

Figure 3-35 Cumulative Energy (Arias Intensity) Time History for Final Modified Horizontal H1 Time History for East-West (X) Direction

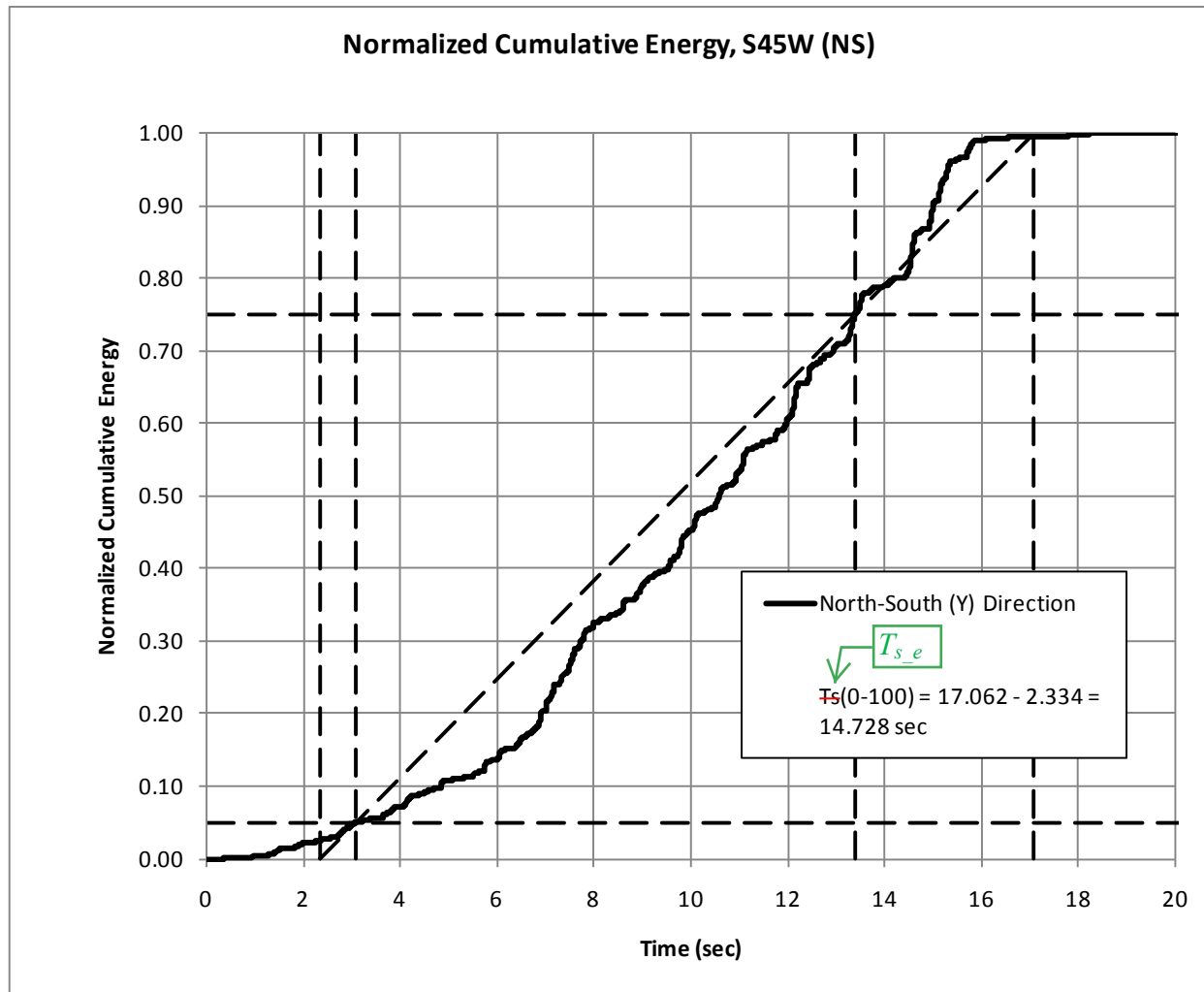


Figure 3-36 Cumulative Energy (Arias Intensity) Time History for Final Modified Horizontal H2 Time History for North-South (Y) Direction

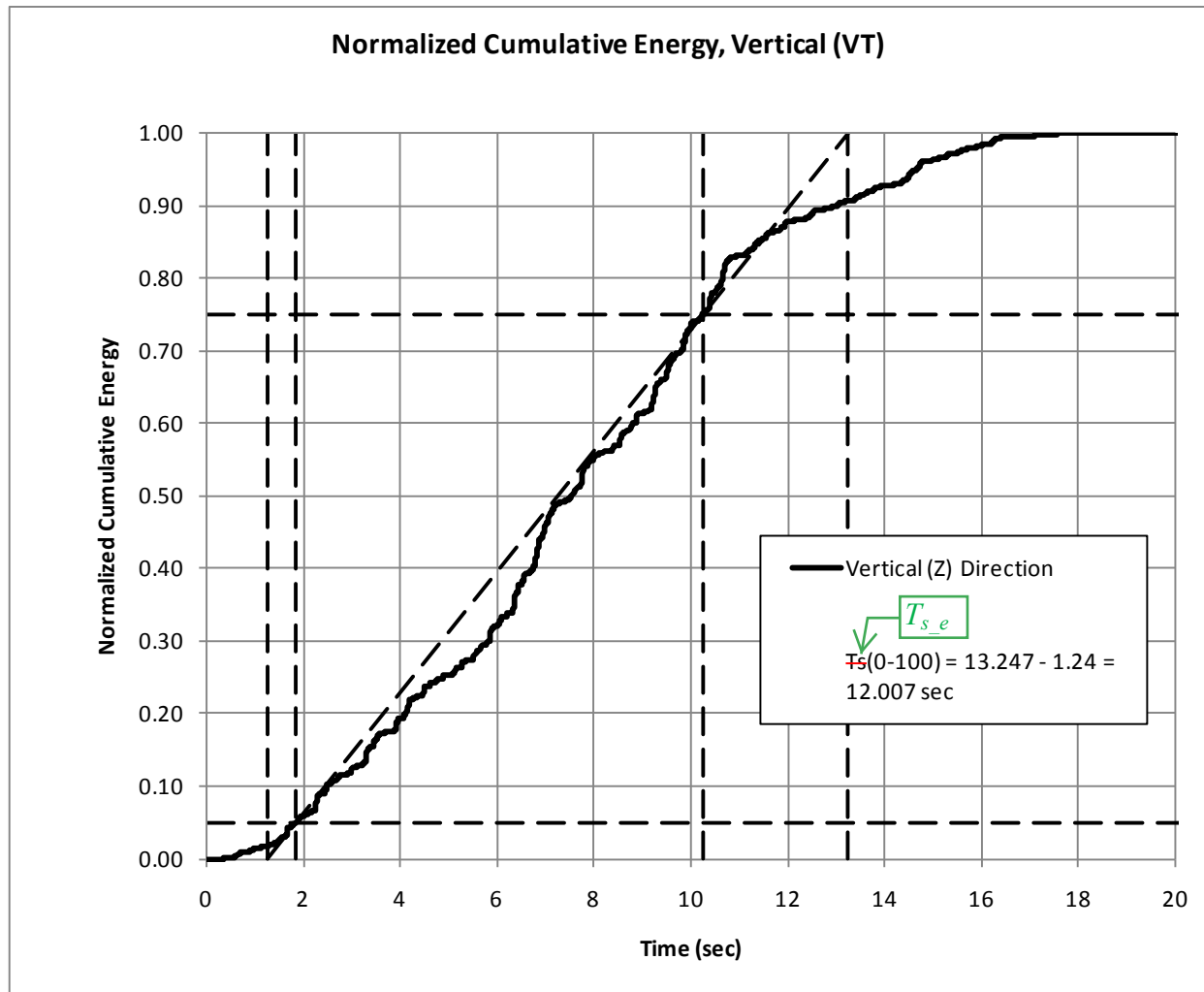


Figure 3-37 Cumulative Energy (Arias Intensity) Time History for Final Modified Vertical VT Time History for Vertical (Z) Direction

accordance with the PSD smoothing procedure recommended in NUREG/CR-5347 (Reference 24). To simplify the representation of the target PSDs shown in Figures 3-20 and 3-21, the smoothed ensemble-mean PSDs obtained from the PSDs of the 30 time history ensembles are segmentally smoothed using log-log amplitude frequency linear functions for seven frequency bands, namely, (a) $0.3 < f \leq 1.5$ Hz, (b) $1.5 < f \leq 4.0$ Hz, (c) $4.0 < f \leq 19$ Hz, (d) $19 < f \leq 40$ Hz, (e) $40 < f \leq 55$ Hz, (f) $55 < f \leq 70$ Hz, and (g) $70 < f \leq 80$ Hz.

