4. POST-EARTHQUAKE EVALUATION

4.1 Scope

There are no modifications to the Guidelines or Commentary of Section 4.1 at this time.

4.2 Preliminary Evaluation

There are no modifications to the Guidelines or Commentary of Section 4.2 at this time.

4.2.1 Evaluation Process

Preliminary evaluation is the process of determining if a building should be subjected to detailed post-earthquake evaluations. Detailed evaluations should be performed for all buildings thought to have experienced strong ground motion, as indicated in Section 4.2.1.1 or for which the other indicators of Section 4.2.1.2 apply. Detailed post-earthquake evaluations include the entire process of determining if a building has experienced significant damage and if damage is found, determining appropriate strategies for occupancy, structural repair and/or modification. Except as indicated in Section 4.2.3, detailed evaluation should, as a minimum, include inspections of a representative sample of moment-resisting (and other type) connections within the building.

4.2.1.1 Ground Motion

There are no modifications to the Guidelines or Commentary of Section 4.2.1.1 at this time.

4.2.1.2 Additional Indicators

There are no modifications to the Guidelines or Commentary of Section 4.2.1.2 at this time.

4.2.2 Evaluation Schedule

There are no modifications to the Guidelines of Section 4.2.2 at this time.

Commentary: It is important to conduct post-earthquake evaluations as soon following the earthquake as is practical. Aftershock activity in the months immediately following an earthquake is likely to produce additional strong ground motion at the site of a damaged building. If there is adequate reason to assume that damage has occurred, then such damage should be expeditiously uncovered and repaired. However, since adequate resources for post-earthquake evaluation may be limited, a staggered schedule is presented, with those buildings having a greater likelihood of damage recommended for evaluation first.

Large magnitude earthquakes are often followed by large magnitude aftershocks. Therefore, it is particularly urgent that post-earthquake evaluations be performed expeditiously following such events. ~~*If insufficient resources are available in the affected region to perform the NDT tests recommended by the Guidelines of Chapter 5, it is recommended that visual inspection, in accordance with Section 5.2.2, proceed as soon as possible*~~*. If visual inspection reveals substantial damage, consideration should be given to vacating the building until either an adequate period of time has passed so as to make the likelihood of very large aftershocks relatively low (e.g. 4 weeks for magnitude 7 and lower, and 8 weeks for magnitudes above this), complete inspections and repairs are made, or a detailed evaluation indicates that the structure retains adequate structural stiffness and strength to resist additional strong ground shaking.* ~~*Preliminary visual inspections should not be used as an alternative to complete evaluation.*~~

~~*The table*~~ *Table 4-1relates the urgency for post-earthquake building evaluation to both the magnitude of the earthquake and the estimated peak ground acceleration experienced by the building site. This is because large magnitude events are more likely to have large magnitude aftershocks and because buildings that experienced stronger ground accelerations are more likely to have been damaged. Except in regions with extensive strong motion instrumentation, estimates of ground motion are quite subjective. Following major damaging earthquakes, government agencies usually produce ground motion maps showing projected acceleration contours. These maps should be used when available. When such maps are not available, ground motions can be estimated using any of several attenuation relationships that have been published.*

4.2.3 Connection Inspections

Except as indicated in Sections 4.2.3.1 and 4.2.3.2, below, ~~D~~detailed evaluations should include inspection of the building's moment-resisting connections in order to determine their condition. As a first pass, inspections may be limited to careful visual inspection of the joint of the beam bottom flange to the column. When such inspection reveals the presence of connection damage, a more thorough inspection of the damaged connection should be conducted. Since moment-resisting frame buildings commonly have many connections, inspections can be quite costly. Therefore, it shall be permissible to limit inspections to~~of~~ a representative sample of WSMF (and other) connections~~, except as indicated in Sections 4.2.3.1 and 4.2.3.2, below.~~ Section 4.3.3 provides three alternative approaches to selecting an appropriate sample of connections for inspection.

4.2.3.1 Analytical Evaluation

There are no modifications to the Guidelines or Commentary of Section 4.2.3.1 at this time.

4.2.3.2 Buildings with Enhanced Connections

There are no modifications to the Guidelines or Commentary of Section 4.2.3.2 at this time.

4.2.4 Previous Evaluations and Inspections

There are no modifications to the Guidelines or Commentary of Section 4.2.4 at this time.

4.3 Detailed Evaluation Procedure

Where detailed evaluation is recommended by Section 4.2, assessment of the post earthquake condition of a building, its ability to resist additional strong ground motion and other loads, and determination of appropriate occupancy, structural repair and/or modification strategies should be based on the results of a detailed inspection and assessment of the extent to which structural systems have been damaged.

