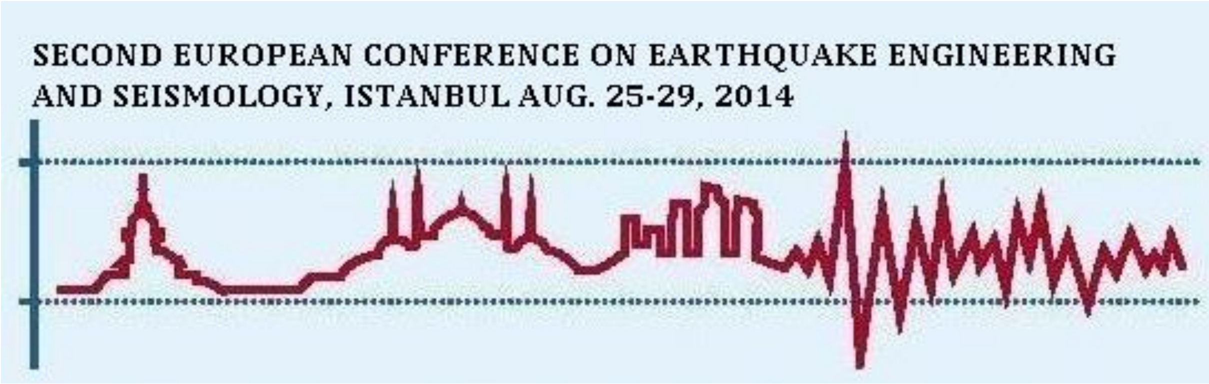

REAL-TIME CONTINUOUS RESPONSE SPECTRA EXCEEDANCE CALCULATION ENABLES RAPID & ROBUST DAMAGE ASSESSMENT

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A novel and robust approach is presented that provides near real-time earthquake alarms for critical structures at distributed locations and large facilities using real-time estimation of response spectra obtained from near free-field motions. Influential studies dating back to the 1980s identified spectral response acceleration as a key ground motion characteristic that correlates well with observed damage in structures, for example Newmark and Hall (1982). Thus, monitoring and reporting on exceedance of spectra-based thresholds are useful tools for assessing the potential for damage to facilities or multi-structure campuses based on input ground motions only. With as little as one strong-motion station per site, this scalable approach can provide rapid alarms on the damage status of remote towns, critical infrastructure (e.g., hospitals, schools) and points of interests (e.g., bridges) for a very large number of locations enabling better rapid decision making during critical and difficult immediate post-earthquake response actions. Details on the novel approach are presented along with an example implementation for a large energy company.

Real-time calculation of PSA exceedance and alarm dissemination are enabled with *Bighorn*, an extension module based on the *Antelope* software package that combines real-time spectral monitoring and alarm capabilities with a robust built-in web display server. *Antelope* is an environmental data collection software package from Boulder Real Time Technologies (BRTT) typically used for very large seismic networks and real-time seismic data analyses. The information flow diagram for *Bighorn* is displayed in Fig 1.

The primary function of Bighorn's engine, *orbsmrsp*, is to produce continuous time-dependent response spectra for incoming acceleration streams. It utilizes expanded floating-point data representations within object ring-buffer (ORB) packets and waveform files in a relational database. This leads to a very fast method for computing response spectra for a large number of channels. A Python script *smrspalarm* evaluates these response spectra for exceedance of the specified spectral limits, reporting any such exceedances via alarm packets that are put in the ORB for use by any alarm processes that need them. The right half of Fig 1 shows the web-display subsystem, which allows alert dissemination, interactive exploration, and alarm cancellation via the world-wide web. This capability is supported by two main programs: *rtwebserver*, which provides an embedded web-server for the *Antelope* monitoring platform; and *rtcache*, which pre-constructs information products (such as downloadable images of spectral plots) to be served by *rtwebserver*.

Response spectra are continuously calculated in real-time by passing the acceleration streams through a set of digital linear recursive filters one for each specified frequency-damping pair. For example, if the acceleration sample rate is 200sps, and a spectrum is defined using 100 frequencies

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and a single damping ratio, then 100 response spectra streams at 200sps will be created. Peak response spectra (PSA) values are obtained during a decimation phase according to a specified decimation factor. This is done by assigning the maximum value of the un-decimated response spectra stream over the time window determined by the decimation factor, to the sample value of the now decimated PSA stream. Continuing from the example above with a decimation factor of 100, this process yields 100 PSA streams at 2sps. Maximum PSA values are then obtained over a specified overlapping process interval. It is these maximum PSA values that are displayed in real-time and compared to the exceedance thresholds.

