June 10, 2010

MEMORANDUM TO: Christine A. Lipa, Branch Chief
Division of Nuclear Materials Safety, Region III

FROM: Christopher Regan, Branch Chief **/RA/**
Structural Mechanics & Materials Branch
Division of Spent Fuel Storage and Transportation

SUBJECT: RESPONSE TO REGION III TECHNICAL ASSISTANCE REQUEST FOR FERMI POWER PLANT, UNIT 2

On April 2, 2010, NRC Region III transmitted a Technical Assistance Request (TAR) to the NMSS Division of Spent Fuel Storage and Transportation (SFST), concerning the independent spent fuel storage installation (ISFSI) pad constructed at the Fermi Power Plant, Unit 2 (Fermi). In your request, you asked that SFST perform a technical review of calculation DC-6382, "Storage Pad Design for ISFSI Casks" Revision B to determine whether the licensee's seismic analysis, and design of the pad met the regulatory requirements of 10 CFR 72. These questions were identified during a Region III inspection at the Fermi Power Plant, Unit 2. The scope of our review was limited to the evaluations provided in the referenced documents (ADAMS Accession Number ML100960336).

SFST has completed its review of the calculation of the Fermi ISFSI pad as documented in the enclosed response. The SFST staff determined that the methodology and approach for the seismic analysis and assessment of differential settlement for the ISFSI pad did not meet the requirements of 10 CFR 72.212(b). As a result, the seismic response of the casks appears to have been under predicted. In view of the fact that the ISFSI pad at Fermi has not been loaded with any storage casks at this point in time, staff found no immediate safety concerns regarding the robustness of the in-place ISFSI pad.

Please feel free to contact us if you have additional questions.

CONTACT: Gordon Bjorkman, SFST
301-492-3298

Docket No: 050-341; 072-00071

Enclosure: SFST Ticket No. 20100008, Response to Region III TAR - Fermi ISFSI Pad Design.

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Response to Region III Technical Assistance Request [TAR]
For Fermi Power Plant, Unit 2
Independent Spent Fuel Storage Installation (ISFSI) Pad
SFST Ticket Number: 20100008
Prepared By: Gordon S. Bjorkman

Scope:

United States Nuclear Regulatory Commission (NRC) Region III requested assistance from the Division of Spent Fuel Storage and Transportation, (NMSS/SFST); by memorandum dated April 2, 2010, to perform a technical review of the Fermi Power Plant, Unit 2 (Fermi) licensee (Detroit Edison) calculation DC-6382 (Reference 1) for the design of the Independent Spent Fuel Storage Installation (ISFSI) Pad to determine whether the licensee's seismic analysis, and design of the pad met the regulatory requirements of 10 CFR 72. This technical review was limited to the licensee's documentation, and the relevant calculations prepared by Fermi and/or their contractors and furnished together with the Technical Assistance Request (TAR) to NMSS/SFST.

The TAR requested assistance to resolve concerns related to the methodology and assumptions used in the seismic analysis of the ISFSI pad and the apparent lack of an evaluation for the effects of differential settlement. The results of the technical review will be forwarded to the United States Nuclear Regulatory Commission (NRC) Region III office to assist in assessing the issues identified in the inspection report(s) related to the adequacy of the design of the ISFSI pad at Fermi.

Problem Statement:

The licensee performed a seismic analysis and soil structure interaction analysis of the Independent Spent Fuel Storage Installation (ISFSI) storage pad in accordance with the guidance described in American Society of Civil Engineers Standard (ASCE) 4-98, "Seismic Analysis of Safety-Related Nuclear Structures" (Reference 2). The structural design of the ISFSI storage pad was performed in accordance with the requirements in American Concrete Institute (ACI) 349 "Code Requirements for Nuclear Safety Related Concrete Structures" (Reference 3). This Technical Assistance Request (TAR) requests a review to determine if the licensee has correctly applied the methodology in ASCE 4-98 and ACI 349 and appropriately calculated loads for the design of the pad.

