Earthquake Mitigation Measures
Christopher Arnold, FAIA, RIBA

Course Objectives

- Understand the principles of seismic design for new buildings
- Know the principles of the evaluation and rehabilitation of existing buildings
- Know the philosophy of nonstructural seismic design
Resisting Ground Motion

EARTHQUAKE WAVES PRODUCE GROUND MOTION THAT PUSHES THE BUILDING BACK AND FORTH VERY RAPIDLY FOR A FEW SECONDS

STRUCTURES MUST BE DESIGNED THAT CAN RESIST THESE FORCES, USUALLY CALLED “LATERAL” FORCES AS DISTINCT FROM “VERTICAL” FORCES-THE BUILDING WEIGHT AND ITS CONTENTS

Vertical and Horizontal Elements

diaphragm (roof)
diaphragm (floor)
lateral resistance bracing
vertical support column
Lateral Force-Resistance Systems

THERE ARE THREE BASIC TYPES OF LATERAL FORCE-RESISTANCE SYSTEMS:

- SHEAR WALLS
- BRACED FRAMES
- MOMENT RESISTANT FRAMES

There are a number of variations of these basic types relating to materials and the ways in which the members are connected.
Lateral Force-Resistance Systems

SHEAR WALLS:
- SHEAR WALLS TRANSMIT SEISMIC FORCES FROM THE BUILDING DIAPHRAGMS (ROOF AND FLOORS) TO THE FOUNDATION
- TO BE EFFECTIVE, THEY RUN FROM THE TOP OF THE BUILDING TO THE FOUNDATION WITH A MINIMUM OF OPENINGS

Lateral Force-Resistance Systems

BRACED FRAMES:
- ACT LIKE SHEAR WALLS
- PROVIDE MORE PLANNING FREEDOM THAN SHEAR WALLS
- GENERALLY USED IN STEEL FRAME STRUCTURES
Lateral Force-Resistance Systems

MOMENT –RESISTANT FRAMES
FRAMES HAVE NO DIAGONAL BRACING

- IF WELL DESIGNED AND CONSTRUCTED
  ARE VERY COLLAPSE- RESTANT
- FORCES ARE RESISTED BY BENDING IN THE
  BEAMMS AND COLUMNS AND BY STRONG
  JOINTS

Seismic Design Examples

Commercial offices with exposed braced frame
Seismic Design Examples

Exposed braced frames

The earthquake as a metaphor: a small office building in Tokyo designed (by a New York architect) to represent earthquake motion
Innovative Seismic Systems

**BASE ISOLATION:**
Base isolation detaches the building superstructure from the ground by use of bearings, so that the full earthquake forces are not transmitted to the building.

**ENERGY DISSIPATING DEVICES:**
Devices to add damping in buildings (hydraulic, friction) are used to reduce the seismic loads imparted on a moment frame structure, reducing the drift and slowing down the shaking.
Innovative Seismic Systems

ECCENTRIC BRACED FRAMES:

- Concentric brace, liable to buckle and distort
- Eccentric brace, with link beams

Strength and Stiffness

STRENGTH IS MEASURED BY THE TOTAL FORCE A STRUCTURAL ELEMENT CAN TAKE WITHOUT FAILING.

STIFFNESS IS MEASURED BY DEFLECTION, THE EXTENT TO WHICH A MEMBER BENDS WHEN LOADED

CODES IMPOSE STRESS AND DEFLECTION LIMITS TO ENSURE SAFETY
Drift

THE TERM “DRIFT” IS USED IN SEISMIC DESIGN TO EXPRESS THE HORIZONTAL DEFLECTION OF A STRUCTURE. IT IS MEASURED AS THE DEFLECTION RELATED TO THE STORY HEIGHT.

