NOBLE DENTON MARINE SERVICES

CSL ROUGH CRANE REPLACEMENT
Examination of Final Configuration of Crane Adaptor Bolting and Flange

Centrica Storage Limited

Report No.: 10016304\106\04\001TN, Rev. O
Date: April 2017

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Project name: CSL Rough Crane Replacement
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Customer: Centrica Storage Limited
Contact person: Ben Roebuck
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DNV GL - Oil & Gas
Noble Denton marine services
4th Floor
Vivo Building
30 Stamford Street
London
SE1 9LQ
Tel: +44 20 3 816 4000

Task and objective:
Assessment of ability of crane pedestal adaptor bolting and bolting flange to resist operating and accidental pedestal loads.

Prepared by:	Verified by:	Approved by:
	Y.G	
Nigel Sims Asset Leader	Yang Guo Senior Engineer	Dr Philip Wicks Manager, SIM & Structures Unit
[Fullname] [title]	[Fullname] [title]	
[Fullname] [title]	[Fullname] [title]	

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1 INTRODUCTION

Centrica Storage Limited (CSL) have requested that the bolting arrangement around the crane pedestal adaptor for the crane on their Rough BP and BD platforms be checked under accidental crane loads and under operating crane loads. This Technical Note describes the work done and its conclusions. This Technical Note builds on work reported previously/1/.

Work is under way to replace the cranes on the Rough BP and BD facilities. The cranes entered service in 1982, so have been in service for some 35 years; they are to be replaced with new units of similar capacity in 2017. The cranes are mounted on cylindrical pedestals fitted adjacent to corners of the modules. At the upper end of the cylinder, a tapered adaptor is fitted which incorporates a circular bolting flange onto which the crane is mounted. The same arrangement is used on both the BP and BD cranes.

For the new cranes, it is required that the pedestals and their supporting structure can resist loads transmitted from the cranes under conditions of catastrophic overload in accordance with Appendix D of reference /1/. These represent loads under which crane components will fail, plus an additional safety factor. Under these accidental loads the pedestal must not collapse; the failure loads of components supporting the crane cabin must be higher than the failure loads for the first crane component to fail.

As part of the crane replacements, new secondary adaptors are to be fitted above the existing adaptors and secured to the existing units with bolts. It is important for ease and speed of fitting that the existing bolt holes on the adaptors can be re-used, to avoid reworking of the holes during installation.

The study reported here addressed the adaptor bolting and adaptor bolting flange under the specified accidental and operating crane loads, considering both strength and fatigue Such bolting is clearly a vital component in the load path.

It is understood that the same structural arrangement and crane will apply to both the BP and BD units; hence the calculations reported here apply to both. Differences in loading history between BP and BD are taken into account in considering fatigue damage from the existing cranes.

The projected life for the platforms is until 2035, i.e. 18 years if crane replacement takes place in 2017.

2 STRUCTURAL ARRANGEMENT

The existing adaptor is welded to the top of the cylindrical crane pedestal. It consists of a flat circular flange supported by two conical steel rings. The flange is drilled to take 72 off 1 ½” diameter bolts. An overview of the adaptor is shown in Figure 2-1/3/.

Above the adaptor, a new secondary adaptor is to be fitted and attached via the bolting flange. Loads from the crane will be transmitted through the secondary adaptor and thence via the 72 bolts to the bolting flange of the adaptor. This secondary adaptor is shown in Figure 2-2. The secondary adaptor is to be supplied by the crane manufacturer; its structural performance is not considered here.

The bolt holes in the existing adaptor are 1 9/16” diameter, to take 1 ½” diameter Imperial bolts. The grade of bolts currently fitted is unknown. It is important for ease and speed of fitting that the existing bolt holes on the adaptor can be re-used, to avoid reworking of the holes during installation. Kenz have specified M36 bolts in the existing holes. These will screw into threaded holes in Kenz’s new secondary adaptor.

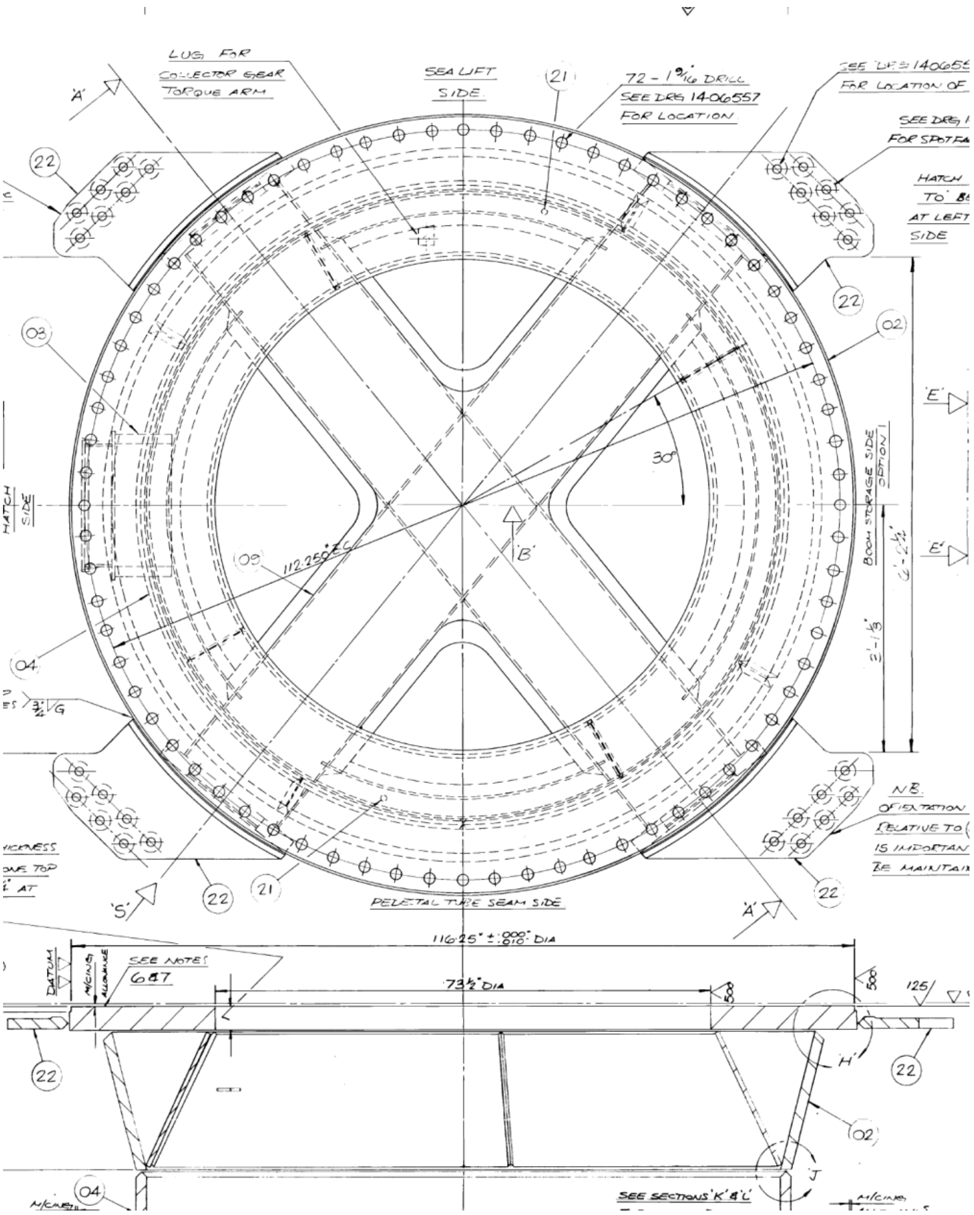
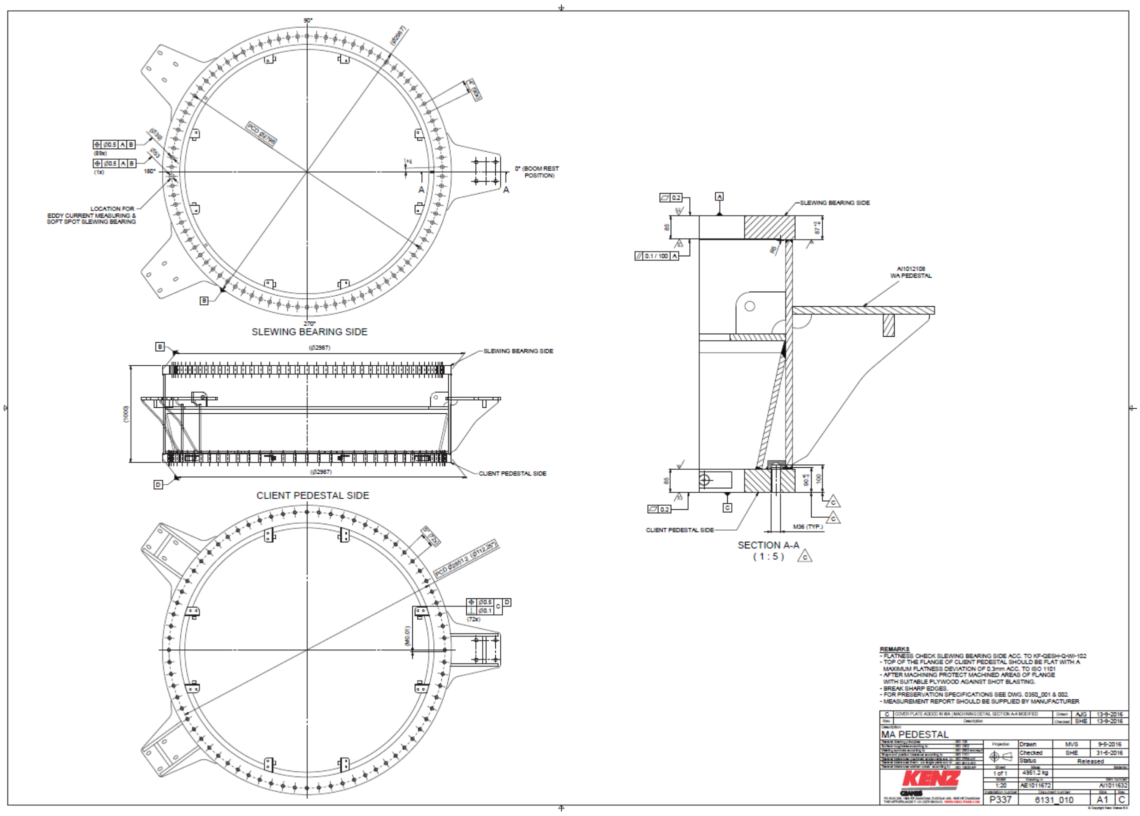


