Concrete Coalition Phase II: Concrete Building Performance Record

Instructions: This form is for use in collecting data for phase two of the Concrete Coalition project: Developing a Global Database of Concrete Buildings Damaged in Earthquakes. For more information about how to use this form, see the sample form or view the demo at: http://concretecoalition.org.

Record ID: 35 **Building Name:** Stanford Museum (**Prepared By:** Quinn Peck

Section 1: Basic Building Information

The front of the Stanford Cantor Art Center. (Poland, 2006)

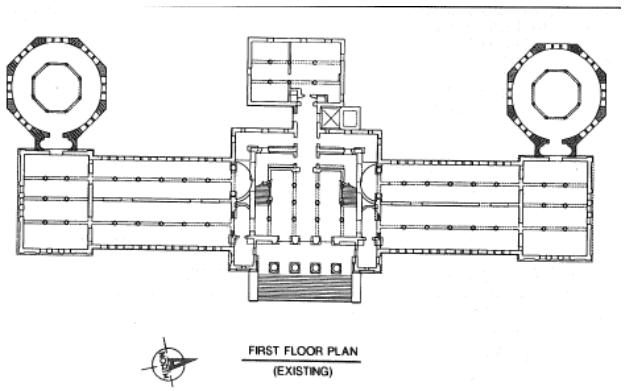
Country:	United States	
State/Province:	California	
City:	Palo Alto	
Latitude:	37.4330	
Longitude:	-122.1705	
Street Address:	328 Lomita Drive, Stanford, CA 94305	
Occupancy:	Unknown	
Height:		ft
Number of Stories:	2	
Number of Stories below ground:	1	
Size:	130000	gsf
Year Built:	1891	
Original Code:	None	
Modification:	Unknown	
Year Modified:	1898-1899, 1902-1906	
Code of Modification:	None	

Section 1: Basic Building Information-(Continued)

Lateral Load System:	Other
Other Lateral Load System:	Interior and exterior unreinforced concrete walls.
Vertical Load System:	Other
Other Vertical Load System:	Unreinforced concrete load bearing walls, cast-in-place reinforced concrete beam and slab floor system.
Foundation:	Other Flared basement column and walls.
Building Description:	The Stanford University Museum of Art (MOA), now known as Cantor Center for Visual Arts, was designed by architects Percy and Hamilton and constructed in 1891. The MOA was the first major public building to utilize the then state of the art twisted steel rebar technology in the floor slabs and beams. The museum underwent two significant expansion projects in the late 1800's and early 1900's in which the addition of two large unreinforced brick masonry wings transformed the museum into the largest (290,000 gsf) private museum in the world. Just months after the second addition was completed, the 1906 San Francisco earthquake destroyed approximately 75% of the museum beyond repair, leaving only the original wing, two octagonal rotundas and small rear wing intact. During the time of the Loma Prieta earthquake, the MOA consisted of the main original wing with plan dimensions of approximately 312 feet by 34 feet and the two rotundas with cross-dimensions of 34 feet. The building was two stories with a full basement. The vertical load resisting system utilized unreinforced concrete walls on the interior and exterior of the building, along with reinforced floor slabs and beams. Reinforcing in the walls was limited to horizontal bars above doorways. The unreinforced concrete walls on the interior and exterior varied in a stepped manner from 12 inches thick in the top story to 48 inches thick in the basement and also worked to resist lateral loads. Concrete core samples indicated that the concrete had a compressive strength of between 0 and 1500 psi with an average of 1000 psi.

Supplemental Basic Information:

Paste in building plans, engineering drawings or sketches

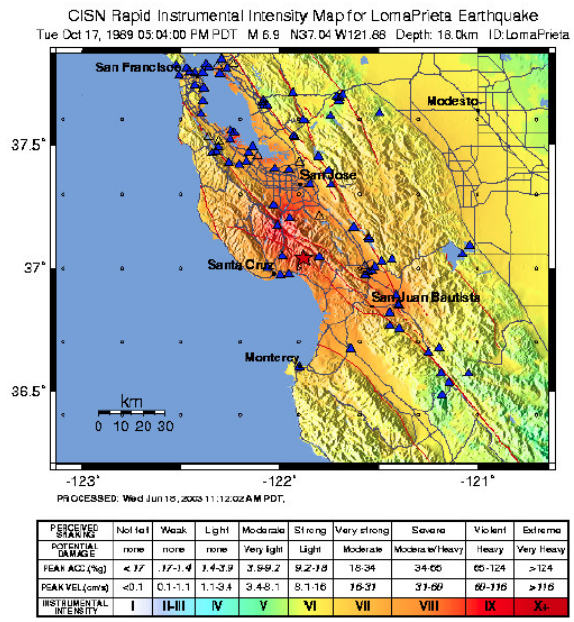
	Insert image here
First floor plan. (Elsesser et al., 1991)	Type image caption here:
Insert image here	Insert image here
Type image caption here:	Type image caption here:

Section 2: Earthquake Information

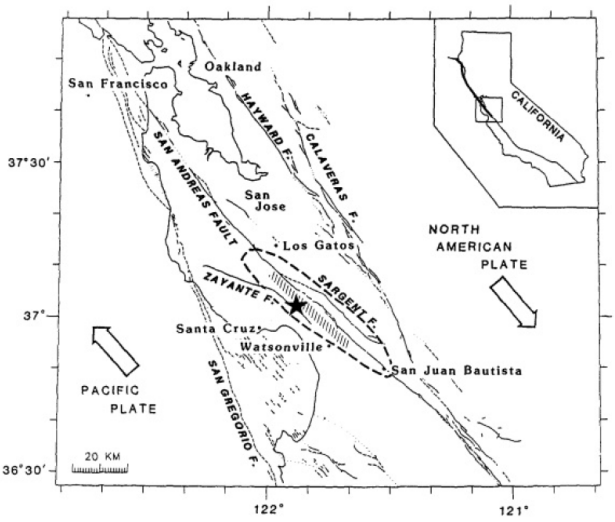
Earthquake Date:	10/17/1989		
Moment Magnitude:	6.9		
Epicentral Distance (km):	51		
Local Intensity:	VII	Intensity Scale:	MMI
Site Description:	The soil at the site of the MOA is sand and gravel with a capacity between 6,000 and 9,000 psf. (Elsesser et al., 1991)		
PGA (max horizontal):	0.27g		
PGA (vertical):	0.11g		
SaT:			
Ground Motion Recording Stations:	USGS Station No. 752 (Menlo Park VA Hospital, Bldg 37)		
Distance to Station (km):	4.0		
Station Latitude:	37.468		
Station Longitude:	-112.157		
Ground Motion Summary:	The October 17, 1898 Loma Prieta earthquake occured along the San Andreas fault near the summit of Loma Prieta Mountain at a depth of approximately 18 kilometers. Geodetic and seismic network data suggest right-lateral strike-slip and reverse movement on a northwest-striking plane dipping 70 degrees to the southwest. The rupture zone had an area of roughly 300 square kilometers. The earthquake and subsequent aftershocks filled a spatial gap in observed seismicity over the previous 20 years.		

Additional Ground Motion Information:

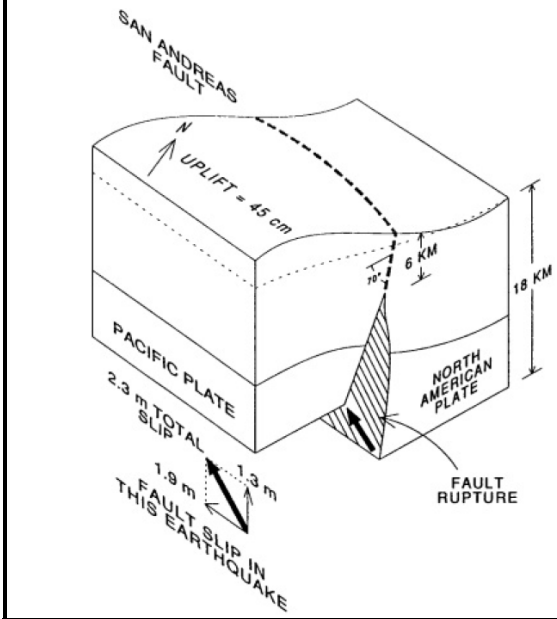
Paste in earthquake maps, spectra, or figures involving the ground motion at the building site



