

REVISED RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.: 182-8160
SRP Section: 03.07.01 – Seismic Design Parameters
Application Section: 3.7.1
Date of RAI Issue: 08/31/2015

Question No. 03.07.01-3

10 CFR 50 Appendix S requires that the safety functions of structures, systems, and components (SSCs) must be assured during and after the vibratory ground motion associated with the safe shutdown earthquake (SSE) ground motion through design, testing, or qualification methods. In accordance with 10 CFR 50 Appendix S, the staff reviewed the adequacy of the method to estimate the power spectral density (PSD) functions for the acceleration time histories for the certified seismic design response spectra (CSDRS) and the hard rock high frequency (HRHF) response spectra (RS). In order for the staff to understand whether the PSD functions were estimated using a method consistent with the guidance of SRP Appendices A and B, the applicant is requested to provide the following additional information.

a) Explain the method used to estimate PSD for the CSDRS time histories

In DCD Section 3.7.1.1.2, the PSDs of the design acceleration time histories are compared to the corresponding target PSD. However, the method to estimate the PSD from an acceleration time history is not provided. Therefore, the applicant is requested to provide a description of the method for the PSD estimation and justify any difference of the method as compared to the guidance provided in SRP 3.7.1. The provided information should include the definition of the strong motion duration, portion of the time history used to compute the Fourier spectra, PSD smoothing, and any normalization parameters used in Fourier transform and PSD calculation.

b) Justification of the method used to estimate PSD for the HRHF time histories

Section 3.5.3 of APR1400-E-S-NR-14004-P, Rev. 1, "Evaluation of Effects of HRHF Response Spectra on SSCs," describes the method used to calculate the PSD function from an acceleration time history. It utilizes an "equivalent stationary strong-motion duration" as the strong motion duration. The equivalent stationary strong motion is defined as the time for a P1-to-P2 rise of the cumulative Arias intensity, divided by (P2-P1). The applicant stated, "the equivalent stationary duration T_s for the entire time histories as determined from Eq. (3-3) is the duration over which the total energy of the time history is built up from 0 to 100 percent with the

constant slope S." In this statement, the parameters P1, P2, and S are not defined. As such, the applicant is requested to provide these three parameters for the three HRHF acceleration time histories. In addition, it appears that the PSD estimate is very sensitive to the choice of P1 and P2; for example a P1=0 and P2=100% will lead to an equivalent stationary strong-motion duration T_s equal to the total duration of the time history. As such, the applicant is also requested to provide a justification for the values of P1 and P2.

Eq. (3-4) is described in Section 3.5.3 as the one-sided PSD, but it appears to be the two-sided PSD formula. Please confirm the validity of Eq. (3-4) and explain how this equation is implemented in the development of target PSDs and in estimating the PSD function for each time history (i.e., one-sided vs two-sided).

Eq. (3-5), the amplitude of the Fourier spectrum, is provided in terms of continuous time t and the integration is performed over the entire time history. Please provide the corresponding equation for the discrete Fourier transform implemented for the APR1400.

Appendices A and B of SRP 3.7.1 indicate that PSD should be estimated based on the strong motion duration. Therefore, the staff requests that the applicant provide a justification for the use of equivalent stationary strong-motion duration. Similarly, the applicant is requested to explain why the entire time histories were used in the Fourier transform. The use of the equivalent stationary strong-motion duration, which is shorter than the entire duration as shown in Figure 3-27 of APR1400-E-S-NR-14004-P, Rev. 1, together with the entire time history used in the Fourier transform, may overestimate the PSD for those frequencies that have very low magnitude but span the entire time history

Response

- (a) The method for computing the PSD of an acceleration time history is in accordance with the guidance in SRP 3.7.1, Revision 4, supplemented with the additional guidance provided in NUREG/CR-5347, Appendix A (January 1989), Page A-5. The summary for computing the PSD of an acceleration time history is described below.

The one-sided PSD, $S_i(f)$ of time history $a_i(t)$ using following equation.

$$S_i(f) = \frac{2|A_i(f)|^2}{T_i^3} \quad (1)$$

where $|A_i(f)|$ is the amplitude of the Fourier spectrum obtained from the following equation:

$$A_i(f) = \int_0^{T_i} a_i(t) e^{-i2\pi f t} dt \quad (2)$$

where T_i is the total duration of the time history $a_i(t)$.

Equation (2) is a symbolic mathematical equation. In actual numerical calculation, the discrete Fourier spectrum is computed using the Fast Fourier Transform algorithm.

The one-sided PSD $S_i(f)$ as given by Equation (1) is in the PSD unit of ($\text{in}^2/\text{sec}^4/\text{Hz}$) and the frequency unit of f associated with Equation (1) is cycle/second (Hz).

If, in Equation (1), the PSD $S_i(f)$ is to be computed in the PSD unit of (in²/sec⁴/rps), where the frequency unit is in radian/second (rps), then Equation (1) should be replaced by the following equation:

$$S_i(f) = \frac{2|A_i(f)|^2}{2\pi T_S^4} \quad (1a)$$

When PSD is computed using Equation (1a), the frequency unit must be in rps (radian/sec), which is commonly expressed using the frequency symbol ω . Using the symbol ω with the frequency unit of rps, Equation (1a) would be more appropriately expressed as follows:

$$S_i(\omega) = \frac{2|A_i(\omega)|^2}{2\pi T_S^4} \quad (1a)$$

and Equation (2) would be more appropriately expressed as:

$$A_i(\omega) = \int_0^{T_i} a_i(t) e^{-i\omega t} dt \quad (2a)$$

The difference of Equation (1) and Equation (1a) is discussed in NUREG/CR-5347, Appendix A (January 1989), Page A-5.

The discrete form of the mathematical Equation (2a) is computed using the following discrete equation:

$$|A_i(\omega_n)| = \Delta t \left| \sum_{j=0}^{N-1} a_i(t_j) e^{-2\pi i(nj/N)} \right| \quad (2b)$$

where $\omega_n = n\Delta\omega = 2\pi n\Delta f = \frac{2\pi n}{(N\Delta t)}$; $n = 0, 1, \dots, N/2$ and $t_j = j\Delta t$, $j = 0, 1, \dots, N-1$.

The time history PSD $S_i(f)$ computed using Equation (1) or (1a) is smoothed using the moving average technique over a ± 20 percent frequency bandwidth centered at the frequency f in accordance with the guidelines in SRP 3.7.1, Revision 4, which refers to NUREG/CR-5347, Appendix B (January 1989).

The definition of strong motion duration is described below.

The full time histories are the time histories of full duration from 0 to 20.48 seconds. The 0% to 100% extended equivalent stationary duration designated as $T_{es}(100\%-0\%)$ is computed as $T_{es}(100\%-0\%) = T_{e100\%} - T_{e0\%} = (T_{75\%} - T_{5\%}) / (75\% - 5\%) = T_{(75\%-5\%)} / 0.7$. The time histories, the Fourier amplitudes, PSD and smoothed PSD for time histories of full duration time histories are shown in Figures 1 through 9, respectively.

The PSDs for time histories of truncated duration are computed in accordance with Appendix B of SRP 3.7.1, Rev. 4. The strong motion durations for the CSDRS compatible time histories are defined as shown in Figures 10 through 12. Using the truncated time histories and the corresponding the strong motion duration, the PSDs for the CSDRS compatible time histories are computed as shown in Figures 13 through 21. The PSDs for the CSDRS compatible time histories envelop 70% of target PSD as

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shown in Figures 15, 18, and 21. Thus, the PSDs for the CSDRS compatible time histories satisfy the requirement of Appendix B of SRP 3.7.1, Rev. 4.

As shown in Figure 22 through 24, it can be concluded that the use of full-duration time history and the corresponding 0% to 100% extended equivalent stationary duration

$T_e(100\%-0\%) = T(75\%-5\%)/0.7$ to compute the time-history PSD is a convenient and valid procedure to generate the time-history PSDs.

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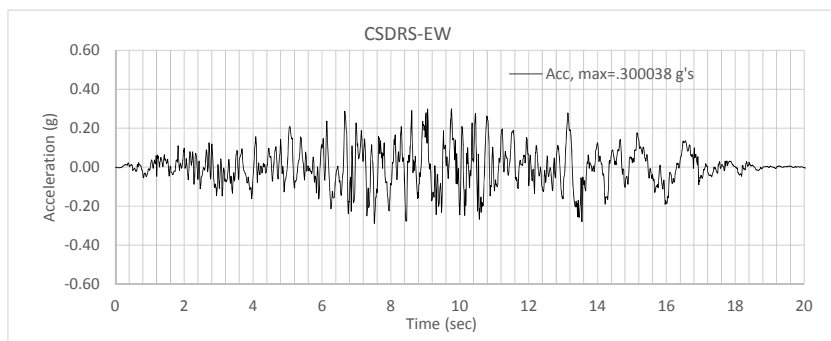


