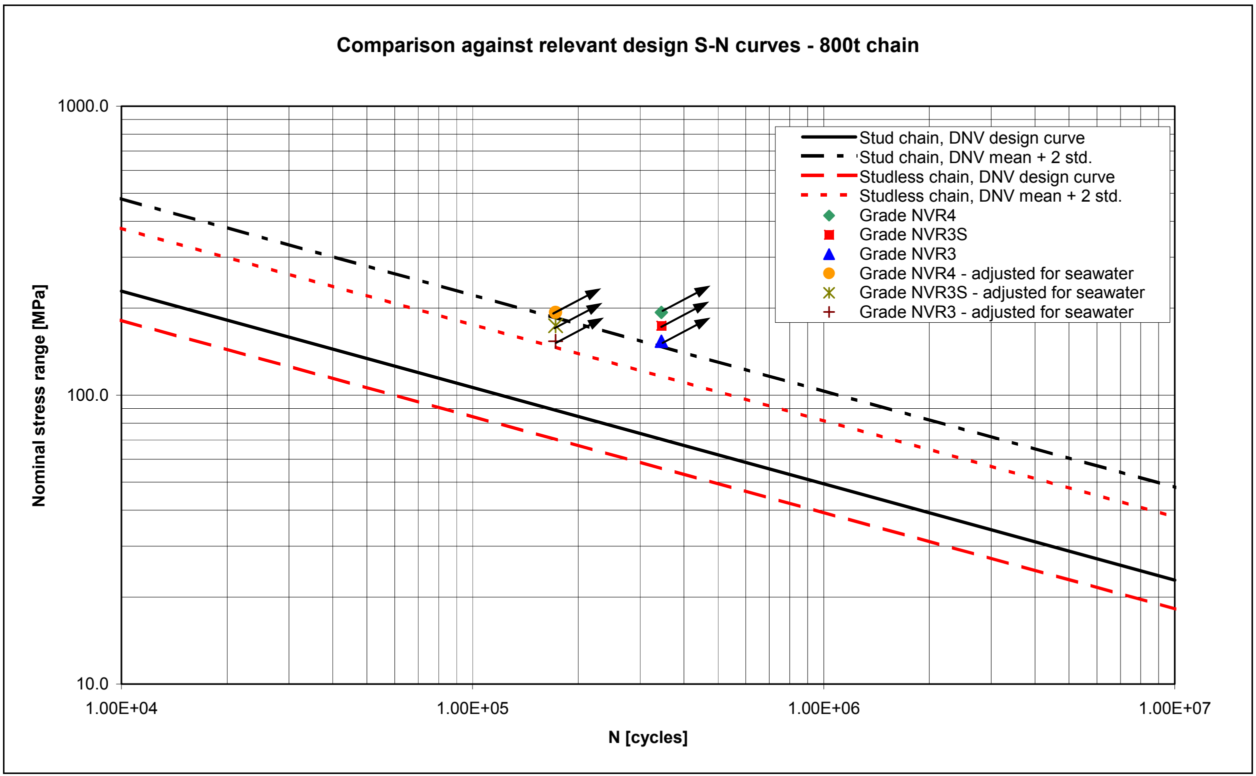

Figure 8 Corresponding chain stress ranges derived from test results.

The results in Table 11, Table 12 and Figure 8 are presented as the stress range in a chain connected to the anchor connector, i.e. the chain and the connector are subject to the same dynamic load because they are linked together. The chain will therefore have to have a fatigue capacity as presented, to be able to withstand the same fatigue loading as the connector.

The results presented in Figure 8 shows that the corresponding stresses in the different types of chains are exceeding the two design curves and the derived upper bound curve for studless chain. The upper bound curve for stud chain is not exceeded for the corresponding chain stress ranges that are adjusted for seawater. It should be noted that there were no indications of failure of the 800t anchor connector, and the capacity of the connector may therefore be larger.

Photographs from this fatigue test can be found in Appendix E.

7 REFERENCES

/1/ Det Norske Veritas: "Certification of Offshore Mooring Chain." Certification Note No. 2.6, August 1995.

/2/ Det Norske Veritas: "Position Mooring." Offshore Standard DNV-OS-E301, June 2001.

/3/ Det Norske Veritas and MARINTEK (SINTEF Group): "DEEPMOOR – Design Methods for Deep Water Mooring Systems. Calibration of a Fatigue Limit State." DNV report no. 98-3110, rev. no. 3.

/4/ American Petroleum Institute: "Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures." API recommended practice 2SK, second edition, December 1996.