Figure 2-1 Pedestal adaptor

Relevant dimensions used in the calculations are sketched in Figure 2-4. Dimensions given in brackets are converted from the inch units on the original drawing (conversion factor 1″ = 25.4 mm).

Kenz’s new secondary adaptor is shown in their drawing number P337 6131-010 rev C, see Figure 2-2. The M36 stud for attachment of the new secondary adaptor is shown in Figure 2-3.



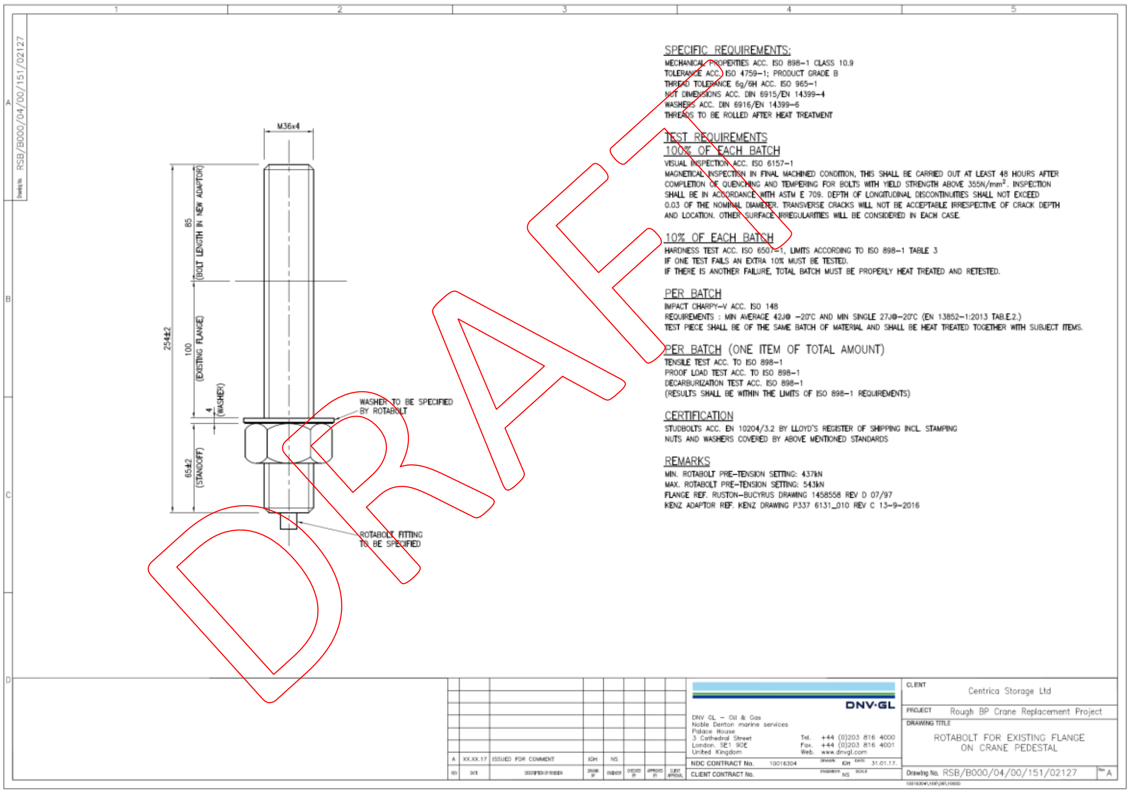
REMARKS
- FLATNESS CHECK SLEWING BEARING SIDE ACC. TO KF-QESH-Q-WI-102
- TOP OF THE FLANGE OF CLIENT PEDESTAL SHOULD BE FLAT WITH A MAXIMUM FLATNESS DEVIATION OF 0.3mm ACC. TO ISO 1101
- AFTER MACHINING PROTECT MACHINED AREAS OF FLANGE WITH SUITABLE PLYWOOD AGAINST SHOT BLASTING.
- BREAK SHARP EDGES.
- FOR PRESERVATION SPECIFICATIONS SEE DWG. 0350_001 & 002.
- MEASUREMENT REPORT SHOULD BE SUPPLIED BY MANUFACTURER

C	COVER PLATE ADDED IN WA | MACHINING DETAIL SECTION A-A MODIFIED	Drawn	AJG	13-9-2016
Rev.	Description	Checked	SHE	13-9-2016

Description: MA PEDESTAL

Projection	Drawn	MVS	9-5-2016
	Checked	SHE	31-5-2016
	Status	Released	
Sheet	Mass	Material	
1 of 1	4951.2 kg		
Scale	Drawing no.	Item number	
1:20	AE1011672	AI1011632	
Installation number	Document number	Size	Rev.
P337	6131_010	A1	C

Figure 2-2 Kenz design for secondary adaptor



SPECIFIC REQUIREMENTS:
MECHANICAL PROPERTIES ACC. ISO 898–1 CLASS 10.9
TOLERANCE ACC. ISO 4759–1; PRODUCT GRADE B
THREAD TOLERANCE 6g/6H ACC. ISO 965–1
NUT DIMENSIONS ACC. DIN 6915/EN 14399–4
WASHERS ACC. DIN 6916/EN 14399–6
THREADS TO BE ROLLED AFTER HEAT TREATMENT

TEST REQUIREMENTS
100% OF EACH BATCH
VISUAL INSPECTION ACC. ISO 6157–1
MAGNETICAL INSPECTION IN FINAL MACHINED CONDITION, THIS SHALL BE CARRIED OUT AT LEAST 48 HOURS AFTER COMPLETION OF QUENCHING AND TEMPERING FOR BOLTS WITH YIELD STRENGTH ABOVE 355N/mm^2. INSPECTION SHALL BE IN ACCORDANCE WITH ASTM E 709. DEPTH OF LONGITUDINAL DISCONTINUITIES SHALL NOT EXCEED 0.03 OF THE NOMINAL DIAMETER. TRANSVERSE CRACKS WILL NOT BE ACCEPTABLE IRRESPECTIVE OF CRACK DEPTH AND LOCATION. OTHER SURFACE IRREGULARITIES WILL BE CONSIDERED IN EACH CASE.

10% OF EACH BATCH
HARDNESS TEST ACC. ISO 6507–1, LIMITS ACCORDING TO ISO 898–1 TABLE 3
IF ONE TEST FAILS AN EXTRA 10% MUST BE TESTED.
IF THERE IS ANOTHER FAILURE, TOTAL BATCH MUST BE PROPERLY HEAT TREATED AND RETESTED.

PER BATCH
IMPACT CHARPY–V ACC. ISO 148
REQUIREMENTS : MIN AVERAGE 42J@ –20°C AND MIN SINGLE 27J@–20°C (EN 13852–1:2013 TAB.E.2.)
TEST PIECE SHALL BE OF THE SAME BATCH OF MATERIAL AND SHALL BE HEAT TREATED TOGETHER WITH SUBJECT ITEMS.

