SEISMICALLY VULNERABLE EXISTING BUILDING FACT SHEET SUMMARY

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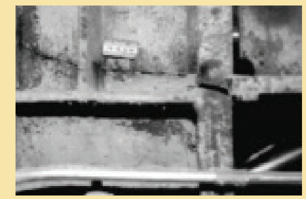
While all buildings are unique, those that fit into the categories presented below typically have common structural issues which significantly affect their seismic performance. These issues present elevated risks for collapse and loss of life during a large earthquake, or severe damage which may affect a building's repairability and a community's resilience after an earthquake. Retrofits of these buildings can significantly improve their response during an earthquake and reduce their risk to building occupants and owners.

WANT TO KNOW MORE? (Link to full document)

	URM UNREINFORCED MASONRY	NDC NON-DUCTILE CONCRETE	SWOF WOOD - SOFT/WEAK OPEN FRONT	RWFD RIGID WALL (CONC. OR MASONRY) / FLEXIBLE ROOF	PN-SMF PRE-NORTHRIDGE STEEL MOMENT FRAME
DEFICIENCY	Lack of Reinforcing	Lack of Confining Reinforcing	Weak Ground Story	Weak Wall to Roof Connection	Brittle Column/Beam Connections
ERA	Most Common pre-1940's	Most Common pre-1980's	Most Common 1950's–1970's	Most Common 1950's–1990's	Most Common 1950's–1990's
TYPICAL BUILDING					
TYPICAL EARTHQUAKE DAMAGE	 	 	 	 	 
Risk to Life Safety (L M H VH)	H–VH	M/H–VH	M–H/VH	M–H	L/M–H
Risk to Property Damage and Business Interruption (L M H VH)	M/H–VH	H–VH	M/H–VH	M–H	M–H
Risk to Community Disruption (L M H VH)	M–H	M–VH	M/H–VH	M–H	M–VH

Risk Level Legend - L: Low, M: Moderate, H: High, VH: Very High • For full list of references for photos, see references sheet • Earthquake damage depicted is based on a large earthquake

BUILDING TYPES

What is this document?

To provide safe and resilient communities, it is essential to address the potential risks posed by existing buildings during seismic events. Earthquakes have historically demonstrated their capacity to inflict devastating damage; impacting lives, livelihoods, and communities. Identifying and comprehending the vulnerabilities of existing buildings is a major step in safeguarding our future. The following pages aim to inform building owners, the public, and policymakers about the seismic vulnerability of certain existing building types and a range of retrofit solutions that may be employed to reduce their impact on our society. Contact your local structural engineer for additional guidance.

Vulnerable buildings encompass a range of construction types that may lack adequate seismic resilience. Some among these are ***Unreinforced Masonry (URM) buildings, Non-Ductile Concrete (NDC) structures, Wood Soft, Weak, and Open Front (Wood SWOF) buildings, Rigid Wall - Flexible Diaphragm (RWFD) constructions, and Pre-1994 Steel Moment Frame (SMF) buildings.*** These building types, occur commonly in our urban landscapes and often exhibit design flaws and materials that can compromise their ability to withstand seismic forces.

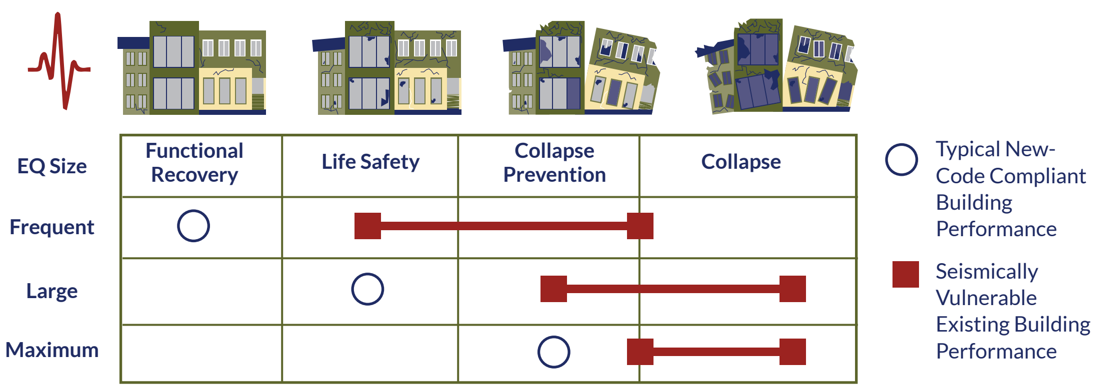
Don't building codes provide safe enough buildings?

