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STRENGTH EVALUATION OF THE ECCS-GDH PIPING CONNECTION AND DETERMINATION OF THE CRITICAL CRACK UNDER WATERHAMMER EVENT

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ABSTRACT

Strength evaluation of the piping connection between the Emergency Core Cooling System (ECCS) and the Group Distribution Header (GDH) under waterhammer event is presented. This includes the determination of critical crack configuration. Strength calculations of the piping connection were performed according to ASME III Subsection NC using the PIPEPLUS computer code. Strength analysis of the ECCS-GDH piping connection showed that the structural integrity would be maintained under waterhammer event. The determination of critical crack configurations was then analyzed by the R6 method using the SACC 4.0 computer program. For comparison sake semi-elliptical critical size surface crack was calculated by ASME XI Appendix C methodology. The 3-D finite element model of ECCS-GDH piping connection was created using ALGOR finite element computer code to analyze stress distribution through the wall in the piping connection. Calculated stress distribution was used in postulated cracks analysis. The most dangerous crack type, size and location, regarding crack propagation, were determined.

KEYWORDS

Waterhammer, strength, crack, piping connection.

INTRODUCTION

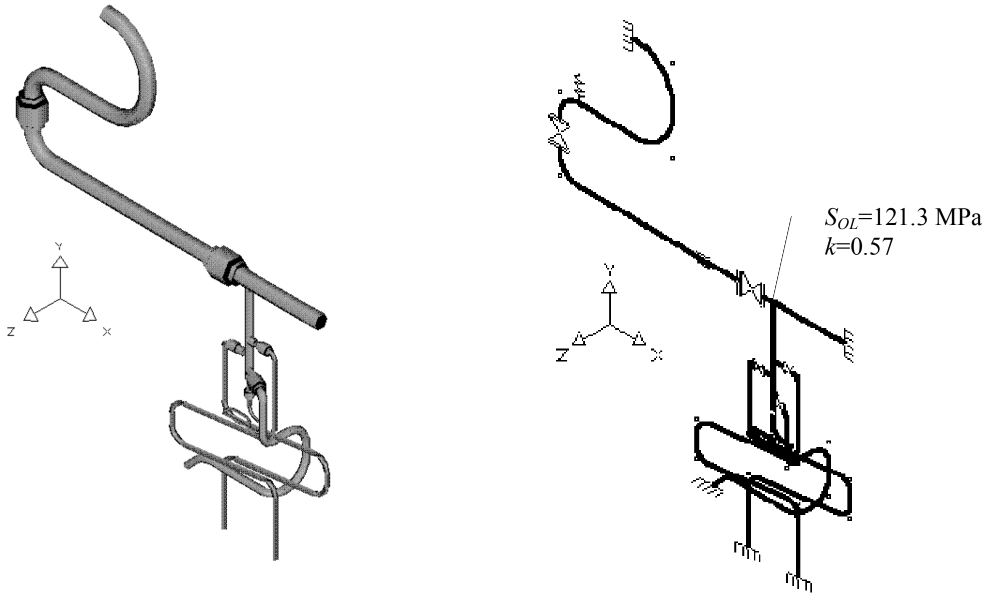
The Ignalina Nuclear Power Plant (NPP) is a twin-unit of RBMK-1500, graphite moderated, boiling water, channeled reactors. The circulation circuit of the RBMK-1500 reactor has a series of check valves in the Group Distribution Headers (GDH) that serve for the coolant distribution to the fuel channels. Following a pipeline or header rupture, protection of the RBMK-1500 reactor core is provided by the emergency core cooling system (ECCS). This supplies water to the core via the GDH. However, to prevent the emergency coolant water leaking through the break, check valves in the GDH have to be closed. In the case of the hypothetical guillotine break of pipelines upstream of GDH, the check valves and adjusted pipeline integrity is a key issue for the reactor safety during rapid closure. A demonstration is needed that the valves and associated pipelines remain intact following such accidents. This includes a structural integrity analysis of the effect of waterhammer, i.e. the pressure pulse generated by the valves slamming closed.

The strength analysis was conducted in the present study using the PIPEPLUS code, the dynamic loads of which were calculated by computer code RELAP5 in thermal-hydraulic analysis. Also, the postulated crack size analysis for determination of the critical crack was conducted by R6 method using the SACC 4.0 computer program. For comparison sake, semi-elliptical critical size surface crack was calculated using ASME XI Appendix C methodology. For crack analysis by R6 method stress distribution in the wall was calculated using 3-D finite element ECCS-GDH pipe connection model constructed by the ALGOR computer program.

