Stewart Brown

From: Evan Rosenbaum [e.rosenbaum@holtec.com]
Sent: Thursday, March 20, 2008 3:30 PM
To: Stewart Brown
Cc: Tammy Morin; Alan Soler; Kris Singh; Chuck Bullard
Subject: Document for 100U Meeting on Friday
Attachments: FINAL GENERAL RESPONSE to 3 I.doc

Mr. Brown,

Our staff has prepared a brief document (attached) to facilitate tomorrow's meeting on our HI-STORM 100U. Ms. Morin is out of the office today, and has asked me to forward the document to you so you can share it with the appropriate NRC attendees in case they wish to review it ahead of time.

Thank you.

Evan

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3.I Structural Evaluation

General Comments

Because a number of RAIs (namely, 3.7, 3.13, 3.14, 3.15, and 3.20) pertain to the use of SASSI for the seismic analysis of the Vertical Ventilated Module (VVM), to place our response to those RAIs in a proper perspective, it is necessary to review the antecedents of the SASSI analysis.

SASSI is a well benchmarked soil/structure interaction analysis code with excellent facilities to model large structures such as a multi-module VVM array. However, SASSI has certain fundamental limitations that prevented Holtec from using it in the seismic analysis of HI-STORM 100U, such as:

i. Inability to simulate impactive events, viz., MPC-to-Divider shell impacts that are intrinsic to any cask's seismic response.

ii. Inability to model non-linear soil effects including soil/structure separation (i.e., lift-off and differential lateral movement and separation of the VVM from the surrounding and underlying substrate).

We considered the limitations of SASSI to be too significant for it to serve as the Design Basis seismic analysis tool. Instead, we turned to LS-DYNA, which has excellent capabilities to simulate the non-linearities of the problem. This decision was guided by the industry's experience in a similar situation that pertained to the analysis of closely spaced free-standing fuel rack modules, when attempts to simulate fuel racks (for underwater wet storage) under earthquake events using a linear model had to be ultimately rejected in favor of a 3-D time-history approach. To avoid repeating the lengthy regulatory reviews and eventual retreat from a linear analysis to a non-linear one, Holtec proposed the use of LS-DYNA (a code well equipped to model impacts and other non-linearities) from the very beginning of the "100U" safety analysis effort in LAR 1014-3 in 2005. Of course, a non-linear code suffers from model size limitations, making it impossible to model all of the modules in a single simulation. To overcome this limitation in the state-of-the-art, Holtec used the only viable approach available, which was to make an ostensibly conservative single module non-linear model. This approach had the quintessential benefit of a 28-year old NRC endorsement in the context of fuel rack seismic analysis, where the "hydraulic coupling" effect coupled the motion of the individual racks in the pool in a phenomenological resemblance to the manner in which the soil continuum influences the motion of the proximate Vertical Ventilated Modules. The initial LS-DYNA model proposed by Holtec made an attempt to simplify the problem somewhat by attaching the internal rattling mass to the container shell and applying an empirical multiplier on the minimum required safety factor to account for their rattling effect. When the SFST demurred on the use of the penalty factor (of 2) on the safety factor to account for internal rattling, the LS-DYNA model was expanded to include the potential of rattling of all unfixed masses, thus dispensing with any recourse to empirical multipliers. At SFST's suggestion, a soil continuum between the foundation pad and the bedrock was added in the illustrative problem, which introduced "flexibility" to the foundation pad (another feature deemed to be desirable as discerned from SFST's RAIs). The updated LS-DYNA model in LAR 1014-6 thus composed, however, retained

its original mission to be *heuristically* conservative (in a direct parallel to the "single rack 3-D non-liner dynamic model" endorsed by the USNRC in the 1980s and thereafter used in fuel rack projects at over sixty different reactors). The essential features of the LS-DYNA non-linear model, articulated in Subsection 3.I.4.7.1 of Supplement 3.I are:

i. A single VVM is modeled on a foundation pad that circumscribes its base, even though the actual pad may extend far beyond;

ii. The soil substrate extends below the pad to the bedrock;

iii. The control motion is applied at bedrock;

iv. The subgrade surrounding the VVM is permitted to exhibit elastic-plastic behavior and

v. The impact forces from the possible rattling of the non-fixed masses, namely, the fuel assemblies, the fuel basket, MPC confinement boundary, and the lid, are simulated in the model faithfully by virtue of the inclusion and realistic modeling of the non-fixed internals.

Holtec's belief in the innate conservatism of the single module LS-DYNA model is premised on the physical reasoning that a truncated foundation base pad would render the structure more apt to sway during a seismic event and thus generate greater impact impulses from the non-fixed masses inside the VVM.