Background:

Title 10 CFR 72.212(b)(2)(i)(B) requires that written evaluations be performed to establish that the cask storage pads and areas have been designed to adequately support the static and dynamic loads of the stored casks, considering potential amplification of earthquakes through soil-structure interaction, soil liquefaction potential, or other soil instability due to vibratory ground motion. At the Fermi Power Plant, Unit 2, the licensee performed calculation DC-6382, "Storage Pad Design for ISFSI Casks", Revision 0, which was subsequently revised to Revision B, to demonstrate compliance with the above regulatory requirement. Calculation DC-6382 was performed to analyze the pad, taking into consideration the soil structure interaction and the soil liquefaction potential, in order to determine the loads on the pad under a design basis seismic event.

During review of Calculation No. DC-6382, the inspectors made a number of observations, which are documented in Attachment A.

Based on these observations, the Region III inspectors have concerns that the licensee has not demonstrated that the Fermi ISFSI pad design meets the requirements stated in 10 CFR72.212(b)(2)(i)(B). In addition, since the methodology of ASCE Standard 4-98 used by the licensee for determining the loads on the pad and the methodology of ACI 349-01 used by the licensee for the structural design of the ISFSI pad involves a number of assumptions, the inspectors need assistance in determining the adequacy of the licensee evaluations.

Action Requested:
For assistance in resolution of the concerns identified in the TAR (Attachment A), the region is requesting a review of the licensee calculation DC-6382 by the NMSS staff. The specific questions / concerns are as follows:

1. Are the methodology and assumptions used in the seismic analysis of the storage pad and for determination of loads on the pad adequate? Does the seismic analysis of the ISFSI storage pad comply with the requirements in ASCE Standard 4-98 Section 3.1 and Section 3.2?

2. Is the licensee justification for seismic stability of ISFSI based on no amplification of the peak vertical and horizontal ground accelerations from the top of the pad to the center of gravity of the storage cask adequate? The licensee's justification for not amplifying the seismic accelerations from the top of the pad to the center of gravity of the cask is that the cask is rigid and that the maximum seismic accelerations of the storage cask are equal to zero period acceleration at the top of the storage pad.

3. Are the methodology and assumptions used in the soil structure interaction analysis of the storage pad for determination of loads on the pad adequate? Does the soil structure interaction analysis of the ISFSI storage pad comply with the requirements in ASCE Standard 4-98 Section 3.3.

4. Are the methodology and assumptions used for the structural design of the ISFSI storage pad adequate? Does ISFSI storage pad design comply with the requirements in ACI 349-01 Section 11 and Section 9.2?

Staff Evaluation of the Licensee's Seismic Soil-Structure Interaction Analysis:

Licensee Seismic Analysis Results

The licensee performed a seismic soil-structure interaction (SSI) analysis of the ISFSI pad using the impedance method given in ASCE 4-98 (Reference 2, Section 3.3.4). This simplified SSI analysis method assumes the ISFSI pad and casks are rigid bodies and models them as lumped masses attached to soil springs and dash-pots.

The licensee developed one single degree of freedom (DOF) model to evaluate horizontal translational motion and another to evaluate vertical translational motion. The lumped mass in each model consisted of the weight of the pad and the smeared weight of all 64 casks. Each model employed two different soil spring stiffnesses, one for the lower bound soil shear wave velocity and one for the upper bound soil shear wave velocity. The frequency results from these models are tabulated below as taken from Reference 1.

Horizontal Translation:

Shear Wave Velocity	Frequency
520 fps	3.35 Hz
1100 fps	7.09 Hz

Vertical Translation:

Shear Wave Velocity	Frequency
520 fps	3.67 Hz
1100 fps	7.76 Hz

The site specific horizontal and vertical spectra are essentially flat between 3.5 Hz and 9.0 Hz with a peak horizontal value of 0.32g and peak vertical value of 0.22g at 10% damping. Given the frequency range associated with the lower and upper bound shear wave velocities, the licensee chose to use the peak 10% damped values and convert them to 20% damped values as allowed by ASCE 4-98 Section 3.1.5.4 (Reference 2). The 20% damped values for horizontal and vertical ground motion are 0.23g and 0.17g respectively.

Staff Assessment

The modeling guidance provided in ASCE 4-98 for the dynamic analysis of structures and seismic SSI analysis is as follows:

Section 3.1.1(d) The model shall represent the actual locations of the centers of masses and centers of rigidity, thus accounting for the torsional effects caused by the eccentricity.