STRENGTH ANALYSIS OF THE ECCS-GDH PIPING CONNECTION

In the case of guillotine rupture of pressure header or guillotine break upstream of GDH, the pressure in the GDH from the side of main circulation pump (MCP) pressure header drops rapidly down to atmospheric pressure, while the pressure in the circulation circuit decreases slowly following the reactor power decrease. A GDH check valve is closed practically instantaneously after initial rupture because of backflow. The closure of GDH check valves prevents the loss of flow from the main circulation circuit (MCC). Rapid closure of these valves leads to coolant flow and pressure pulses.

The strength analysis of the ECCS-GDH piping under waterhammer event was performed using the PIPEPLUS code. Constructed finite element (FE) model of GDH connection with ECCS pipelines is shown in Figure 1.



a b

Figure 1: Finite element model ECCS-GDH piping: a – 3-D view, b - model with boundary elements

It was assumed in the calculations that the initial coolant temperature in the GDH-ECCS connecting pipelines is equal to 285 °C while the pressure is equal to 10.12 MPa. Dynamic forces generated by the coolant pressure pulses in the case of waterhammer were calculated using the RELAP5 code. The calculated dynamic force versus time is presented in Figure 2.

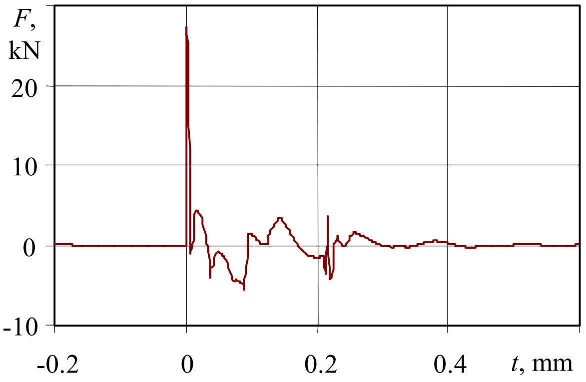


Figure 2: Force history in ECCS-GDH piping during waterhammer event

PIPEPLUS performs time history analysis using the modal superposition method. In order to investigate the correct value of the cutoff frequency, the following equation of motion was used for a single-degree-of-freedom system [1]:

$$\ddot{u} + 2\omega\zeta\dot{u} + \omega^2 u = F(t)\,. \tag{1}$$

Terms of equation (1) are the following: u is displacement, $\dot{u}$ is velocity of displacement, $\ddot{u}$ is acceleration of displacement, ζ is damping ratio, ω is natural frequency, $F(t)$ is external force function. The cutoff frequency of 400 Hz was used for dynamic analysis.

The SAR report [2] indicates that the equipment and piping of the Ignalina NPP primary circuit are classified as a system of the second safety class except the fuel channels and the drum separators, which are referred to the first safety class. Therefore, ASME III Subsection NC [3] (class 2 components) criteria were used for strength evaluation of ECCS-GDH piping connection under waterhammer event.

According to ASME III Subsection NC [3] the effects of pressure, weight, other sustained loads, and occasional loads, including non-reversing dynamic loads, for which Level B service limits are designated, must meet the requirement of equations (2)

$$S_{OL} = B_1\frac{P_{\max}D_o}{2t} + B_2\left(\frac{M_A + M_B}{Z}\right) \le 1.8S_h \quad \text{and} \quad S_{OL} < 1.5\sigma_y \tag{2}$$

Terms of equations (2) are the following: S_{OL} is stress due to effects of pressure, weight, other sustained loads, and occasional loads, including non-reversing dynamic loads; B_1, B_2 are primary stress indices for the specific product under investigation; P_{max} is peak pressure, D_o is outside pipe diameter; t is nominal wall thickness; M_A is resultant moment loading on cross section due to weight and other sustained loads; M_B is resultant moment loading on cross section due to non-reversing dynamic loads; Z is section modulus; S_h is allowable stress of material at temperature consistent with the loading under consideration; σ_y is yield strength of material at temperature consistent with the loading under consideration.

The pipelines upstream of GDH and ECCS are produced from austenitic steel 08Ch18N10T, the allowable stress of which is S_h=118 MPa at temperature T=285 °C.

Strength evaluation results of ECCS-GDH piping connection under waterhammer event according to ASME III Subsection NC criteria are presented in TABLE 1 and Figure 1. Static forces and moments acting on the ECCS-GDH piping connection are part of the strength analysis obtained the PIPEPLUS code. These loads are used in 3-D ECCS-GDH piping connection model constructed for the analysis of stress distribution through the thickness, the results of which are used in the crack analysis.

