5. Seismic Upgrade

5.1 Scope

Seismic upgrade measures for steel components and elements of welded steel moment-frame (WSMF) structures are described in this chapter. Information needed for simplified and systematic upgrade of steel buildings is presented herein.

5.2 Codes and Standards

Table 5-1 indicates the general codes, standards, and guideline documents that are applicable to seismic upgrades for WSMF structures, and the extent to which they are applicable.

Table 5-1 Applicable Codes, Standards and Guideline Documents

Designation	Title	Applicability
FEMA-273	*NEHRP Guidelines for the Seismic Rehabilitation of Buildings*	Provides general performance-based guidelines, that are modified herein
FEMA-302	*NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*	Governs the detailing, materials and workmanship for new construction employed in upgrade design
AWS D1.1	*Structural Welding Code – Steel*	Governs the requirements for design, materials and workmanship for structural welding
AISC/LRFD	*Specification for the Design of Steel Structures*	Provides design requirements for bolting, welding, computation of member capacities, to the extent referenced herein
NIST/AISC (Gross, et al. 1999)	*Recommendations for Seismic Upgrade of Steel Structures*	Provides design procedures for specific types of connection upgrades, as referenced herein

Commentary: FEMA-273 provides guidelines for determining force and deformation demands for the design of rehabilitation systems for structures to meet specific performance objectives. As described in the commentary to Section 3.1 of this publication, FEMA-273 takes a somewhat different approach to the definition of performance objectives than do these Recommended Criteria. Also, FEMA-273 was published prior to much of the extensive research on WSMFs conducted under this project as well as research conducted by other organizations following the 1994 Northridge earthquake. These Recommended Criteria contain information that specifically updates the recommendations contained in FEMA-273, with regard to the upgrade (rehabilitation) of WSMF structures. FEMA-273 provides a more comprehensive treatment on other

building upgrade issues, including provision of procedures for rehabilitation of foundations, diaphragms and nonstructural components. The guidelines contained in these Recommended Criteria only address the upgrade of the steel frame itself. Refer to FEMA-273 for guidelines on the upgrade of these other systems.

Prior to performing an upgrade on any existing building it is advisable to discuss the proposed design criteria with the building official. Although the building code for new construction is not intended to apply to existing buildings, in some jurisdictions building officials require that upgrades be designed to conform to the strength requirements of the current prevailing code, or a fraction thereof. In 1991, language was introduced into the Uniform Building Code specifically permitting voluntary seismic upgrades of buildings without requiring complete conformance with the building code design criteria as long as it could be demonstrated that the following conditions did not occur:

- *The upgrade work does not create a structural irregularity or make an existing irregular condition more severe*
- *The upgrade work does not deliver more load to an existing element than it can withstand*
- *The upgrade work does not create an unsafe condition.*

Similar language has recently been introduced into the 2000 International Building Code. The upgrade criteria contained in these Recommended Criteria presume that the above permissive language is incorporated into the local building code or that the building official is willing to accept upgrades designed to criteria other than that contained in the building code.

Although these Recommended Criteria suggest that upgrades designed in accordance with the criteria need not comply with the strength and drift limits specified by the applicable building code for new construction, new work performed as part of the upgrade should conform to all materials, detailing, and workmanship criteria of the code, as supplemented by these Recommended Criteria.

5.3 Upgrade Objectives and Criteria

Two approaches are available for seismic upgrade of steel moment-frame structures – a Simplified approach and a Systematic approach. In the Simplified approach, modifications are made to individual moment-resisting connections to improve their ability to provide ductile inelastic behavior. No analyses or evaluations are performed as part of the design of these modifications to assess whether the overall structural system is capable of meeting specific performance objectives. In the Systematic approach, a complete evaluation of the performance capability of the structure is performed in order to verify the performance capability of the upgraded structure. Upgrades may include connection modifications, providing supplemental

lateral force resisting elements, such as braced frames or shear walls, or introducing response modification measures such as base isolation or energy dissipation devices.

