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Sent: Thursday, November 21, 2013 4:19 PM
To: FermiCOL Resource
Subject: FW: Scanned Package Given to Staff (Part 4 of 6)
Attachments: Audited Materials 11-21-2013 - Part 4.pdf

From: Michael K Brandon [mailto:brandonm@dteenergy.com]
Sent: Thursday, November 21, 2013 4:13 PM
To: Govan, Tekia
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From: Govan, Tekia

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3.7-20

(1 page)

slightly higher response. The planned fill concrete with shear dowels is anticipated to remain essentially linear under the anticipated ground motion levels. Thus, the shear modulus reduction values for the fill concrete were set to 0.9999 for strain levels less than 3 percent and to 0.999 at higher strain levels.

Below the engineered granular backfill and fill concrete, the remaining portion of the full soil column and FWSC site response analysis profiles consists of dolomite and claystone bedrock, as discussed in Subsection 2.5.2.5.1.2. The bedrock is expected to remain essentially linear at low to moderate levels of shaking. Damping within the in-situ dolomite and claystone bedrock is characterized by a high-frequency attenuation parameter κ that ranges from 0.001 and 0.003 seconds (Subsection 2.5.2.5.1). The values of κ established in Subsection 2.5.2.5.1 were used to develop the site response analysis for the Fermi 3 site.

As part of the development of the SSI inputs, the representation of damping in the in-situ bedrock was simplified from the seven different damping layers indicated in FSAR Table 2.5.2-213 and Table 2.5.2-214 to the four different damping layers listed in FSAR Table 3.7.1-201, Table 3.7.1-202, and Table 3.7.1-203. Sensitivity studies indicated that this simplification in the number of layers produces less than 0.1 percent difference in the mean amplification functions.

3.7.1.1.4.1.1.3 **Randomization of Dynamic Properties**

Site response analyses for the full soil column and FWSC profiles were conducted using randomized dynamic soil properties following the methods described in Subsection 2.5.2.5.1.3. The randomized dynamic properties included shear wave velocity, modulus reduction, and damping. Additionally, the locations of velocity layer boundaries were randomized to vary uniformly within the range of layer thickness observed in the site borings.

Sixty randomized V_S profiles were generated for each of the LR, IR, and UR site response analysis profiles (a total of 180 randomized V_S profiles for development of the PBSRS and SCOR FIRS). Sixty randomized V_S profiles were also generated for the FWSC site response analysis profile. The statistics of the randomized profiles are summarized by comparing to the input target values for median velocity and standard deviation (sigma) of ln(V_S) for the LR, IR, UR, and FWSC profiles. As an example of this process, Figure 3.7.1-204 to Figure 3.7.1-206 show the 60 randomized velocity profiles and the statistics of the randomized shear wave velocity profiles for the IR site response analysis profile.

The modulus reduction and damping relationships associated with the LR, IR, and UR full column site response analysis profiles were also randomized as shown on Figure 3.7.1-207, Figure 3.7.1-208, and Figure 3.7.1-209, respectively. The standard deviation in the modulus reduction

3.7-21 (3 pages)

model for V_{S30} values of 830 m/s (2,720 ft/s) and 421 m/s (1,380 ft/s). These V_{S30} values corresponded to the firm rock and soft rock categories of Campbell and Bozorgnia (Reference 3.7.1-213). The result suggests a trend similar to the Campbell and Bozorgnia (Reference 3.7.1-213) result.

Figure 3.7.1-220 shows V/H spectral ratios as a function of frequency used for generating the vertical PBSRS at the finished ground level grade, and the V/H spectral ratios recommended by NUREG/CR- 6728 (Reference 3.7.1-202) for CEUS bedrock sites with a PGA between 0.2 g and 0.5 g. The V/H spectral ratios used for generating the vertical PBSRS are based on the V/H spectral ratios recommended by NUREG/CR-6728 (Reference 3.7.1-202) for CEUS bedrock sites with a shift in the frequencies above 10 Hz to represent the shift in the peak V/H spectral ratios towards lower frequencies in the Campbell and Bozorgnia (Reference 3.7.1-213) and Gülerce and Abrahamson (Reference 3.7.1-215) comparisons. Additionally, at frequencies below 9 Hz, the V/H spectral ratio is reduced slightly to reflect the differences observed in the Campbell and Bozorgnia (Reference 3.7.1-213) and Gülerce and Abrahamson (Reference 3.7.1-215) comparisons. The resulting vertical PBSRS is listed in Table 3.7.1-205 along with the values of V/H. Figure 3.7.1-221 shows the horizontal and vertical PBSRS (5 percent damping) at the finished ground level grade.

