Replacement Divider Plate Performance Under LOCA Loading

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Abstract

A primary divider plate in a nuclear steam generator is required to perform its partitioning function with a minimum of cross leakage, without degradation in operating performance and without loss of structural integrity resulting from normal and accident loading. The design of the replacement divider plate for normal operating conditions is discussed in some detail in reference 1 and 2. This paper describes the structural response of the replacement divider plate to the severe loading resulting from a burst primary pipe. The loads for which the divider plate structural performance must be evaluated are mild to severe differential pressure transients resulting from several postulated sizes and types of pipe break scenarios. In the unlikely event of a severe Loss of Coolant Accident(LOCA) the divider plate or parts thereof must not exit the steam generator nor completely block the outlet nozzle. For the milder LOCA loads, the integrity of the divider plate and seat bars must be maintained. Analysis for the milder LOCA loads was carried out employing a conservative approach which ignores the actual interaction between the structure and the primary fluid. For these load cases it was shown that the divider plate does not become disengaged from the seat bars. For the more severe pipe breaks, the thermal-hydraulic analysis was coupled iteratively with the structural analysis, thereby taking into account divider plate deformation, in order to obtain a better prediction of the behaviour of the divider plate. In this manner substantial reduction in divider plate response to the more severe LOCA loading was achieved. It has been shown that, for the case of a postulated Large LOCA (100% reactor inlet header) ,the disengagement of the divider plate from the seat bars results in an opening smaller than 1% of the divider plate area.

1.0 Introduction

The primary divider plate in a nuclear steam generator performs the function of diverting the reactor outlet D_2O flow up through the U-tube bundle thereby cooling it before its return to the reactor. This function is therefore of prime importance in transferring the heat removed from the fuel in the reactor core to the steam generator secondary side thereby generating steam. In carrying-out these functions the divider plate is normally subjected to an operating pressure load equal to that of the pressure drop through the U-tubes of approximately 35 PSI. To accommodate this operating load with sufficient margin, the divider plate is designed for a static pressure drop of 60 PSI. The design method is discussed in the papers of references 1 and 2.

Well into the design and manufacture of the lead replacement divider plates for Hydro Quebec, additional design requirements were identified by the Gentilly 2 Safety Analysis Group. The new requirements stipulated that in the unlikely event of a burst primary pipe accident (LOCA), the divider plate must not generate loose parts that could exit the steam generator nor must it completely block the outlet nozzle. For the smaller LOCA events, the integrity of the divider plate and seat bars must be maintained.

The discussion that follows briefly reviews the unique design features of the replacement divider plate and describes in some detail the method of analysis developed to evaluate the replacement divider plate behaviour under LOCA loads.

2.0 Features of the Replacement Divider Plate

The replacement divider plate is a strong, light-weight, integral construction designed for ease of installation and minimum by-pass leakage. The features included in the design of the replacement divider plate were primarily intended to reduce leakage and thereby lower RIH temperature. Because the design is a single piece, the flow leakage crevice area is much smaller than the original design. The only leak path is around the periphery of the divider plate at the tongue and groove joint (See Figure 1). Erosion resistant material is employed at these sliding joints to ensure that leakage rates do not increase with time.

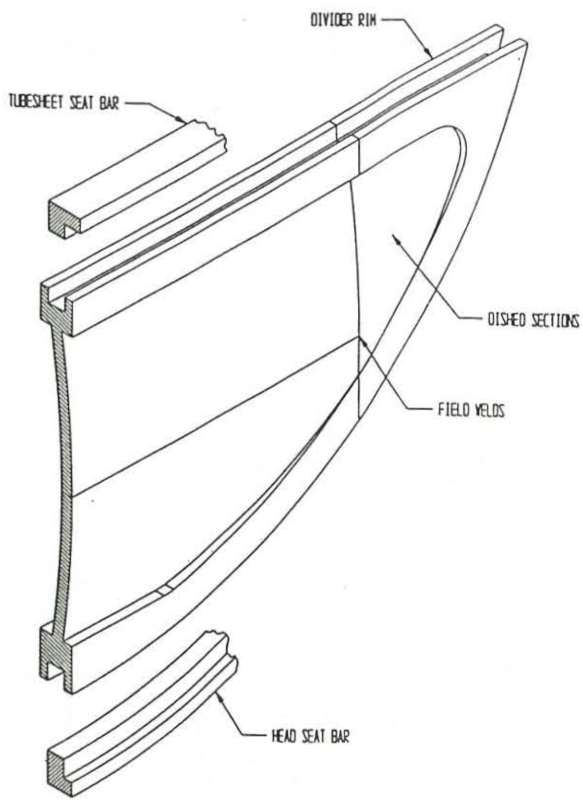


Figure 1: Welded Floating Divider Plate

The original primary divider plate was a segmented design 1-1/2 inches thick (See Figure 2). The replacement divider plate is only 3/4 inches thick. It has been curved in order to provide the necessary strength thereby providing a relatively lighter weight for ease of installation, minimizing weld volume (and radiation exposure to welders) and minimum distortion due to welding that could result in binding of the divider plate on the seat bars. The design has been patented by B&W(3).