Figure 1 Time History of Full Duration for CSDRS-EW

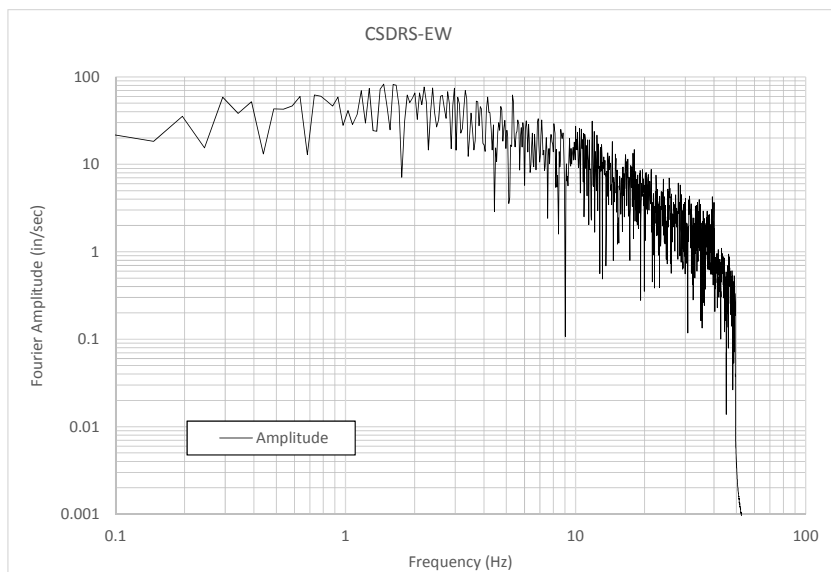


Figure 2 Fourier Amplitudes of Time History of Full Duration for CSDRS-EW

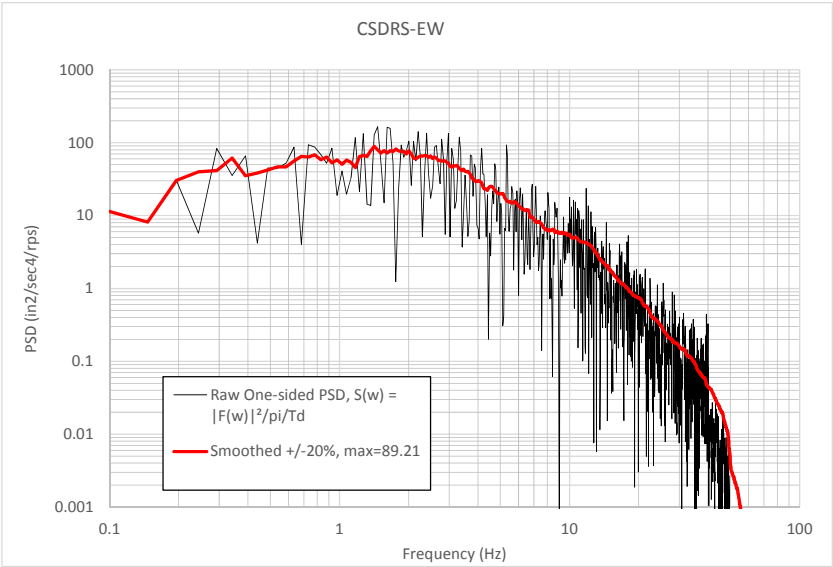


Figure 3 Raw One-sided PSD and Smoothed PSD of Time History of Full Duration for CSDRS-EW

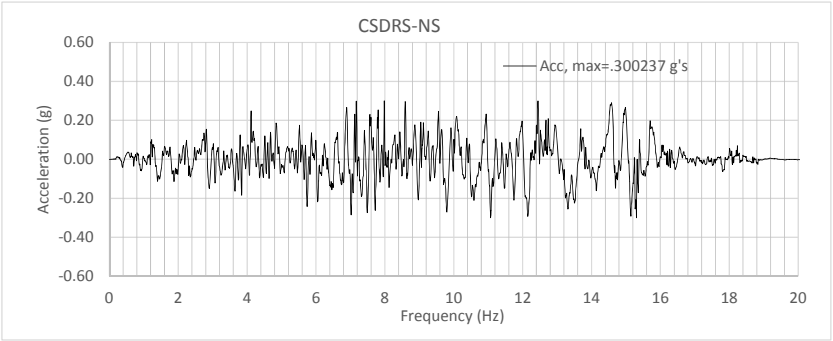


Figure 4 Time History of Full Duration for CSDRS-NS

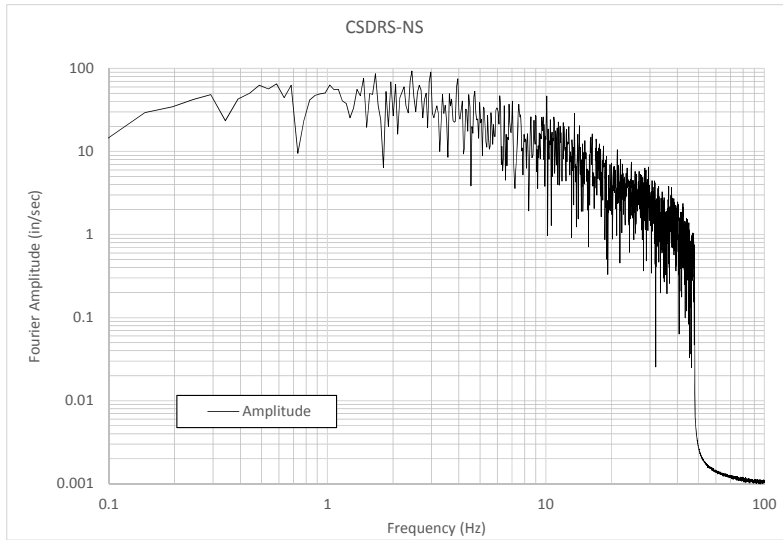


Figure 5 Fourier Amplitudes of Time History of Full Duration for CSDRS-NS

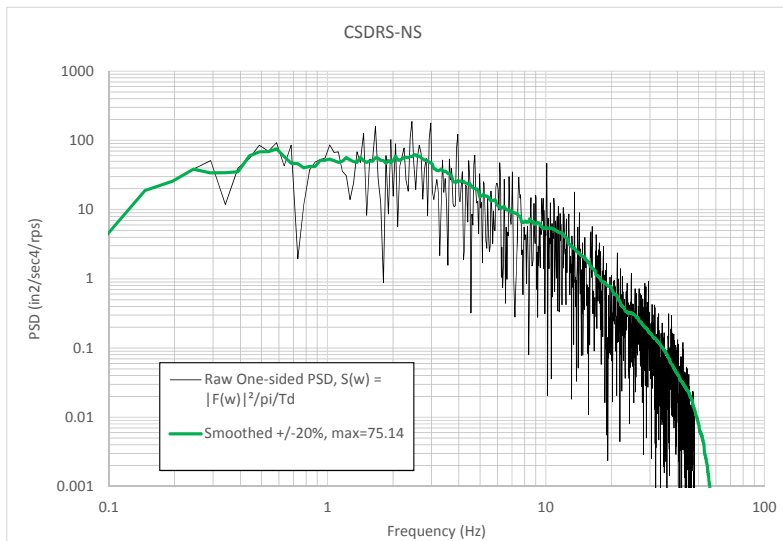


Figure 6 Raw One-sided PSD and Smoothed PSD of Time History of Full Duration for CSDRS-NS

