Stress Analysis of Sleeve Repaired Elbow-Elbow Weld Joint

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ABSTRACT

Three dimensional finite element analysis of sleeve repair at weld location between a 90° elbow in vertical plane and a 60° elbow in horizontal plane is performed. Two cases of a sound weld and a complete circumferentially cracked weld are studied. If geometry near weld region is simulated as axisymmetric and finite element analysis done general stress pattern obtained is similar to that from 3-D analysis. Stress concentration factors for repaired geometry are estimated from axisymmetric analysis. Transient analysis for thermal shock condition is performed for axisymmetric geometry and compared with the behaviour of elbow joint before repair.

1.0 INTRODUCTION

Cracks in heat affected zone(HAZ) of weld joints due to intergrannular stress corrosion cracking have been observed in BWR pipings all over the world. One of possible methods to create a new local pressure boundary is to weld a sleeve around the cracked part. Since it forms a part of primary pressure boundary, a detailed stress analysis of the repaired region is called for. In the present paper a specific case of such type of sleeve repair done around a weld joint between two elbows has been analysed. The elbows are 200mm NB (8" sch 80) and lie in two different geometrical planes. One of them is a 90° elbow in vertical plane while other one is 60° elbow in horizontal plane. Sleeve is a two piece split cylindrical pipe of 250mm NB (10"sch 80) size and welded around cracked weld. Sleeve length is 100mm and is sufficient to avoid interference between HAZs of new welds with HAZ of original weld. The ends of sleeve are contoured for fitup with elbows. The joint in piping system is subjected to internal pressure and forces due to constrained movement as well as thermal transients. A small hole is drilled for equalising the pressure between elbows and sleeve.

Flexibility and stress concentration factors for this geometry are not available in literature. Present paper gives results of a three dimensional finite element analysis performed on repair region. Analysis has been carried out for two cases, namely, (i) with a sound, and (ii) complete circumferentially cracked weld conditions. The geometry has first been analyzed for internal pressure. The lines of equivalent von-Mises stress on meridional plane along the elbow runs are presented. Since three dimensional analysis requires enormous amount of computational efforts, the geometry around repair region is approximated as axisymmetric. Finite element analysis of this approximated geometry was performed for internal pressure. Variation of stress intensity is presented. Stress concentration factors based on axisymmetric geometry are also given

Behaviour of simulated axisymmetric geometry under transient thermal shock condition is analysed and compared with that of geometry before repair.

2.0 FINITE ELEMENT ANALYSIS

2.1 Stress analysis

Fig.1 gives the FE discretization of the elbows and sleeve. A total 480 numbers of 8-noded brick elements are used. Circumference is divided into 16 elements. Total numbers of d.o.f. are 2448 and 2528 respectively for the cases when sound and completely severed weld conditions are assumed. In the second case two adjacent faces of the elbows are free to have differential movement with respect to each other. The effect of pipe connected at far end of 90° elbow is simulated by restricting circumferential displacement on circular plane. Points at circumference of far end of 60° elbow are restrained for movements. The element nodal connection is generated by routine 'GENDAT' /1/ and analysis performed using code 'SOLID' /2/. A pressure of 86.2 MPa is applied at inside surfaces of elements and on element surfaces surrounding annulus. A uniform longitudinal pressure (=pd/4t) is applied at far end face of 90° elbow.

Fig.2 shows the finite element modelling for simulated axisymmetric geometry near the repair region. Only one half of the geometry is analysed and symmetry conditions imposed at sleeve half length. Total 244 eight- and seven-noded isoparametric elements with total 1664 d.o.f. are used to model the geometry. Analysis is performed using code 'PLAXIS' /3/.

2.2 Thermal analysis

Transient thermal analysis of simulated axisymmetric geometry is performed for step temperature change from 323°K to 552°K. Geometry with enclosed water and thermal insulation is idealized using 158 numbers of 4- and 5- noded isoparametric elements (Fig.3). The thermal properties of water are taken as average of those at room and maximum temperatures. Equivalent thermal conductivity of water is calculated accounting for heat flow by conduction and convection /4/. Film heat transfer coefficient of 1.14W/mm^{2}K is used. Three different time steps of 0.001, 0.01 and 0.1 hrs. are taken for time gradually increasing from zero instant. For geometry before repair a unit length of elbow is taken for transient thermal analysis as no axial heat flow occurs.

