TMS
DISASTER INVESTIGATION REPORT

PERFORMANCE OF MASONRY STRUCTURES IN THE NISQUALLY, WASHINGTON EARTHQUAKE OF FEBRUARY 28, 2001

A Report by the Disaster Investigation Reconnaissance Team of TMS

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THE MASONRY SOCIETY

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1.1 The Masonry Society

The Masonry Society (TMS) is a professional/technical association dedicated to the advancement of scientific, engineering, architectural and construction knowledge of masonry. These objectives are pursued through stimulation of research and education and the dissemination of information on masonry materials, design and construction.

1.2 Disclaimer

The material presented in this report has been prepared in accordance with generally recognized engineering principles and practices, and is for general information only. This information should not be used without first securing competent advice with respect to its suitability for any general or specific application. References in this report to specific structures are for general information only, and are not specific judgments regarding the response of these buildings to the Nisqually earthquake. The opinions expressed in this report are those of the investigators, and have been reviewed by the Publications Committee and the Technical Activities Committee of The Masonry Society. TMS and the Council for Masonry Research (CMR) assume no responsibility or liability for an individual's use of the information provided in this document. Mention of trade names or commercial products does not constitute endorsement, condemnation, or recommendation for use.

1.3 TMS Investigating Disasters Program

Immediately following a natural catastrophe, the principal focus lies in providing emergency relief and maintenance of public safety. In the United States, these objectives are the mission of local jurisdictions aided by national organizations, such as the Federal Emergency Management Agency.

Another important objective of post-disaster reconnaissance is to investigate the behavior of buildings and other structures under extreme loads; document and learn from their performance under such loadings; and apply this newly acquired knowledge to the design and construction of future structures. Recognizing those needs, the Council for Masonry Research (CMR) funded The Masonry Society (TMS) to develop and maintain the TMS "Investigating Disasters" Program. Since its inception, the Program has continued under the auspices of TMS, with funding from CMR for some investigations. The overall objective of the Program is to prepare professional masonry engineers, architects, researchers, and educators to organize and conduct future disaster investigations on short notice.

The purpose of the reconnaissance is to study damaged and undamaged structures in regions affected by natural disasters, thereby gaining insight into the performance of masonry during such events. As follow-up to an investigation, design, construction, and maintenance practices are reviewed to determine if there exists a need to change these procedures, thus resulting in more favorable performance of masonry in future disasters. Since its inception, TMS has investigated the performance of masonry after the Northridge, CA earthquake, following the wakes of Hurricanes Opal and Fran, and after a series of tornadoes in Minnesota and Tennessee. For more information about the TMS Investigating Disasters Program contact the TMS office.

1.4 Acknowledgements

The investigation and subsequent analysis and report preparation are made possible through the volunteer efforts of TMS Investigators as well as local masonry professionals including those involved in design, construction and manufacturing. Specifically the team would like to thank Mr. Ed Huston (Smith and Huston, Inc., Seattle, WA) and Mr. Tom Young (Northwest Concrete Masonry Association, Belleview, WA) for their assistance in preparing for field reconnaissance. The Team would also like to thank Mr. Skip Angel and Mr. Gary Rust (Mutual Materials Co., Tacoma, WA) for their assistance in observing structures in both Tacoma and Olympia. Skip and Gary provided valuable input on the locations of older structures as well as new construction.

1.5 Investigation Team

Immediately following the event, TMS mobilized a disaster investigation team with the support of CMR. The team arrived on site on March 1, 2001 for a three-day reconnaissance of the performance of masonry structures in the affected region. The team included team leader Trey Hamilton (University of Florida), Rich Allen (Brick Industry Association), Bill Kjorlien (Southern Brick Institute) and Jason Thompson (National Concrete Masonry Association). This report is based on observations taken in the field by the Team for three days following the event. The investigation focused on the Cities of Seattle, Olympia, and Tacoma. In addition, the performance of structures in several residential areas and smaller towns in the region were examined and documented.

1.6 Nisqually Earthquake

On Wednesday, February 28, 2001 at 10:55 am local time, an earthquake struck western Washington State near Seattle, Olympia, and the surrounding Puget Sound area. The earthquake had a reported moment magnitude of 6.8 (Bray et al. 2001) with shaking lasting for approximately 40 seconds in some areas. The epicenter was located 11 miles northeast of Olympia near Anderson Island in the Nisqually River delta, with the focus approximately 32 miles (51 km) underground (Figure 1). Two mild aftershocks were detected on the day following the initial event, along with two small earthquakes (moment magnitude 1.2 and 1.3) at depths of 16 miles (25 km) and 17 miles (28 km) focused almost directly above the main shock location. This was the largest earthquake to strike the area in more than 50 years and local newspapers quoted the estimated damages at nearly $2 billion.