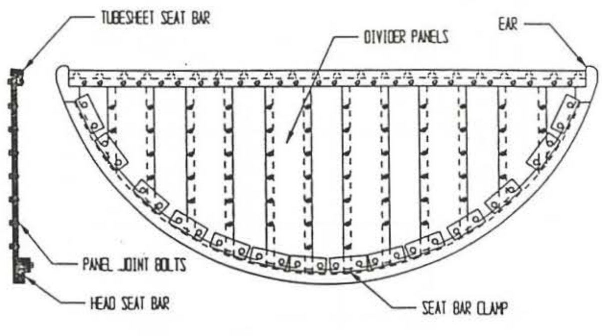


Figure 2: Segmented Divider Plate

3.0 Dynamic Analysis for LOCA Loading

(i) LOCA Loads

The original divider plate transient differential pressure loads were computed by Hydro-Quebec Safety Analysis Group by employing the thermal-hydraulic Code SOPHT-G2 version 03.02. These loads do not take into account divider plate deformation. Several LOCA loads were eventually identified. These transient loads are shown in Figure 3 through 6. As can be seen, some of the loads are clearly much more severe than the loading for which the replacement divider plate was originally designed. (Note: these pressure-time curves hereafter are referred to as original pressure versus time curves)

(ii) Preliminary Structural Analysis

Initially a non-linear transient dynamic analysis utilizing ABAQUS EXPLICIT Version 5.5 was carried out to determine the sensitivity of the divider plate response to variations in the assumed friction factor at the tongue and groove joint and to confirm earlier dynamic analysis carried out by Ontario Hydro. For simplicity, the preliminary structural analyses were carried out conservatively assuming that the thermal-hydraulic solution and the structural solution do not affect each other.