The resulting horizontal and vertical, piecewise log-log linear, ensemble-mean PSDs generated for the seven frequency bands are the target PSDs compatible with the APR1400 HRHF horizontal and vertical response spectra for the frequency range $0.3 \leq f \leq 80$ Hz and are tabulated in Tables 3-7 and 3-8. The smoothed ensemble-mean PSDs and the piecewise log-log linear smoothed PSDs are shown in Figures 3-22 and 3-23 for the horizontal and vertical motions, respectively. The horizontal target PSD is compared with the PSDs for the CEUS rock sites for magnitudes of 6 to 7 with epicentral distances of $R = 0$ to 100 km as given in Table 1 of SRP 3.7.1, Appendix B, in Figure 3-24. As shown in this figure, the horizontal target PSD generated to be compatible with the APR1400 HRHF horizontal response spectra envelops the PSDs given in Table 1 in SRP 3.7.1, Appendix B, for magnitudes of $M = 6$ to 7 and epicentral distances of $R = 0$ to 100 km.

The target PSDs given in Tables 3-7 and 3-8, which are designated in this report as $S_H(f)$ and $S_V(f)$, respectively, are the target PSDs for checking adequacy of the PSDs as functions of frequency of the generated horizontal and vertical HRHF response spectrum-compatible design time histories.

1.8.2 Minimum Required Target PSDs

The minimum required horizontal and vertical target PSDs, designated as $\bar{S}_H(f)$ and $\bar{S}_V(f)$, for checking power adequacy of the horizontal and vertical time histories are obtained as 80 percent of the target PSD, $S_H(f)$ and $S_V(f)$, given in Section 3.5.1:

$$\bar{S}_H(f) = 0.8 \times S_H(f) \quad ; \quad \bar{S}_V(f) = 0.8 \times S_V(f) \quad (3-1)$$

The horizontal and vertical target and minimum required target PSDs are shown in Figures 3-25 and 3-26. The minimum required target PSDs shown in these figures are used to compare the PSDs of the generated horizontal and vertical HRHF response spectrum-compatible time histories to demonstrate adequacy in power density contents.

1.8.3 Calculation of Time History PSDs

To obtain the PSDs of the generated spectrum-compatible time histories for comparison with the minimum required horizontal and vertical target PSDs, the following calculation steps are used for each acceleration time history $a_i(t)$, $i = \text{H1H, H2H, VTH}$.

- (1) Calculate the (equivalent stationary) strong-motion duration T_s^i for the time history $a_i(t)$ using the following equations:

$$E_i(t_p^i) = \int_0^{t_p^i} a_i^2(t) dt; \quad i = \text{H1H, H2H, VTH} \quad (3-2)$$

$$T_s^i = \frac{t_{p2}^i - t_{p1}^i}{p_2 - p_1} \quad (3-3)$$

Where P_1 and P_2 , $P_1 < P_2$, are the ratio of the cumulative energies $E_i(t_{p1}^i)$ and $E_i(t_{p2}^i)$ to the total cumulative energy of the entire time history; and where t_{p1}^i and t_{p2}^i , $t_{p1}^i < t_{p2}^i$, are the

times at which the ratios P_1 and P_2 are reached. The ratios P_1 and P_2 , and the corresponding over the duration $t_s^i = t_{p2}^i - t_{p1}^i$ can best be fitted by a straight line (i.e., constant energy buildup) having a constant slope $S = [E_i(t_{p2}^i) - E_i(t_{p1}^i)] / (t_{p2}^i - t_{p1}^i)$. The equivalent stationary duration T_s^i for the entire time history 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 .

This procedure of calculating T_s^i is illustrated in Figure 3-27. P1=0% to P2=100%

- (2) Compute the one-sided PSD, $S_i(f)$ of the time history $a_i(t)$ using the following equations:

$$S_i(f) = \frac{|A_i(f)|^2}{T_s^i} \quad (3-4)$$

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

$$A_i(f) = \int_0^{T_i} a_i(t) e^{-2\pi f t} dt \quad (3-5)$$

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

- (3) Smooth the time history PSD $S_i(f)$ using the moving average technique over a ± 20 percent frequency bandwidth centered at the frequency f , in accordance with the guidelines in NUREG/CR-5347 (Reference 24), to give the smoothed time history PSD $\tilde{S}_i(f)$.

The smoothed time history PSD, $\tilde{S}_i(f)$, obtained from step (c) above is then compared with the minimum required target PSD, $\tilde{S}_i(f)$, to check the adequacy of the power content of the generated time history.

1.9 Generation Results

The acceleration time histories generated using the procedure described in Section 3.4 consist of two horizontal (H1H and H2H) and one vertical (VTH) components. Time histories H1H, H2H, and VTH are applied in the horizontal E-W, horizontal N-S, and vertical directions, respectively. The time interval of time history digitization, Δt , is 0.005 second, which corresponds to the highest frequency of interest of 100 Hz.

The horizontal H1H acceleration time history is plotted along with the integrated velocity and displacement time histories in Figure 3-28. The comparison of the time history response spectra with the corresponding horizontal target HRHF response spectra for the corresponding damping values are shown in Figure 3-29. Similar results for the horizontal H2H time history are shown in Figures 3-30 and 3-31. Similar results for the vertical time history VTH are shown in Figures 3-32 and 3-33.

The maximum acceleration (A), maximum velocity (V), maximum displacement (D) and V/A and AD/V² ratios of the generated H1H, H2H, and VTH time histories are listed in Table 3-9

To show the statistical independence of the set of time histories, the cross-correlation coefficients of pairs of the HRHF response spectrum-compatible time histories are given in Table 3-10. The values all are below 0.16, thus satisfying the SRP Section 3.7.1 (Reference 15) threshold for statistical independence.

The discrete form of the mathematical Equation (3-5) 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 $t_j = j\Delta t, j = 0, 1, \dots, N-1$.

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In SRP 3.7.1, the requirement of minimum power spectral density (PSD) to prevent the design ground acceleration time histories from having a deficiency of power over any frequency range is described. SRP 3.7.1 specifies that the use of a single time history is justified by satisfying a target PSD requirement in addition to the design response spectra enveloping requirements.

Since the original NRC RG 1.60 horizontal spectrum and the horizontal CSDRS are identical for frequencies less than 9 Hz, no modification to the target horizontal PSD is done in this frequency range.

The time-history simulation method described in NUREG/CR-5347 (Reference 8) is used to develop the CSDRS-compatible horizontal target PSD in the higher frequency range above 9 Hz. The resulting piecewise log-log linear horizontal target PSD developed is given in Table 3.7-3. The minimum required horizontal PSD is then 0.8 times the horizontal target PSD.

The vertical target PSD, compatible with the vertical CSDRS, is obtained from the horizontal target PSD, compatible with the horizontal CSDRS using the following equation:

$$S_V(f) = [R_V(f, 2\%) / R_H(f, 2\%)]^2 \times S_H(f)$$

where $R_H(f, 2\%)$ and $R_V(f, 2\%)$ are, respectively, the 2 percent damped horizontal and vertical CSDRS values at the frequency (f). The detailed procedure for generating target PSD is described in Technical Report, APR1400-E-S-NR-14001-P (Reference 9). The minimum required vertical PSD is then 0.8 times the vertical target PSD.

The PSDs of the design acceleration time histories are presented in Figures 3.7-9 through 3.7-11. The PSDs of the design acceleration time histories exceed the minimum required PSD throughout the entire frequency range. The PSDs presented are the averaged PSDs obtained over a moving frequency band of ± 20 percent centered at each frequency. The PSD amplitude at frequency (f) has the averaged PSD amplitude between the frequency range of $0.8f$ and $1.2f$ as stated in Appendix A of SRP 3.7.1.

The PSDs of the design acceleration time histories in accordance with SRP 3.7.1, Revision 4, Appendix B are computed to further demonstrate satisfying the PSD requirement. As shown in Figure 3.7-9 (b) through 3.7-11(b), the PSDs are reasonable compared with the PSDs consistent with SRP 3.7.1, Revision 4, Appendix B.

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The time histories are developed following the spectrum matching acceptance criteria of Option 1, Approach 1, in Section II of SRP 3.7.1. The comparison plots of the response spectra of the time histories versus the HRHF response spectra for 2, 3, 4, 5, 7, and 10 percent critical dampings are shown in Figures 3.7-17, 3.7-18, and 3.7-19. The figures demonstrate that the time histories envelop the HRHF response spectra for those damping values, satisfying the requirement of SRP 3.7.1 that no more than 5 points fall below and by no more than 10 percent below the HRHF response spectra.