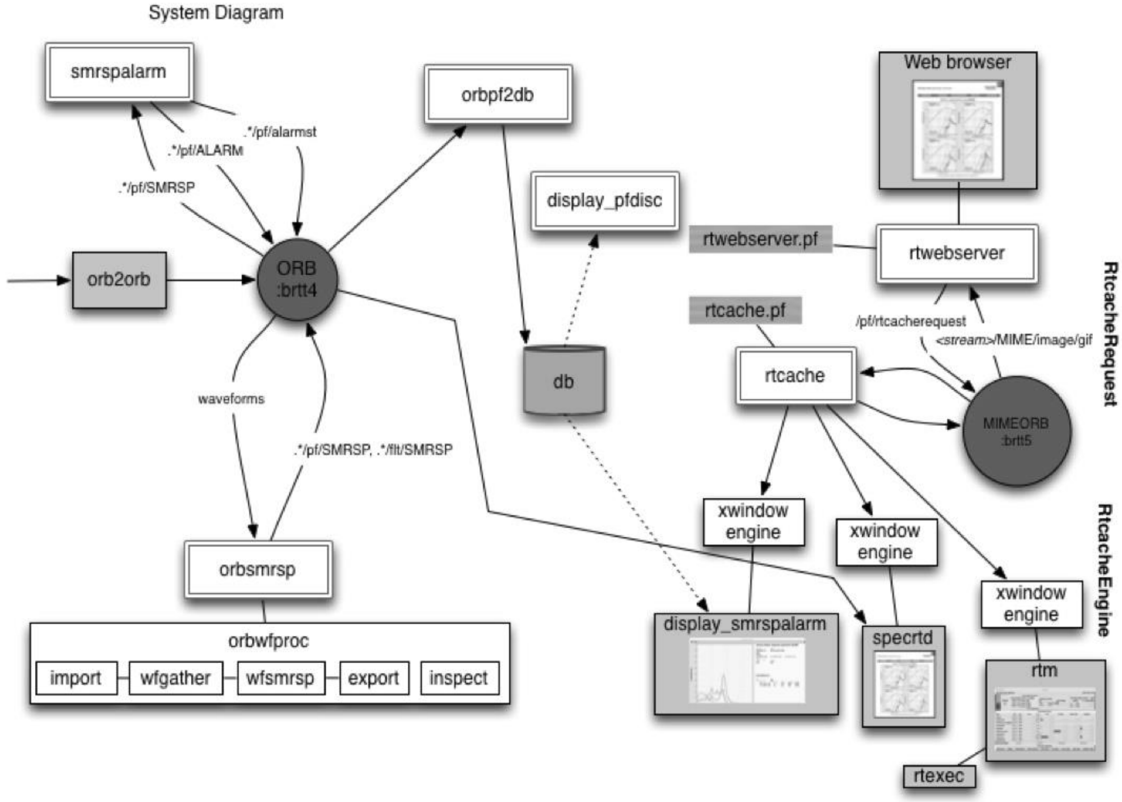

Figure 1. Bighorn information flow diagram

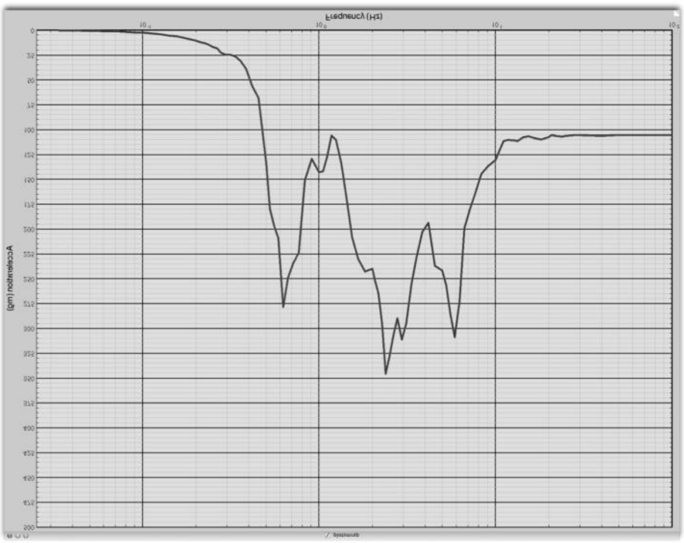

Figure 2. Comparison of two response spectra calculated in real-time and standard post-event procedures shows identical lines for both procedures.

As proof of concept, known example waveform data sets were fed into the system as streaming acceleration. Fig 2 shows one real-time response spectrum and the spectrum calculated using standard post-event procedures. The results from the two methods are indistinguishable.