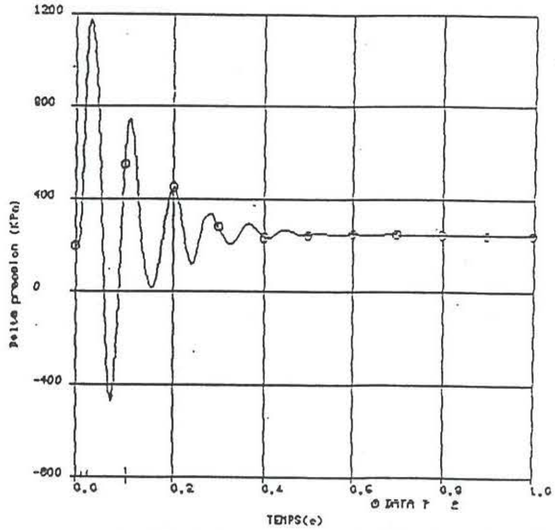


Figure 3: Divider Plate Loading — 5% Equivalent RIH Break

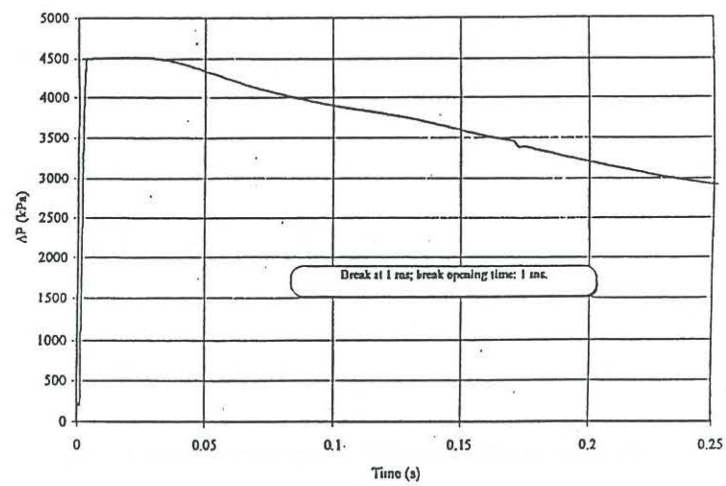


Figure 5: Divider Plate Loading — 100% Pump Suction Break

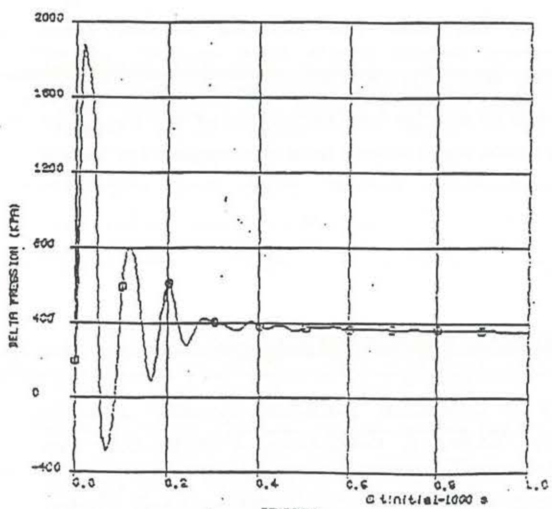


Figure 4: Divider Plate Loading — 7.5% Equivalent RIH Break

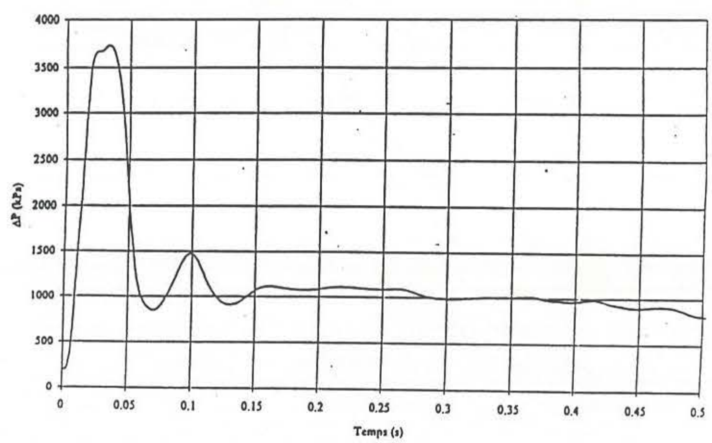


Figure 6: Divider Plate Loading — 100% RIH Break

Initially three load cases were considered, 5%, 7-1/2% RIH Breaks and a 100% Pump Suction. The effect of friction factors from 0.2 to 1.2 was evaluated. This sensitivity study indicated that an increase in friction factor will tend to reduced the rate of deformation of the divider plate resulting from a given differential pressure transient.

Mixed results were obtained in the aforementioned analyses (See section 4.0) and it became clear that if realistic results were to be obtained for the more severe load cases it would be necessary to allow for the effects of the deformation of the divider plate.

In the initial dynamic analysis two important effects that tend to reduce the response of the divider plate were conservatively ignored. These are, bypass leakage resulting from the open area formed when the divider plate starts to disengage and differential pressure reduction resulting from the deforming divider plate pushing primary fluid out of the steam generator outlet nozzle.

To take these effects into account, and thereby effectively reduce the load on the divider plate, requires that the thermal- hydraulic solution be 'coupled' with the structural solution. To achieve this, an iterative procedure was developed that manually links the Hydro-Quebec thermal- hydraulic analysis with the B&W structural analysis. How this 'coupling' is achieved is included in the discussion that follows.

(iii) Thermal-Hydraulic and Structural Coupling

The thermal-hydraulic analysis (HQ) is manually linked with the structural analysis (B&W) as shown in Figure 7. An original pressure versus time curve (P-T) for the first iteration was run for an interval from t_0 to a suitable time t_1 at which time a certain amount of displaced primary fluid volume, resulting from divider plate deformation, is reached. The volume reduction of the outlet side as a function of time for this interval was provided to HQ for input into the thermal hydraulic analysis. The thermal hydraulic analysis was re-run for the same time interval taking into account the displaced volume function and a new pressure versus time load curve computed for the interval. A check is made to determine if the P-T curve has converged by comparing it to the prior curve. If it has not converged the displaced volume versus time curve is recomputed based on the current structural run and the procedure repeated until convergence of two serial P-T curves is achieved.