~~According to SRP 3.7.1, the ratio V/A and AD/V^2 should be consistent with characteristic values for the magnitude and distance of the appropriate controlling events defining the uniform hazard response spectra. The target and target ranges of values for the other design ground motion time history parameters are the median (m) values and the median (m) \pm one standard deviation (σ) (i.e., $m \pm \sigma$) ranges. The determination of these target and target ranges of values is based on the methodologies and ground motion databases as described in NUREG/CR-6728. Table 3.7-4 shows a comparison of the ratios V/A and AD/V^2 for the time histories and the guidance in NUREG/CR-6728 and that the ratios are between the target values, target median $\pm \sigma$.~~

For the development of the HRHF-response spectra-compatible target PSDs in the frequency range from 0.3 to 80 Hz, the time-history simulation method described in NUREG/CR-5347 is used. The resulting piecewise log-log linear horizontal and vertical target PSD developed is given in Tables 3.7-5 and 3.7-6. The minimum required horizontal and vertical PSD is then 0.8 times the horizontal and vertical target PSD.

The PSDs of the acceleration time histories compatible with the HRHF response spectra are presented in Figures 3.7-20 through 3.7-22. The PSDs of the acceleration time histories exceed the minimum required PSD throughout the entire frequency range.

The evaluation methodology and results of the APR1400 for the HRHF seismic input motions are provided in Appendix 3.7B.

3.7.1.2 Percentage of Critical Damping Values

Damping values used for various nuclear safety-related SSCs are based on NRC RG 1.61 (Reference 10). These values are expressed in percentages of critical damping and are given in Table 3.7-7. Damping values of soil to be used in soil-structure interaction

The PSDs of the acceleration time histories compatible with the HRHF response spectra in accordance with SRP 3.7.1, Revision 4, Appendix B are computed to further demonstrate satisfying the PSD requirement. As shown in Figure 3.7-20 (b) through 3.7-22(b), the PSDs are reasonable compared with the PSDs consistent with SRP 3.7.1, Revision 4, Appendix B.

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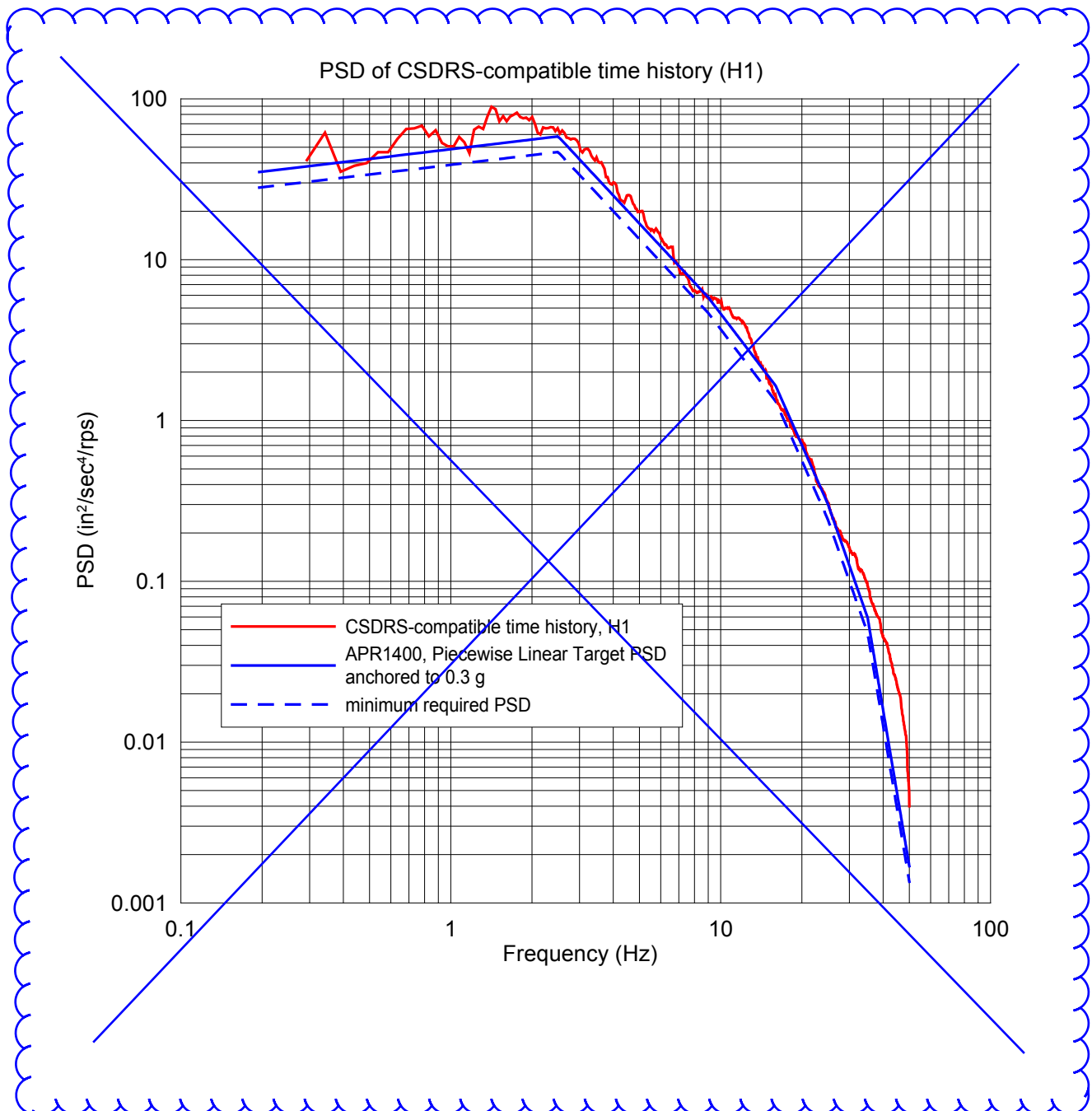
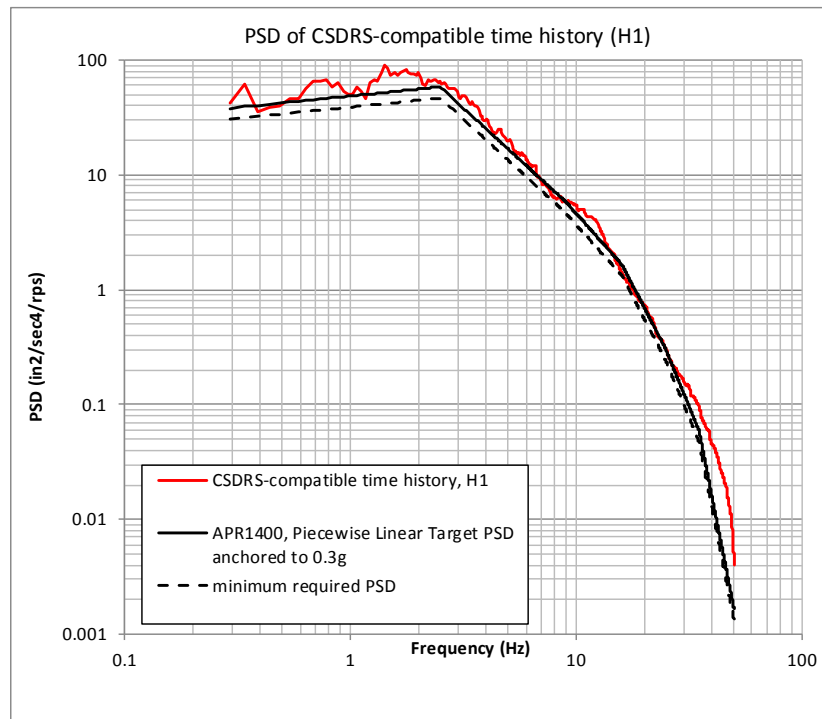
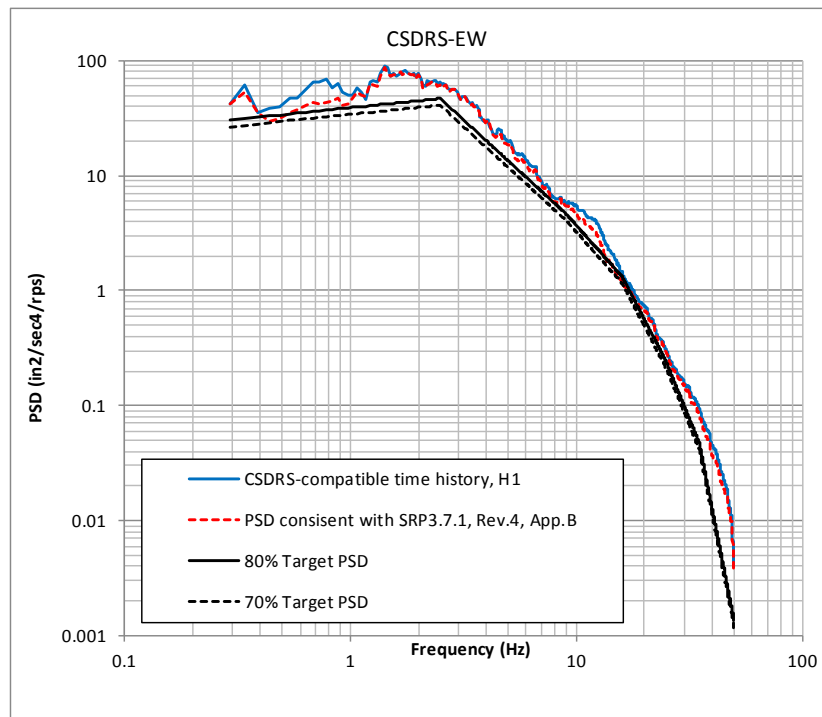