8 APPENDICES

Appendix A Function test of 1500t MBL connector – Photographs

Appendix B Fatigue test of 1500t MBL connector – Test 1 – Photographs

Appendix C Fatigue test of 1500t MBL connector – Test 1 – MPI report

Appendix D Fatigue test of 1500t MBL connector – Test 2 – Photographs

Appendix E Fatigue test of 800t MBL connector – Photographs

APPENDIX A

FUNCTION TEST OF 1500T MBL CONNECTOR

PHOTOGRAPHS

-o0o-

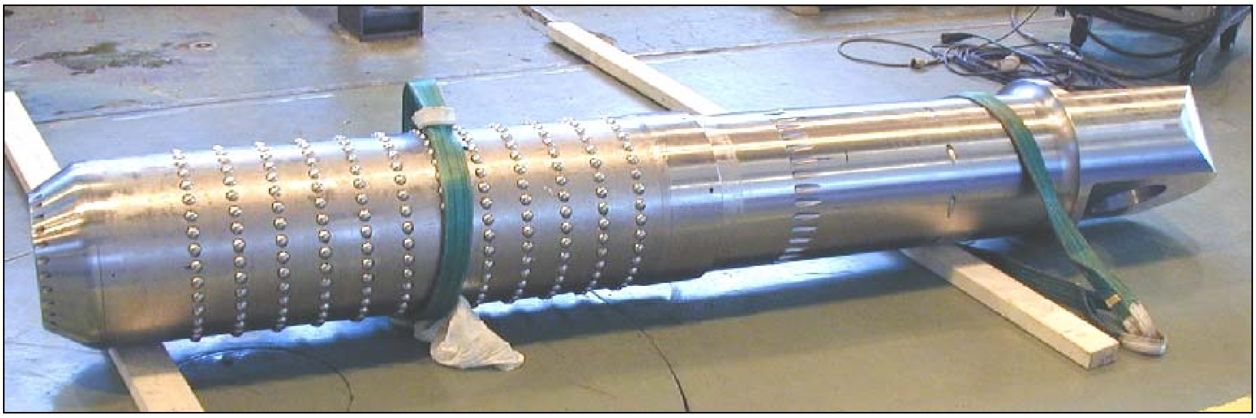

Figure 9 Mandrel as delivered from BSW.

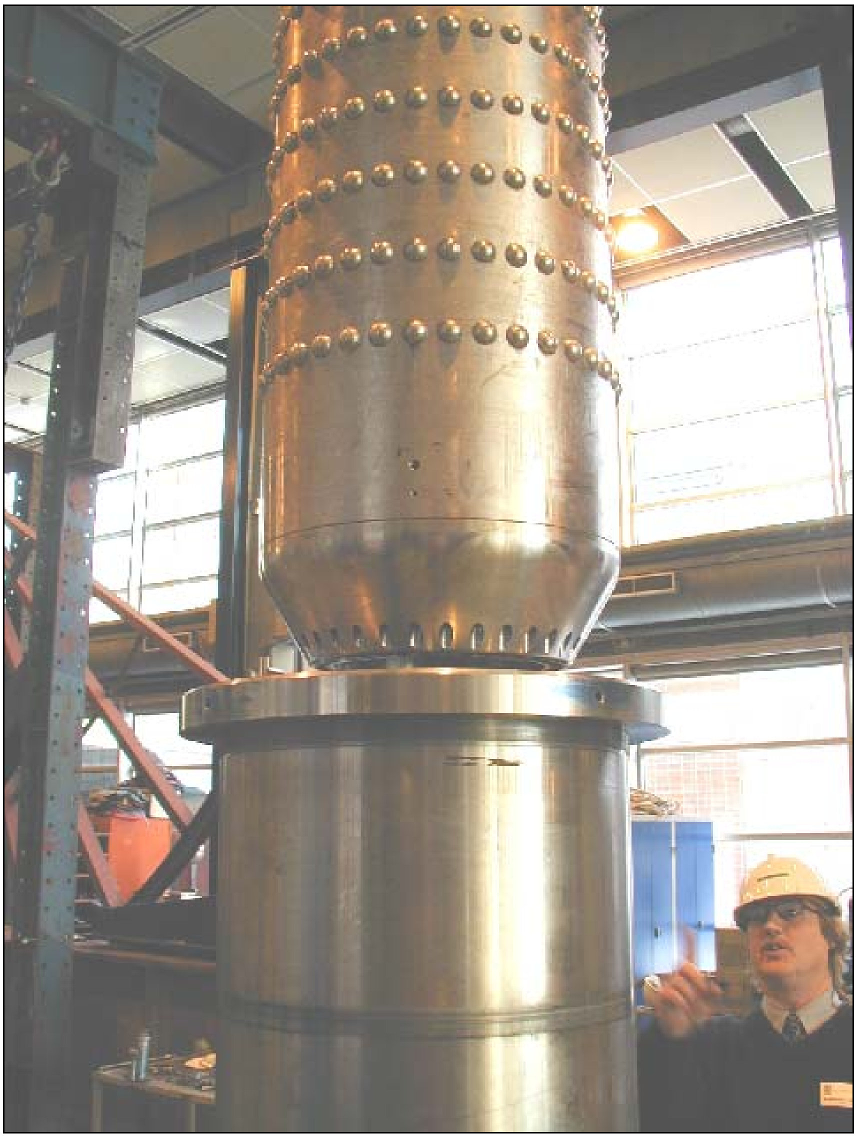

Figure 10 Mandrel being connected with receptacle.

Figure 11 Indents in the receptacle after functionality test.

