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Generation of strong ground motion records by Numerical Simulation coupled with Artificial Neural Networks

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Outline

- Fault-to-Site decoupled analysis

Alternative approach : key features

Coupled analysis (SPEED+ANN)

- VERIFICATION (SPEED) $\rightarrow$ Long Period Spectral Ordinates
- SIMULATION (ANN) $\rightarrow$ Short Period Spectral Ordinates

Alternative approach : key features

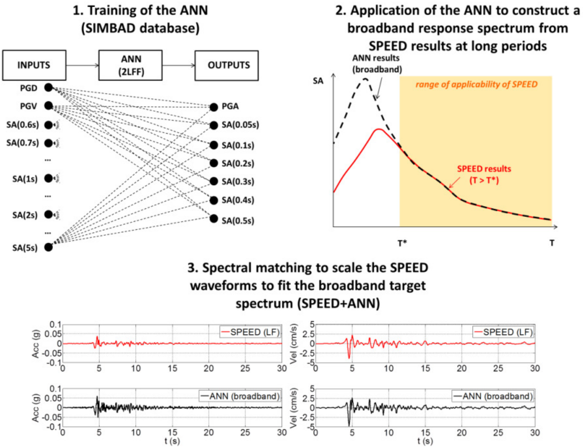


FIGURE 1 – Sketch of the procedure to generate BB ground motions from large scale scenarios. Reprinted from[2]

Alternative approach : example

1. **Records from database**
2. Numerical Simulations
3. Broad-Band Mashup
4. Short period ANN
5. Spectral Matching

Records from database

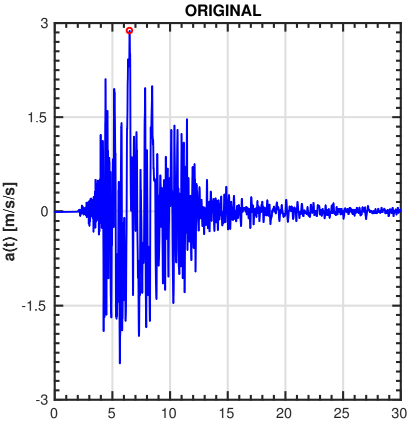


FIGURE 2 – **ORIGINAL** and **FILTERED** (low-pass - 1.5 Hz) Acceleration Time-Histories

```
%% *ORIGINAL RECORDS — STRUCTURE*
rec.org =

    mon: [1x1 struct]    % monitor
    syn: {[1x1 struct]}  % synthetics/records
    bhr: [1x1 struct]    % borehole

%% *FILTERED RECORDS — STRUCTURE*
rec.fil =

    mon: [1x1 struct]    % monitor
    syn: {[1x1 struct]}  % synthetics/records
    bhr: [1x1 struct]    % borehole
```

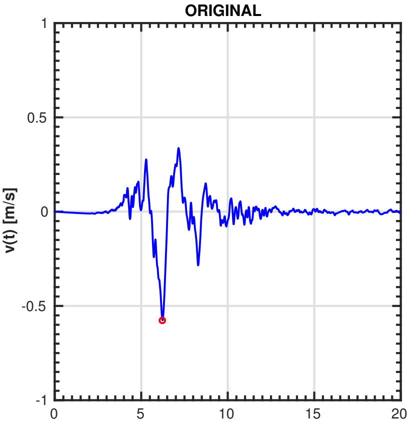


FIGURE 2 – **ORIGINAL** and **FILTERED** (low-pass - 1.5 Hz) Velocity Time-Histories

```
%% *BOREHOLE STRUCTURE*
rec.org(fil).bhr =

        pt:  '.../records'
        st:  {[1x1 struct]}
        (id: {'MRN';...}; ni: {'IT',...}; dv: {'01',...})
        ns:  numel(st)
        ev:  {'20120529.070003'}
        ne:  numel(ev)
        tp:  {'itaca'} % ('itaca','kknpp')
        lb:  {'Main Shock'}
        nd:  [1,...] % number of device (st.dv) per station
        rs:  {3x1 cell} ('e';'n';'z') % reference system
        cp:  {'n'} % directions
        nc:  numel(cp)
        ci:  2 % index of cp in rs
        rc:  {'a'} % motion component
        nr:  numel(rc)
       lfr:  []
       hfr:  1.5000
        % record names
        nm:  {'.../records/...
        ...IT.MRN..HNN.D.20120529.070003.C.ACC.ASC'}
        na:  numel(nm) % total number of records
```