3.0 RESULTS AND DISCUSSIONS

Fig.4 shows the variation of hoop stresses along elbow run on θ=0° plane. A θ-plane is defined as section of elbows cut by a curved plane making angle θ from the diametral plane containing centre of 90° vertical elbow. Figs.5 and 6 respectively show variations of effective von-Mises stresses on θ=90° plane for cases when a sound, and complete circumferentially cracked weld conditions are assumed. The hoop stress away from the repair region is approximately 80MPa. General levels of both hoop and von-Mises stresses decrease in sleeve showing peaking at corners. Comparison of Figs.5 and 6 indicates that general stress levels away from sleeve are nearly equal for two cases. However, maximum von-Mises stress of 93.1 MPa is obtained in second case as compared to 64.4 MPa in first case. Figs.7 and 8 show the variations of hoop stress and stress intensity /5/ obtained from axisymmetric analysis. Comparison of Figs.4 and 7 indicates that general stress levels from detailed 3-D and simulated axisymmetric analyses are of similar magnitudes. Both indicate peaking at corners at inside of sleeve. However due to relatively coarser mesh employed in 3-D analysis peak stress value is lower than that calculated from axisymmetric analysis. Similar observations are made from stress-intensity and von-Mises stress plots from axisymmetric and 3-D analyses. Hoop stress concentration factor at point A (Fig.7) as obtained from axisymmetric analysis compared to corresponding membrane stress in straight pipe is 3.44.

Fig.9 shows the temperature distributions at points 1,2,3 and 4 (Fig.9) with time. A steady state temperature of 550°K is attained in 0.4 hrs. Thermal lags of differing magnitudes are observed at different points. The temperature variation of a point on OD of the elbow before repair is also shown in the figure. There is a wide variation of temperature at a given time along a section cross sleeve after repair compared to that in section before repair.

4.0 CONCLUSIONS

(1) Detailed three dimensional and simulated axisymmetric finite element analyses are performed for sleeve repaired elbow-elbow weld joint. Stresses from simulated axisymmetric analysis are same as those from 3-D analysis.

(2) Stress concentration factor of 3.44 is obtained in hoop direction.

(3) The stresses can be used for fracture and fatigue crack growth analyses. Material test data under service conditions will be required.

(4) Behaviour under thermal shock load is studied for geometry after repair and compared with behaviour before repair. Thermal lags are observed across the section after repair. Transient temperatures can be used for thermal stress evaluations.

REFERENCES

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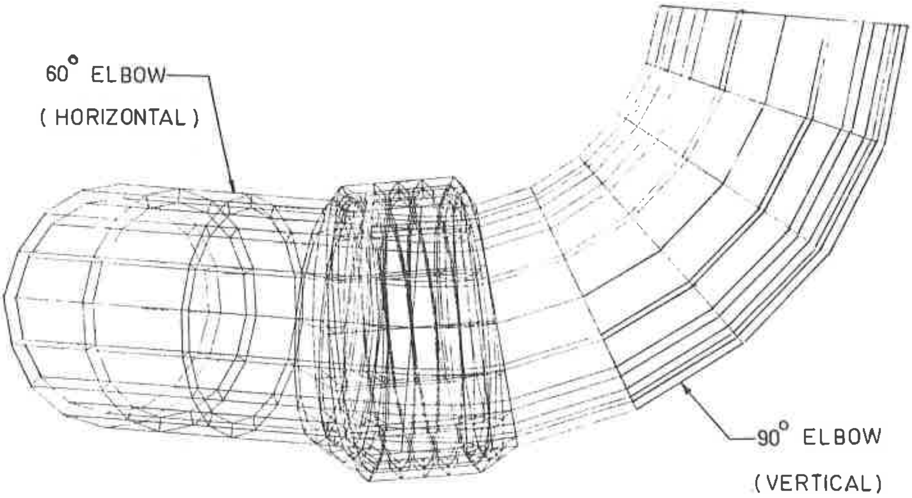

