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STRUCTURAL EVALUATION OF A HIGH CAPACITY NON-WELDED BASKET DESIGN

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ABSTRACT

Higher capacity baskets for storage and transport of spent fuel provide an advantage of ALARA during loading operations and optimal use of space on the storage location. In this paper the impact analyses for a system to store and transport 87 BWR fuel assemblies are presented. The basket is a series of tubes with pins positioned at the tube corners (slots) to prevent relative motion of the tubes during the accident. With the absence of welds, immediate fabrication advantages are identified and flexibility mitigates stresses arising from thermal expansion. In the storage condition the overpack shown is a thick carbon steel liner inside a 20 inch thick concrete cylinder where as for the transport condition the overpack is a transport cask consisting of a lead lined multiple cylinders. In each condition, the gap between the canister and the overpack is different as well as the decelerations associated with the accident condition. This requires separate analyses to be performed for each. Initial evaluations decoupled the basket from the overpack response during the accident conditions, but the review process resulted in evaluation of a full length canister model with a detailed model of the basket contained in the canister. Two types of evaluations are performed; an evaluation of the geometric stability due to fabrication tolerances and a detailed evaluation of the deformation of the pin-slot region. The loadings employed in the evaluation consist of deceleration time histories obtained from separate models for the storage cask and the transport cask. While the paper will present an overall explanation of the generation of the loadings on the basket, the principle focus is on the basket response. Results for the basket evaluations indicate that the geometric positioning of the fuel is maintained during the accident conditions for both storage and transport scenarios.

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INTRODUCTION

The objectives in designing a basket for the storage of spent fuel are to increase its capacity as well as providing a design to minimize fabrication costs. The key to fabrication reduction costs is simplicity of design and use of materials not particularly subject to volatile markets. A prototype for such a design is shown in Figure 1. The basket cross section is comprised of cells which correspond to a carbon steel tube and adjacent cells formed by the tubes. Tubes maintain their position by two assemblies; a pin-slot assembly and exoskeleton type weldments at the exterior of the basket, as indicated in Figure 1. Locations of the pin assemblies are shown in Figure 2.

While the pin assemblies numbered 1 through 8 in Figure 2 have limited motion due to fabrication, the connector pin assemblies at each end do not. The basket, as shown in Figure 2 is contained in a stainless steel canister with a lid welded at the top after the fuel has been inserted into the basket in the spent fuel pool. The final configuration of the welded canister is the placing of the canister inside a vertical concrete overpack (concrete cask whose wall is 20 inches thick and contains a numerous reinforcement bars). Rejection of the spent fuel heat is by convection in the vertical annulus between the canister and the concrete cask.

STORAGE EVALUATION

The most severe storage loading condition is the tip over accident condition in which the concrete cask is considered to tip over in a non-mechanistic manner (the concrete cask is designed to maintain its vertical position during a Safe Shutdown Earthquake condition or impact by tornado missiles). A separate evaluation of the loaded concrete cask impacting the concrete pad resting on soil is performed to identify the acceleration time history to be imposed on the basket containing design basis weight fuel assemblies (further details are contained in Ref. 1). The evaluation of the basket involves two aspects:

1) The evaluation of the stresses in the tubes and weldments using standard methodology used in storage evaluations (Ref. 1).

2) The evaluation of the stability of the basket taking into account maximum gap conditions in the basket between the tubes.

In this paper, the evaluation of the stability of the BWR 87 fuel assembly basket is presented. . The geometric stability of the basket ensures that the fuel tubes retain their initial geometric configuration and all the pin-slot connections remain engaged after the tip-over accident. To observe the dynamic responses of the fuel tube assemblies and the pin-slot interface due to the tip over deceleration loading, a transient analysis is performed using a LS-DYNA (Ref. 2) model corresponding to a 10-inch 87 BWR assembly periodic section (see Figure 3). The periodic model conservatively ignores the effect of tube and support weldment stiffness, multiple pins at the tube interface surface along the length of the tubes, and the connector pin assembly at both ends of the tubes. The model represents the fuel assembly as brick elements with low elastic moduli to account for the mass and for the ability of the fuel to apply secondary impacts on the walls of the fuel tube during the deceleration. Details of the pin assembly and bosses connecting the weldments to the tubes are shown in Figure 4 and Figure 5. The finite element mesh of the pin assembly shown in Figure 4 contains adequate elements to define the interface between the tube slots and the pins. The boss model in Figure 5 shows how model allows for the relative motion of the tubes and weldments due to maximum gaps occurring in fabrication.

