ANALYSIS OF THE REPLACEMENT NEED FOR THE CONTAINMENT ANCHORING BOLTS OF THE LOVIISA NPP ESTIMATED BY THE STRENGTH ASSESSMENT

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1.1 DESCRIPTION OF THE CONTAINMENT

The type of the containment building is a double-containment, the purpose of which is to produce the isolating protection between the processes of the reactor building and the environment. The outer concrete shell of the containment building gives the external protection to the process and to the inner steel shell against the future effects of the environment and the purpose of the inner steel shell is to prevent the emissions from getting directly into the environment in any process situation. The free-standing inner steel shell has been anchored from its bottom on the ring plate on the elevation +9.60 which from the middle part extends downwards as the reactor pit reaching the reactor pit base slab on the bedrock.

These reinforced concrete structures together with the vertical structures, which support the material air lock and the elevation +9.60, form the entity which in this report is called the reinforced concrete part of the containment building. The inner steel shell is a welded steel pressure vessel which consists of the hemispherical dome, of the cylinder-shaped central part and of the bottom slab in plane, whose central part forms the cylinder-shaped reactor pit. For an external overpressure the cylinder part has been equipped with five stiffening rings which have been placed outside the inner steel shell. The route of material traffic and passenger traffic to the protection building goes through the personnel air lock, through the auxiliary personnel air lock and through the material air lock. The containment manholes are airlocks, which means that the opening of two consecutive doors that has been prevented mechanically. The doors of manholes can be opened and closed both by motor-driven mechanisms and manually. The inner diameter of the protection building is 44.400 m. The steel parts of the containment form the welded sheet structure. The thickness of the wall of the cylinder part is 26 mm, in the area between the anchor ring and of the lowest stiffening ring and 20 mm in other areas.

The hemispherical dome wall thickness is 15 mm. The inner steel shell has been stiffened with five stiffening rings. The width of the web sheet of the stiffening ring is 550 mm and the thickness of the web sheet is 20 mm. The width of the inner flange of the stiffening ring is 408 mm and the thickness of the inner flange 30 mm. The width of the outer flange of the stiffening ring is 300 mm and the thickness of the outer flange is 30 mm. The inner steel shell is anchored to the elevation +9.60 by the anchor ring and with the aid of 576. The diameter of the anchor bolts is 44 mm in the first unit of the plant and 50 mm in the second unit of the plant. The anchor bolts are pre-stressed up to 400 MN/m^2 stress value. The anchor ring is 620 mm wide. The thickness of the anchor ring is 60 mm. The anchor ring has been welded to the base ring of the cylinder part of the inner steel shell with a T-weld. The height of the base ring is 520 mm and the thickness of the base ring is 45 mm. The reinforced concrete parts of the protection building are the elevation +9.60, which forms the bottom slab of the protection building and reactor pit, which is located in the middle of the bottom slab of the protection building. The reinforced concrete parts of the protection building have been dimensioned on the basis on strength requirements. The 8 mm thick steel liner plate in the inner surface of reinforced concrete structures ensures the tightness. The thickness of the elevation +9.60 is 1300 mm. The thickness of the outer cylinder wall of the reactor pit is 800 mm. The thickness of the bottom slab of the reactor pit is 750 mm. The bottom slab of the reactor pit rests directly on the bedrock.

The ring-shaped reinforced concrete slab on the elevation +9.60 forms the bottom slab of the containment building. The length of the inner radius of the base slab is 5360 mm and the length of the outer radius of the bottom slab is 23750 mm. The base slab is 1170 mm thick. The I - profile shaped liner plate root supports have been welded to the starter bars that have been left in the body casting. The surface of root supports has been finished with grouting. The liner plate has been welded to the root supports on the elevation +9.60. The elevation +9.60 has been supported from its lower part on the nearly continuous circular cylinder walls the inner radii of which are 5310, 12600, 20400 and 23600 mm. Furthermore, the lower surface of the elevation +9.60 is supported by columns on radii 9550 mm and 16300 mm. The uplift force of the outer edge caused by the internal pressure load of the containment has been supported on the exterior wall of the reactor building. The reinforced concrete structures above the elevation +9.60 have been supported on the glide bearings on the elevation +9.60. There is the opening of the size of 4 x 4 m^2 in the elevation +9.60 for the material air lock and a number of process piping penetrations, which have been localized to five protected groups in the outer edge of the elevation. Outer cylinder of the reactor pit reaches from the elevation -2.25 up to elevation +8.30. The inner radius of the cylinder is 5300 mm and the thickness of the cylinder is 600mm. The cylinder contains 48 pieces of the penetration for the instrumentation pipes. The material air lock is the hexahedral reinforced concrete structure. Its length is 7210 mm and its width is 6360 mm. The floor of the material air lock is at the elevation +3.00 and the roof is at the elevation +8.30.

