INTERIM GUIDELINES:
Evaluation, Repair, Modification and Design of Steel Moment Frames

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SAC Program to Reduce Earthquake Hazards in Steel Moment Resisting Frame Structures

Foreword and Disclaimer

The purpose of this document is to provide engineers and building officials with guidance on engineering procedures for evaluation, repair, modification and design of welded steel moment frame structures, to reduce the risks associated with earthquake-induced damage. The recommendations were developed by practicing engineers based on professional judgment and experience and a preliminary program of laboratory, field and analytical research. This preliminary research, known as the SAC Phase 1 program, commenced in November, 1994 and continued through the publication of these Interim Guidelines. Independent review and guidance was provided by an advisory panel comprised of experts from industry, practice and academia. Every reasonable effort has been made to assure the efficacy of the Interim Guidelines contained herein. However, users are cautioned that research into the behavior of these structures is continuing. The results of this research may invalidate or suggest the need for modification of recommendations contained herein. **No warranty is offered with regard to the recommendations contained herein, either by the Federal Emergency Management Agency, the SAC Joint Venture, the individual joint venture partners, their directors, members or employees. These organizations and their employees do not assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any of the information, products or processes included in this publication. The reader is cautioned to carefully review the material presented herein.** Such information must be used together with sound engineering judgment when applied to specific engineering projects. These Interim Guidelines have been developed by the SAC Joint Venture with funding provided by the Federal Emergency Management Agency, under contract number EMW-95-K-4672.

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OVERVIEW

The Northridge Earthquake of January 17, 1994, dramatically demonstrated that the prequalified, welded beam-to-column moment connection used for Special Moment Resisting Frames is much more susceptible to damage than was previously thought. The stability of moment frame structures in earthquakes is dependent on the capacity of the beam-column connection to remain intact and to resist tendencies to rotate, induced by the swaying of the building. These connections were believed to be ductile and capable of withstanding repeated cycles of large inelastic deformation. Although many affected connections were not damaged, a wide spectrum of unexpected brittle connection damage did occur, ranging from minor cracking observable only by detailed nondestructive testing (NDT) to completely severed columns. The most commonly observed damage occurred at the welds of girder bottom flanges to columns. Complete brittle fractures of the girder flange to column connections occurred in some cases. While no casualties or collapses occurred as a result of these connection failures, and some welded steel moment frame (WSMF) buildings were not damaged, the incidence of damage was sufficiently high in regions of strong motion to cause wide-spread concern by structural engineers and building officials.

No comprehensive tabulation is yet available to determine how many steel buildings were damaged in the Northridge Earthquake. More than 100 damaged buildings have been identified so far, including hospitals and other health care facilities, government, civic and private offices, cultural facilities, residential structures, and commercial and industrial buildings. The effect of these observations has been a loss of confidence in the procedures used in the past to design and construct welded connections in steel moment frames, and a concern that structures incorporating these connections may not be adequately safe.

It must be understood that the structural engineering community was surprised by the performance of these modern, code conforming structures. Prior to the discovery of this damage, many thought that WSMF structures were nearly invulnerable to earthquake damage. The unexpected brittle fracturing and attendant loss of connection strength resulted in serious degradation of the overall lateral-load-resisting capability of some affected buildings. Further, the ability of existing WSMF buildings to withstand earthquake-induced ground motion is now understood to be significantly less than that previously assumed. Research conducted to date has identified some, but probably not all, of the factors leading to this observed unsatisfactory behavior. At the same time, this research has indicated methods that can be used to improve the ability of these critical connections to more reliably withstand multiple, large, inelastic cycles. These include alterations in the basic design approach as well as improved practices for specification and control of materials and workmanship.

While the work is not yet complete, and future research is likely to provide both more reliable and more economical methods of improving the performance of these structures, the current investigations have led to many design and retrofit measures that can be used today to provide more reliable and consistent performance of these buildings than occurred in the Northridge

Earthquake. These are presented in these Interim Guidelines. They should not, however, be viewed as the only way of achieving these results, and the exercise of independent engineering judgment and alternative rational analytical approaches should be considered. It is anticipated that additional studies, planned by SAC and others, will lead to further improvements in our understanding of the problems, ability to predict probable earthquake performance and methods to design and construct more reliable structures.

There are many complex issues involved in the evaluation, repair, modification and design of WSMF buildings for reliable earthquake performance. These include considerations of metallurgy, welding, fracture mechanics, systems behavior, and basic issues related to fabrication and erection practice. Much remains to be learned in each of these areas. Engineers not familiar with the issues involved are cautioned to obtain qualified advice and third party review when contemplating design decisions that represent significant departures from these Interim Guidelines.