History provides us with valuable lessons about the behavior of buildings during seismic events. Past earthquakes have exposed building vulnerabilities, leading to significant damage and tragic loss of life. Through these experiences, engineers and researchers have gained valuable insights, shaping the evolution of building codes and seismic design practices.

Over time, building codes have been subject to revisions to incorporate advancements in seismic engineering and mitigate vulnerabilities in new construction. These codes have addressed known risks, mandating seismic design features in contemporary buildings. While each revised building code serves to protect future construction, they often do not mandate the retrofitting of existing buildings. Retrofitting, the process of strengthening older buildings to meet modern seismic standards, plays a crucial role in enhancing community resilience. Some jurisdictions have taken action to reduce the seismic risk in their building stock by implementing seismic retrofit ordinances. Check your locality for active or past retrofit ordinances.

SEISMIC HAZARDS

Expected Building Performance



Earthquakes don't kill people, buildings do.

Each floor of a multi-story commercial building typically weighs several million pounds.

No building code is retroactive.

RETROFIT

Why Retrofit?

When not retrofitted, these existing building types typically face a much higher risk of collapse during a significant seismic event, increasing the likelihood of fatalities.. For more frequent earthquakes these buildings may experience a disproportionate amount of structural damage leading to loss of occupancy, and potential demolition.

The benefits of seismic retro-fitting include:

- Enhanced protection of building occupants.
- Reduction in physical damage to buildings.
- Lessened disruption and forced relocation for businesses, fostering quicker recovery following an earthquake.

How do we know if a building is "Seismically Vulnerable"?

While all buildings are unique, those falling into the categories presented in the following pages typically have design characteristics that significantly impact their seismic performance. With proper investigation and evaluation, engineers can evaluate a building to understand the expected seismic performance of the as-built conditions and the benefits of potential retrofit schemes for the building.

NOTE: It is important to acknowledge the unique characteristics of each building and earthquake, and the varying levels of damage that can be expected from a single seismic event. This document explores five specific building types, however, there are other known vulnerable building types and vulnerable building traits. Retrofit costs and techniques will vary depending on the building's complexity and the site's seismicity. The following pages provide sliding scales describing relative risk for general types of vulnerable buildings, all known to have a high likelihood of seismic deficiencies which may lead to poor seismic performance. Ultimately, each building is unique, and only a thorough structural engineering evaluation can identify specific risks and seismic deficiencies accurately. Building owners who suspect their building may be seismically vulnerable should speak to a licensed Design Professional experienced in seismic engnieering for advice.

UNREINFORCED MASONRY BUILDINGS

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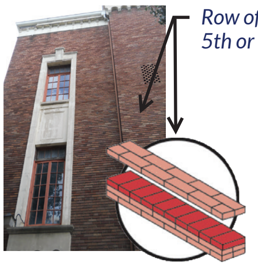
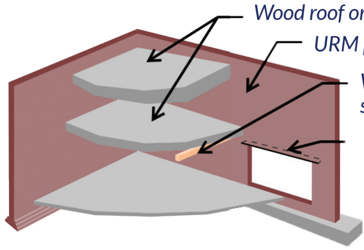
BUILDING DESCRIPTION

An Unreinforced Masonry Building (URM) is a form of construction that is typically comprised of walls made of brick or stone that are bonded together with mortar without steel reinforcing. URM buildings were commonly constructed prior to the 1933 Long Beach earthquake but were prohibited over time due to their seismic vulnerabilities.