Figure 2 shows the intensity of shaking in the Puget Sound region. The map indicates that the perceived shaking in Tacoma was relatively light to moderate, while that in Seattle and Olympia was strong with localized very strong shaking.

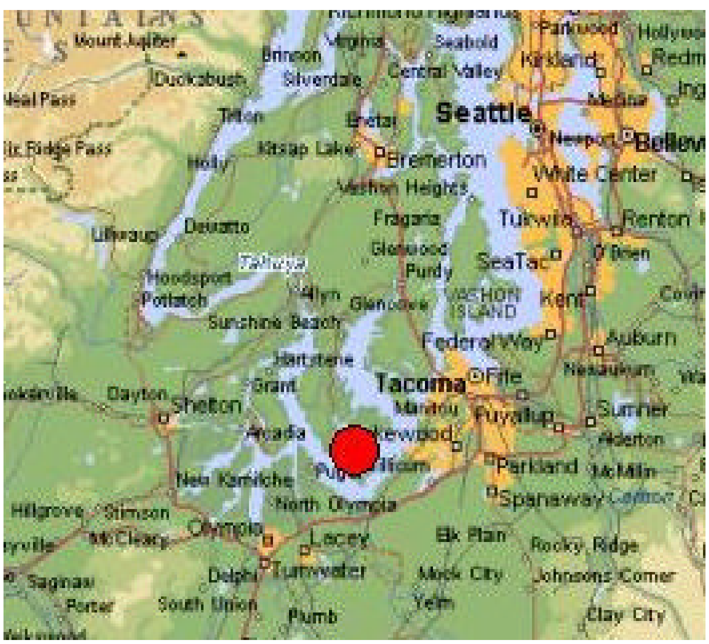
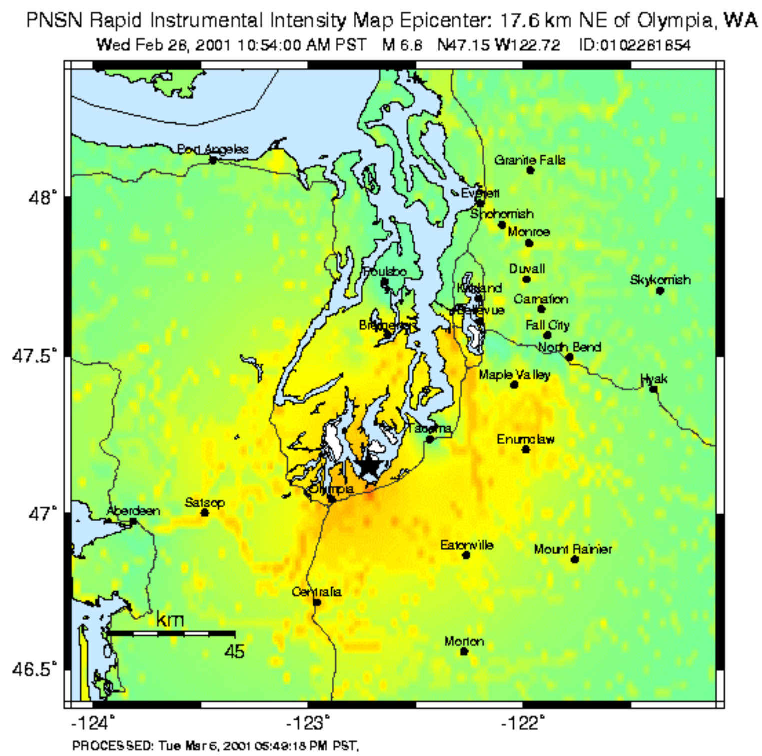


Figure 1. Epicenter location (source USGS, http://earthquake.usgs.gov/activity/latest/eq_01_02_28).



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 2. Intensity scale map (source USGS, best viewed in color, http://spike.geophys.washington.edu/shake/0102281854/intensity.html).