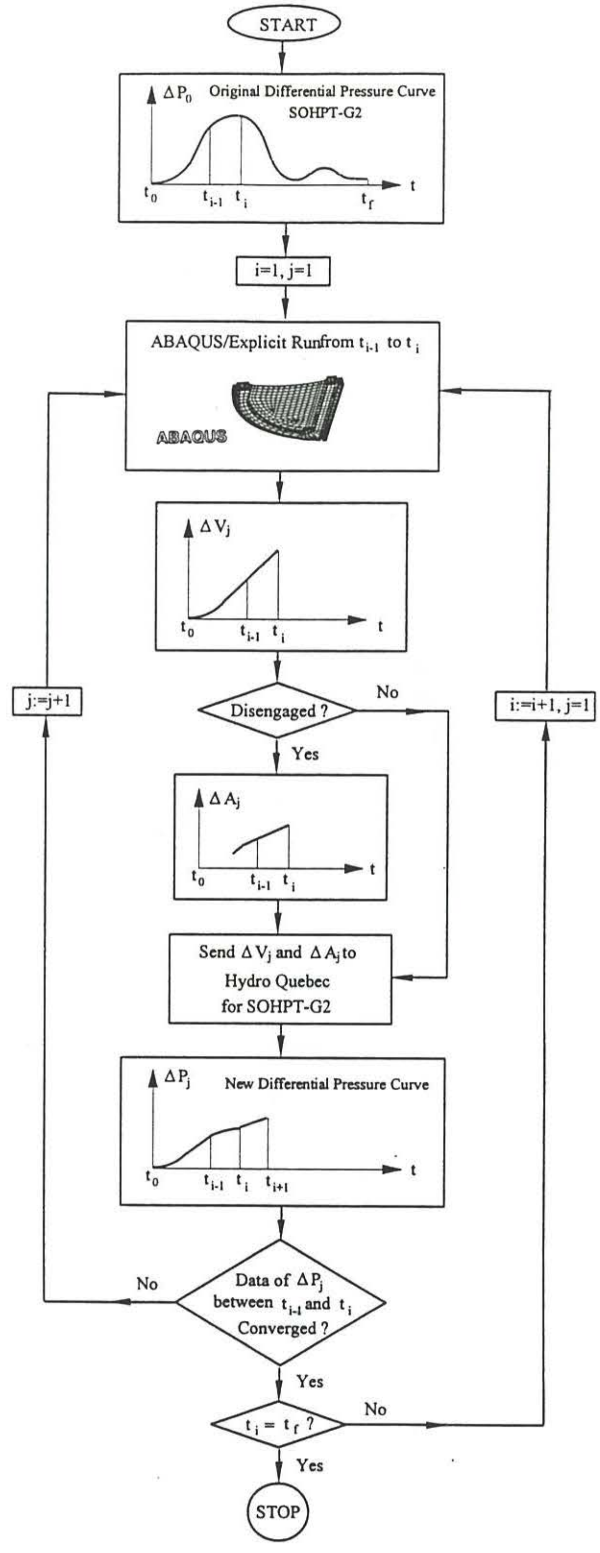


Figure 7: Flow Chart of the Analysis

At some point in time, for the more severe loads, the tubesheet seat bar and divider plate start to disengage and a by-pass leakage flow results. This by-pass flow will tend to reduce the response of the divider plate still further so it too is included in the iteration procedure in a similar manner to the displaced volume. Figure 7 illustrates how this is incorporated.

The above procedure was employed to analyse divider plate response to the 100% RIH Break. This load case is shown in Figure 6. Again, these original loads had been determined based on the assumption that the divider plate remains in place without any deformation and does not by-pass primary fluid beyond that predicted for normal operating conditions.

4.0 Discussion of Results and Conclusion

The results of the initial conservative analysis for the 5% and 7-1/2% RIH breaks indicate that the divider plate remains fully engaged with the seat bars on both the primary head and tubesheet. For the 100% Pump Suction Break the divider plate completely disengaged. However owing to its construction details, it can not exit the primary head to form a loose part. With such a high load, seat bar weld failure was a very significant concern. If the seat bar welds fail, the seat bar becomes a loose part since it can easily exit the primary head of the steam generator. The seat bar weld strains were shown to be acceptable thus precluding the loose parts concern. This conclusion can be broadened because the loading employed is conservative as discussed below. We can conclude that even for the most severe loading, the seat bar welds will not fail and therefore the seat bars will not become loose parts.

Even though the LOCA requirements were not considered when setting the replacement divider plate design, the curved divider plate concept appears to be fortuitous in dealing with the large deformations that result from the more severe LOCA loads. Because the design is curved, it can deflect more than 4 inches under the severe LOCA loading without significantly reducing the engagement of the divider plate on the seat bars. Considerably more deflection is required in order to cause the complete disengagement of the divider plate from the seat bars. This large deflection results in considerable load reduction owing to the relatively large volume of primary fluid that must be displaced out the primary outlet nozzle by the deforming divider plate and the increase in available volume on the primary inlet side of the steam generator. Furthermore, the significant by-pass flow area that opens up before the divider plate becomes entirely disengaged from the seat bars also tends to reduce the original LOCA loading.