Commentary: Throughout the period that steel moment-frame construction has been popular, the objective of the building code has been to provide buildings with the capability to resist the following: minor earthquakes without damage; moderate earthquakes without structural damage but with some nonstructural damage; major earthquakes with potentially significant structural and nonstructural damage, but not so much damage as to pose a significant threat to life safety; and the most severe levels of shaking anticipated to occur at a site without collapse. The ability of code-conforming structures actually to provide this performance has been mixed. In general, most code-conforming buildings have met the latter two goals well, but have experienced more damage at moderate levels of shaking than would seem to be desirable. To the extent that the code provisions that prevailed at the time a building was designed and constructed were adequate to meet these objectives, except that connections were more vulnerable to damage than originally believed, the use of the simplified upgrade approach, as described in these Recommended Criteria, will restore structures to the originally intended performance capability.

In the simplified upgrade approach, individual moment-resisting connections of the structure are upgraded to provide capacity for ductile behavior comparable to that presumed to exist at the time of the original design. The adequacy of other elements of the structure, including its basic configuration, strength, stiffness, and the compactness of sections are not evaluated and are not upgraded. As a result, no specific performance can be associated with structures that are upgraded using the simplified approach, unless a detailed performance evaluation is undertaken, in accordance with the procedures of Chapter 3.

In the systematic upgrade method a performance evaluation is performed as an inherent part of the design evaluation process. This permits upgrade work to be designed for specific performance objectives, which may be the same as, superior to, or less than those originally intended at the time of building design. Regardless of the selected objectives, the systematic approach will provide greater confidence in the ability of the structure to actually achieve the intended performance than does the simplified approach.

5.3.1 Simplified Upgrade

In simplified upgrade, vulnerable connections are upgraded, through a variety of measures, to provide more reliable performance of the individual connections. No overall evaluation of the performance of the structure, with upgrade modifications, is performed. Presuming that the structure, as originally designed and constructed, conformed to the applicable building code requirements, but incorporated fracture-vulnerable connections, this method of upgrade could be used to restore the structure to its originally intended performance capability.

In simplified upgrade, the individual beam-column connections of the existing lateral-force-resisting system for the welded steel moment-frame structure are modified to provide equivalent interstory drift capacity to that required for a new WSMF structure having the same structural system. Existing WSMF structures will typically have been designed, either as Ordinary Moment Frames (OMF) or Special Moment Frames (SMF). Chapter 6 of these *Recommended Criteria* provides design criteria for selected pre-qualified connection upgrades, that are accepted generically as being capable of providing the necessary drift angle capacity for either OMF service, SMF service, or both. Chapter 6 also provides project-specific qualification procedures that may be used to affirm that other connection upgrades provide the desired drift angle capacity.

Commentary: The intent of Simplified Upgrade is to reduce the susceptibility of moment-resisting beam-column connections detailed and constructed in accordance with typical pre-1994 practice to premature, brittle fracture damage. When selecting Simplified Upgrade it is inherently accepted that the susceptibility of such moment-resisting connections to brittle fracture damage is the only significant vulnerability of the structure and that mitigation of this vulnerability will result in a structure with acceptable performance characteristics, relative to those intended at the time of the original design. This may or may not actually be the case, and can be verified only by a detailed performance evaluation.

Unless original design documents are available, and indicate the design intent with regard to the structural system, it should be presumed that the original design intent for the structure was to be equivalent to an SMF. If design documents are available, these may identify the original intended structural system, as being either an SMF, an OMF or a Ductile Moment-Resisting Frame. The original design intent for structures indicated as Ductile Moment-Resisting Frames should be considered equivalent to that for SMF.

5.3.2 Systematic Upgrade

In systematic upgrade, a detailed performance evaluation of the structure is performed in its existing configuration and its ability to meet desired performance objectives is determined in accordance with the procedures of Chapter 3. If it is found that there is an inadequate level of confidence that the structure is capable of meeting the desired performance objectives, then structural modifications are performed to improve the probable performance and increase the level of confidence. These modifications could include connection improvement measures, such as those available for simplified rehabilitation, but could also address systemic issues such as the basic strength and stiffness of the structure, the presence of irregularities or other vulnerabilities. An iterative process is followed in which a performance evaluation of the building in accordance with Chapter 3 is performed assuming proposed modifications are in place, and if the desired confidence of achieving the performance objective is not indicated, additional modifications are performed.

