# Acceptance Review
# of
# Holtec International Topical Report HI-2125263R0
# "Dynamic Analysis of a Freestanding Stack
# Subject to a Postulated Earthquake"


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By letter dated January 24, 2013, Holtec International (Holtec) submitted Topical Report HI-2125263R0, "Dynamic Analysis of a Freestanding Stack Subjected to a Postulated Earthquake" (ML130280423) for U.S. Nuclear Regulatory Commission (NRC) review and approval under the NRC's licensing topical report program. The topical report was submitted to the Division of Spent Fuel Storage and Transportation (SFST) in the Office of Nuclear Material Safety and Safeguards. This document is the NRC staff's acceptance review of the subject topical report to ensure that it contains complete and sufficient technical content and descriptive narrative to initiate the NRC staff's detailed technical review and the development a draft Safety Evaluation Report (SER).

## ACCEPTANCE REVIEW SUMMARY

SFST staff has reviewed the topical report and concludes that there is insufficient technical content and descriptive narrative to accept the topical report for further technical review. The deficiencies in the topical report are in five general subject areas:

1. Treatment of Damping
2. Design Basis for the Mating Device Connections
3. Development of the Finite Element Model
4. Calculation of Mean Response
5. Acceptance Criteria for Sliding

These deficiencies are discussed in greater detail below.

## DISCUSSION OF TOPICAL REPORT DEFICIENCIES

### 1. Treatment of Damping

One of the most important aspects in the seismic stability analysis of the rocking of a free-standing structure is the treatment of damping. Essentially, there are three mechanisms by which the free-rocking of such a body dissipates motion with each successive impact, these include: 1) conservation of momentum, 2) material/structural damping, and 3) coulomb or friction damping. However, a finite element model of the Stack may also contain other forms of

damping, such as contact damping. In the treatment of damping, the primary concern is to assure that none of these damping mechanisms are "double counted" in the construction of the finite element dynamic model. This is why benchmarking of the finite element model is essential.

Additional damping may also be incorporated into the finite element model by inclusion of heavily damped materials into features of the support structure at the base of the Stack. Upper and lower bound damping ranges for these materials should be documented in the topical report. Only lower bound damping values should be used in the seismic stability analyses.

Regarding the damping values to be used in the finite element model of the Stack, the topical report states at the bottom of page 20,

> As can be inferred from the finite element modeling of the Stack components, the damping effect is incorporated in the solution process by the selection of material constitutive properties. Therefore, it is not necessary to estimate damping in the structure using empirical guidance [4.3] or idealized mathematical models [4.4,4.5]. However, parameter analyses to quantify damping between HI-STORM and a thick concrete foundation on LS-DYNA show that the impact damping can be significant [4.6].

The "empirical guidance" found in Reference 4.3, which is Regulatory Guide 1.61, Revision 1, "Damping Values for Seismic Design of Nuclear Power Plants," lists material damping values as a function of stress level and should be the referenced source in the topical report to estimate material (structural) damping.

The quotation cited above also incorrectly characterizes Reference 4.5 as dealing with "idealized mathematical models." Reference 4.5 is an experimental investigation of the free rocking of concrete blocks on hard timber or concrete surfaces, in which the experimental results are compared to the analytical solution for a simple rocking model (SRM) that had been developed by Housner. Housner’s model and Housner’s equation are discussed in Reference 4.4. Based on the experimental results the authors of Reference 4.5 conclude "The SRM predicted the free rocking half-periods in general agreement with the measured values for tests performed on rigid foundations i.e., timber or concrete. . . . In the case of timber or concrete, the tests showed that the apparent coefficient of restitution, r, was close to the calculated values using SRM."

To avoid excessive damping or the double-counting of damping in the Stack model, the topical report should include a performance requirement to demonstrate that the Stack Model (HI-TRAC, MPC, MD, and HI-STORM) rocking freely on a hard surface produces a coefficient of restitution (COR) and associated equivalent viscous damping that is in agreement with the results from Housner's equation.

With respect to the damping used for the HI-DAMP layer, which is composed of a special material and inserted between the HERMIT base and the support foundation, the topical report only states that "The... damping values... are obtained from the manufacturer's data." In Appendix A of the topical report it states that the minimum critical damping of this material is 14.3%.

