Proceedings of PVP2008
2008 ASME Pressure Vessels and Piping Division Conference
July 27-31, 2008, Chicago, Illinois, USA

PVP2008-61244

UNIQUE METHOD FOR GENERATING DESIGN EARTHQUAKE TIME HISTORY SEEDS

R. E. Spears, Ph.D.
Senior Research Engineer
Idaho National Laboratory
Tel: 208-526-4109
Fax: 208-526-4311
E-Mail: Robert.Spears@inl.gov

ABSTRACT

A method has been developed which takes a single seed earthquake time history and produces multiple similar seed earthquake time histories. These new time histories possess important frequency and cumulative energy attributes of the original while having a correlation less than 30% (per the ASCE/SEI 43-05 Section 2.4 [1]). They are produced by taking the fast Fourier transform of the original seed. The averaged amplitudes are then pared with random phase angles and the inverse fast Fourier transform is taken to produce a new time history. The average amplitude through time is then adjusted to encourage a similar cumulative energy curve. Next, the displacement is modified to approximate the original curve using Fourier techniques. Finally, the correlation is checked to ensure it is less than 30%. This process does not guarantee that the correlation will be less than 30% for all of a given set of new curves. It does provide a simple tool where a few additional iterations of the process should produce a set of seed earthquake time histories meeting the correlation criteria.

INTRODUCTION

Time history analysis is an important technique for structural seismic analysis especially when the evaluated structural response is nonlinear. To perform such an analysis, a representative earthquake acceleration time history (or seed acceleration time history) is established for a structure being evaluated. Manipulations of the seed are then performed to create a modified acceleration time history (or design acceleration time history) that produces a design acceleration response (per the ASCE/SEI 43-05 Section 2.4 [1]). This design acceleration time history can then be used for seismic analysis. Depending on the type of seismic analysis being performed, several design acceleration time histories may be required. The method described in this paper is a way to develop as many additional seed acceleration time histories as are required for a given seismic analysis.

This method is accomplished in three steps. First, averaged acceleration time history and Fourier transform amplitudes are gathered from the original seed. Second, a new acceleration time history is generated using averaged data along with randomly generated Fourier transform phase angles. Third, velocity and displacement shaping is performed to give the new seed a similar motion to the original seed. Precautions are taken during this process in an attempt to keep the correlation less than 0.30 between the original and new seed acceleration time histories (per the requirements of ASCE/SEI 43-05 Section 2.4 [1]).

While the method has been tested on many seed acceleration time histories, this paper will use results from one example to demonstrate the method. The example is based on an original seed acceleration time history with a time step of 0.005 seconds.

Figures 1 – 5 show the important data of the original seed used in generating the new seed. Figures 1 - 3 show the original seed acceleration, velocity, and displacement time histories. The original seed velocity and seed displacement time histories are derived using Fourier transform techniques. Figure 4 shows the Fourier transform of the original seed acceleration time history. Figure 5 is a trapezoidal rule evaluation of the original seed acceleration to plot cumulative energy (Eq. 2.4-2 in ASCE 4-98 [2]). The plot shown is scaled to the final cumulative energy.

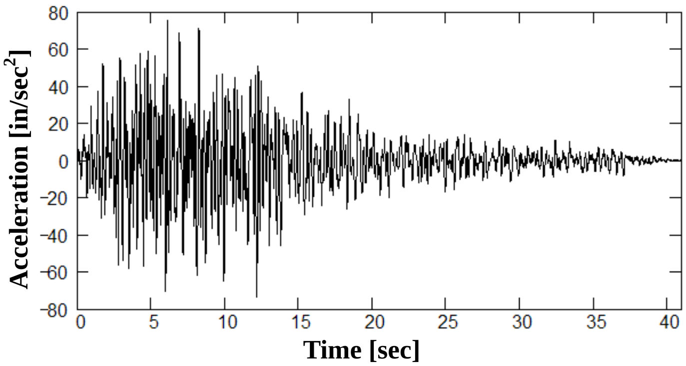

Figure 1. Original seed acceleration.