The wall thicknesses vary from 720 mm up to 820 mm. There are two doors in the material air lock and there is a hatch in the roof of the lock. Both the doors and the hatch on the roof are steel framed structures. The structures of the material air lock are supported on the walls and columns. There are ten process pipe penetration in the dome part of the steel containment building. In the cylinder part of the containment building there are 32 process pipe penetrations and 452 electrical penetrations. The electrical penetrations are located between the anchor ring and the lowest stiffening ring in the cylindrical part of the inner steel shell. There are 164 vertical process pipe penetrations in the bottom slab of the containment building. There are 48 process pipe penetrations in the outer cylinder of the reactor pit. The outer containment building does not belong to the scope of the investigations described in this document. The cross-section of the reactor building of the Loviisa nuclear power plant is depicted in the Figure 1.

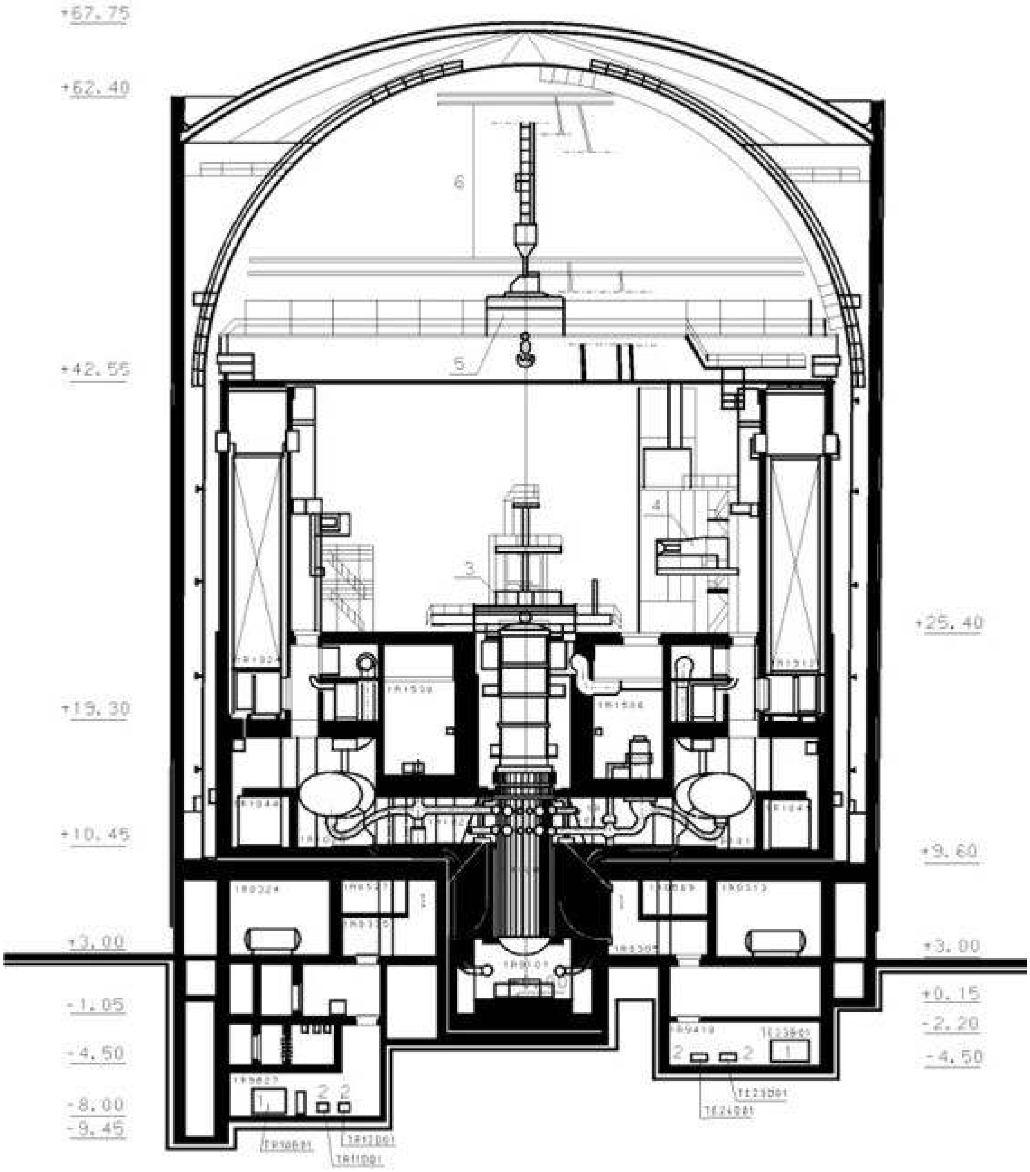

FIG. 1. The cross-section of the Loviisa nuclear power plant.

1.2 Material properties used in the analysis

1.2.1 The steel metal of the steel containment

The Rautarukki Corporation has supplied the pressure vessel steel RAEX 38 P with the properties listed in Table 1.

Table 1 The containment sheet metal properties

RAUTARUUKKI CORPORATION Research department	RAEX 38 The extra strength spec treated pressure vessel stee	Steel book 6:22:02 Steel sheet guide March1971