Examples of Unreinforced Masonry Buildings



Typical URM Building with Terra Cotta Features



Schematic of Typical URM Building

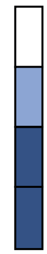
Most Common Era of Construction in California

Pre 1940's

Gradually replaced by reinforced brick and CMU construction. Disallowed in the 1961 code for resisting earthquakes.

Typical Building Architecture

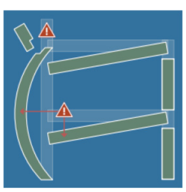
- Red brick, stone, or hollow clay tile exterior walls
- Steel lintel or arched brickwork over windows
- Typically warehousing, maintenance, or historic buildings



SEISMIC RISK

Potential Damage to Unreinforced Masonry Building

- *Localized to complete collapse*
- *Collapse of Beam/Truss/Girder*
- *Walls pull away from floors/roofs and collapse[2]*
- *Floor/Roof sheathing distortion*

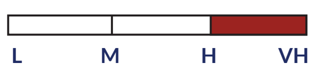


Damage to a School in Long Beach following the March 10,1933 earthquake[3]

Wall cracking and permanent offsets are common in even moderate earthquakes.

Lack of appropriate connection between roof and wall causing wall failure.

Risk to Life Safety



- High risk of falling hazards, especially parapets
- Moderate to high risk of partial wall or roof failure
- Wall loss can lead to partial or complete collapse

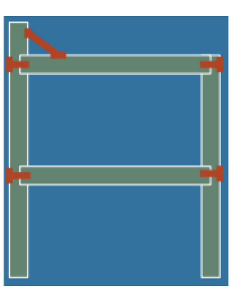
Risk to Property Damage and Business Interruption

- Property owners and tenants should expect significant disruption in a moderate event and some level of collapse in a large event
- Repair is difficult and costly. Demolition likely.

Risk to Community Disruption

- Building type was typically used for lower impact functions such as warehousing / maintenance
- Adaptive reuse has elevated the function, longevity and impact of URM losses in California

RETROFIT



Typical Schematic Retrofit of Parapet and Wall to Floor Connections[2]

Common Retrofit Methods

- Parapet Bracing: Sloped or vertical ties to roof
- Strengthening of floor and roof to wall connections
- Floor and roof diaphragm sheathing strengthening
- Wall strengthening for lateral stability
- Shear wall strengthening with new reinforced concrete shear walls or steel braced frames
- Addition of columns to support beams/trusses at URM walls

Retrofit Considerations

- Many local jurisdictions have implemented mandatory retrofit ordinances that vary in scope.
- Some retrofit ordinances only mandate anchorage of exterior walls/parapets while others mandate full retrofit.
- Buildings with past retrofits will vary in performance depending on level of retrofit performed.
- Diaphragm strengthening may require removal of roofing. Timing this scope, if required, with planned re-roofing is suggested.

Risk Level Legend - L: Low, M: Moderate, H: High, VH: Very High

NON-DUCTILE CONCRETE BUILDINGS

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BUILDING DESCRIPTION

A Non-Ductile Concrete Building (NDC) is a building with significant concrete structural elements, including columns, walls, beams, and floor slabs. These buildings were constructed before modern building code requirements for earthquake resistance were implemented following the 1971 San Fernando Earthquake. These elements may be susceptible to sudden and severe damage or failure, (instead of a "ductile" response), during large earthquakes due to archaic design and construction practices for the steel reinforcing bars in the concrete.

Example of Non-Ductile Concrete Building

Image of heavily damaged non-ductile concrete building

Most Common Era of Construction in California

1900s — 1980s

Concrete buildings built prior to codes requiring ductile design practice

Typical Building Architecture

- Concrete frame or shear wall buildings with inadequate reinforcing steel
- Identification of non-ductile concrete buildings is difficult[2]
- These buildings may have masonry infill between columns.