Figure 3.7-9 Comparison of PSD of H1 Design Ground Motion, Target PSD, and Minimum Required PSD

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(a) Comparison of PSD of H1 Design Ground Motion and Target PSD and Minimum Required PSD



(b) Comparison of PSD for H1 Design Ground Motion and PSD Consistent with SRP 3.7.1, Rev.4, Appendix B

Figure 3.7-9 Comparison of PSD for H1 Design Ground Motion

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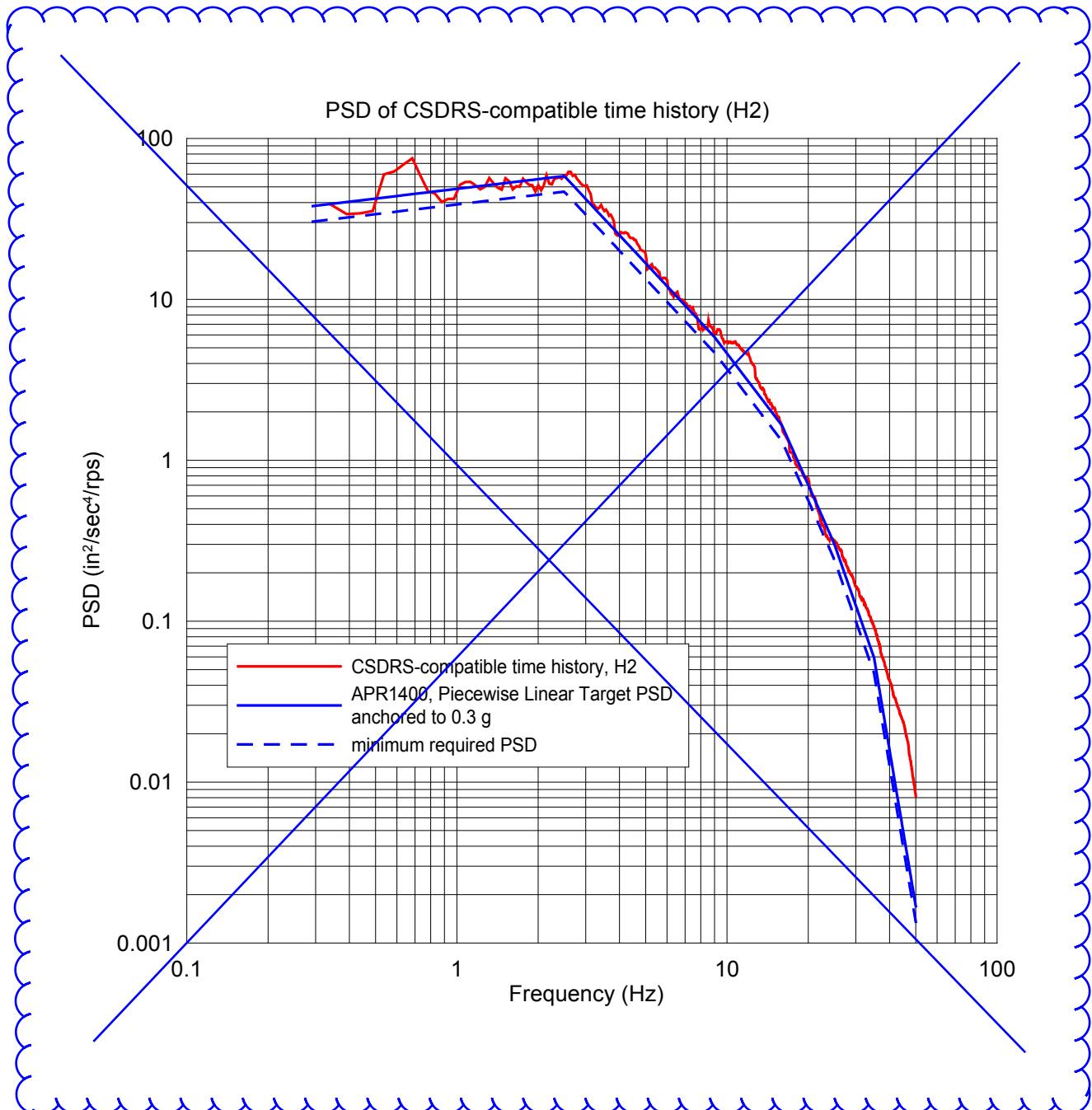
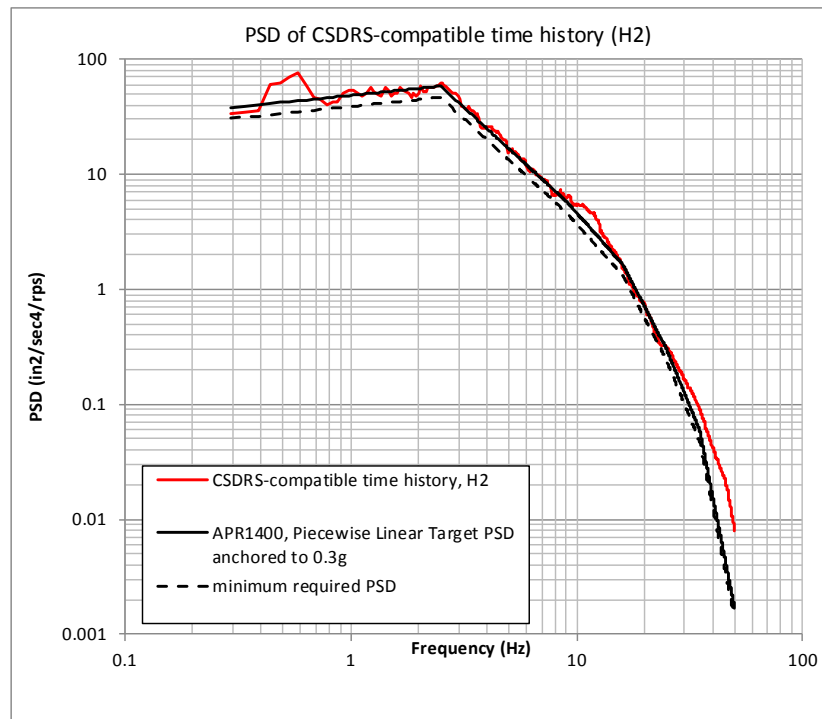
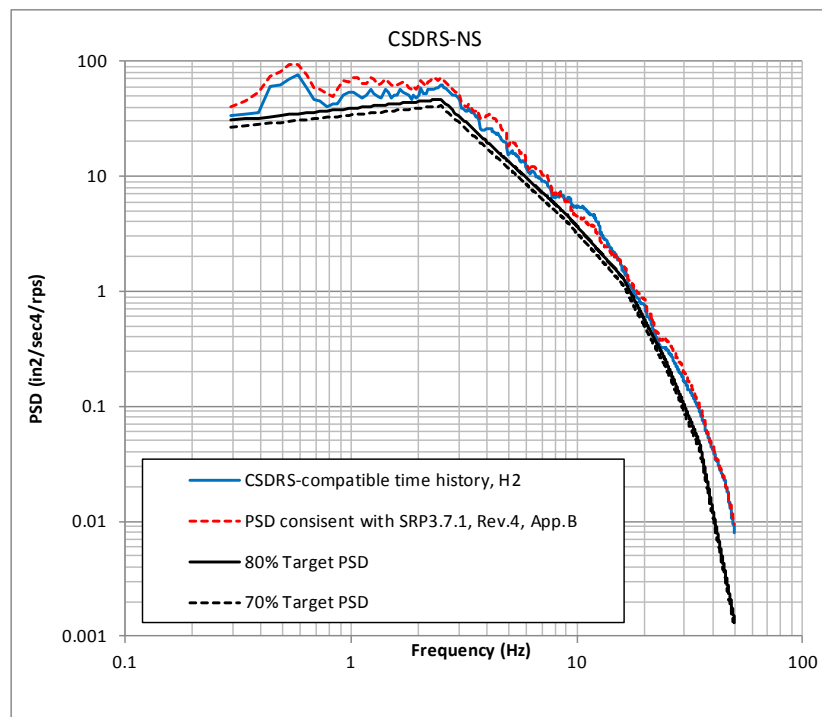