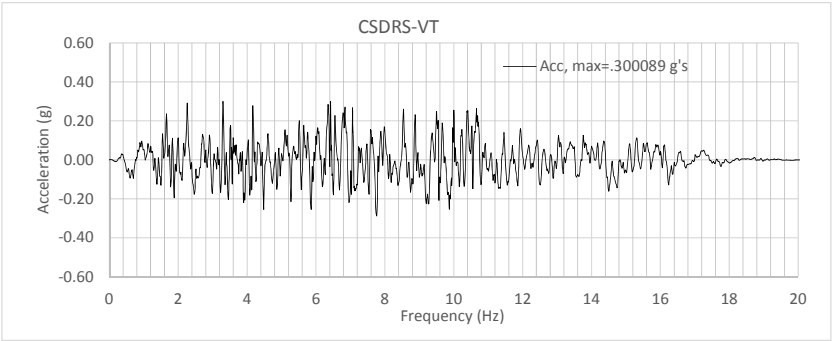


Figure 7 Time History of Full Duration for CSDRS-VT

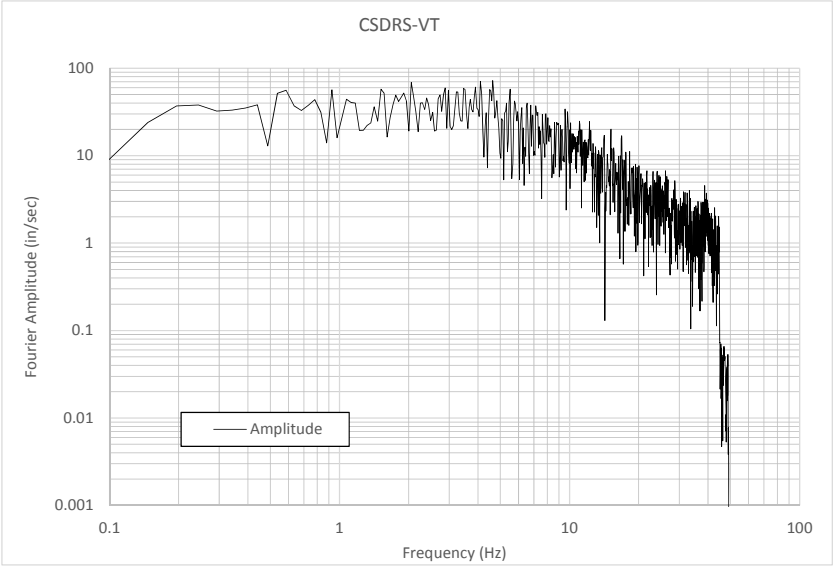


Figure 8 Fourier Amplitudes of Time History of Full Duration for CSDRS-VT

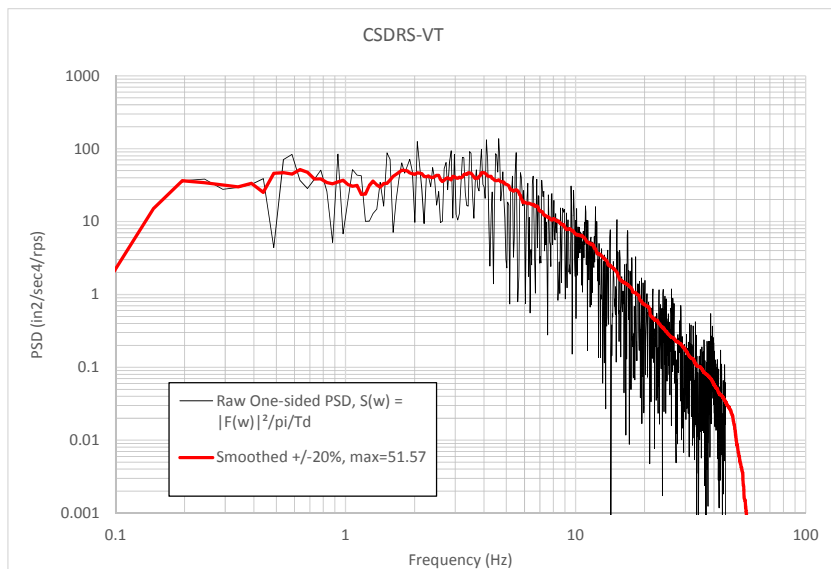


Figure 9 Raw One-sided PSD and Smoothed PSD of Time History of Full Duration for CSDRS-VT

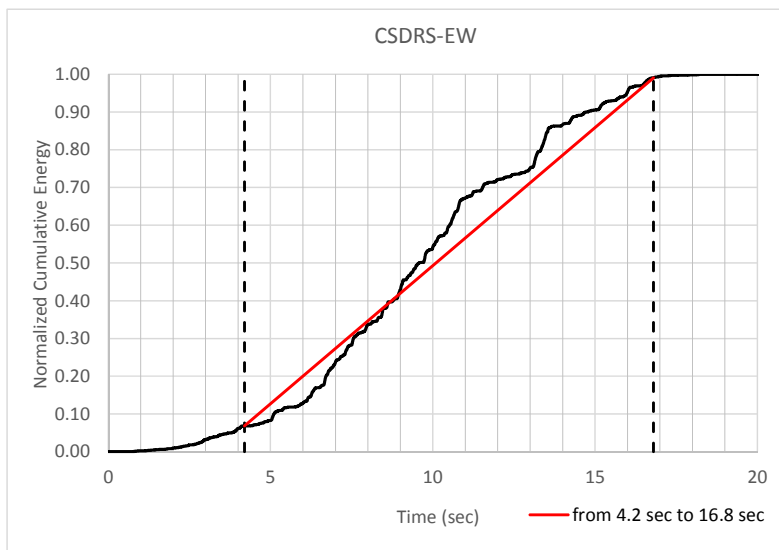


Figure 10 Cumulative Energy (Arias Intensity) Time History for CSDRS-EW

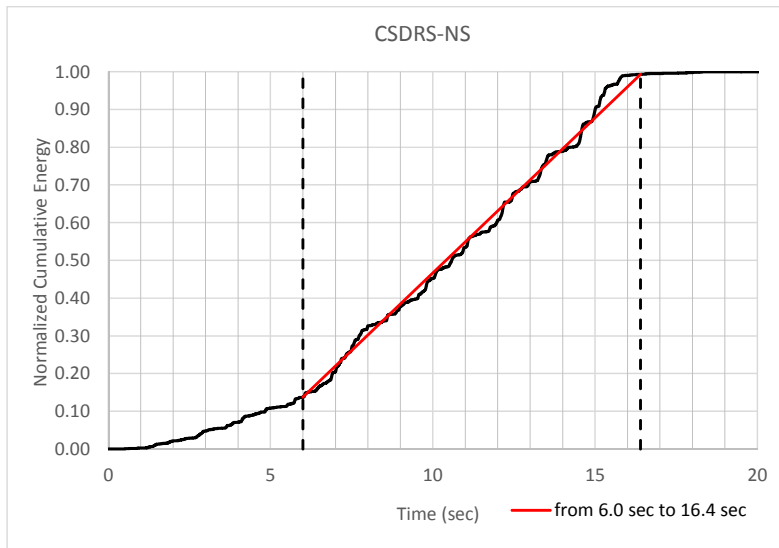


Figure 11 Cumulative Energy (Arias Intensity) Time History for CSDRS-NS

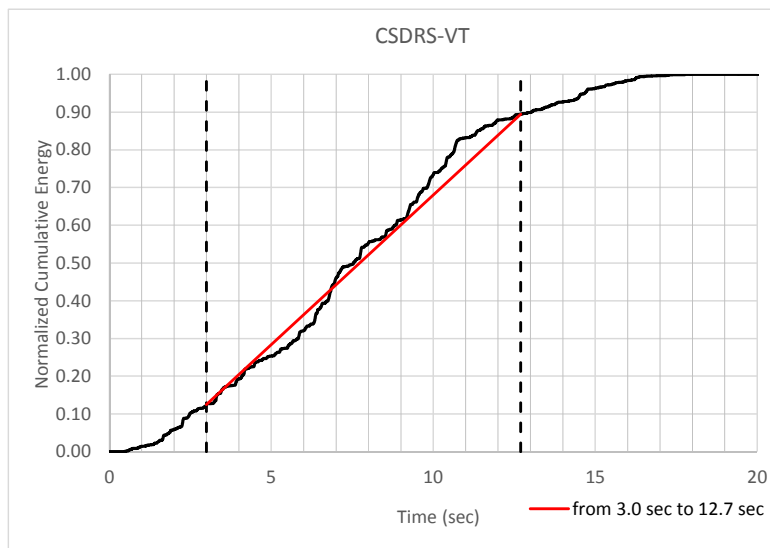


Figure 12 Cumulative Energy (Arias Intensity) Time History for CSDRS-VT

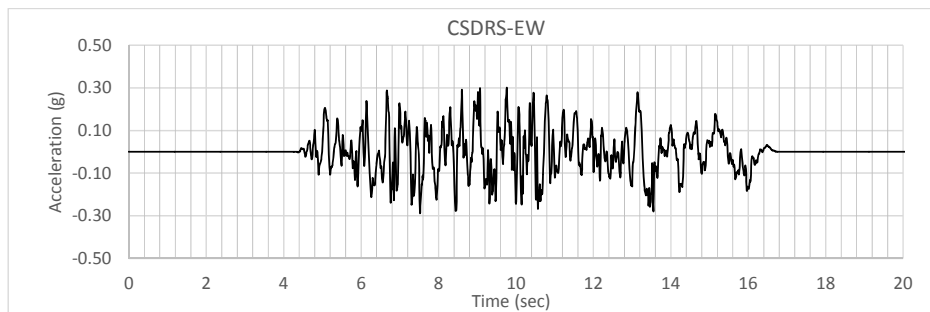


Figure 13 Time History of Truncated Duration from 4.2 sec to 16.8 sec for CSDRS-EW

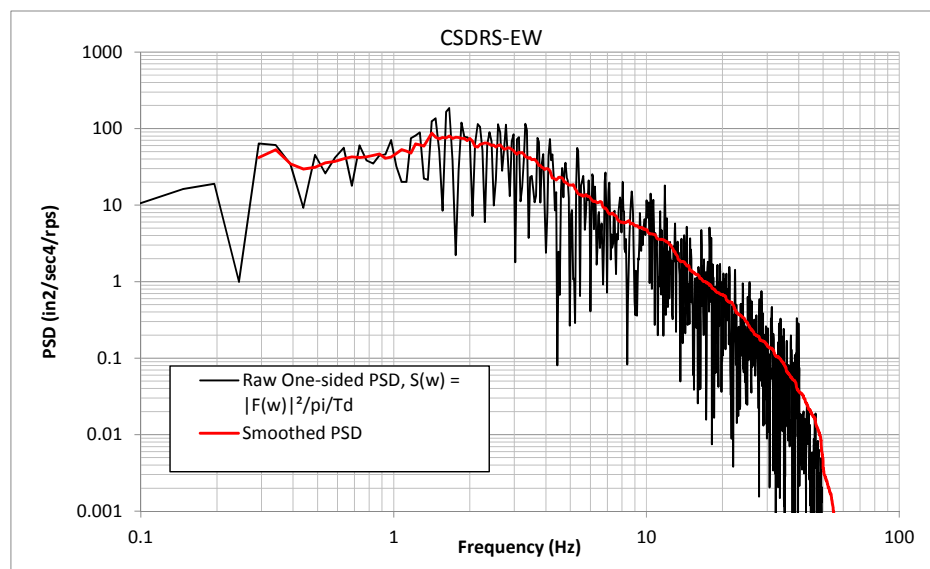


Figure 14 Raw One-sided PSD and Smoothed PSD of Time History of Truncated Duration from 4.2 sec to 16.8 sec for CSDRS-EW