Prior to performing a systematic seismic upgrade, one or more suitable performance objectives must be selected as the basis for design. Performance objectives should be selected in accordance with Section 3.2. A performance evaluation should be conducted of the structure, to determine a level of confidence associated with its ability to meet these performance objectives. If sufficient confidence is not attained, then upgrade modifications should be developed, either to reduce the response of the structure to earthquake ground shaking, such that acceptable confidence of achieving the desired performance is attained, or to increase the capacity of the structure to withstand earthquake response and provide acceptable confidence.

Commentary: Performance objectives, selected in accordance with Section 3.2 are not completely compatible with those selected in accordance with FEMA-273. In FEMA-273, a performance objective is defined as consisting of two parts – a desired performance level, of which there are three (Immediate Occupancy, Life Safety, and Collapse Prevention) and a desired ground shaking spectrum for which this performance level is not to be exceeded. In these guidelines, only two performance levels are defined (Immediate Occupancy and Collapse Prevention) and a level of confidence with regard to providing the desired performance for a given ground shaking hazard is developed.

The Immediate Occupancy level defined in these Recommended Criteria, is similar, but not identical, to the Immediate Occupancy level of FEMA-273. The Collapse Prevention level of these Recommended Criteria may be taken as equivalent to the Collapse Prevention level of FEMA-273. If it is desired to attain performance equivalent to the Life Safety level of FEMA-273, using these Recommended Criteria, this may be attained by using 75% of the acceptance criteria (e.g., for drift capacities, strength capacities) specified in these guidelines for Collapse Prevention.

To create performance objectives, using these Recommended Criteria, that are roughly equivalent to those contained in FEMA-273, it is necessary to associate a probability of exceedance, within a specified period (e.g., 50 years) with the response spectrum used to define the hazard under the FEMA-273 criteria. Upgrade designs that provide a 90% confidence level for the desired performance level based on global interstory drift, column compression and column splice tension and a 50% confidence level for local connection behavior at this probability may be deemed equivalent to the intended performance of FEMA-273.

The global interstory drift, capacities and resistance factors contained in Chapter 3 are based on typical, regular welded steel moment-frame (WSMF) configurations. When adding structural systems that affect the dynamic characteristics of the WSMF (e.g., braced frames or shear walls), these default factors are no longer valid. For such structural upgrades, the demand and resistance factors contained in Chapter 3 may be applied to the calculation of confidence relative to local connection, column compression and column splice

tension behavior. If the new lateral-force-resisting elements, for example, shear walls or braced frames, are designed in accordance with the comparable performance objectives of FEMA-273, they may be presumed to provide adequate confidence with regard to global building behavior. Alternatively, the detailed performance evaluation procedures of Appendix A may be used to confirm global behavior.

5.4 Upgrade Strategies

A systematic upgrade may be accomplished by any one or more of the following means, as required to obtain a structure that provides suitable confidence of capability to provide the desired performance:

- Connection modifications (Section 5.4.1)
- Removal or lessening of existing irregularities and discontinuities (Section 5.4.2)
- Global structural stiffening (Section 5.4.3)
- Global structural strengthening (Section 5.4.4)
- Mass reduction (Section 5.4.5)
- Seismic isolation (Section 5.4.6)
- Supplemental energy dissipation (section 5.4.7)

Commentary: A building's response to earthquake ground shaking results in the development of forces and deformations in the structure. In Chapter 3 of these Recommended Criteria, a procedure is defined for determining a level of confidence with regard to the ability of a structure to resist these forces and deformations with a defined probability of exceeding one or more performance levels. This confidence level is tied to the confidence parameter l calculated as the ratio of the factored demands $g g_a D$ to the factored capacity $f C$ to resist these demands. Values of the parameter l less than 1 indicate relatively high confidence, while values above 1 indicate progressively lower confidence.

