S. M. BAN’KO, S. V. KOBEL’SKII, I. SAMARDŽIĆ

ISSN 0543-5846
METABK 53(4) 634-636 (2014)
UDC – UDK 621.721.052:539.4.014=111

THE STRESS–STRAIN STATE OF THE CRACKED WELDED JOINT BETWEEN THE HEADER AND THE SHELL OF PGV-1000M STEAM GENERATOR

Received – Prispjelo: 2013-12-25
Accepted – Prihvaćeno: 2014-05-20
Preliminary Note – Prethodno priopćenje

The three-dimensional elastoplastic stress–strain state of the cracked welded joint between the “hot” header and the shell of PGV-1000M steam generator is numerically analyzed. The crack is located on the inside surface of the connector pipe, near the fillet. The effect of the loading history on the crack-tip stress-intensity factor is assessed.

Keywords: welded joint, stress–strain state, crack, steam generator, mixed finite-element scheme

INTRODUCTION

Ensuring the safe operation of nuclear power plants and their essential components, such as steam generators (SG), is an important theoretical and practical task.

Inspections of PGV-1000 steam generators currently operating at Ukrainian and Russian NPP revealed cracks near the fillet of the welded joint between the header and the SG shell. Therefore, there is a pressing need for refined models of steam generator to analyze the stress state of a welded joint with a crack.

The numerical strength analysis of the welded joint carried out in [1–5] by Ukrainian and Russian experts involved the determination of the elastic stress–strain state (SSS). The three-dimensional SSS of the welded joint was for the first time analyzed at the G. S. Pisarenko Institute for Problems of Strength when simulating the operational loads on SG [2]. The later papers [6–8] by scientists of the institute report on a numerical analysis of the elastoplastic SSS of the welded joint induced by the post-maintenance thermal treatment intended to relieve the undesirable residual stresses. The influence of the geometry of a cavity near the fillet of the welded joint on its stress–strain state was studied in [9, 10].

It should be noted that recent studies addressed the problem of reducing the stresses around the fillet of the welded joint without cracks. The present paper reports on the results of a numerical strength analysis of a welded joint with a crack near the fillet performed when simulating the operating load conditions with allowance for elastoplastic behavior of the material near the crack.

S. M. Ban’ko, S. V. Kobelsky, G. S. Pisarenko Institute for Problems of Strength of the National Academy of Sciences of Ukraine, Kiev, Ukraine; I. Samardžić,Faculty of Mechanical Engineering in Slavonski Brod, Croatia

MAIN TEXT

The three-dimensional elastoplastic SSS of the welded joint with a crack can be analyzed using the mixed finite-element scheme [11], which provides the numerical stability and high accuracy of the solutions for displacements, stresses, and strains. This scheme is implemented in the Space-Relax software [12], which is certified for use in the safety assessment of nuclear power plants.

The formulated problem was solved in two stages. At the first stage, the elastoplastic problem was solved using the design model without crack. The model consisting of SG shell, “hot” header, main circulation line (MCL), and reactor vessel is shown in Figure 1.

The second stage involved the solution of the problem for a fragment (Figure 2) of the welded joint with a surface semi-elliptical crack in the zone of maximum