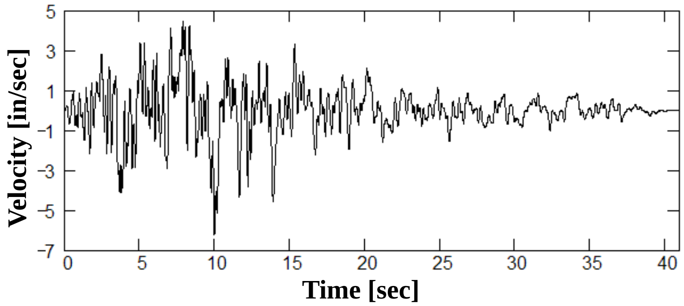

Figure 2. Original seed velocity.

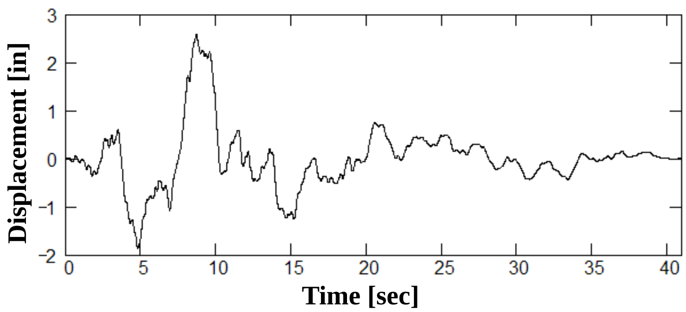

Figure 3. Original seed displacement.

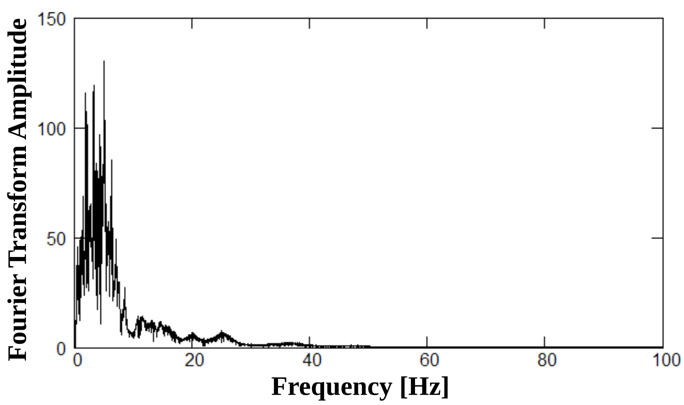

Figure 4. Original seed acceleration Fourier transform.

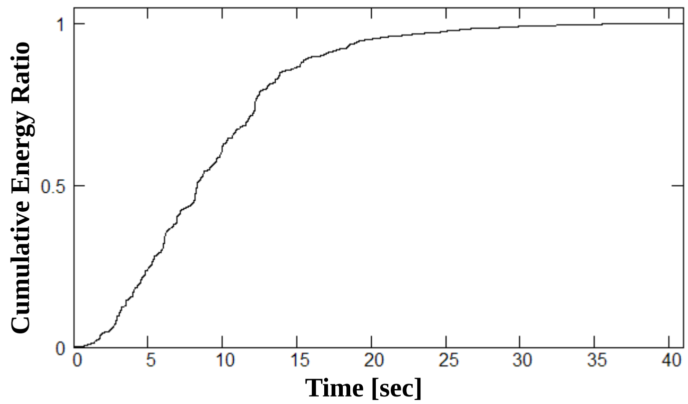

Figure 5. Original seed cumulative energy ratio.

Many subroutines are used in the modification process. A few important ones are discussed here. First, there is an integrator subroutine that uses Fourier transform techniques along with an input acceleration time history to produce resulting velocity and displacement time histories. Second and third subroutines are used to cause the final velocity and displacement time histories to end with zero amplitude. Zeroing is performed after every acceleration time history modification to maintain control of drift. The second subroutine operates with sine and cosine waves one half and one quarter the lowest frequency used in the fast Fourier transform. The waves are scaled to perform the zeroing and added to the acceleration time history. It is used where modifications to the start and end of the acceleration time history are not desirable. The third subroutine operates with smooth polynomial acceleration curves added to the start and end of the acceleration time history. It is used where modifications to the middle of the acceleration time history are not desirable. Fourth, a subroutine is written that produces a smooth linear transition from one time history to another. This is used primarily to transition modified time histories back to an unmodified time histories at its start and end. A fifth subroutine is written to compare a given time history to a target time history. The target time history is a time history with a general shape that is desirable, but an exact fit of it is not desirable. Then using a defined band of Fourier transform frequencies, a best fit adjustment time history is established to reduce the difference between the given time history and the target time history. If the time history is not acceleration (i.e. velocity or displacement), conversion of the adjusted time history to acceleration takes place in the frequency domain.