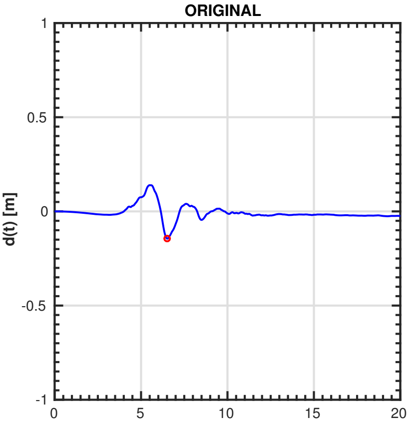


FIGURE 2 – **ORIGINAL** and **FILTERED** (low-pass - 1.5 Hz) Displacement Time-Histories

```
%% *MONITOR STRUCTURE*
rec.org(fil).mon =

      na: 1 % total number of records
      nc: numel(cp)
      nr: numel(rc)
      cp: {'n'} % directions
      rc: {'a'} % motion component
     dtm: 0.0050 % dtm(idx) time step per each record
     ntm: 14000  % ntm(idx) number of time steps
     vtm: {[14000x1 double]} % vtm{idx}: time vector
     vTn: [1001x1 double] % vTn{1} natural period vector
      nT: 1001
    zeta: 0.0500
     nfr: 16385
     dfr: 0.0122
     nNy: 8193
     vfr: {[16385x1 double]} % vfr{idx} frequency vector
```

Records from database

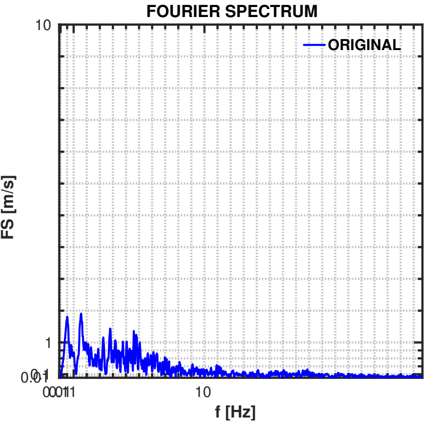


FIGURE 2 – **ORIGINAL** and **FILTERED** (low-pass - 1.5 Hz) records Fourier Spectra

```
%% *SYNTHETIC STRUCTURE*
rec.org(fil).syn{idx} =

    tha: [1x1 struct] % acceleration
    thv: [1x1 struct] % velocity
    thd: [1x1 struct] % displacement
    AT5: [1x1 struct] % t(5%) arias
    AI5: [1x1 struct] % idx(5%) arias
    Ain: [1x1 struct] % arias intensity
    pga: [1x1 struct] % pga
    pgv: [1x1 struct] % pgv
    pgd: [1x1 struct] % pgd
    rsd: [1x1 struct] % disp. response spectrum
    psa: [1x1 struct] % pseudo-spectral acceleration
    fsa: [1x1 struct] % acc. fourier spectrum
```

