Finite Element Stress Analysis of Welded Seal Closures

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SUMMARY

This paper presents a theoretical study of two bolted joints using welded seal membranes instead of gaskets. The two closures manways here analyzed are from a Steam Generator (SG) and a Pressurizer (PR) (see Fig.1) of a compact PWR nuclear reactor current under design. The analyses done, by the FEM, show the points of high stress concentrations as well as the preload applied on the closure bolt sets necessary to prevent leakage. The analyses show the stress levels on the weld, which is not common in literature. A provisional and hypothetical minimum criterion to prevent leakage is here assumed. Some modifications on the flange geometry of the closures are introduced to reduce the high stress levels acting on the weld string of the seal weld. The preload values obtained are compared to those minimum values preconceived by standards (ASME, 1986).

INTRODUCTION

Nuclear bolted joints claim today for more attention in the Nuclear Power Plant (NPP) industry. Welded seal membrane may be an option to face the problem of leaks, although some maintenance problems are met due to the frequency of the inspections the equipment must be submited along a NPP lifetime. At each inspection the weld has to be destroyed and redone. Bolted joints are complex structural elements and many factors could be pointed out to influence directly its performance. The principal factors are easily found in the literature (Bickford,1985). According to Bickford, loose bolts and joint leaks answered for more than 35% of the total failure of bolted joints reported between January 1980 and March 1984. The lack of proper preload on the bolts and a provisional criterion to prevent the leaks are the main objects focused on this work. In the analyses attention was given to the stresses acting on the seal membrane, on the bolts and on the weld string of the seal membrane. The compliance with ASME Code, subsection NB, limits are also performed.

FINITE ELEMENT MODEL

The analyses overtaken used two axissymetric finite element models (DeSalvo,1985) one for the SG and the other for the PR. The flanges and the manway openings (nozzles) are meshed with solid axissymmetric elements, an equivalent beam element with equivalent properties represents the set of bolts. Interface (gap) elements to simulate the contact between flange-membrane and membrane-nozzle are also considered. Fig.2 shows the finite element models of the SG and PR closure analyses. The set of bolts discretized as an equivalent axissymmetric beam has the following equivalent cross sectional properties:

$$A = nAb/2\pi \quad (mm2/rad) \quad \text{and}$$
$$I = nIb/2\pi \quad (mm4/rad)$$

where: n = Number of Bolts
Ab(Ib) = Area (Inertia) of one bolt only

The connection of the bolt threads into the equipment nozzle wall and the action of the bolt heads onto the flanges are modeled by rigid links, so that the bolt bending stress can be well obtained. The loads are applied in a real sequence, first the preload and then the internal pressure. The preload is applied by an initial deformation which action is initialy balanced by a couple of equivalent forces acting on the ends of the bolt equivalent beam element. This is due to the non-linearities of the inteface (gap) elements. This balanced force is step by step released so that the actual calculated preload can act. The ASME code (App. E & F,1986) states the minimun bolt cross-sectional area and preconceives also a minimum value of the preload for gasket joints. For welded seal joints the minimum preload value may be taken equal to the total hydrostatic end force, since the parameters m and y (ASME-NB) may be zero.

STRESS LIMITS AND LEAKAGE CRITERIA

The stresses of interest are those at the interface surface in contact with the area next to the weld, the stress in the weld string of the membrane seal and its soroundings and the stresses on the bolts. The ASME code states the following stress limits for the normal operating loads.

a) Primary plus Secondary Stress (Seal & Weld):

$$PL + Pb + Q \leq 3Sm$$

where: PL is the local primary membrane stress
Pb is the primary bending stress
Q is the secondary stress
Sm is the allowable stress limits

b) Bearing Stress:

$$\bar{\sigma} \leq Sy$$

where: $\bar{\sigma}$ is the mean value
Sy is the yielding material stress

c) Bolt Stress

The ASME Code limits is 2Sm for the average stress and 3Sm for the total stress.

d) Provisional Leakage Criteria

A provisional and hypothetical criterion was stablished in order to assure a base of minimun confidence that leaks, due to the welding rupture, would not occur. A base for this criterion is the preservation, in any load condition (preload and preload + internal pressure), of a minimum contact length between seal membrane and external nozzle wall immediately before the weld string. In this manner, bending deflexion will not charge the weld string, which is known to be a delicated region. 4mm was chosen, this length is equal to the seal membrane thickness, and it is supposed to be a sufficient length to avoid high bending stress in the seal weld. Any other reasonable method could be used, it is important to protect the weld against excessive stress states.