High-Rise *10+ stories*

Mid-Rise *~5 stories*

Multi-Story *2-3 stories*

Single Story

SEISMIC RISK

Potential Damage to Non-Ductile Concrete Buildings

- *Diagonal cracks in walls*
- *Soft/weak story sidesway failure (open front)*
- *Shear failure of columns*
- *Columns punch through slabs*
- *Collapse: Partial or Complete*

The Pyne Gould Corp. Building collapsed during the 2011 Christchurch Earthquake [8]

Non-ductile failure of a shear-controlled captive column after the Northridge earthquake.

Risk to Life Safety (L M H VH)

- High risk of brittle, sudden failure
- Historically higher risk of collapse and fatalities compared to modern buildings[1]
- Heavy construction type resulting in high seismic forces

Risk to Property Damage and Business Interruption (L M H VH)

- Collapse risk leads to significant financial losses in both property damage and business interruption.
- High expected economic loss when compared with ductile buildings[1]
- Repair of damaged non-ductile concrete may be infeasible

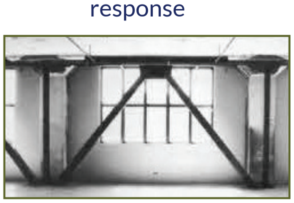
Risk to Community Disruption (L M H VH)

- Many serve as government, institutional, residential, or critical service facilities
- Represent a significant percentage of the current vulnerable building stock[3]
- Tend to be larger and located in densely populated urban areas

RETROFIT

Common Retrofit Methods

- Add bracing/walls, or strengthen existing elements.
- Address irregularities such as weak or "soft" stories; vertically discontinuous columns & walls; large floor openings; abrupt changes in the lateral force resisting system between stories
- Supplemental reinforcing or wrapping of existing elements can improve their ductility where deficiencies or vulnerabilities occur.
- Adding dampers can reduce the seismic response

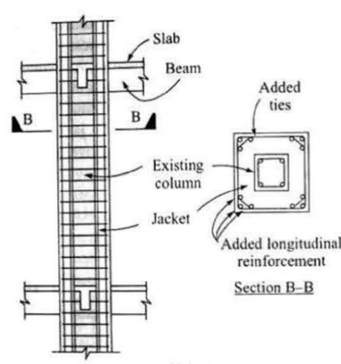


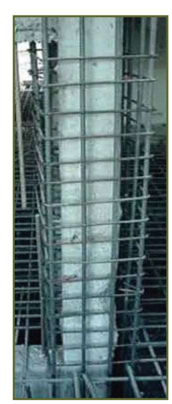
Added Steel Bracing

Added New Concrete Walls

Retrofit Considerations

- In general, the goal is stiffening the structure to decrease the sidesway to protect building elements that are inadequately reinforced.
- An optimal cost/benefit retrofit solution may be to correct the riskiest elements, which may avoid full-height retrofitting.
- Advanced analysis may substantially reduce the required retrofit scope.
- Deferred maintenance may lead to deterioration to the point where demolition and reconstruction is more efficient than retrofitting.





Reinforced Concrete Columns

WOOD-FRAMED SOFT/WEAK STORY BUILDINGS

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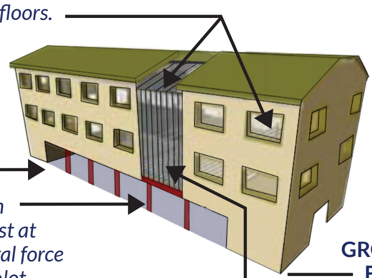
BUILDING DESCRIPTION

A Wood Framed Soft / Weak Story Building (SWOF: Soft, Weak or Open-Front) is a wood building structure with a first floor wall framing system that is significantly weaker in stiffness and strength than the wall framing system above. These buildings are typically associated with first floor car parking or retail space under the building structure above. Wood structures built prior to the adoption and enforcement of the 1976 Uniform Building Code by local governing jurisdiction are considered to be the most susceptible to first floor collapse during strong earthquake shaking.