In the tip over the cask is rotating about its base, and the acceleration of the basket monotonically decreases from the top end to the base of the cask. In terms of the maximum inertial loading, the location of maximum loading occurs at the top of the basket. However, since the canister aspect ratio is approximately 2.5, and the ends of the canister shell are welded to thick plates, the displacement of the canister limits the deformation of the basket. Consequently, the maximum radial displacement of the canister wall is not at the top, but is dependent on the uniform varying acceleration. To accurately determine the canister shell displacements another more complete ANSYS (Ref. 3) model of the basket, canister and concrete cask is required, which is shown in Figure 6. The typical ANSYS model in Figure 6 is a half symmetry model for the basket in the

45° orientation. Where as the LS-DYNA model simulates the pins, slots and boss behavior, the ANSYS model is intended to account for the tube displacement affecting the canister shell displacement. The ANSYS model accounts for the maximum fabrication gaps for the tubes and the bosses connecting the weldments to the tubes. The canister shell displacements from the ANSYS solution is used to form the boundary condition for the canister shell shown in Figure 3. For any specified basket orientation, both models (Figure 3 and Figure 6) had the baskets in the same angular orientation. For basket orientations such as 22.5°, the full ANSYS model (not a half symmetry model) was required.

While the stresses and inelastic strains are calculated, and inelastic properties are used for the basket and canister model, the objective of the evaluation centers on basket stability, indicating that the safety factor needs to be defined in terms of the inertial loading. The safety factor is defined as the factor applied to the acceleration for the basket loading in which the basket tubes maintain their geometric stability in the designed and fabricated configuration. In this evaluation, a factor of 1.5 is applied to both analyses. The 1.5 factor is applied to the ANSYS model (Figure 6) defining the canister shell displacements (to used in the model in Figure 3) as well as to the acceleration time history used for the transient evaluation of the basket model (Figure 3) using LS-DYNA. Using a factor of 1.5 confirms that the minimum safety factor for basket stability is greater than 1.5.

This procedure of solving two models is repeated using different angular orientations of the basket. It was determined from the ANSYS solution that the maximum canister shell displacements did not correspond to the location of the maximum inertial loading. To ensure that the bounding conditions were obtained, the canister shell displacements at a location having a larger acceleration were used in a separate LS-DYNA evaluation of the model in Figure 3. A typical displacement pattern from the ANSYS model is shown in Figure 7. The displacement plot shows that the maximum downward shell displacements occur at approximately 75° from the impact plane and slightly below the axial midpoint of the canister. The shell displacements are affected by the basket orientation, but not to a significant extent. Figure 8 shows the typical response for the gap as a function of time for both the pin as well as for the boss motion. The evaluations showed that the response is linear (absence of permanent set) and that the maximum gap tends to occur near the end of the solution after the peak accelerations have been reached. The size of the gaps and a review of the displacement of the tubes and pins confirmed that the pins remained in the slot and no buckling or other detrimental behavior resulted from the analyses using 1.5 times the design basis accelerations.

CONCLUSIONS

Considering the number of significant conservatisms in the periodic models, it is concluded that the factor of safety for the BWR basket stability for the cask tip-over accident is considerably greater than 1.5.

REFERENCES

1) MAGNASTOR Safety Analysis Report, July 2007, NAC International, Norcross GA
2) LS-DYNA, Version 970, LSTC, Livermore CA
3) ANSY, Version 10, ANSYS INC, Canonsburg, PA