Theb method of manufacturing

Compacted and special treated LD-steel

COMPOSITION

RAEX 38-P	C %	Si %	Mn %	P %	S %	N %
max.	0.18	0.5	1.6	0.035	0.035	0.007
mean range	0.16 -0.18	0.4 -0.5	1.3 -1.4			

MICROCOMPOSITION IMPURITIES

AL >= 0.02 Nb ~ 0.03%	Cr < 0.05 Ni < 0.05 Mo < 0.05 Cu < 0.10%

EQUIVALENT CARBON CONTENT

Cekv = C + Mn/6 + (Cr +Mo +V)/5 +(Ni +Cu)/ Cekv = 0.41 5-40 mm Cekv =0.45 (40) +60 mm

STRENGTH PROPERTIES

QUALITY CLASSES	Thickness mm	□B kp/mm2	□SU kp/mm2	□SO kp/mm2	□5 %	Charpy tes T °C	KV kpm	Bending test 18 □
RAEX 383 RAEX 384 RAEX 385 P	5-60	□□̃□□	□□	□□	□□	0 -20 -40	2.8 2.8 2.8	2a

ROLLING AND HEAT TREATMENT

The grain structure and strength are ensured by normalizing the sheets after rolling

TESTING

The testing is carried out for every rolled un-treated sheet

THE COMPOSITION CERTIFICATE

.The composition certificate according to DIN 50049 standard

PROPERTIES FOR DESIGN

a) The containers and pressure vessels in the temperatures below 20 ºC □$_{yield}$ = 36 kp/cm^2
b) The containers, pressure vessels and boilers. Max. operation temperature +350 ºC

Temperature(º	20º	50º	75º	100º	150º	200º	250º	300º	350º	400º
□$_{yield}$	36.0	35.5	35.0	34.0	32.0	30.0	28.0	25.5	22.5	(19.5)

1.1.1 Anchor bolt material properties

The steel containment designer Sulzer Brothers Ltd. [1] has specified the anchor bolt material properties in the form given in Table 2.

Table 2 The Sulzer Brothers specification for anchor bolt material properties.