Typical Wood Framed Building



Schematic of typical soft story wood framed building[1]

Most Common Era of Construction in California

1950s — 1970s

Soft/weak story wood framed buildings built prior to the publishing of the 1976 California Building Code. (Note: Not all California Building Departments Adopted this Code)

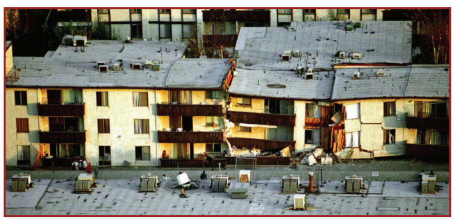
Typical Building Architecture

- Typically two-story or taller wood framed residential (apartment, condominium), small commercial and retail buildings. Some up to 5 stories in height
- Typically buildings with stucco exteriors and open parking, garages, or retail at first floor level under a portion of the building

High-Rise *10+ stories*
Mid-Rise *~5 stories*
Multi-Story *2-3 stories*
Single Story

SEISMIC RISK

Potential Damage To Wood-Framed Soft/Weak Story Building



The Northridge Meadows apartment complex first floor collapsed during the M6.7 earthquake on Jan. 17, 1994.[3]

Nearly collapsed building first floor near Beach and Divisadero Streets in San Francisco during the Loma Prieta earthquake on Oct. 17, 1989.[4]

Risk to Life Safety — L M H VH

- High risk of first floor partial or total building collapse
- Very high potential for injuries to building occupants and death at collapsed floor levels
- Collapse may prevent egress (stairs and exit path) from upper floor levels.

Risk to Property Damage and Business Interruption — L M H VH

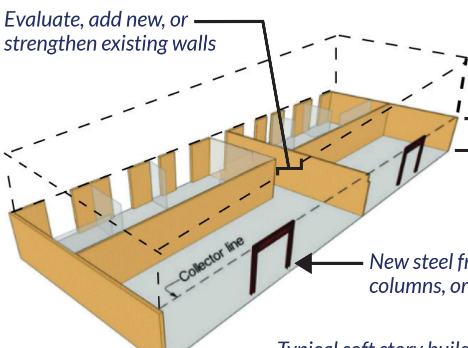
- First floor partial or total collapse results in demolition of the remainder of the building.
- When buildings severely damaged, relocated residents or tenants may fear returning to building if repaired.

Risk to Community Disruption — L M H VH

- Loss of one's living space results in relocation, possibly requiring finding a new job in a new community or city.
- Loss of commercial / retail space resulting in business closure or relocating to a new community causing economic hardship

RETROFIT

Typical Seismic Retrofit



Typical soft story building strengthening[2]
(Only 1st story strengthening shown for clarity)

Common Retrofit Methods

- Strengthening of first floor by addition of wood shear walls, steel moment frames, or steel cantilever columns.
- Proprietary retrofit systems have been developed by private vendors as an alternate to common established building code systems.

Retrofit Considerations

- Many local jurisdictions have implemented mandatory retrofit strengthening ordinances that vary in scope.
- Some retrofit ordinances only mandate exterior open line retrofits while others mandate full story retrofit.
- Building seismic performance will vary depending on level of retrofit selected by Owner. Owner should speak to a licensed Design Professional experienced in seismic engineering for advice.

Risk Level Legend - L: Low, M: Moderate, H: High, VH: Very High

RIGID WALL-FLEXIBLE DIAPHRAGM BUILDINGS

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BUILDING DESCRIPTION

Rigid Wall-Flexible Diaphragm (RWFD) buildings are typically one or two story commercial buildings with reinforced concrete or reinforced masonry walls. They have "flexible" roof diaphragms that consist of wood or steel beams, trusses, or rafters with wood sheathing or metal decking above. They may also have flexible diaphragms at intermediate floor levels.