FIG. 1 – 3 DIMENSIONAL F. E. MESH
TOTAL ELEMENTS = 480

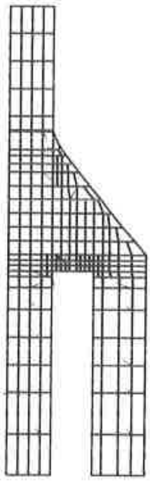

FIG. 2 – AXISYMMETRIC F. E. MESH
TOTAL ELEMENTS – 244

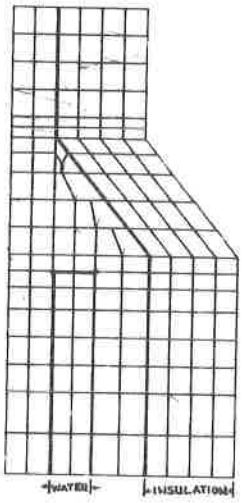

FIG. 3 F. E. MESH FOR THERMAL ANALYSIS
TOTAL ELEMENTS = 158

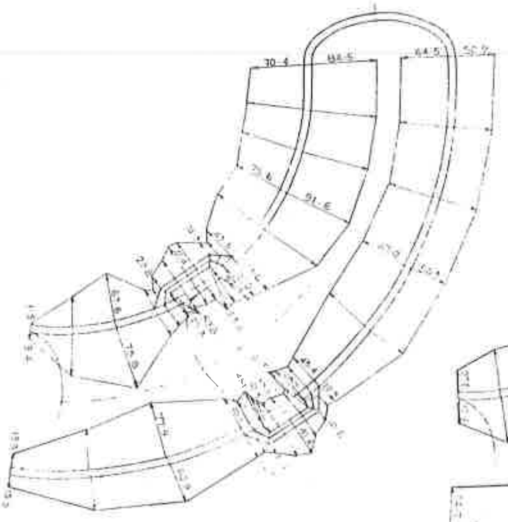

FIG. 4 - HOOP STRESS VARIATION
($\theta = 0^{\circ}$ PLANE) MPa
SOUND WELD CONDITION

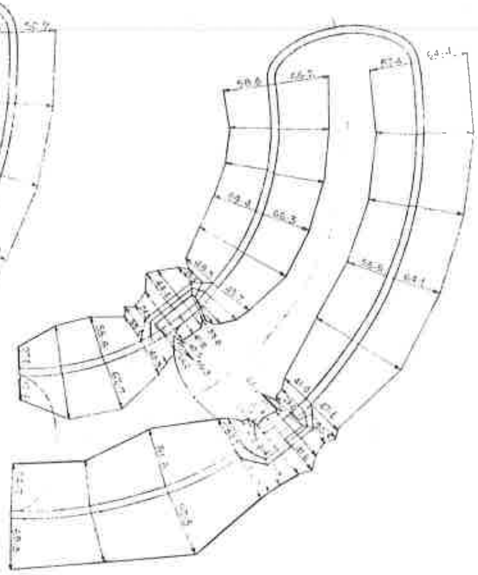

FIG. 5 - EFFECTIVE von-Mises STRESS
VARIATION ($\theta = 90^{\circ}$ PLANE) MPa
SOUND WELD CONDITION

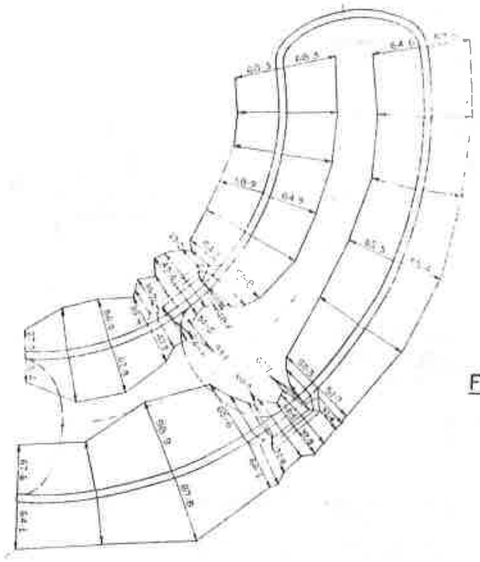

FIG. 6 - EFFECTIVE von-Mises STRESS
VARIATION. ($\theta = 90^{\circ}$ PLANE) MPa
COMPLETE CIRCUMFERENTIAL
CRACK.

