Construction in Seismic Regions: A Safety Issue Uncovered

Throughout the last fifty years, there has been an increasing awareness of the need to provide a higher level of safety to building occupants in seismically-active regions. Knowledge gained from observations of earthquake damage, testing, and computer modeling has resulted in stricter building codes and, consequently, a more stringent design and construction approach. Public and commercial buildings now have more shear panels, tie-down bolts, welds, deeper sections and robust ductile framing systems. In the multi-family and single family residential realm, units that would normally be composed of merely wood, nails, and plywood sheathing are now being built with metal straps, metal clips, larger foundations, and even steel walls.

During this time that safety awareness has increased, there has also been a large, unprecedented, building boom. Urban growth has accelerated to a point where demand for quick, affordable construction is higher than ever. In the housing market, for example, one result of this demand has been larger amounts of custom and tract houses being built in record time at lower costs. It is theorized that at one point, building officials could not perform inspections as often as desired, because they did not have the resources to face the building boom.

Unfortunately, the end result is a significant amount of construction that has not been built per the original engineer's intended design. In other words, it is fair to say that many structures may be missing the critical elements needed for seismic restraint. Incidentally, if enough components are missing during a large enough earthquake, excessive damage and even collapse may occur.

In this article, Allana Buick & Bers, Inc. (ABB) explores two case studies of residential buildings where seismic restraining elements were omitted during construction. Both buildings were built within the last 25 years and are both in the highest seismic zone, zone 4. Although both case studies are based in California, the lessons learned apply to Hawaii. The Big Island of Hawaii is classified as a seismic zone 4. (For reference, Kauai is located within zone 1, Oahu is in zone 2a, and Maui, Molokai and Lanai are in zone 2b.) This article examines the field analysis methods, the missing critical components, and the required repairs to solve these issues.

Case Study 1 – Condominiums, San Francisco, California

The first case study is a group of condominiums in a large development just south of San Francisco, California (*see figure 1*). The buildings were undergoing a series of improvements which included new windows, siding, and roofing. During the course of removal of the existing exterior finishes, it was noted that many seismic hold-downs were not installed in critical areas as highlighted in red in *figure 2*.

Figure 1: Condominiums, San Francisco, CA

Figure 2: Missing hold-downs (red dotted lines indicate intended locations)

Hold-downs are steel ties that prevent the building from overturning during an earthquake (*see figures 3a and 3b*), which is achieved by anchoring the structure to the ground.

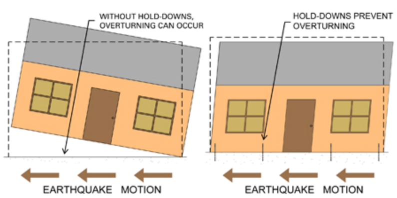

Figure 3a: Overturning of a building

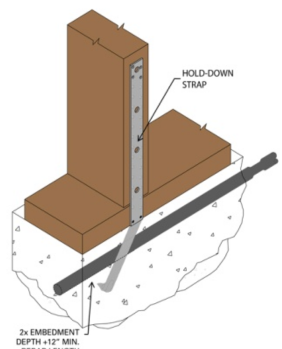

Figure 3b: Typical hold-down which can prevent overturning

To address the problem, ABB engineered a repair consisting of a strap nailed to the walls of the building and anchored to the foundation via epoxy anchored bolts (*see figures 4a and 4b*). Special care had to be given regarding the bolt locations because the foundation had tension-cable reinforcement (also known as a "post-tension" foundation).

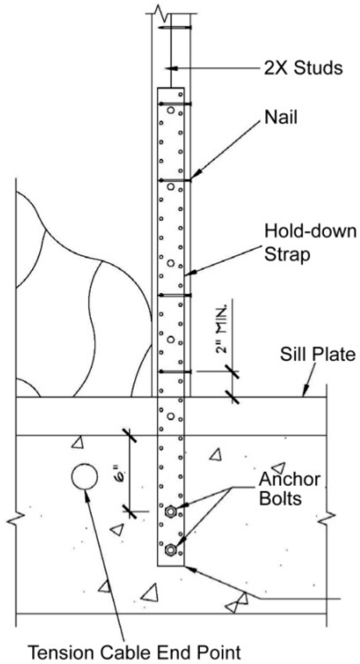

Figure 4a: Hold-down repair detail

Figure 4b: Hold-down repair installed

These buildings had additional structural compromises including shear transfer clips not being installed in many locations; specifically the red-lined area illustrated in *figure 5*. Shear transfer clips (*see figure 6*) are steel plates that allow earthquake forces to be transferred from each floor level into the walls at each adjoining level.