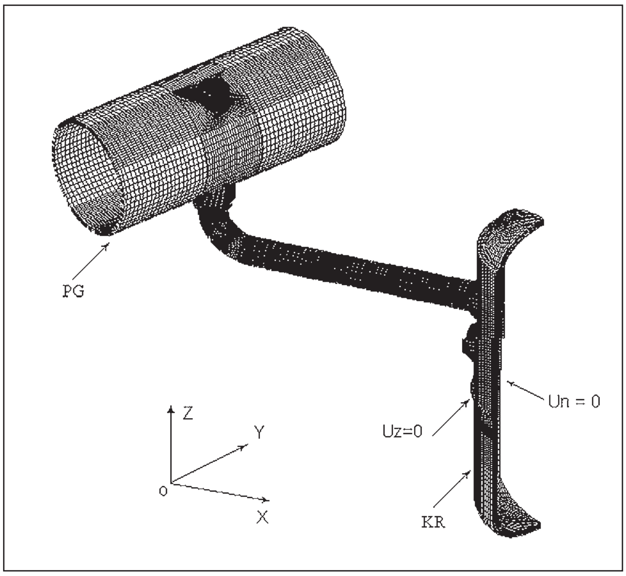

Figure 1 Reactor model

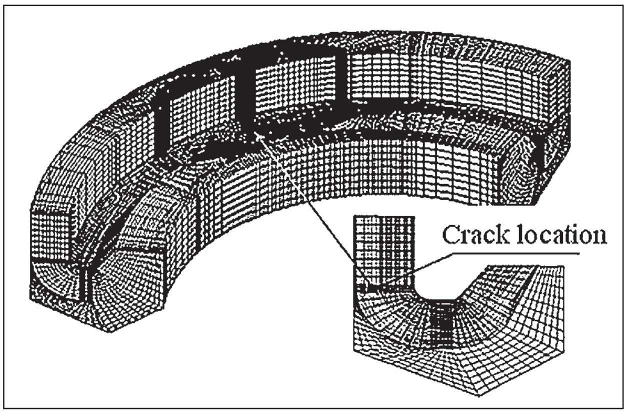

Figure 2 Finite-element model of a fragment of welded joint with a crack

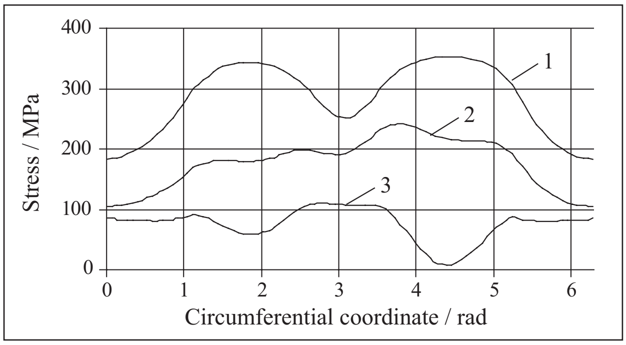

Figure 4 Distribution of the axial stress σ_z over the pocket wall: 1 – HT, 2 – unloading after HT, 3 – NO

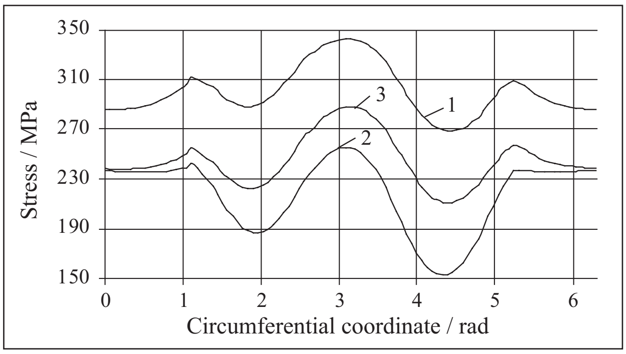

Figure 5 Distribution of hoop stress σ_φ over the pocket wall: 1 – HT, 2 – unloading after HT, 3 – NO

stresses determined at the first stage. The displacements determined at the first stage were used as the boundary conditions at the second stage.

The solution was obtained considering the loading history for the following loading sequence: hydraulic testing (HT) for the primary and secondary circuits → unloading after HT → normal operation (NO). The primary and secondary pressures were assumed to be 24,5 and 10,78 MPa, respectively, during the testing, and 16,0 and 6,0 MPa during normal operation.

The most stressed zone is the thinnest portion of the welded joint (Figure 3). It takes up the load exerted by the MCL on the SG, the weight of the header and coolant, and the pressures in the primary and secondary circuits.

Figures 4 and 5 show the variation in the axial (σ_z) and hoop (σ_φ) stresses (calculated at the first stage of solution) on the wall of the “pocket” along the circumference at a distance of 20 mm from the bottom of the pocket.

The Figures demonstrate the essentially nonuniform circumferential distribution of the stresses. The stress σ_z peaks (354 MPa) during HT, decreases to 110 MPa during the unloading after HT, and increases to 241 MPa during NO. The peak values of σ_φ observed during HT, unloading, and NO are 342, 256, and 288 MPa, respectively.

