

Guide for Strengthening and Repairing Existing Structures



American Welding Society



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An American National Standard

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American National Standards Institute
July 1, 2009

Guide for Strengthening and Repairing Existing Structures

1st Edition

Prepared by the
American Welding Society (AWS) D1 Structural Welding Committee

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This guide provides information on strengthening and repairing existing structures. Included are sections on weldability, evaluation of existing welds, testing and sampling, heat straightening, and damage repair.



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Foreword

This foreword is not part of [AWS D1.7/D1.7M:2010](#), *Guide for Strengthening and Repairing Existing Structures*, but is included for informational purposes only.

This guide has been developed to assist in the task of strengthening and repairing existing structures. The guide includes information to assist both Engineers and Contractors in order to provide general direction and guidance on weld repairs, weld strengthening, and other procedures to correct challenging issues faced while dealing with existing structures.

Informative Annexes. These annexes are not part of this guide but are provided to clarify the guide's recommendations by showing examples, providing information, or suggesting alternative good practices.

Errata. It is the Structural Welding Committee's Policy that all errata should be made available to users of the code. Therefore, any significant errata will be published in the Society News Section of the *Welding Journal* and posted on the AWS web site at: <http://www.aws.org/technical/d1/>.

Suggestions. Your comments for improving [AWS D1.7/D1.7M:2010](#), *Guide for Strengthening and Repairing Existing Structures* are welcome. Submit comments to the Managing Director, Technical Services Division, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126; telephone (305) 443-9353; fax (305) 443-5951; e-mail info@aws.org; or via the AWS web site <<http://www.aws.org>>.

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Guide for Strengthening and Repairing Existing Structures

1. General Provisions

1.1 Scope. This document contains basic information pertinent to the welded strengthening and repair of existing steel structures. The information contained in this guide is intended for both Engineers and Contractors with the purpose of providing direction and guidance to perform weld repairs, weld strengthening, and other weld procedures to correct problematic issues with existing structures. This guide contains background information that will be useful to the Engineer who is obligated under AWS D1.1/D1.1M:2008 Clause 8 to provide a comprehensive plan to address projects that involve strengthening and repairing of steel structures. The approach to the strengthening and repairing of these materials is to be developed using the information provided herein.

This guide is intended to apply to the strengthening and repair of existing structures made of the following materials:

- (1) Steel with a minimum specified yield strength of 100 ksi [690 MPa] or less
- (2) Cast iron
- (3) Wrought iron

Strengthening or repairing an existing structure includes modifications to meet new serviceability or load requirements as well as corrections made to repair conditions unsuitable for future use specified by the Engineer. The Engineer should prepare a contract for the work including, but not limited to, design, workmanship, inspection, acceptance criteria, and documentation. Except as modified in this clause, provisions of this guide should apply to the strengthening and repair of existing structures, including heat straightening of distorted members.

1.2 Limitations. This guide is intended to assist in the evaluation of existing structural elements and the development of appropriate procedures for repairing those elements. It does not provide exhaustive coverage of any specific topic.

This guide is intended to apply to the strengthening and repair of existing buildings and other structural systems. It is not intended to apply to:

- (1) Structures made of steels less than 1/8 in [3 mm] thick
- (2) Pressure vessels and pressure piping
- (3) Structures made of materials other than those listed under the scope
- (4) Seismic upgrades
- (5) New construction

Whereas this guide is not intended to apply the application outside the scope, the principles contained in this guide may be applied to other materials and applications. The Engineer is advised to use caution and engineering judgment for application outside the scope of this guide.

More importantly, it is critical to state here that this document does not provide detailed specific procedures and direction to correct any specific strengthening or repair operation regardless of how common or standard the procedure may be. Instead, information supplied herein as well as that material referenced in Annex A is intended to provide users with an overall approach to weld modifications as they pertain to: strengthening and repair; technical resources to develop

appropriate detailed specific strengthening and repair contract documents or procedures; summarized guidance on typical weldability of common metals; summarized guidance for testing the serviceability of the procedures and a summary of common procedures and approaches that are intended to be modified for the specific procedure.