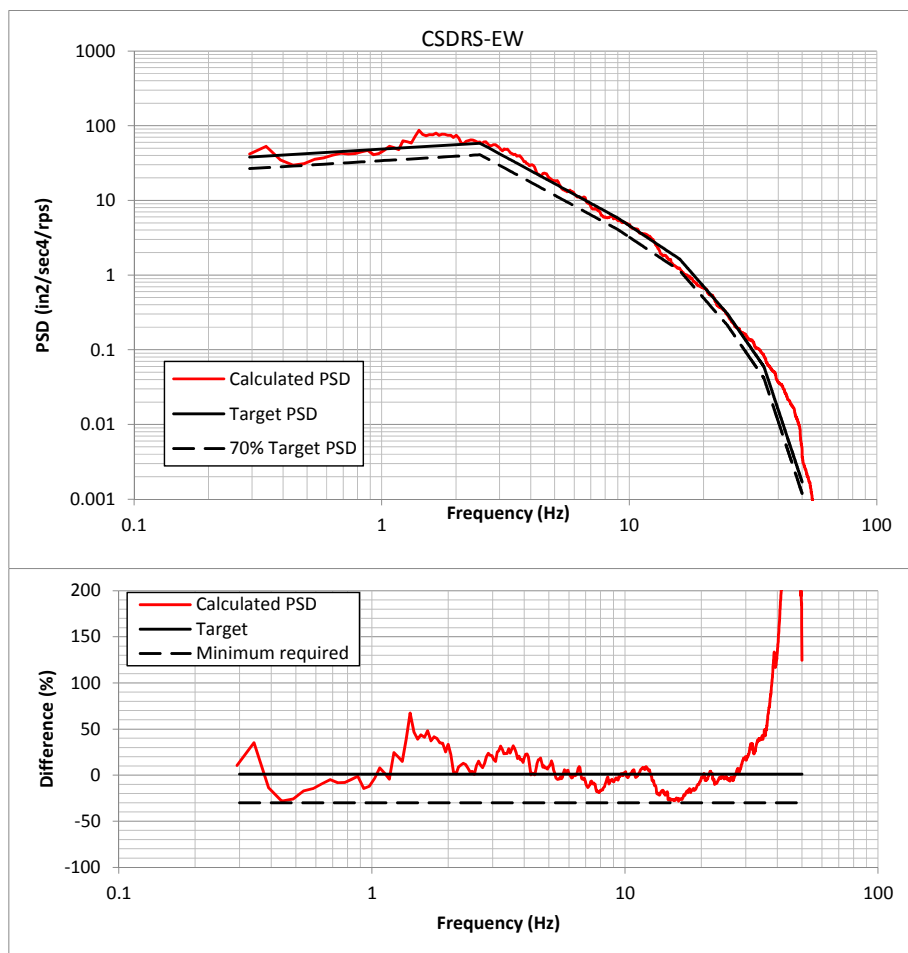


Figure 15 Comparison of Minimum-Required Target PSD for Horizontal Time History and PSD of Time History of Truncated Duration from 4.2 sec to 16.8 sec for CSDRS-EW

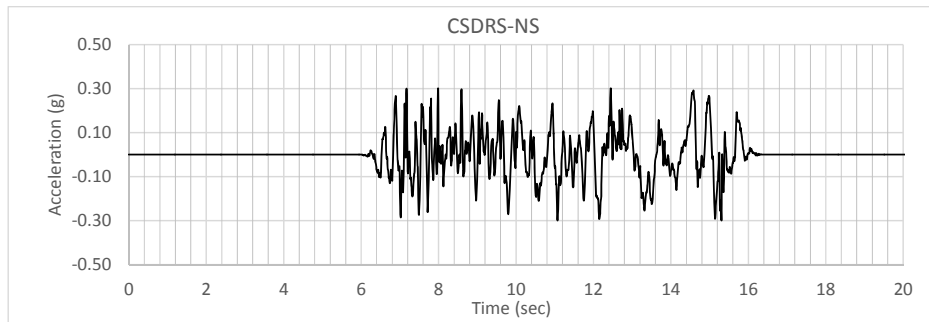


Figure 16 Time History of Truncated Duration from 6.0 sec to 16.4 sec for CSDRS-NS

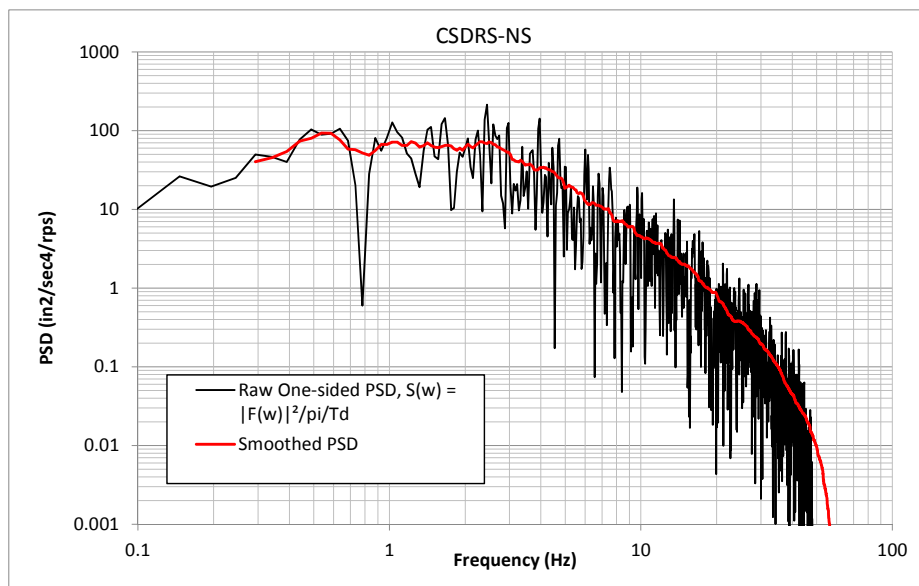


Figure 17 Raw One-sided PSD and Smoothed PSD of Time History of Truncated Duration from 6.0 sec to 16.4 sec for CSDRS-NS

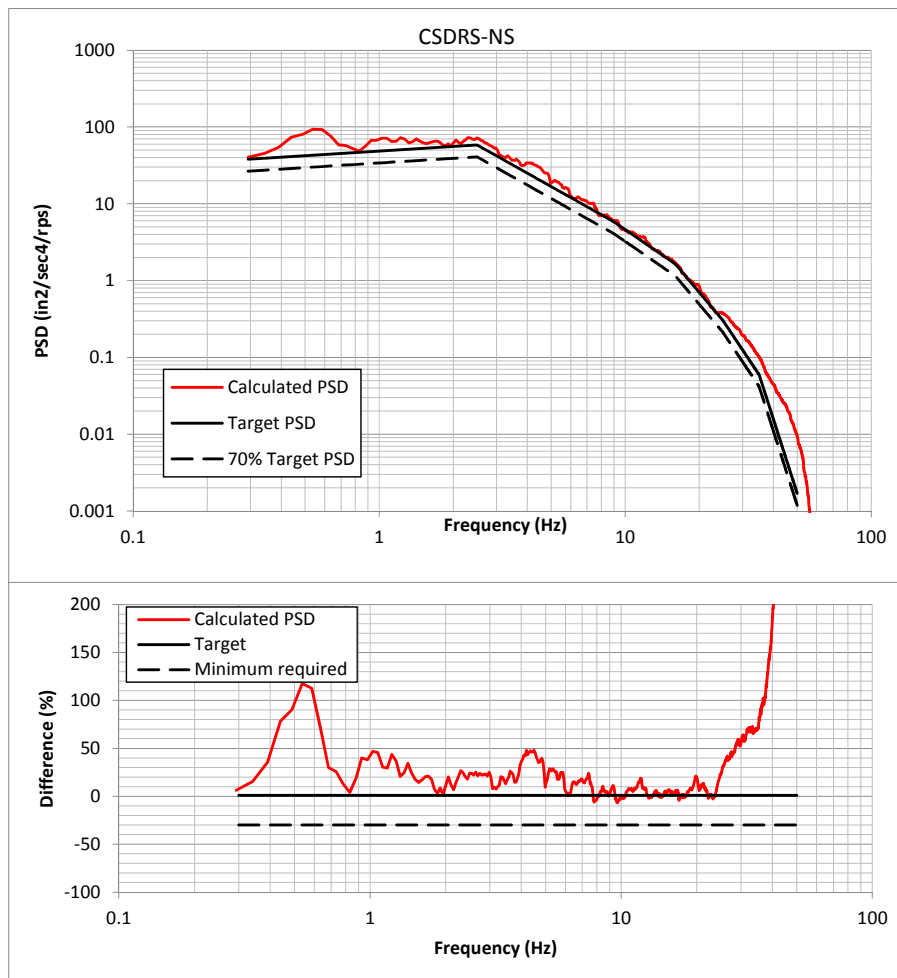


Figure 18 Comparison of Minimum-Required Target PSD for Horizontal Time History and PSD of Time History of Truncated Duration from 6.0 sec to 16.4 sec for CSDRS-NS

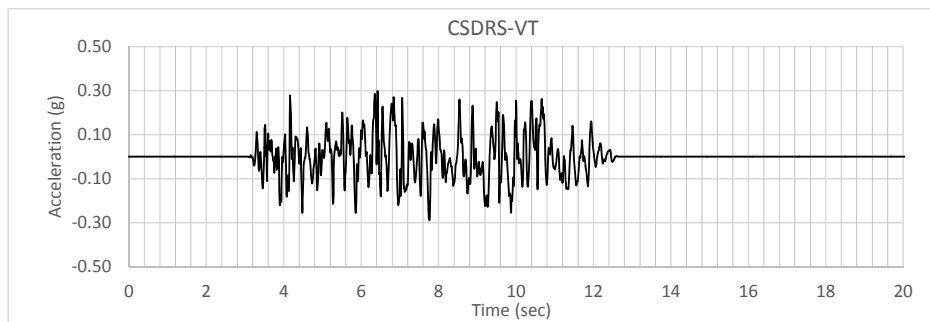


Figure 19 Time History of Truncated Duration from 3.0 sec to 12.7 sec for CSDRS-VT