It was reported that one person suffered an earthquake-related heart attack and approximately 400 people were injured, predominately as a result of falling debris. The Cities of Seattle and Olympia red-tagged (prohibited entry) or yellow-tagged (restricted entry) a total of 232 buildings with the majority of these occurring in Seattle (187). An additional 50 structures were red- or yellow-tagged in surrounding cities, counties, and unincorporated areas. Preliminary data from the 31 Pacific Northwest Seismograph Network strong motion measuring stations in the region indicated that only 13 of these stations had peak ground accelerations greater than 0.1g and only two stations recorded values greater than 0.25g. (EERI 2001)

In contrast, the Northridge, California Earthquake caused 50 deaths (22 heart attacks) and at least 5,000 injuries. The City of Los Angeles red-tagged or yellow-tagged more than 10,000 buildings and evacuated more than 25,000 dwellings. In Northridge there was 15 to 20 seconds of shaking greater than 0.05g and 6 to 8 seconds of shaking greater than 0.5g. Over 3,500 aftershocks occurred in the first two weeks after the event with more than 1,000 of these 3.5 magnitude or greater (TMS 1994)

large regional differences in the geologic conditions in Puget Sound caused significant variation in ground motion from site to site. Holocene deltas exist at the mouths of the Duwamish, Puyallup, and Nisqually Rivers, which originate on the slopes of Mount Rainier. Sediments from erosion and large landslides blanket the valley bottoms. These deltas are now heavily developed in both Seattle (Duwamish River) and Tacoma (Puyallup River). In Seattle, former meanders and other depressions along the Duwamish River valley were filled to allow development. Much of this fill was placed hydraulically (washed to the tidal flats from surrounding higher ground) from about 1890 to 1930, when the Seattle landscape reached its current form. Consequently, many important industrial, port, and transportation facilities are founded on loose, saturated soil deposits, both man-made and natural. (EERI 2001)

1.7 Older Construction

1.7.1 Seattle

The significant damage observed in the Seattle area was confined to the downtown area, which has older URM structures founded on saturated fill material. The Pioneer Square area in downtown Seattle is located just adjacent to the waterfront (Figure 3). The area was filled and developed in the late 1800's and early 1900's. Consequently, there is a concentration of 2- to 5- story residential and commercial URM buildings in Pioneer Square and south downtown (SoDo) Seattle. A few of the structures observed carried historical markers indicating construction dates near the turn of the century. Seattle does not have mandatory strengthening requirements for URM buildings. However, several of the URM buildings observed appeared to have been strengthened with roof and floor ties as evidenced by regular patterns of anchor ends visible on the exterior (Figure 4).

The URM damage patterns observed during the investigation were typical of damage encountered in this type of construction. The most common damage observed was that of falling parapets that were unbraced (Figure 5). More severely damaged URM structures had lost entire upper sections of bearing walls. Many of the older URM bearing wall buildings have timber roof and floor framing. The flexible roof and floor diaphragms undergo large displacements during shaking, which can cause significant outward forces on the URM walls, particularly at the midspan of the roof and floor diaphragms. Figure 6 shows buildings in which the bearing walls appear to have been pushed out at approximately the middle of the building. Damage was also noted in URM elements between openings (Figure 7). Most of the pier damage noted was that of diagonal cracking primarily following the mortar joints. Evidence of corner separation and hammering between structures was noted (Figure 8 and Figure 9).