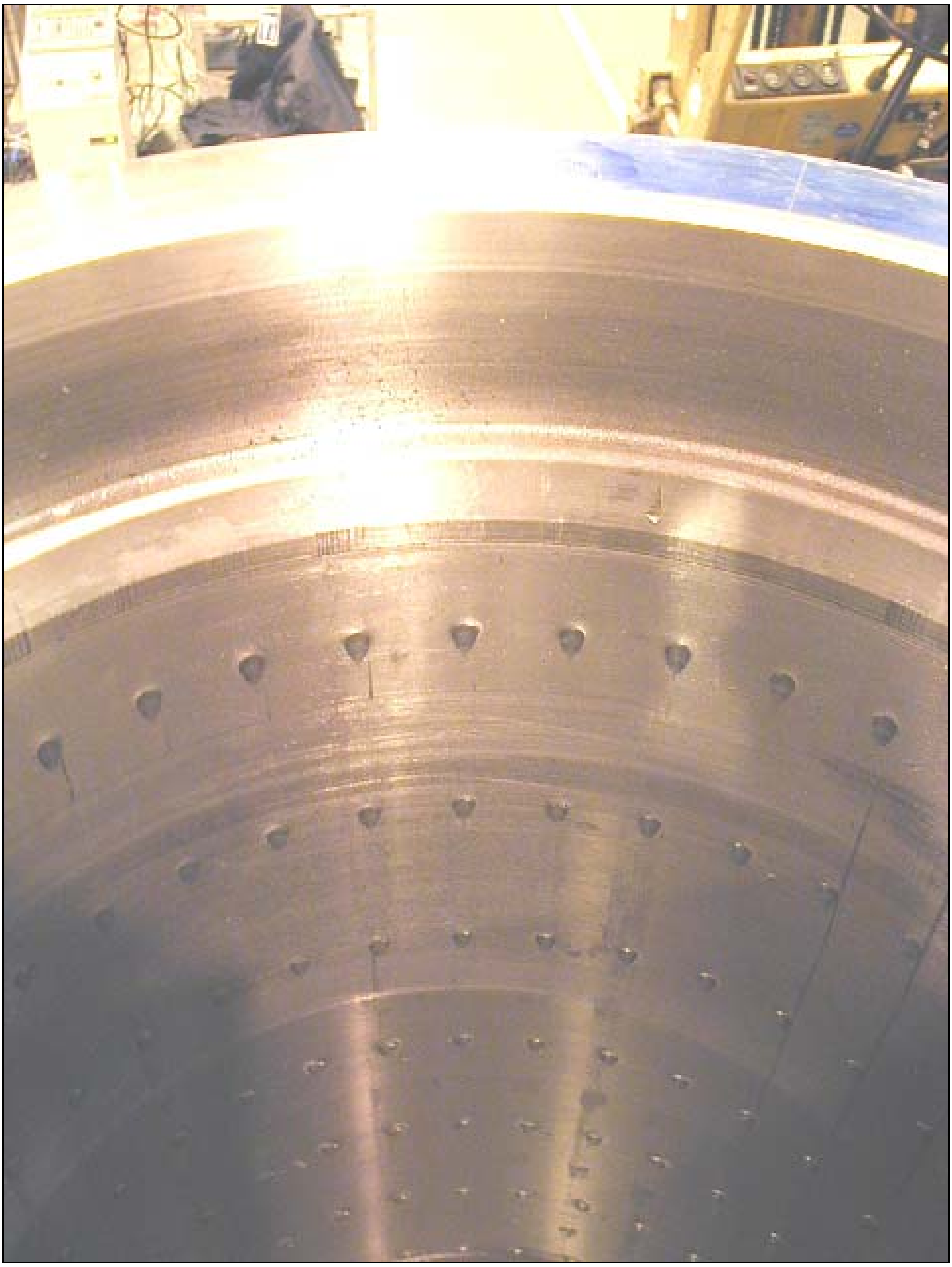

Figure 12   Indents in the receptacle after functionality test.