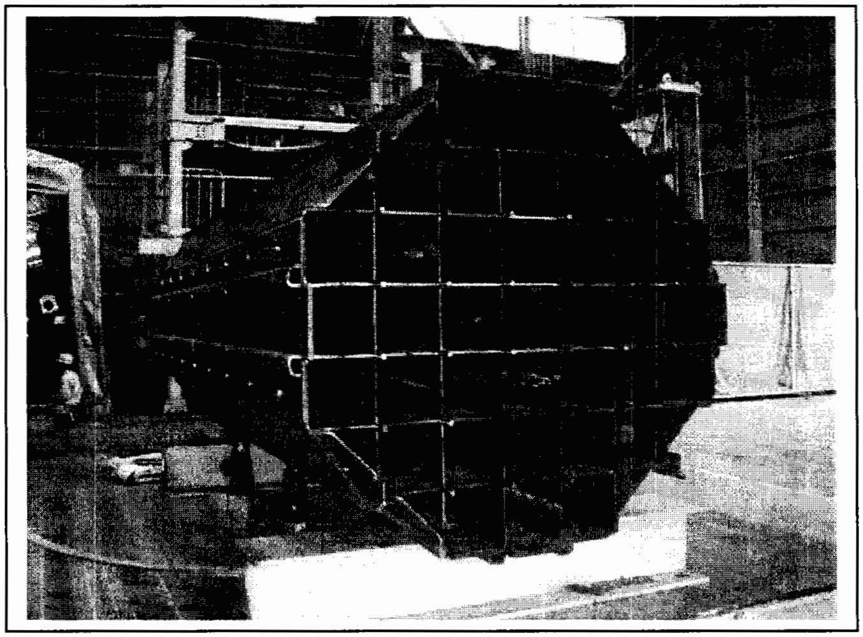

Figure 1. Prototype PWR 37 Fuel Assembly Basket

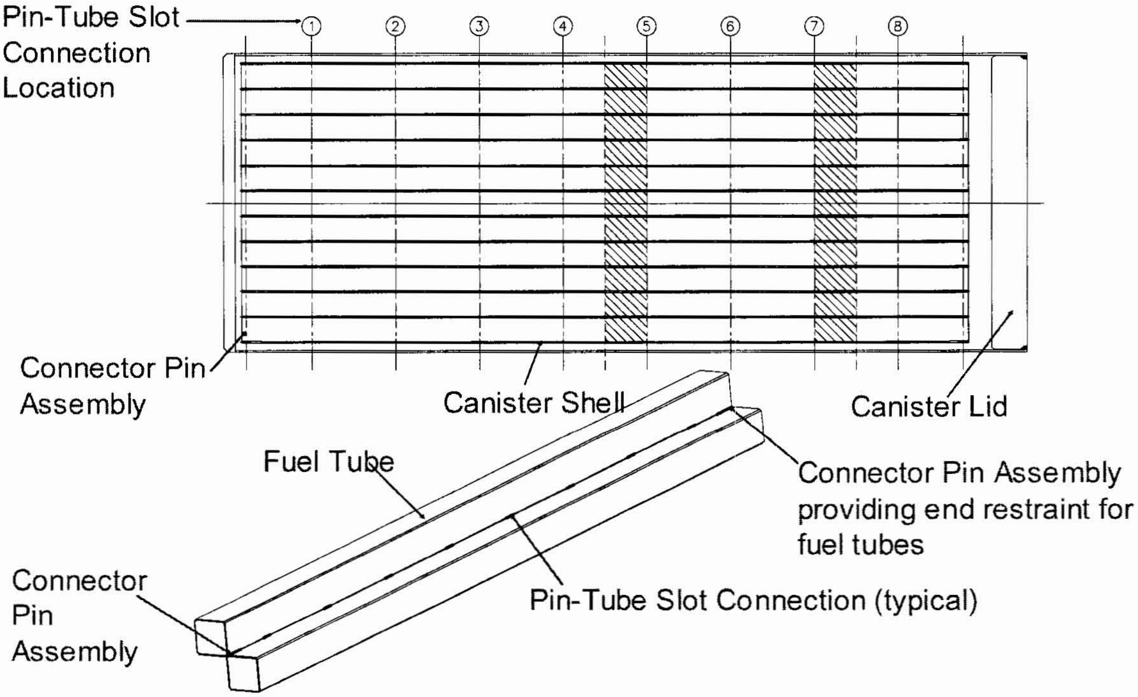

Figure 2. Locations of the Pin Assemblies for a Typical Basket

