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Subsea Bolt Study: Technical Gaps in Current Standards and Requirements

Analysis of Domestic Oil and Gas Standards with Comparison to Other Domestic Industries and the International Oil and Gas Industry

Energy Systems Division

Report Authors
This report was prepared by the Global Energy Solutions team under the direction of interim manager Bruce Hamilton.

Data Used in This Report
The data used in this report was obtained before December 2017. Any updated information after this date is not included. In addition, the project database is preliminary and has not been finalized..

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Subsea Bolt Study: Technical Gaps in Current Standards and Requirements

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Comparisons of Domestic Oil and Gas Standards versus Other Domestic Industries and International Oil and Gas Industry

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Energy Systems Division, Argonne National Laboratory

October 15, 2018

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Acronym or Abbreviation	Explanation
AISI	American Iron and Steel Institute
API	American Petroleum Institute
ANSI	American National Standards Institute
Argonne	Argonne National Laboratory
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BS	British Standards
BSEE	Bureau of Safety and Environmental Enforcement, an agency within the U. S. Department of Interior
BSL	Bolting Service Level
BPVC	Boiler and Pressure Vessel Code (ASME)
CRA	Corrosion-Resistant Alloy Steel
DNV-GL	Det Norske Veritas and Germanischer Lloyd
DOE	U. S. Department of Energy
DOI	United States Department of the Interior
DTI	Direct-Tension Indicating
EAC	Environmentally Assisted Cracking
EMI	Electromagnetic Interference
EPRI	Electric Power Research Institute
ESD	Electrostatic Discharge
ft	Foot-unit of length
HRFe	Hands Free Riser System (Drill Quip, Inc)
HRC	Hardness Rockwell C scale
in	Inch abbreviation unit
ksi	One thousand pounds per square inch

Acronym or Abbreviation	Explanation
ISO	International Organization for Standards
lbs	Pounds abbreviation unit
ml/l	Milliliter per liter
NACE	National Association for Corrosion Engineers International (formerly)
NASA	National Aeronautics and Space Administration
NDE	Nondestructive Examination
NORSOK	Norsk Sokkels Konduranseposisjon
NRC	Nuclear Regulatory Commission
OCS	Outer Continental Shelf
OEM	Original Equipment Manufacturer
OTC	Offshore Technology Conference
QA	Quality Assurance
SAE	Society of Automotive Engineers
US	United States
USCG	United States Coast Guard

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A third Argonne intern, Mr. Bradley Munson, compiled information about the relationships of standards and researched some topical avenues concerning fatigue, corrosion, and coatings. He recently completed a bachelor's degree in physics at North Central College. In the fall of 2017, he commenced graduate studies in physics at Louisiana State University in Baton Rouge, LA. His current objective is to complete a PhD in Astrophysics.

I also wish to thank Ms. Nicole Amon and Ms. Josie Sutter, both undergraduate students at the College of DuPage. Both have assisted in data collection and the preparation of the preliminary database of relevant standards. They have also contributed significantly to the final data entry and quality checking of the database.

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Executive Summary

This study analyzed content of bolt and fastener related standards with an emphasis on requirements applicable to subsea drill-through equipment used in oil and gas exploration and development. With some exceptions, these are standards in force as of January 2017. The work was done by Argonne National Laboratory (Argonne).

As the regulator for all offshore oil and gas exploration and production in the U.S. Outer Continental Shelf (OCS), the U.S. Department of the Interior (DOI) Bureau of Safety and Environmental Enforcement (BSEE) wishes to understand how a time snapshot of the subsea oil and gas bolt standards in its regulatory jurisdiction compares with those in other industries and countries. In particular, BSEE needs to know whether there are any "gaps" in the bolt standards or requirements that could foster, promote, or lead to unsafe conditions on the OCS.

In this study, Argonne focused primarily on alloy steel threaded fasteners, mostly because these critical subsea components have failed in recent history. The most challenging applications involve corrosion-resistant alloys. The U.S. oil and gas industry's standards systems address both low alloy steel and corrosion-resistant alloys.