ORIGINAL SEED AVERAGING

To produce a new seed that is similar in cumulative energy ratio and frequency content yet has low correlation relative to the original seed, original seed averaging is performed. Amplitude averaging of the original acceleration time history seed is evaluated to address cumulative energy ratio. Amplitude averaging of the Fourier transform is evaluated to address the frequency content.

Figure 6 shows the original acceleration time history seed and its average amplitude. In this example the averaging is performed over 200 data point intervals.

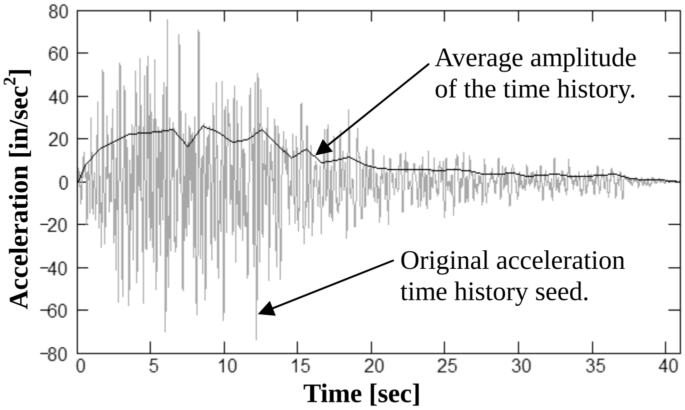

Figure 6. Average time history amplitude.

Figure 7 shows the Fourier transform of the original acceleration time history seed and its average amplitude. In this example the averaging is performed over 50 data point intervals. The numbers of data points used in the averaging intervals are somewhat arbitrary and represent parameters that can be varied to meet the needs of a given acceleration time history. The intent is to get a smooth curve following along the path of the data.

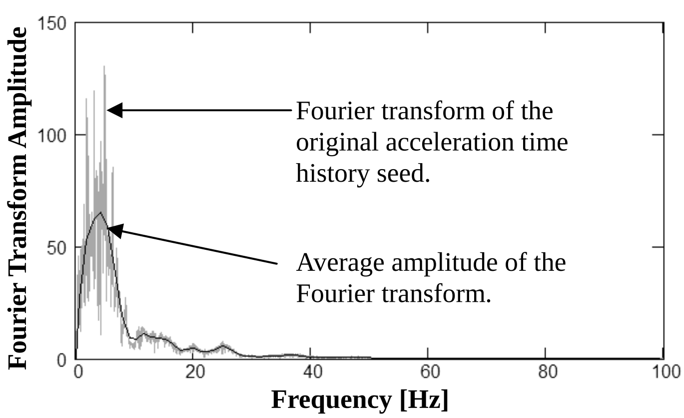

Figure 7. Average Fourier transform amplitude.

SHAPING NEW SEED ACCELERATION

To produce the new acceleration time history seed, the first step is to use the average amplitude for the Fourier transform paired with randomly generated phase angles. Taking the inverse Fourier transform of this produces an acceleration time history with similar frequency content to the original acceleration time history. Figure 8 shows an example of an acceleration time history that results. Also shown is the original acceleration time history for comparison.