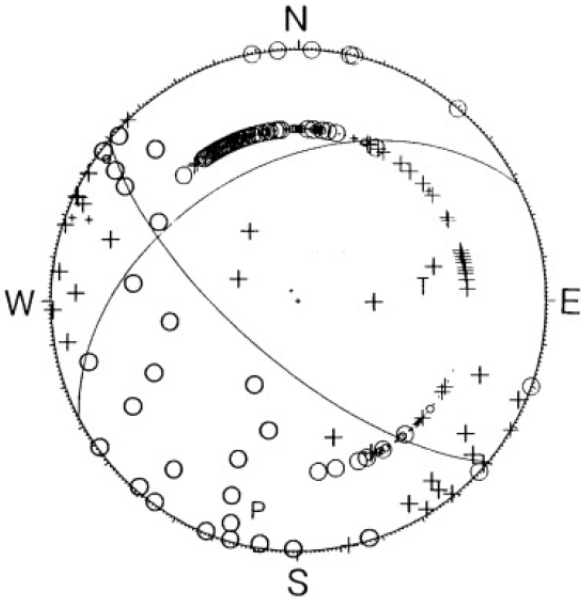
Shaking intensity for Loma Prieta earthquake. (USGS, 2009)



Map of the San Francisco Bay area showing the location of the major faults (light lines) in the San Andreas fault system. The zone of aftershocks (heavy broken line) extends from Lexington Reservoir, near Los Gatos, to Pajaro Gap, near San Juan Bautista. Hatchures indicate surface projection of the rupture plane inferred from postseimic geodetic observations. Location of the main shock epicenter (star) on the southwest edge of the aftershock zone is a result of its projection onto the surface from a depth of 18 km on a southwest-dipping fault plane. (Borcherdt et al., 1990)



Schematic diagram showing the inferred motion on the San Andreas fault. (Borcherdt, 1990)



Lower hemisphere plot of fault-plane solution for the Loma Prieta main shock, using 267 stations. Circles and pluses indicate dilatational and compressional arrivals, respectively. (Borcherdt, 1990)

Section 3: Damage Information

Performance Summary:	As in the 1906 earthquake, the Loma Prieta caused extensive damage in the Stanford Museum of Art. It was closed to the public immediately after the earthquake and remained unoccupied ten years, until it was reopened as the Iris & B. Gerald Cantor Center for Visual Arts.
Damage State Description:	The Loma Prieta earthquake caused major cracking throughout the unreinforced concrete walls in the main wing and severe cracking in the second floor slab of the side galleries and the vaulted ceiling over the main lobby. A number of concrete walls were cracked in a stepped pattern that mirrored the location of the construction joints and voids within the walls. Cracking was also observed around many window and door openings. The rotundas were also extensively damaged, with severe cracking in the unreinforced masonry walls. Large segments of these walls displaced from the second floor slab by up to two inches. The damage to the walls and separation from the slab left the rotundas with negligible lateral resistant and minimal gravity support.
Summary of Causes of Damage:	1. The overall lack of reinforcing throughout the museum resulted in significant cracking, especially around wall openings and diaphragm transition zones. 2. The thick, stiff unreinforced concrete walls had a tendency to rock, leading to cracking along the construction joints. 3. The minor amount of reinforcing in the diaphragms were unable to adequately transfer the seismic forces in to the walls, resulting in diaphragm separation at various locations throughout the museum.