PER BATCH (ONE ITEM OF TOTAL AMOUNT)
TENSILE TEST ACC. TO ISO 898–1
PROOF LOAD TEST ACC. TO ISO 898–1
DECARBURIZATION TEST ACC. ISO 898–1
(RESULTS SHALL BE WITHIN THE LIMITS OF ISO 898–1 REQUIREMENTS)

CERTIFICATION
STUDBOLTS ACC. EN 10204/3.2 BY LLOYD'S REGISTER OF SHIPPING INCL. STAMPING
NUTS AND WASHERS COVERED BY ABOVE MENTIONED STANDARDS

REMARKS
MIN. ROTABOLT PRE–TENSION SETTING: 437kN
MAX. ROTABOLT PRE–TENSION SETTING: 543kN
FLANGE REF. RUSTON–BUCYRUS DRAWING 1458558 REV D 07/97
KENZ ADAPTOR REF. KENZ DRAWING P337 6131_010 REV C 13–9–2016

REV	DATE	DESCRIPTION OF REVISION	DRAWN BY	ENGINEER	CHECKED BY	APPROVED BY	CLIENT APPROVAL
A	XX.XX.17	ISSUED FOR COMMENT	IGH	NS			

DNV GL – Oil & Gas
Noble Denton marine services
Palace House
3 Cathedral Street
London. SE1 9DE
United Kingdom
Tel. +44 (0)203 816 4000
Fax. +44 (0)203 816 4001
Web. www.dnvgl.com

NDC CONTRACT No. 10016304 DRAWN IGH DATE 31.01.17.
CLIENT CONTRACT No. ENGINEER NS SCALE

CLIENT Centrica Storage Ltd
PROJECT Rough BP Crane Replacement Project
DRAWING TITLE ROTABOLT FOR EXISTING FLANGE ON CRANE PEDESTAL
Drawing No. RSB/B000/04/00/151/02127 Rev A

Figure 2-3 M36 stud for attachment of new secondary adaptor

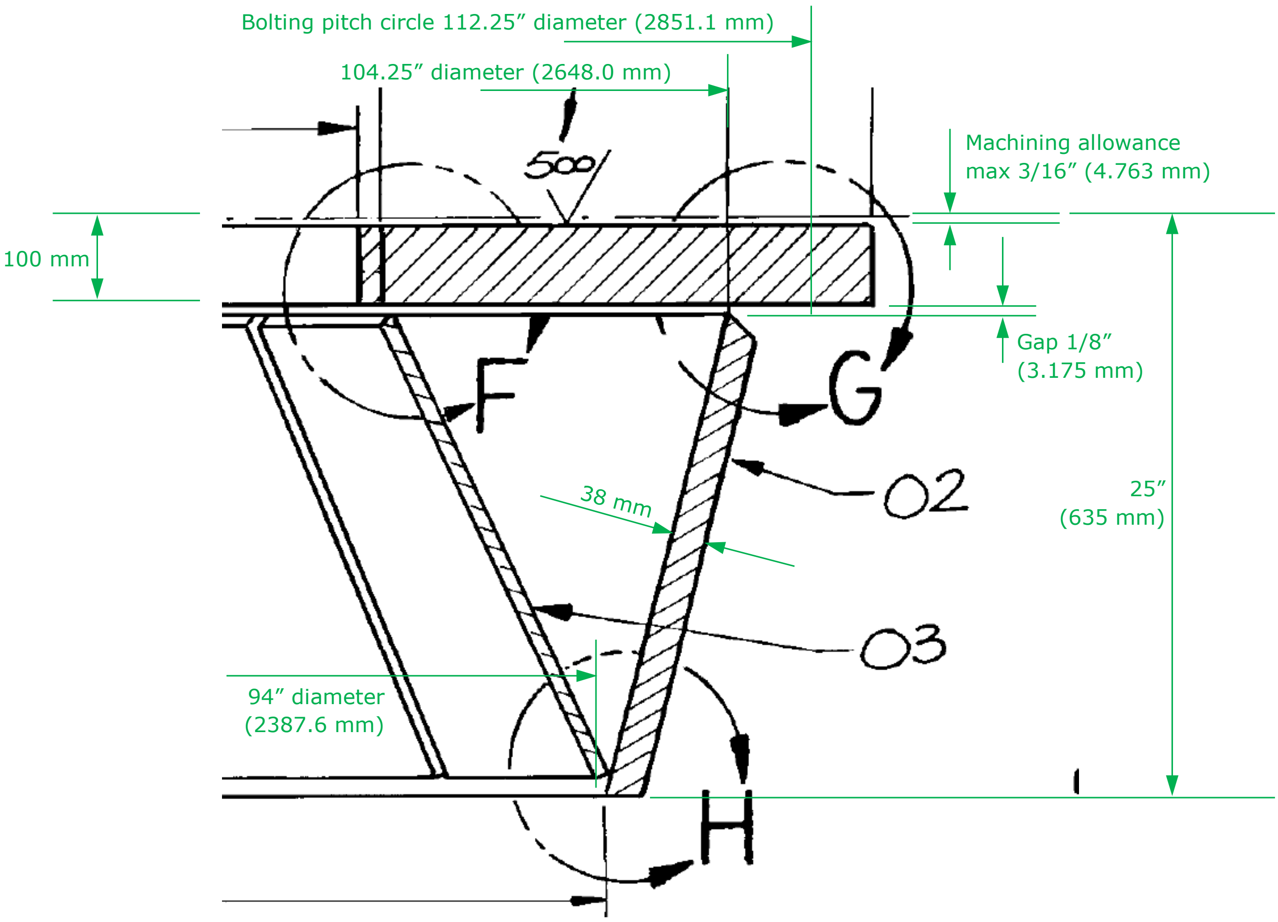


Figure 2-4 **Selected relevant dimensions, existing adaptor**

3 CRANE LOADING

The crane loadings considered here are:

- Operating loads – maximum loads arising during normal crane operations, provided by Kenz /4/ to CSL as "Fact. Load incl. Ped. SF (Incl. wind)";
- Accidental loads – loads which the pedestal must resist without failure were provided by Kenz /4/ to CSL as "Minimum Failure Load Client Ped"

The values of these loads are shown in Table 3-1.

Table 3-1 Crane loading

Load	Description	Operating loads	Accidental loads
M (kNm)	Bending moment on pedestal	17,677	38,733
Msl (kNm)	Torsional moment on pedestal	1,869	2,000
Fax (kN)	Axial load on pedestal (downwards)	1,594	2,280
Frad (kN)	Shear force radial to pedestal	115	113

4 BOLT LOADING

4.1 Calculation of individual bolt loads

Bolt loads were calculated by applying the provided pedestal load values over the full bolt circle. Axial and shear loads were distributed equally across all bolts. The torsional moment (Msl) was taken as resisted equally on all bolts, via shear in the bolts acting on the bolt pitch circle. The bending moment was distributed to give a linear distribution, so that force carried by a bolt was proportional to its lever arm from the pedestal centreline as sketched in Figure 4-1.

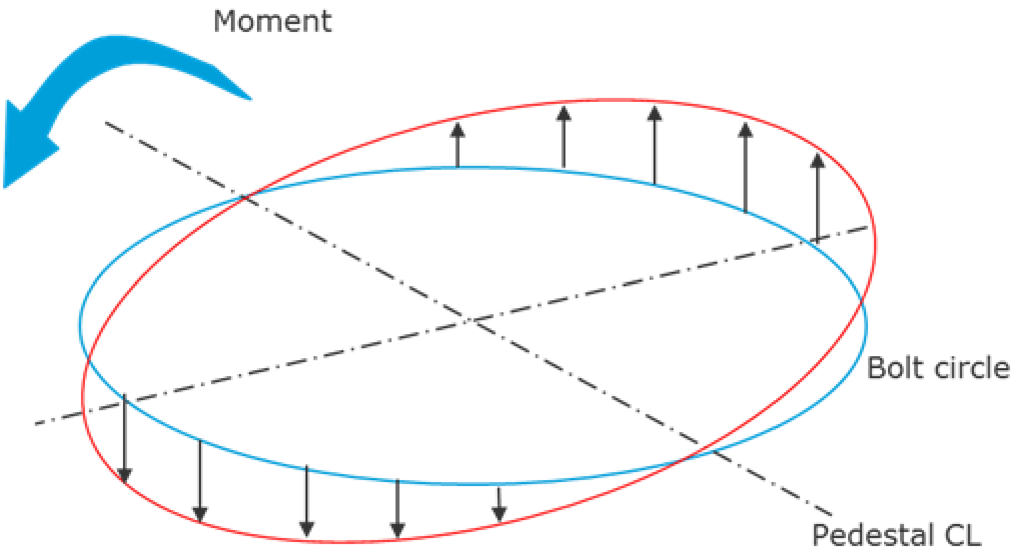


Figure 4-1 Calculation of bolt load due to moment

All load components were taken as acting simultaneously, with the axial load acting downwards (i.e. producing a compressive load, thus tending to reduce the tension in the bolts). Kenz confirmed /5/ that the moment and axial force in the accidental loading occur together. They also noted that "The axial force Fax is caused by the rope being pulled under these conditions (for instance entanglement of the hoisting hook at the support vessel while support vessel shifts away"; the axial force was therefore taken as compressive, acting downwards.