Figure 3.7-10 Comparison of PSD of H2 Design Ground Motion, Target PSD, and Minimum Required PSD

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(a) Comparison of PSD of H2 Design Ground Motion and Target PSD and Minimum Required PSD



(b) Comparison of PSD for H2 Design Ground Motion and PSD Consistent with SRP 3.7.1, Rev.4, Appendix B

Figure 3.7-10 Comparison of PSD for H2 Design Ground Motion

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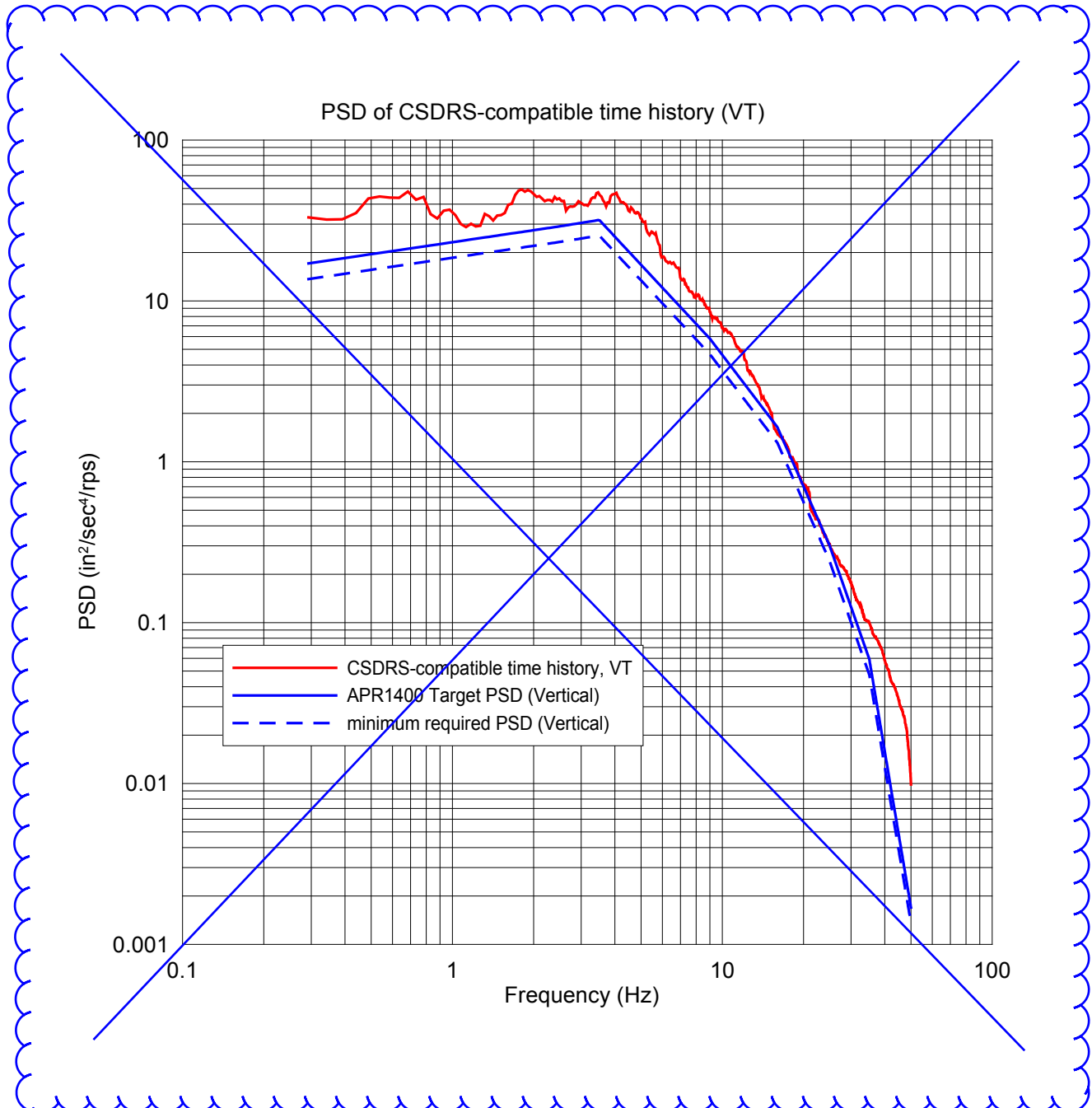
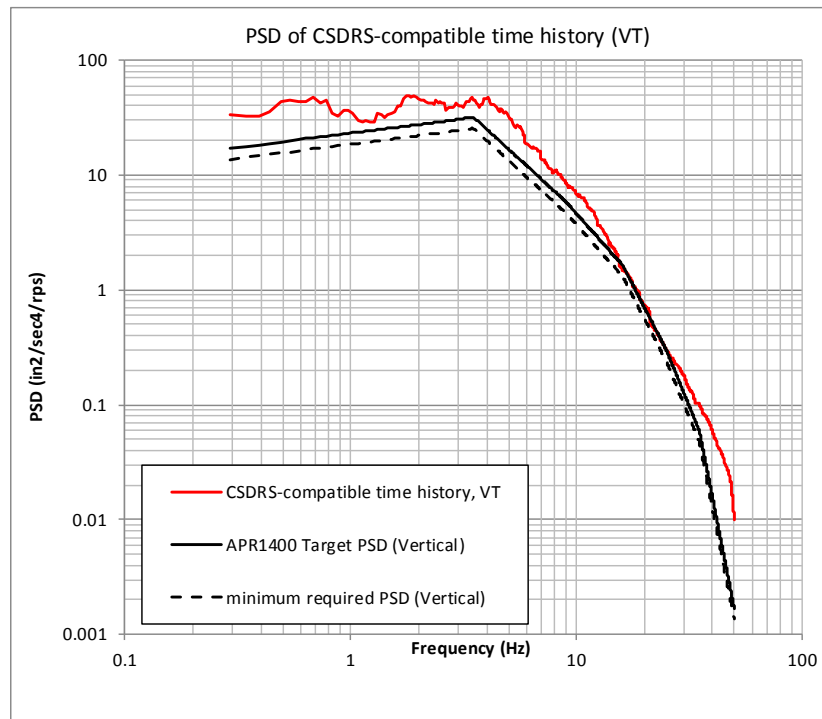
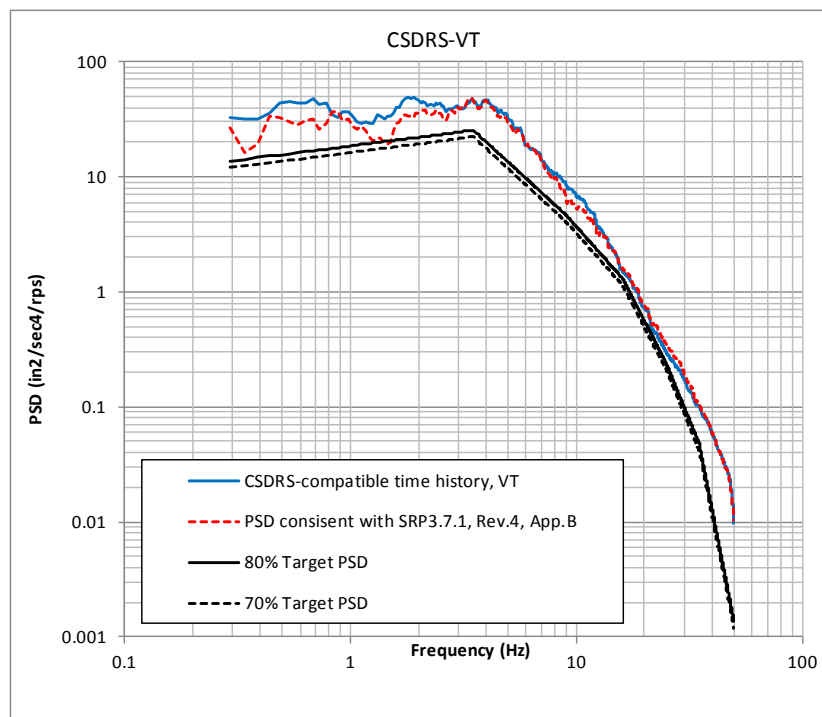