RESULTS

The main numerical results taken from the FEM analyses, considering the geometry showed in Fig. 1, are summaryzed in table I. In that table Fp is the preload force on the bolts obtained from the model; Fa is the preload force preconceived by ASME standards; S is the stress intensity calculated from the FE model and Sad is the allowable stress calculated as indicated in the last paragraph.

Table-I: Results obtained with the original flange design

	Steam Generator	Pressurizer
Preload forces (Fp/Fa)	1.00	1.38
Max S/Sad (weld) - preload	1.20	1.20
Max S/Sad (weld) - preload + pressure	1.17	0.68*

* the provisional leakage criterion was not reached.

Due to space limitation only the results of the SG analysis are shown. The PR analysis results are qualitatively similars.

Figures 3 and 4 depict the isostress lines and show off also the stress concentration points in the regions next to the weld string during the preload and after the total pressurization of the equipments. The high stress points detected on the weld string are above the limits prescribed before, suggesting that the initial design of the manway closures have to be modified. The high stresses are concentrated in a limited area and may be classified as secondary stresses, which yielding of the material in that area would produce a better stress redistribution. However the high stress levels obtained are not desired. Regions with elevate stress values are natural candidates to potential failures and might be avoided anyhow, mainly when the equipment is part of the the cooling system of a NPP, which loss of coolant must be avoided by any possible means. Another reason is that the weld region may have imperfections not always detected by the quality control and the weld material ductile properties may present some modification due to the high temperature employed during the welding process.

Analyzing the physics of the problem it was easy to note that the high stress levels on the welds were just because the flanges are directly supported onto the weld string heads. The welds work as the center of rotation for the flanges. The rotation of the flanges appear because of the bending deformations produced by the preload and by the pressurization. During the preload, the seal membrane does not deform at all, however when the equipment is pressurized the seal touches the flange following its angular deformation next to the weld string. In order to control this problem, geometrical modification was introduced in each flange and the rotating point moved to a region away from the weld head. The modified flange geometries are shown in Fig. 5 for the PR and in Fig. 6 for the SG. The alpha angle option (fig.5), specially calculated to close during pressurization, seams impracticable, while the groove used in the SG flange (fig.6) can well be done. Table II and figs. 7, 8 (for SG) shows the results obtained for the new geometry configuration of the flanges. It shows the relief in the maximum stresses values found on the seal welds and confirms the efficiency of the modifications introduced to diminish the stress levels on that region. In this case all the stresses complyed with the ASME limits.

Table-II: Results with the modification

	Steam Generator	Pressurizer
Preload forces (Fp/Fa)	1.00	1.30
Max S/Sad (seal) - preload	0.63	0.57
Max S/Sad (seal) - preload + pressure	0.72	0.58

CONCLUSIONS

The analyses of the bolted joints of the manway nozzles of the PR and SG, revealed that little modifications can lead the design to a much better stress state. In those cases the modifications allowed a great relief on the stress states of the seal welds both during the preload of the bolts and additionally during the pressurization of the equipments. The importance of this paper is that it analyzes the stress states on the weld, a task not frequently done because engineers consider welding a complicated and uncertain region. With respect to the use of seal membranes on NPP equipments the principal problem is that welding have to be destroyed and redone at each equipment inspection. A special material layer (inconel) could be used to receive those weld application. Additionally, if the welding have to be performed manually the quality of the welding could be penalized due to the limited time the welder would have, because of the radioactive wastes. Automation could be used. Finally this work also shows that the preload suggested by the standards is not - sometimes- appropriate to prevent high stress levels on the welds.

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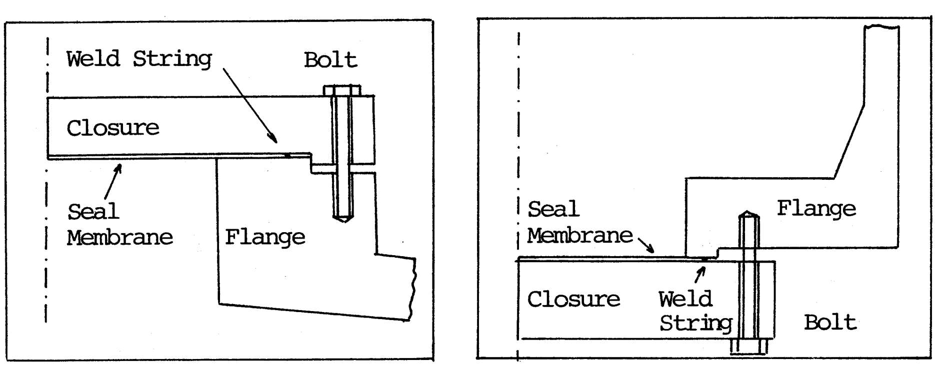

