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APPENDIX D
Objects that were Thrown, Toppled, or Slid by the 2008 Wells, Nevada Earthquake

by

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INTRODUCTION

The February 21, 2008 Wells, Nevada earthquake occurred in northeastern Nevada (figure 1), a part of the state that is poorly seismically monitored because of the low population density. The earthquake was fairly close to Wells, within a few kilometers, so shaking of the town was quite pronounced and damaging.

There were no seismometers in the City of Wells during the magnitude 6 earthquake, but the directions that several objects slid or were thrown from the shaking were recorded in case this information is useful in understanding strong ground motion or earthquake source modeling. These included a large substation transformer, industrial water heaters, and high school wood-shop equipment. In addition, the direction that one brick chimney was toppled, the directions that some crowning bond beams were thrown, and some preferential directions that contents were thrown were also recorded. When possible, the direction and distance the object slid, walked, or was thrown was noted. The directions noted are shown in figure 2.

Note that these kinds of data are perishable and in general must be made right away after the event. Just as road crews in their quest to get the roads open again can blade away the best possible offset marker in the field along a fault before the geologist can get there, so too is a vigorous clean-up and recovery effort going to erase tracks of fallen materials and moved objects. The more subtle the track or fallen object, the more perishable it will be. Fallen objects in areas that are cordoned off will last the longest (unless aftershocks cause more damage and complicate the signal). It is also worth remembering that in areas where serious losses have occurred, people’s tolerance for scientists making measurements of their damage can decrease with time. In the case of the Wells High School woodshop, the measurements were tabulated and given to the engineer who was trying to understand the damage of the building and develop the reconstruction plans.

The direction of major ground movement indicated by the sliding was 45° oblique to the long dimension of the high school gym and auditorium (271° +/-10° ground movement versus a 225° direction of the long direction high school), which appeared to move back-and-forth the most from shaking, as evidenced from internal pounding damage and slightly cocked chimney with a tension crack. It shows that there can be a difference of at least 45° between a shaking direction indicated by a building and that indicated by free-standing objects.

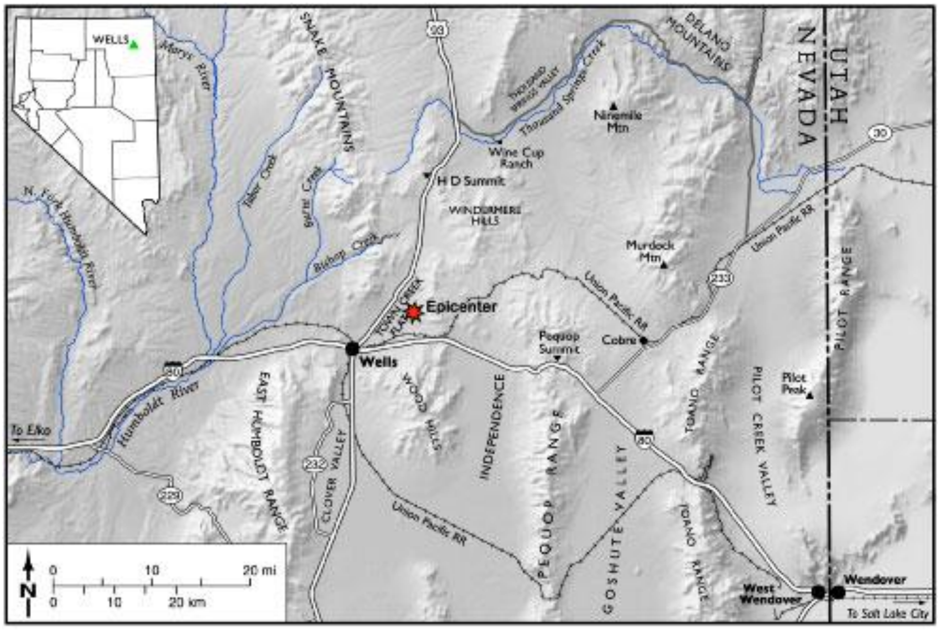

Figure 1. Locations of Wells, Nevada and the epicenter of the 2008 earthquake.