1.3 Approval. All references to “approval” should be interpreted to mean approval by the Engineer.

1.4 Safety Precautions. Safety and health issues and concerns are beyond the scope of this standard and therefore are not fully addressed herein. However, in addition to the material supplied in subsequent chapters of this document, pertinent information can be found in the following standalone documents: ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal, state, and local regulations. Other pertinent information can be found in the manufacturer’s safety literature on equipment and materials. These documents should be referred to and followed as required.

NOTE: This guide may involve hazardous materials, operations, and equipment. The document does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices. The user should determine the applicability of any regulatory limitations prior to use.

1.5 Standard Units of Measure. This guide makes use of both U.S. Customary Units and the International System of Units (SI). The latter are shown within brackets ([]) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system should be used independently of the other.

2. Normative References

The standards listed below contain provisions, which, through reference in this text, constitute mandatory provisions of this AWS guide. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

A list of informative documents referenced in this guide is included in Annex A. There are numerous documents that exist and are available that cover repairs to existing structures published by AISC, AASHTO, and AREMA. These and other documents will be referenced in Annex A and are all intended to provide a guide for successful strengthening and repair.

American Welding Society (AWS) standards¹:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

3. Terms and Definitions

AWS A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document.

Engineer. The “Engineer” is the duly designated individual who represents the Owner on all matters within the scope of the guide.

Contractor. The “Contractor” is any company, or that individual representing a company, responsible for the manufacture, preparation and/or installation of items, in conformance with the provisions of this guide.

Inspector. The “Inspector” shall be defined as the duly designated person who acts for, and in behalf of, the Contractor or the Engineer on all inspection and quality matters within the scope of the contract documents, any governing code, or as specified by the Engineer.

Owner. “Owner” is the organization (private or public), the individual or company that exercises legal ownership of the final product or structural assembly.

¹ ANSI Z49.1 and AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

4. Weldability

4.1 Scope

This clause addresses the weldability of structural steels and older steels and irons used in steel construction; provides guidance on the welding of these metals, including selection of filler metals, welding techniques, and welding procedures; and offers other information useful to designers, welding engineers, and Contractors. It is expected that other D1 documents will be a major reference to support the material presented in this clause. Documents and guides found in Clause 2 Normative References and Annex A Informative References will also support examining the weldability of materials covered by this document.

4.2 Introduction

AWS A3.0:2001 defines weldability as:

The capacity of material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service.

Strengthening and repair present numerous challenges to both Engineers and those performing the work. Often, one of the first tasks is to determine if the material is weldable using conventional welding procedures and techniques. If records of the original construction exist, they should be reviewed to determine base metal type and properties. Mechanical and/or compositional tests may be necessary to identify the material, determine its composition, and evaluate its weldability. Older structural steels and other materials (cast steel, iron, etc.) may require the use of welding procedures that are more demanding than those for new construction and newer materials. The access and positions available for performing the work may be less than optimal or desirable. Also, for the most part, structures that were constructed by welding regardless of age are suitable for weld repair now. Materials should always be identified to assure chemical compositions acceptable for the project needs.

Most steels are weldable but the composition, strength, and original method of manufacture can greatly affect the materials, procedures, and techniques necessary to accomplish the required operations. Metals are considered to have good weldability if, when used in properly designed and detailed connections, the following are achieved:

- (1) Welding can be accomplished with common, welding processes (SMAW, FCAW, GMAW except GMAW-S, and SAW).
- (2) The resulting joint has minimal risk of cracking due to poor fabrication or other quality problems.
- (3) The welded joint assembly can provide the required structural and mechanical properties in both the weld and adjacent base metal without the use of stress relief heat treatment, postweld heat treatment, or other special procedural controls.

AWS D1.1/D1.1M:2008 and AASHTO/AWS D1.5M/D1.5:2008 list specific weldable grades of steel used in structural applications, both prequalified and those that require qualification testing. Steels not listed in current or previous versions of AWS D1 documents warrant consideration to determine weldability. Structural steels produced to current ASTM specifications generally provide limits in composition, strength, thickness, production method, and other factors that affect weldability. Other ASTM steels, including unlisted hollow structural sections and unlisted sheet steels, do not contain all the limits necessary to ensure good weldability without special considerations.