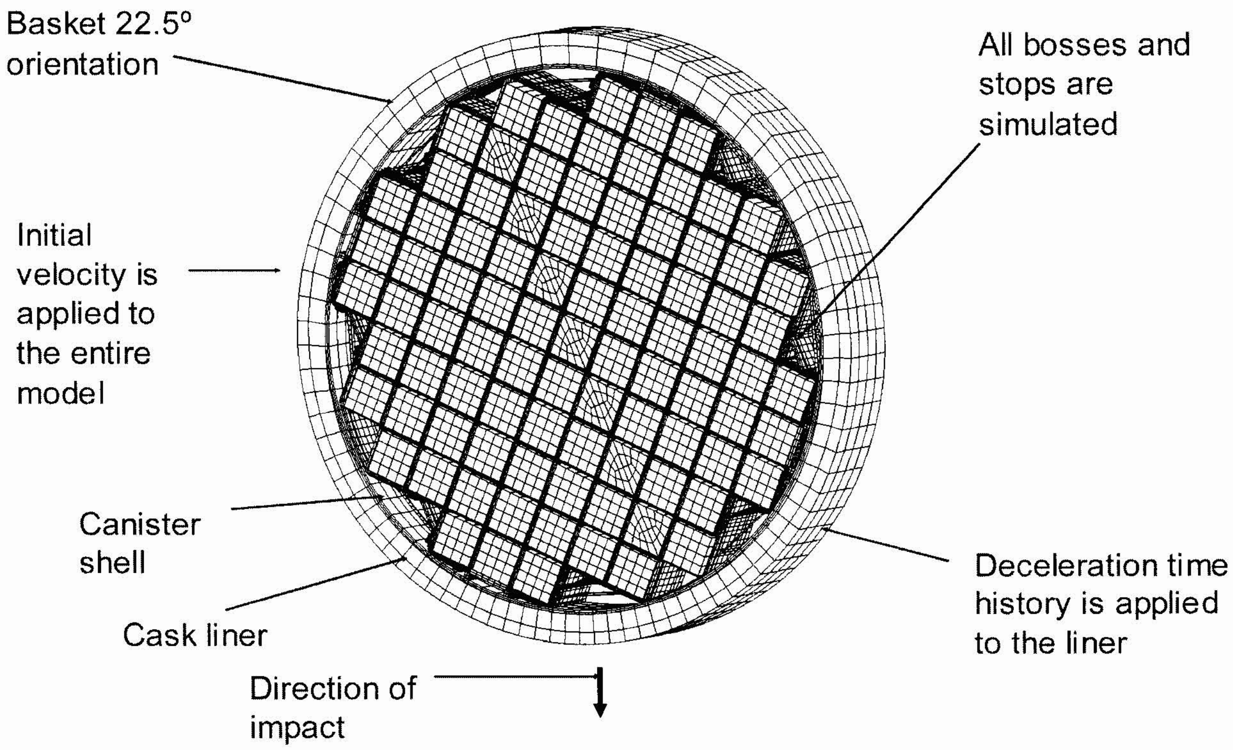

Figure 3. 87 BWR Fuel Assembly LS-DYNA Model - Periodic Section

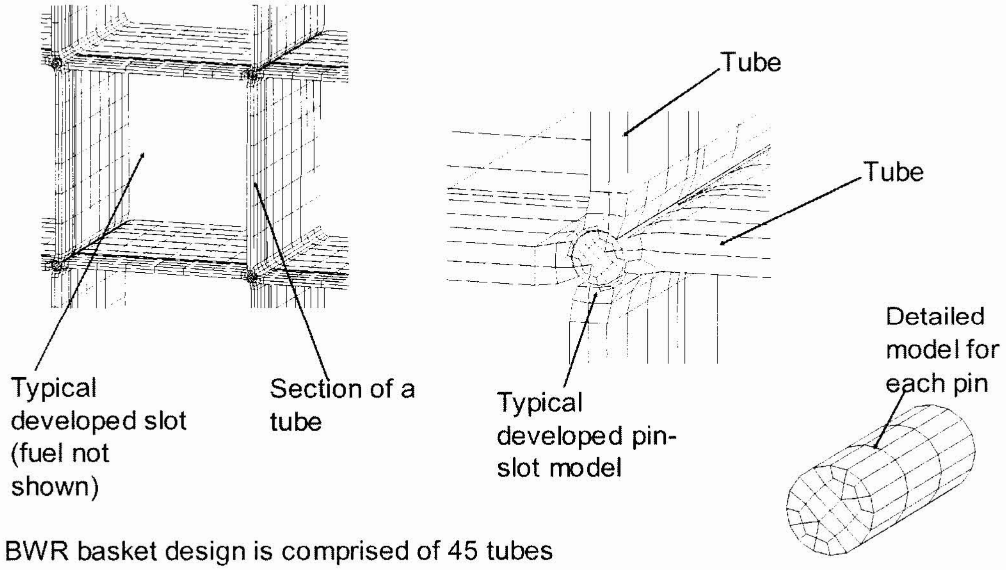

Figure 4. Details of the 87 Fuel Assembly BWR Tube and Pin Model