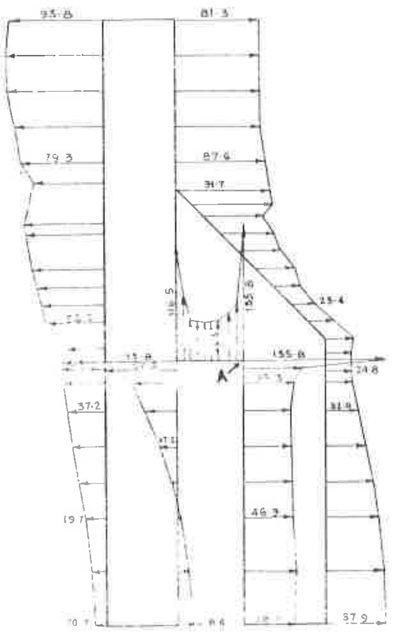

FIG. 7 - AXISYMMETRIC GEOMETRY HOOP STRESS VARIATION MPa

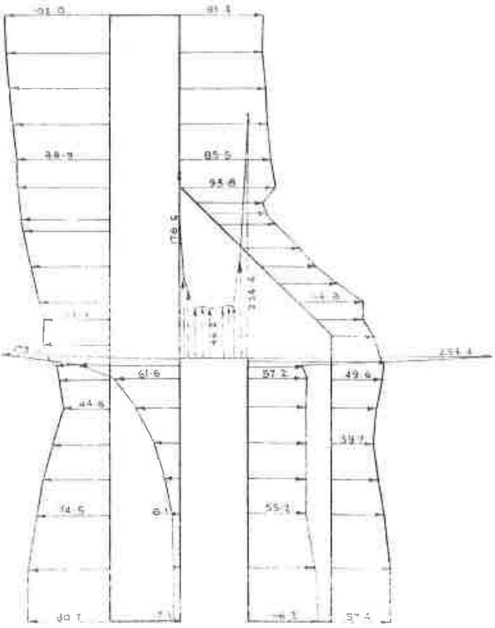

FIG. 8 - AXISYMMETRIC GEOMETRY STRESS INTENSITY VARIATION MPa

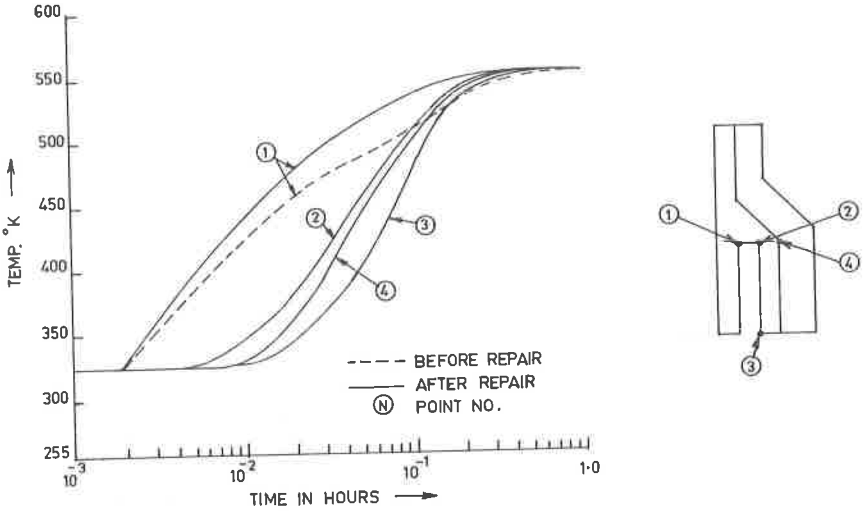

FIG. 9 - TRANSIENT THERMAL BEHAVIOR UNDER THERMAL SHOCK CONDITION