A metal with poor weldability may be successfully welded with the use of appropriate joint design, filler metals and welding procedures, including preheat and possibly postheat. If these variables are not carefully selected and controlled, the weld, heat-affected zone (HAZ), and/or base metal may crack or contain other significant discontinuities; the mechanical properties of the weld and HAZ may fail to provide the necessary strength, ductility, or notch toughness to perform adequately in service.

The properties of steel are affected by the heating and subsequent cooling from the welding operation. Cooling the weld and HAZ too rapidly may result in a product low in ductility and notch toughness, leading to brittleness or cracking. Extremely slow cooling may lower yield and/or tensile strength. As welds cool, they create shrinkage stresses and strains that approach yield, so ductility and toughness are needed, particularly if stress concentrations from weld discontinuities, material defects, geometric transitions, and notches are present. Material composition, grain size, thickness effects, and other factors affect ductility and notch toughness. Overheating (in terms of both peak temperature and duration) may also be detrimental, particularly for Thermomechanically Controlled Processing (TMCP), Quenched and Self-Tempered (QST), Quenched and Tempered (Q&T), or micro-alloyed steels.

4.3 Structural Metals

4.3.1 Historic Steels. In the 1800s, wrought iron was the predominant structural metal used for the construction of buildings and bridges. Cast iron was also commonly used for compression members such as columns as well as connection material. The use of steel became more common near the end of this time period, with structural steel becoming available starting in the 1880s. Prior to about 1910, there was little standardization in the industry. Each steel manufacturer adhered to their own standards. This resulted in steel with a wide variety of chemical and mechanical properties, some with good weldability, some with poor weldability.

From approximately 1900 through 1939, a medium carbon steel designated ASTM A 9 was predominantly used for buildings. For bridges, ASTM A 7 was used. In 1939 these two standards were combined into ASTM A 7, and this steel continued in use until 1966. Riveting was the dominant method of connecting material, which limited the need for weldable material. ASTM A 7 and ASTM A 9 were generally accepted as weldable steel, but both had a wider range of carbon content and fewer limits on other alloys and undesirable elements than permitted by ASTM A 36, their eventual successor. ASTM A 373 steel, an interim steel specification before the adoption of ASTM A 36 in 1962, provided better assurance of good weldability than ASTM A 7. Electrodes in the E60 classes were routinely used for ASTM A 7 and ASTM A 9 steels, and E70 class electrodes came into use in the early 1960s.

The American Institute of Steel Construction Design Guide 15, *Rehabilitation and Retrofit Guide, a Reference for Historic Shapes and Specifications* is a helpful tool in investigating and identifying old steel sections, structural design properties, and applicable standards. By determining the member size, it may be possible to identify the manufacturer and the approximate time of production, which in turn may provide guidance regarding the weldability of the steel. It also provides the allowable design stresses permitted during various time periods, assisting one in determining the filler metal strength requirements for repairs.

4.3.2 Structural Steels. Several methods may be used to identify existing steels to determine chemistry and mechanical properties. These are presented in Clause 4.4. A metallurgical test report can be obtained from small sample chips or drillings that provide the chemical analysis of the steel. This, in turn, can be used to establish the weldability using the principles of carbon equivalency and also cite particular concerns for potential welding problems from high levels of particular elements.

When welding procedures are developed for older steels, it may be helpful and more economical to develop the procedures based upon actual composition, rather than the maximum compositional limits permitted for the particular steel grade being welded. When this approach is used, a sufficient number of tests should be conducted to determine the probable composition of members and connection materials that are not specifically tested.