These brief discussions from page 20 and the brief sentence quoted above constitute the entire discussion of damping in the topical report. In addition, there is no discussion of performing a

free rocking analysis of the Stack finite element model in order to benchmark the model and its damping against experimental test data or validated theoretical solutions, such as Housner's equation. The topical report must contain a thorough technical discussion of damping, including the delineation of uncertainties and the basis for using certain damping values. The topical report gives no guidance on the structural, material and contact damping to be used or the reason why these damping values are appropriate.

As a point of interest, on January 31, 2013, in preparation for a site visit and inspection, Exelon Corporation made a presentation to NRC Region III and SFST staff titled "Unrestrained Stack at Braidwood Station -- Analysis and Evaluation," which Holtec staff attended. Exelon and its consultants performed a nonlinear seismic analysis of a Stack consisting of the same components referred to in the topical report, namely HI-TRAC, MPC, MD, HI-STORM, HERMIT, HI-DAMP and Support Foundation. In their presentation, Exelon states that only 4% contact damping and no structural damping will be used in the finite element model and that the material damping in the HI-DAMP pad is completely ignored. In addition, Exelon performed free rocking analyses of the finite element model and benchmarked the analysis results against experimental data and theoretical solutions. Exelon's approach for performing a nonlinear seismic analysis of a Stack contrasts sharply with the approach in the topical report.

For the condition where the HERMIT and HI-DAMP are not used, the topical report provides limited guidance. For example, the last sentence of Section 3.0(c) states the following:

> If HI-DAMP and/or HERMIT are not used, then the interface properties (stiffness, damping and/or coefficient of friction) at the base of the HI-STORM must be adjusted accordingly.

On page 20, Section 4.1 it states that:

> [F]or conservatism, the coefficient of friction at the interface between the foundation and the HI-STORM is treated as a variable parameter and analyses shall be performed at an upper bound (0.8) and a lower bound (0.2) COF values.

While this provides guidance for COF, it provides no guidance with respect to damping, which has a significant influence on response, other than to state that "... the damping effect is incorporated in the solution process by the selection of material constitutive properties." No guidance is provided as to what are appropriate values for material and structural damping or contact and impact damping.

Thus, the topical report provides no guidance on how to evaluate damping through the benchmarking of the model against published test data, which the NRC staff believes Holtec must do, or justify an alternative. This is an important step in determining the correct amount of damping and is necessary to ensure that damping is not "double counted."

## 2. Design Basis for the Mating Device Connections

Section 4.2(ii) of the topical report states:

> The contact interfaces between the HI-TRAC bottom flange and the Mating Device and the HI-STORM top plate and the Mating Device are assigned a coefficient of friction (COF) of 0.5, which is a reasonable value for steel on steel in the dry condition per [4.7]. The use of a singular value at these interfaces is adequate since the Mating Device bolts prevent relative sliding between components.

This last sentence is ambiguous and would seem to imply a bearing type connection, yet friction is relied upon to resist a substantial portion of the seismically induced lateral shear forces. What the design basis for the connection is, and how the connection is expected to perform, are not discussed. In addition, there is no discussion on the variability of the steel on steel static COF under clean dry conditions. Section 4.1(4) mentions that the lower bound steel on steel COF in a dry environment ranges from 0.39 to 0.42. Also, there is no discussion regarding the actual conditions that may exist at the steel on steel interfaces. For example, a thin oxide layer on these surfaces could significantly lower the COF and substantially increase the shear forces on the bolts.

The first sentence in Section 3.0(d) states:

> The bolts joining the Mating Device to the casks below and above are installed without any pre-stress or significant torque.

Given that (1) the bolts are not pre-stressed, (2) gaps between various components will allow the connection interfaces to slip, (3) the vertical normal force at the connection interfaces can vary significantly with the vertical seismic response, and (4) there may be considerable uncertainty in the value of the static COF, it is likely that the bolts will need to be designed to resist a large portion of the lateral seismic loads. This needs to be integrated into the connection design basis, and the load path through the connections needs to be clearly explained. Without such guidance, analysts will be unable to correctly model the connections.

Appendix B of the topical report evaluates the shear and axial forces in the bolts between the HI-TRAC and HI-STORM interfaces with the Mating Device. The shear forces in the bolts appear to be quite low relative to the total shear force that could be transmitted across the interfaces. To gain an understanding of the behavior of these connections, the topical report must address the amount of total shear force resisted by the bolts and the amount resisted by friction across each interface, or the applicant must justify an alternative evaluation. In addition, there is no discussion on the sensitivity of the bolt shear forces to changes in the COF. Such a sensitivity evaluation should be done to provide confidence in the topical report guidance.