If upon evaluation in accordance with Chapter 3, it is found that an inadequate level of confidence is obtained with regard to the ability of the structure to meet a desired performance objective, an upgrade can be performed to improve this confidence. To be effective, this upgrade must be able either to increase the capacity of the structure, and its various elements to resist the forces and displacements induced by earthquake response, or alternatively, the amount of force and deformation that a structure develops (the demands) must be reduced. As a third alternative, it may be possible to attain a higher level of confidence with regard to the probable performance of a structure by obtaining better information on the structure's construction and by performing more detailed and certain analyses of the structure's response to ground shaking. The

following sections provide information on alternative methods of modifying a structure to either increase its capacity or decrease the demands. Appendix A provides guidelines for improving confidence with regard to the structure's performance, through the use of more accurate analyses and evaluations.

5.4.1 Connection Modifications

Connection modifications are intended to upgrade the ability of individual connections to withstand expected rotational deformations with suitably low probability of unacceptable damage. This is judged to have been achieved when the ratio of factored drift angle capacity fC of the individual connections to withstand the factored demands gg_aD determined from an analytical evaluation of structural performance, results in an acceptable confidence index l. Connection upgrades accomplish this in two ways. First, the upgrades directly improve the interstory drift angle capacity of individual connections, resulting in a reduced value of λ for local behavior. Second, if connections are upgraded to Special-Moment-Frame-compatible detailing, the connections are converted from type 2 (brittle behavior) to type 1 (ductile behavior) permitting use of increased global interstory drift capacities and reduced demand factors. Chapter 3 provides more information on these issues. Chapter 6 presents a series of pre-qualified connection upgrades, together with design procedures, the limiting parameters for which these upgrades are pre-qualified, and the drift angle capacities of the upgraded connections. Chapter 6 also presents a project-specific connection qualification procedure for use in determining appropriate drift angle capacities and capacity factors, for connection upgrades that are not included in the prequalifications.

Commentary: Connection upgrades are a method of increasing the local capacity of the individual connections to withstand inelastic deformation demands, as measured by drift angle. These upgrades do not, in general, reduce the demands produced in a structure by earthquake response. Therefore, connection upgrades are not, by themselves, particularly effective in improving the performance of structures that experience excessive demands due to inadequate frame stiffness or strength, or inappropriate frame configuration. Such vulnerabilities are better addressed with other upgrade strategies. For many structures, it may be necessary both to reduce the demands produced by earthquake response as well as increase the capacity of the individual connections to resist this response. In such cases, connection upgrades should be performed together with other upgrade strategies.

Although connection upgrade strategies directly address the single most common vulnerability of steel moment-frame structures – connections prone to premature brittle fracture – these upgrades can be quite costly, particularly in large structures with many connections. In some cases, it may be more cost effective to adopt strategies intended to reduce demands on connections rather than to increase individual connection capacities.

Some connection upgrade details have the potential to grossly affect the inelastic response behavior of frames. For example, some connection upgrades may shift the zones of plastic deformation from the beam column-joint to the beam, column or panel zone. Such modifications of inelastic response behavior will alter the demands placed on the individual connections, as well as the frame as a whole, and should be considered when connection upgrade strategies are adopted.

Connection upgrades that improve the drift angle capacity of the connections compatible with Special Moment-Frame requirements for new construction also result in a decrease in uncertainty relative to probable frame behavior. This is because of the reduced propensity for brittle fracture of the connections. This reduction in uncertainty is reflected in the use of demand factors appropriate for Type 1 connections, as described in Chapter 3.

5.4.2 Lessening or Removal of Irregularities

Many existing welded steel moment-frame buildings incorporate one or more structural irregularities. Some irregularities, such as soft stories, weak stories, torsional irregularities, and discontinuous structural systems can result in poor structural performance. Typically this poor performance occurs due to the concentration of force and inelastic deformation demand in the area of the irregularity. Often, the structural elements in the area of the irregularity are incapable of withstanding these locally increased demands. Structural upgrades that remove or lessen these irregularities have the effect of decreasing this concentrated demand resulting in a more uniform distribution of deformation and energy dissipation throughout the structure.

A structural irregularity should not be considered to be a problem unless a structural performance evaluation, conducted in accordance with Chapter 3 of these *Recommended Criteria*, indicates that structural demands, e.g., interstory drift or column axial load, in the area of the irregularity are in excess of the acceptance criteria for the desired structural performance level. Where an undesirable irregularity exists, it can usually be eliminated or reduced through the local introduction of new structural elements or through strengthening and stiffening of existing elements. When such features are introduced, a re-evaluation of the entire structure should be performed to ensure that the measure will result in adequate performance and that some new irregularity or vulnerability has not been inadvertently introduced into the structure.