4.3.3 Classification of Steels. Steels have been commonly categorized based upon the composition of the steel. First, using the carbon content; second, by the addition of designated alloys of given percentages; and third, by special methods of production. Common terms for steels that have been or are used for structural applications are:

- (1) Low carbon steels

- (2) Medium carbon steels
- (3) High strength, low alloy (HSLA) steels
- (4) Thermomechanically Controlled Process (TMCP) steels
- (5) Quenched and Tempered (Q&T) steels
- (6) Quenched and Self-Tempered (QST) steels

Other steels, such as stainless steels, may be used for limited structural applications. Their use is not addressed in this document. Recommended D1 documents that may be used to establish welding requirements include [AWS D1.1/D1.1M, Structural Welding Code—Steel](#), [AWS D1.2/D1.2M, Structural Welding Code—Aluminum](#), [AWS D1.3/D1.3M, Structural Welding Code—Sheet Steel](#), [AWS D1.4/D1.4M, Structural Welding Code—Reinforcing Steel](#), [AASHTO/AWS D1.5M/D1.5, Bridge Welding Code](#), [AWS D1.6/D1.6M, Structural Welding Code—Stainless Steel](#), [AWS D1.8/D1.8M, Structural Welding Code—Seismic Supplement](#), and [AWS D1.9, Structural Welding Code—Titanium](#).

4.3.3.1 Low Carbon Steels. Low carbon steels contain less than 0.30% carbon. These may be welded without significant difficulty provided the steel temperature is above 32°F [0°C], and if the material is relatively thin, 3/4 in [18 mm] or less. Lower steel temperatures and thicker sections warrant the use of preheat, low-hydrogen electrodes, or both. It should be noted, however, that preheat and interpass temperature maintenance needs to be considered regardless of thickness only that in some cases ambient air temperature may be sufficient. High levels of other elements such as sulfur, other alloys, and *tramp* elements can affect weldability and should be considered. Sulfur is particularly common in older steels.

4.3.3.2 Medium Carbon Steels. Medium carbon steels contain between 0.30% and 0.60% carbon. They were used where high strength and high notch toughness were desired. The higher carbon level increased the effectiveness of hardening and tempering. Some alloying elements may have been added to the composition to improve hardenability. The range in carbon content from 0.30% to 0.60% creates a wide range of mechanical properties and weldability. Steels at the lower portion of the range of carbon content, near 0.30%, have good weldability and may be welded using standard welding procedures and techniques. Steels at the upper portion of the range of carbon content, near 0.60%, may form very hard HAZs, as high as Rockwell C 63, and significant martensite, unless special welding procedures are used. With low ductility, the HAZ is susceptible to cracking upon cooling to ambient temperature. With low notch toughness, there is a greater risk of cracking in service if subjected to impact loads. Preheating the steel and/or the use of controlled cooling or postheating reduces the cooling rate of the weld and HAZ, thereby reducing the likelihood of martensite formation.

4.3.3.3 High Strength Low Alloy (HSLA) Steels. High strength, low alloy (HSLA) steels came into structural use with the adoption of [ASTM A 242](#) and [ASTM A 441](#) steels in 1963, and [ASTM A 572](#) and [ASTM A 588](#) steels in 1968. HSLA steel specifications offer a wider variety of mechanical properties than do carbon steel specifications. As steel producers developed specific steel compositions to meet these mechanical property requirements, designated grades and steel types were assigned with tight control compositions often specific to the producer. The producers required or limited carbon, manganese, and various alloying elements to specific levels or ranges, and in some cases specific combinations. Depending upon type, there could be considerable variation in the alloy and combinations of alloy for a given HSLA steel grade. For most HSLA structural steels, carbon content is relatively low when compared to carbon steels, typically between 0.10% and 0.25% and the total alloy content is less than 2%.

Because of the presence of additional alloys and higher levels of alloy, the weldability of HSLA steels is somewhat less than that of carbon steels with similar carbon levels. Although weldability generally decreases as the strength increases, the common structural HSLA steels are not considerably higher in strength than similar carbon steels used in construction.

4.3.3.4 Thermomechanically Controlled Processing (TMCP) Steels. The production of some HSLA as well as other steels uses thermomechanically controlled processing. Thermomechanically Controlled Processing Steels (TMPC) are steels which exhibit ultra fine grain structures resulting from controlled rolling and accelerated cooling to provide the desired mechanical properties. Weldability is similar to Q&T steels.