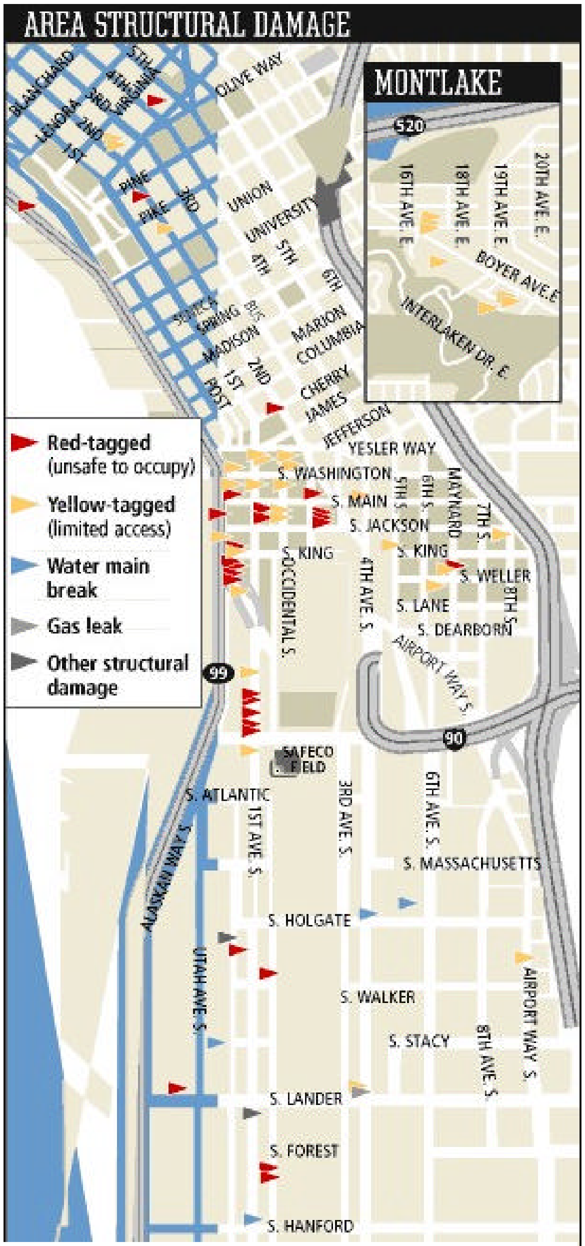


Figure 3. Damage in Downtown and South Downtown (SoDo) Seattle (Seattle Post-Intelligencer, Saturday, March 3, 2001).

Figure 4. Floor and roof ties in strengthened URM structure.

Figure 5. Loss of unbraced parapet in URM building.

Figure 6. URM bearing wall structures with partial loss of wall.

Figure 7. Damage in URM walls with masonry openings.

Figure 8. Corner separation perhaps due to flexible floor-diaphragm connections.

Figure 9. Parapet and wall damage due to pounding.

Many URM structures as well as newer structures in downtown Seattle sustained little or no externally visible damage. Most of the newer structures appeared to be structural concrete or steel frames with masonry veneer. In addition, modern masonry structures in the downtown and outlying areas of Seattle were observed with no signs of damage.

Older residential structures in the Montlake area of Seattle were observed. Many of these structures are clay masonry and appeared to be bearing wall construction. No damaged structures were encountered. However, a few damaged chimneys were noted.

1.7.2 Tacoma

Downtown Tacoma was observed with little damage found in new or older construction. The buildings shown in Figure 10 are situated on the west side of Tacoma Avenue, which runs near the waterfront at Commencement Bay. No signs of external damage to these structures were noted. Figure 11 shows Stadium High School, which was originally constructed in 1891 as a luxury hotel. The building custodian indicated that a stone cap on a spire fell off during shaking and punched through the roof below. No other damage was found.

Figure 10. Older undamaged URM structures along Tacoma Avenue in Tacoma, WA.

Figure 11. Stadium High School in Tacoma. Constructed in 1891.

1.7.3 Olympia

Although not as extensive as Seattle, downtown Olympia did have some significantly damaged structures. The most prominent was that of the state capitol building dome. In Olympia (including the capitol campus), 5 buildings were red-tagged and 45 were yellow-tagged. As with Seattle, a number of older URM structures sustained parapet or partial wall collapse (Figure 12).

Figure 12. Partial wall collapse of URM building on Capitol Way in Olympia.

1.8 Newer Construction

During the investigation activity, a number of new buildings were visited in which little or no damage was apparent. Figure 13 shows the recently completed Safeco field near downtown Seattle. The photo shows the pedestrian ramps that serve the stadium seating. The ramps are constructed of structural steel with brick veneer. There was some cracking and spalling noted in the veneer as can be seen in the figure. However, the spalling appears to have occurred at an expansion joint. Consequently, it was not possible to determine if the spalling was a pre-existing condition caused by brick expansion or was caused by the earthquake.

Figure 14 shows an institutional structure with clay brick veneer over a structural steel frame. This structure is located in Lacey, a suburb of Olympia located approximately 3 miles southeast of downtown Olympia.

Figure 15 shows a multistory concrete masonry hotel located in downtown Olympia near the capitol building. It appeared that the masonry provides both the lateral and gravity load resistance for the structure (and so is likely reinforced). This is based on exterior observation and is unconfirmed. Minor cracking was noted in the slab-wall connections at some of the balconies, but no significant distress was noted on the exterior walls.

Figure 16 shows a new three-story brick veneer on wood frame building located in Olympia. The building was constructed using 22 gauge galvanized metal ties in the first story and seismic ties in the remaining stories. No signs of damage to this structure were noted.