The 60 randomized full soil column profiles were developed for each of the nine alternative sets of dynamic propertied (three alternative sets of engineered granular backfill properties and three alternative sets of damping values in the in situ bedrock). These 540 profiles were then used in site response analyses with the time histories matched to the 10^{-4} and 10^{-5} HF and LF DEL, DEM, and DEH response spectra. The results of these calculations produced a total of 1,620 profiles of strain-compatible dynamic properties for each of the 10^{-4} and 10^{-5} HF and LF exceedance levels of input motion. Each strain-compatible profile was assigned a weight equal to the product of the weights on the corresponding branches of the site response logic tree shown in Figure 3.7.1-210. The resulting values of shear wave velocity and damping in each soil layer were then ranked in increasing order and the empirical 16th, 50th, and 84th percentile values were identified for the four loading levels.

3.7.1.1.4.3.3 Deterministic Profiles for SSI Analyses

Three deterministic profiles, the best estimate (BE), lower bound (LB), and upper bound (UB), were developed from the full soil column site response analysis following the requirements of Standard Review Plan (SRP) 3.7.2 and guidance from the Interim Staff Guidance DC/COL-ISG-017. These profiles were based on the statistics of the iterated soil properties for the randomized full soil column profile described in Subsection 3.7.1.1.4.1.1.3, and include the engineered granular backfill above the top of the Bass Islands Group bedrock.

The deterministic BE profile with engineered granular backfill above the top of the Bass Islands Group bedrock was set equal to values interpolated between the median iterated soil properties for the 10^{-4} and 10^{-5} exceedance level ground motions using linear interpolation based on the PGA values for the 10^{-4} and 10^{-5} UHRS and the PGA for the PBSRS. The 50th percentile properties for the HF and LF input motions were averaged to produce the BE profile. The resulting subsurface layers and the corresponding strain

compatible dynamic engineering properties for the full soil column BE profile are listed in Table 3.7.1-206.

The deterministic LB profile with engineered granular backfill above the top of the Bass Islands Group bedrock was set equal to the 16th percentile of the distribution of randomized soil properties interpolated between the 10^{-4} and 10^{-5} exceedance level ground motions, and the deterministic UB profile with engineered granular backfill above the top of the Bass Islands Group bedrock was set equal to the 84th percentile of the distribution of randomized soil properties interpolated between the 10^{-4} and 10^{-5} exceedance level ground motions. The range in the UB and LB shear wave velocities was increased where necessary to maintain the minimum variation from the shear modulus for the deterministic BE profile (G_{BE}) required in SRP 3.7.2. The minimum variation is defined by a multiplicative factor of 1 plus the minimum coefficient of variation (COV) in shear modulus such that G_{UB} is greater than or equal to the G_{BE} x $(1+COV_{min})$ and G_{LB} is less than or equal to G_{BE} / $(1+COV_{min})$. SRP 3.7.2 specifies that the minimum COV for well studied sites is 0.5 and for sites less well investigated the minimum COV should be at least 1.0. The in-situ subsurface materials have been well investigated at the Fermi 3 site and a COV of 0.5 was used to establish the minimum variation in G between the LB, BE, and UB profiles in these materials. However, properties of the engineered granular backfill are estimates based on a range of possible characteristics. Therefore, a minimum COV of 1.0 was used in establishing the minimum variation in G between the LB, BE, and UB profiles in the engineered granular backfill. Table 3.7.1-207 and Table 3.7.1-208 list the resulting subsurface layers and the corresponding strain compatible dynamic engineering properties for the LB and UB deterministic profiles, respectively, with engineered granular backfill above the top of the Bass Islands Group bedrock.

To maximize the range of values, the minimum values from the LF and HF ground motions were used for the 16th percentile and the maximum of the LF and HF ground motions were used for the 84th percentile.

