SECTION 7

Engineered Buildings—Field Investigation

Types of Data to Be Collected and Recorded

A field investigator looking at engineered buildings is expected to assess the type of damage to buildings. Not all buildings of similar type and size will respond in the same way to the same intensity of ground shaking, even if they all meet the building code. Damage must be documented for enough similar buildings in the same area of seismic intensity—both damaged and undamaged—so that both an average level of damage and the variety of the damage can be determined. It is important to note what did not fail, as well as what did. Whenever possible, get the drawings for the building. This is important in determining how closely design was followed in construction, for performing static and dynamic analyses, and for developing capacity/demand ratios.

In addition to identifying damage to individual structures, field investigators should make an overall building survey on a block-by-block basis. Mark out an area of 9 blocks or so, and make a detailed map of what types of buildings are/were in each block and how much damage each one suffered. Knowing that one unreinforced masonry building was damaged is not nearly as valuable as knowing that there were 50 unreinforced masonry buildings in an X-square-block area and that only one suffered damage. A square block chart is available at the end of this section.

Categories of Damage

The following damage categories can be applied to most buildings (investigation may indicate a need to modify these categories for some applications):

None	No damage.
Slight	Isolated nonstructural damage; repair costs less than 5 percent of market value of the building.
Moderate	Considerable nonstructural and slight structural damage; repair costs less than 25 percent of market value.
Severe	Considerable structural and extensive nonstructural damage; repair costs less than 50 percent of market value.
Total	More economical to demolish than repair.
Collapse	Structural collapse.

CHECKLIST

Engineered Buildings

Moment-Resisting Frames

In General

1. Observe behavior of frame as a whole, with particular attention to failure modes, signs of distress, loading variations, types of connections, and inelastic behavior.
2. Observe structural damage caused by deformation affecting adjacent elements.
3. Note damage to nonstructural elements such as infill walls, stairs, and partitions, as well as their influence on structural damage.

4. Note quality of welded, bolted, nailed, and riveted connections.

Reinforced Concrete Moment-Resisting Frames

1. Note general pattern of cracking and any evidence of brittle or ductile behavior. Was there axial load cracking (tensile or compressive)? Shear or diagonal tension cracks?
2. Column performance:
    a. Was tie installation less than current code?
    b. Note mid-height column performance with reduced ties.
    c. What was longitudinal bar splice performance? Offset bar or column performance?
3. Beam performance:
    a. Describe shear performance versus shear capacity.
    b. Was there distress at bar cutoffs or splices?
    c. What was performance of bottom bar anchorage at column?
4. Joint performance:
    a. What was the relative column/beam strength versus performance?
    b. What was joint performance relative to current code?
    c. Describe any joint eccentricity such as beam centerline offset from column centerline.
5. Where possible, determine reinforcing details such as ties, stirrups, and splices of longitudinal steel if plans are available or bars are visible.

Steel Moment-Resisting Frames

1. Note location of any buckling.
2. Determine relative strength of beams and columns.
3. Note performance of column splices and joints.
4. Did heavy jumbo sections perform differently than the rest of the structure?
5. What was performance at offsets or transfer girders?
6. Was there any tendency to develop a general plastic mode as indicated by permanent story drift?
7. Note any signs of failure in welds, including cracks, lamellar tearing, or laminations.
8. Observe plastic hinge development in columns and/or beams.
9. Examine moment connections. Note type, flexibility, stiffeners, and ductility.
10. How did column bases behave? Describe effects on anchor bolts, local column buckling, connection material, and grout.
11. Note performance of stairs and escalators, including any movement at connections and interaction with frame.

Steel-Braced Frames

1. Describe brace performance.
2. What are connection details?

3. What was KL/r?
4. Compare brace pattern versus performance (chevron, k-braced, etc.).
5. Detail signs of distress in eccentric braced frame performance.
6. What was connection performance?
7. Note any effects in offset braces or changes in stiffness.

Masonry Buildings

1. Describe wall performance versus reinforcing details.
2. Note pier/spandrel performance versus detail.
3. What was performance of floor-to-wall and roof-to-wall anchorage?
4. What was quality of workmanship on grout, mortar, etc.?
5. What was placement of reinforcing? Were there any omissions?

Concrete Buildings

Precast Concrete Buildings

1. Describe behavior of the overall structural system.
2. Evaluate joint performance versus detail.
3. Note performance of buildings that have no topping slab.
4. Describe performance of ties/lack of ties.
5. Note connections between elements, between elements and frames, and between element and foundations.
6. Did cracking occur due to vertical motions or reversals?
7. Determine quality of construction materials in concrete as indicated by movements at construction joints, rock pockets, and lack of bond or cover of reinforcing. Describe any obvious omissions. If plans are available, note any deviations from design in placement or reinforcement.