TEMP.	Y.S.	Sm	E	alfa	Cp	lambda
ºC	kp/cm^2	kp/cm^2	kp/cm^2	cm/cmºC	J/kgºC	W/mºC
-40	-	-	-	-	-	-
-20	-	-	-	-	-	-
0	-	-	-	-	-	-
+20	7382	1758	$2.1x10^6$	$1.11x10^{-5}$	488	50.0
+40	-	1758	$2.08x10^6$	$1.12x10^{-5}$	-	49.1
+60	-	1758	$2.06x10^6$	$1.13x10^{-5}$	-	48.2
+80	-	1758	$2.04x10^6$	$1.14x10^{-5}$	-	47.4
+100	-	1758	$2.02x10^6$	$1.15x10^{-5}$	-	46.5
Ref.	3)	2)	4)	5)	1)	2)

Steel class: ASME SA-193 Grade B7, Nominal Composition: 1 Cr - 0.2 Mo, Specified minimum tensile strength = 125 000 psi (8788 kp/cm^2), Specified minimum yield strength= 105000 psi. (7382 kp/cm^2), The notation used in last row of Table 2 is explained as follows:

1) Sulzer Werstoff - Normen Blatt N 007.586
2) ASME Code Section VIII, Div. 1, Table UCS 23, Summer 1969.
3) ASME Code Section III, Table N -422
4) ASME Code Section III, Table N -427
5) ASME Code Section III, Table N -426

1.1.2 The material properties of the reinforced concrete parts of the containment building

The strength of the concrete in the containment building is AK 30 and the strength of rebars in the containment building is A 400 H according to the Finnish concrete code [2].

1.2 The original design loads

The oads used in the original design of the containment have been given in Table 3.

DESIGN CONDITION	
Design Internal Pressure P_D	0.70 kp/cm^2
Design Temperature T_D	70 °C
Design External Pressure Pc	0.035kp/cm^2
TEST CONDITION (Pneumatic Test)	
Test Pressure P_T	0.875 kp/cm^2
Test Temperature T_T	0 ^{o}C
MAXIMUM OPERATING CONDITION	
Max. internal pressure $P_{MA.X}$	0.70 kp/cm^2
Max. wall temperature T_{MAX}	70 ^{o}C

Table 3 Original design loads

2 ANALYSIS MODELS

The containment model including the elevation +9.60 and the reactor pit structures as well as the steel liner on top of these structures is described in the following section Further, the supporting reinforced concrete structures beneath the elevation +9.60 have been taken into consideration in the modeling.

2.1 The anchor bolts embedded in steel ducts in elevation +9.60

The elevation +9.60 - and cylinder wall and base plate of the reactor pit have been modeled with aid of 8 - node solid elements. The penetrations of the elevation +9.60 as well as the penetrations of the reactor pit have been taken into account in the modeling. Figure 2 shows the part of the containment model depicting the elevation +9.60 and the reactor pit structures.

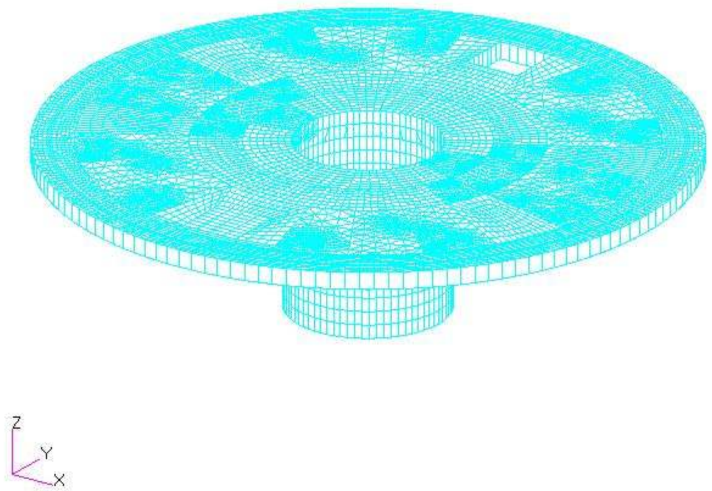

FIG. 2. The part of the containment model depicting the structures of the elevation +9.60 and the reactor pit

2.2 The modeling of the applied anchor bolt pre-stress, pressure and temperature loads

The numerical analyses of the containment model containing 1000 000 degrees of freedom were carried out with the aid of MSC/Nastran [3] and Abaqus/Standard [4] finite element analysis programs.

The load is the incrementally rising pressure load and the incrementally rising temperature. As the applied load is increased, the limit value of the carrying capacity of the containment steel shell will be reached with the value 0.303125 MN/m^2 of internal absolute pressure and with the value 81 deg C of the temperature. The yield limit of the steel shell has been used by a value 200 MN/m^2 which holds true even up to +350 deg C temperature. A value 700 MN/m^2 has been used as the yield limit of anchor bolts.