APPENDIX B

FATIGUE TEST OF 1500T MBL CONNECTOR – TEST 1 PHOTOGRAPHS

-o0o-

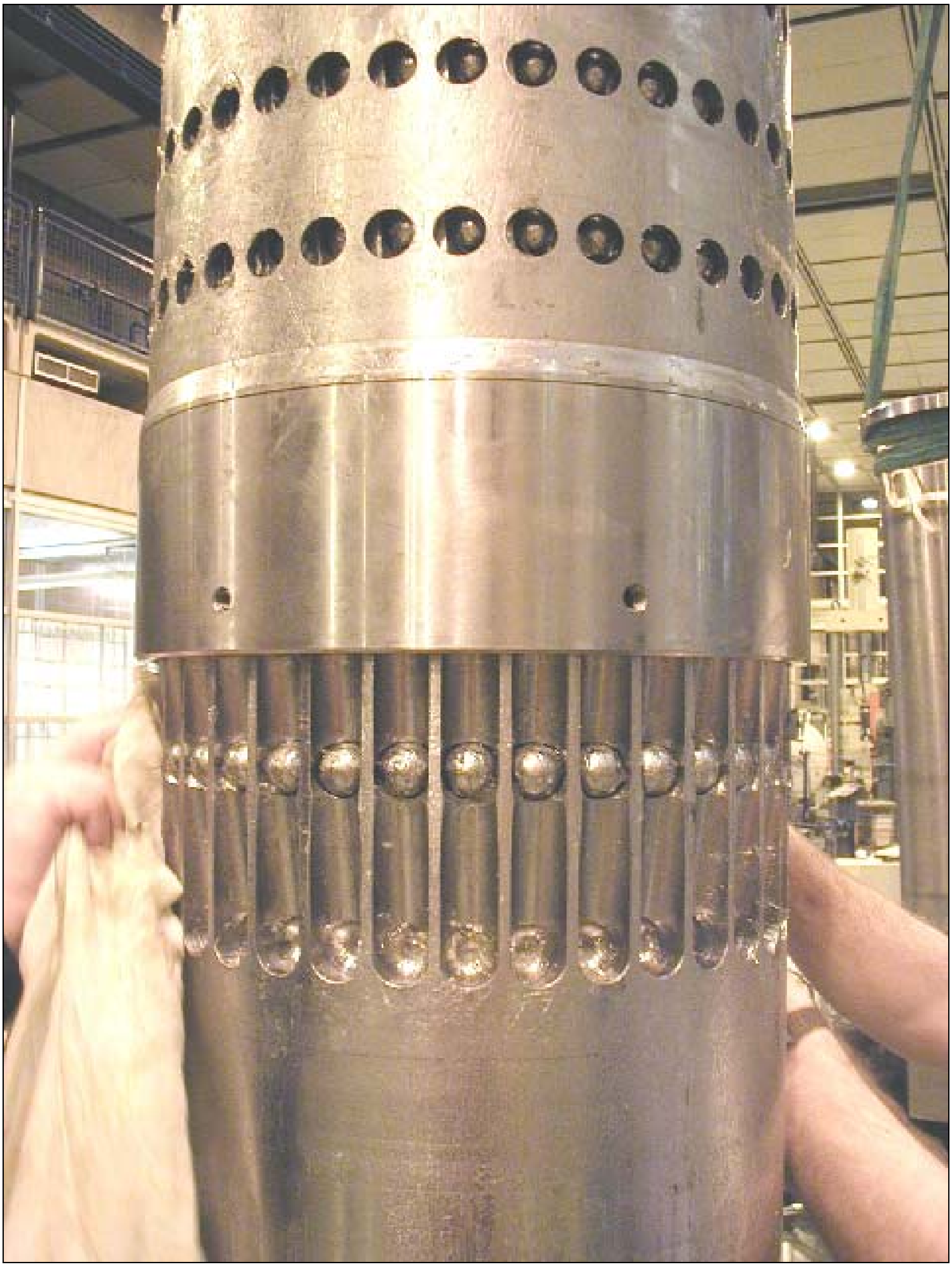

Figure 13 Mandrel being prepared for testing with only two rows of balls.

Figure 14 Anchor connector installed in test rig (with two rows of balls).

Figure 15 Mandrel being taken out of receptacle after testing.

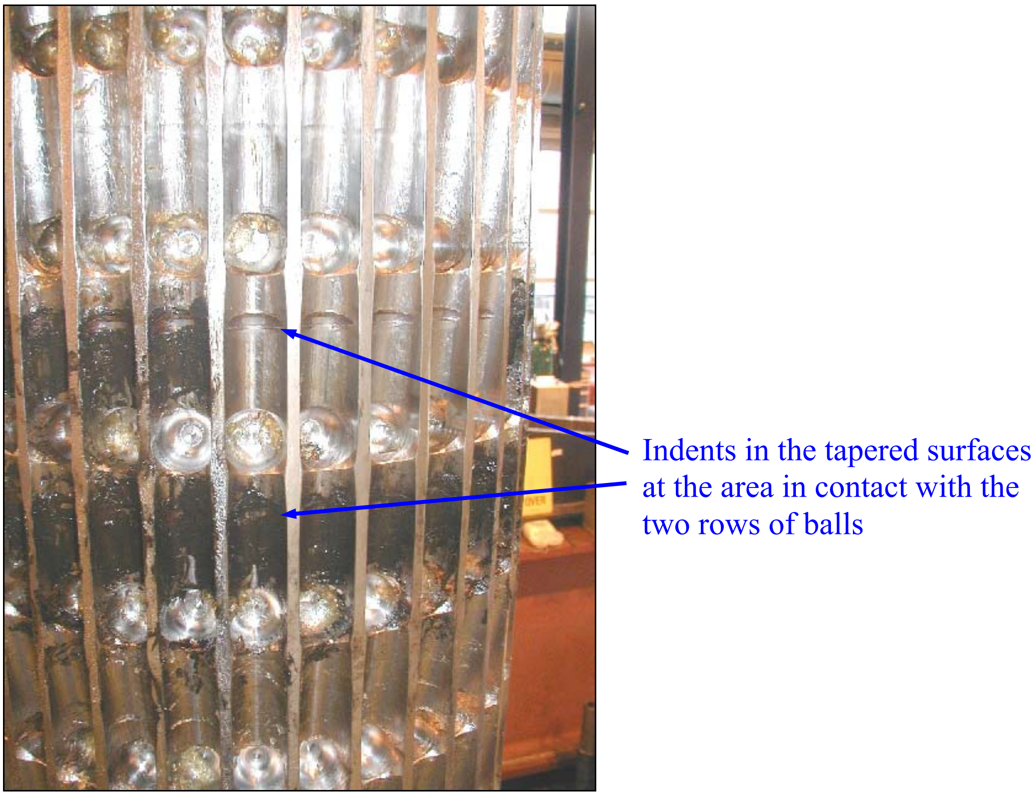

Figure 16 Tapered surfaces on mandrel after testing.