TABLE 1

STRENGTH EVALUATION RESULTS OF ECCS-GDH PIPING CONNECTION UNDER WATERHAMMER EVENT

S_{OL}, MPa	$1.8S_h$, MPa	$k=S_{OL}/(1.8S_h)$
121.3	212.4	0.57

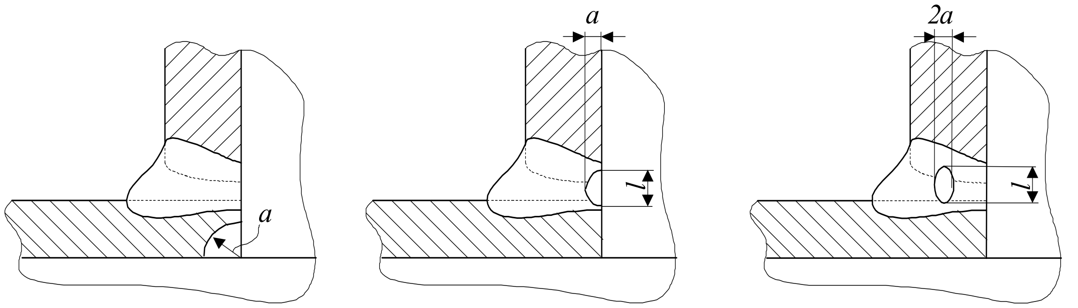
The results of strength calculations (TABLE 1) show, that ECCS-GDH piping connection meets ASME III Subsection NC strength criteria under waterhammer event.

CRITICAL CRACK SIZE CALCULATIONS

The purpose of postulated crack analysis was to determine the most dangerous crack type, size and location for ECCS-GDH piping connection under waterhammer event. Cracks of three types were postulated:

1) Crack in the corner (Figure 3 a),
2) Finite axial semi-elliptical internal surface crack in the weld (Figure 3 b),
3) Axial embedded crack in the weld (Figure 3 c).

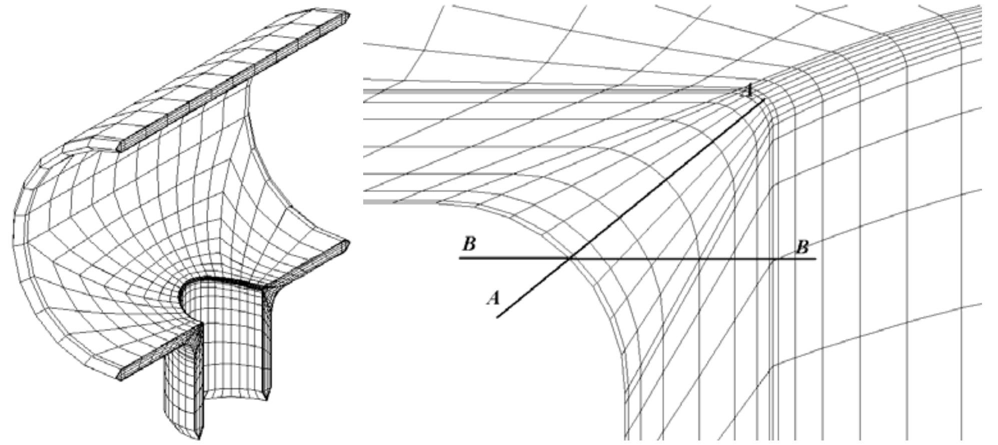
Circumferential cracks were not analyzed because stresses in axial direction are lower than in circumferential and, therefore, critical axial crack size will be less than critical circumferential crack size.



a b c

Figure 3: Postulated cracks: a - corner crack; b - finite axial semi-elliptical internal surface crack in the weld; c - axial embedded crack in the weld

The critical sizes of postulated cracks were calculated by R6 method [4] using computer program SACC 4.0 [5]. In the SACC program it is assumed that a stress is obtained under the linear elastic behavior of material. Detailed stress analysis of ECCS-GDH piping connection was performed in order to have through-wall stress distribution for critical crack size calculations. The 3-D finite element model of ECCS-GDH piping connection using 8-node isoparametric brick elements was constructed using computer code ALGOR (Figure 4 a). The forces and moments acting in ECCS-GDH piping connection under waterhammer event calculated in stress analysis by PIPEPLUS code were included in the model.



a b

Figure 4: ECCS-GDH piping connection: a - 3-D FE model, b - location of sections A-A and B-B

Stress distribution in section A-A (Figure 4 b) is used for the analysis of postulated crack in the corner (Figure 3 a). Stress distribution in section B-B (Figure 4 b) is used for the analysis of postulated finite axial semi-elliptical internal surface crack in the weld (Figure 3 b) and axial embedded crack in the weld (Figure 3 c). For the calculation of critical crack size through-section stresses are resolved to membrane stresses and bending stresses. Membrane stress is considered as primary stress and bending stress is considered as secondary stress.