2.2.1 The Abaqus analyses

2.2.1.1 Properties of the model

The following assumptions were made nn the Abaqus analysis: 1) contact condition between elevation +9.60 and the foot ring of steel containment shell; 2) the bolt pre-stress is 400 MPa; 3) the other applied loads are internal pressure and temperature; 4) bolts are modeled in two ways using beam and truss elements; 5) bolts are modeled as ideal elasto-plastic von Mises material elements, the bolt material yield limit 700MPa; 6) all other elements (steel or concrete) in the model are linearly elastic; 7) the analysis is carried out with large displacement theory. The Abaqus model is depicted in the Figure 3.

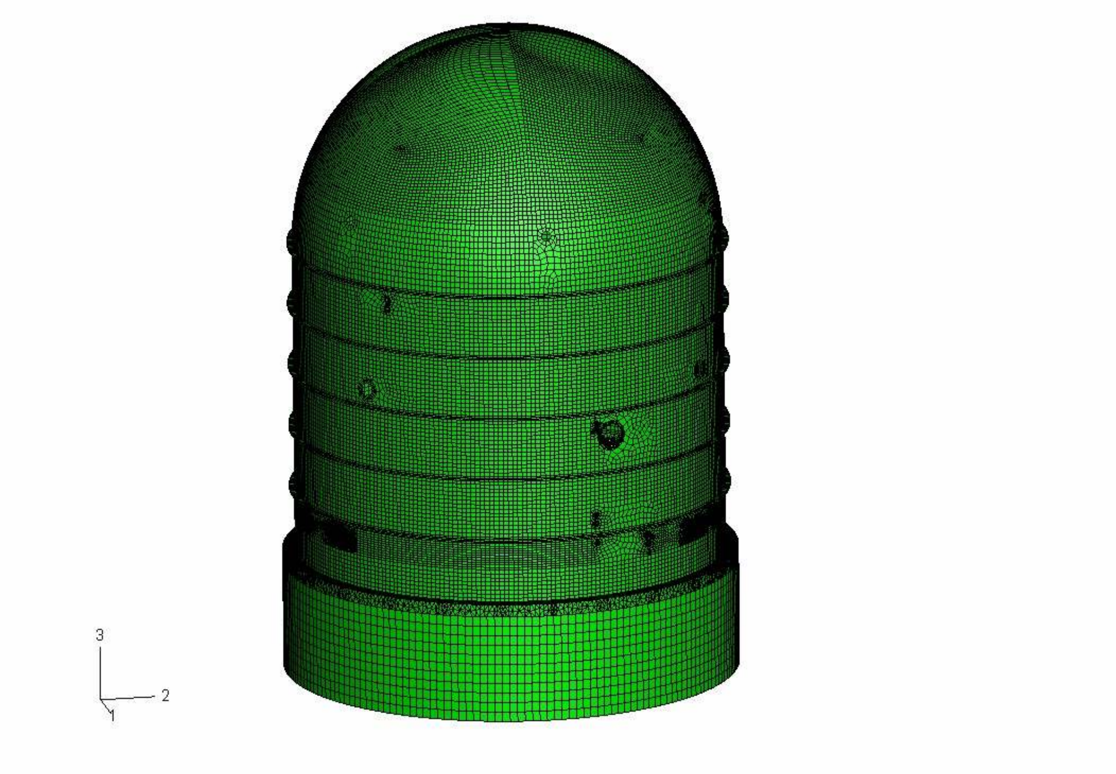

FIG. 3. The finite element model of the containment building

2.2.1.2 Results

The limit capacity of anchor bolts in Abaqus analysis was 0.5 MN/m^2 of internal overpressure, and 185 ºC of internal temperature. In that case the most stressed bolt had been reached the yield stress of 700 MN/m^2 and the tension of the least stressed bolt was 662 MN/m^2. The yellow curve marked by squares depicts the most stressed bolt stress history in the Nastran analysis. The green curve marked by triangles depicts the least stressed bolt stress history in the Nastran analysis. The internal overpressure in the Nastran analysis rises from zero to the value of 0.41875 MN/m^2 and the internal temperature rises from the value of zero to the value of 157 ºC. The material of anchor bolts is elasto-plastic and theyield limit of the material is 700 MN/m^2. The anchor bolts in the Nastran analysis are not bolts are not pre-stressed. In the limit state according to Nastran analysis the most stressed bolt is in yield stress of 700 MN/m^2 and the tension of the least stresses bolt is 411 MN/m^2. The bolt stress histories of Abaqus and Nastran analyses are given in Figure 4.