Note that:

- The pedestal failure loads given by Kenz are understood to already include a pedestal factor of 1.3 /11/.
- The radial forces Frad as supplied by Kenz were taken as acting at the level of the bolting ring - any additional offset would increase the moment on the ring.

On this basis, the individual bolt loads were calculated as shown in Table 4-1.

Table 4-1 Calculated loads per bolt

	Operating loads	**Accidental loads**
Axial load/bolt (kN)	322.0	722.3
Shear load/bolt (kN)	19.8	21.1

4.2 Stiffness analysis of the joint

To assess the possibility of prying action, the combined joint was modelled in finite elements. The model is shown in Figure 4-2. This model represented the lower flange of the Kenz adaptor plus the existing flange; the two were connected by a simple representation of the bolt, the model covering one half bolt spacing. The mating faces of the lower and upper flanges were coupled vertically; these couplings were progressively released to simulate separation under load, as noted below. Vertical coupling was also used to connect the bolt head and the lower flange.

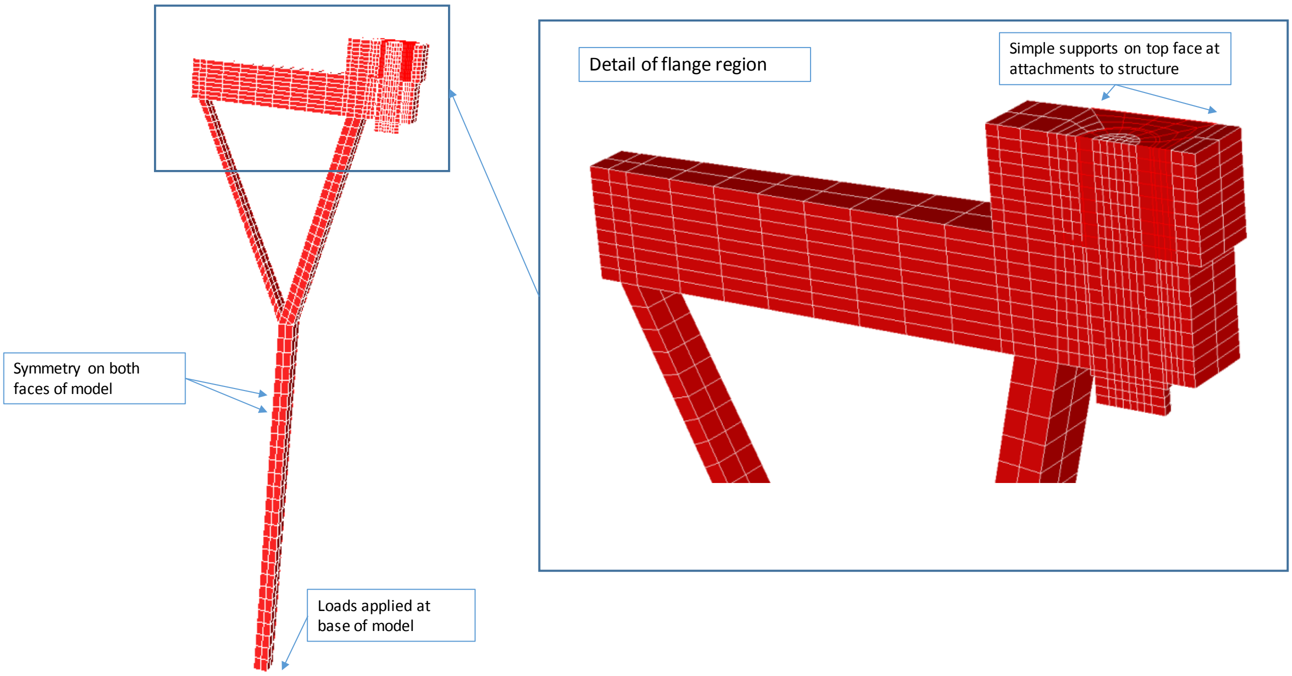


Figure 4-2 Finite element (FE) model

The bolt was pretensioned using temperature loads, thermally shrinking the bolt material passing through the lower flange to produce an axial bolt stress. The pretension applied corresponded to a bolt pretensioned to 70% of the yield stress of grade 10.9 material; 2.23.8 of reference /6/ specifies this as the minimum pretension for joints subjected to fluctuating or reversal of loads. Minimum pretension will allow maximum separation in the joint, should that occur.

Axial load was applied to the pedestal body, at the lower end of the model. The upper flange was simply supported where the Kenz adaptor steelwork is attached (see Figure 4-2 and Figure 2-2). A set of cases were considered as summarised in Table 4-2 below (note that these are the loads acting on the model, i.e. on one half of one bolt). Iterative analyses were used, releasing the coupling between lower and upper flanges in areas of tension normal to the mating faces to simulate separation of the flanges.

Table 4-2 Summary of FE runs

	External load (kN)	Axial load in bolt (N)
Clampup only	0	514.7
30kN	30	515.9
90kN	90	525.1
operating	161	559.0
accidental	361.15	687.5

Bolt loads from these runs are plotted against applied load in Figure 4-3; these are the loads on a single bolt spacing. It can be seen that the bolt load increases as the extent of flange separation increases.

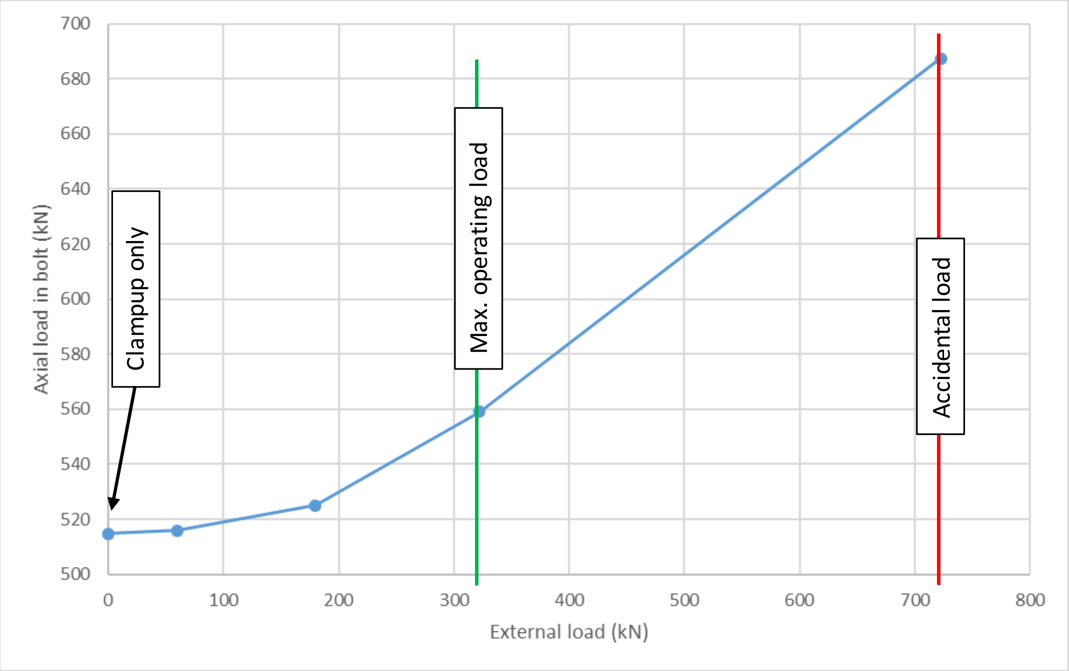


Figure 4-3 Axial bolt load vs applied external load

5 STRESSES IN BOLTING

5.1 Axial stresses

M36x4 bolts have been specified for the joint by Kenz/7/. These bolts have a stress area of 817 mm^2. With this cross-section area, the nominal stresses are shown in Table 5-1

Table 5-1 **Calculated bolt stresses**

	Operating loads	Accidental loads
Axial stress (MPa)	394	884
Nominal shear stress (MPa)	24	26

CSL intend the use of RotaBolts in these locations; such bolts include a mechanism for checking the applied axial tension in the bolts. A small hole is drilled along the bolts to incorporate the mechanism, giving a small reduction in cross-section area of the order of 3.8%. Such holes would increase the stress values to those shown in Table 5-2.