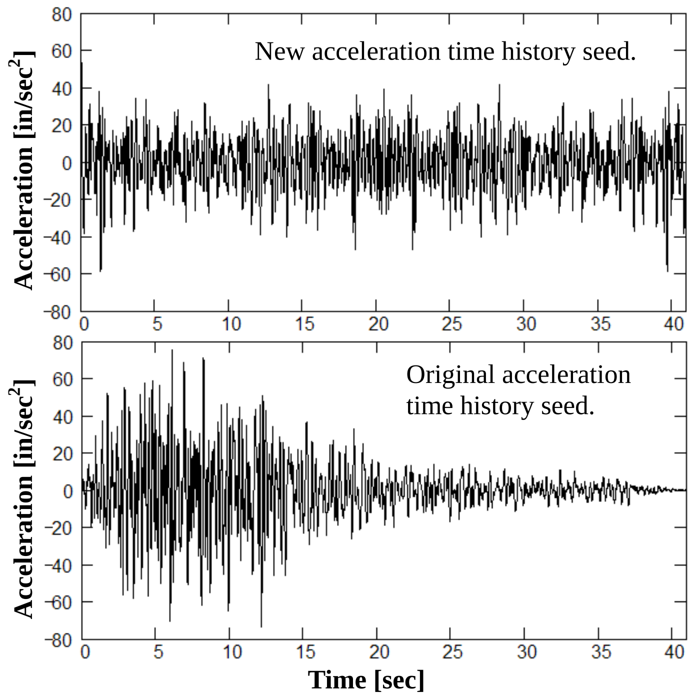

Figure 8. First step new and original seeds.

The second step is to find the average amplitude of the new acceleration time history seed in the same manner as done on the original acceleration time history seed. Using the ratio of the average curves, the new acceleration time history seed is scaled to produce a similar amplitude variation through time to that of the original. Additionally, the start and end of the new acceleration time history are linearly smoothed to the original acceleration time history. This is a cosmetic adjustment to help the appearance of the new acceleration time history seed. It is performed only in the region below 5% cumulative energy and above 75% cumulative energy as this is outside the region of most concern in ASCE/SEI 43-05 Section 2.4 [1]. In this example, the smoothing occurs only in the region below 1% cumulative energy and above 99% cumulative energy. Figure 9 shows the results of this modification along with the original acceleration time history for comparison.

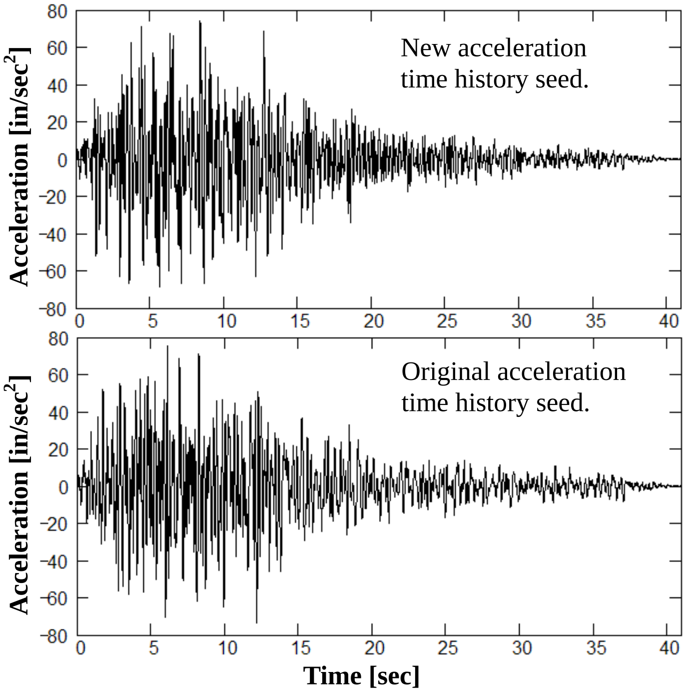

Figure 9. Second step new and original seeds.

Integrating the new acceleration time history seed produces velocity and displacement plots as shown in Figures 10 and 11.

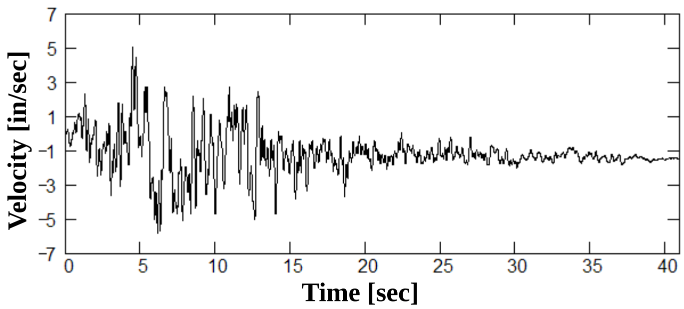

Figure 10. Second step new seed velocity.

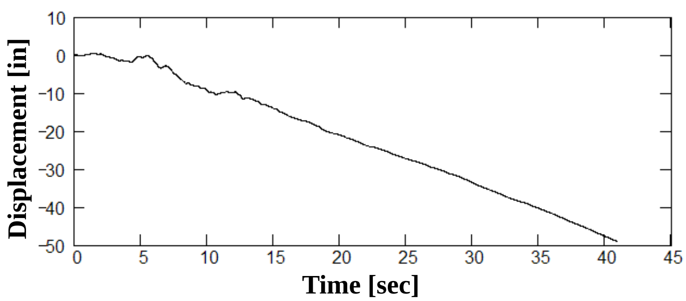

Figure 11. Second step new seed displacement.