Records from database

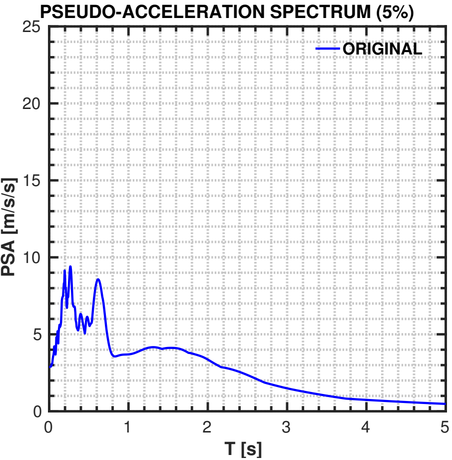


FIGURE 2 – **ORIGINAL** and **FILTERED** (low-pass - 1.5 Hz) Pseudo-Spectral Acceleration

```
%% *SYNTHETIC STRUCTURE*
rec.org(fil).syn{idx} =

    tha.dir
    thv.dir
    thd.dir
    AT5.dir
    AI5.dir
    Ain.dir
    pga.dir
    pgv.dir
    pgd.dir
    rsd.dir
    psa.dir
    fsa.dir

    dir = 'e';'n';'z'
```

Alternative approach : example

1. Records from database
2. **Numerical Simulations**
3. Broad-Band Mashup
4. Short period ANN
5. Spectral Matching

Numerical Simulations

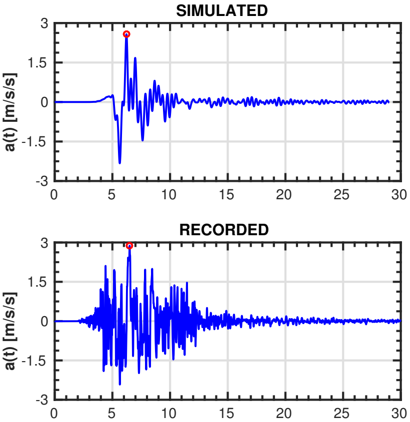


FIGURE 3 – **SIMULATED** and **RECORDED** Acceleration Time-Histories

```
%% *SIMULATIONS — STRUCTURE*
nss.org =

        mon: [1x1 struct]   % monitor
        syn: {[1x1 struct]} % synthetics/records
        bhr: [1x1 struct]   % borehole

%% ORIGINAL RECORDS — STRUCTURE*
rec.org =

        mon: [1x1 struct]   % monitor
        syn: {[1x1 struct]} % synthetics/records
        bhr: [1x1 struct]   % borehole
```

Numerical Simulations

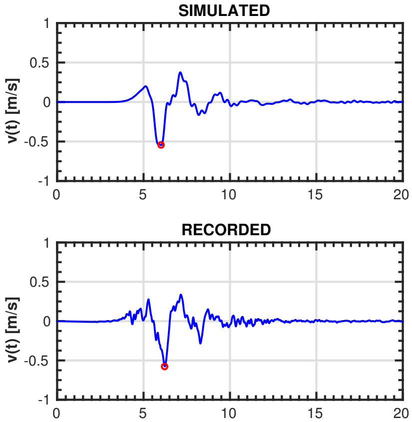


FIGURE 3 – **SIMULATED** and **RECORDED** Velocity Time-Histories

```
%% *MONITOR STRUCTURE*
nss.org.mon =
       pt: '.../monitor' % absolute path to monitor datab
       fn: '.../SM_Stations_Monitors.csv' % metadata file
       tp: 'S' % type of simulation ('S'=speed,'H'=hisada
       id: 16928 % monitor id
       fa: 1.3000 % LF for hybridization
       fb: 1.7000 % HF for hybridization
      lfr: [] % LF for high-pass filtering
      hfr: [] % HF for low-pass filtering
      dep: 4.1000 % epicentral distance
       st: {'MIR01'} % site name
       na: 1 % total number of records
       nc: numel(cp)
       nr: numel(rc)
       cp: {'n'} % directions
       rc: {'a'} % motion component
      dtm: 0.0100 % dtm(idx) time step per each record
      ntm: 3001  % ntm(idx) number of time steps
      vtm: {[3000x1 double]} % vtm{idx}: time vector
      vTn: [1001x1 double] % vTn{1} natural period vector
       nT: 1001
     zeta: 0.0500
      nfr: 4097
      dfr: 0.0244
      nNy: 2049
      vfr: {[4097x1 double]} % vfr{idx} frequency vector
```