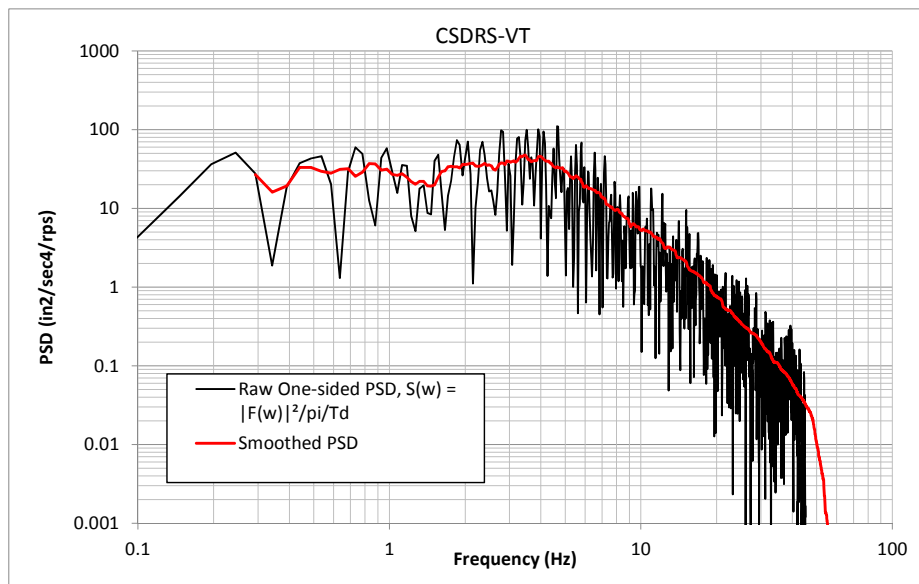


Figure 20 Raw One-sided PSD and Smoothed PSD of Time History of Truncated Duration from 3.0 sec to 12.7 sec for CSDRS-VT

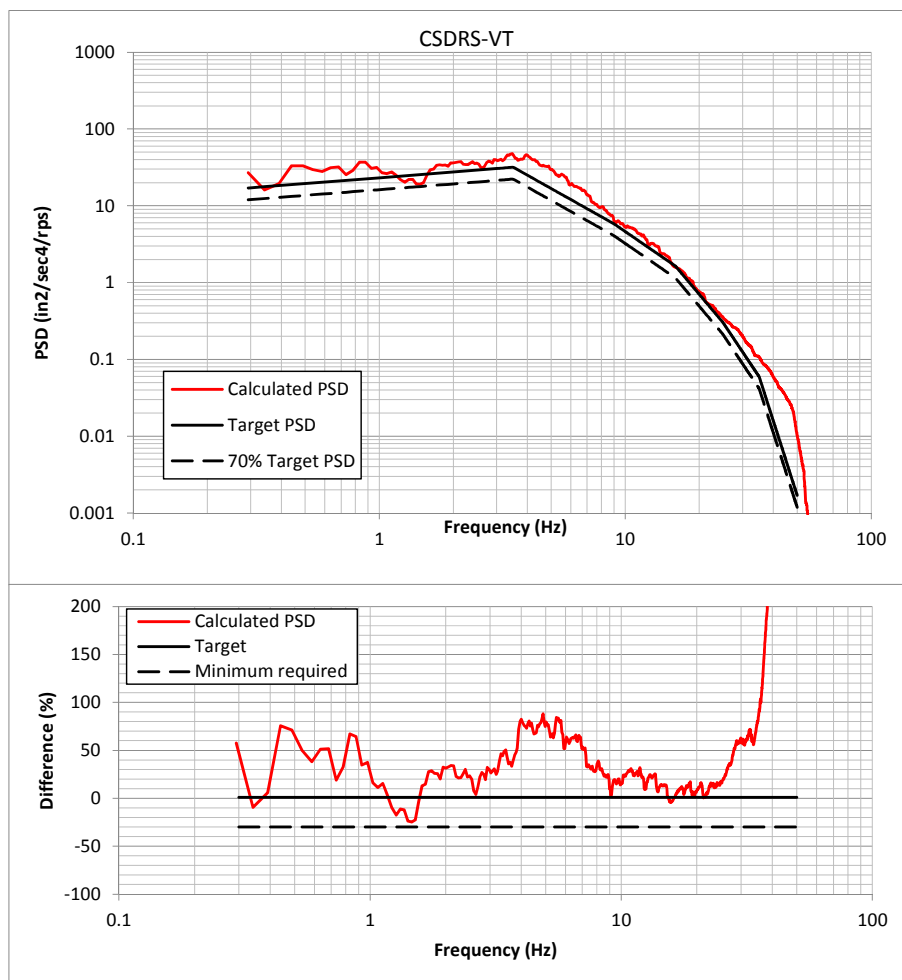


Figure 21 Comparison of Minimum-Required Target PSD for Horizontal Time History and PSD of Time History of Truncated Duration from 3.0 sec to 12.7 sec for CSDRS-VT

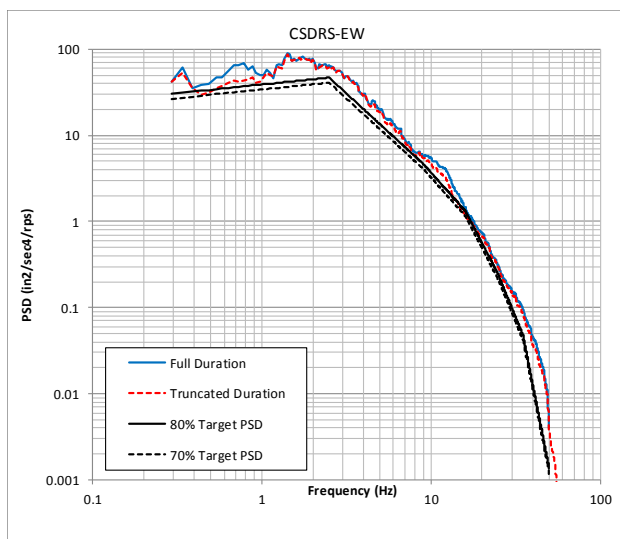


Figure 22 Comparison of PSDs between Time History of Full Duration and Time History of Truncated Duration for CSDRS-EW

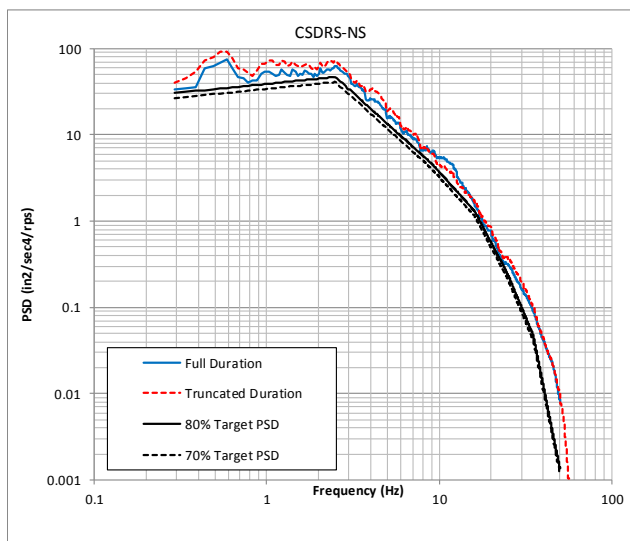


Figure 23 Comparison of PSDs between Time History of Full Duration and Time History of Truncated Duration for CSDRS-NS

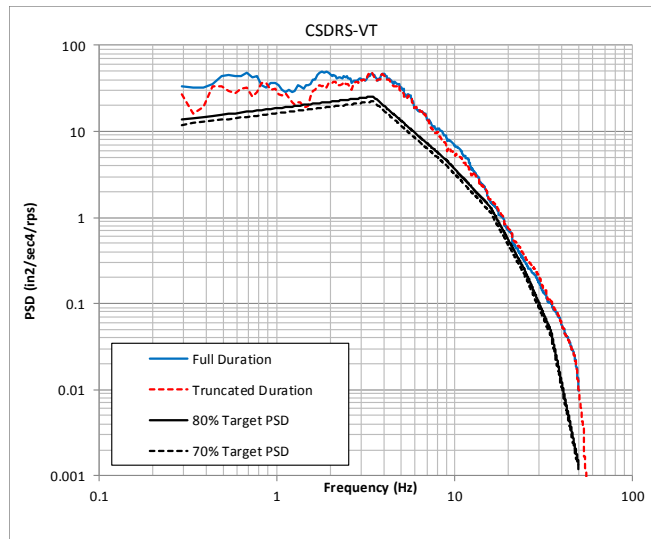


Figure 24 Comparison of PSDs between Time History of Full Duration and Time History of Truncated Duration for CSDRS-VT

- (b) Equation (3-4) in APR1400-E-S-NR-14004-P/NP, Rev. 1, for calculation of the one-sided PSD, $S_i(f)$ of the time history $a_i(t)$, a factor of 2 is missing. For the explanation of Equation (3-4) for the calculation of the one-sided PSD, please refer to the explanations provided previously in response to Question 03.07.01-3 (a).

The discrete form of the mathematical Equation (3-5) in APR1400-E-S-NR-14004-P/NP, Rev. 1 is computed using the following discrete equation:

$$|A_i(\omega_n)| = \Delta t \left| \sum_{j=0}^{N-1} a_i(t_j) e^{-2\pi i(nj/N)} \right| \quad (3-6)$$

where $\omega_n = n\Delta\omega = 2\pi n\Delta f = \frac{2\pi n}{N\Delta t}$; $n = 0, 1, \dots, N/2$ and $t_j = j\Delta t$, $j = 0, 1, \dots, N-1$.