Existing Buildings: Rehabilitation

THE MOST SIGNIFICANT SEISMIC RISK IS FROM OUR EXISTING OLDER BUILDING STOCK

- MANY OF THE SEISMICALLY PRONE AREAS OF THE COUNTRY HAVE ONLY RECENTLY ENFORCED SEISMIC DESIGN FOR NEW BUILDINGS
Existing Buildings: Rehabilitation

THE BASIC CONCEPTS OF SEISMIC DESIGN ARE THE SAME FOR NEW AND EXISTING BUILDINGS, BUT EXISTING BUILDINGS MUST BE EVALUATED TO DETERMINE THEIR LEVEL OF SEISMIC DEFICIENCY

Existing Buildings: Rehabilitation

PHILOSOPHY

- Existing buildings should be treated differently from new buildings
- Archaic systems and materials must be recognized and incorporated
- Seismic design forces are often taken smaller (commonly 75%) than those required for new buildings
Existing Buildings: Rehabilitation

CODE REQUIREMENTS FOR EXISTING BUILDINGS ARE ACTIVE AND PASSIVE:

- Active policies require that specified seismic criteria must be met in a certain time frame
- Passive policies require minimum seismic standards in existing buildings only when the owner “triggers” compliance
- Typically “triggers” are often not defined in the code

Existing Buildings: Rehabilitation

ACTIVE CODE PROVISIONS ARE JURISDICTIONAL POLICY DECISIONS TO REDUCE SEISMIC RISK

- CALIFORNIA (SB 547-1986) REQUIRED LOCAL JURISDICTIONS TO DEVELOP INVENTORIES OF THEIR UNREINFORCED MASONRY BUILDINGS
- CALIFORNIA (SB 1953-1994) REQUIRED ALL HOSPITALS TO BE CODE-COMPLIANT BY THE YEAR 2030
Existing Buildings: Rehabilitation

In 1985 FEMA initiated a program to provide education and technical guidelines for existing buildings. Some significant publications are:

- Rapid Visual Screening (RVS), FEMA 154.
- Seismic Evaluation of Existing Buildings, FEMA 178, and 310, and ASCE 31
- Benefit-Cost Model, FEMA 227

Typical costs of seismic rehabilitation, FEMA 156

NEHRP Guidelines for the Seismic Rehabilitation of Buildings, FEMA 273 and 356

Development of a Standardized Regional Loss Estimation Methodology (HAZUS)

Subsequent to the original development activity, HAZUS was expanded to include loss estimates for wind and flood.
The FEMA Model Building Types

THE FEMA PROGRAM DEVELOPED A SET OF 17 MODEL BUILDING TYPES SIGNIFICANT FOR SEISMIC EVALUATION AND DESIGN.

FEMA Building Type W1: Wood, light frame, small residence

The FEMA Model Building Types

FEMA Building Type 12 STEEL BRACED FRAMES

These buildings consist of a frame assembly of steel columns and beams, lateral forces are resisted by diagonal bracing or shear walls. Floor slabs are cast-in-place concrete slabs or metal deck and concrete. These buildings are typically used for buildings similar to Steel Moment Frames, although as more often low rise.

The 52A building type is similar but has floors and roof that act as flexible diaphragms such as wood, or unprotected metal deck. This is a relatively uncommon building type and is used mostly for smaller office or commercial buildings in which the fire ratings of concrete floor is not needed.
The FEMA Model Building Types

**FEMA Building Type 54** STEEL FRAMES with concrete shearwalls

*Punched* concrete exterior walls are an alternate shear wall configuration. Vertical shafts often constructed of concrete.

These buildings consist of an essentially complete frame assembly of steel beams and steel columns. The floors are concrete slabs or concrete filled over metal deck. The buildings feature a significant number of concrete walls effectively acting as shear walls, either as vertical transportation cores, isolated in selected bays, or as perimeter wall systems. The steel columns and beam system may act only to carry gravity loads or may have rigid connections to act as a moment frame. This building type is generally used as an alternate for steel moment or braced frame in similar circumstances. These buildings will usually be mid- or low-rise.

**FEMA Building Type C3** CONCRETE FRAMES with infill masonry shear walls

Interior partitions or shaft walls often built with clay tile. Concrete beams and columns or slabs and columns supporting slabs without gravity beams. Exterior walls, and possibly some interior walls, are constructed of unreinforced solid clay brick, concrete block, or hollow clay tile masonry infilling the space between columns and beams. Windows and doors may be present in the infill walls but to act effectively as shear resisting elements, the infill masonry must be constructed tightly against the columns and beams. The building type is similar to S5 but is more often used for industrial and warehouse occupancies.