SHAPING NEW SEED VELOCITY & DISPLACEMENT

ASCE/SEI 43-05 [1] defines proportions between the peak acceleration, velocity, and displacement values that should remain similar during time history manipulation. Consequently, it is desirable for the new acceleration, velocity, and displacement curves to have proportions similar to that of the original curves. To enforce these proportions, three manipulations are performed. First, the subroutine using sine waves is used to manipulate the new acceleration time history to cause the velocity and displacement to end at zero amplitude. Figures 12 and 13 show the results of this manipulation.

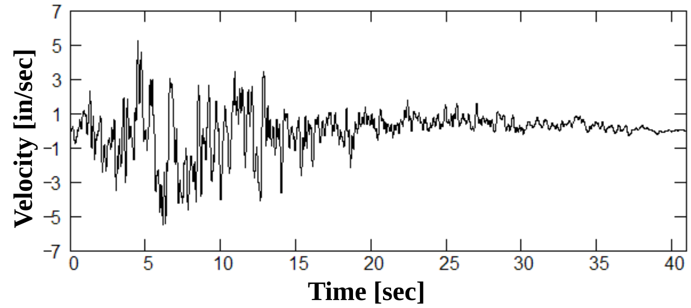

Figure 12. Velocity with end amplitude of zero.

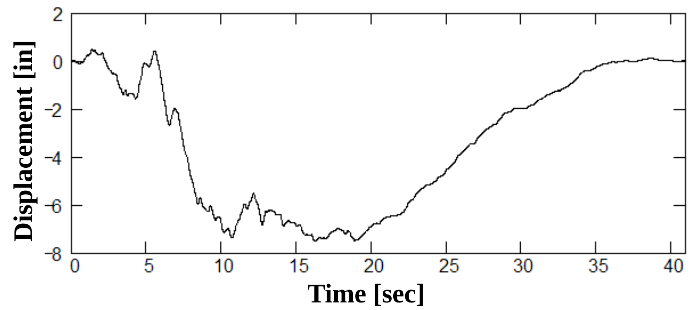

Figure 13. Displacement with end amplitude of zero.

Second, scaling is performed considering the original displacement time history as a target with a frequency band of 0 Hz to 0.5 Hz. Using a relatively small frequency band helps to maintain a low correlation between the original and new acceleration time history seeds. The displacement modifications are then converted to acceleration and used to adjust the acceleration time history. Figures 14 and 15 show the results of this manipulation.

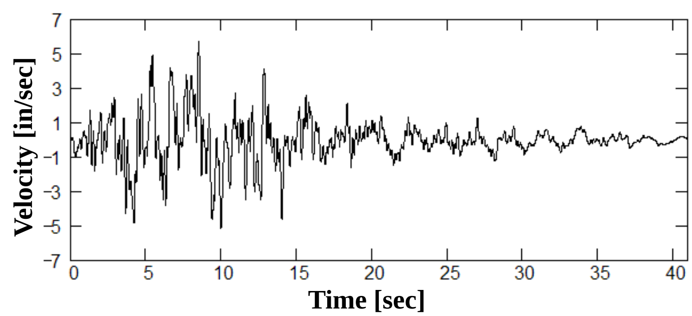

Figure 14. Velocity modified to target displacement.

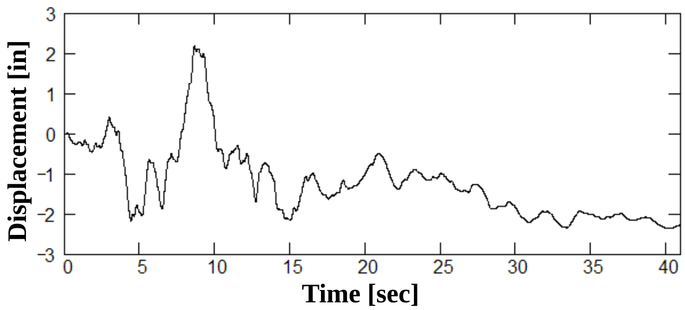

Figure 15. Displacement modified to target displacement.