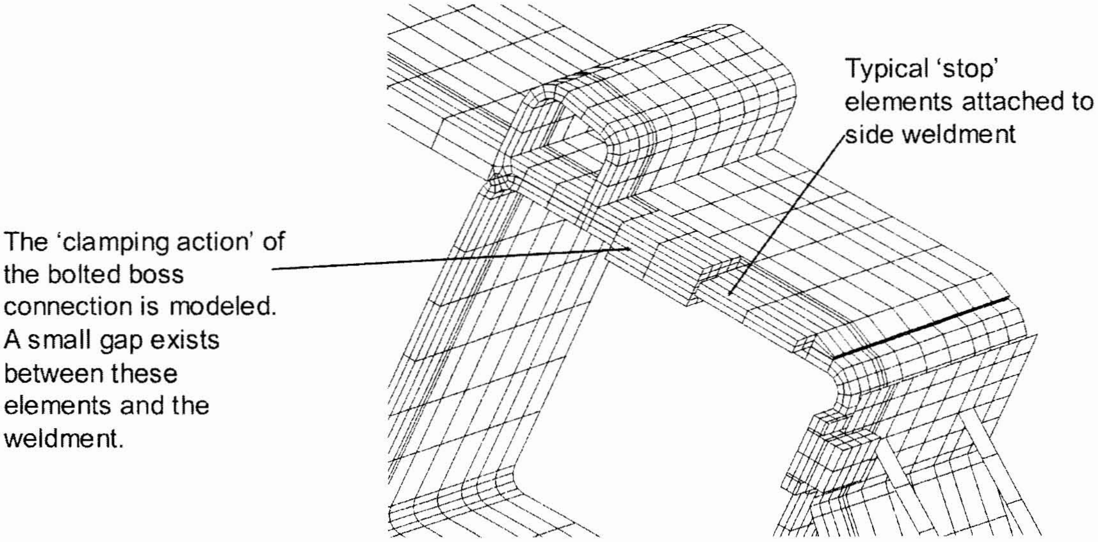

Figure 5. Details of a Typical Boss for the 87 Fuel Assembly BWR Basket Model

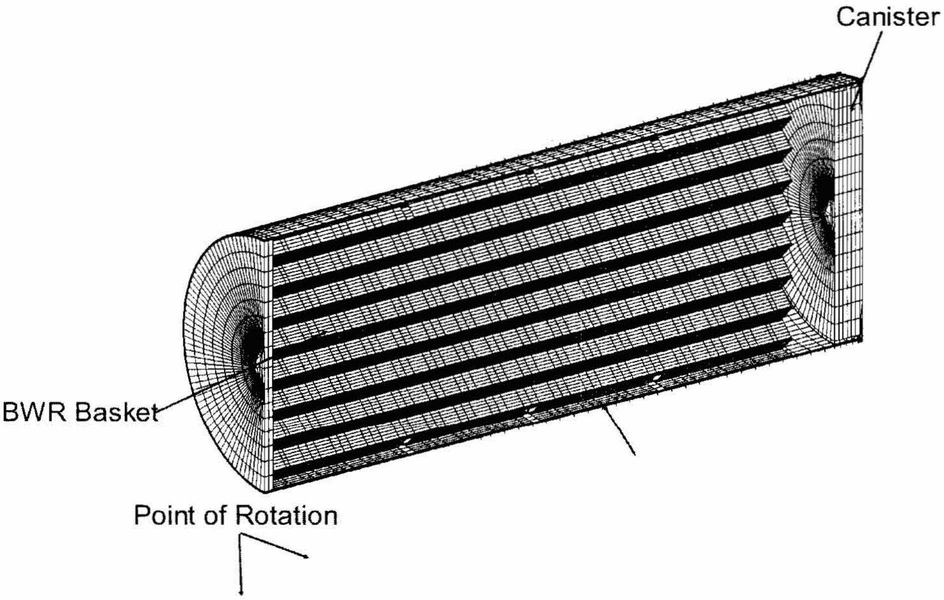

Figure 6. Half Symmetry ANSYS Model of the 87 Fuel Assembly BWR Basket