5.4.3 Global Structural Stiffening

Damage to both structural and nonstructural elements is closely related to the amount of deformation induced in a building by its response to ground shaking. Global structural stiffening is intended to directly reduce the amount of this lateral deformation through introduction of stiffening elements. Although reinforcement of connections often results in some structural stiffening, this is typically not a significant effect and is not by itself adequate to result in substantial reductions in lateral deformation. In order to have a noticeable effect on performance,

substantial stiffening is typically required. In some cases it may be possible to accomplish this by converting some beam-column connections that were not originally connected for moment-resistance, into moment-resisting connections. If this is done, care must be taken to ensure that the beams and columns are adequate for the stresses induced by this approach. The most effective way to increase the stiffness of a WSMF structure is to add braced frames and/or shear walls to the seismic force resisting system.

Although global stiffening is effective in reducing the amount of deformation induced in a structure due to its earthquake response, it also typically results in some increase in the level of forces delivered to the structure and its nonstructural components. When evaluating the performance of the upgraded structure, it is important to evaluate all elements, including those that were determined to be adequate prior to the upgrade, as the additional forces delivered to these elements by the stiffened structure may result in poorer performance than previously indicated in evaluations of the performance of the existing structure, without such upgrades.

FEMA-273 provides modeling guidance and acceptance criteria for bracing and shear wall elements used to structurally stiffen a steel moment-frame structure. Upgrades using this strategy shall be conducted by designing the upgrade elements using the guidelines of *FEMA-273*. The performance of WSMF elements of the structure, including connections, columns and column splices shall be evaluated using the procedures of Chapter 3. If the new stiffening elements have been designed in accordance with the guidelines of FEMA-273, it may be presumed that a 90% level of confidence with regard to global building behavior can be attained. If desired, the user may confirm the adequacy of global performance of the upgraded structure, using the procedures of Appendix A of this document to determine the global drift capacity.

5.4.4 Global Structural Strengthening

Typically, WSMF structures do not exhibit poor performance as a result of inadequate strength to resist lateral forces. Rather, they exhibit poor performance because they are excessively flexible, have excessive irregularities or have vulnerable details and connections. However, if a performance evaluation of a WSMF structure indicates inadequate performance due to a global lack of adequate ability to resist lateral forces, such as those produced by ground shaking, strengthening of the structure can be achieved by many of the same means used for structural stiffening, as indicated in Section 5.4.3. In addition, global strengthening can be achieved by cover plating members of the lateral-force-resisting system in order to provide them with additional strength. When global strengthening is performed, the building, including structural and nonstructural elements, is likely to experience greater forces. Therefore, when evaluating the performance of the upgraded structure, it is important to evaluate all elements, including those that were determined to be adequate prior to the upgrade, as the additional forces delivered to these elements by the stiffened structure may result in poorer performance than previously indicated in evaluations of the performance of the existing structure, without such upgrades.

FEMA-273 provides modeling guidance and acceptance criteria for bracing and shear wall elements used to structurally stiffen or strengthen a WSMF structure. Upgrades using this

strategy shall be conducted by designing the upgrade elements using the guidelines of *FEMA-273*. The performance of elements of the structure, including connections, columns and column splices shall be evaluated using the procedures of Chapter 3. If the new strengthening elements have been designed in accordance with the guidelines of *FEMA-273*, it may be presumed that a 90% level of confidence with regard to global building behavior can be attained. If desired, the user may confirm the adequacy of global performance of the upgraded structure, using the procedures of Appendix A to determine the global drift capacity.