In order to obtain complete data on a building's post-earthquake condition, it is necessary to inspect each of the building's moment-resisting frame elements and their connections. However, such extensive inspections could be very costly. As an alternative to that approach, this Section presents a series of procedures by which a representative sample of beam-column connections is selected and inspected. ~~This Section presents one approach for making such assessments.~~ In this approach, the results of the sample inspections are used to calculate a cumulative damage index, D, for the structure as well as the probability that if all of the building's connections had been inspected, the damage index at any floor of the structure ~~has~~ would have been found to exceed~~ed~~ a value of 1/3. General occupancy, structural repair and modification recommendations are made based upon the values calculated for these damage indices. In particular, a calculated damage index of 1/3 is used to indicate, in the absence of more detailed analyses, that a potentially hazardous condition may exist.

The structural engineer may use other procedures consistent with the principles of statistics and structural mechanics to determine the residual strength and stiffness of the structure in the as-damaged state and the acceptability of such characteristics relative to the criteria contained in the building code, or other rational criteria acceptable to the building official.

There are no modifications to the Commentary of Section 4.3 at this time.

4.3.1 Eight Step Evaluation Procedure

Post-earthquake evaluation should be carried out under the direct supervision of a structural engineer. The following eight-step procedure may be used to determine the condition of the structure and to develop occupancy, repair and modification strategies. Note that this procedure is written presuming that inspection is limited to a representative sample of the total number of connections present in the building. If all connections in the building are to be inspected, steps 1, 2, 4 and 6 may be omitted.

Step 1: The moment-resisting connections in the building are categorized into two or more "groups" (Section 4.3.2 and 4.4) comprised of connections expected to have similar probabilities of being damaged.

Complete steps 2 through 7 below, for each group of connections.

Step 2: Determine the minimum number of connections in each group that should be inspected and select the specific sample of connections to be inspected. (Section 4.3.3)

Step 3: Inspect the selected set of connections using the technical guidelines of Section 5.2. and determine connection damage indices, d_j, for each inspected connection (Section 4.3.4)

Step 4: If inspected connections are found to be seriously damaged, perform additional inspections of connections adjacent to the damaged connections. (Section 4.3.5)

Step 5: Determine the average damage index (d_{avg}) for connections in each group, and then the average damage index at a typical floor. (Section 4.3.6)

Step 6: Given the average damage index for connections in the group, determine the probability, P, that the connection damage index for any group, at a floor level, exceeds 1/3, and determine the maximum estimated damage index for any floor, D_{max}. (Section 4.3.7)

Step 7: Based on the calculated damage indices and statistics, determine appropriate occupancy, structural repair and modification strategies (Section 4.3.8). If deemed appropriate, the structural engineer may conduct detailed structural analyses of the building in the as-damaged state, to obtain improved understanding of its residual condition and to confirm that the recommended strategies are appropriate or to suggest alternative strategies.

Step 8: Report the results of the inspection and evaluation process to the building official and building owner. (Section 4.3.9)

Sections 4.3.2 through 4.3.9 indicate how these steps should be performed.

There are no modifications to the Commentary of Section 4.3.1 at this time.

4.3.2 Step 1—Categorize Connections by Groups

There are no modifications to the Guidelines or Commentary of Section 4.3.2 at this time.

4.3.3 Step 2—Select Samples of Connections for Inspection

There are no modifications to the Guidelines or Commentary of Section 4.3.3 at this time.

4.3.3.1 Method A - Random Selection

There are no modifications to the Guidelines or Commentary of Section 4.3.3.1 at this time.

4.3.3.2 Method B - Deterministic Selection

There are no modifications to the Guidelines or Commentary of Section 4.3.3.2 at this time.

4.3.3.3 Method C - Analytical Selection

There are no modifications to the Guidelines or Commentary of Section 4.3.3.3 at this time.

4.3.4 Step 3—Inspect the Selected Samples of Connections

There are no modifications to the Guidelines of Section 4.3.4 at this time.

~~Commentary: The sample size suggested for inspection in the methods of Section 4.3.3 are based on full inspection using both visual (Section 5.3.1) and NDT techniques (Section 5.3.2) at all connections in the sample. Other methods of selection and inspection may be used as provided in Section 4.3, with the approval of the building official. One such approach might be the visual-only inspection of the bottom girder flange to column connection, but with the inspection of a large fraction of the total connections in the group, possibly including all of them. If properly performed, such an inspection procedure would detect almost all instances of the most severe damage but would not detect weld defects (W1a), or root cracking (W1b), nor lamellar damage in columns (C5). The occurrence of a few of these conditions, randomly scattered through the building would not greatly affect the assessment of the building's post-earthquake condition, or the calculation of the damage index. However, if a large number of such defects were present in the building, this would be significant to the overall assessment. Therefore, such an inspection approach should probably include confirming NDT investigations of at least a representative sample of the total connections investigated. If within that sample, significant incidence of visually hidden damage is found, then full NDT investigations should be performed, as suggested by these Interim Guidelines. Similarly, if visual damage is found at the bottom flange, then complete connection inspection should be performed to determine if other types of damage are also present.~~