The aforementioned means of reducing the response of the divider plate that were not included in the initial analysis have a very significant beneficial effect that results in considerably less divider plate deformation. Figure 8 shows the 100 % RIH LOCA with and without taking into account the deformation of the divider plate. As indicated, the maximum pressure load is much less severe when the deformation of the divider plate was modelled. This, in effect, shows the load reductions achieved by the iteration technique developed to 'couple' the thermal-hydraulic and structural solutions. Figure 9 shows the maximum velocity of the divider plate. As can be seen the divider plate has come to a stop and has started to return to its original position.

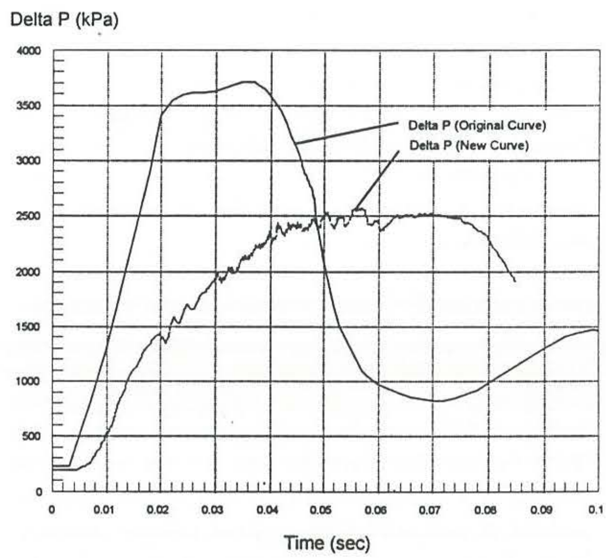


Figure 8: Comparison of the One-Step Analysis and the Iterative Analysis

The results confirm that for the 100% RIH break (Figure 6) the divider plate only slightly disengages with the tubesheet seat bar(approx. 1% of divider plate area). Figure 10 shows the deformed shape at t=80msecs. Deformation is shown with a magnification factor of 1.0.

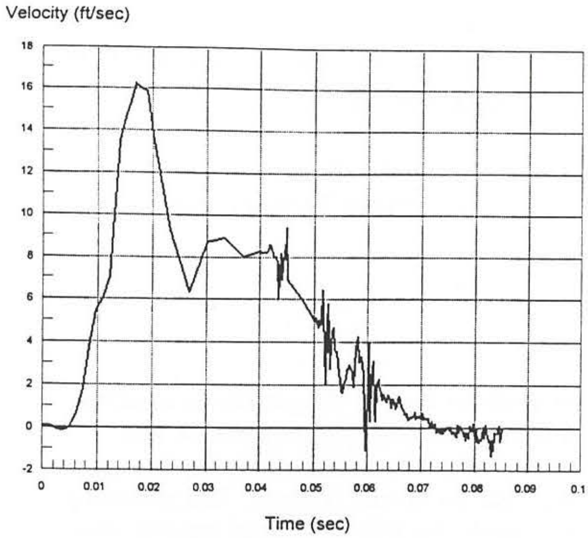
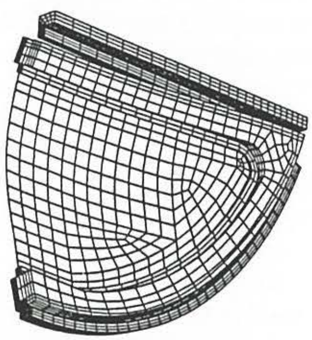


Figure 9: Maximum Velocity of the Divider Plate



DISPLACEMENT MAGNIFICATION FACTOR= 1.00

Figure 10: Deformation of the Divider Plate for 100% RIH Break(t=80 msecs)

5.0 References

1. Gentilly-2 and Pt. Lepreau Divider Plate Replacement-W.Schneider, G.McClellan, S.Weston, E.Kiisel, C.Holmes, Babcock and Wilcox, J. Forest, Hydro Quebec, K.Verma, New Brunswick Power. 17th Annual Canadian Nuclear Society Conference, Fredricton, New Brunswick, June 9-12,1996

2. Gentilly-2 Divider Plate Replacement- J. Forest, E.Kiisel, G.McClellan, W.Schneider. Canadian Nuclear Society, Third International Conference on CANDU Maintenance, November 21,1995

3. U.S. Patent No. 5,623,763, Method of Replacing a Primary Divider Plate in a Steam Generator, Inventors: H.G.McClellan and W.G.Schneider

6.0 Acknowledgements

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