a) Pressurizer b) Steam Generator

Figs. 1

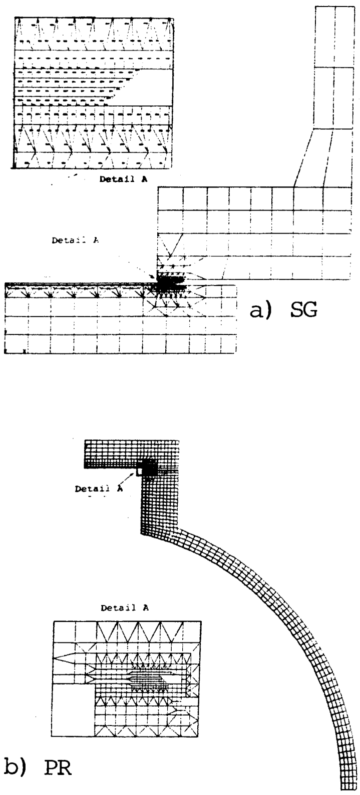

Fig. 2 FE Models

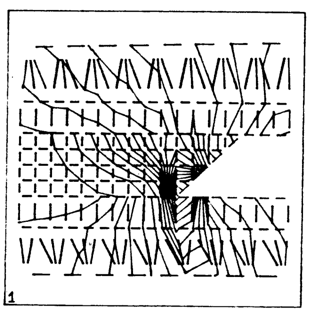

Fig. 3 Stress-preload phase

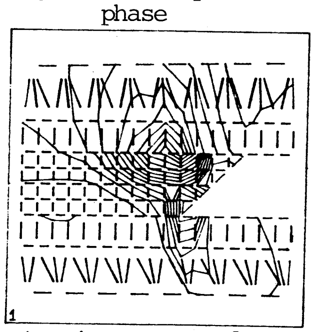

Fig. 4 Stress-preload + pressurization

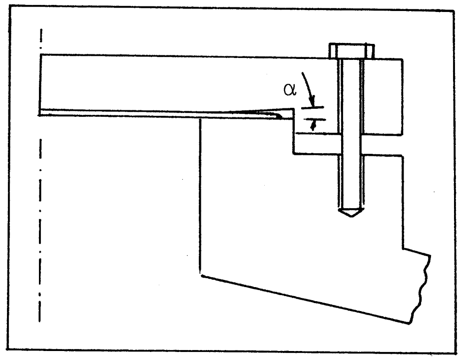

Fig. 5 Proposed geometrical modification - PR

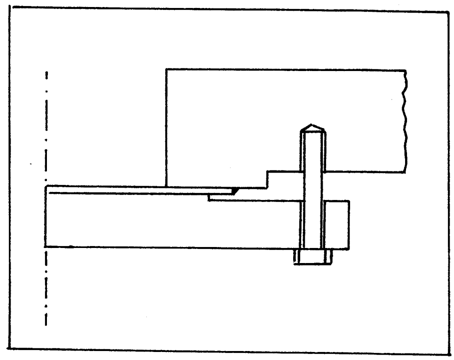

Fig. 6 Proposed geometrical modification - SG

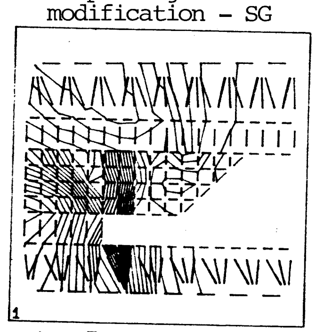

Fig. 7 Stress-preload phase

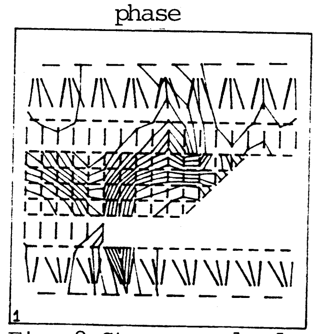

Fig. 8 Stress-preload + pressurization