4.3.4.1 Damage Characterization

Characterize the observed damage at each of the inspected connections by assigning a connection damage index, d_j, obtained either from Table 4-3a or Table 4-3b. Table 4-3a presents damage indices for individual classes of damage and a rule for combining indices where a connection has more than one type of damage. Table 4-3b provides combined indices for the more common combinations of damage.

Table 4-3a - Connection Damage Indices

Type	Location	Description[1]	Index[2] d_j
G1	Girder	Buckled Flange	4
G2	Girder	Yielded Flange	1
G3	Girder	Top or Bottom Flange fracture in HAZ	8
G4	Girder	Top or Bottom Flange fracture outside HAZ	8
G5	Girder	Top and Bottom Flange fracture	10
G6	Girder	Yielding or Buckling of Web	4
G7	Girder	Fracture of Web	10
G8	Girder	Lateral-torsional Buckling	8
C1	Column	Incipient flange crack (detectable by UT)	4
C2	Column	Flange tear-out or divot	8
C3	Column	Full or partial flange crack outside HAZ	8
C4	Column	Full or partial flange crack in HAZ	8
C5	Column	Lamellar flange tearing	6
C6	Column	Buckled Flange	8
C7	Column	Fractured column splice	8
W1a	CJP weld	Minor root indication - thickness <3/16" or $t_f/4$; width < $b_f/4$	0~~1~~
W1b	CJP weld	Root indication - thickness > 3/16" or $t_f/4$ or width > $b_f/4$	0~~4~~
W2	CJP weld	Crack through weld metal thickness	8
W3	CJP weld	Fracture at girder interface	8
W4	CJP weld	Fracture at column interface	8
W5	CJP weld	Root indication—non-rejectable	0
S1a	Shear tab	Partial crack at weld to column (beam flanges sound)	4
S1b	Shear tab	Partial crack at weld to column (beam flange cracked)	8
S2a	Shear tab	Crack in Supplemental Weld (beam flanges sound)	1
S2b	Shear tab	Crack in Supplemental Weld (beam flange cracked)	8
S3	Shear tab	Fracture through tab at bolt holes	10
S4	Shear tab	Yielding or buckling of tab	6
S5	Shear tab	Damaged, or missing bolts[4]	6
S6	Shear tab	Full length fracture of weld to column	10
P1	Panel Zone	Fracture, buckle, or yield of continuity plate[3]	4
P2	Panel Zone	Fracture of continuity plate welds[3]	4
P3	Panel Zone	Yielding or ductile deformation of web[3]	1
P4	Panel Zone	Fracture of doubler plate welds[3]	4
P5	Panel Zone	Partial depth fracture in doubler plate[3]	4
P6	Panel Zone	Partial depth fracture in web[3]	8
P7	Panel Zone	Full (or near full) depth fracture in web or doubler plate[3]	8
P8	Panel Zone	Web buckling[3]	6
P9	Panel Zone	Fully severed column	10

Notes To Table 4-3a:

1. See Figures 3-2 through 3-6 for illustrations of these types of damage.
2. Where multiple damage types have occurred in a single connection, then:
    a. Sum the damage indices for all types of damage with d=1 and treat as one type. If multiple types still exist; then:

b. For two types of damage refer to Table 4-3b. If the combination is not present in Table 4-3b and the damage indices for both types are greater than or equal to 4, use 10 as the damage index for the connection. If one is less than 4, use the greater value as the damage index for the connection.
c. If three or more types of damage apply and at least one is greater than 4, use an index value of 10, otherwise use the greatest of the applicable individual indices.

3. Panel zone damage should be reflected in the damage index for all moment connections attached to the damaged panel zone within the assembly.
4. Missing or loose bolts may be a result of construction error rather than damage. The condition of the metal around the bolt holes, and the presence of fireproofing or other material in the holes can provide clues to this. Where it is determined that construction error is the cause, the condition should be corrected and a damage index of "0" assigned.