Holtec's emphasis from the very beginning, it should be noted, has been to devise a reliably robust and bounding seismic analysis model that will ensure that the SSI analysis of a proposed physical facility design at a particular site will be unfailingly conservative. This approach is also wholly consistent with the direction espoused by the SFST to minimize license amendment requests and to prevent throttling of site-specific improvements. Thus, in the SAR, while the LS-DYNA model is implemented as an illustrative physical problem, it is *not* meant to be the *licensing basis configuration.*

Finally,to place the ongoing effort in the historical perspective,the trajectory of the seismic analysis model, that spans almost three years,and involved an acceptance review, and two distinct amendment requests is summarized in the table below followed by explanatory verbiage.

Item	Date of Occurrence	Comments
LAR 1014-3	12/30/04	Initial Submittal
Acceptance Review	3/11/05; 3/23/05	Holtec requests suspension of review subsequent to NRC's Acceptance Review to incorporate enhancements; NRC documents structural issues, but none pertain to multiple VVMs or the LS-DYNA seismic model.
Resubmittal of Enhanced LAR 1014-3	5/16/05	-
RAI #1from SFST	11/30/05	No RAIs concerning the single VVM aspects of the LS-DYNA model

Holtec International submits RAI #1 Responses and Revised LAR 1014-3	2/18/06	The revised SAR continues to use the same LS-DYNA model because there were no RAIs that necessitated any change to it.
RAI #2 from SFST	6/6/06	New questions on dynamic analysis simulation (LS-DYNA) model including effect of internals, effect of substrate below pad, pad flexibility, and multiple VVMs.
Holtec/NRC Clarification Meeting	6/28/06	Holtec proposed to respond to all seismic analyses-related RAIs as follows: Include required methodology for site specific analysis of a single VVM as part of CoC. Includes illustrative solution that includes MPC, fuel basket, individual fuel assemblies, but applies control motion at base of foundation support pad. Rely on enhanced safety factor to provide margins for multiple VVMs. The Staff expressed no opposition to Holtec's proposed approach.
Holtec International submits RAI #2 Responses and Revised LAR 1014-3	7/10/06	Holtec revised the SAR to comply with the consensus reached in the July 10, 2006 meeting.
NRC Teleconference and Letter	11/16/06; 11/21/06	SFST informs Holtec that the revised submittal is not adequate. With NRC's consent, Holtec withdrew 100U material from LAR 1014-3 so that other items in LAR 1014-3 can be reviewed to completion.
Holtec/NRC Meeting to Outline Path Forward on 100U	12/11/06	Holtec proposes a confirmatory analysis plan using SASSI to focus on effect of multiple VVMs to examine the conservatism of its LS-DYNA solution. SFST concurs with the plan.
Holtec/NRC Pre-Submittal Meeting for LAR 1014-6	3/27/07	Holtec International presents results of the analysis plan presented previously on December 11, 2006, including confirmatory SASSI simulation with multiple VVMs and LS-DYNA single VVM solution. Staff concurs that results presented in meeting fully address all concerns raised during review of LAR 1014-3.
Initial Submittal of LAR 1014-6	4/27/07	Includes results from SASSI and LS-DYNA solution presented in the March 27th submittal.
RAI #1 for LAR 1014-6	2/28/08	New RAIs on seismic analysis surface.

From Holtec's vantage point, as noted in the above table, the lack of questions on RAI Round #1 in LAR 1014-3 seemed to confirm our LS-DYNA model's conservative credentials. However, in

RAI Round #2 dated June 6, 2006, this LS-DYNA solution became the object of new queries focused on its (admitted) lack of ability to model the multi-module arrays and concerns that the single VVM model did not model all components, such as flexible pad, rattling internals, etc. The Staff asked Holtec to demonstrate that the presence of multiple modules will not invalidate the conclusions from the LS-DYNA design basis solution. Holtec responded to RAI #2 with a revised submittal of LAR 1014-3.

Unfortunately, the timing of the Round #2 RAIs and the extensive amount of technical work needed to answer them to the complete satisfaction of the SFST eventually led Holtec, even after submitting the responses to the Round #2 RAIs together with the revised LAR 1014-3, to jettison the "100U" material from LAR 1014-3 so that the SFST could move to complete the review process on the remaining items. Holtec moved on to make a fresh submittal (LAR 1014-6) focused on the 100U.