Third, the subroutine using the smooth polynomial acceleration curves is applied to the new acceleration time history to cause the velocity and displacement to end at zero amplitude. Figures 16 and 17 show the results of this manipulation.

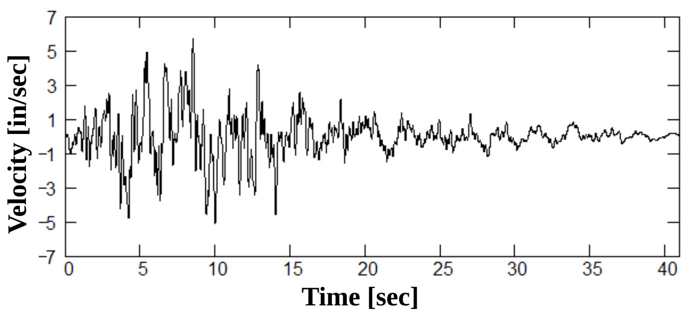

Figure 16. Velocity zeroed with polynomial curves.

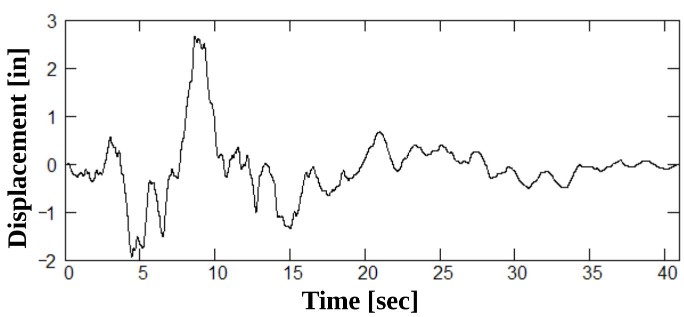

Figure 17. Displacement zeroed with polynomial curves.

At this point, a usable set of curves has been produced. For cosmetic reasons, however, smoothing and zeroing is performed again. Figures 18 – 22 show the final results of the new time history seed and the original time history seed. In this example the correlation between the new acceleration time history seed and the original acceleration time history seed is 0.004. This is much less than the 0.30 required per ASCE/SEI 43-05 Section 2.4 [1].

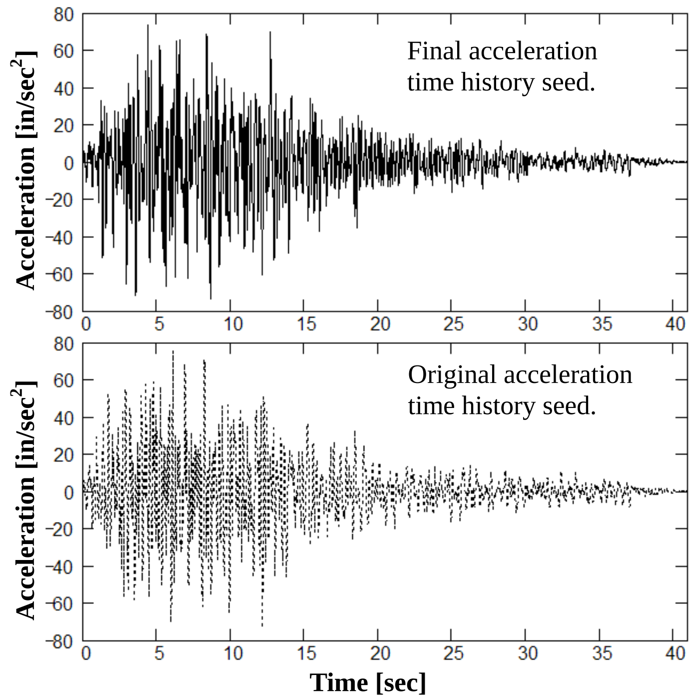

Figure 18. Final acceleration time history comparison.

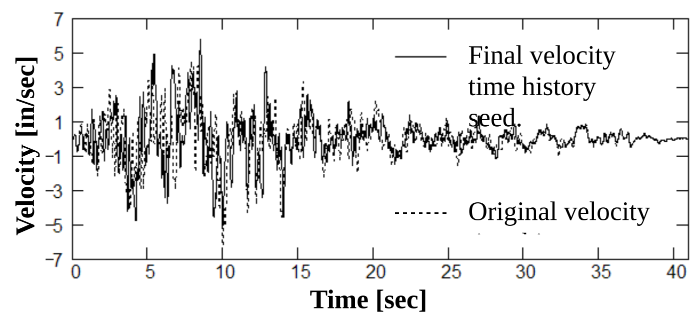

Figure 19. Final velocity time history comparison.