Prestressed/Post-Tensioned Concrete Buildings

1. Describe type of prestress system. Were tendons grouted?
2. What were effects of vertical acceleration (reverse shear cracks, etc.)?
3. How did anchorage perform?
4. Describe the post-tensioned slab-to-wall performance compared to details. Were there any slip planes?
5. Did cracking due to vertical motions or reversals occur?
6. Describe performance of joints between and within horizontal and vertical elements.

Wood Frame Buildings

1. Determine shear wall performance.
    a. Describe nailing patterns.
    b. What was performance of hold-downs?
    c. What was performance of sheathing materials?
2. Note distressed areas and whether or not proper connections existed.

3. Document distress of buildings relying on gypsum board sheathing or other systems, including plywood.
4. Describe effects of spaced sheathing on roof performance.
5. Document performance of masonry veneer or chimney versus anchorage details.
6. If drawings are available, detail how structure was designed versus how it was constructed. Pay particular attention to any failed connections.
7. Describe construction practices, including bolting, connection eccentricities, edge distances, bearing areas, and split or checked material.
8. Document influence of dry rot, pest infestation, or other deterioration.

Portable Buildings, Including Manufactured Housing

1. Note contruction materials (wood, steel, concrete, etc.)
2. Describe lateral load resisting system for the building superstructure (wood shearwall, steel frame).
3. Describe behavior of overall building superstructure.
4. Note if building had anchorage to the earth and if it moved from its original position.
5. Note type of foundation (stacked wood, masonry units, concrete, steel jackstands).
6. Describe connections between supports and building.
7. Note presence of any earthquake bracing systems and describe. Describe behavior of foundation system.
8. Did supports or bracing systems punch through floors, if failure occurred?
9. Note non-structural damage—ceiling tiles, ceiling grid system, light fixtures, window breakage, furnishings overturned, etc.
10. Did any light fixtures, HVAC units, or air diffusers fall to floor or hang significantly lower?
11. Describe damage at module lines.
12. Describe damage to utilities serving building, and whether damage brought about subsequent damage to building or site.

Shear Walls

In General

1. Look for post-construction modifications (such as holes cut for doorways) that lack adequate strengthening.
2. Note damage to other elements due to shear wall deformation.
3. Note number and placement.

Poured-in-Place Concrete Shear Walls

1. Determine layout and vertical continuity of shear walls in each story and pattern of damage.
2. Note pattern of concrete cracks and crushing in damaged areas.
3. Was there movement at construction joints? Note cracks and implied condition of keys and dowels if they cannot be directly observed.
4. Describe any discontinuity of materials at construction joints.

5. What was performance of joinery between shear walls, diaphragms, framing members, floors, and foundations?
6. Note the presence, continuity, and extent of opening reinforcement. What were types and locations of splicing (if plans are available or bars are visible)?
7. What was quality of concrete?
8. What was connection of infill shear walls to the frame? How did it perform?

Precast Concrete Shear Walls

In addition to the checklist for poured concrete:

1. Determine type and condition of inserts or other fasteners to the frame, between units, and to the diaphragms.
2. What is the system of load transfer among units? Between units and the structural frame? Between units and the foundation?
3. Determine development of diaphragm chords. Did edge members resist tension and compression?

Masonry Shear Walls

In addition to the checklist for poured concrete:

1. Note condition of mortar and grout, quality of construction, and type of bond.
2. Were concrete columns poured before or after masonry walls were constructed? Generally, columns poured afterward have exhibited better bond to masonry.
3. Document location of cracking (through mortar or units).
4. What was connection of foundations?

Wood Shear Walls

1. What type of sheathing was used? Blocked or unblocked plywood, straight or diagonal boards, metal straps?
2. Note type, pattern, spacing, and condition of sheathing fasteners.
3. Did buckling, splitting, or delamination of sheathing occur?
4. Describe anchorage and development of ties, struts, chords, or other members transferring concentrated loads among elements of the structure.
5. Describe connections to foundations.

Steel Shear Walls

1. Document type of wall (corrugated or stiffened sheet) and the connections between panels and to supports.
2. Did out-of-plane buckling or tension failures occur?
3. Describe shear transfer elements to frame and foundation.
4. Note shear transfer elements between units.

Base-Isolated Structures

1. Identify number, type and size of isolators and determine if back-stop (fail-safe) devices are used to limit horizontal and/or vertical displacements.
2. Determine maximum amount of movement in isolators (longitudinal and transverse components) and note any residual offsets. Does this vary throughout

building (due to possible torsional effects) or is it relatively constant (translation only)?

3. Note external condition of isolators, particularly if damaged or showing signs of distress.
4. Determine if back-stops engaged, and note any damage sustained.
5. Note condition of all utility lines (power, telephone, water, waste water, other) and architectural elements that cross or bridge isolator interface. Could these items have affected performance of building through accidental (unintended) restraint?
6. Note condition of clearance gap around building. Is there debris or any obstruction in gap which may have affected performance of building?