Numerical Simulations

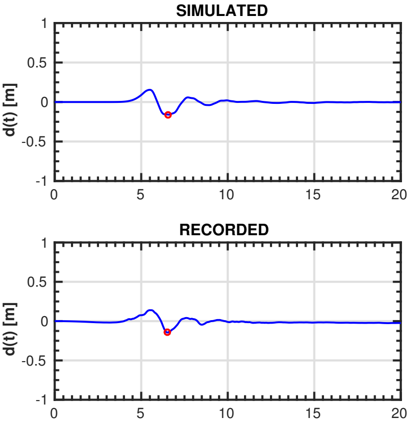


FIGURE 3 – **SIMULATED** and **RECORDED** Displacement Time-Histories

Numerical Simulations

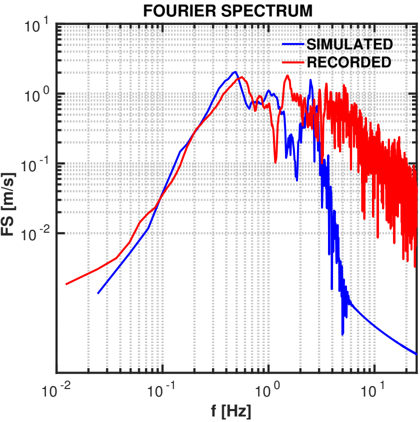


FIGURE 3 – **SIMULATED** and **RECORDED** Fourier Spectra

```
%% *SYNTHETIC STRUCTURE*
nss.org.syn{idx} =

    tha: [1x1 struct] % acceleration
    thv: [1x1 struct] % velocity
    thd: [1x1 struct] % displacement
    AT5: [1x1 struct] % t(5%) arias
    AI5: [1x1 struct] % idx(5%) arias
    Ain: [1x1 struct] % arias intensity
    pga: [1x1 struct] % pga
    pgv: [1x1 struct] % pgv
    pgd: [1x1 struct] % pgd
    rsd: [1x1 struct] % disp. response spectrum
    psa: [1x1 struct] % pseudo-spectral acceleration
    fsa: [1x1 struct] % acc. fourier spectrum
```

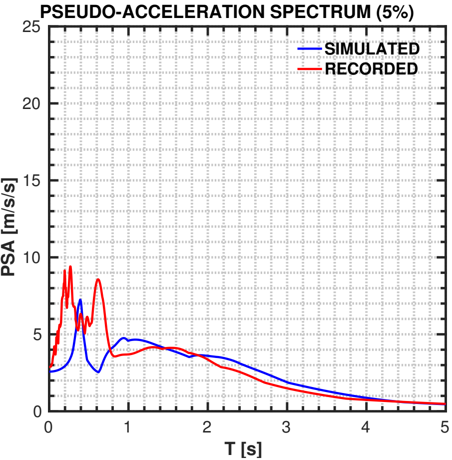


FIGURE 3 – **SIMULATED** and **RECORDED** Pseudo-Spectral Acceleration

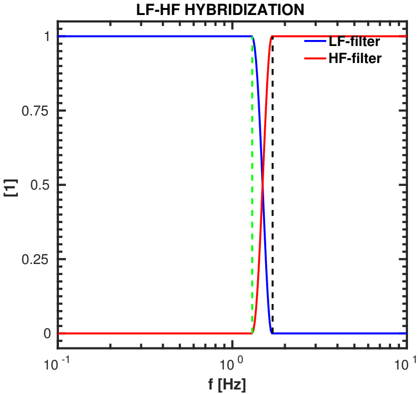
```
%% *SYNTHETIC STRUCTURE*
nss.syn{idx} =

    tha.dir
    thv.dir
    thd.dir
    AT5.dir
    AI5.dir
    Ain.dir
    pga.dir
    pgv.dir
    pgd.dir
    rsd.dir
    psa.dir
    fsa.dir

    dir = 'e';'n';'z'
```