Figure 3.7.1-222 shows the full soil column LB, BE, and UB subsurface shear wave velocity profiles with engineered granular backfill above the top of the Bass Islands Group bedrock for the Fermi 3 site. The corresponding damping ratios were obtained from the statistics of the iterated profiles assuming negative correlation between shear wave velocity (V_S) and damping: that is, the 16th percentile damping for the full soil column UB profile and the 84th percentile damping for the full soil column LB profile. The compression wave velocities were based on the shear wave velocities in the LB, BE, and UB shear wave velocity profiles

with engineered granular backfill above the top of the Bass Islands Group bedrock, the recommend Poisson's ratios in Table 2.5.4-202, and the relationship from Kramer (Reference 3.7.1-206) presented as follows:

$$\frac{V_P}{V_S} = \sqrt{\frac{2-2v}{1-2v}} \qquad \text{[Eq. 6]}$$

Where:

V_P is the compression wave velocity

V_S is the shear wave velocity

v is the Poisson's ratio

The bedrock and portions of the engineered granular backfill are below the groundwater table at the Fermi 3 site. The compression wave velocities in the bedrock exceeded the 1,460 m/s (4,790 ft/sec) the compression wave velocity of water from the DCD; therefore, a minimum compression wave velocity of 1,460 m/s (4,790 ft/sec) for the bedrock below the groundwater table was not imposed. In the engineered granular backfill, the compression wave velocities were less than the minimum value of 1,460 m/s (4,790 ft/sec) below the anticipated groundwater table. However, the compression wave velocities were not increased to the minimum value of 1,460 m/s (4,790 ft/sec) in the engineered granular backfill. Instead, the compression wave velocities were increased to the lower value of either 1,460 m/s (4,790 ft/sec) or the compression wave velocity that resulted in a maximum Poisson's ratio of 0.48 for the corresponding LB, BE, and UB shear wave velocity.

Figure 3.7.1-223 shows the LB, BE, and UB subsurface shear wave velocity profiles without engineered granular backfill above the top of the Bass Islands Group bedrock for the Fermi 3 site near the RB/FB and CB. Table 3.7.1-209, Table 3.7.1-210, and Table 3.7.1-211 present the BE, LB, and UB deterministic profiles without the engineered granular backfill above the top of the Bass Islands Group bedrock. The deterministic profiles without the engineered granular backfill above the top of the Bass Islands Group bedrock are the same as the deterministic profiles for the full soil column below the top of the Bass Islands Group bedrock.

3.7.1.1.4.4 SCOR FIRS for the RB/FB and CB

The process described in Subsection 3.7.1.1.4.3 was used to develop the SCOR FIRS at the RB/FB and CB foundation levels. The SCOR FIRS are shown on Figure 3.7.1-224 and Figure 3.7.1-225 for the RB/FB and

3.7-23 (13 pages)

presented in Table 3.7.1-219. Figure 3.7.1-245 to Figure 3.7.1-250 present the matched time histories (outcropping motions) compatible with the RB/FB and CB enhanced SCOR FIRS at the foundation levels. The duration and the value of PGV/PGA (Table 3.7.1-219) are generally consistent with the characteristic values reported in NUREG/CR-6728 (Reference 3.7.1-202); however, the values of PGA*PGD/PGV^2 are larger. The hard rock UHRS for the Fermi 3 site represents a combination of hazard from large, distant earthquakes and smaller, closer earthquakes. Thus, it is expected that the PGA is enriched to represent smaller magnitude, closer earthquakes. Spectral matching of the time histories to response spectra extended to a period of 10 seconds also enriches the PGD values, leading to an increase in the values of PGA*PGD/PGV^2.

Insert 3.7.1-1 →

~~As an additional demonstration of sufficient power in the spectrally matched time histories, the PSD were calculated for the frequency range of 0.3 to 50 Hz and compared to the target PSD based on the guidelines and procedures provided in Appendix B of SRP 3.7.1. The target PSD were developed by enveloping the magnitude-distance bins for the CEUS rock sites given in of Appendix B of SRP 3.7.1 that correspond to the RE's in Table 2.5.2-212 for the 10^{-4} and 10^{-5} exceedance levels of ground motion. The target PSD for the RB/FB and CB were then determined by scaling the enveloping spectrum by the square of the PGA (spectral acceleration at 100 Hz) based on the enhanced SCOR FIRS in Table 3.7.1-214 and Table 3.7.1-215, respectively. The duration of near maximum and nearly stationary power used to calculate the PSD for the spectrally matched time histories was determined in accordance with SRP 3.7.1 and the additional guidance in NUREG/CR-5347 (Reference 3.7.1-221). Figure 3.7.1-251 presents the duration measurements for the horizontal components of the matched time histories compatible with the RB/FB enhanced SCOR FIRS. These measurements resulted in duration values of 30 and 31.5 seconds, which were slightly greater than the duration for the Arias Intensity to increase from 5 to 75 percent. Figure 3.7.1-252 and Figure 3.7.1-253 present the scaled target PSD based on Appendix B of SRP 3.7.1, 80 percent of the target PSD, and the PSD for the horizontal spectrally matched time histories for the RB/FB and CB, respectively. The PSD for the spectrally matched time histories envelop the corresponding target PSDs and, thus, satisfy the SRP 3.7.1 criterion of enveloping 80 percent of the target PSD to demonstrate there is no deficiency of power.~~