Table 5-2 **Calculated bolt stresses accounting for RotaBolt hole**

	Operating loads	Accidental loads
Axial stress (MPa)	410	919
Nominal shear stress (MPa)	25	27

For Grade 10.9 bolts, the ”yield” stress (0.2% proof stress) is specified as 900 MPa nominal and 940 MPa minimum, with tensile strength 1000 MPa nominal and 1040 MPa minimum. Comparing these with the values of Table 5-2,

- The calculated shear stresses in the bolts are low, at around 3% of tensile yield stress;
- Under operating loads,
    - Compared with yield, the calculated axial stress is around 44% of yield;
    - Compared with tensile strength, the calculated axial stress is around 39% of tensile strength;
- Under accidental loads,
    - Compared with yield, the calculated axial stress is around 98% of yield;
    - Compared with tensile strength, the calculated axial stress is around 88% of tensile strength;
- Given the low value of shear stress, tension will dominate.

FE results (see section 4.2) indicate that the actual bolt loads, accounting for pretensioning to 70% yield, will be changed from those given above; recalculating using the bolt loads from the FE analyses gives tensile loads and stresses as in Table 5-3.

Table 5-3 Bolt loads from FE analyses and corresponding stresses

	Operating loads	**Accidental loads**
Axial load (kN)	559	688
Axial stress (MPa)	710	874
Axial stress/ grade 10.9 yield	0.76	0.93
Axial stress/ grade 10.9 ultimate	0.68	0.84

5.2 Thread stripping check

In cases where engaged thread lengths are short, stripping of threads can occur. In the present arrangement, bolts will be inserted through the lower flange and engaged in threaded holes in the upper flange. A detail from the drawing of Kenz’s adaptor design is shown below in Figure 5-1.

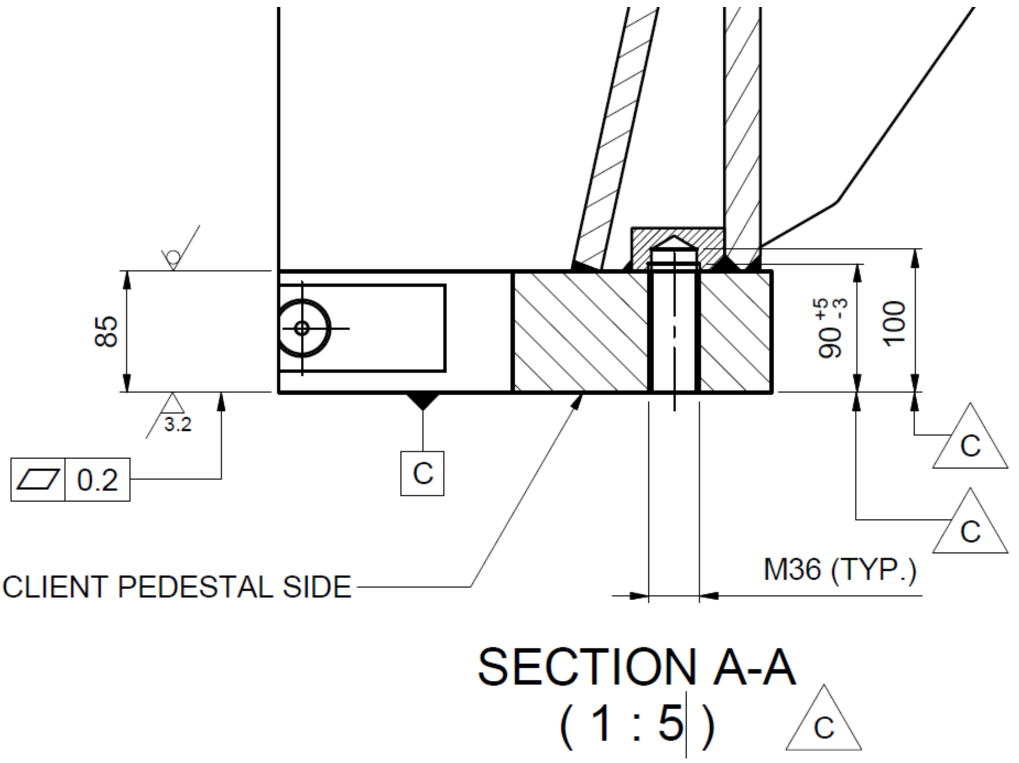


Figure 5-1 Detail of new secondary adaptor (see Figure 2-2)

For M36 bolts, the thread shear area at the minor and major thread diameters may be calculated as

Minor diameter 30.654 mm

Major diameter 36.0 mm

Thickness of threaded flange 85 mm

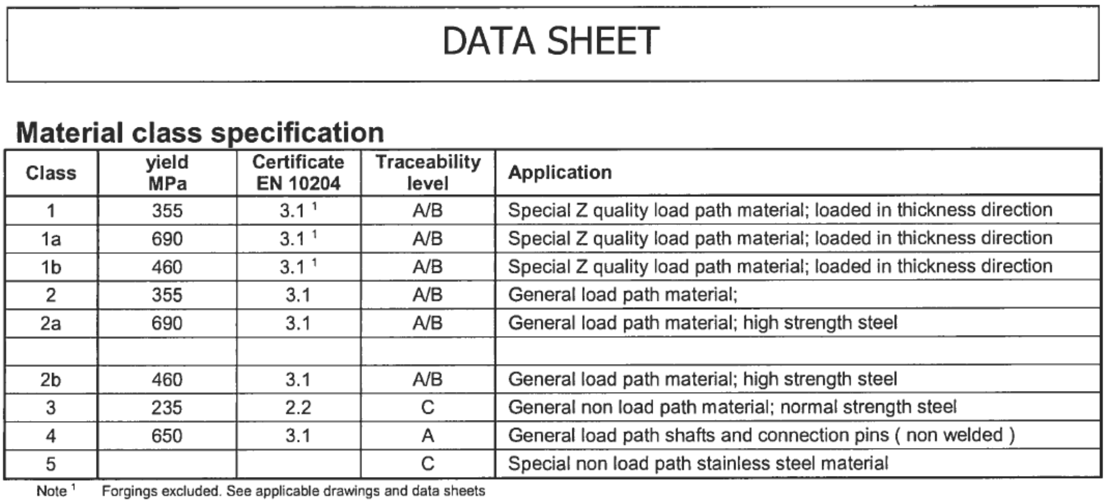
Shear area in thread, fully engaged with flange

Minor diameter = π.D.t = 8185 mm^2

Major diameter = π.D.t = 9613 mm^2

On the minor diameter, shear failure of the thread would involve the bolt material. Here, for grade 10.9 bolt material, nominal yield stress = 900 MPa; taking shear yield as 0.577 of tensile yield, shear yield stress is approximately 519 MPa or 519 N/mm^2 so thread capacity is 8185 x 519 = 4,248,015 N or 4284 kN.

On the major diameter, shear failure of the thread would involve the flange material of the new secondary adaptor. The material here is Class 1b /8/ as shown in Figure 5-2. For S460N steel, the minimum yield at 85 mm thick is 400 MPa; taking shear yield as 0.577 of tensile yield, shear yield stress is approximately 230 MPa or 230 N/mm^2 so thread capacity is 9613 x 230 = 2,210,990 N or 2211 kN.



DATA SHEET

Material class specification

Class	yield MPa	Certificate EN 10204	Traceability level	Application
1	355	3.1 [1]	A/B	Special Z quality load path material; loaded in thickness direction
1a	690	3.1 [1]	A/B	Special Z quality load path material; loaded in thickness direction
1b	460	3.1 [1]	A/B	Special Z quality load path material; loaded in thickness direction
2	355	3.1	A/B	General load path material;
2a	690	3.1	A/B	General load path material; high strength steel
2b	460	3.1	A/B	General load path material; high strength steel
3	235	2.2	C	General non load path material; normal strength steel
4	650	3.1	A	General load path shafts and connection pins (non welded)
5			C	Special non load path stainless steel material

Note [1] Forgings excluded. See applicable drawings and data sheets

Figure 5-2 Kenz material classes/9/

The bolt load under accidental loading is 722.3 kN (see Table 4-1) so with the thread fully engaged in the upper flange, accidental load is approximately 33% of thread capacity. At lower thread engagements the capacity will decrease in proportion; using this approach, the minimum thread engagement in the flange of the secondary adaptor to avoid thread stripping is 28.1 mm. The expected engagement is c 85 mm.