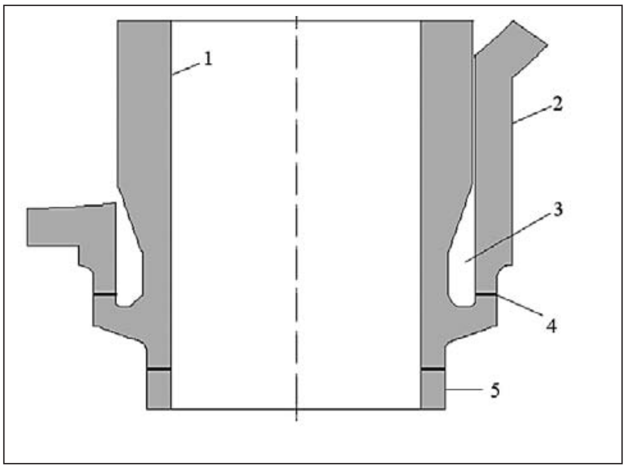

Figure 3 Schematic of the welded joint between SG shell and header: 1 – header; 2 – connector pipe; 3 – “pocket”; 4 – weld; 5 – MCL

The strength analysis of the welded joint was performed for its fragment with a semi-elliptic crack with different values of depth *a* and aspect ratio *a/c*: *a* = 18 mm, *a/c* = 2/3; *a* = 36 mm, *a/c* = 1/4; *a* = 50 mm, *a/c* = 1/4. Figure 6 shows the distribution of stress-intensity factors (SIF) along the fronts of postulated cracks in the case of HT. Graphs are built in relative coordinates: along the X-axis is deferred ratio of length of front of each crack to a maximum length of the crack front, along the Y-axis is deferred ratio SIF for each crack to a maximum of SIF (K1/K1max).

Comparing the calculated results for different cracks reveals that the SIF is maximum for a 50 mm crack.

The effect of the loading history on the distribution of SIF along the crack front was studied for the follow-

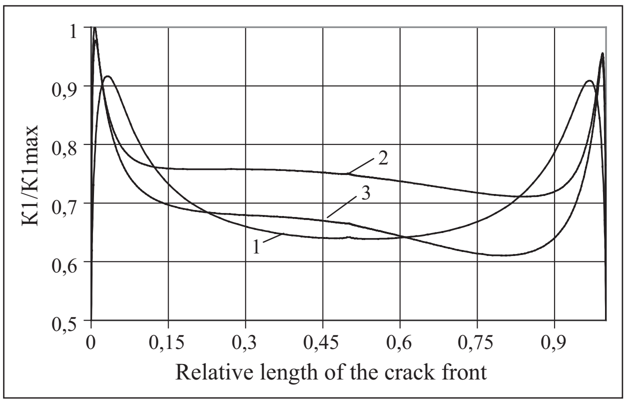

Figure 6 SIF distribution during HT: 1 – *a* = 18 mm, 2 – *a* = 36 mm, 3 – *a* = 50 mm

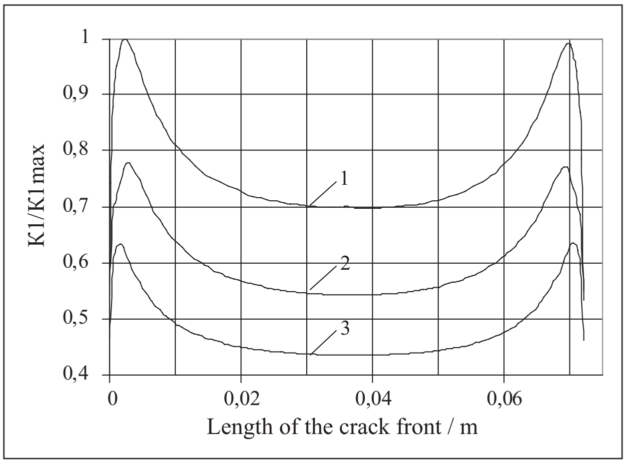

Figure 7 SIP distribution for an 18-mm crack: 1 — HT, 2 – HT → unloading → NO, 3 — NO

ing loading sequence: HT for the primary and secondary circuits → unloading after HT → NO. Figure 7 shows the calculated SIF for an 18 mm crack. It can be seen that these SIF values are higher by 23 % than the values disregarding the loading history.

CONCLUSIONS

The stress state of the welded joint connecting the "hot" header and the shell of PGV-1000M steam generator and having a crack near the fillet has been numerically analyzed with and without regard to the loading history.

It has been shown that disregarding the loading history underestimates the crack-tip SIF.

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Note: The responsible translator for English language is L.M. Konstyantynova, Pisarenko Institute for Problems of Strength of the National Academy of Sciences of Ukraine, Kiev, Ukraine