To understand the basics of subsea environmental parameters, Argonne reviewed limited historic failure work for bolts subjected to different tensile loadings and extended subsea exposure. One example is the mid-1970s publication on the U.S. Navy's exposure of 20,000 bolt specimens representing 475 different alloys to a variety of corrosion and loads submerged in the Pacific Ocean. Among the American Iron and Steel Institute (AISI) 4340 alloy bolts under load (up to 75% of yield strength), there were no failures among 176 specimens exposed for as long as 2 years. Among the AISI 4130 specimens, there was only one failure among the 60 specimens. Both these alloys are similar to those used in the current standards associated with the U.S. oil and gas industry. That same Navy study evaluated nickel-based alloys, but the specimens were not alloys commonly referenced in U.S. oil and gas industry bolting standards. Subsea parameters such as temperature, pressure, salinity, oxygen, and pH vary with depth. The Navy study indicated that both pH and oxygen have minimum values around 2500 ft in the Pacific Ocean, while temperature gradually decreases and salinity increases with depth. Such environmental variables together with the variations of materials, coatings, and functional requirements provide some perspective regarding the challenge of producing reliable fasteners for the oil and gas industry.

The gap analysis study began with a collection of relevant standards from the American Petroleum Industry (API) and expanded to other standards, such as those published by ANSI,

ASME, and ASTM and referred to in the API standards. For bolts, some key standards refer to other standards with more detailed requirements.

Argonne developed a preliminary database of more than 24,000 specific records associated with more than 300 bolt-related standards. Each record has seven fields that identify detailed fastener/bolt parameters, the relevant topic, the industry, and keywords. This preliminary database is in Microsoft Access™ and Microsoft Excel™ formats.

Argonne used these database capability tools to search for common themes and patterns. From these searches, distinct patterns emerged among groups of standards. Major findings (gaps) fall into the following three general areas:

1. Bolt fatigue criteria were not found in any of the ASTM Core Group standards[1] or API Core Group standards[2] yet they appear in some similar international standards such as DNVGL-RP-005 ("Fatigue Design of Offshore Steel Structures") and a similar U.S. document ANSI AISC 360-05 ("Specification for Structural Steel Buildings").

   Recommendations:

   - **API standards should consistently recognize bolts and bolt design principles as part of assemblies and components throughout the API portfolio of subsea drill-through equipment standards, specifications, and/or practices.**

   - **API should consider adding definite fatigue requirements for bolting to drill-through standards for critical applications. Such criteria should be correlate with bolt service levels.**

2. Systems approach to cathodic protection and other corrosion-related failure mitigation practices are needed. Numerous standalone standards exist in topical areas, but unfortunately, the interrelationships are not addressed clearly in the oil and gas industry standards system. This area appears to be left to reasonable science and engineering practice.

   - Cathodic protection requirements were not found in any of the ASTM Core Group standards and, within the API Core Group, only appear in API 16F (Specification for Marine Drilling Riser Equipment) and 16D ("Specification for Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment") with the latter

[1] ASTM Core Group is ASTM A193/193M, A194/194M, A320/320M, A453/453M, A540/540M, A962/962M, A1082/1082M

[2] API Core Group is: API 16A, 16AR, 16C, 16D, 16F, 16Q, Standard 53, and 6a.

referencing NACE RP-0176 (“Corrosion Control of Steel Fixed Offshore Structures Associated with Petroleum Production”

- Within the ASTM Core Group, hydrogen embrittlement is only mentioned in ASTM A193/A193M (“Standard Specification for Alloy-Steel and Stainless Steel Bolting for High-Temperature or High-Pressure Service and Other Special Purpose Applications”) and A194/A194M (“Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High-Pressure or High-Temperature Service or Both”). The remaining standards in the ASTM Core Group, including A962/A962M (“Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range”), do not address this subject. Within the API Core Group, hydrogen embrittlement concerns are address through hardness limits such as 34HRC in API 16A (“Specification for Drill-Through Equipment”) and API 53 (“Blowout Prevention Equipment Systems for Drilling Wells”) introduces the subject as a caution for equipment modifications.

- Within the ASTM Core Group, coatings are only addressed in ASTM A193/A193M and A194/A194M with a reference to ASTM B633 (“Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel”). ASTM B633 references ASTM B849 (“Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement”), ASTM B850 (“Guide for Post-Coating Treatments or Iron or Steel for Reducing the Risk of Hydrogen Embrittlement”) and ASTM F1941 (“Specification for Electrodeposited Coatings on Iron and Steel”). However, the introduction of ASTM F1941 calls for this standard to supersede ASTM B633 for mechanical tensioners and places a limit on hardness of 31 HRC. ASTM F1941 does not reference ASTM B850, and ASTM B849 addresses heat treatment in the event the purchaser does not specify an alternate heat treatment.