Figure 2. Locations of seven areas where objects were thrown, toppled, or slid in response to the ground motion from the 2008 Wells earthquake. This is a small subset of sites where measurements could have been made, but it serves as an example of the kinds of measurements that can be made; not all locations are on this map. **Red**–objects that were thrown; **yellow**–objects that were slid; **orange** double arrow–strongest shaking direction that contents were thrown. Objects are described in the listing below:

Description of numbered objects located on figure 2.

1. Crowning concrete bond beams were thrown in the historical district.
2. Toppling of exterior house chimney.
3. Seven pieces of shop equipment slid 4.5 to 10 cm between 261° and 291°.
4. Library where north-south shelves threw books, whereas the east-west shelves did not.
5. 100-gallon water heaters slid but remained attached.
6. Televisions were thrown/toppled from the northwest-oriented walls and not from northeast-oriented walls, mostly in the second story rooms of a motel.
7. Half-full 15,000-gallon fuel tank slid 10 to15 cm on concrete pad.

THINGS THAT WERE THROWN BY THE EARTHQUAKE

Only two observations are included in the category of things that were thrown, partly because it is not always clear when objects were actually thrown versus toppled or cantilevered out. I suspect many more things could have been added to this category if there were more people making observations.

Thrown Crowning Bond Beams in the Historical District–Location 1 on Figure 2

Crowning concrete bond beams were thrown from the western sides of two buildings in the historical district and may be indicators of a strong ground motion pulse or oscillation in a northwest-southeast direction. There was other damage in the historical district that was consistent with this shaking direction as well, such as the northwest-directed total collapse of the San Marin Hotel and the large sections of the northwest wall of the Nevada Hotel that fell out, but these can be explained by other things, such as the free-standing northwestern side of the San Marin Hotel versus the southeastern side which was buttressed against the Eagle Club.

On figure 2, there are two arrows shown at Location 1 in the historical district. The arrow on the right side, just below the number "1" is the western side of the Wells Chalet, and the arrow to the left is the western side of the El Rancho Hotel. Both of these are two-story buildings, and the building's response to the shaking has to also be considered, but their response was to the strong ground motion. As mentioned in the high school example, the actual ground motion can be at 45° to the building response.

The entire concrete crowning bond beam was thrown to the northwest off the western side of the Bullshead Bar and the Wells Chalet, and appears to have hit a balcony, a car, and the ground in large pieces (figures 3, 5, 6, 7, and 8); fractures that were seen in the bond beam midway down the block between the two buildings were sub-evenly spaced transverse cracks that may have been caused as the beam hit the ground unevenly (figure 7). The western side of the Wells Chalet is shown in figure 3. Note also the crowning bond beam corner on the ground lying northwest (left of photo) of the corner of the building it was on top of. The remnant of a short top wall the beam was on is shown in figure 4. The beam fell in a 315° direction away from the building. The building likely influenced the throwing of the bond beam, especially the amount of throw, but the direction was likely strongly influenced by ground motion and the direction is comparable to the direction a chimney was toppled about two-and-a-half blocks to the south (300° at Location 2 in figure 2).

Figure 3. View to the northeast along the sidewalk along the northwestern side of the Wells Chalet (near) and the Bullshead Bar (down the block where the collapsed balcony is). The corner of the crowning concrete bond beam can be seen as can the corner of the building it was on top of. The corner is only a couple to few decimeters to the southwest of the building corner whereas the estimated horizontal distance between where the bond beam was at the two-story roof level and where it impacted the car as indicated by the divot in its roof is 1.8 m, +/- 0.5 m. *Photograph by Utah Division of Homeland Security.*

Figure 4. Remaining upper part of the southwest corner of the Wells Chalet. The crowning bond beam sat on top of at least 10 and as many as 14 courses of bricks, and fell off with at least seven or eight courses, but limited perhaps by the strength of the underlying bond beam. Note the spalled off parts of the upper part of the concrete beam; this damage may have been inflicted by the rocking back-and-forth of the upper part of this wall/parapet.

Figure 5. Car hit by the falling bond beam and bricks. The divot in the roof shows where the impact was.