Section 3.1.4.1(b) When appropriate, three translational and three rotational DOF shall be used at each node point. Some DOF may be neglected, such as rotation, provided their exclusion does not affect the response significantly. The following conditions shall be met:

1. Structural mass shall be lumped so that the total mass, as well as the center of gravity, is preserved, both for the total structure and for any of its major components that respond in the direction of motion.

2. The number of dynamic DOF, and hence the number of lumped masses, shall be selected so that all significant vibration modes of the structure can be evaluated.

Section 3.3.1.8(a) Structural models defined in Section 3.1 may be simplified for SSI analysis. Simplified models may be used provided they adequately represent the mass and stiffness effects of the structure and adequately match the dominant frequencies, related mode shapes, and participation factors of the more detailed structure model.

As discussed in the previous section, for both horizontal and vertical seismic input motion, the licensee constructed a single degree of freedom model lumping all of the pad and cask mass together at a single mass point, and only considered translational motion while ignoring the effects of rocking and torsion. In the licensee's calculation (Reference 1) there is no discussion as to why it was appropriate to lump all of the cask and pad mass at a single mass point or why the rocking and torsional modes of response were not considered, as required by the ASCE 4-98 Sections cited above, and which the licensee used as the referenced basis for construction of the SSI ISFSI pad model.

In addition, only one configuration of casks (all 64) on the pad was considered. In Section 9.5 of the licensee's calculation (Reference 1), where the results of the static computer analyses are presented, many cask loading configurations were considered, yet for the seismic SSI analysis only one configuration was used. This single configuration and lumped mass approach results in no eccentricity of the cask mass with respect to the center of rigidity, which in turn precludes any rocking or torsional response. This approach disregards the modeling guidelines of ASCE 4-98, and the licensee provides no explanation for deviating from these guidelines.

Staff's Independent SSI Analysis

To attempt to quantify the impact of the licensee's deviations from the guidelines of ASCE 4-98, the staff developed a number of two degree of freedom models following the guidelines of ASCE 4-98. The staff only performed analyses for a site soil shear wave velocity of 520 fps. Four analysis cases were evaluated.

1. Horizontal Translation + Rocking — All 64 Casks on Pad
2. Horizontal Translation + Rocking — 8 Casks in Row 1
3. Horizontal Translation + Torsion — 8 Casks in Row 1
4. Vertical Translation + Rocking — 8 Casks in Row 1

For each case the staff calculated mode frequencies, mode shapes and participation factors. The spectral acceleration associated with each frequency was taken from the 20% damped response spectra and modal responses were combined using the SRSS method. The results from these four cases are given in Table 1 below:

TABLE 1

Analysis Case	SRSS Response at Cask c.g.
1	0.231 g
2	0.231 g
3	0.254 g
4	0.181 g

Combining the two horizontal spatial responses (Cases 2 and 3) using the 100-40-40 method given in ASCE 4-98 Section 3.2.7.1.2, the staff obtained a maximum horizontal response of 0.27g. The staff and licensee maximum responses are compared in Table 2 below.

TABLE 2

	Licensee Responses	Staff Response
Horizontal	0.23g	0.27g
Vertical	0.17g	0.19g

For the analysis cases considered by the staff, these results show that not following the guidelines of ASCE 4-98 results in an underestimate of seismic response. It is important to note that both results assume the pad is rigid, when in fact; a two foot thick pad with plan dimensions of 141’ x 141’ is not rigid. Section C3.3.1.6 of ASCE 4-98 discusses the effects of mat (pad) flexibility. This section states that

> “For typical nuclear power plant structures, the effect of mat flexibility for mat foundations… need not be considered in SSI analysis. Although foundations and walls may appear to be flexible when taken by themselves, an effective stiffness of the foundation must be evaluated to adequately assess its flexibility. The effective stiffness is a function of the foundation itself and the stiffening effect of structural elements tied to the foundation. The latter item contributes significant stiffening effects in typical nuclear power plant containment and shear wall structures.”

Since there are no structural elements tied to the foundation pad, the pad must be considered flexible and its effects considered.