Figure 5: The red dashes show where shear transfer clips should have been installed

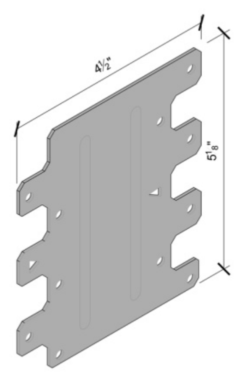

Figure 6: Typical shear transfer clip (courtesy Simpson

Strong-Tie)

Simply put, shear transfer clips prevent sliding (*see figure 7*). The repair method involved installing the clips in the appropriate locations as indicated in the red outline in *figure 8*.

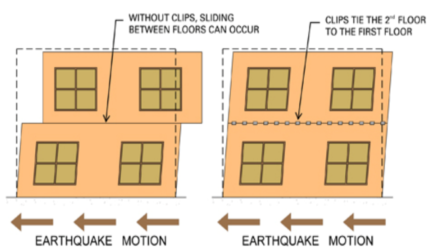

Figure 7: Building with shear transfer clips (left) and without shear transfer clips (right)

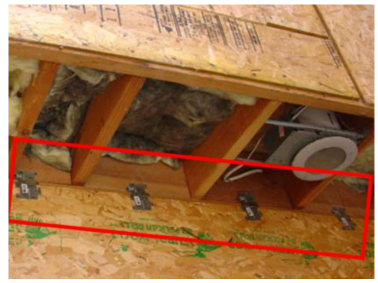

Figure 8: Installation of shear transfer clips

Case Study 2 – Single-family Residence, Santa Barbara, California
This Case Study consists of a single-family residence outside of Santa Barbara, California (*see figure 9*).

Figure 9: Single-family Residence, Santa Barbara, CA

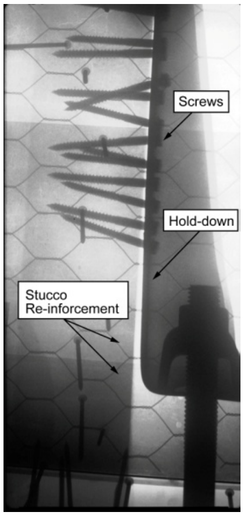

Figure 10: Xray photograph a steel hold-down

Various metal seismic restraining components were observed to be missing in the basement of the house. This prompted an extensive review of the building's seismic continuity. However, the owner did not want the interior or exterior finishes to be removed or damaged for the investigation. Because the components under scrutiny were made of steel, ABB decided to use Xray technology to determine the existence of the hardware. Xray locations were randomly chosen by a professional statistician to avoid bias in the assessment.

Xrays are a form of high energy, short-wave radiation. They have the ability to pass through relatively dense materials with light-like behavior. In the case of a building assembly, the radiation will pass through wood and lightweight finishes but is absorbed by denser materials like steel. As a result, Xray photography can give a clear representation of metal components in a wall assembly.

In our investigation, the Xrays were taken on site using a small, low power, battery powered Xray tube. An Xray sensitive reusable film was placed behind the object of interest. The region around the machine was cleared of occupants and the Xray tube was energized thus exposing the film to the radiation. The image was then developed on site with a digital scanner and stored on a laptop computer. *Figure 10* shows a resulting Xray depicting a hold-down.

However, in another location, Xrays showed that no hold-down existed. Multiple Xray images were taken and eventually it was concluded that the hold-down wasn't installed (*see figure 11*).

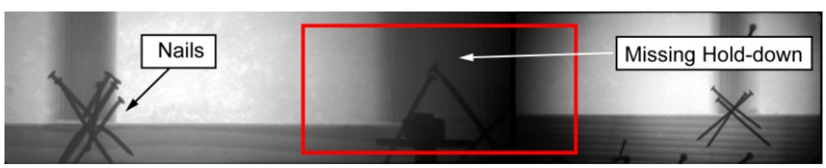

Figure 11: Missing hold-down as seen by Xray photography. Red Region indicates the zone where the hold-down should have been installed.

Similarly, ABB was able to use Xray photography to look for horizontal seismic steel straps. In an earthquake, a building will tend to "tear" apart between regions of different mass and geometry as illustrated in *figure 12a*. Steel straps of proper length and thickness can prevent this from occurring (*see figure 12b*).