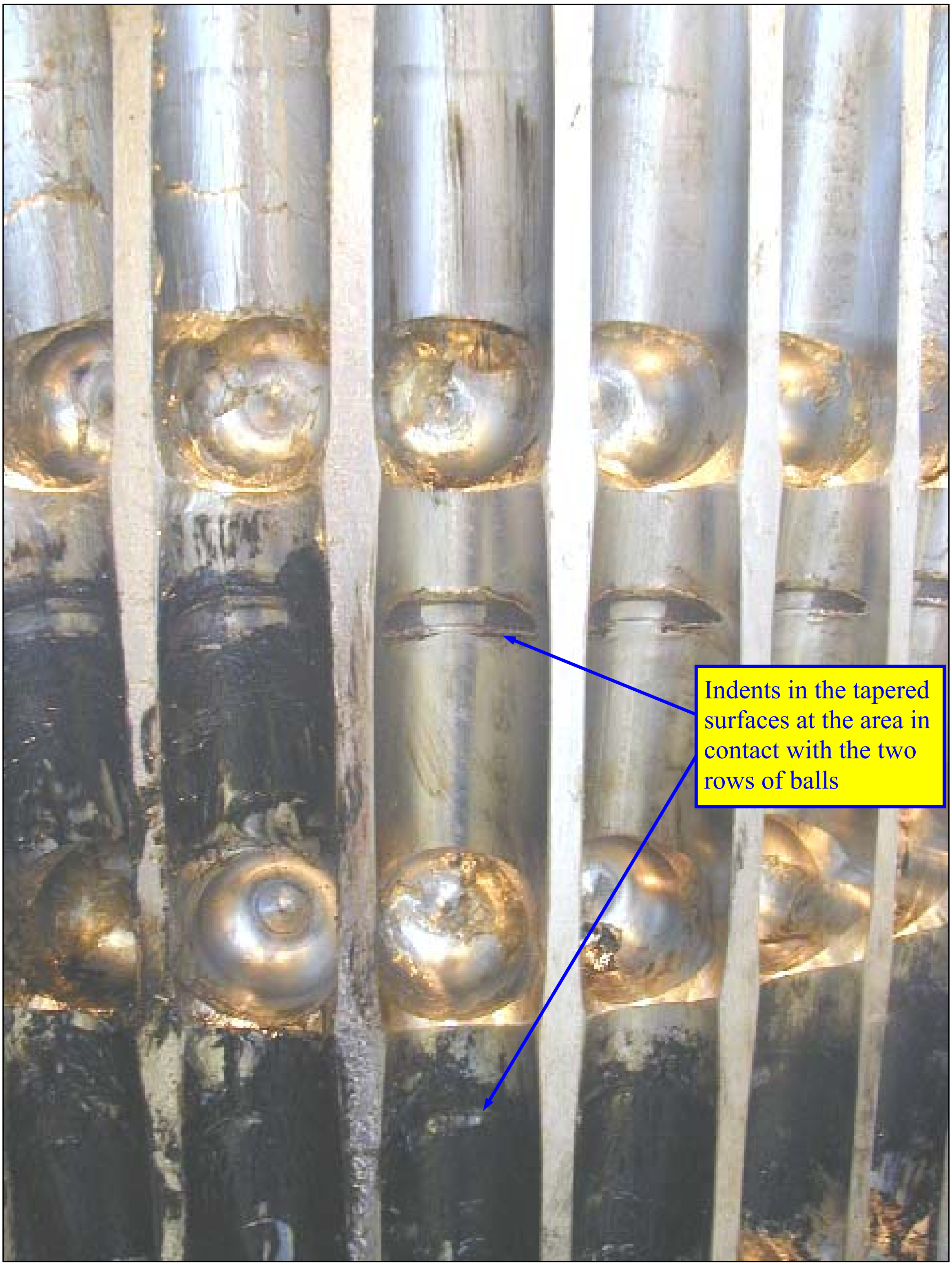

Figure 17 Close-up of tapered surfaces on mandrel after testing.