Prior to making the LAR 1014-6 submittal however, there was interaction with SFST through a public meeting. It was suggested by SFST (and agreed to wholeheartedly by Holtec) that to address the outstanding SSI issues, including the "multi-module effect" question definitively, the linear SSI code SASSI could be employed. The interaction on this matter with the SFST led to Holtec proposing the performance of a number of multi-module, linear, soil/structure interaction studies on a 5x5 array with different patterns of loaded VVMs, by a third-party Holtec contractor. The single module characteristics used in the LD-DYNA methodology illustration problem would be retained so that it would be possible to not only study the effect of multiple modules, but also to compare this multi-module SASSI solution with the single module LS-DYNA solution.

The specific multi-module SASSI study plan was discussed and finalized in a public meeting on December 11, 2006. The analysis effort was completed and presented to SFST in a public meeting on March 17, 2007. The result, summarized in the table below for ease of reference, showed that:

- The single module LS-DYNA non-linear solution bounded every multi-module linear SASSI simulation by *large margins.*

- The multi-module effect is rather modest and the single module nonlinear (LS-DYNA) solution suffices to insure a bounding result.

The following table summarizes the results from the two codes and illustrates the overarching conservatism of the LS-DYNA solution:

Item	LS-DYNA	SASSI	Ratio of LS-Dyna-to-SASSI results
Max.CEC Primary STRESS	10 ksi	4.8 ksi	2.08
OVALITY (MEASURED AT MID-HEIGHT)	0.13 in	0.02 in	6.5
DISPLACEMENT DIFFERENCE BETWEEN TOP LID AND BASE OF VVM	3.87 in (include movement of lid relative to shell and rigid body rotation of shell)	0.155 in (includes some rigid body rotation of support pad)	25
PEAK PAD HORIZONTAL ACCELERATION AT BASE OF PAD DIRECTLY UNDER VVM CENTERLINE (UNFILTERED VALUE)	27 G"S (INCLUDES EFFECT OF IMPACTS)	0.692 G"S (NO IMPACT EFFECT)	39
PEAK FORCE ON PAD	612 kip (vertical) 257 kip (horizontal)	259.9 kip (vertical) 104.0 kip (horizontal)	2.35 2.47

NOTE: PAD FORCES FOR SASSI SOLUTION BASED ON LOADED VVM CENTROID ACCELERATIONS OF 1G HORIZONTAL AND 1.667 G VERTICAL

With the stout conservatism in the LS-DYNA model reaffirmed by the SASSI analyses, shared with the Staff on March 27, 2007, and positively received by the Staff during the public meeting, Holtec believed that a complete intellectual concurrence with the SFST on this matter had been reached, which led the Company to present the SAR in its present form in the April 27, 2007 submittal. Specifically, the single VVM non-linear LS-DYNA model was retained as the *Design Basis Analysis* model and the SASSI multi-body linear model studies were incorporated into the FSAR to memorialize the confirmatory work. The linear model implemented on SASSI is not designated as a design basis model and, therefore, evaluations to explore uncertainties and biases through sensitivity studies had not been performed on it. In the design of a specific ISFSI, sensitivity studies on all parameters subject to a significant uncertainty will be necessary as mandated in our QA program. However, to further emphasize the need for a sensitivity study, additional verbiage in the FSAR is being added. To summarize:

i. The ability of the LS-DYNA non-linear model described in Subsection 3.I.4.7.1 of the FSAR to prognosticate the system response in a conservative manner has been confirmed by making a series of parallel simulations on SASSI (a linear SSI code) and so documented in the FSAR.

ii. The FSAR will require that, for a specific ISFSI design, the LS-DYNA model will need to meet the provisions of ASCE 4-98 and ASCE/SEI 43-05 that could be applicable to the underground HI-STORM 100U, including a requirement for sensitivity analysis.

Finally, it should be clarified that the problem solved in the FSAR Supplement 3.I, using the LS-DYNA model, is only intended to serve as the illustration of the methodology, not define some "bounding" physical problem. Indeed, it is not practical (or necessary) to define a bounding

problem because of the numerous variables involved. This situation is no different from the ISFSI pads for the aboveground casks, where the variability in the subgrade properties led the NRC to specify the broad requirements (viz., AC-349) rather than a specific design. Likewise, the seismic limits for the aboveground HI-STORM are specified as a methodology if the empirical limits are not met (See Tech. Spec. Appendix B, Section 3.4). Reliance on a well articulated methodology to design *interfacing* structures has, quite fittingly, been an integral part of the general CoC approach enunciated by the government nearly two decades ago. The proposed Tech. Spec. for HI-STORM 100U for seismic evaluation is configured in a similar spirit.

The responses to the specific RAIs on SSI analysis rely on the foregoing historical information as the underlying subtext.