Insert 3.7.1-1

To demonstrate that there are no significant gaps in power for the spectrally-matched time histories, power spectral densities (PSD) were calculated for the frequency range of 0.3 to 50 Hz following the guidance in SRP 3.7.1, Appendix B. The equivalent stationary duration, T_D, used to calculate the PSD for the spectrally-matched time histories was established in general accordance with SRP 3.7.1 and the additional guidance in NUREG/CR-5347 (Reference 3.7.1-221). Figure 3.7.1-251 presents the normalized Arias intensities for the horizontal components, H1 and H2, of the spectrally matched time histories compatible with the RB/FB enhanced SCOR FIRS. The normalized Arias intensity plots for the spectrally matched time histories compatible with the CB enhanced SCOR FIRS are not presented since they are essentially identical to Figure 3.7.1-251.

The PSD was evaluated using the following two approaches for computing the Fourier amplitudes:

- Using the full duration of the spectrally matched time histories.
- Using only the portion of the spectrally matched time histories corresponding to the equivalent stationary duration.

Appendix B of NUREG/CR-5347 (Reference 3.7.1-221) indicates that T_D is estimated by identifying the portion of the time history where the slope (power) of a cumulative energy plot (represented by normalized Arias intensity) is nearly constant and near maximum. Figure 3.7.1-251 provides a range of estimates of constant power slopes for the two horizontal RB/FB components.

The Fermi 3 FIRS represent the combined effects of two distinct earthquakes, a nearby moderate magnitude earthquake and a distant large earthquake (New Madrid). The seed time history for spectral matching was selected to represent the long duration expected in a distant recording of a large magnitude earthquake. As illustrated by the spectrally matched acceleration and velocity time histories on Figures 3.7.1-245 and 3.7.1-246, the time histories exhibit non-stationarity that results in high frequency energy more prominent in the early portion of the records and low frequency energy more prominent in the latter portion of the records. Because of the long duration and non-stationarity of the recording, longer values of T_D are needed to better represent the energy content of the recordings. Therefore, the time for the Arias intensities to rise from 0 to 100 percent is used to establish T_D instead of the more commonly used time to rise from 5 to 75 percent Arias intensity. This time was established by extending the constant power slopes to 0 percent and 100 percent Arias intensity, as shown on Figure 3.7.1-251, and the time between the intersection with the 0 and 100 percent Arias intensity levels was used to establish a value of T_D.

Use of the full duration of the spectrally matched time history records to compute the Fourier amplitudes for the PSD captures the full frequency content of the records, which is consistent with the SSI analyses that also use the full duration time history records. Values of T_D of 30 seconds for the H1 component and 31.5 seconds for the H2 component were selected from the range of estimated values for the PSD calculation using the full duration of the spectrally

Insert 3.7.1-1 (Continued)

matched time histories. The resulting PSDs for the horizontal spectrally matched time histories are shown on Figure 3.7.1-252, Figure 3.7.1-253, Figure 3.7.1-254, and Figure 3.7.1-255 for the RB/FB H1 component, the RB/FB H2 component, the CB H1 component, and CB H2 component, respectively. As demonstrated in these figures, with the full duration considered, the spectrally matched time histories have no significant gaps in power over the frequency range of 0.3 to 50 Hz.

Appendix B of SRP 3.7.1 indicates the PSD is calculated using the portion of the spectrally matched time history corresponding to T_D. The effect of using only the TD portion of the time histories to compute the PSD is illustrated on Figure 3.7.1-252 through Figure 3.7.1-255. On each figure, the different PSD are calculated using the portion of the spectrally matched time history windowed to the different T_D values shown on Figure 3.7.1-251. Outside of the TD window, a two second duration cosine taper was applied to reduce the time history amplitude to zero.

