

## **B. Fitness-for-Service Evaluation of Bulkheads**

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### **Introduction**

Four separate details of tainter valve bulkheads were evaluated to assess their fitness-for-service (FFS). These joint details included (1) incomplete joint penetration in skin plate splicing, (2) cracking at corner of skin/web/stiffener intersection, (3) undercut at skin/stiffener weld, and (4) notch at edge and corner of thermally cut valve opening. The fracture analyses of details (1) through (3) used the finite element analysis procedure, which also incorporated the effect of welding-induced residual stresses. The theoretical stress-intensity analysis was conducted to assess the edge and corner notches, without considering the residual stress effect. The FFS assessment was conducted in conformance with the PD6493 guidelines to assess the safety and reliability of existing bulkhead structures in which flaws have been found. Both Levels 1 and 2 assessments were conducted using the results obtained from the fracture mechanics analyses. Critical flaw dimensions were determined.

### **Technical Approach**

Four joint details and their associated flaw types were reviewed. The finite element fracture analysis models were generated with the design loads applied along models' loading boundaries. Essential data for analysis included mechanical properties, joint dimensions, applied nominal stresses, and joint details including the dimension and geometry of the flaw conditions. Prior to the fracture analysis, welding-induced residual stresses were estimated using the plasticity-based numerical procedure. The residual stresses were incorporated in the flaw assessments except for the valve opening. The fracture analyses estimated the respective stress intensity factors, which were compared with material's fracture toughness. The maximum flaw sizes were determined by limiting the fracture driving force to material's fracture toughness. The estimated fracture driving forces were then evaluated using the failure-assessment-diagram (FAD) to assess the safety and reliability of the structures.

### **Results and Discussion**

(1) Cracks not greater than 1/8" size is acceptable in most of the welds, except the following situations: (a) Fillet toe crack in either W- or WT-connection when plane strain fracture toughness (25 ksi sqt in) is experienced. In this situation, the maximum acceptable crack size reduces to 1/16". However, when welding-induced residual stress is considered, 1/8" toe crack is acceptable. (b) For incomplete joint penetration situation in WT-connection, Level 3 evaluation is required to assess its FFS acceptance criterion if residual stress is of a concern. Level 2 assessment shows that any incomplete joint penetration condition in WT-connection is not permissible. (2) The FFS acceptance criterion for toe cracks obtained from this study is much looser than the AWS D1.1 acceptance requirements. Per D1.1 visual inspection acceptance requirement on undercut, the statically loaded connections with material less than 1" thick, undercut shall not exceed 1/32" with the following exception: undercut shall not exceed 1/16" for any accumulated length up to 2" in any 12" continuous weld. The FFS assessment results permit 1/16" to 1/8" crack-like undercuts depending upon material's fracture toughness. For cyclically loaded connection, in primary members, it shall be not more than 0.01" deep when the weld is transverse to tensile stress under any design loading

condition. Undercut shall be no more than 1/32" deep for all other cases. (3) Per AWS D1.1, Provision 5.15.4.3, it requires the surface roughness of all thermally cut surfaces not greater than 0.001" for material up to 4" thick. Roughness exceeding this value and notches or gouges not more than 3/16" deep may be repaired by grinding if the nominal cross-section area is not reduced by more than 2%. The FFS assessment shows the acceptable surface notches be 1/64" (0.016"), which is 16 times greater than that permissible by D1.1 requirement.

### **Conclusions**

The recommended acceptable flaw or crack sizes based on the FFS assessment results using the fracture toughness value (25 ksi sqt in) for various joint details are summarized as follows: (1) Skin Plate Splicing: 1/8" incomplete joint penetration and 1/16" fillet weld toe crack for W-connection and WT-connection. (2) Toe Crack: 1/8" for the corner joint and the stiffener/skin plate fillet weld. (3) Cut Edge: 1/8" for the straight edge and 1/64" for the corner edge.