Referring to the previous explanation in the in response to Question 03.07.01-3 (a), the equivalent strong motion duration is defined by Equation (3-3) as

$$T_{e-s}^i = \frac{T_{75\%}^i - T_{5\%}^i}{75\% - 5\%} \quad (3-3)$$

Since the slope S of the cumulative energy over the strong motion duration $T_{75\%}^i - T_{5\%}^i$ is constant, Equation (3-3) given above can be recast into the following:

$$T_{e-s}^i = \frac{T_{75\%}^i - T_{5\%}^i}{75\% - 5\%} = \frac{T_{e-100\%}^i - T_{e-0\%}^i}{100\% - 0\%} = T_{e-100\%}^i - T_{e-0\%}^i \quad (3-3a)$$

Equation (3-3a) indicates that when the entire time history is used to compute the cumulative energy from 0% to 100%, the equivalent stationary strong-motion duration as defined by Equation (3-3) or (3-3a) should be used. This calculation preserves the slope S of the cumulative energy over the strong motion duration $T_{75\%}^i - T_{5\%}^i$, the procedure does not overestimate the PSD for those frequencies that have very low magnitude but span the entire time history.

The reason to use the equivalent stationary strong-motion duration as defined above and the Fourier transform of the time history over the entire time-history duration is for convenience since the Fourier transform of the input time history is normally computed for the entire time-history duration.

The PSDs for the HRHF RS compatible time histories are computed using the procedure which is described in response to Question 03.07.01-3 (a) as shown in Figure 25 through 36. The PSDs for the HRHF RS compatible time histories satisfy requirement of Appendix B of SRP 3.7.1, Rev. 4 as shown in Figure 30, 33, and 36. The comparison of PSDs between using full duration and truncated durations are shown in Figure 37 through 39.

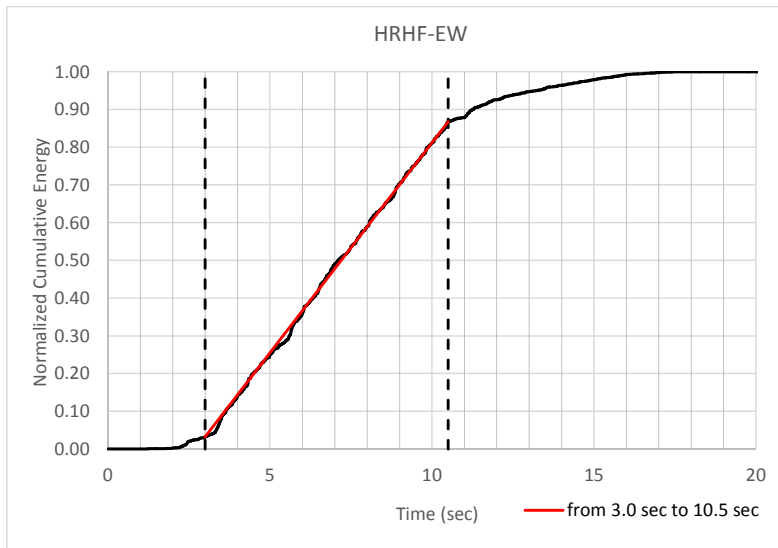


Figure 25 Cumulative Energy (Arias Intensity) Time History for HRHF-EW

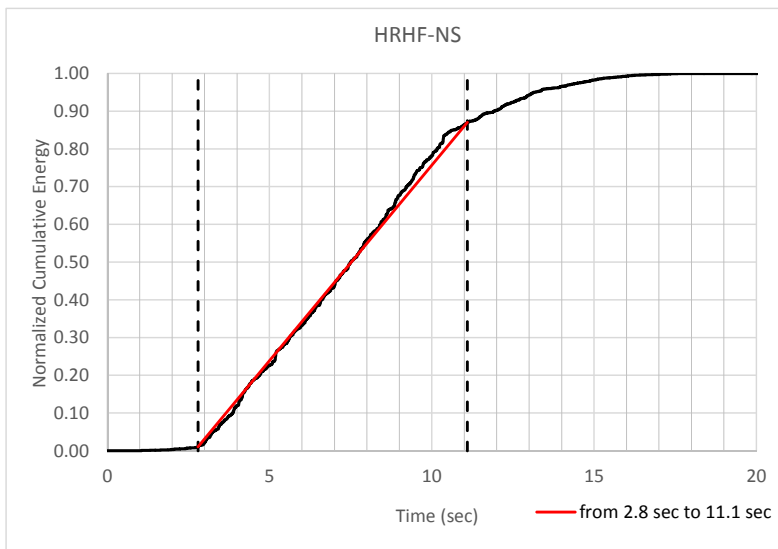


Figure 26 Cumulative Energy (Arias Intensity) Time History for HRHF-NS

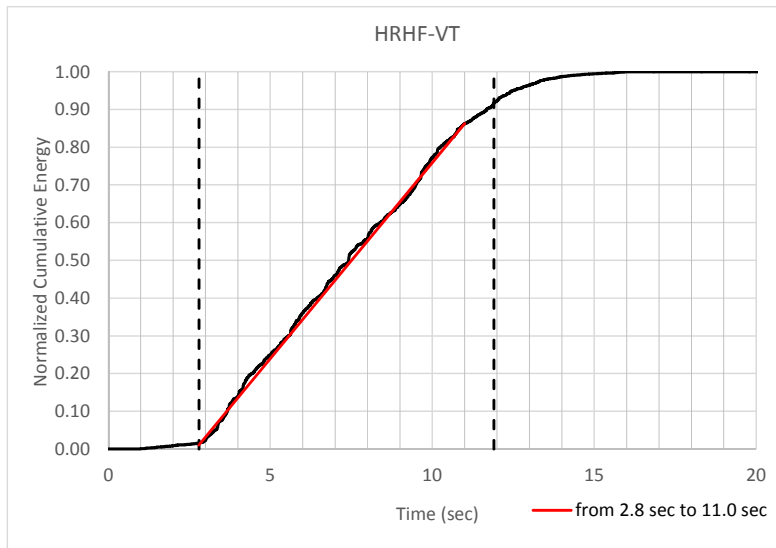


Figure 27 Cumulative Energy (Arias Intensity) Time History for HRHF-VT

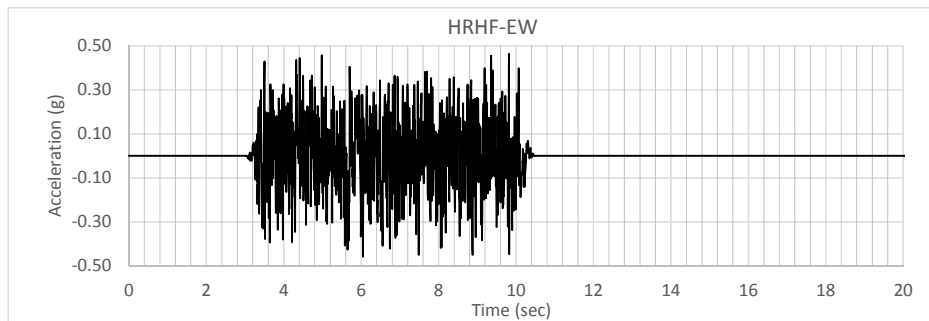


Figure 28 Time History of Truncated Duration from 3.0 sec to 10.5 sec for HRHF-EW

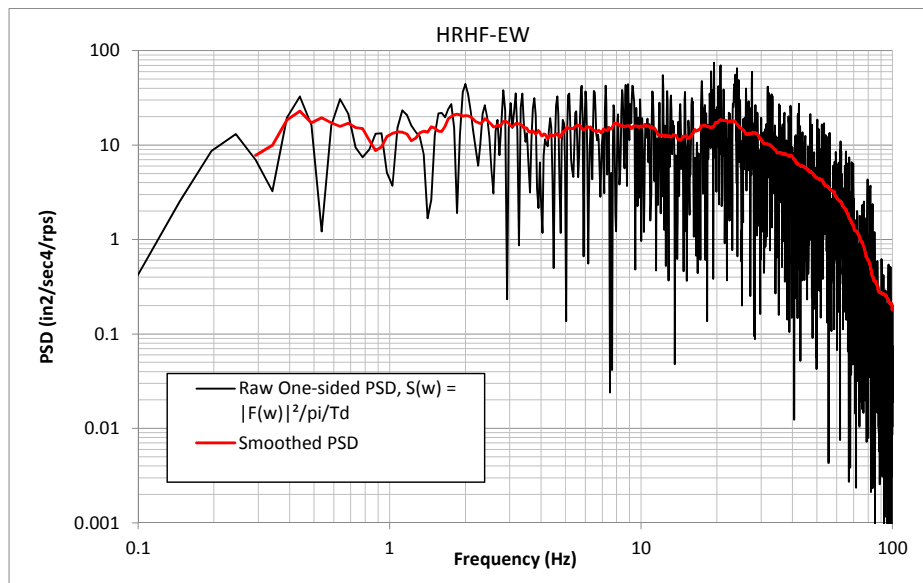


Figure 29 Raw One-sided PSD and Smoothed PSD of Time History of Truncated Duration from 3.0 sec to 10.5 sec for HRHF-EW