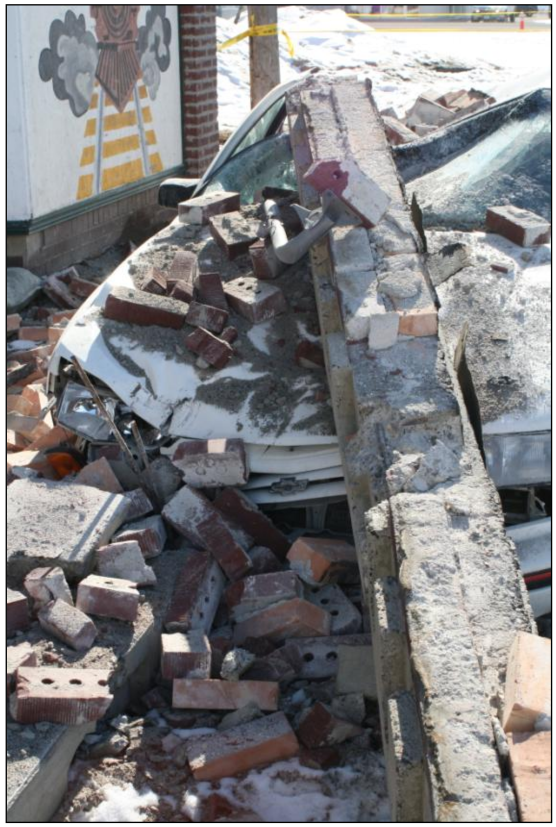

Figure 6. Front end of the car hit by the bond beam in figures 4 and 5. The actual point of impact appears to be just to the right of the headlight, not where the bond beam finally came to rest. This point is in line with the impact on the roof. The car is partly on the sidewalk and it is unknown if this was its original position or whether it was shifted there.

Figure 7. Section of sub-evenly spaced transverse cracks that may have been formed from the uneven impact of the bond beam on the ground; this is the same bond beam that crushed the car that is shown in figures 3, 5, and 6. Here, about midway down the block, the bond beam is close to the building. This pattern is mostly present in this area, which is the area between the two buildings; the bond beam may have fallen off at slightly different times or may have been delayed by the impact on the balcony causing a differential impact with the ground.

Figure 8. Northern part of the fallen crowning bond beam in front of the Bullshead Bar. The bond beam is currently about 0.5 to 1 m from the building.