Recommendation:

- **The standards organizations should consider systems focused corrosion management for oil and gas drill-through equipment. A first step, if not already completed, would be for the standards organizations to achieve consistency and clarity of application regarding coating and hydrogen embrittlement topics within ASTM B633 (“Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel”), ASTM B849, ASTM B850 (“Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement”), and ASTM F1941.**

3. Traceability or chain of custody (the ability to completely identify the origin and history of a particular bolt) is, in many cases, left to the discretion of the bolt purchaser or equipment owner. Notably, standards API 20E ("Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries") and API 20F ("Corrosion-Resistant Bolting for Use in the Petroleum and Natural Gas Industries") require a "record of qualification," but do not clearly define responsibility for a "chain of custody" after shipping to the user (as this is left to the purchaser). Such tracking is most important for bolts used for critical applications (presumably bolt service level [BSL] 3 as defined in API 20E). Traceability would be desirable to aid failure forensics for noncritical applications and to identify non-approved venders and manufacturers. Traceability should record and track numerous parameters for any type of critical bolt or fastener for the expected lifecycle of the application (Currently API 20E and API 20F only require records retention for 10 years which could be less than the actual service life). Appropriate metallurgy is one essential parameter for reliability and intended performance.

Recommendations:

- **Standards organizations should clarify roles and responsibilities regarding records retention requirements, particularly those associated with traceability for bolts used in critical applications over their entire life cycles. Recordsrecord should include detailed information about coatings, all materials processes, supply chain performers, and quality assurance.**

- **To facilitate implementation of the record of qualification API should continue incorporating API 20E ("Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries") and API 20F ("Corrosion-Resistant Bolting for Use in the Petroleum and Natural Gas Industries") into API's offshore equipment standards. Each standards committee (including the API 6A ["Specification for Wellhead and Christmas Tree Equipment"] committee) should evaluate API 20E and API 20F for the particular situations of each standard, but deviations from the standards should be minimal.**

The foregoing are considered the most significant technical gaps in the standards. While these gap areas may be addressed by the subsea oil and gas industry voluntarily, based on the standards system, they are not systematically and uniformly required or enforced. In part, this is due to current oil and gas industry standards not consistently calling out or referencing comprehensive criteria for bolts and fasteners specifically. The API has begun a multiyear effort to reconcile such issues. The latest API 53 is an example of progress in this area with numerous mentions of bolting as is the publishing and revisions of the two API bolt standards API 20E ("Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries") and

API 20F ("Corrosion-Resistant Bolting for Use in the Petroleum and Natural Gas Industries"). In the opinion of the author there still remains a need to evaluate and, as appropriate, incorporate requirements in the findings areas in key subsea equipment standards including API 6A and API 16A ("Specification for Drill-Through Equipment").

During the gap analysis, Argonne observed a variety of topical areas where oil and gas industry standards could be improved. The areas for BSEE are

- Track API action on amending API 20E to add an acceptance criteria for proprietary materials. Possible language: *Proprietary grade must be equivalent or better than the most appropriate ASTM grade in the standard for the application;*
- Evaluate bolting service levels and record of qualification requirements in API 20E and API 20F (in terms of safety and regulatory value) and consider including these standards in regulations;
- Monitor ASTM progress on changes to ASTM B633, ASTM B849, ASTM B850, ASTM F1941, and other ASTM standards to clarify coating requirements applicable to subsea bolting and fasteners;
- Consider clarifying meaning of "shall" in regulations for referenced documents pertaining to subsea bolting; and
- For the present, support continued inclusion of API 20E and API 20F in the API drill-through subsea equipment standards system.

