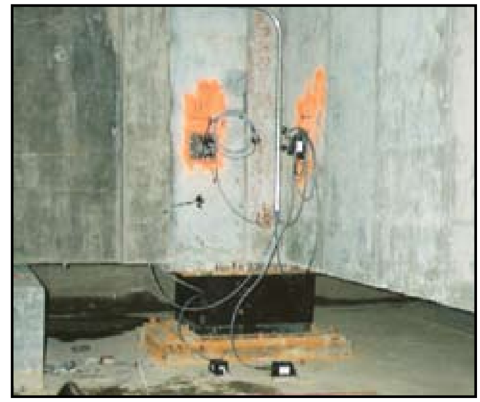
Strong Motion Instrumentation of Buildings

By Anthony F. Shakal, Ph.D. and Moh J. Huang, Ph.D., P.E.

The measurement of the response of buildings during earthquake shaking provides direct information on the forces experienced and can provide verification of design assumptions. Strong motion instrumentation of buildings has become much more convenient, reliable and accurate in recent years. For reference, during the 1971 San Fernando earthquake, in which the first large set of strong motion records was obtained, the records were all obtained on film. This film needed to be developed carefully just to get the peak motion, and then laboriously digitized to obtain the displacement and spectral values. In contrast, current accelerographs record the motion in solid-state memory, already digitized. This makes it easy for computers to recover and process the data for rapid usage after an earthquake. Current quality instruments, well installed and maintained, almost guarantee quality data, even after months if not years at standby, activating within milliseconds to record the entire motion once earthquake shaking starts.



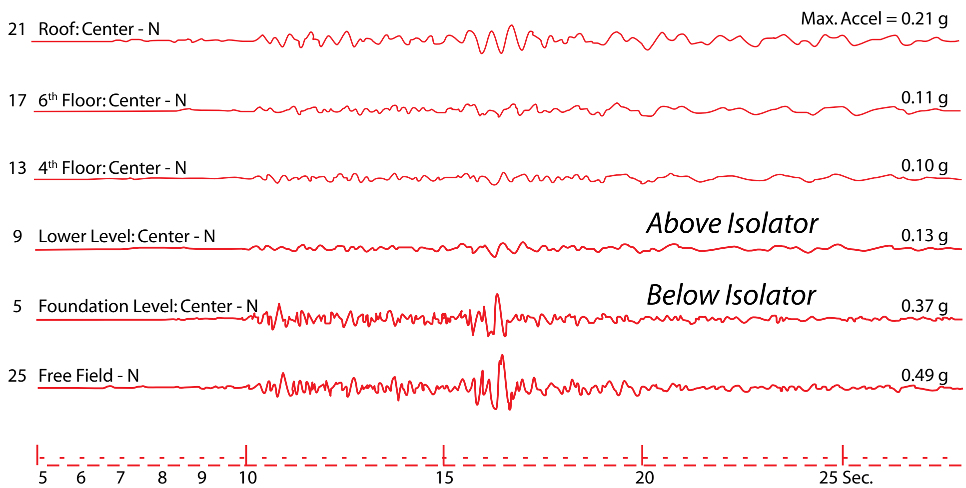


Figure 1: Strong motion records from a 7-story base-isolated hospital in Los Angeles (upper left). Accelerometers are mounted above and below the isolators (upper right). The accelerations recorded in the 1994 Northridge earthquake (lower) clearly show reduction above the isolators relative to the motion at the foundation and in a parking lot nearby.

Sensor Locations

The location of sensors is very important in getting key information about the building response. The minimal instrumentation called for in some building codes specifies a triaxial instrument, measuring the acceleration in the vertical and two horizontal directions, at the base, midheight and top of the building. These three locations, with a total of nine accelerometers, provide basic information about the motion of the building but are too limited to identify torsional motion or motion in most modes of the building. A more extensive instrument layout, as typically used by the California Strong Motion Instrumentation Program (CSMIP) in the California Geological Survey and its partner in the U.S. Geological Survey, often has accelerometers at eight or more locations. These locations are chosen so that as much information as possible is recovered about the global motion of the building as well as the motion in the first few translational and torsional modes. For special research studies, some buildings have been instrumented with 50 or more sensors, with sensors at each floor.

Installation

The instrumentation process is important in ensuring that quality data is obtained once an earthquake occurs. Since sensor voltages are typically quite small (a few volts), electrical noise sources can be a problem unless the system is adequately shielded and grounded. Modern strong motion systems typically have a noise level of a fraction of a gal (i.e., 0.1% of the acceleration due to gravity) and a maximum recording capacity of 2 g or more. The low noise level is important to control the noise in the numeric integration necessary in processing the record to obtain displacement and long period spectral values. In the best systems, the sensors are cabled to a central recorder where all channels are recorded together. In any case, common triggering and timing in the recording of all sensors is critical.