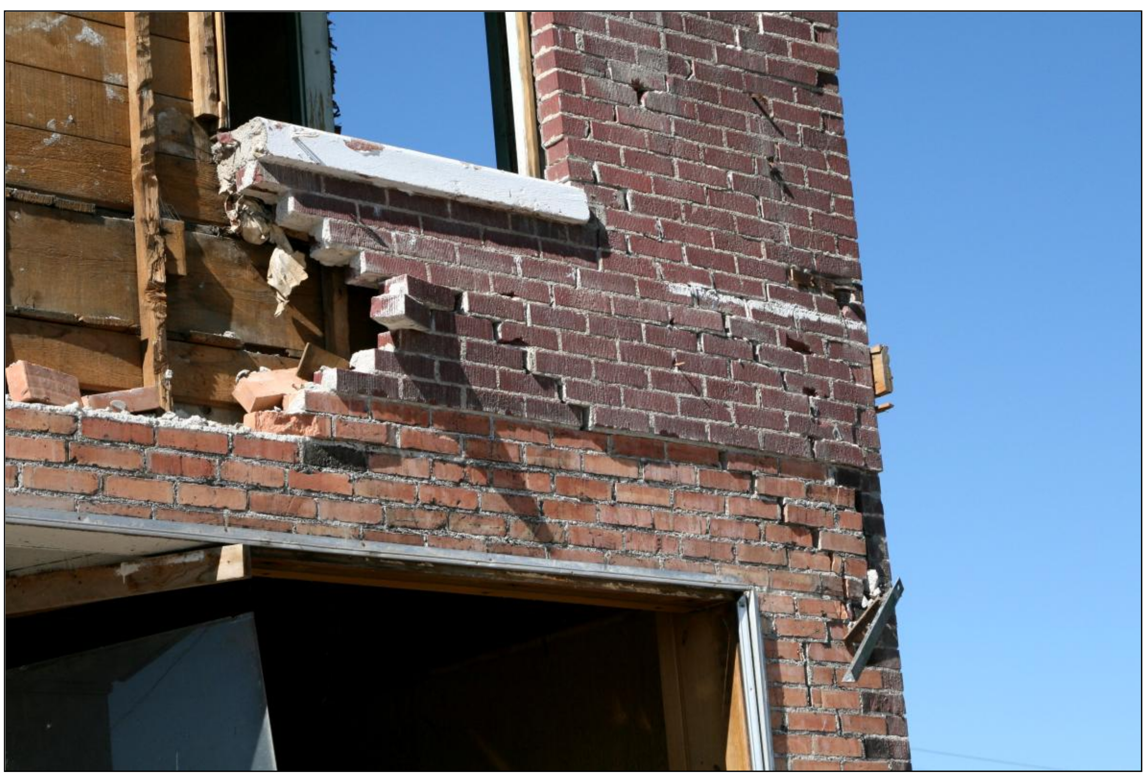

Figure 9. “X” fracture patterns in the remaining brick veneer in this northeast-facing wall of the Bullshead Bar indicates the building rocked parallel to the wall. The eastern part of the crowning bond beam on this wall fell on the roof, whereas the rest fell off the side.

Figure 10. Large concrete beam on the southwestern side of the Wells Chalet where it has punched a hole in the southeast wall. This supports a major rocking of the Wells Chalet in a northwest-southeast direction of excitation, or ground motion.

Figure 11. Northwestern side of the El Rancho Hotel and the small one-story house to the northwest of the building. A piece of the bond beam from the El Rancho can be seen caught up against the metal stove pipe that fell far enough west to clear the crest of the roof of the house and the bricks from the damaged house chimney are strewn to the northwest on the house roof, indicating strong ground motion in a northwest-southeast direction.

The El Rancho Hotel was diagonally across the street to the northwest from the Wells Chalet and had crowning bond beams fall off three sides, but it particularly was thrown or cantilevered out on the western side; this is the second arrow on the left at location 1 on figure 2. In figure 11, a portion of the bond beam that cleared the crest of the roof of the adjacent building can be seen caught against a metal smoke stack. The bricks from the destroyed chimney on the house are also strewn down the house in a northwest direction, and this is a one-story building with the short dimension in the northwest direction, limiting the response of the building.

THINGS THAT WERE TOPPLED BY THE EARTHQUAKE

Although it was not always clear how things toppled or how a progressive failure versus a clean failure influenced the direction of a toppled object, this is the most common kind of measurement that could be made. Many features exist of the outside of buildings that can be observed, and contents inside buildings can also exhibit a preferential toppling direction, but this commonly has a component of the building response to it. An example is two parallel walls that things fell off of versus the other walls, where thing stayed put, which happened in many homes in the Wells downtown. What makes it a topple failure versus a free fall, is an orderly arrangement on the ground of the bricks of the chimney or wall that fell, versus a pile of bricks near the edge of the break. It certainly doesn't have to be perfectly in order, although it is remarkable how it can be, but in general the top of the object is near the outside of the debris field, and the base is close in.

Figure 12. Chimney that was toppled and lies in a rough order with the bricks from the bottom of the chimney near its base and the bricks from near the top of the chimney near where the fence was crushed.

Toppled House Chimney – Location 2 on Figure 2

41° 06.521’ N; -114° 57.758’ W

An example of an exterior house chimney that toppled is shown in figure 12, near the corner of Ruby Avenue and 6th Street. The direction of the toppled chimney was measured, and it was consistent with the break-off pattern left at the top of the chimney (divot where it fell and high side where it broke clean when it lifted off of that side). The break at the top is clean and all the bricks that fell from the chimney are on the northwestern side of the chimney. The chimney fell in the direction of 300°.

Preferential Content Dislocation Direction – Location 4 on Figure 2

The single-story Wells library is at Location 4, in a building oriented in a north-south direction. The book shelves in the building are oriented north-south and east-west. Librarians who were cleaning up the books noted that books were thrown or toppled from the bookshelves oriented north-south, whereas neither the books, nor free-standing items on top of the books fell from the east-west bookshelves. Thus, the motion that shook the books out was in the direction of east-west (90°–270°) but may have been modulated by the building.