For the RB/FB H1 component shown on Figure 3.7.1-252, the PSD for the windowed time histories are similar to the PSD computed using the full duration time history. There is a decrease in amplitude at frequencies above 30 Hz and below 1 Hz. The observed decreases reflect the fact that some of the energy content at these frequencies occurs outside of the selected T_D time window. For the shortest T_D of 30 seconds, a narrow dip in power occurs in the low frequency range near 0.4 Hz. However, the PSD for the windowed time histories are generally similar to the PSD using the full duration time history and show no significant gaps in power.

Figure 3.7.1-253 shows the results for the RB/FB H2 component. The PSD for the windowed time histories are also similar to the PSD computed using the full duration time history. There is a decrease in amplitude at frequencies above 25 Hz, and between 0.7 and 1 Hz, again reflecting that some of the energy content at these frequencies occurs outside of the selected T_D time window. As was the case for the H1 component, the PSD for the windowed time histories are generally similar to the PSD using the full duration time history and show no significant gaps in power.

Figure 3.7.1-254 and Figure 3.7.1-255 show the corresponding comparisons for the CB H1 and CB H2 components, respectively. The results are similar to those shown for the corresponding RB/FB components.

In summary, the PSDs computed using the full duration, spectrally matched time histories show that there are no significant gaps in power over the frequency range of 0.3 to 50 Hz. PSDs computed using the windowed portion of the spectrally matched time histories corresponding to T_D also show no significant gaps in power. There is a narrow dip in power near 0.4 Hz using the window corresponding to a T_D of 30 seconds for the H1 component for both the RB/FB and CB. However, extending TD to 32, 34, or 36 seconds eliminates this narrow dip. The PSD computed using the windowed time histories show a decrease in power compared to PSD computed using the full duration time histories above 25 Hz. This difference indicates a degree of non-stationarity in the time histories, but does not produce significant gaps in the frequency range of 0.3 to 50 Hz.

In accordance with Interim Staff Guidance DC/COL-ISG-017 and the NEI developed white paper (Reference 3.7.1-201), the spectrally-matched time histories compatible with the RB/FB and CB enhanced SCOR FIRS were then input as outcropping motions at the foundation level into the LB, BE, and UB deterministic profiles without engineered granular backfill above the top of the Bass Islands Group bedrock to compute the resulting in-column motions at the RB/FB and CB foundation levels using the program SHAKE (Reference 3.7.1-222). A total of 18 SHAKE analyses were performed using combinations of the LB, BE, and UB deterministic profiles without engineered granular backfill above the top of the Bass Islands Group bedrock, the three time history components (two horizontal and one vertical components) and the two foundation levels (RB/FB and CB). The SHAKE analyses were performed using the LB, BE, and UB deterministic profiles in Table 3.7.1-209, Table 3.7.1-210, and Table 3.7.1-211 without iteration of soil properties to generate in-column motions at the foundation levels for input into the Fermi 3 site specific SSI analysis without engineered granular backfill above the top of the Bass Islands Group bedrock.

In-column motions at the foundation levels were also generated for the LB, BE, and UB deterministic profiles with engineered granular backfill above the top of the Bass Islands Group bedrock in Table 3.7.1-206, Table 3.7.1-207, and Table 3.7.1-208. The SHAKE analyses were performed using the spectrally-matched time histories compatible with the RB/FB and CB enhanced SCOR FIRS and without iteration of soil properties to generate 18 additional in-column motions at the foundation levels for the Fermi 3 site specific SSI analysis with engineered granular backfill above the top of the Bass Islands Group bedrock.

To evaluate the energy present at different frequencies in the 36 in-column acceleration time histories, power spectra were computed for each of the time histories. The cumulative power was then calculated from 0 to 100 Hz to determine what percentage of power is below 50 Hz in the in-column acceleration time histories. As an example, Figure ~~3.7.1-254~~ presents the power spectrum and cumulative power plots for the horizontal (H1 and H2) in-column acceleration time history compatible with the BE deterministic profile without engineered granular backfill above the top of the Bass Islands Group bedrock. Table 3.7.1-220 presents the percentage of the cumulative power below 50 Hz for each in-column acceleration time history. The horizontal components include

3.7.1-256