Record ID: 35 **Building Name:** Stanford Museum of Art **Prepared By:** Quinn Peck

Section 4: Observed Design and Construction Characteristics-Construction Quality

	Notes	Contribution to Observed Damage: Unlikely	Possible	Likely	Unknown	N/A
Materials						
Concrete		◉	○	○	○	○
Reinforcing steel	Rather than the common deformed bars used today, the MOA utilized twisted square bars.	○	◉	○	○	○
Execution						
Conveyance/ placement of concrete		○	○	○	◉	○
Rebar	Much of the structure was completely unreinforced, with steel only present in the floor slabs and above door jambs.	◉	○	○	○	○
Field variance with design documents		○	○	○	◉	○
Other Factors						
Please Specify:		○	○	○	◉	○

Record ID: 35 **Building Name:** Stanford Museum of Art **Prepared By:** Quinn Peck

Section 4: Observed Design and Construction Characteristics-Configuration

	Notes	Contribution to Observed Damage: Unlikely	Possible	Likely	Unknown	N/A
Plan Irregularities						
Torsion		○	◉	○	○	○
Perimeter boundary		○	◉	○	○	○
Diaphragm		○	◉	○	○	○
Out-of-plane offsets in lateral resisting system		◉	○	○	○	○
Non-orthogonal systems		○	◉	○	○	○

Record ID: 35 **Building Name:** Stanford Museum of Art **Prepared By:** Quinn Peck

Section 4: Observed Design and Construction Characteristics-Configuration-(Continued)

	Notes	Contribution to Observed Damage Unlikely	Possible	Likely	Unknown	N/A
Vertical Irregularities						
Soft Story		◉	○	○	○	○
Weak story		◉	○	○	○	○
Mass distribution		◉	○	○	○	○
Geometric variability of lateral resisting system		◉	○	○	○	○
In-plane discontinuity of lateral resisting system		◉	○	○	○	○
Setbacks		◉	○	○	○	○
Change in stiffness		◉	○	○	○	○
Other Factors						
Please Specify:		○	○	○	◉	○

Record ID: 35 **Building Name:** Stanford Museum of Art **Prepared By:** Quinn Peck

Section 4: Observed Design and Construction Characteristics-Lateral Load Resisting System-General

	Notes	Contribution to Observed Damage: Unlikely	Possible	Likely	Unknown	N/A
Strength						
Overall lack of strength		○	○	◉	○	○
Stiffness						
Extreme Flexibility		◉	○	○	○	○
Load Path						
Collectors/Struts		○	◉	○	○	○
Anchorage of nonstructural elements		○	◉	○	○	○
Out-of-plane capacity of walls		◉	○	○	○	○
Diaphragm chords		○	◉	○	○	○
Diaphragm openings		○	◉	○	○	○
Other Factors						
Please Specify:		○	○	○	◉	○

Record ID: 35 **Building Name:** Stanford Museum of Art **Prepared By:** Quinn Peck

Section 4: Observed Design and Construction Characteristics-Lateral Load Resisting System-Frames

	Notes	Contribution to Observed Damage: Unlikely	Possible	Likely	Unknown	N/A
Columns						
Shear strength		○	○	○	○	◉
Flexural strength		○	○	○	○	◉
Axial load ratio (P/Ac/fc')		○	○	○	○	◉
"Vertical" load columns drift capacity		○	○	○	○	◉
Interference of frame action by infill		○	○	○	○	◉
Beams						
Strength relative to columns		○	○	○	○	◉
Shear controlled behavior		○	○	○	○	◉
Continuity of longitudinal reinforcing		○	○	○	○	◉
Loss of vertical capacity		○	○	○	○	◉

Section 4: Observed Design and Construction Characteristics-Lateral Load Resisting System-Frames-Continued

	Notes	Contribution to Observed Damage: Unlikely	Possible	Likely	Unknown	N/A
Beams –(continued)						
Interference of frame action by infill		○	○	○	○	◉
Joints						
Interior		○	○	○	○	◉
Exterior		○	○	○	○	◉
Corner		○	○	○	○	◉
Other Factors						
Please Specify:		○	○	○	○	◉

Record ID: 35 **Building Name:** Stanford Museum of Art **Prepared By:** Quinn Peck

Section 4: Observed Design and Construction Characteristics-Lateral Load Resisting System-Shear Walls

	Notes	Contribution to Observed Damage: Unlikely	Possible	Likely	Unknown	N/A
Shear						
Diagonal tension/compression		○	○	○	◉	○
Sliding shear		○	○	○	◉	○
Flexure/shear		○	○	○	◉	○
Flexure						
Compression zone buckling capacity		○	○	○	◉	○
Boundary reinforcing fracture/buckling		○	○	○	◉	○
Discontinuity of wall		○	○	○	◉	○
Boundary Reinforcing at openings		○	○	◉	○	○
Other Factors						
Please Specify:		○	○	○	◉	○