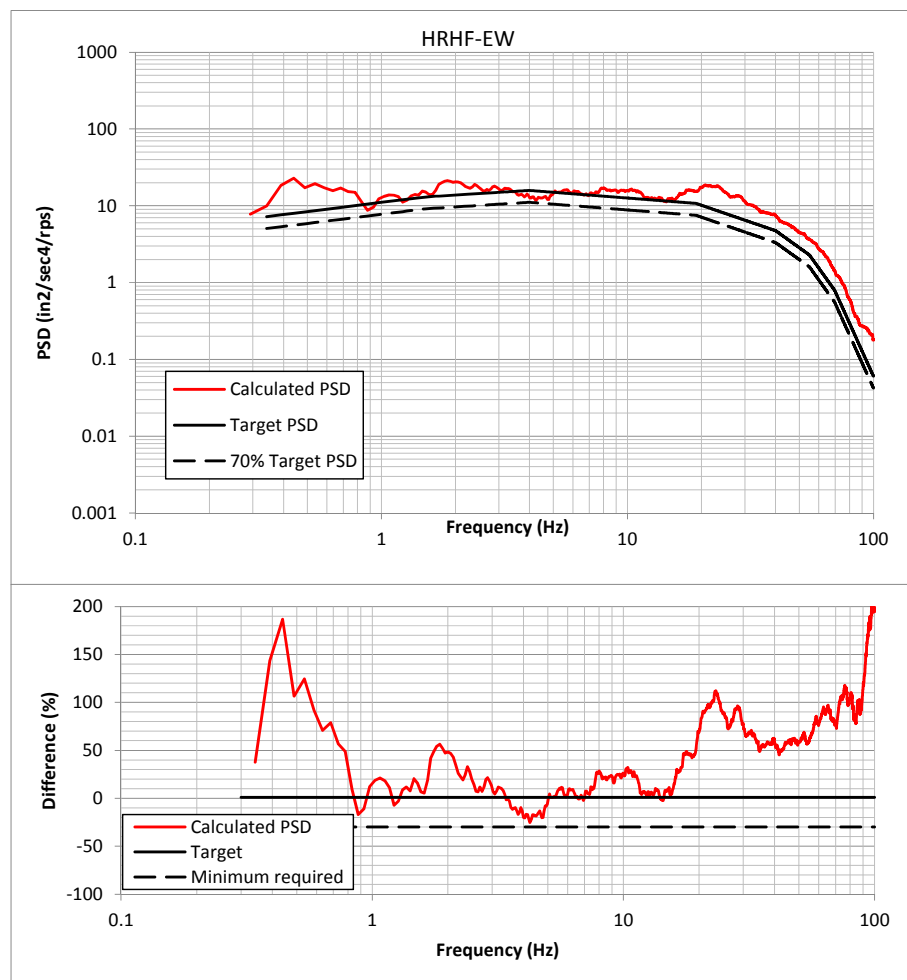


Figure 30 Comparison of Minimum-Required Target PSD for Horizontal Time History and PSD of Time History of Truncated Duration from 3.0 sec to 10.5 sec for HRHF-EW

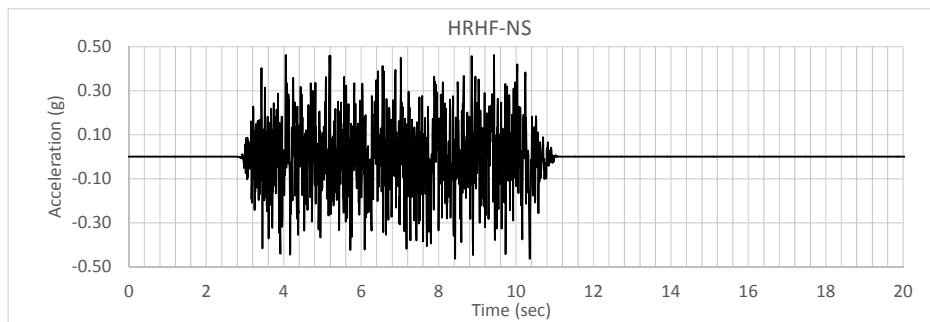


Figure 31 Time History of Truncated Duration from 2.8 sec to 11.1 sec for HRHF-NS

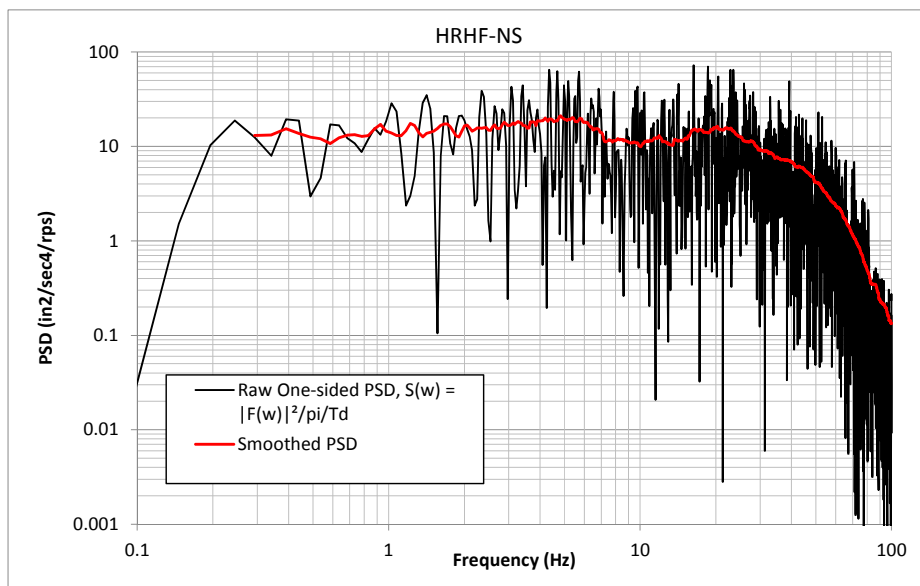


Figure 32 Raw One-sided PSD and Smoothed PSD of Time History of Truncated Duration from 2.8 sec to 11.1 sec for HRHF-NS

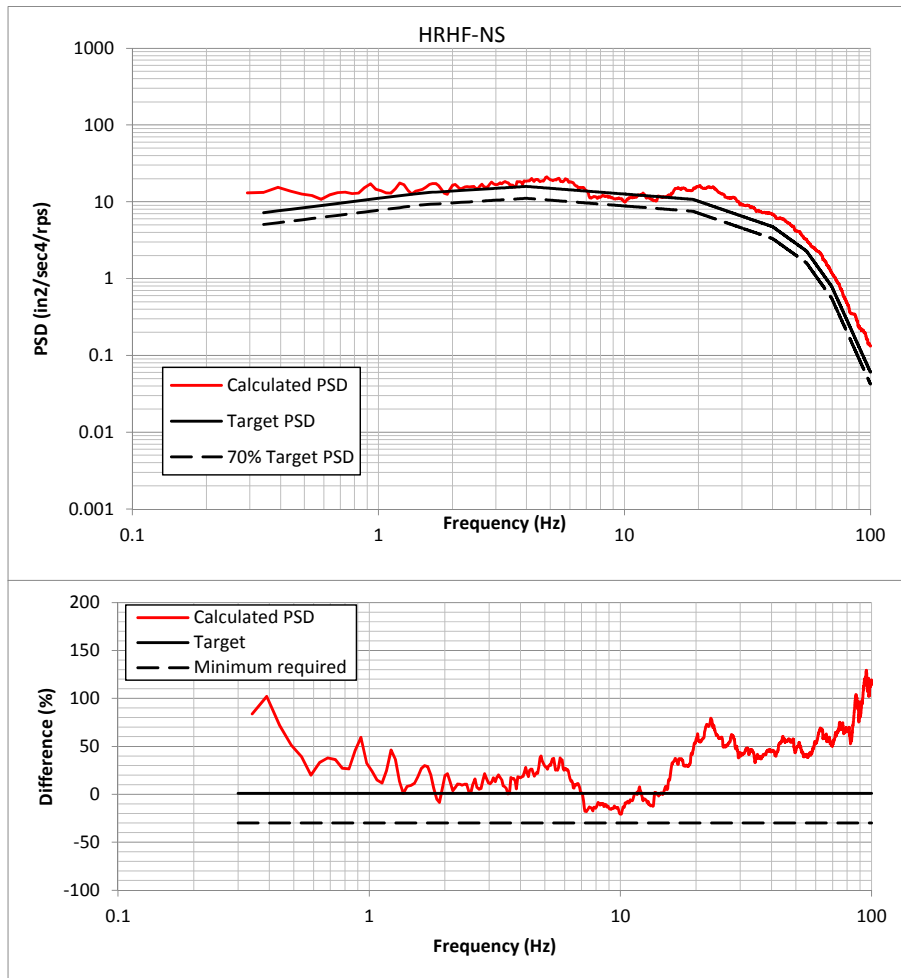


Figure 33 Comparison of Minimum-Required Target PSD for Horizontal Time History and PSD of Time History of Truncated Duration from 2.8 sec to 11.1 sec for HRHF-NS

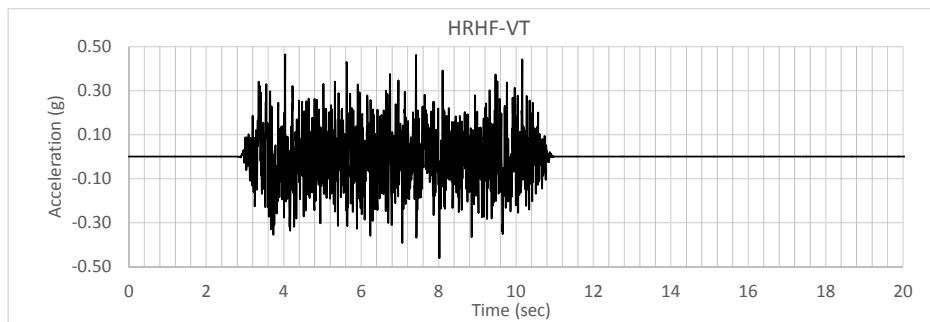


Figure 34 Time History of Truncated Duration from 2.8 sec to 11.0 sec for HRHF-VT