Figure 3.7-11 Comparison of PSD of VT Design Ground Motion, Target PSD, and Minimum Required PSD

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(a) Comparison of PSD of VT Design Ground Motion and Target PSD and Minimum Required PSD



(b) Comparison of PSD for VT Design Ground Motion and PSD Consistent with SRP 3.7.1, Rev.4, Appendix B

Figure 3.7-11 Comparison of PSD for VT Design Ground Motion

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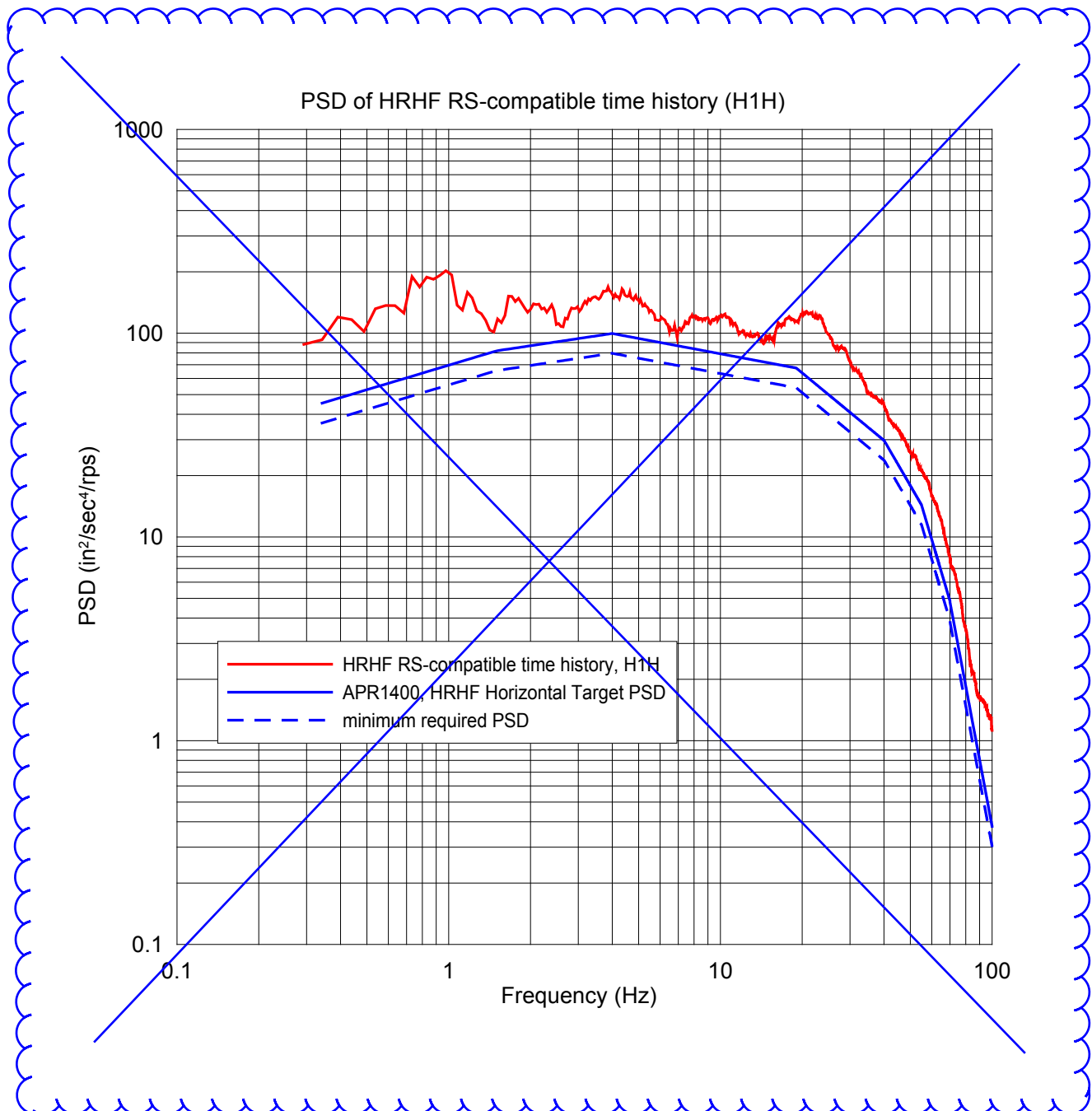
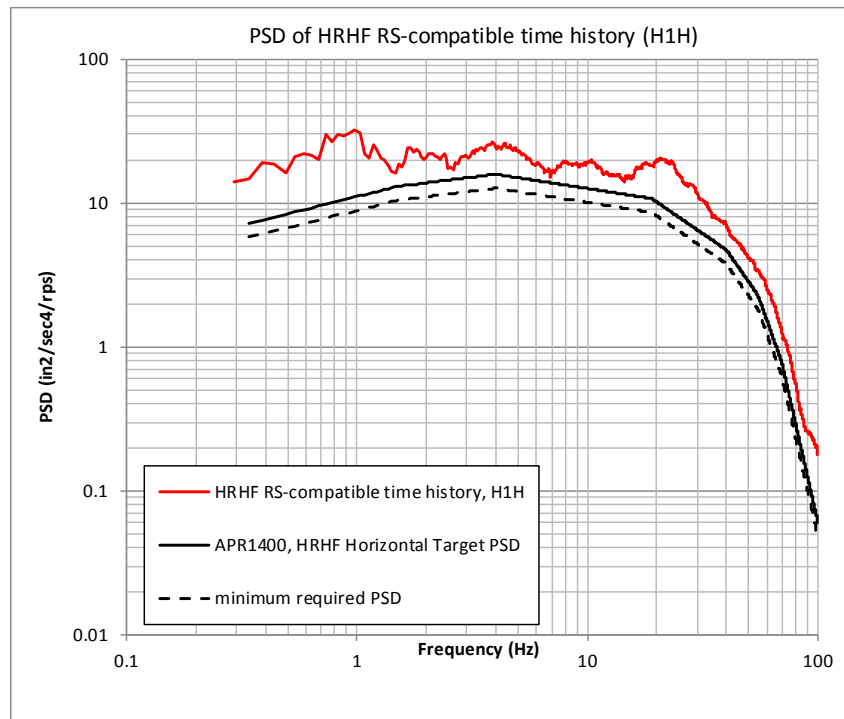
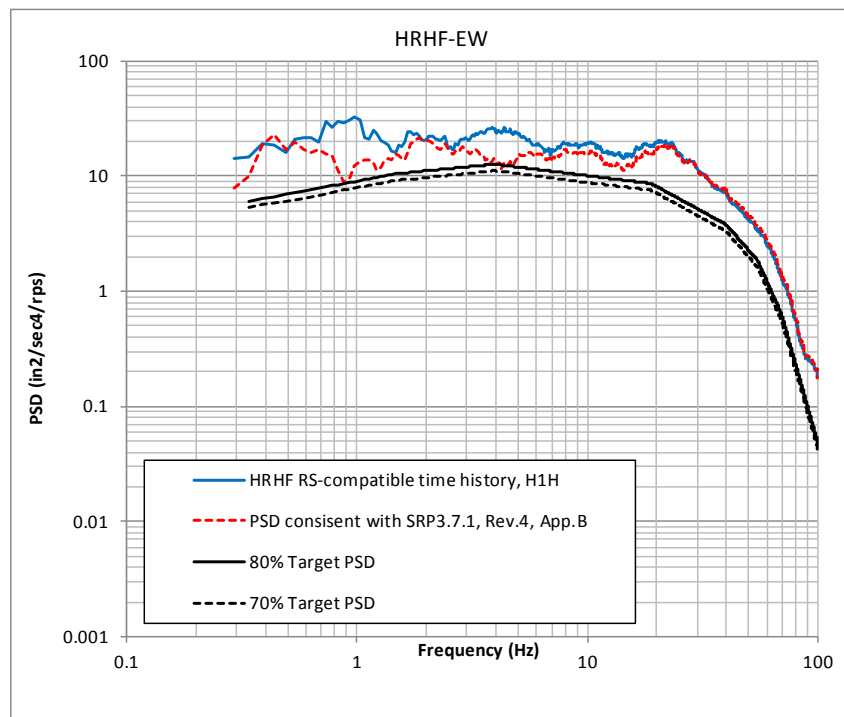