6 BOLTING FLANGE

6.1 Method of calculation

Stresses in the existing bolting flange were calculated, treating the flange as a cantilever beam as sketched in Figure 6-1. Since the number of bolts is large at 72, one bolt space covers only 5° so treating it as a simple cantilever under the maximum tensile bolt load is considered reasonable.

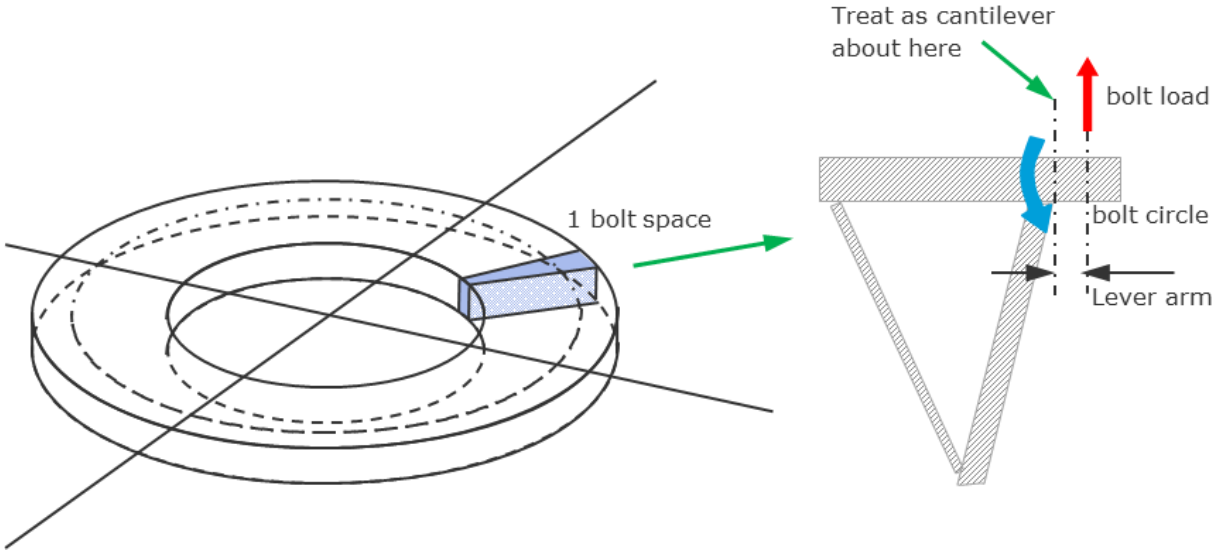


Figure 6-1 Flange calculation

From the geometry of the flange (see Figure 2-4), a lever arm of 61.7 mm may be calculated from the bolting pitch circle to the outer edge of the conical plate contact with the flange.

The flange section was taken as one bolt space wide at the outside of the supporting cone and with a thickness allowing for the maximum machining allowance of 3/16", i.e. 119.0 mm wide by 95.24 mm thick, giving a section modulus of 179.89 x 10^{-6} m^3.

The flange material has properties as shown in Table 6-1 /14/.

Table 6-1 Flange material properties /8/

	Yield stress (MPa)	UTS (MPa)
Specified	315	490
Actual	346	480

6.2 Operating loads

To check stresses in the flange under operating loads, the maximum bolt loads listed above in section 4 were applied, i.e. 322 kN of axial load and 19.8 kN of shear load per bolt.

With the flange properties of the preceding section, this gave a bending moment of 19,866.5 Nm and a bending stress in the flange root of 19,866.5/179.89 x 10^{-6} / 10^{6} MPa = 110.4 MPa.

The calculated stress is 35% of the specified flange material yield stress and 32% of the actual yield stress shown in the material mill certificate /14/.

6.3 Accidental loads

Under accidental loads, it was considered reasonable to permit yielding of the flange.

To check the flange strength under accidental loads, the bolt load was taken as the calculated failure load of a grade 10.9 M36 bolt, using the stress area and material tensile strength as in section 5, i.e. area 817 mm^2 and tensile strength 1040 MPa giving a failure load of 850 kN;

Using these values, the calculated flange stresses are summarised in Table 6-2.

Table 6-2 Bolting flange: elastic stress calculation

Bolt failure load (kN)	Flange moment (Nm)	Flange elastic stress (MPa)
850	52,445	292

Thus the calculated bolt failure load gives a moment within the actual elastic property of the flange. In practice some yielding may be expected local to the attachment to the pedestal, due to the local stress concentration. Although not specifically designed to examine this detail, the finite element model described in section 4.2 indicated a local nodal averaged von Mises stress at the corner of 381 MPa under pretension + accidental load, or approximately 10% over yield. As can be seen from the plot below, this peak stress is a result of the local concentration. (Note that the high stresses at the ends of the bolt hole are a result of load transfer from the bolt.)

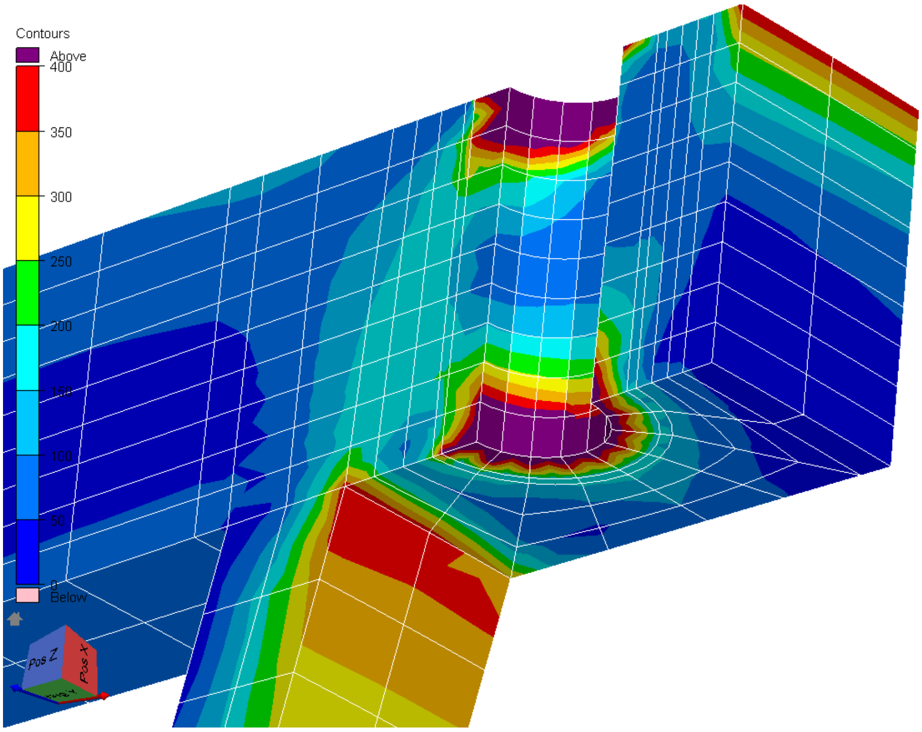


Figure 6-2 Von Mises stresses (MPa) - pretension plus accidental load

7 FATIGUE CHECKS

7.1 Fatigue in bolts

Fatigue lives for the bolts have been calculated based on the MIPEG crane history data provided for the BP and BD platforms/15/,/16/. This system records the lift history of the crane and includes figures for the lift weight and for the moment applied to the crane over a period of some 11 years. For structural fatigue, it has been assumed /15/,/16/ that the pattern of lifts with the new crane will be the same as the recorded history with the existing crane. The recorded history, adjusted for weight & CG data for the new crane, thus allows a lift pattern to be established for assessing future fatigue damage for crane operations.