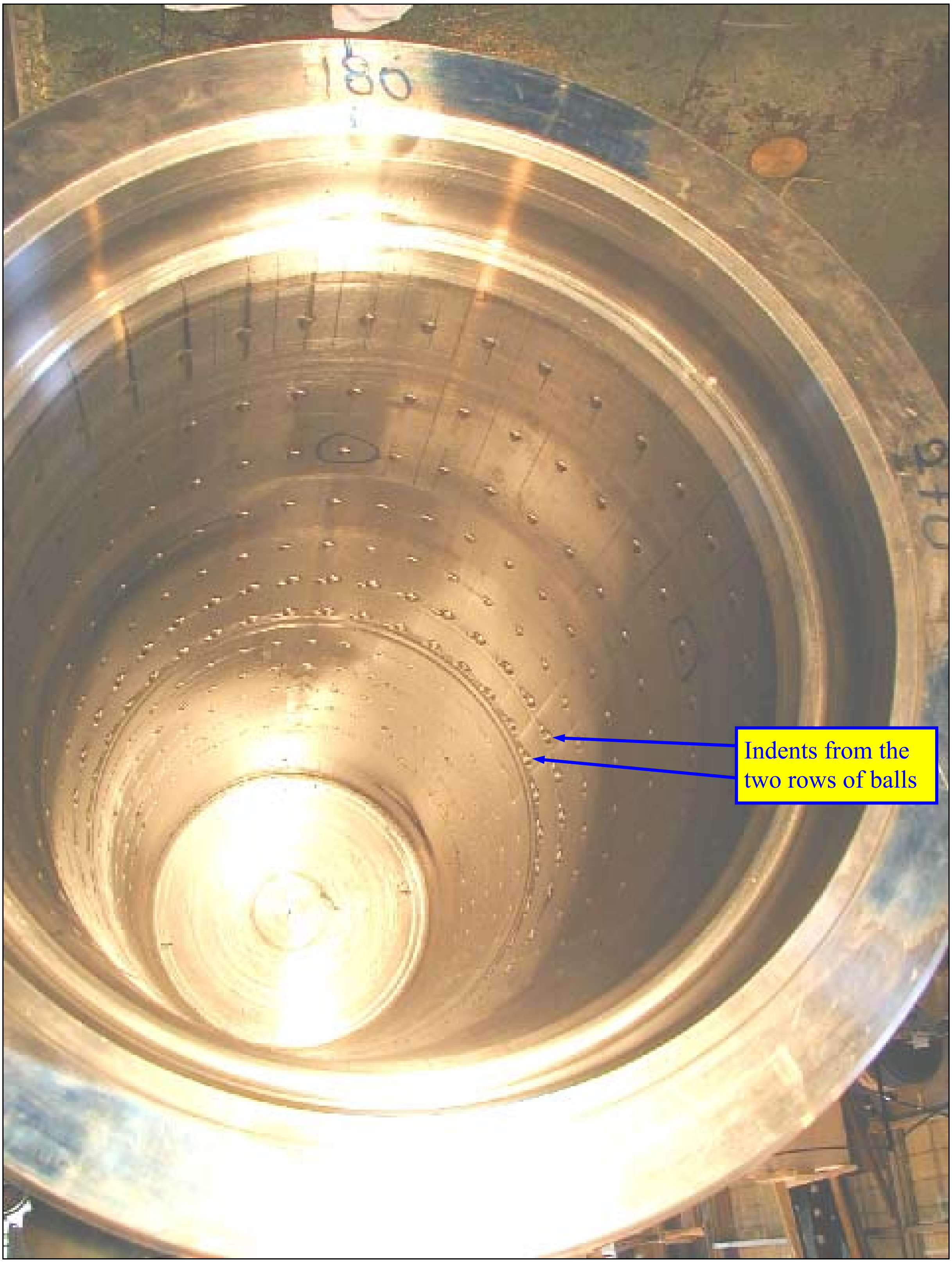

Figure 18 Indents inside of receptacle after testing.