Table 4-3b - Connection Damage Indices for Common Damage Combinations[1]

Girder, Column or Weld Damage	Shear Tab Damage	Damage Index	Girder, Column or Weld Damage	Shear Tab Damage	Damage Index
G3 or G4	S1a	8	C5	S1a	6
	S1b	10		S1b	10
	S2a	8		S2a	6
	S2b	10		S2b	10
	S3	10		S3	10
	S4	10		S4	10
	S5	10		S5	10
	S6	10		S6	10
C2	S1a	8	W2, W3, or W4	S1a	8
	S1b	10		S1b	10
	S2a	8		S2a	8
	S2b	10		S2b	10
	S3	10		S3	10
	S4	10		S4	10
	S5	10		S5	10
	S6	10		S6	10
C3 or C4	S1a	8			
	S1b	10			
	S2a	8			
	S2b	10			
	S3	10			
	S4	10			
	S5	10			
	S6	10			

1. See Table 4-3a, footnote 2 for combinations other than those contained in this table.

More complete descriptions (including sketches) of the various types of damage are provided in Section 3.1. When the engineer can show by rational analysis that other values for the relative severities of damage are appropriate, these may be substituted for the damage indices provided in the tables. A full reporting of the basis for these different values should be provided to the building official, upon request.

Commentary: The connection damage indices provided in Table 4-3 (ranging from 0 to 10) represent judgmental estimates of the relative severities of this damage. An index of 0 indicates no damage and an index of 10 indicates very severe damage.

When initially developed, these connection damage indices were conceptualized as estimates of the connection's lost capacity to reliably participate in the building's lateral-force-resisting system in future earthquakes (with 0 indicating no loss of capacity and 10 indicating complete loss of capacity). However, due to the limited data available, no direct correlation between these damage indices and the actual residual strength and stiffness of a damaged connection was ever made. They do provide a convenient measure, however, of the extent of damage that various connections in a building have experienced.

When FEMA-267 was first published, weld root discontinuities, Type W1a and defects, type W1b, were classified as damage in Table 4-3a with damage indices of 1 and 4, respectively assigned. Recent evidence and investigations, however, suggest strongly that these W1 conditions are not likely to be damage, and also are difficult to reliably detect. As a result, with the publication of Interim Guidelines Advisory No. 2, the damage indices for these conditions has been reduced to a null value, consistent with classifying them as pre-existing conditions, rather than damage.

It should be noted that the reduced damage index associated with these conditions is not intended to indicate that these are not a concern with regard to future performance of the building. In particular, type W1b conditions can serve as ready initiators for the types of brittle fractures associated with the other damage types and connections having such conditions are more susceptible to future earthquake-induced damage than connections that do not have these conditions. Correction of these conditions should generally be considered an upgrade or modification, rather than a damage repair.

4.3.5 Step 4—Inspect Connections Adjacent to Damaged Connections

There are no modifications to the Guidelines or Commentary of Section 4.3.5 at this time.

4.3.6 Step 5—Determine Average Damage Index for Each Group

There are no modifications to the Guidelines or Commentary of Section 4.3.6 at this time.

4.3.7 Step 6—Determine the Probability that the Connections in a Group at a Floor Level Sustained Excessive Damage

There are no modifications to the Guidelines or Commentary of Section 4.3.7 at this time.

4.3.7.1 Some Connections in Group Not Inspected

There are no modifications to the Guidelines or Commentary of Section 4.3.7.1 at this time.

4.3.7.2 All Connections in Group Inspected

There are no modifications to the Guidelines or Commentary of Section 4.3.7.2 at this time.

4.3.8 Step 7—Determine Recommended Recovery Strategies for the Building

There are no modifications to the Guidelines or Commentary of Section 4.3.8 at this time.

4.3.9 Step 8 - Evaluation Report

There are no modifications to the Guidelines or Commentary of Section 4.3.9 at this time.

4.4 Alternative Group Selection for Torsional Response

There are no modifications to the Guidelines or Commentary of Section 4.4 at this time.

4.5 Qualified Independent Engineering Review

There are no modifications to the Guidelines or Commentary of Section 4.5 at this time.

4.5.1 Timing of Independent Review

There are no modifications to the Guidelines or Commentary of Section 4.5.1 at this time.

4.5.2 Qualifications and Terms of Employment

There are no modifications to the Guidelines or Commentary of Section 4.5.2 at this time.

4.5.3 Scope of Review

There are no modifications to the Guidelines or Commentary of Section 4.5.3 at this time.

4.5.4 Reports

There are no modifications to the Guidelines or Commentary of Section 4.5.4 at this time.

4.5.5 Responses and Corrective Actions

There are no modifications to the Guidelines or Commentary of Section 4.5.5 at this time.

4.5.6 Distribution of Reports

There are no modifications to the Guidelines or Commentary of Section 4.5.6 at this time.

4.5.7 Engineer of Record

There are no modifications to the Guidelines or Commentary of Section 4.5.7 at this time.

4.5.8 Resolution of Differences

There are no modifications to the Guidelines or Commentary of Section 4.5.8 at this time.