Alternative approach : example

1. Records from database
2. Numerical Simulations
3. **Broad-Band Mashup**
4. Short period ANN
5. Spectral Matching



Broad-Band Mashup

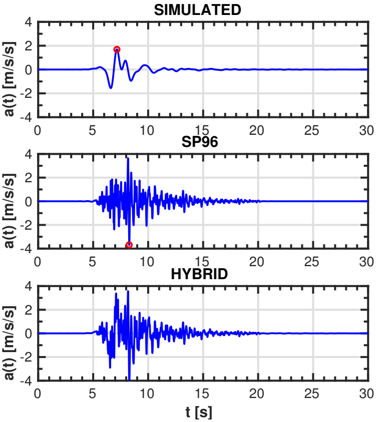


FIGURE 4 – **SIMULATED**,**SP96** [1] and **HYBRID** Acceleration Time-Histories

```
%% *SP96 SYNTHETICS — STRUCTURE*
sps.org =

     mon: [1x1 struct]   % monitor
     mtd: [1x1 struct]   % metadata
     syn: {[1x1 struct]} % synthetics/records

%% HYBRID SYNTHETICS — STRUCTURE*
hbs =

     mon: [1x1 struct]   % monitor
     syn: {[1x1 struct]} % synthetics/records
```

Broad-Band Mashup

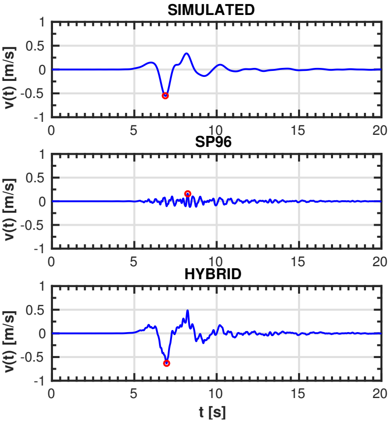


FIGURE 4 – **SIMULATED**,**SP96** [1] and **HYBRID** Velocity Time-Histories

```
%% *SP96 METADATA STRUCTURE
sps.org.mtd

    fn:  '.../metadata.dat' % metadata filename
    mw:  6 % magnitude
    dtm:  0.0100 % time-step
    scc:  0 % site conditions (0=rock; 1=shallow all.;
   % 2=deep alluvium)
    sst:  0 % st. dev. of GMPE (0=median value,1=84th pe
    scl:  0.0100 % scl (scale factor [1=cm/s/s])
    ivd:  0 % flag for output in vel./dis.
```

Broad-Band Mashup

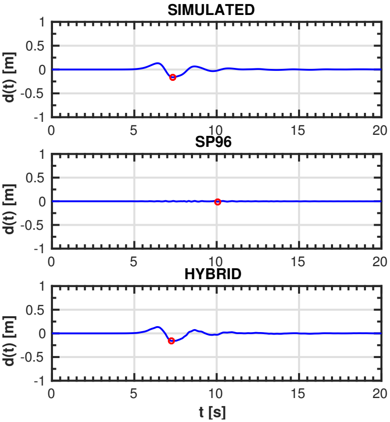


FIGURE 4 – **SIMULATED**,**SP96** [1] and **HYBRID** Displacement Time-Histories

```
%% *SP96 SYNTHETICS STRUCTURE*
sps.org.syn{idx} =

    tha: [1x1 struct] % acceleration
    thv: [1x1 struct] % velocity
    thd: [1x1 struct] % displacement
    AT5: [1x1 struct] % t(5%) arias
    AI5: [1x1 struct] % idx(5%) arias
    Ain: [1x1 struct] % arias intensity
    pga: [1x1 struct] % pga
    pgv: [1x1 struct] % pgv
    pgd: [1x1 struct] % pgd
    rsd: [1x1 struct] % disp. response spectrum
    psa: [1x1 struct] % pseudo-spectral acceleration
    fsa: [1x1 struct] % acc. fourier spectrum
```