Figure 17 shows a new YMCA facility located in Tacoma constructed of reinforced concrete masonry where no damage was noted.

Figure 18 shows what appeared to be a cast-in-place, post-tensioned concrete parking garage. The exterior of the garage was covered with concrete masonry screen wall that did not appear to be tied to the structure, except at its edges. The screen wall did not have any visible signs of damage.

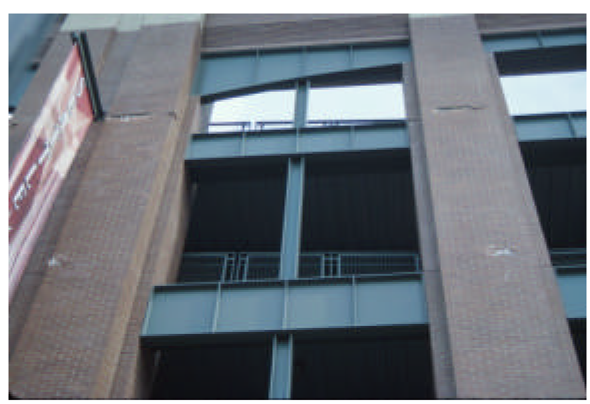


Figure 13. Safeco Field (Seattle).

Figure 14. St. Martin's College Library new brick veneer building (Lacey).

Figure 15. Ramada Inn in downtown Olympia on Capitol Way.

Figure 16. Three-story brick veneer on wood frame structure (Olympia).

Figure 17. Lakewood Family YMCA (Tacoma).

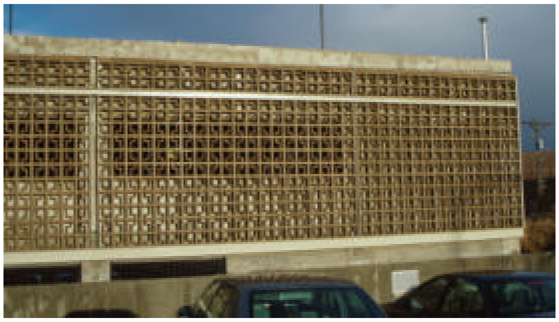


Figure 18. Concrete masonry screen wall on parking garage (Tacoma).

1.9 Chimneys

Newspaper reports indicated that there was widespread chimney damage in residential structures throughout the Puget Sound area because of the earthquake. The disaster investigation team focused on the residential areas around Olympia. Typical examples of chimney failures encountered are shown in Figure 19 through Figure 21. The failures were confined to unreinforced chimneys, constructed without reinforcement and ties that are required by modern codes.

Lack of maintenance also appeared to have contributed to some of the chimney failures. In most observed failures the chimneys appeared to have pre-existing cracks and, in some cases, vegetation was observed growing out of the mortar joints (Figure 19). Further, many of these poorly maintained chimneys were constructed over 80 years ago, and were thus likely constructed with sand-lime mortar since their construction preceded the widespread use of portland cement in mortar. The combination of poor maintenance, weak mortar, and lack of reinforcement and ties made these older unreinforced chimneys particularly vulnerable to earthquake damage.

Figure 19. Vegetation growing on damaged chimney.

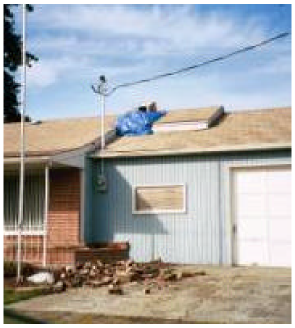


Figure 20. Chimney collapse.

The team observed, in several areas, that the chimneys of residences on one side of the street experienced significant damage, while those chimneys on the other side of the street exhibited no observable damage. This difference in performance was likely due to the differences in the construction methods used from one area to another. For example, Mr. Gary Rust of Mutual Materials was able to point out chimneys that were known to be constructed and detailed in accordance with the 1997 UBC (Figure 22). None of these newer chimneys were observed to be damaged. As an example of the differences in the performance of chimneys in a region the damaged chimney shown in Figure 21was across the street from the undamaged chimney shown in Figure 22. The unreinforced chimney collapsed while the properly constructed and detailed chimney showed no signs of damage.

Figure 21. Partial chimney collapse. No reinforcement or ties were found.

Figure 22. Chimney across the street from that shown in Figure 21.