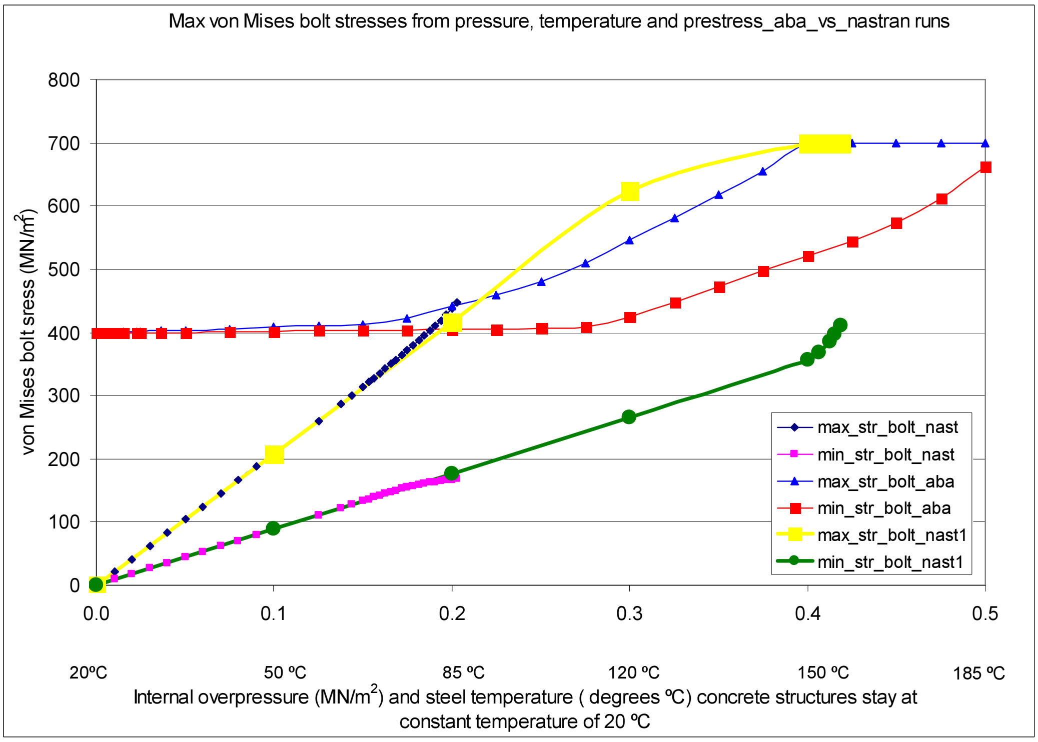

FIG. 4. The anchor bolt stress histories

3 CONCLUSION

One can conclude from the results of section 2 that the limit capacity of the anchor bolts with respect to the containment steel shell can be expressed with the aid of the quotient $0.41785 MN/m^2 / 0.203125 MN/m^2$, which equals to 2, in other words the capacity of bolts with respect to the steel shell of the containment is double.

The anchor bolts do not form the weak link of the containment building. Their capacity is twice as large as the capacity of the containment shell steel sheet.

The corrosion allowances that are used in developing the criteria for anchor bolt replacement are deduced with the aid of the results of the performed analysis.

4 REFERENCES

[1] Sulzer Ltd., Nuclear Components, "Containment Loviisa -1, Basic Size Calculation, Stress Report", Document Number: LO1-CON-301, January 22, 1971.
[2] The design code for reinforced concrete structures, BY4, Betoniyhdistys, Helsinki, 1965.
[3] MSC/Nastran, User's manual, McNeal/Schwendler Corp.,Los Angeles, CA, U.S.A. 2006.
[4] Abaqus Standard, User's Manual, ABAQUS INC., 2006, Providence, Rhode Island, U.S.A.