Record ID: 35 **Building Name:** Stanford Museum of Art **Prepared By:** Quinn Peck

Section 4: Observed Design and Construction Characteristics-Lateral Load Resisting System-Infills

	Notes	Contribution to Observed Damage: Unlikely	Possible	Likely	Unknown	N/A
Unreinforced		○	○	◉	○	○
Interference with frame action		○	○	○	◉	○
Out-of-plane		○	◉	○	○	○
Attachment to framing		○	○	○	◉	○

Other Factors

Please Specify:		○	○	○	◉	○

Record ID: 35 **Building Name:** Stanford Museum of Art **Prepared By:** Quinn Peck

Section 4: Observed Design and Construction Characteristics-Lateral Load Resisting System-Other

	Notes	Contribution to Observed Damage: Unlikely	Possible	Likely	Unknown	N/A
Foundations						
Liquefaction		○	○	○	◉	○
Pile/pier tension capacity		○	○	○	◉	○
Spread footing capacity		○	○	○	◉	○
Other:						
Please Specify:		○	○	○	◉	○
Miscellaneous						
Pounding		○	◉	○	○	○
Surface Rupture		○	○	○	◉	○
Other:						
Please Specify:		○	○	○	◉	○

Illustrations of damage:

Paste in drawings, sketches or photos of building damage

Damage to the interior of the museum. (Poland, 2006)

Damage to the interior of the museum. (Poland, 2006)

Damage to the ceiling and archway above the lobby. (Poland, 2006)

Damage to the interior of one of the octagonal rotundas. (Poland, 2006)

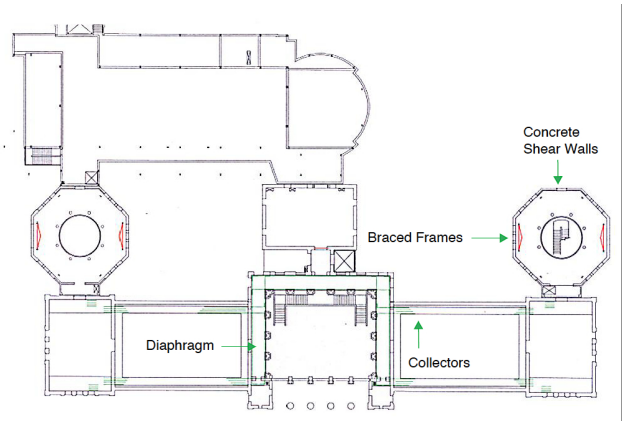
Record ID: 35 **Building Name:** Stanford Museum c **Prepared By:** Quinn Peck

Section 4: Repair and Retrofit Information

Type of retrofit or repair:	Improved Performance
Other:	
Performance Level:	Unknown
Hazard Level:	Unknown
Code:	Unknown
Other:	
Lateral Analysis:	Unknown
Other:	
Design Strategy:	The Stanford Museum of Art was retrofitted based on the observed damage patterns in both the Loma Prieta earthquake and the 1906 earthquake. The designers realized that the structure's unique structural system had a tendency to rock in discrete blocks when lateral forces were applied. In a large earthquake, the broad unreinforced concrete shear walls were expected to crack and settle into a stable rocking motion. Rather than attempting to retrofit the structure to dissipate seismic energy through inelastic deformation, the building's natural rocking motion was harnessed as the method of energy dissipation.
Retrofit Summary:	The designers installed shear walls and braced frames in strategic locations that allowed the building's natural rocking behavior to dissipate seismic energy while reducing the overall damage to the structure. Collectors and chords were added throughout the building to ensure that diaphragm forces could be adequately transferred to these new lateral force-resisting elements without causing significant damage. New steel trusses were also installed in the roof diaphragm of the main gallery wings.