The influence of pad flexibility on response can be estimated from Reference 7, in which a series of SASSI SSI analyses are performed for a range of pad thicknesses from a very flexible 1.5 foot thick pad to a much stiffer 4.0 foot thick pad. By comparing the response at the cask center of gravity of the 4 foot thick pad to the response at the cask center of gravity of a more flexible 2 foot thick pad, which is the thickness of the licensee’s pad, an estimate of the effect of pad flexibility on response can be made. Reference 7 considers two cases, one with 3 casks on the pad and another with all casks on the pad. From the seismic response output in the long (y) direction of the pad for three casks on the pad the response at the cask c.g. for a 4 foot thick pad is 0.172g and the response for a 2 foot thick pad is 0.206g. This results in an estimated increase in cask response due to pad flexibility of 1.20 (0.206/0.172 = 1.20) for the case of three casks on the pad. For the case in Reference 7 with all casks on the pad the increase in cask response due to pad flexibility is 1.05. This lower value results from the close interaction of adjacent casks when all casks are on the pad. The influence of pad flexibility on vertical response is small and can be neglected. Accounting for pad flexibility using the higher of the two values, the estimated response comparison is shown in Table 3.

<u>TABLE 3</u>

	Licensee One DOF Model	Staff Two DOF Model	Pad Flexibility Factor	Staff Estimated Final Response	Percent Increase
Horizontal	0.23g	0.27g	1.2	0.32g	40
Vertical	0.17g	0.19g	1.0	0.19g	12

Based on the staff’s independent assessment, the staff finds that by not following the modeling guidelines of ASCE 4-98 for performing a seismic SSI analysis and by not considering the influence of pad flexibility on response, the licensee may have significantly under-predicted the seismic response of the casks, and thus significantly under-estimated the seismic demand on the ISFSI pad.

Staff Evaluation of Differential Settlement:

The ACI 349-01 Code (Reference 3), which is the criteria document for the design of the ISFSI pad, states in Section 9.2.2 that "Where the structural effects of differential settlement, creep or shrinkage may be significant, they shall be included with dead load D in Load Combinations…." In response to Region III inspection questions the licensee contends that by having analyzed the pad for two different sets of modulus of sub-grade reactions with four different values at various locations beneath the pad that the effects of differential settlement have been considered (References 5 and 6).

Staff Assessment

On page 9 of the licensee's calculation (Reference 1) the soil sub-grade moduli are given for the center, middle, edges and corners of the ISFSI pad for the upper and lower bound soil properties, where the highest values are at the corners and edges of the pad. This distribution of higher soil spring stiffness around the pad perimeter and lower soil spring stiffness in the middle and center of the pad is the necessary distribution of soil foundation spring stiffnesses required to duplicate the behavior of a pad resting on actual soil (i.e., an elastic half-space). If an elastic half-space finite element model were used instead of a soil spring model to support the pad, this same distribution of soil spring stiffness would occur naturally. It is precisely because a soil foundation spring model is being used for the analysis instead of an elastic half-space foundation model that this distribution of soil spring stiffness must be used. The differences in stiffness among the soil sub-grade moduli within these four regions beneath the pad have nothing to do with differential settlement caused by soil consolidation and creep under load over time. The staff was unable to find evidence that an analysis of soil consolidation and settlement due to long term loading was performed by the licensee. Without such an analysis the effects of differential settlement cannot be evaluated. Therefore, the staff finds the licensee's argument that differential settlement has been incorporated in the calculation by virtue of the distribution of soil spring stiffnesses that were used to be without merit.

Summary and Conclusions:

NRC/HQ -SFST staff reviewed the licensee calculation DC-6382 and other pertinent documents presented to the NRC/HQ staff, for the Fermi ISFSI pad and storage casks. The purpose of the calculation by the licensee was to evaluate the seismic response of the ISFSI pad under the SSE for the site, and to qualify structural design of the ISFSI pad for all other design loads. In response to the concerns posed by the region, SFST staff finds the following:

(1) In the licensee calculation DC-6382 there is no discussion as to why it was appropriate to lump all of the cask mass with the pad mass at a single mass point, or why the rocking and torsional modes of response were not considered, as required by the ASCE Standard 4-98. In addition, only one configuration of all 64 casks on the pad was considered. In Section 9.5 of DC-6382, where the results of the static computer analyses are presented, many cask loading configurations were considered, yet for the seismic SSI analysis only one configuration was used. This single configuration and lumped mass approach used by the licensee results in no eccentricity of the cask mass with respect to the center of rigidity, which in turn precludes any rocking or torsional response. This approach disregards the modeling guidelines of ASCE 4-98, and the licensee provides no explanation for deviating from these guidelines.