The current judgment given in these Interim Guidelines is that the historic practices used for the design and construction of WSMF connections do not provide adequate levels of building reliability and safety and should not continue to be used in the construction of new buildings intended to resist earthquake ground shaking through inelastic behavior. The risk to public safety associated with the continued use of existing WSMF buildings is probably no greater than that associated with many other types of existing buildings with known seismic vulnerabilities, which are not currently the subject of mandatory seismic rehabilitation programs. The earthquake risk of WSMF buildings, in general, may be evaluated in accordance with the following general principles:

1. The historic practices and designs used for WSMF connections are no longer appropriate for design and construction of new steel buildings likely to experience large inelastic demands from earthquakes. Until research is completed, and better information becomes available, the procedures contained in these Interim Guidelines for the design of new buildings should be used in their place. The use of alternative systems, including bolted construction, braced construction, and moment-resisting frames incorporating partially restrained (PR) joints could also be considered, but are not directly addressed by these Interim Guidelines.

2. As a class, existing undamaged WSMF buildings appear to have a lower risk of collapse than many other types of buildings with known seismic vulnerabilities, the performance of which is currently implicitly accepted. Consequently, mandated or emergency programs to upgrade the performance of these buildings does not appear necessary to achieve levels of life safety protection currently tolerated by society. However, the risk of collapse is definitely greater than previously thought. Individual owners should be made aware of the increased level of seismic risk and encouraged to perform modifications to provide more reliable seismic performance, particularly in building housing many persons, or in critical occupancies.

3. Following strong earthquake-induced ground shaking, WSMF buildings incorporating the vulnerable welded moment-resisting connections should be subjected to rigorous evaluations to determine the extent and implications of any damage sustained. These Interim Guidelines may be used to determine which buildings should be evaluated, and for developing an appropriate program to perform such evaluations.

4. Structural repair and modification programs for damaged WSMF buildings should consider the seismic risk inherent in the building including the local seismicity, site geologic conditions, the building's individual construction characteristics, intended occupancy and the costs associated with alternative actions. The Interim Guidelines provided in this document for repair can restore a building's pre-earthquake seismic resistance, but not significantly improve its original levels of safety or reduce the inherent seismic risk. The Interim Guidelines provided in this document for structural modification (upgrading) can be used both to improve building safety and reduce seismic risk. Except in those cases where regulation sets minimum acceptable standards for repair, the ultimate responsibility for deciding whether a building should be modified for improved performance lies with the building owner. It is the structural engineer's responsibility to provide the owner with sufficient information upon which to base a decision. The following may be considered by engineers to provide such information:

    a) When a WSMF has experienced damage to only a few of its moment-resisting connections this damage should be repaired in an expeditious manner. Repair to the original configuration, with proper materials and workmanship, will essentially restore the structure's original earthquake-resisting capacity. However, it will not result in any significant improvement in the building's future performance. The fact that the building experienced only light damage should not be considered a demonstration that the building has a high degree of earthquake resistance and in future earthquakes either more or less damage may be experienced, depending on the particular characteristics of the event.

       Connections which have been damaged can be economically modified at the same time that repairs are made. However, in buildings where damage is limited, modification of the few damaged connections will not result in any significant improvement in the future earthquake performance of the building. Modification of connections throughout the structure, or provision of an alternative lateral force resisting system should be considered as a method of substantially improving probable building performance; however, this will entail a significant cost premium over the basic repair project.

    b) When a WSMF has experienced damage to a significant percentage of its moment-resisting connections (on the order of 25% in any direction of resistance), in addition to repair, consideration should be given to modifying the configuration of the individual damaged connections and possibly some or all of the undamaged connections to provide improved performance in the future. Modification of only some connections, and not others, may cause an increase in vulnerability, due to unbalanced concentrations of stiffness and strength. Therefore, such partial modifications should be made with due consideration of the effect on overall system behavior. Repair and/or modification should be completed expeditiously by structural engineers who are experienced in the design of WSMF buildings and understand the features which caused the observed damage.

c) When a WSMF building has had many seriously damaged connections (on the order of 50% in direction of resistance), owners should be informed that this damage may have highlighted basic deficiencies in the existing structural system, or a geologic feature which unusually amplifies site motion. In such cases the existing system should be both repaired and modified to provide an acceptably reliable structural system. Modifications may consist either of local reinforcement of individual connections and/or alteration of the structure's basic lateral-force-resisting system. Such modifications could include addition of braced frames, shear walls, energy dissipation devices, base isolation and similar measures.

These principles are for regular buildings that have good characteristics of design, materials, and construction workmanship. Buildings with clear and apparent seismic deficiencies pose substantial life safety hazards regardless of the type of structural system employed, or material type. Such deficiencies include incomplete load paths, incompatible structural systems, irregular configurations such as soft or weak stories or torsional irregularity, and improper construction practices. Any such deficiencies found in a WSMF should be corrected.

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