Broad-Band Mashup

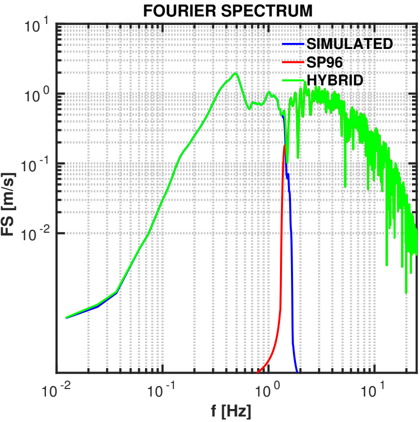


FIGURE 4 – **SIMULATED**,**SP96** [1] and **HYBRID** Fourier Spectra

```
%% *HYBRID SYNTHETIC STRUCTURE*
hbs.syn{idx} =

    tha: [1x1 struct] % acceleration
    thv: [1x1 struct] % velocity
    thd: [1x1 struct] % displacement
    AT5: [1x1 struct] % t(5%) arias
    AI5: [1x1 struct] % idx(5%) arias
    Ain: [1x1 struct] % arias intensity
    pga: [1x1 struct] % pga
    pgv: [1x1 struct] % pgv
    pgd: [1x1 struct] % pgd
    rsd: [1x1 struct] % disp. response spectrum
    psa: [1x1 struct] % pseudo-spectral acceleration
    fsa: [1x1 struct] % acc. fourier spectrum
```

Broad-Band Mashup

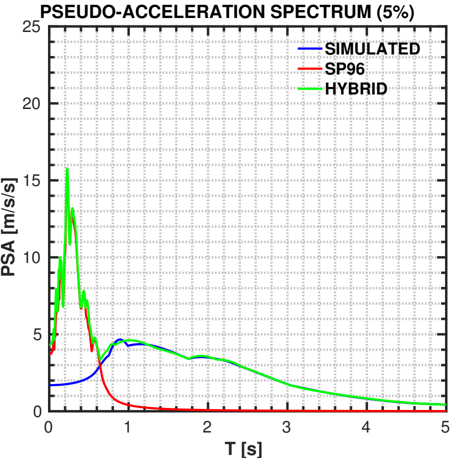


FIGURE 4 – **SIMULATED**,**SP96** [1] and **HYBRID** Pseudo-Spectral Acceleration