To attempt to quantify the impact of the licensee's deviations from the guidelines of ASCE 4-98, the staff developed a number of two degree of freedom models following the guidelines of ASCE 4-98. Based on the staff's independent assessment, the staff finds that by not following the modeling guidelines of ASCE 4-98 for performing a seismic SSI analysis and by not considering the influence of pad flexibility on response, the licensee may have significantly under-predicted the seismic response of the casks, and thus significantly under-estimated the seismic demand on the ISFSI pad.

(2) In response to Region III inspection questions regarding differential settlement, the licensee contended that by having analyzed the ISFSI pad for two different sets of modulus of sub-grade reactions with four different values at various locations beneath the pad, that the effects of differential settlement have been considered. In the licensee calculation DC-6382 the soil sub-grade moduli are given for the center, middle, edges and corners of the ISFSI pad for the upper and lower bound soil properties, where the highest values are at the corners and edges of the pad. This distribution of higher soil spring stiffness around the pad perimeter and lower soil spring stiffness in the middle and center of the pad is the necessary distribution of soil foundation spring stiffness required to duplicate the behavior of a pad resting on an elastic half-space. If an elastic half-space finite element model were used instead of a soil spring model to support the pad, this same distribution of soil spring stiffness would occur naturally. It is precisely because a soil spring model is being used for the analysis instead of an elastic half-space that this distribution of soil spring stiffness must be used.

The staff concludes that the differences in stiffness among the soil sub-grade moduli within these four regions beneath the pad have nothing to do with differential settlement caused by soil consolidation under load over time. The staff was unable to find evidence that an analysis of soil consolidation and settlement due to long term loading was performed by the licensee. Without such an analysis the effects of differential settlement cannot be evaluated. Therefore, the staff finds the licensee's argument that differential settlement has been incorporated in the calculation by virtue of the distribution of soil spring stiffnesses that were used to be without merit.

The SFST staff does not concur with the methodology and approach currently presented for the seismic analysis and assessment of differential settlement for reasons discussed above. The results and conclusions presented by the licensee are therefore not acceptable to the staff. In view of the fact that the ISFSI pad at Fermi has not been loaded with any storage casks at this point in time, staff found no immediate safety concerns regarding the robustness of the in-place ISFSI pad. However, the documentation provided, to date, falls short of demonstrating that the pad meets regulations specified in 10 CFR 72.212(b).

References

1. Calculation No. DC-6382, “Storage Pad Design for ISFSI Casks” Revision B, ML100900249
2. American Society of Civil Engineers Standard ASCE 4-98, “Seismic Analysis of Safety-Related Nuclear Structures”, 2000
3. American Concrete Institute ACI 349-01, “Code Requirements for Nuclear Safety Related Concrete Structures”, 2001
4. Certificate of Compliance (COC) for Spent Fuel Storage Casks issued to HOLTEC International, Docket No. 72-1014, Certificate No. 1014, Amendment No. 5, ML082030116
5. ISFSI Pad Inspection Document – “Response to Questions on December 1, 2009” ML100900268
6. ISFSI Pad Inspection Document – “Response to Questions on December 29, 2009,” ML100900270
7. Bjorkman,G., et al.,”Influence of ISFSI Design Parameters on the Seismic Response of Dry Storage Casks,” *Transactions*, Structural Mechanics in Reactor Technology Conference, Washington DC, August 2001.

ATTACHMENT A

REGION III TECHNICAL ASSISTANCE REQUEST
FOR FERMI POWER PLANT, UNIT 2
INDEPENDENT SPENT FUEL STORAGE INSTALLATION (ISFSI) PAD

Package Accession No. ML100960336