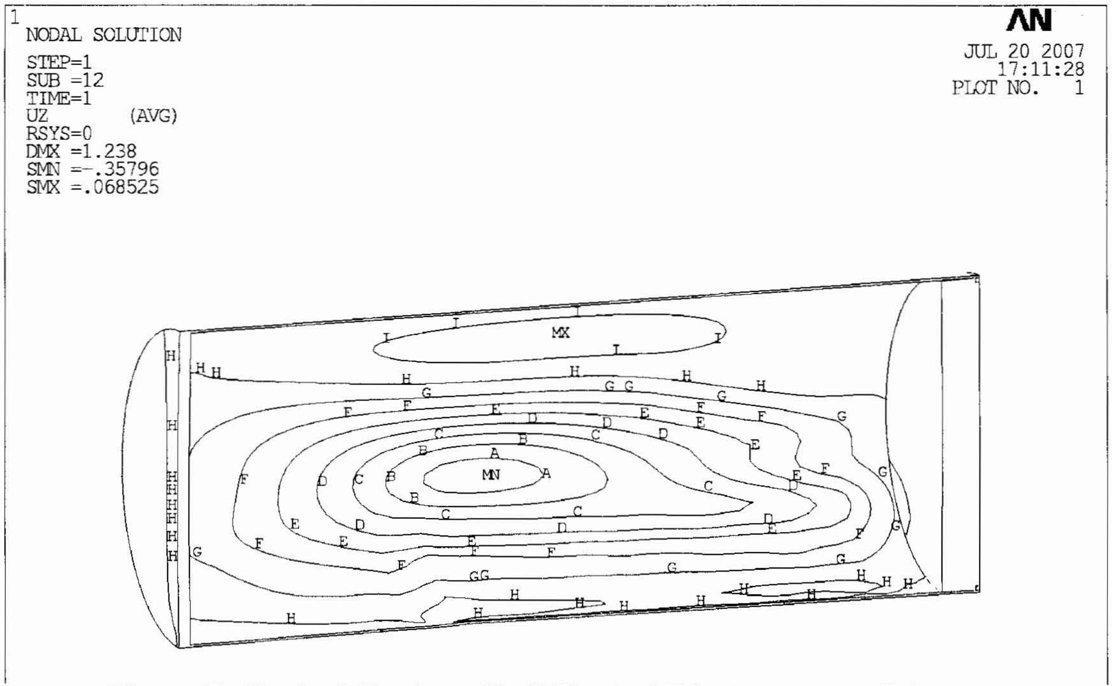

Figure 7. Typical Canister Shell Vertical Displacements (in)

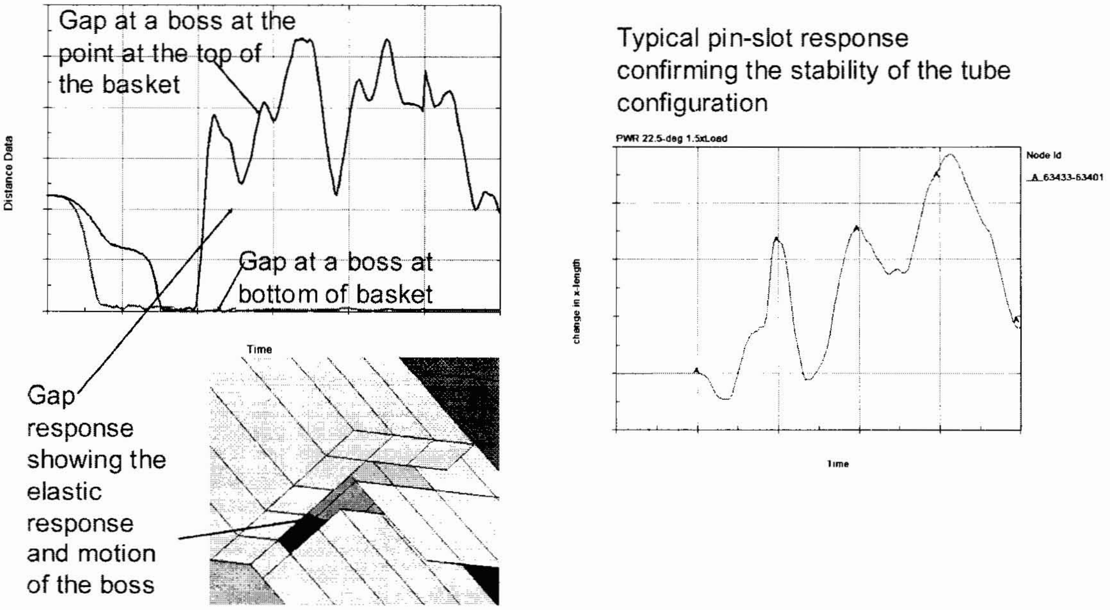

Figure 8. Typical LS-DYNA Displacements of the Boss and Pin