## 3. Development of the Finite Element Model

One of the four components of the *calculational framework* discussed on page 10 of the topical report is the "Modeling of the HI-STORM/Mating Device/HI-TRAC/MPC assemblage in LS-DYNA including the fasteners used to connect interfacing parts." This is the most important and complex component of the calculational framework, and as such one would have expected an extensive discussion of the topic. Instead, there are only two pages of narrative devoted to the development of the finite element model; and the discussion in those pages is incomplete.

Table 4.2 lists the structural components of the HI-TRAC, Mating Device, and HI-STORM, and the general element types and material definitions associated with each component. However, none of this is discussed in the text. Only an informed user of explicit dynamics codes would realize that eight of the structural components with element types described as "Constant Stress Solid Elements" are actually hexahedral elements with reduced (single point) integration. These elements are subject to zero energy deformation modes, commonly called hourglassing, which can often produce significant errors in results unless hourglassing is properly controlled. Hourglassing is controlled by introducing stiffness or viscous damping into the element. It is important to know the type of hourglass control used and the level of stiffness or viscous damping employed. Except for a few brief comments in other parts of the topical report, this is not discussed in the model development section, and thus the NRC staff is not able to evaluate the soundness of Holtec's approach.

For example, the staff cannot determine the integration order that should be used for thin and thick shell elements and what other element options should be chosen. One of the problems in using the LS-DYNA program is that LS-DYNA does not always remove poorly behaving element formulations and options. Therefore, the topical report should be as specific as possible in identifying element types to be used, options to choose and integration schemes that produce acceptable results. In addition, a cautionary note should be added to limit the use of tetrahedron elements, especially in regions of high stress.

Further, the contact/friction definitions used between contacting surfaces and the parameters chosen for each definition are not discussed. The basis for mesh refinement of critical components is not discussed. How bolt models were constructed and why these models are expected to perform accurately is also not discussed.

Figures 7.2.7 through 7.2.10 mention "Spotweld Constraints" in the legend of the figures, yet there is no discussion of the modeling of the spotwelds, where they are located in the model, or their applicability to the finite element model.

**4. Calculation of Mean Response**

When calculating the best estimate response for rocking and sliding, ASCE 43-05 uses the 95% and 5% confidence bands in selecting the value of COF to be used assuming that low values of COF produce maximum sliding and high values produce maximum rocking. When the HERMIT is used, the values of COF range between 0.10 and 0.26. From this range, three COF values were chosen for analysis, an upper bound value, an intermediate value and a lower bound value. In keeping with the philosophy of ASCE 43-05, the value of COF to be used from this range to predict the best estimate response is the COF value that produces the best estimate sliding response results consistent with a 95% confidence that the best estimate value would not have been exceeded had another COF value been used. Therefore, the best estimate response should be the maximum of the mean response of the five time histories from each of the three COF values used, and not the mean response of all fifteen responses (i.e., 3 COF values X 5 time histories), unless the applicant can justify an alternative.

## 5. Acceptance Criteria for Sliding

Section 5.1(b) "Sliding Criteria" states that:

> The factor of safety against sliding is defined as the ratio of the lateral displacement that will cause the Stack's centerline to cross its footprint (before the beginning of the earthquake) due to the maximum migration CPR (see Glossary) during the earthquake. The minimum sliding safety factor, using the mean plus one standard deviation value (CPR), must be > 3.0.

This criterion is not acceptable because it does not consider the limits of the support surface upon which the Stack rests. The criteria must be revised to ensure that the edge of the Stack does not slide beyond the limits of the support surface for a maximum migration equal to the maximum mean sliding response from the five time histories multiplied by a factor of safety of 3.0.

With respect to using the mean plus one standard deviation of each of the response parameters, however, the staff finds that, because a safety factor of 3.0 is being used, it is acceptable to use the maximum mean response from the five time histories, instead of the mean plus one standard deviation together with a factor of safety of 3.0 for both rocking and sliding. This is consistent with the guidance in ASCE 43-05 and NUREG-0800.

## CONCLUSION

For the reasons discussed above, this topical report lacks sufficient technical detail and rigor for the NRC to perform a detailed technical review, or for licensees to perform an analysis of the stack-up that will demonstrate with reasonable assurance the safe performance of the stack-up during a seismic event.