> *Commentary: Since WSMF structures are anticipated to exhibit significant response within the inelastic range, it can be difficult to determine if the inability of a structure to provide adequate performance is a result of inadequate strength as opposed to stiffness. Generally, global structural strength is closely related to a structure's ability to provide Immediate Occupancy performance, while global stiffness is more closely related to Collapse Prevention performance. An inability of a structure to provide adequate confidence of achievement of Collapse Prevention performance will usually be most effectively mitigated through addition of structural stiffness, rather than strength. Similarly, an inability of a structure to provide adequate confidence of achievement of Immediate Occupancy performance can often best be addressed through addition of global structural strengthening.*

5.4.5 Mass Reduction

The reduction of mass in a structure can improve its performance in several ways. One effect of mass reduction is a decrease in the periods of vibration of the structure. Since buildings of decreased period generally exhibit lower deformation response than do buildings of longer period, this results in decreased deformation and damage. The seismic forces experienced by a structure are proportional to the acceleration induced by the earthquake and the structure's mass. By reducing the structure's mass it is possible to reduce directly the amount of seismic force induced in the structure, which also reduces the potential damage.

Methods of reducing the mass of a steel moment-frame structure can include: replacement of heavy exterior cladding systems with lighter systems; removal of unused equipment and storage loads; replacement of masonry partition walls with lighter systems; and removal of one or more stories. As with other upgrade techniques, a complete re-evaluation of the upgraded structure's performance should be conducted, following development of an upgrade alternative.

> *Commentary: The most beneficial effect of mass reduction as an upgrade strategy is that it leads to a shortening of the structural period, and a corresponding reduction in the spectral displacement demand on the structure, produced by typical earthquake ground motions. However, period is related to mass through a square root relationship. Thus, substantial reductions in mass are necessary to have a meaningful effect on lateral displacement demand.*

5.4.6 Seismic Isolation

Seismic isolation is a relatively new method of improving the seismic performance of an existing structure. Seismic isolation improves structural performance through two basic effects. First, it is used to significantly lengthen the period of the structure, potentially in combination with the introduction of significant damping. The combined effect of the change in the structure's period and the introduction of supplemental damping results in greatly reduced seismic inertial forces on the building. Isolation systems are also typically designed such that they are more flexible than the supported structure, such that most of the earthquake induced deformation and energy dissipation is accommodated within the isolation system, rather than being transmitted to the structure. The result is that the components of the isolation system experience very large deformation and energy dissipation demands, while the structure above the isolation system sees relatively low levels of seismic induced lateral forces and deformations, and therefore, low levels of damage.

Seismic isolation tends to be most effective as an upgrade measure when a relatively heavy and stiff superstructure is mounted on relatively flexible isolators. Typically the period of the isolated structure (including the isolation system) is on the order of 2 to 3 seconds. Isolation is most effective when the initial period of the non-isolated structure is on the order of 1 second or less. Since most steel moment-frame (WSMF) structures have periods in excess of 1 second, this will not often be an effective method of upgrading WSMF structures, unless it is combined with supplemental global stiffening of the structure.

FEMA-273 provides modeling guidelines and acceptance criteria for isolation systems for use in performance evaluation of isolated structures. Upgrades using this strategy shall be conducted by designing the upgrade elements using the guidelines of *FEMA-273*. The performance of elements of the structure shall then be evaluated using the procedures of Chapter 3, with the mathematical model modified to include the effects of the upgrade elements on structural response. For purposes of performance evaluation, the interstory drift of the isolation system shall be neglected. Global interstory drift demand shall be taken as the maximum of the interstory drifts predicted for the superstructure, considering the effects of the isolation system in the model.

> *Commentary: Performance evaluation conducted in accordance with the procedures of Chapter 3 uses maximum predicted interstory drift demand as one of the primary parameters evaluated. The primary effect of base isolation is to substantially reduce the interstory drift demand within the structure. The base isolation system should be designed in accordance with the procedures of FEMA-273. The performance of the superstructure should be evaluated using the procedures of Chapter 3 and taking the interstory drift demand as that predicted for the frame, in an analysis in which the base isolation system as well as the frame is modeled.*

5.4.7 Supplemental Energy Dissipation

The intent of seismic upgrades employing supplemental energy dissipation devices, also called dampers, is to reduce the amount of deformation induced in the structure during its response to ground shaking. In this respect, it is similar to upgrades accomplished through global structural stiffening. However, rather than introducing stiffening to a structure, this upgrade technique reduces deformation through the dissipation of energy within a series of devices that are introduced into the structure as part of the upgrade. The effect of this dissipated energy is to increase the structure's effective damping, and thereby, to reduce its lateral displacement response.