1.10 Veneer

Very few veneer-clad buildings were observed to have sustained earthquake damage. The team had anticipated that some of the older residential structures with veneer might show signs of problems, particularly if they were not properly constructed and detailed. Accordingly, the residential investigation team (Kjorlien and Allen) visited over 30 residences throughout Olympia that incorporated veneer and wood frame backup construction.

The owners of a two-story, brick veneer, wood-frame residence visited by the team provided information on the construction materials and methods. The brick was reportedly attached to the wood frame with 22 gage wall ties, and 8d galvanized nails. The wall ties were attached to the studs at a spacing of 16 inches horizontally and 17 inches vertically (or every six courses), resulting in one tie per 1.9 sq ft. Joint reinforcement was not used. Exterior sheathing was ½-in. oriented strand board (OSB). Several interior walls were designed and constructed as shear walls. The 1997 UBC requires galvanized, 22 gage wall ties at no more than one per two square feet. In Seismic Zones 3 and 4, the code also requires that the ties engage horizontal joint reinforcement. Their house is within seven miles of the epicenter and the owners indicated that it shook violently. However, they indicated that no new cracks formed in the house as a result of the earthquake. Two hairline cracks were observed in the detached garage that may have been caused by the earthquake. The mason contractor that built this house was interviewed and confirmed the methods and materials used in construction.

The older residential structures observed showed no outward signs of veneer distress. These included homes in which chimneys had failed. In addition, a number of newly constructed homes in which the veneers were reported to be detailed in accordance with the 1997 UBC were visited. These newer homes showed no indication problems related to the earthquake.

Two cases of veneer failure to commercial structures were located. The first was in the City of Renton on State Road 167. Figure 23 shows the single story structure that contains a restaurant. The workers at the site indicated that the veneer had pulled away from the back-up concrete masonry (CMU) as a result of the earthquake, but had not completely collapsed. The photo shows the veneer after it had been pulled off of the surface for repair. It appeared from observation of the removed brick that the wall ties were not installed properly. Corrugated ties were found at the ends of the wall panel, but no anchorage was found in the interior of the panel. Furthermore, the corrugated ties had been embedded in bed joints but not attached to the existing CMU backup wall.

The second commercial veneer failure was observed on the recently retrofitted Starbucks corporate headquarters in Seattle. Figure 24 shows the north wing of the building during demolition and repair. The figure shows the layer of brick at the roofline that has pulled away from the underlying concrete frame. Access was not allowed to the building, so it is not clear if the veneer was properly tied to the frame. In addition, it was observed that the parapet was constructed with two wythes. This changes to single wythe at the top of the upper-most concrete spandrel beam. It is possible that the parapet failed first, pulling some of the veneer from the face of the concrete beam.

Figure 23. Veneer Failure in Renton, WA.

Figure 24. Veneer failure at Starbucks Building in Seattle, WA.

1.11 Summary of Observations

- Ground motion was not as severe as in the Northridge earthquake. Only two of the 31 seismological sites in the area registered peak ground accelerations greater that 0.25g.
- Localized damage was observed in a number of areas. Damage appeared to be restricted to older URM commercial buildings in downtown Seattle (Pioneer Square and south downtown) and Olympia. This correlates with areas that are known to have loose, saturated fill material.
- Chimney failures were noted on older residential structures.
- Major structural damage appeared to be very limited, with the majority of damage limited to URM parapet and partial wall collapse.

1.12 Conclusions

In general, the performance of masonry in the affected areas was favorable, with limited damage being observed. Parapet damage, cracking, and evidence of pounding were visible on older unreinforced masonry (URM) structures in Pioneer Square (Seattle) and downtown Olympia. No damage was observed on new construction in Seattle, Tacoma, or Olympia. Residential structures were also examined in Seattle and Olympia. New as well as older homes with masonry veneer appeared to have performed well. However, a number of older, unreinforced chimneys sustained damage or completely collapsed. In general, no failures were observed that have not already been observed and documented in previous earthquakes.

Caution in interpreting the effects of this earthquake is warranted. The Nisqually earthquake was relatively light. As such, it is probably not a good earthquake on which to base a judgment of the performance of masonry under extreme events.

1.13 References

1. Bray et al. "Some Observations of Geotechnical Aspects of the February 28, 2001, Nisqually Earthquake in Olympia, South Seattle, and Tacoma, Washington," a NSF-PEER sponsored reconnaissance effort, http://peer.berkeley.edu/nisqually/geotech/index.html, March 2001.

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4. *Uniform Building Code*, International Conference of Building Officials, Whittier, CA, 1997.