In assessing the fatigue lives of the bolts, only damage from the new crane configuration was considered – new bolts will be installed with the new crane. The sequence of calculation was:

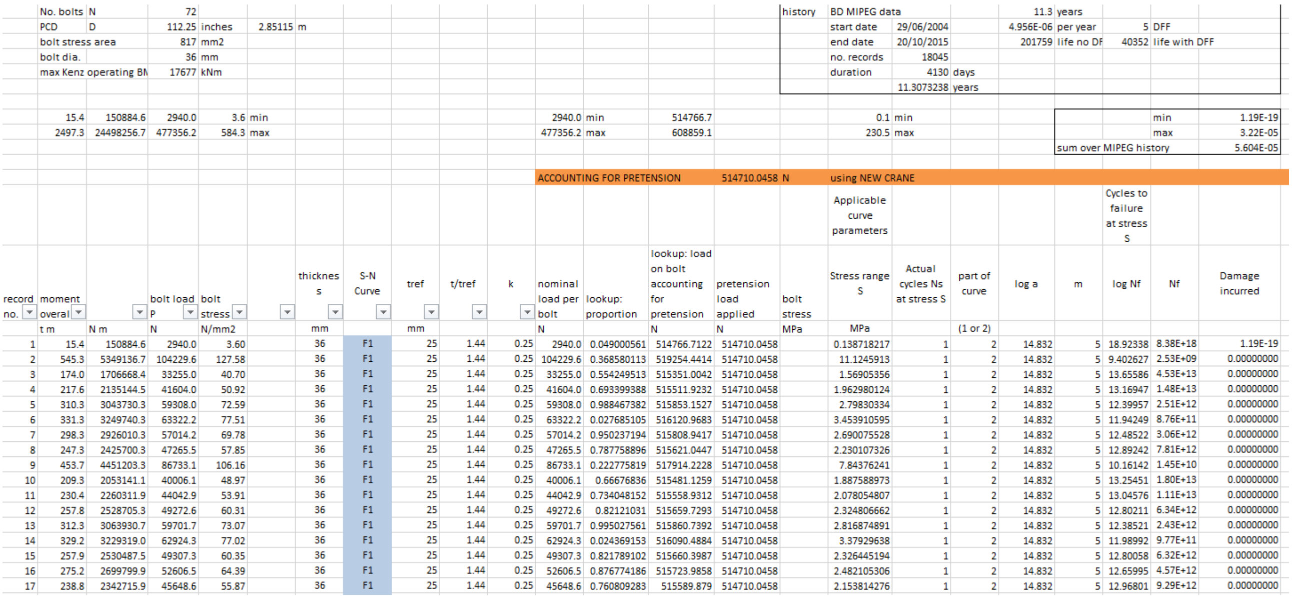
For each single recorded lift, using the new crane data,

- Calculate the maximum nominal load on an individual bolt position on the bolt circle, due to the crane moment;
- Interpolate to get the bolt load (see Figure 4-3)

- Calculate the change in bolt load, as the difference between pretension load and bolt load;
- Calculate the stress range for this single cycle;
- Use the F1 S-N curve /17/ to calculate the damage from a single cycle at this stress range.

Summing the damage figures from all recorded cycles gave the total damage over the period covered by the MIPEG records; from this, an annual damage rate was calculated.

Note that this calculation assumes that each bolt sees the maximum lift moment for every single lift; in practice this should be conservative. A sample of the calculation, showing a few lifts only, can be seen in Figure 7-1



No. bolts	N	72			
PCD	D	112.25	inches	2.85115	m
bolt stress area		817	mm2		
bolt dia.		36	mm		
max Kenz operating BM		17677	kNm		

history	BD MIPEG data		11.3	years
	start date	29/06/2004	4.956E-06	per year
	end date	20/10/2015	201759	life no DF
	no. records	18045		
	duration	4130	days	
		11.3073238	years	

5 DFF

40352 life with DFF

15.4 150884.6 2940.0 3.6 min 2940.0 min 514766.7 0.1 min

2497.3 24498256.7 477356.2 584.3 max 477356.2 max 608859.1 230.5 max

min	1.19E-19
max	3.22E-05
sum over MIPEG history	5.604E-05

ACCOUNTING FOR PRETENSION 514710.0458 N using NEW CRANE

																Applicable curve parameters					Cycles to failure at stress S		
record no.	moment overal		bolt load P	bolt stress		thickness	S-N Curve	tref	t/tref	k	nominal load per bolt	lookup: proportion	lookup: load on bolt accounting for pretension	pretension load applied	bolt stress	Stress range S	Actual cycles Ns at stress S	part of curve	log a	m	log Nf	Nf	Damage incurred
	t m	N m	N	N/mm2		mm		mm			N		N	N	MPa	MPa		(1 or 2)					
1	15.4	150884.6	2940.0	3.60		36	F1	25	1.44	0.25	2940.0	0.049000561	514766.7122	514710.0458		0.138718217	1	2	14.832	5	18.92338	8.38E+18	1.19E-19
2	545.3	5349136.7	104229.6	127.58		36	F1	25	1.44	0.25	104229.6	0.368580113	519254.4414	514710.0458		11.1245913	1	2	14.832	5	9.402627	2.53E+09	0.00000000
3	174.0	1706668.4	33255.0	40.70		36	F1	25	1.44	0.25	33255.0	0.554249513	515351.0042	514710.0458		1.56905356	1	2	14.832	5	13.65586	4.53E+13	0.00000000
4	217.6	2135144.5	41604.0	50.92		36	F1	25	1.44	0.25	41604.0	0.693399388	515511.9232	514710.0458		1.962980124	1	2	14.832	5	13.16947	1.48E+13	0.00000000
5	310.3	3043730.3	59308.0	72.59		36	F1	25	1.44	0.25	59308.0	0.988467382	515853.1527	514710.0458		2.79830334	1	2	14.832	5	12.39957	2.51E+12	0.00000000
6	331.3	3249740.3	63322.2	77.51		36	F1	25	1.44	0.25	63322.2	0.027685105	516120.9683	514710.0458		3.453910595	1	2	14.832	5	11.94249	8.76E+11	0.00000000
7	298.3	2926010.3	57014.2	69.78		36	F1	25	1.44	0.25	57014.2	0.950237194	515808.9417	514710.0458		2.690075528	1	2	14.832	5	12.48522	3.06E+12	0.00000000
8	247.3	2425700.3	47265.5	57.85		36	F1	25	1.44	0.25	47265.5	0.787758896	515621.0447	514710.0458		2.230107326	1	2	14.832	5	12.89242	7.81E+12	0.00000000
9	453.7	4451203.3	86733.1	106.16		36	F1	25	1.44	0.25	86733.1	0.222775819	517914.2228	514710.0458		7.84376241	1	2	14.832	5	10.16142	1.45E+10	0.00000000
10	209.3	2053141.1	40006.1	48.97		36	F1	25	1.44	0.25	40006.1	0.66676836	515481.1259	514710.0458		1.887588973	1	2	14.832	5	13.25451	1.80E+13	0.00000000
11	230.4	2260311.9	44042.9	53.91		36	F1	25	1.44	0.25	44042.9	0.734048152	515558.9312	514710.0458		2.078054807	1	2	14.832	5	13.04576	1.11E+13	0.00000000
12	257.8	2528705.3	49272.6	60.31		36	F1	25	1.44	0.25	49272.6	0.82121031	515659.7293	514710.0458		2.324806662	1	2	14.832	5	12.80211	6.34E+12	0.00000000
13	312.3	3063930.7	59701.7	73.07		36	F1	25	1.44	0.25	59701.7	0.995027561	515860.7392	514710.0458		2.816874891	1	2	14.832	5	12.38521	2.43E+12	0.00000000
14	329.2	3229319.0	62924.3	77.02		36	F1	25	1.44	0.25	62924.3	0.024369153	516090.4884	514710.0458		3.37929638	1	2	14.832	5	11.98992	9.77E+11	0.00000000
15	257.9	2530487.5	49307.3	60.35		36	F1	25	1.44	0.25	49307.3	0.821789102	515660.3987	514710.0458		2.326445194	1	2	14.832	5	12.80058	6.32E+12	0.00000000
16	275.2	2699799.9	52606.5	64.39		36	F1	25	1.44	0.25	52606.5	0.876774186	515723.9858	514710.0458		2.482105306	1	2	14.832	5	12.65995	4.57E+12	0.00000000
17	238.8	2342715.9	45648.6	55.87		36	F1	25	1.44	0.25	45648.6	0.760809283	515589.879	514710.0458		2.153814276	1	2	14.832	5	12.96801	9.29E+12	0.00000000

Figure 7-1 Illustration of calculation for bolt fatigue damage

Table 7-1 Calculated bolt fatigue - new crane

Crane	Number of MIPEG records	Period covered by MIPEG records (years)	Total damage calculated, F1 curve	Annual damage rate	Implied life (no DFF) (years)	Implied life (DFF=5) (years)
BP	1,8045	11.3	5.604E-05	4.956E-06	201,759	40,352
BD	34,119	11.0	2.213E-05	2.013E-06	496,892	99,378

7.2 Fatigue in bolting flange

Fatigue was checked adjacent to the lower corner of the existing bolting flange, where it attached to the conical portion of the pedestal. Principal stresses at a node located at the corner were used for the calculation This is clearly less than t/2 from the corner and hence conservative.