Depending on what is available for or required with respect to exceedance criteria, spectral thresholds could be in the form of Design Response Spectra (DRS), Maximum Credible Earthquake (MCE), Operational Basis Earthquake (OBE), Safe Shutdown Earthquake (SSE), or even a constant spectral acceleration limit value.

All information and alarms are shown in a web user interface that would be managed centrally by the responsible regional/national agency and accessible locally by first responders and disaster coordinators (e.g., firemen, police) at municipality or facility levels. Because the real-time approach is most valuable for an extensive geographical distribution of locations, the primary display is map-based where different localities are shown as colored icons representing the current alarm status. Using the icons (or via the menu) the operator can drilldown to a location map. At this level, each icon represents the status of a given station represented by the user-defined marker color. For example, a red-colored box represents alarm exceedance and orange-colored box represents a state-of-health (SOH) issue such as low battery voltage or broken communication. In the event of an exceedance, alarms are issued and an event report is made available for further evaluation by a civil engineer – Fig 3.

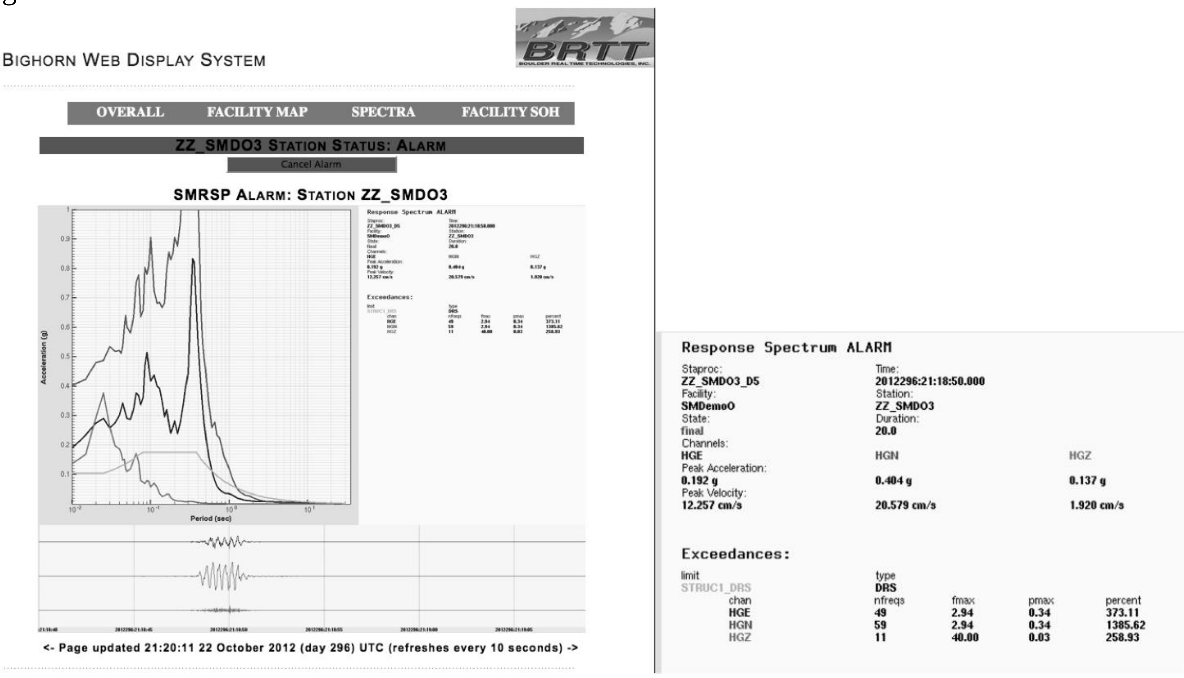

Figure 3. *Bighorn* web display: event report with zoomed in insert

The event report displays the cumulative response spectra, which are equivalent to the post-event calculated spectra – see Fig 3. It also shows the exceedance threshold spectra, the acceleration waveforms, and an event summary. The event summary includes parameters such as peak acceleration, peak velocity, and several exceedance statistics.

In conclusion, the *Bighorn* post-earthquake alarm system implements a novel and robust approach for providing spectral limit exceedance alarms using real-time estimation of response spectra obtained from near free-field motions was presented. The *Bighorn* solution represents a paradigm shift in how strong-motion data is continuously processed in real-time. This method enables remote alerting on possible damages for a large number of critical structures without knowledge of earthquake parameters and applying ground motion prediction equations.

REFERENCES

Newmark NM and Hall WJ (1982) Earthquake spectra and design, Engineering Monographs on Earthquake Criteria, Structural Design, and Strong Motion Records, EERI, Oakland, CA