Figure 3.7-20 Comparison of PSD of H1H, HRHF Target PSD, and Minimum Required PSD

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(a) Comparison of PSD of H1H and HRHF Target PSD and Minimum Required PSD



(b) Comparison of PSD for H1H and PSD Consistent with SRP 3.7.1, Rev.4, Appendix B

Figure 3.7-20 Comparison of PSD for H1H

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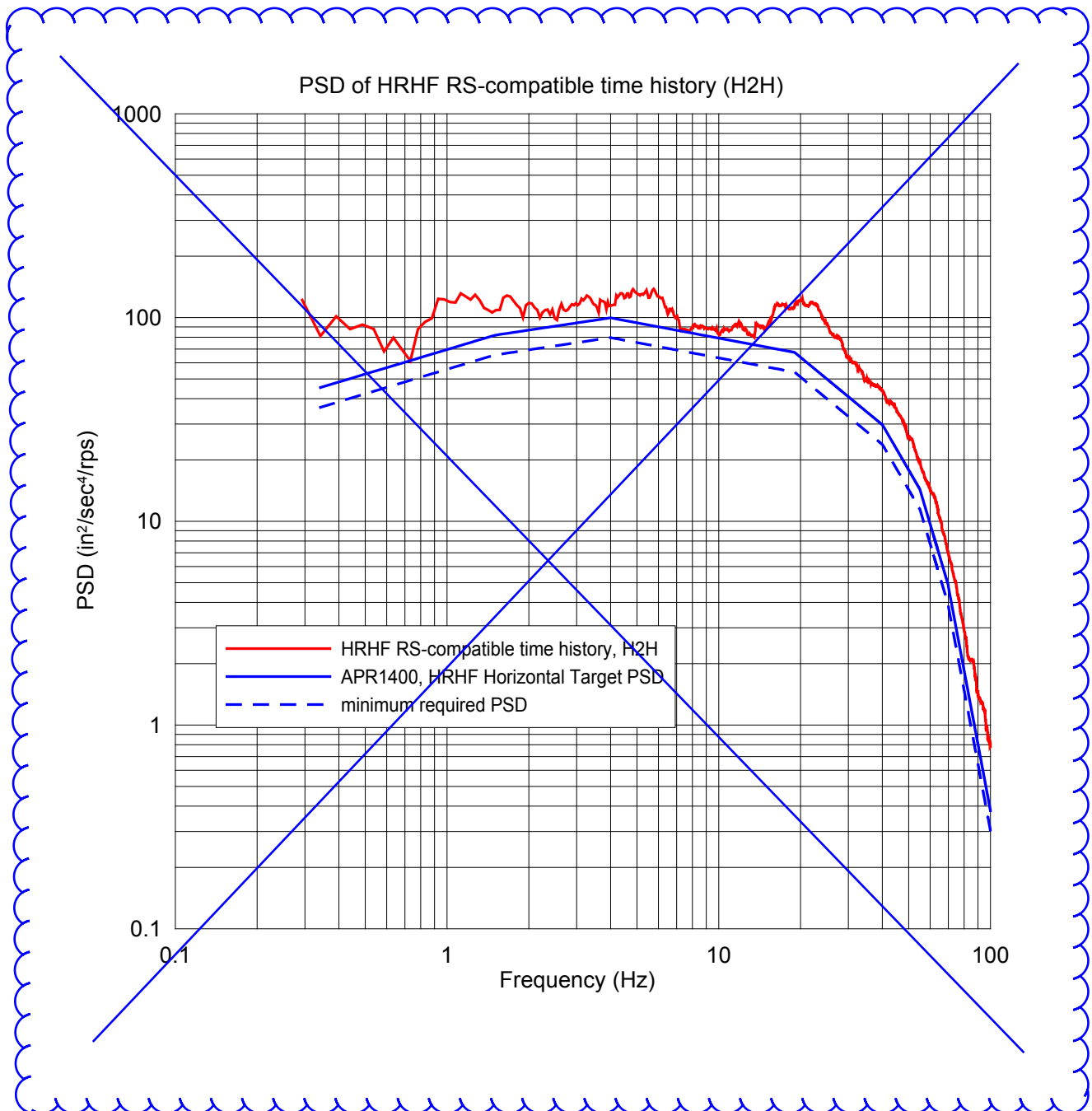
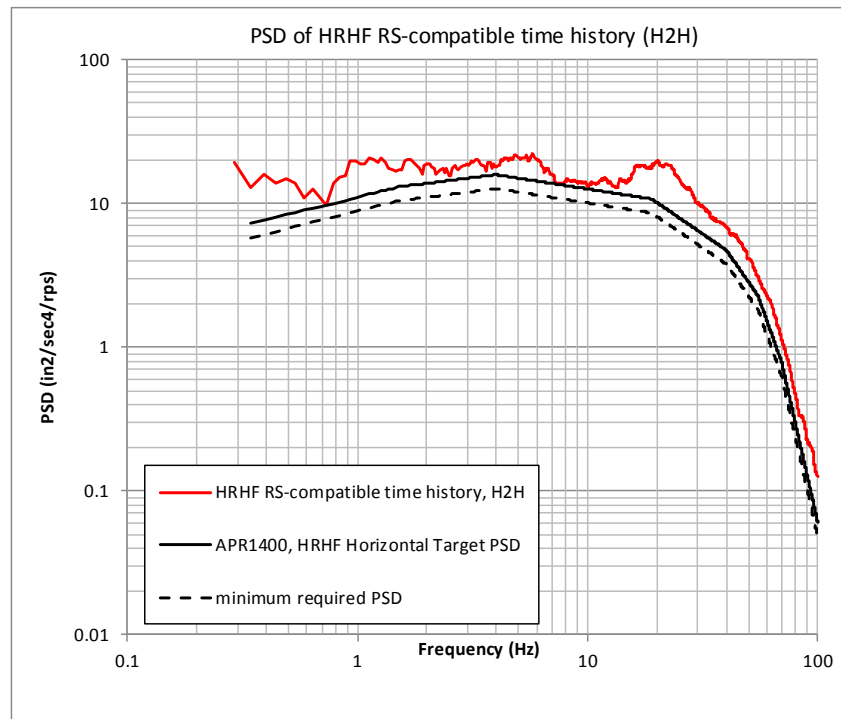
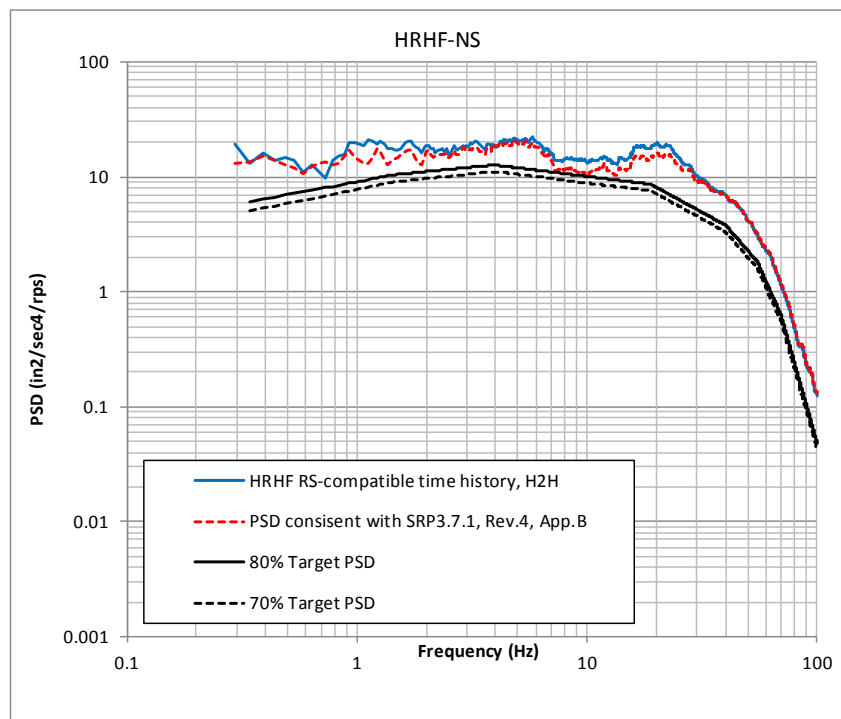