The C3A building type is similar but has floors and roof that act as flexible diaphragms such as wood, or applied metal deck. This building type is often found except as one story industrial buildings.
The FEMA Model Building Types

EXAMPLE MODEL BUILDING TYPES:

Performance Damage Levels

FEMA HAS DEVELOPED DESCRIPTIONS OF DAMAGE LEVELS RELATED TO PERFORMANCE-BASED DESIGN (FEMA 356):

- OPERATIONAL
- IMMEDIATE OCCUPANCY
- LIFE SAFETY
- COLLAPSE PREVENTION
Rehabilitation Categories

THREE BASIC CATEGORIES OF REHABILITATION MEASURES

- MODIFICATION OF “GLOBAL” BEHAVIOR
- MODIFICATION OF “LOCAL” BEHAVIOR
- IMPROVING CONNECTIVITY

Other Rehabilitation Issues

SOME OTHER ISSUES RELATED TO REHABILITATION:

- INADEQUATE RECOGNITION OF DISRUPTION TO OCCUPANTS
- COLLATERAL REQUIRED WORK
Rehabilitation Examples

Steel braced frame inserted in a small commercial structure

Steel braced frame on exterior of building to avoid construction on the building interior

Steel moment frame for a commercial retrofit. The large (white) double frame is placed behind the original façade columns.

Steel moment frame (gray) placed within the recess
Rehabilitation Examples

New end wall (gray) that wraps around side of a large academic building to provide additional strength. The building was occupied during construction.

Historic Building Rehabilitation

HISTORIC BUILDINGS PRESENT SPECIAL PROBLEMS FOR REHABILITATION

- PRESERVATION GUIDELINES MAY LIMIT APPLICATION OF OTHERWISE APPROPRIATE SEISMIC UPGRADING
- GENERALLY, LOWER PERFORMANCE LEVELS ALLOWED FOR HISTORIC BUILDINGS
- SPECIAL METHODS NEEDED TO ACHIEVE HIGH PERFORMANCE
**Historic Building Examples**

Base isolation of San Francisco City Hall enabled high safety level without compromising preservation standards.

Original Stanford University quadrangle retrofitted over a 40-year period with evolving techniques. Earliest sections were gutted and new interior structure constructed. Later sections retrofitted with new interior shear walls leaving wood floors and heavy timber roofs intact.
Nonstructural Components

THE DESIGN APPROACH TO PROTECTING NONSTRUCTURAL COMPONENTS AND SYSTEMS

- ADEQUATE SUPPORT AGAINST ACCELERATION FORCES
- PROVIDING LATERAL BRACING TO SUSPENDED ELEMENTS
- ISOLATING COMPONENTS SUCH AS HEAVY CLADDING FROM THE STRUCTURE

Protection for emergency battery power supply
Nonstructural Components

NONSTRUCTURAL DESIGN EXAMPLES

Suspended ceiling bracing  Safety wires for lighting fixture

Partition bracing  Bracing for URM parapet
Nonstructural Components

Lateral bracing for ductwork (left) and bracing for suspended piping (right)

Nonstructural Components

Typical connection system for heavy concrete exterior cladding attached to steel structure.
Conclusions

THIS PRESENTATION HAS OUTLINED THE PRINCIPLES OF SEISMIC DESIGN FOR NEW BUILDINGS

THE PRINCIPLES OF SEISMIC DESIGN ARE THE SAME FOR NEW AND EXISTING BUILDINGS, BUT THE PROCEDURES ARE DIFFERENT

EXISTING BUILDINGS MUST BE EVALUATED TO DETERMINE THEIR SEISMIC DEFICIENCIES

PRINCIPLES OF DESIGN FOR THE PROTECTION OF NONSTRUCTURAL COMPONENTS IS OUTLINED