Refer to Section 9, Lifelines—Field Investigation, for checklists for utility lines.

Diaphragms

1. Describe overall diaphragm system and its performance, including any local buckling.
2. Did diaphragms deflect as anticipated?
3. Determine influence of torsion, discontinuities, reentrant corners, openings, and flexibility on performance of building.
4. Was transfer of force to walls adequate?
5. Did diaphragm provide lateral support to walls? Check condition of attachments. Did lateral diaphragm deformations contribute to wall damage?
6. What was method of transferring loads between diaphragms and other parts of resisting systems?
7. What was performance of chords? Drag struts? Continuity ties?
8. Note diaphragm webs at points of concentrated loading. How did they perform?
9. Determine relative behavior of plywood diaphragms with and without steel anchors connecting joists to walls.
10. Observe connections and performance of metal deck, fiberboard, pressed paper, cellular concrete, and precast concrete panels.
11. Note concrete topping slab on precast elements, particularly its bond to the elements and any evidence of slab buckling.
12. Observe performance of gypsum deck, its forms, and supporting members.
13. Were horizontal rod bracing systems adequate in terms of connections and rod yielding? Were rod ends upset or straight?
14. Document influence of deterioration.

Foundations

Refer to Section 6, Geotechnical Engineering—Field Investigation, for checklists: Soil-Structure Interaction and Settlement.

1. Document evidence of excessive foundation movement or failure such as:

a. Vertical movement: Punching or rotation of columns relative to footing or slab on grade, gaps under footings, rocking of footings, damage to grade beams, settlement of foundations, and tension cracks in piles.
b. Horizontal movement: Open cracks in basement slab, cracks and/or offsets in basement walls, open cracks between backfill and foundation walls, rotation of footings, and cracking or rupture of pile foundations.

2. What is condition of backfilling around structure? Describe soil type, water presence, cracks, subsidence, slumping, movement of attachments (stairs, walks, etc.), and any breakage of utility lines.
3. Note any surface ground ruptures in soils around building, especially those involving vertical or horizontal offset.
4. Did subsoil liquefaction (sand boils) occur?
5. Note basement walls and any horizontal cracks indicating high dynamic soil pressure.
6. Describe influence of batter piles on building behavior.
7. What is depth to water table?
8. Observe influence of deterioration.

Previously Repaired and Strengthened Buildings

1. Note existence and types of repair and/or strengthening details.
2. What code was used if the building was strengthened?
3. If repairs were of mortar and/or plastic adhesive, did failures occur in original materials, in repair materials, or in the bond between the two?
4. Was there evidence of unrepaired or inadequately repaired damage?
5. Is there evidence of parapet removal and/or anchoring?
6. If school building strengthening program was in place, was it effective?

Internal Utilities

Refer to Section 9, Lifelines—Field Investigation, for checklist.

Nonstructural Damage

Note also nonstructural damage to engineered buildings, such as damage to elevators, ceilings, light fixtures, windows, partitions, cabinets, equipment, vibration isolators, file cabinets, shelving, piping, veneer, etc.

Refer to Section 11, Architectural and Nonstructural Elements—Field Investigation, for applicable damage checklists.

Field Investigation Form—Engineered Buildings

Name of Investigator:________________________ Date: ___________

Building Information

Building type:

Address or location: When built:

Number of stories: Basement(s):

Vertical load system:

Lateral load system:

Condition of walls:

Condition of foundations:

Building configuration:

Evidence of torsional response:

Quality of construction:

Strong motion recording instruments present?

Site Information

Types of soils:

Site: Slope % Level:

Sand boils present?

Ground faulting present?

Earthquake Damage to Building

____

____

____

____

Total estimated loss:

Less than 10% 10–50% over 50%

Is building functional? Yes____ No____ If no, why not?

Status of utilities:

Casualties: Deaths Injuries Unknown

Estimated Modified Mercalli Intensity:

Does building warrant further investigation? Yes_____ No_____

If yes, why?

Nonstructural Damage

Note performance of elevators, ceilings, light fixtures, sprinklers, windows, partitions, cabinets, equipment, vibration isolators, file cabinets, shelving, piping, veneer, etc.

Refer to Section 8, Industrial Facilities—Field Investigation, for applicable damage checklists.

Miscellaneous Data

Architect: Engineer:

Are plans available? Yes No

Where?

Photos: Yes No Roll #: Frame(s) #:

Use back of this sheet for sketches and additional notes.

Square Block Damage Assessment Form

Structure types:

URM—Unreinforced masonry

WF—Wood frame

C—Concrete

MR—Moment-resisting

S—Steel

BI—Base Isolated

Categories of damage:

N—None

S—Slight

M—Moderate

V—Severe

T—Total

C—Collapse

Recommendations for Further Research on Engineered Buildings