Example of Rigid Wall Flexible Diaphragm Buildings

Typical RWFD building (concrete tilt-up)

Typical area of RWFD construction

Most Common Era of Construction in California

1950s — 1990s

Concrete or Reinforced Masonry buildings designed prior to the implementation of the 1997 Uniform Building Code.

Typical Building Architecture

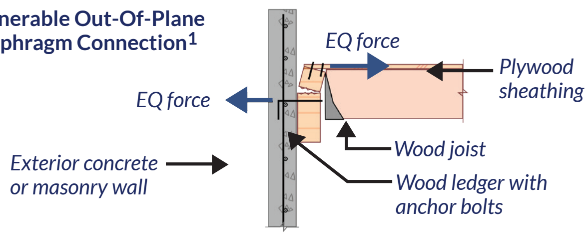
- Warehouses, industrial buildings, office buildings, large retail structures
- Tilt-Up concrete (cast on site) can be solid panel or may have large window or door openings in later era construction
- Large single-story reinforced masonry block structures

High-Rise *10+ stories*
Mid-Rise *~5 stories*
Multi-Story *2-3 stories*
Single Story

SEISMIC RISK

Potential Damage to Rigid Wall-Flexible Diaphragm Buildings

Typical Vulnerable Out-Of-Plane Wall to Diaphragm Connection[1]



Wall and roof collapse of a Tilt-up concrete buildings

- Most common failure observed in past earthquakes is at connection between roof and exterior concrete walls.
- Local collapse at roof to wall connections potentially extending further back into building
- Fractures or failures of anchors at connections plates between tilt up panels. Similar failures at base of wall to foundation connections

Risk to Life Safety

L M H VH

- High risk for collapsed walls and roofs, especially in buildings constructed prior to mid 1970's
- Risk to life safety is dependent on number of building occupants (lower for warehouses, higher for offices)

Risk to Property Damage and Business Interruption

L M H VH

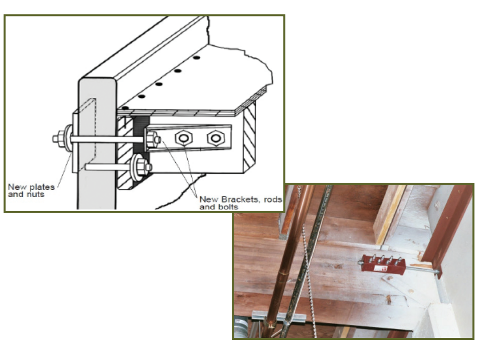
- High risk of local collapses from wall to roof connection failures
- High impact to affected business (local collapses would red-tag facilities)
- Repair/replacement costs lower compared to other building types

Risk to Community Disruption

L M H VH

- Minor impact to adjacent properties (low-rise)
- Key businesses may cause large community disruption, while certain business may have little impact.

RETROFIT



A typical retrofit with new wall anchors at roof-to-wall or roof-to-floor connections[2]

Common Retrofit Methods

- Strengthening of roof to wall connections
- Strengthening of roof diaphragm
- Addition/strengthening of roof cross-ties
- Strengthening of panel-to-panel connections and panel-to-foundation connections for tilt-ups
- Wall strengthening sometimes required at large openings

Retrofit Considerations

- Retrofits in these buildings are generally comparatively less costly than in other building types.
- Costly finishes and ceilings are less common in most RWFD buildings, making retrofit access easier and less expensive.
- Diaphragm strengthening may require removal of roofing. Timing this scope, if required, with planned re-roof is suggested.
- Advanced analysis typically does not improve retrofit scope