Figure 3.7-21 Comparison of PSD of H2H, HRHF Target PSD, and Minimum Required PSD

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(a) Comparison of PSD of H2H and HRHF Target PSD and Minimum Required PSD



(b) Comparison of PSD for H2H and PSD Consistent with SRP 3.7.1, Rev.4, Appendix B

Figure 3.7-21 Comparison of PSD for H2H

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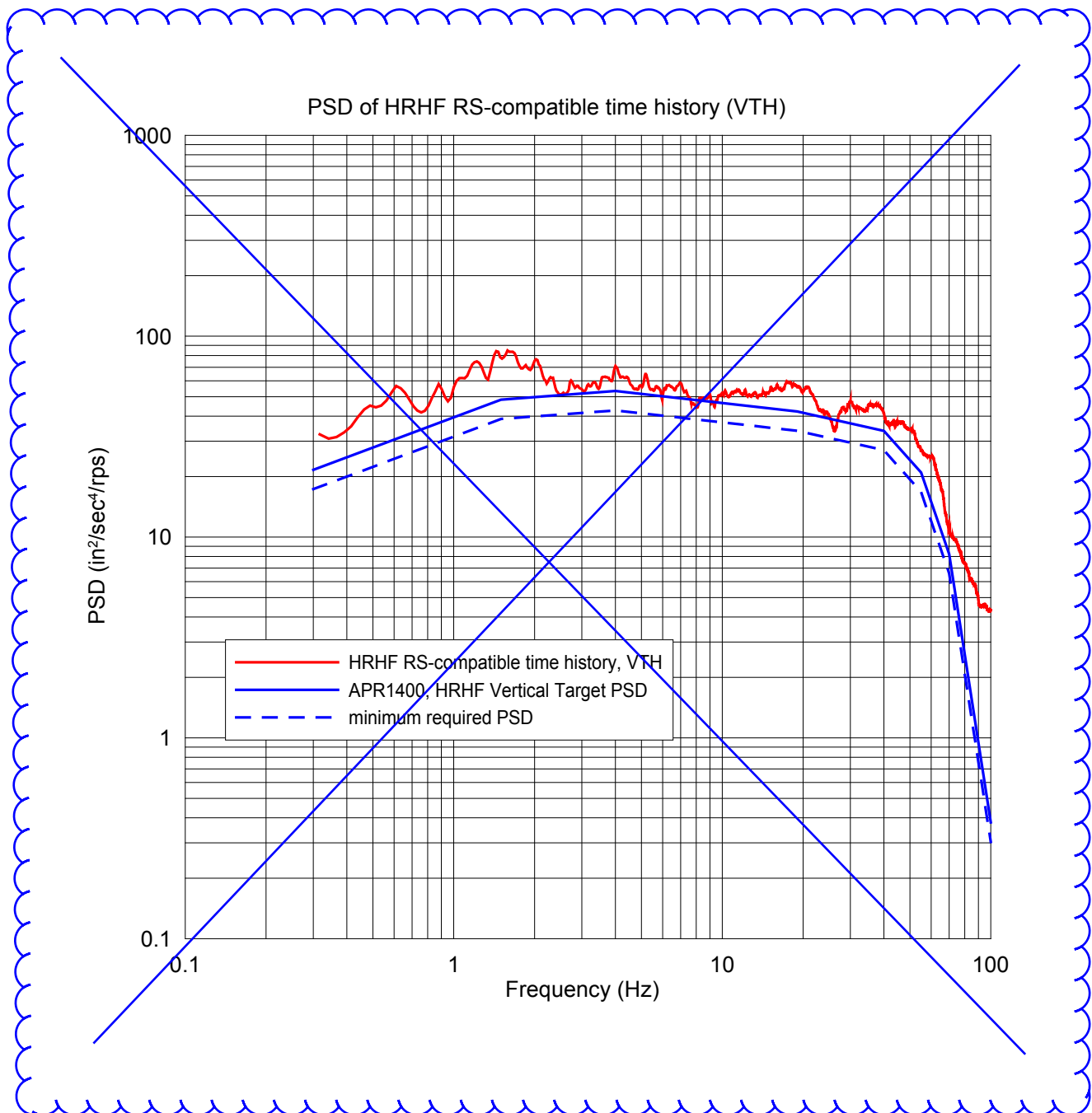
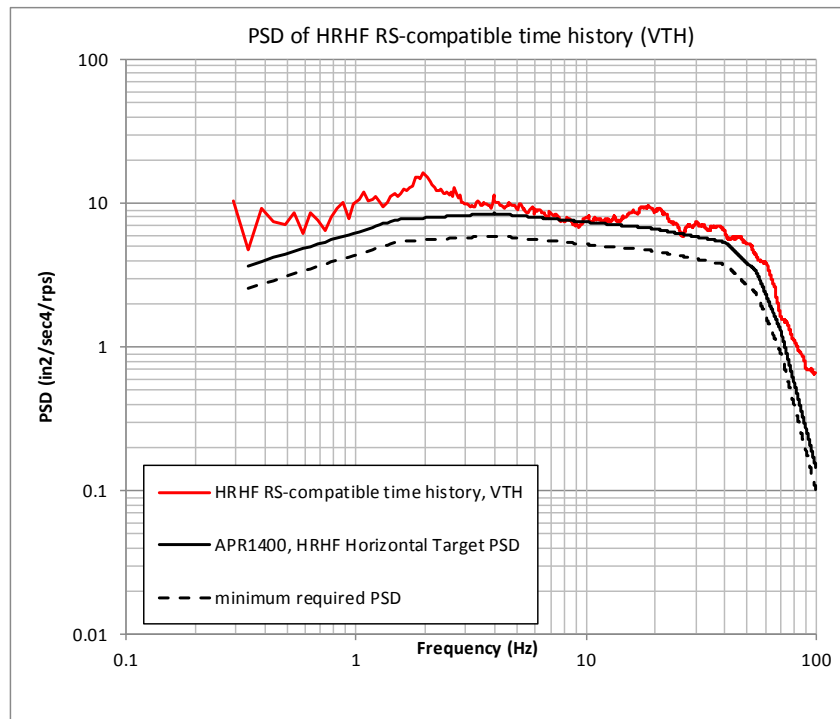
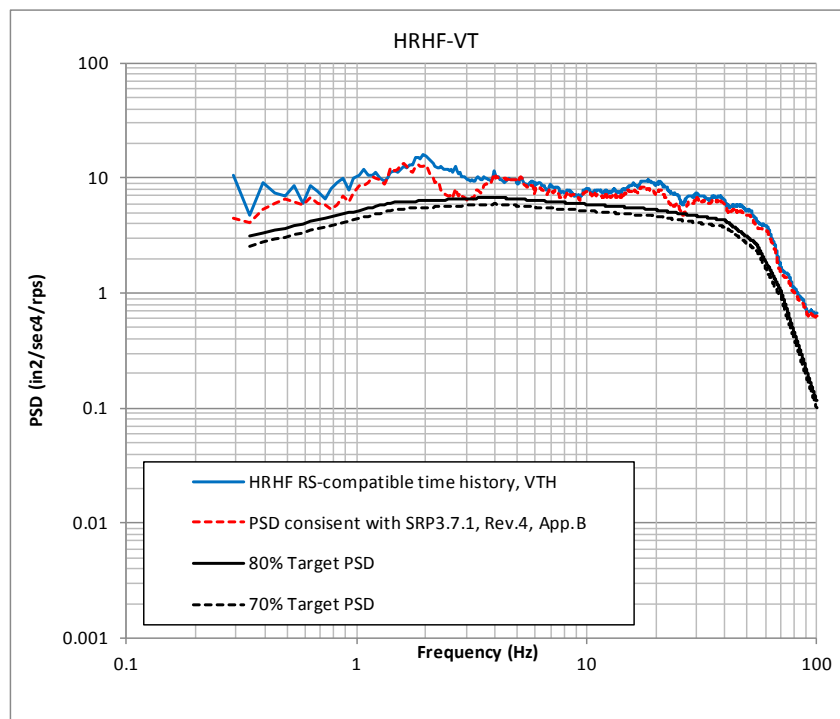


Figure 3.7-22 Comparison of PSD of VTH, HRHF Target PSD, and Minimum Required PSD

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(a) Comparison of PSD of VTH and HRHF Target PSD and Minimum Required PSD



(b) Comparison of PSD for VTH and PSD Consistent with SRP 3.7.1, Rev.4, Appendix B

Figure 3.7-22 Comparison of PSD for VTH