Alternative approach : example

1. Records from database
2. Numerical Simulations
3. Broad-Band Mashup
4. **Short period ANN**
5. Spectral Matching

Short period simulation via ANN

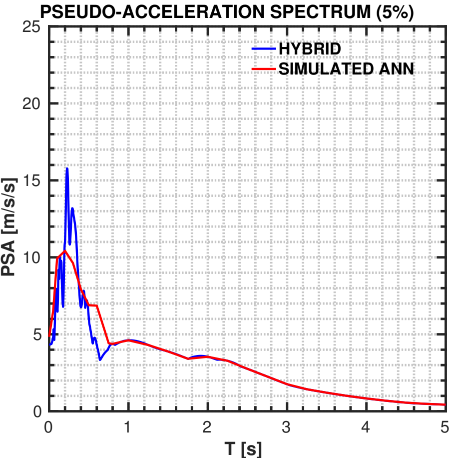


FIGURE 5 – **HYBRID** Pseudo-Spectral Acceleration

Alternative approach : example

1. Records from database
2. Numerical Simulations
3. Broad-Band Mashup
4. Short period ANN
5. **Spectral Matching**

Spectral Matching

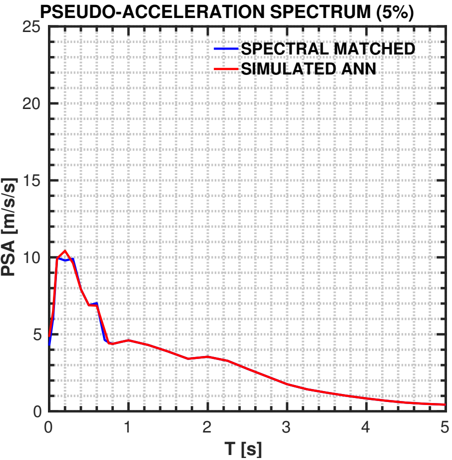


FIGURE 6 – **SPECTRAL-MATCHED** and **ANN** Pseudo-Spectral Acceleration

Spectral Matching

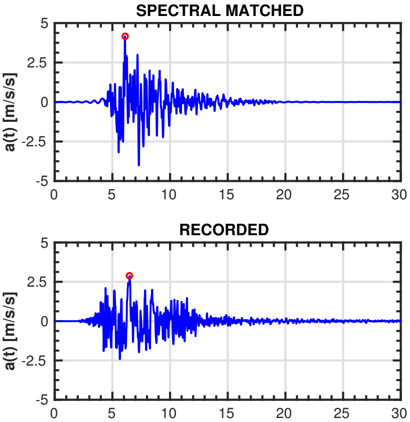


FIGURE 6 – **SPECTRAL-MATCHED** and **RECORDED** Acceleration Time-Histories

Spectral Matching

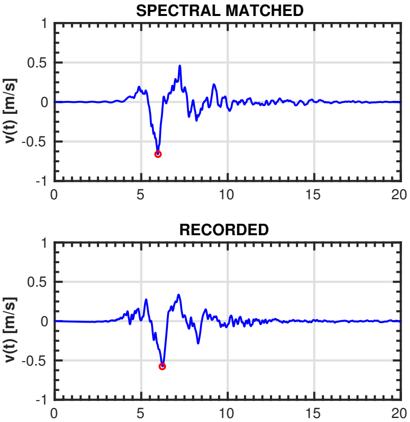


FIGURE 6 – **SPECTRAL-MATCHED** and **RECORDED** Velocity Time-Histories

Spectral Matching

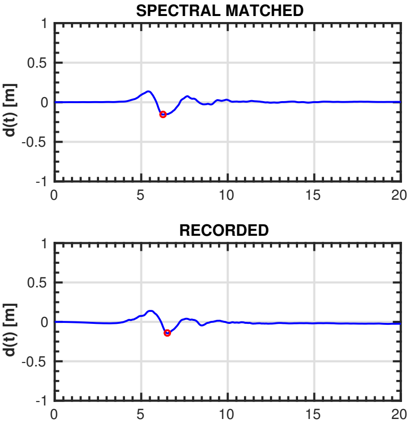


FIGURE 6 – **SPECTRAL-MATCHED** and **RECORDED** Displacement Time-Histories

Spectral Matching

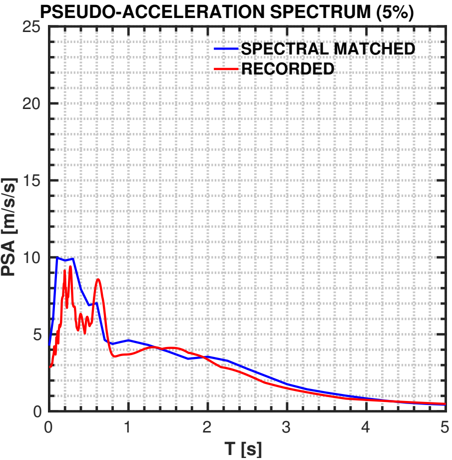


FIGURE 6 – **SPECTRAL-MATCHED** and **RECORDED** Pseudo-Spectral Acceleration

Induced Strong Motion Effects
on Kashiwazaki-Kariwa Nuclear Power Plant

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F. Sabetta and A. Pugliese.
Estimation of Response Spectra and Simulation of Nonstationary Earthquake Ground Motions.
Bulletin of the Seismological Society of America, 86(2) :337–352, 1996.

M Stupazzini, A. Allmann, M. Käser, I. Mazzieri, A.G. Özcebe, R. Paolucci, and C. Smerzini.
PSHAe (Probabilistic Seismic Hazard Analysis enhanced) : the case of Istanbul.
In *Proceedings of the Tenth Pacific Conference on Earthquake Engineering Building an Earthquake-Resilient Pacific*, pages 1–8, 2015.