4.3.3.5 Quenched and Tempered (Q&T) Steels. Quenched and Tempered (Q&T) steels are produced by heating the steel to a specific minimum temperature. The steel is then quenched in water or oil to cool it below a maximum temperature, then tempered by reheating the steel to above a minimum tempering temperature and allowing the steel to cool

at a controlled rate. The tempering temperature is well below the initial heating temperature. The quenching operation adds strength to the steel, but decreases ductility and notch toughness. Through tempering, the quenched steel's toughness and ductility is restored to adequate levels. Steels of this type are sensitive to the heating and cooling rates associated with welding. Excessive heat can lead to loss of strength. When heat is applied too rapidly, it can also lead to brittleness, low ductility and toughness, with a high risk for weld or HAZ cracking. Therefore, prior to production welding, welding procedures should be tested using representative joints and steels to verify that adequate quality and mechanical properties will be achieved and maintained. In addition to welding, the mechanical properties of Q&T steels may similarly be adversely affected by improper heating during cambering or straightening operations.

4.3.3.6 Quenched and Self-Tempered (QST) Steels. Quenched and Self-Tempered (QST) steels have evolved from TMCP steel production. The QST process controls chemical composition and manufacturing processes, starting with ingot or bloom reheating with the use of in-line interrupted quenching and self-tempering. The steel is partially quenched during the hot-rolling operation and tempers itself using residual internal heat. QST steels have improved weldability when compared to traditional quench and tempered steels. ASTM A 913 steel, adopted in 1993, is the common structural QST steel, and is manufactured under patent. QST steels have lower alloy content and improved weldability when compared to traditional Q&T steels, but excessive heat can still lead to loss of strength.

4.3.4 Cast Steels. Steel castings for structural applications are typically produced to various commercial standards based on mechanical properties rather than composition. The weldability of steel castings is therefore unknown unless the composition is known. In general, the weldability of a steel casting can be determined using the same methodology for rolled structural steels of similar composition. The weldability of a steel casting of a given composition is similar to that of a rolled structural steel of the same composition and heat treatment, if any. Welding materials and procedures similar to those used for the rolled structural steel may be used.

4.3.5 Cast Iron. Compared to structural steels, structural cast irons typically have higher carbon and silicon content. Because cast iron is typically less ductile than steel, there is a higher risk of cracking from welding and higher risk of poor mechanical properties in the weld and HAZ. Because of the high levels of carbon and silicon, welds on cast iron require careful control of cooling rates to minimize cracking tendencies. When needed, sufficient ductility in the weld area may be achieved using special high-nickel electrodes.

4.3.6 Wrought Iron. When wrought iron is involved, mechanical means of making structural connections should be considered first. If mechanical connections are impractical, welding should be done with caution. Wrought iron generally contains layers of silica and slag inclusions that run along the direction of rolling; therefore, the material is very weak in the through-thickness direction. If welding is necessary, the connection and joint should be configured so that the wrought iron will not be subjected to through-thickness stresses from applied loads. Joint details should minimize through-thickness shrinkage stresses.

4.4 Weldability Based on Steel Composition

The composition of the steel is a key parameter when determining its weldability. Consideration of the presence and percentage of individual elements, as well as the combination of specific individual elements with other elements, and the total effect of all elements combined is often necessary.

Of all elements other than iron, carbon is the most important element that affects weldability. Other elements have less effect on weldability and their importance and effect, weighted in comparison to carbon, is conveyed through the use of a carbon equivalency calculation.

As the carbon equivalent value increases, weldability decreases. The hardness, and hence brittleness, of a HAZ upon weld cooling is indicated through carbon equivalency. Weldability is inversely related to hardenability, as weldability decreases hardenability increases and visa versa. Steel with high hardenability will have a higher risk of cracking when welded. Conversely, steel having low hardenability will have less risk of cracking when properly welded.

The steel's production method, if known, should be considered in evaluating the weldability of the steel and development of suitable welding procedure specifications. Older steels were likely ingot cast, making them more susceptible to segregation, laminations, and other internal discontinuities. Modern steels, starting in the 1980s, may have been continuous cast, reducing the frequency and size of these internal discontinuities. These modern steels have commonly been deoxidized, and this improvement in production is not readily apparent from chemical composition. Elements such as