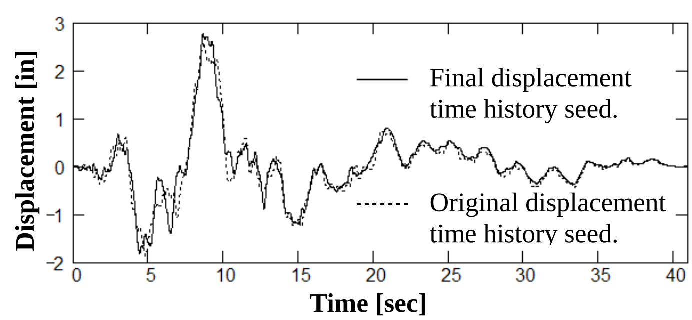

Figure 20. Final displacement time history comparison.

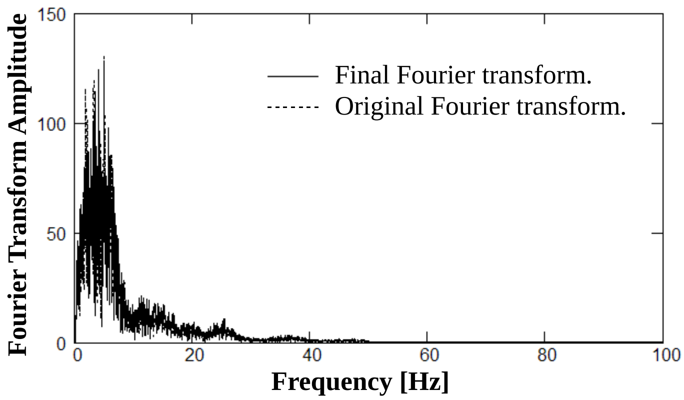

Figure 21. Final Fourier transform comparison.

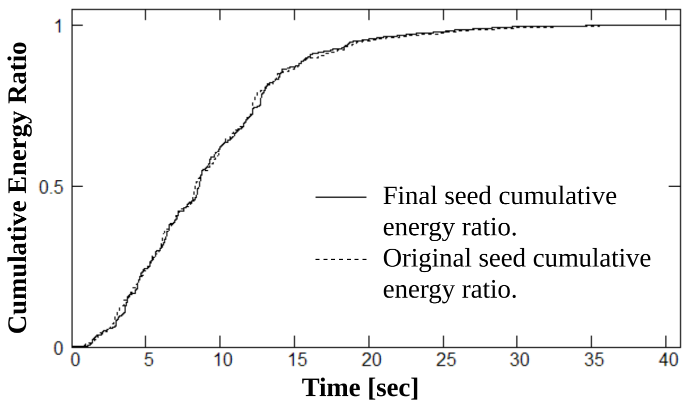

Figure 22. Final cumulative energy ratio comparison.

CONCLUSION

A method has been developed which takes a single seed earthquake time history and produces multiple similar seed earthquake time histories. These new acceleration time histories possess important frequency and cumulative energy attributes of the original while having a correlation less than 30% (per the code). This process does not guarantee that the correlation will be less than 30% for all of a given set of new curves. It does provide a simple tool where a few additional iterations of the process should produce a set of seed earthquake time histories meeting the correlation criteria. The example shown in this paper having a correlation of 0.4% demonstrates the low correlation potential of the method.

Response spectra produced by the new seed acceleration time histories will most likely vary from the original seed acceleration time history. Similar to the original seed acceleration time history, manipulations are needed on the new seeds to produce design time histories (per the ASCE/SEI 43-05 Section 2.4 [1]). This process on the new seed acceleration time histories should be no more difficult than for that of the original seed acceleration time history.

ACKNOWLEDGEMENTS

This manuscript has been authored by Battelle Energy Alliance, LLC under Contract No. DE-AC07-05ID14517 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a nonexclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

REFERENCES

[1] ASCE/SEI 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, 2005.

[2] ASCE 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary, American Society of Civil Engineers, 1998.