Illustrations of Repair or Retrofit:

Paste in drawings, sketches or photos of building repair or retrofit



Strengthening scheme for the museum. (Poland, 2006)

Installation of new reinforced concrete column in the museum lobby. (Poland, 2006)

Retrofit of gallery ring. (Poland, 2006)

Retrofit of museum lobby. (Poland, 2006)

Record ID: 35 **Building Name:** Stanford Museum c **Prepared By:** Quinn Peck

Additional Notes:	
Section 1	
Section 2	
Section 3	
Section 4	A full set of architectural and structural drawings for the retrofitted museum can be found in the Degenkolb archives.

Appendix 1: Supplemental Basic Information

File Location	/static/data/2-supplemental-basic-information/USA004_Cover_Image.jpg
File Caption	The front of the Stanford Cantor Art Center. (Poland, 2006)
File Location	/static/data/2-supplemental-basic-information/USA004_Plan_1.jpg
File Caption	First floor plan. (Elsesser et al., 1991)
File Location	
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Appendix 2: Additional Ground Motion Location

File Location	/static/data/3-additional-ground-motion/USA004_Ground_Mc
File Caption	Shaking intensity for Loma Prieta earthquake. (USGS, 2009)
File Location	/static/data/3-additional-ground-motion/USA004_Ground_Mc
File Caption	Map of the San Francisco Bay area showing the location of the major faults (light lines) in the San Andreas fault system. The zone of aftershocks (heavy broken line) extends from Lexington Reservoir, near Los Gatos, to Pajaro Gap, near San Juan Bautista. Hatchures indicate surface projection of the rupture plane inferred from postseimic geodetic observations. Location of the main shock epicenter (star) on the southwest edge of the aftershock zone is a result of its projection onto the surface from a depth of 18 km on a southwest-dipping fault plane. (Borcherdt et al., 1990)
File Location	/static/data/3-additional-ground-motion/USA004_Ground_Mc
File Caption	Schematic diagram showing the inferred motion on the San Andreas fault. (Borcherdt, 1990)
File Location	/static/data/3-additional-ground-motion/USA004_Ground_Mc
File Caption	Lower hemisphere plot of fault-plane solution for the Loma Prieta main shock, using 267 stations. Circles and pluses indicate dilatational and compressional arrivals, respectively. (Borcherdt, 1990)
File Location	/static/data/3-additional-ground-motion/USA004_Ground_Mc
File Caption	Cross sections of seismicity along the San Andreas fault from north of San Francisco to south of Parkfield, California: (a) seismicity recorded during the 20-year period prior to the earthquake, (b) aftershocks of the Loma Prieta earthquake, (c) background seismicity plus aftershocks. (Borcherdt, et al., 1990)
File Location	/static/data/3-additional-ground-motion/USA004_Ground_Mc
File Caption	Map and cross sections showing spatial distribution of aftershocks from October 17 through October 31. (Borcherdt et al., 1990)
File Location	/static/data/3-additional-ground-motion/USA004_Ground_Mc
File Caption	Preliminary map showing the distribution of Modified Mercalli intensity for the 1989 Loma Prieta earthquake. Intensity values for localities are given in Arabic numbers. Roman numerals represent the intensity level between isoseismal lines. Location of the epicenter is shown by the circled star. (Plafker and Galloway, 1989)
File Location	
File Caption	
File Location	
File Caption	
File Location	
File Caption	

Appendix 3: Illustrations of Damage

File Location	/static/data/4-illustration-of-damage/USA004_Damage_1.jpe
File Caption	Damage to the interior of the museum. (Poland, 2006)
File Location	/static/data/4-illustration-of-damage/USA004_Damage_2.jpe
File Caption	Damage to the interior of the museum. (Poland, 2006)
File Location	/static/data/4-illustration-of-damage/USA004_Damage_3.jpe
File Caption	Damage to the ceiling and archway above the lobby. (Poland, 2006)
File Location	/static/data/4-illustration-of-damage/USA004_Damage_4.jpe
File Caption	Damage to the interior of one of the octagonal rotundas. (Poland, 2006)
File Location	/static/data/4-illustration-of-damage/USA004_Damage_5.jpe
File Caption	Damage at openings in unreinforced masonry walls in one of the rotundas. (Poland, 2006)
File Location	/static/data/4-illustration-of-damage/USA004_Damage_6.jpe
File Caption	Close up of cracking in rotunda wall. (Poland, 2006)
File Location	/static/data/4-illustration-of-damage/USA004_Damage_7.jpe
File Caption	Damage above and below openings in unreinforced concrete wall. Note the limited amount of twisted reinforcing steel. (Poland, 2006)
File Location	/static/data/4-illustration-of-damage/USA004_Damage_8.jpe
File Caption	Close up of cracking in lobby walls. (Poland, 2006)
File Location	/static/data/4-illustration-of-damage/USA004_Damage_9.jpe
File Caption	Cracking in second-floor diaphragm. (Poland, 2006)
File Location	/static/data/4-illustration-of-damage/USA004_Damage_10 .jp
File Caption	Cracking in second-floor diaphragm. (Poland, 2006)