Risk Level Legend - L: Low, M: Moderate, H: High, VH: Very High

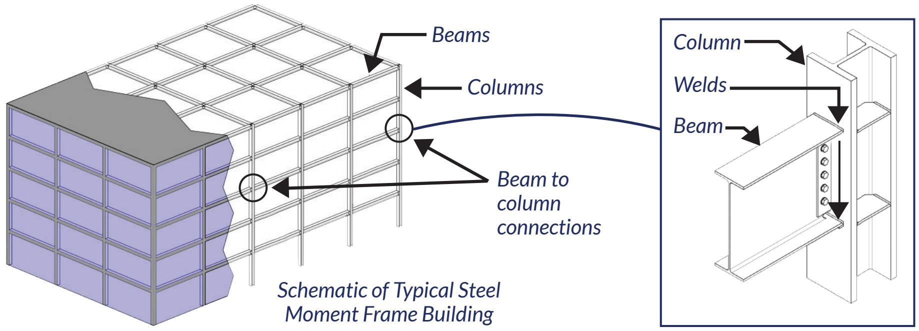
PRE-NORTHRIDGE STEEL MOMENT FRAME BUILDINGS

BUILDING DESCRIPTION

A Pre-Northridge Welded Steel Moment Frame (PN-SMF) is an assembly of beams and columns rigidly joined together to resist seismic forces and built prior to the implementation of code changes that followed the 1994 Northridge Earthquake. PN-SMF buildings are susceptible to connection damage and failures as a result of connection geometry, deficient welding, and other factors.

Typical City High Rise Buildings[1]

Typical Pre-Northridge Steel Moment Frame Building



Schematic of Typical Steel Moment Frame Building

Typical Pre-Northridge Welded Steel Moment Frame Beam-to-Column Connection[2]

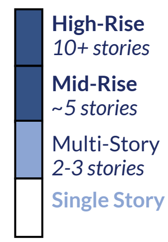
Most Common Era of Construction in California

1950s — 1990s

Welded steel frame buildings built prior to the emergency provisions update to the 1994 Uniform Building Code.

Typical Building Architecture

- Characterized by glazed exteriors and abundant windows
- Most buildings over 160 feet tall built between the 1960's and 1990's are moment frame structures[2]
- Often commercial and government buildings in high-rise downtown areas



SEISMIC RISK

Potential Damage to Pre-Northridge Steel Moment Frame Buildings

- Fractured beam-to-column connections
- Fractured column splice connections
- Excessive deformation leading to non-structural damage and permanent building displacement
- Collapse of stairs and other drift sensitive non-structural elements

Column flange fracture from the Northridge Earthquake[2]*. Roughly 100 SMF buildings had verified structural damage.*[3]

Fractured welded connections could lead to localized collapse.[1]

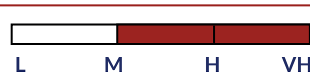
Risk to Life Safety

- High risk of falling hazards and impact to egress (exterior walls, stairs, and exit paths)
- Historically less prone to collapse than other vulnerable building types, higher risk in long duration earthquakes
- Generally high occupancy buildings.

Risk to Property Damage and Business Interruption

- Building movement during an earthquake will likely cause damage in non-structural components (walls, fire sprinklers, stairs, etc...)
- Connection damage detection is both difficult and costly and can displace tenants from repair areas[1]

Risk to Community Disruption



- Typically tall and large square footage buildings that are located in city centers with the potential for a high tenant displacement following an earthquake.
- Often important facilities, including hospitals and government buildings[1]

RETROFIT

Common Retrofit Methods

- Strengthening of beam-column and column splice connections
- Addition of steel braces or concrete walls
- Addition of energy dissipation systems (damping "shock-absorbers")

Retrofit Considerations

- Retrofitting can be phased during tenant improvement projects as retrofits often require demolition and restoration of costly architectural finishes.
- Advanced structural analysis may significantly reduce the required retrofit scope.

Risk Level Legend - L: Low, M: Moderate, H: High, VH: Very High

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