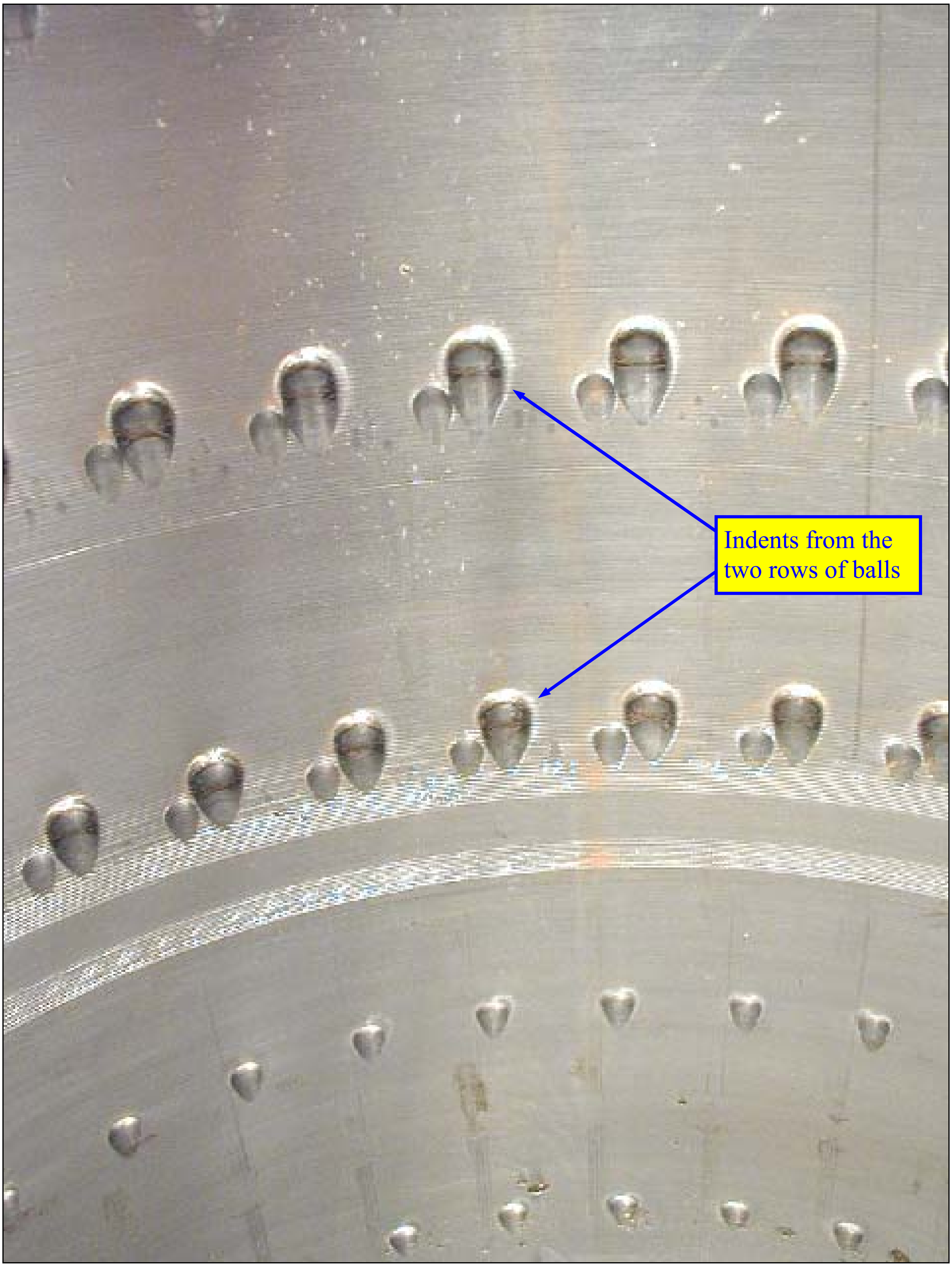

Figure 19 Close-up of indents inside of receptacle after testing.

Figure 20 Magnetic particle inspection (MPI) after testing.

APPENDIX C

FATIGUE TEST OF 1500T MBL CONNECTOR – TEST 1

MPI REPORT

-o0o-

APPENDIX D

FATIGUE TEST OF 1500T MBL CONNECTOR – TEST 2

PHOTOGRAPHS

-o0o-

Figure 21   Anchor connector installed in test rig.

Figure 22 Anchor connector installed in test rig.

Figure 23 Anchor connector disassembled after testing.

Figure 24 Indents inside of receptacle after testing.

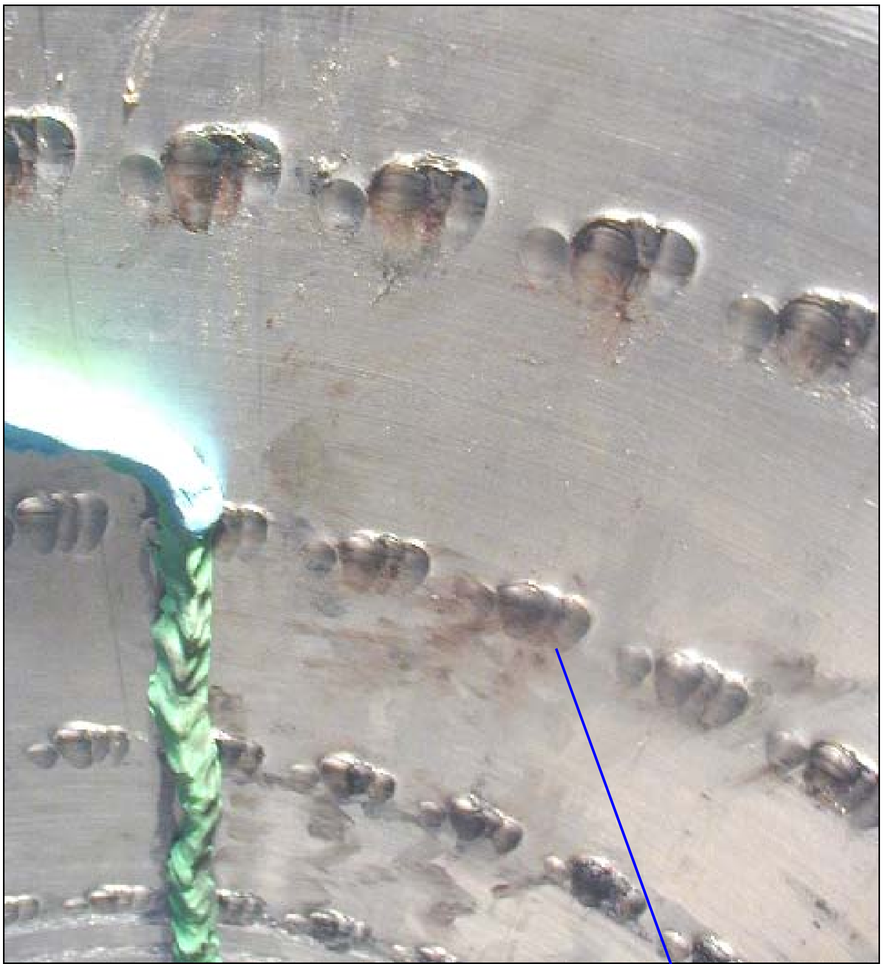

Figure 25 Close-up of indents inside of receptacle after testing.

Figure 26 Close-up of indents inside of receptacle after testing.

APPENDIX E

FATIGUE TEST OF 800T MBL CONNECTOR PHOTOGRAPHS

-o0o-

Figure 27 Anchor connector installed in test rig.

Figure 28 Anchor connector disassembled after testing.