Appendix 4: Illustrations of Repair/Retrofit

File Location	/static/data/5-illustration-of-repair-retrofit/USA004_Repair_1.j
File Caption	Strengthening scheme for the museum. (Poland, 2006)
File Location	/static/data/5-illustration-of-repair-retrofit/USA004_Repair_2.j
File Caption	Installation of new reinforced concrete column in the museum lobby. (Poland, 2006)
File Location	/static/data/5-illustration-of-repair-retrofit/USA004_Repair_3.j
File Caption	Retrofit of gallery ring. (Poland, 2006)
File Location	/static/data/5-illustration-of-repair-retrofit/USA004_Repair_4.j
File Caption	Retrofit of museum lobby. (Poland, 2006)
File Location	/static/data/5-illustration-of-repair-retrofit/USA004_Repair_5.j
File Caption	Installation of concrete shear walls in rotunda. (Poland, 2006)
File Location	/static/data/5-illustration-of-repair-retrofit/USA004_Repair_6.j
File Caption	Installation of concrete shear wall in rotunda. (Poland, 2006)
File Location	/static/data/5-illustration-of-repair-retrofit/USA004_Repair_7.j
File Caption	Installation of braced frame in rotunda. (Poland, 2006)
File Location	/static/data/5-illustration-of-repair-retrofit/USA004_Repair_8.j
File Caption	Installation of braced frame in rotunda. (Poland, 2006)
File Location	
File Caption	
File Location	
File Caption	

Appendix 5: References

Citation	Elsesser, E., Naaseh, S., Walters, M., Sattary, V., and Whittaker, A., 2001. Repair of five historic buildings damaged by the Loma Prieta earthquake, *The Seismic Retrofit of Historic Buildings Conference*, San Francisco, CA
Link to Purchase	http://nisee.berkeley.edu/elibrary/Text/200803133
File Location	
Citation	Borcherdt, R. D. and Donovan, N. C., 1990. Ground Motion, *Earthquake Spectra,* **6**, Supplement, 25–80.
Link to Purchase	http://eqs.eeri.org/resource/1/easpef/v6/iS1/p25_s1?isAutho
File Location	
Citation	United States Geological Survey (USGS), 2009. *CISN Rapid Instrumental Intensity Map for Loma Prieta Earthquake,* http://earthquake.usgs.gov/earthquakes/shakemap/nc/shake/LomaPrieta/ (20 July 2012).
Link to Purchase	
File Location	/static/data/3-additional-ground-motion/USA004_Ground_Mc
Citation	Plafker, G., and J. Galloway, 1989. Lessons learned from the Loma Prieta, California earthquake of October 17, 1989. USGS Circular 1045, 48 pp.
Link to Purchase	
File Location	/static/data/6-references/USA004_Reference_4.pdf
Citation	Borcherdt, R. D. and Donovan, N. C., 1990. Geosciences, *Earthquake Spectra,* **6**, Supplement, 7–24.
Link to Purchase	http://eqs.eeri.org/resource/1/easpef/v6/iS1/p7_s1?isAuthori:
File Location	

Appendix 5: References-(Continued)

Citation	Poland, Chris, 2006. "Restraint, Respect, and Rehabilitate: A Tale of Three Seismic Projects at Stanford." Stanford University. Stanford, California. 17 January 2006.
Link to Purchase	
File Location	
Citation	
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