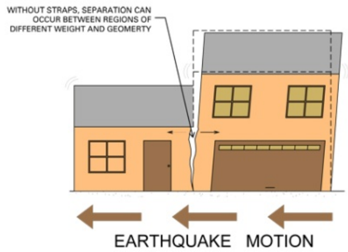

Figure 12a: Building without a strap

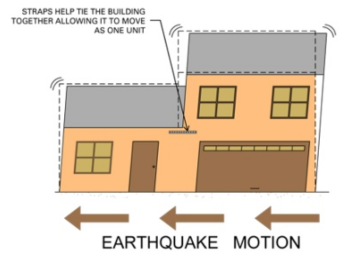

Figure 12b: Building with a strap

The Xrays depicted the existence and non-existence of seismic straps. *Figure 13a* shows a seismic strap installed; whereas *figure 13b* shows no strap was installed in the intended location.

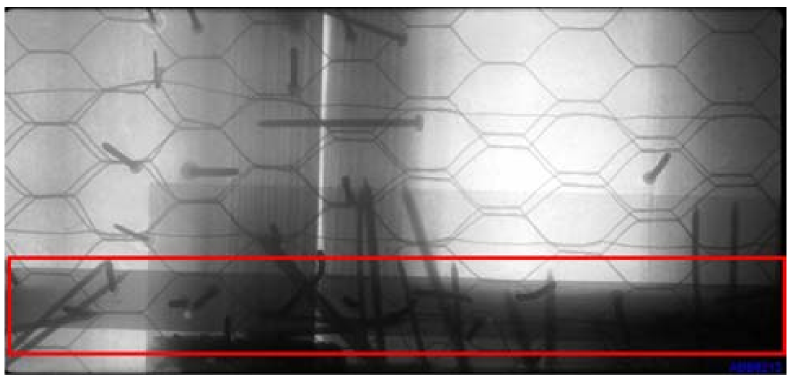

Figure 13a: Strap installed

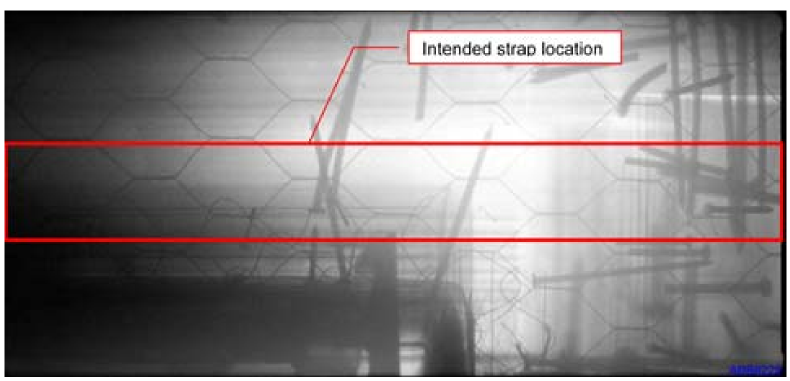

Figure 13b: No strap installed

With regard to the straps and hold-downs mentioned, it was decided in court that each missing component be installed per the original engineer's plans.

Conclusion

In conclusion, the seismic restraining components discussed in these two case studies, such as the hold-downs, clips, and straps are essential for any building in a seismic zone. Generally, the absence of these components is not visible without removing exterior finishes to make that determination. However, ABB demonstrated non-evasive methods for determining the existence/non-existence of these critical items using Xray technology. Upon determining the location of the missing components, the removal and remediation of the exterior finishes were very minimal and cost effective to improving structural integrity and aesthetic appearance.

The proper installation of these components is affordable and the money spent is small relative to the potentially large amount of damage that can result if they are not installed. Additionally, components may be inadvertently omitted and a building without the proper seismic hardware can be unsafe in an earthquake jeopardizing the life of those inhabiting it.

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Justin Bettner, P.E. and Ian Forsyth, P.E. of Allana Buick & Bers, Inc. (ABB) contributed to this article. ABB provides architectural, engineering, and construction management services to clients from their offices in Honolulu, Lahaina, San Francisco, Los Angeles, San Diego, Las Vegas, Sacramento and Seattle. With a Hawaii-based staff of twenty six they annually service dozens of Hawaii clients. For more information about this article and/or ABB, please visit www.abbae.com or contact Ian Forsyth at (808) 538-0115.