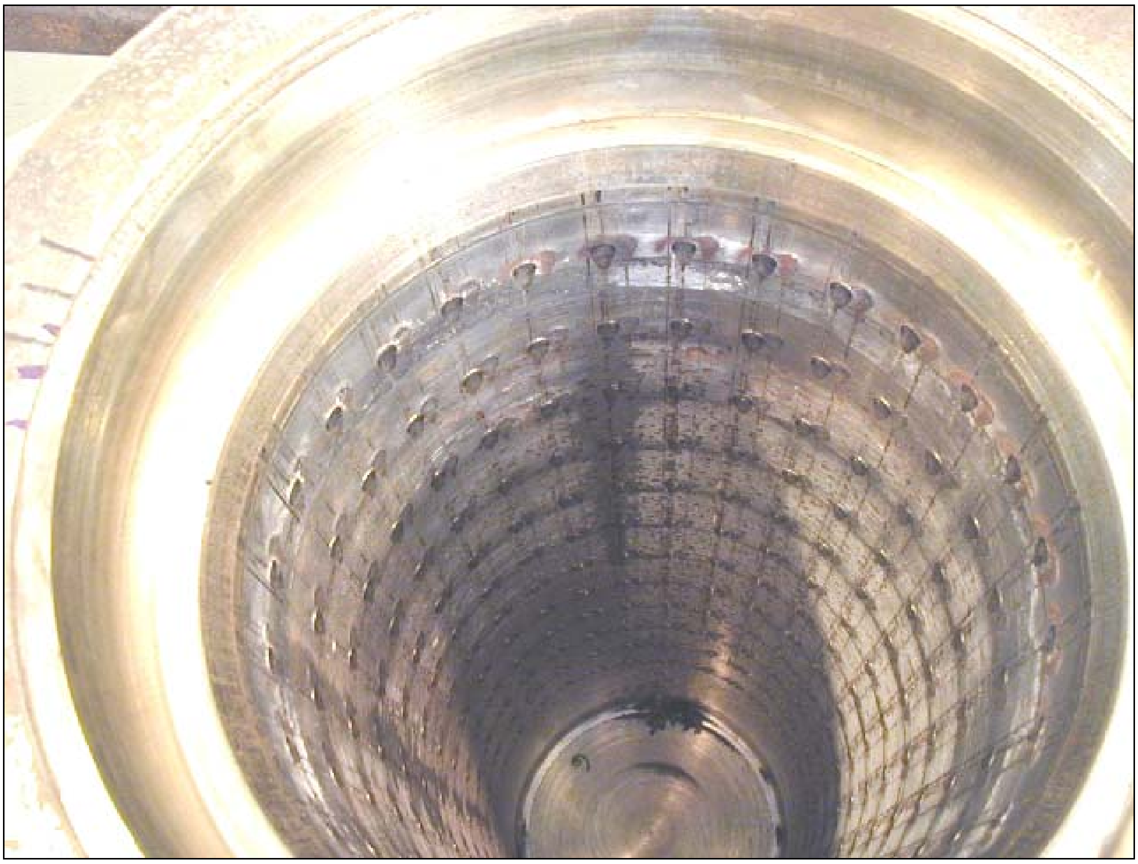

Figure 29 Indents inside of receptacle after testing.

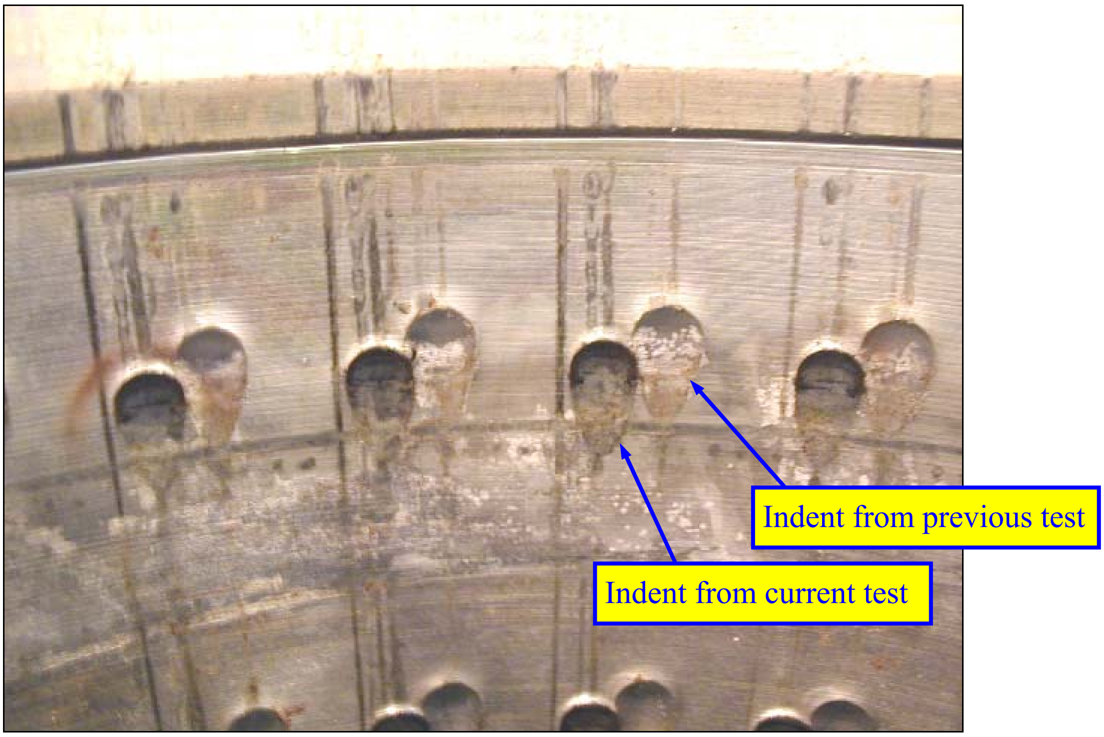

Figure 30 Close-up of indents inside of receptacle after testing.

- o0o -