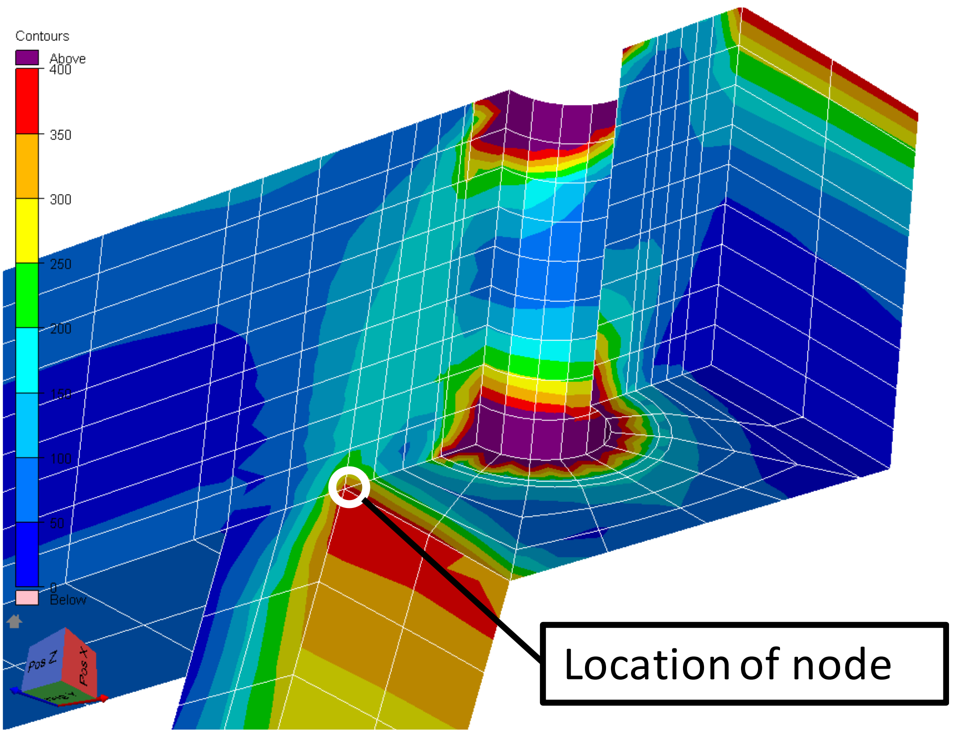


Figure 7-2 Location of node used for fatigue calculation

The calculation approach was similar to that used for the bolts (see section 7.1) in that it was based on damage calculated for each MIPEG record to arrive at an annual damage rate, using the 'D' S-N curve. However, for the flange damage from the existing crane was taken into account. As with the bolt calculation, interpolation was used within the FE model results to take account of the nonlinearity of stresses with load due to flange separation (see Figure 7-3).

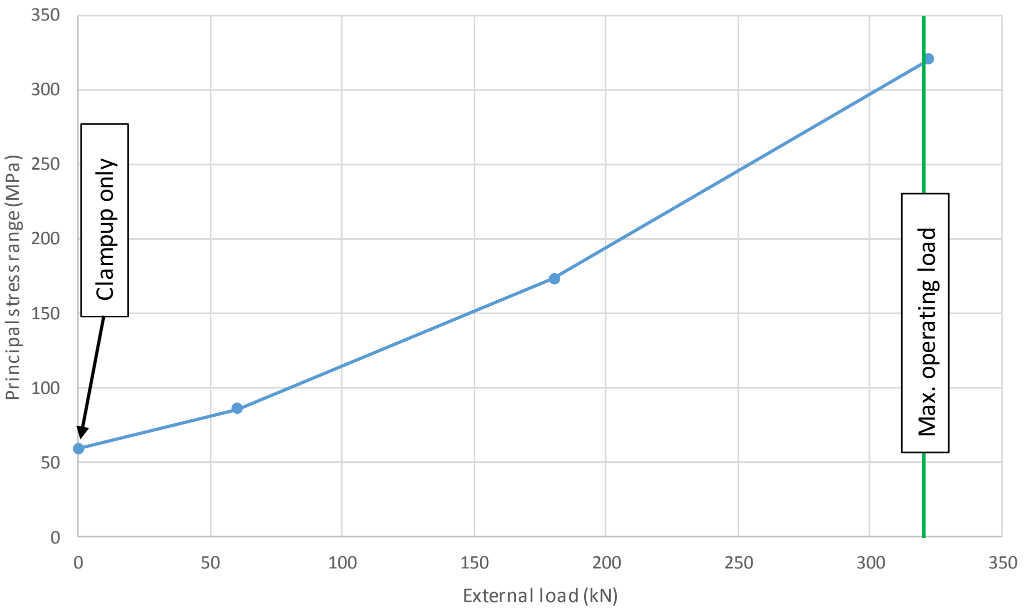


Figure 7-3 Principal stress range vs applied external load

Results of the calculation are shown in Table 7-2.

Table 7-2 Calculated flange fatigue - old and new cranes

			Old crane			New crane		
Crane	Number of MIPEG records	Period covered by MIPEG records (years)	Annual damage rate	Total damage, 35 years	Remaining capacity	Annual damage rate	Implied life (no DFF) (years)	Implied life (DFF=5) (years)
BP	18045	11.3	3.395E-04	1.188E-02	9.881E-01	2.221E-03	445	89
BD	34119	11.0	3.601E-04	1.260E-02	9.874E-01	4.060E-03	243	49

8 CONCLUSIONS

8.1 Strength

- Under operating loads,
    - the calculated axial bolt stress is around 44% of yield for grade 10.9 bolts, the FE analysis gave 76% yield including pretensioning;
    - the calculated axial bolt stress is around 39% of tensile strength for grade 10.9 bolts, the FE analysis showed 68% including pretensioning;
    - the calculated flange bending stress is 35% of the specified flange material yield stress and 32% of the actual yield stress shown in the material mill certificate /14/
- Under accidental loads,
    - the calculated axial bolt stress is around 98% of yield for grade 10.9 bolts, the FE analysis gave 93% yield including pretensioning;
    - the calculated bolt axial stress is around 88% of tensile strength for grade 10.9 bolts, the FE analysis gave 84% including pretensioning;
    - calculating bending of the flange under the failure load of an M36 grade 10.9 bolt indicates a bending stress of 292 MPa, below the specified 315 MPa yield stress of the flange material; in practice some local yielding is likely due to local concentration effects.

8.2 Fatigue

The projected life for the platform is until 2035, i.e. 18 years if crane replacement takes place in 2017.

The fatigue lives of bolts under the anticipated new crane loads appear adequate, well in excess of 18 years. The fatigue lives of the flanges have been calculated as a minimum of 49 years, taking into account a design fatigue factor (DFF) of 5, i.e. approximately 2.7 times the desired life.

9 REFERENCES

/1/ DNV GL report, "Examination of crane adapter bolting and flange", DNV GL document number 10016304\90\04\001TN, Rev. 1, June 2016

/2/ EN 13852-1:2013, Cranes, Offshore Cranes, Part 1: General-purpose offshore cranes

/3/ Ruston-Bucyrus drawing 148557 Rev D, 14-01-1982

/4/ Kenz Cranes document number 0310_002 rev C, Installation number P337/P338, Centrica Storage: Rough 47/3B BD & BP Platform, 31-03-2016

/5/ Kenz email forwarded by CSL 31-03-2016, DNV GL ref. 10016304\89\010i

/6/ Lloyd's Register, "Code for Lifting Appliances in a Marine Environment", July 2016

/7/ Email from B Roebuck, CSL to Nigel Sims, DNV GL: "Bolting information", 15-11-2016, DNV GL ref.10.016304\106\002i

/8/ Email from B Roebuck, CSL to Nigel Sims, DNV GL: "RotaBolts - offshore use", 23-03-2017, DNV GL ref.10.016304\106\053i

/9/ Kenz Cranes document number 0340_001 rev C, Project no. P337N001, Centrica Storage: Structural Material Specification, 09-03-2016

/10/ NS-EN 10025-3 January 2205: Table 5

/11/ Email from B Roebuck, CSL to Wei Zhao, DNV GL: "C15062 - Crane Replacement Project - Minimum Failure Load of Client's Pedestal - Clarification Required", 03-03-2016, DNV GL ref.10.138332\04\920i

/12/ Research Council on Structural Connections (RCSC), Specification for Structural Joints Using High-Strength Bolts, 2009

/13/ Unbrako Engineering Guide – Socket Products, Unbrako Group, Deepak Fasteners Ltd

/14/ Ruston Bucyrus mill certificate for flange: certificate no. 61955, supplied in pdf form of Data Dossier - MK100 Marine Crane - Serial No.39586-L6243 CD - 3 Volumes Part A - Ruston-Bucyrus - Rough 47-3B - Sheet 2 of 2.pdf by CSL, DNV GL ref. 10016304\89\014i.

/15/ DNV GL report, "Rough BP Crane Pedestal Fatigue Analysis" DNV GL document number 10.138332.00\38\08\001R, Rev. 0 May 2016

/16/ DNV GL report, "Rough BD East Crane Pedestal Fatigue Analysis" DNV GL document number 10.016304\82\08\001R, Rev. 0 June 2016

/17/ DNV GL-RP-0005:2014-06, RP-C203 Fatigue Design of Offshore Steel Structures, 2014.