A number of different types of energy dissipation devices are commercially available. These include fluid-viscous dampers, visco-elastic dampers, friction dampers, and hysteretic dampers. Each of these devices has unique force-displacement-velocity relationships, and therefore affect the structure's response in a somewhat different manner.

The energy dissipated by a damping device is the integrated product of the amount of force the device exerts on the structure (or is exerted on the device by the structure) and the distance through which this force acts. In many ways, welded steel moment-frame structures are ideal candidates for upgrades employing energy dissipation devices because they are inherently flexible structures permitting damper elements to dissipate large amounts of energy at relatively low force levels. This is important because large damper forces can create large concentrated forces in the structure.

Energy dissipation devices are typically introduced into a structure as part of a braced frame, where the devices are either introduced in series with the braces in the frame, or actually serve as the braces in the frame. Upgrades using this strategy should be conducted by designing the upgrade elements using the guidelines of *FEMA-273*. The performance of elements of the structure should then be evaluated using the procedures of Chapter 3, with the mathematical model modified to include the effects of the upgrade elements on structural response.

5.5 As-Built Conditions

5.5.1 General

Prior to performing an upgrade design, sufficient information on the configuration and material properties of the existing structure must be obtained to permit a detailed evaluation, in accordance with Chapter 3. Refer to Chapter 2 for criteria on obtaining as-built information.

Quantification of in-place material properties and verification of the existing system configuration and condition are necessary to analyze or evaluate a building. Chapters 2 and 3 identify properties requiring consideration and provide criteria for their acquisition. Condition assessment is an important aspect of planning and executing seismic upgrade of an existing building. One of the most important steps in condition assessment is a visit to the building for visual inspection.

The extent of in-place materials testing and condition assessment that must be accomplished is related to availability and accuracy of construction and as-built records, the quality of materials used and construction performed, and the physical condition of the structure. Data such as the properties and grades of material used in component and connection fabrication may be effectively used to reduce the amount of in-place testing required. The design professional is encouraged to research and acquire all available records from original construction.

5.5.2 Material and Section Properties

Material and section properties of existing components shall be determined in accordance with the criteria outlined in Chapter 2.

5.6 Upgrade Components

New components, constructed as part of upgrades of existing WSMF structures shall conform to the requirements of this section.

5.6.1 Material Specifications

Structural steel should conform to the specifications and grades permitted by the building code, unless a project-specific qualification testing program is performed to demonstrate acceptable performance of alternative materials.

5.6.2 Material Strength Properties

The *AISC Seismic Provisions* (AISC, 1997) state:

> *When required by these provisions, the required strength of a connection or related member shall be determined from the Expected Yield Strength F_{ye} of the connected member, where*

$$F_{ye} = R_y F_y \tag{5-1}$$

The Provisions further state that *"R_y shall be taken as 1.5 for ASTM A36 and 1.3 for A572 Grade 42. For rolled shapes and bars of other grades of steel and for plates, R_y shall be taken as 1.1. Other values of R_y are permitted to be used if the value of F_{ye} is determined by testing that is conducted in accordance with the requirements for the specified grade of steel."*

ASTM has recently issued a new specification, A992, for structural steel shape. This specification is similar to the ASTM A572 specification for Grade 50 steels, except that more restrictive limits apply to the permissible variation in yield strength, the ratio of yield to tensile strength and certain other properties, than contained in ASTM A572. This material specification was specifically developed by the steel industry in response to concerns raised by structural engineers with regard to the large variations in properties inherent in the A572 specification, and the difficulties this presented with regard to design for inelastic behavior and seismic resistance. The A992 material will eventually become the recommended basic grade of steel for use in seismic force resisting systems. Since material has only recently been produced under this specification, statistical data on the actual variation of strength properties produced by the mills

is not currently available. Until such data does become available, use of the R_y values indicated for ASTM A572, Grade 50 is recommended.

5.6.3 Mathematical Modeling

The stiffness and strength of upgrade elements shall be included in the mathematical model using the same criteria provided for modeling of existing elements as outlined in Chapter 3.