The calculated critical crack in the corner (Figure 3 a) size is a_{cr}=13.2 mm. For the calculation of critical crack size of the finite axial semi-elliptical internal surface crack in the weld (Figure 3 b) and axial embedded crack in the weld (Figure 3 c) different ratios of crack length l and depth a are assumed. Calculation results of finite axial semi-elliptical internal surface crack in the weld (Figure 3 b) and axial embedded crack in the weld (Figure 3 c) as critical crack depth versus length are presented in Figure 5. Embedded crack analysis in program SACC is limited by crack depth and wall thickness ratio $2a/t \leq 0.9$ and crack depth and length ratio $l/2a \geq 1$. Semi-elliptical internal surface crack analysis is limited by crack depth and wall thickness ratio $a/t \leq 0.8$ and crack depth and length ratio $2 \leq l/a \leq 10$. Thus in Figure 5 maximum depth of embedded crack with ratio $l/2a<1$ conservatively is assumed the same as the embedded crack with ratio $l/2a=1$. Maximum depth of semi-elliptical crack with ratio $l/a<2$ conservatively is assumed the same as semi-elliptical crack with ratio $l/a=2$.

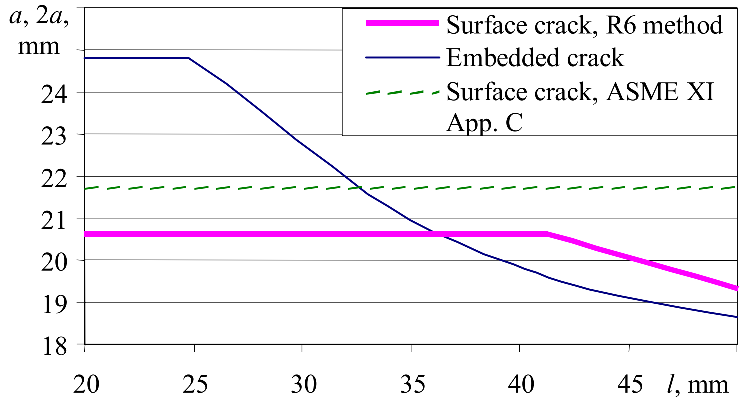


Figure 5: Critical crack depth versus crack length

For comparison sake semi-elliptical internal surface crack in the weld (Figure 3 b) critical crack size was calculated according to ASME XI Appendix C methodology [6]. Different ratios of crack length l and depth a were assumed. For all l/a ratios under consideration calculations reaches crack size limitations, i.e. crack depth reach 75% of wall thickness (dotted line in Figure 5).

The results of crack analysis shows, that even if the length of axial embedded crack in the weld and finite axial semi-elliptical internal surface crack in the weld are exceeding weld limits, critical crack depth is much larger than critical depth of crack in the corner. A crack in the corner of ECCS-GDH piping connection is the most dangerous crack for this construction.

CONCLUSIONS

The strength analysis of Ignalina NPP ECCS-GDH piping connection showed that calculated stresses do not exceed allowable stresses according to ASME III Subsection NC, i.e. structural integrity of ECCS-GDH piping connection will not be lost under waterhammer event. Crack analysis showed that the most dangerous is corner crack critical depth of which calculated according to the method R6 is a_{cr}=13.2 mm.

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REFERENCES

1. Gupta, A.K. (1993). *Response Spectrum Method in Seismic Analysis and Design of Structures*. CRC Press, Tokyo.
2. (1996). *Ignalina Nuclear Power Plant Safety Analysis Report, Volume 1, Task Group 1, Section 5, Subsection 1, Primary Circuit.* Ignalina NPP, Visaginas.
3. (1995). *Rules for Construction of Nuclear Power Plant Components: ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NC, Class 2 Components*. The American Society of Mechanical Engineers, New York.
4. *Assessment of the Integrity of Structures Containing Defects* (1996). Nuclear Electric Ltd., Gloucester.
5. Andersson, P., Bergman, M., Brickstad, B., Dahlberg, L., Nilsson, F. and Sattary-Far, I. (1996). *A Procedure for Safety Assessment of Components with Cracks - Handbook*. SAQ Kontroll AB, Stockholm.
6. *Evaluation of Flaws in Austenitic Piping: ASME Boiler and Pressure Vessel Code, Section XI, Appendix C* (1995). The American Society of Mechanical Engineers, New York pp. 381-394.