Processing

The processing of records by specialized software is important to render the records useful in understanding the structure response. Processing began as a developmental effort at Caltech in the 1970s and has become relatively standardized. In general, for moderate and larger motion (e.g., 10% g and over), current processing will yield accurate accelerations and displacements over frequencies from DC (capturing residual tilt, if present) to 40 Hz or higher. The processing of residual displacement, as in determining residual inter-story drift in a building, is more challenging and requires a good accelerometer and specialized processing. GPS is becoming increasingly useful for residual displacement determination, though at significant cost. Residual displacement across seismic isolators and dampers can be measured economically by relative displacement sensors.

Applications

An important application of building instrumentation is the measurement of the actual building response, for comparison to design targets of building performance during the earthquake. The measured building motions can verify fundamental design assumptions, as well as guide future designs. This can lead to improved, more effective yet economical designs, ultimately yielding code provisions that are designed – but not over designed – for expected seismic motions. On the shorter term, an increasing application of strong motion measurements is in guiding post earthquake decisions. Building officials and owners can make informed decisions about occupancy and business resumption using actual measured motions, and referring to threshold levels previously developed, quickly make decisions after an earthquake. Some cities, like San Francisco, have begun an official program for post earthquake business resumption that incorporates measured motions.

Examples

Several interesting and important records have been obtained in base-isolated buildings, for which accelerometers have been placed above and below the isolation plane. *Figure 1* shows accelerations recorded in a 7-story hospital in Los Angeles during the 1994 Northridge earthquake. A reduction in the acceleration above the isolators relative to the input motion is clearly apparent. Records from another building type, high rise buildings, often clearly show the response of the building in its fundamental mode continuing well after the input ground motion is over. Many other examples of strong-motion records from instrumented buildings are available at the Center for Engineering Strong Motion Data at **www.strongmotioncenter.org**.

Summary

The routine measurement of strong motion in buildings during earthquakes has become much more convenient, reliable and accurate during recent years. Large and small buildings and bridges are being instrumented.▪

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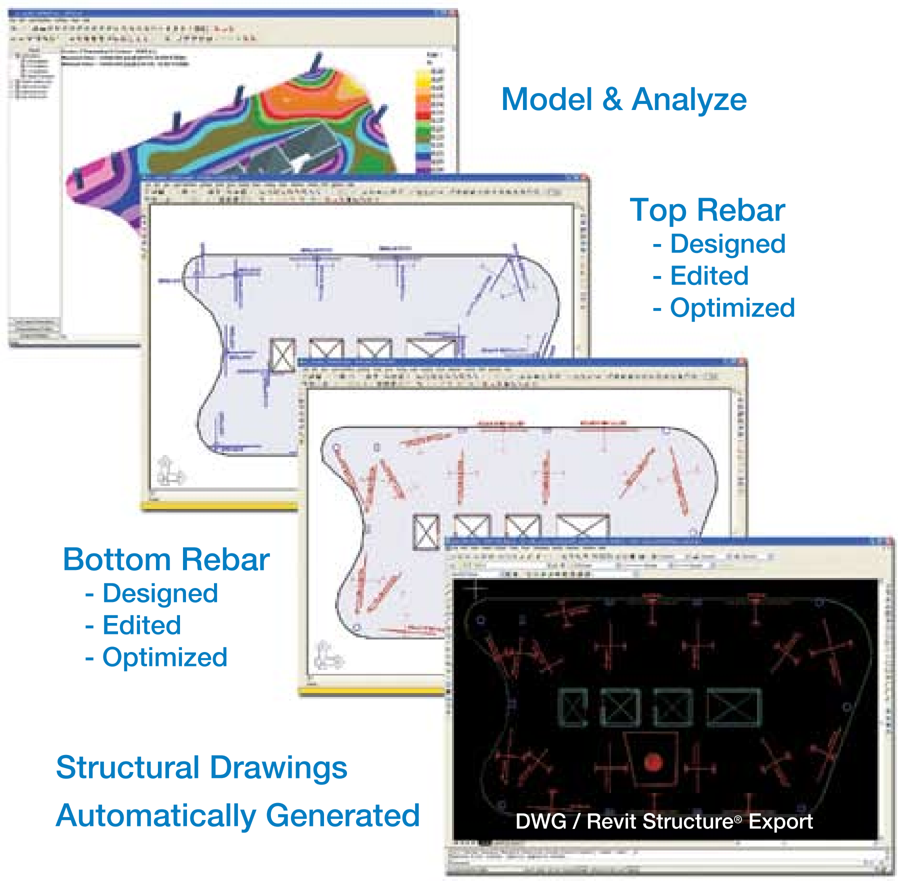

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