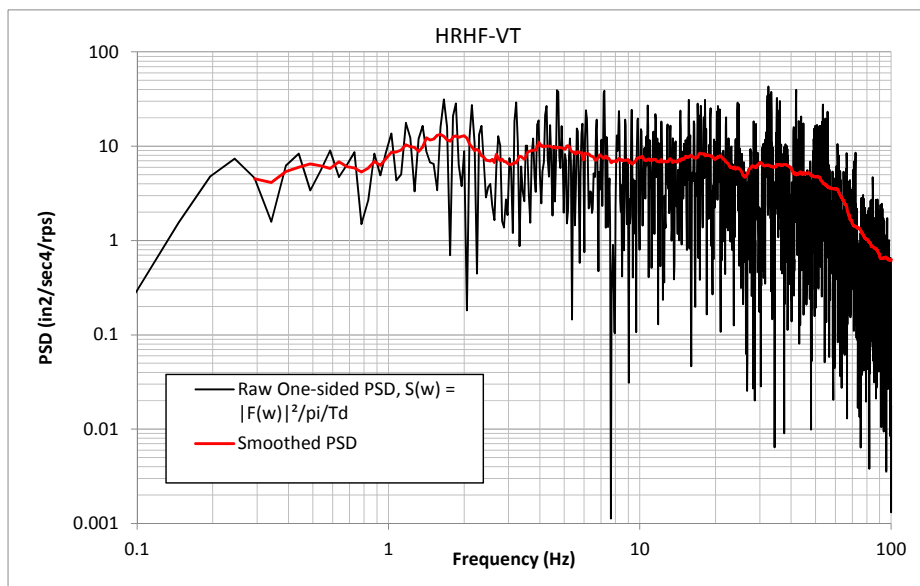


Figure 35 Raw One-sided PSD and Smoothed PSD of Time History of Truncated Duration from 2.8 sec to 11.0 sec for HRHF-VT

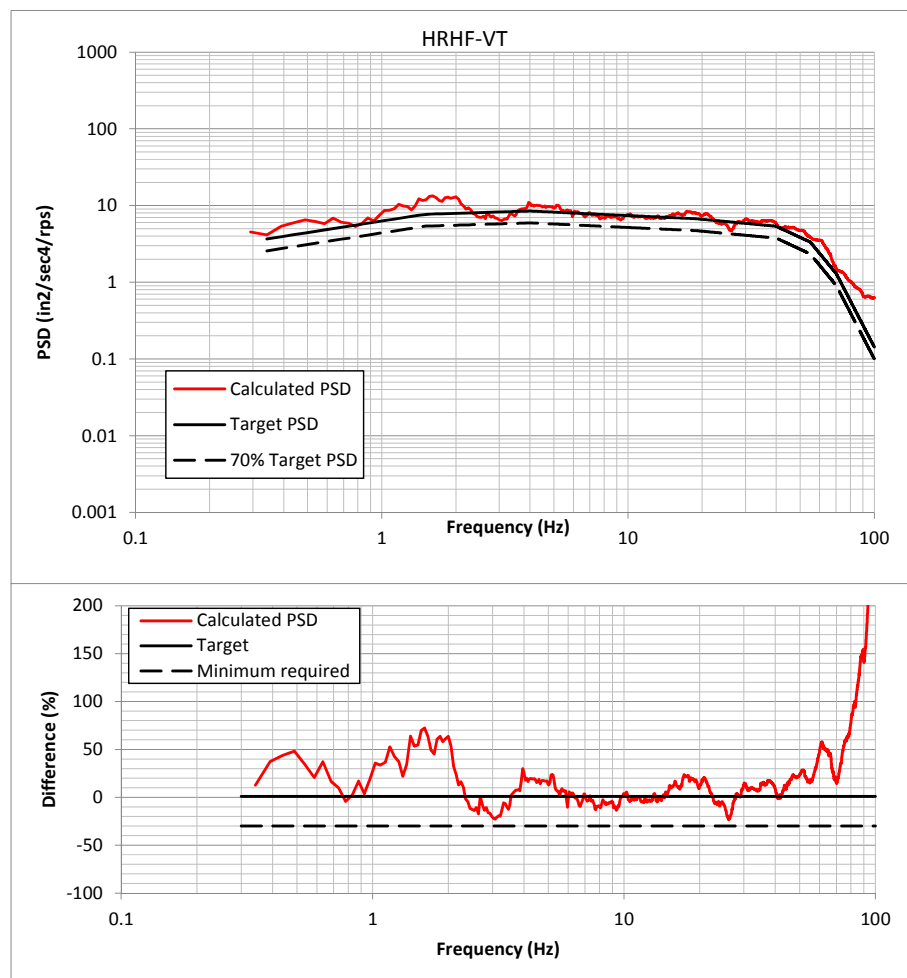


Figure 36 Comparison of Minimum-Required Target PSD for Horizontal Time History and PSD of Time History of Truncated Duration from 2.8 sec to 11.0 sec for HRHF-VT

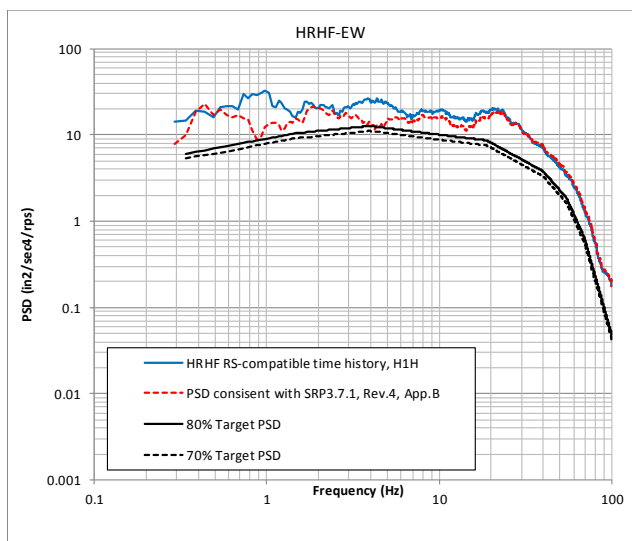


Figure 37 Comparison of PSDs between Time History of Full Duration and Time History of Truncated Duration for HRHF RS-EW

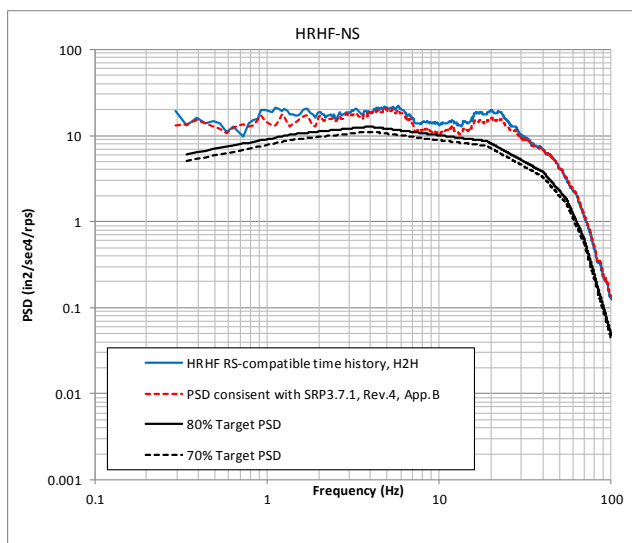


Figure 38 Comparison of PSDs between Time History of Full Duration and Time History of Truncated Duration for HRHF RS-NS

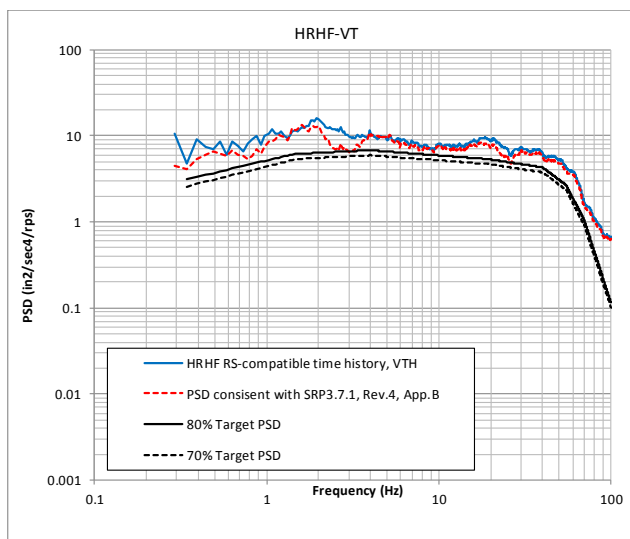


Figure 39 Comparison of PSDs between Time History of Full Duration and Time History of Truncated Duration for HRHF RS-VT

Impact on DCD

DCD Section 3.7.1.1.2, 3.7.1.1.3, Figure 3.7-9 through 3.7-11, and Figures 3.7-20 through 3.7-22 will be revised, as indicated in attachment associated with this response.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

[Technical Report APR1400-E-S-NR-14001-P/NP, Rev.0, Figures 3-35 through 3-37 and Technical Report APR1400-E-S-NR-14004-P/NP, Rev. 1, Section 1.8.3](#) will be revised, as indicated in the attachment associated with this response.