Preferential Content Dislocation Direction – Location 6 on Figure 2

A two-story hotel at Location 6, just northeast of the 4-Way Stop between 6th Street and Highway 93, had televisions and cabinets along the northern and southern walls that toppled, whereas similar items along the western and eastern walls stayed up. Thus, the stronger motion was in a northerly-southerly direction (23°–203°), but motion may have been modulated by the building, and amplified by the increased drift of the second story.

THINGS THAT WERE SLID BECAUSE OF THE GROUND MOTION

The direction that objects slide during an earthquake depends on the direction of ground motion, the mass distribution in the object, the eccentricity of the object, and whether the object is attached to the building or infrastructure in some way. Unattached, equidimensional objects that slide on smooth surfaces may offer the best directional information for ground motion that was available from the Wells earthquake. Objects that are attached can still commonly offer a major component of the ground motion. Some objects were observed to walk, hop, and wobble in response to the earthquake.

Wells High School Woodshop – Location 3 on Figure 2

41°06.548' N; -114°58.214’ W (location outside immediately to the east of the shop)

I measured seven items that slid or walked (figures 12 to 22). The directions they slid varied from 261° to 291°. Three and possibly four pieces of equipment showed evidence of slight counter-clockwise rotation (<10°?). It was difficult to measure and project magnetic north into the building, thus there is an uncertainty of +/-10° in these measurements. The overall direction of sliding of this equipment can be characterized as in a direction of 271° +/-10°, or just about due west (corrected to true north). Most equipment was free standing and not restricted. Most items slid 4.5 to 10 cm in a relatively smooth track. An exception is the radial arm saw table that has rubber feet (figure 21); its track showed hesitations. A band saw appeared to walk, taking a few steps (figures 19 and 20). The floor was smooth concrete (smooth to the touch) with some sawdust on it. The sawdust appeared to be cleared out of the track in most cases. Special thanks to the shop teacher and students for preserving the tracks and for not using the machines for several days until I could get back to measure them.

Figure 12. Southwestern part of the high school wood shop. The shop had been swept but a halo of sawdust was left around the equipment so the tracks could be measured.

Figure 13. Router table which has slid towards the lower left side of the photograph as the ground moved in one or more pulses in the opposite direction.

Figure 14. Jumping and sliding track of a router leg; the ruler is in the same position as in figure 13. Note the initial location of the right side of the round silver foot at approximately 8 cm on the ruler. There is a rough circle of where the contact was initially on the floor and an area of sawdust inside this circle. The left side of this circle has some dust on. This leg of the machine appears to have jumped at the start to have left this track; the jump is about the width of the foot, or about 2 cm. At 4+ cm on the ruler the area of cleared dust in the track has an abrupt, concave to the left shape indicating the foot was back in contact with the floor at that point and was sliding to the left at that point. The foot slides 3 to 4 cm to the left, and then changes direction almost 80° and slides 1.5 to 2 cm towards the lower left corner. The total offset of the main displacement to the left was about 6.5 cm in a direction of 271°. Not all the tracks from the legs of the router are the same indicating there is some modulation of these tracks from the response of the router to the shaking.

Figure 15. Router leg track from the front right leg in figure 13. This leg slid in a very gentle arc, starting in a 291° direction and within ~1 cm changing to an approximate direction of 277°. This track is about 7 cm long. The finger scrape was an observation of the roughness of the floor, which had a very smooth concrete finish.

Figure 16. Massive free-standing metal press.

Figure 17. Tracks of the feet of the massive metal press shown in figure 16.

Figure 18. Fairly straight tracks in constant contact with the floor from these hard rubber feet, with possible rubber scrape marks in the upper track. These two legs slid in the same direction, 281° and about the same distance, 9.5 cm.

Figure 19. Band saw that walked in response to the earthquake, probably because of its vertical eccentricity and heavy base.

Figure 20. Rocking and twisting of bandsaw shown in figure 19. left footprints made from the sawdust within the base of the machine. The largest step is the first, then there are ghost prints indicating the saw rocked back and forth with some rotation in between steps an addition four times to get to its final position. The final position showed counterclockwise rotation of about 30° from the initial position.

Figure 21. A relatively light radial arm saw table with four legs and rubber feet shows several (seven?) steps it made during the earthquake as it shuddered across the floor, perhaps with each oscillation of strong shaking. The tracks from the western legs were 14 and 15 cm in a direction of 261°.

Figure 22. These table tops with a locker base were the most equidimensional objects in the shop with a relatively even distribution of mass slid the general direction of all the objects, suggesting they were the most precise measurements that could be made (had the least modulation from the object itself). There were two tables like this and both were moved uniformly 4.5 cm in a direction of 271°.

Figure 23. Wobbling pattern back-and-forth of a round metal object in the shop; the direction generally matched the other tracks but it was not measured.

Figure 24. Large chimney on the northeastern side of the Wells High School auditorium. The top of the chimney was cocked back towards the building, as indicated by the tension cracks on the opposite side and the bricks that were thrown out of the unreinforced brick chimney. The tension cracks on the side of the chimney indicate a hinge point near the contact of the chimney and the top of the roof. The direction of ground motion indicated by the chimney is about 45° of the ground movement direction indicated in the woodshop, which is immediately to the west of the chimney; this is an example of how different the direction of strongest shaking from a building and that from free-standing equipment can be.

Station Class RTE AS Transformer at a Substation West of Wells

41° 06.782' N; -114° 58.661' W

A transformer weighing 102,000 pounds (46,200 kg) located just west of the map area shown in figure 2 slid and rotated on its concrete base. The movement made a connecting electric cable on top tighten up and a ground wire cable on bottom taut. The transformer rotated clockwise a little on its pad (figures 26 and 27). The southeast corner moved 14 cm in a direction of 260° and the northeast corner moved 11 cm in a direction of 245°. These two adjacent corners are a distance of 171 cm apart. The transformer is on an even-surfaced concrete pad. These measurements are +/-10°.

A 92,600-pound (41,950 kg), unattached transformer sitting not far from the measured one did not appear to have moved.

Figure 25. The transformer on the left is the one that was shifted by the earthquake ground motion.

Figure 26. Wells Rural Electric worker indicates where the corner of the transformer was before the earthquake shifted it into the position now shown in the photograph. The transformer has since been reset to its original position.

Figure 27. Northeastern side of the transformer base showing the prior mark of where it was before the earthquake.

Industrial Water Heaters at Truck Stop – Location 5 on Figure 2

Two water heaters moved at the truck stop and casino on the east side of town. One heater had since been moved back to its original position, but the technician who moved it back showed me what he had done, and the other was still in its slid position. The latter was at:

41° 06.054' N; -114° 57.379' W

The full 100-gallon water heater (figure 28) slid in a direction of 175° +/-10° about 9.5 to 10 cm (figure 29). It was restricted at the top by rigid piping that pulled along with the tank. The floor was an even, semi-smooth concrete with some rust.

The other water heater moved in a similar, if not exactly the same, direction and had flexible hosing, but had been reset before I could view it.

Figure 28. The blue industrial water heater that slid in the basement of the 4-Way Casino.

Figure 29. The foot of the water heater and the rusted footprint of its pre-earthquake location.

Bonneville Transloader Inc. Shifted, Above-Ground 15,000-Gallon Fuel Tanks – Location 7 on Figure 2

41° 06.470’ N; -114° 57.198’ W

Three 15,000-gallon fuel tanks that were connected by a pipe near their base were slid on a concrete pad by the shaking, just north of where U.S. Highway 93 crosses over the railroad tracks that go through Wells. The tanks were about half full at the time of the earthquake and were slid 10 to 15 cm in a direction of 240° +/-5°. The tank had been reset when visited, but the direction could be reconstructed in the field as shown in the photo in figure 31.

Figure 30. Fuel tanks that were shifted by the earthquake.

Figure 31. The fuel tank was shifted as indicated by the cast of its edge that was left in the snow. This is the farthest tank shown in figure 30. *Photograph by BTI employee.*