Specific Recommendations for API are:

- Amend the proprietary grade in API 20E to include and acceptance criteria. Possible language: *Proprietary grade must be equivalent or better than the most appropriate ASTM grade in the standard for the application*;
- Achieve consistency between API 20E and API 20F with regard to auditable and traceable requirements for record of qualification and content of these records.
- Define which standards take precedence over others in API 20E and API 20F;
- Adopt and consistently define common and widely used terms such as "manufacturer" and "original equipment manufacturer (OEM) to lessen confusion about roles and responsibilities;
- Define "critical application" for standards consistency and relate to bolt service levels; Strengthen date and version criteria for normative references (standards organizations);

- Clarify criteria for tapped holes and tapped inserts in the standards system, including accommodations for different materials;
- Provide consistent and static guidance in oil and gas bolting standard on which version(s) of a referenced document is to be used (ASTM); and
- As applicable, add coatings and hydrogen embrittlement measures to the lists for the record of qualification for API 20E and API 20F.

A recommendation for ASTM (in addition to the expectation that coating requirements will be clarified in the oil and gas bolt standards):

- Clarify the apparently inconsistent guidance on referenced standards versions in their oil and gas bolting standards. Different criteria appears in the common standard (ASTM A962/A962M) than in some standards that reference that common document.

Argonne recommends that these findings, observations, and recommendations be made available to the oil and gas industry in the hope that responsible organizations will address each gap area in good faith, determine where improvements can and should be made, and then take reasonable actions to improve the standards and bolting reliability.

1.0 Introduction

In recent history, several bolt failures have occurred during oil and gas operations in the Gulf of Mexico. Had critical components involved pressure barriers, these failures may have resulted in a costly loss of well control and significant environmental impact. There is considerable incentive to avoid such incidents, and the U.S. Department of the Interior Bureau of Safety and Environmental Enforcement (BSEE) is pursuing several avenues to identify and address the root causes of such failures. One such avenue is this review of a snapshot of relevant bolt standards that apply to subsea equipment and the attempt to identify standard gaps.

This report will compare standards requirements across international borders and between industries. It will also identify some alternate technologies that may be useful in some situations.

This study began in January 2017 with the identification and collection of available standards pertaining to alloy steel bolts.[3] At the onset of the study, the Argonne technical team had general knowledge of industry standards and codes, background about the American Petroleum Institute (API) standards system, familiarity with the structure and organization of BSEE regulations, and understanding of typical conditions fasteners experience in subsea service.

After reviewing the scope of a few bolt-related standards, this study isolated common subsea oil and gas fastener standards in use as of January 2017. A review of the normative references in these standards expanded the collection, as did bolt-related word searches. Word searches of individual standards; collection directories; the IHS Engineering Workbench; and the IHS Engineering Standards, a standards subscription service available through the Argonne reference library provided more detail. With some exceptions, these steps identified standards used in domestic industries. Further, Argonne accessed a collection of standards another laboratory had assembled. This combined collection included international oil and gas industry standards.

Finally, virtually every standard has normative or referenced standards linking to two, three, or more tiers of narrower standards. As a general practice, unless a topic was considered a potential failure-related issue, second- and third-tier references were not obtained and reviewed in entirety. Without this convention, the collection could have easily grown substantially beyond the several hundred used to support the evaluation and conclusions of this report.[4]

[3] There are exceptions in the report, such as when a standard applies to both alloy steel and corrosion-resistant materials.

[4] A more detailed explanation in this area appears in Section 4.3.

Examples of sources of the standards and regulations reviewed are the:

- API;
- ANSI (American National Standards Institute);
- ASME (American Society of Mechanical Engineers);
- ASTM (American Society for Testing and Materials);
- DNV-GL (Det Norske Veritas and Germanischer Lloyd);
- ISO (International Organization for Standards);
- NACE International (formerly known as the National Association of Corrosion Engineers);
- NASA (National Aeronautics and Space Administration);
- NORSOK (Norsk Sokkels Konkuranseposisjon); and
- NRC (U.S. Nuclear Regulatory Commission).

These are just a few examples, and some of these sources are used domestically and worldwide. For example, organizations such as ISO, ANSI, and NACE publish standards and list multiple designations. Other times, organizations such as ASME print and distribute domestic standards in multiple languages so that standards can be widely used by international industries as well.

2.0 Typical Subsea Environment and Some Experimental Findings

2.1 Varying Subsea Environment

In addition to differing standards and mechanical design requirements, subsea bolting experiences varying seawater properties. Variables include pressure, ocean currents, temperature, salinity, pH, and oxygen concentration as shown in Figure 1[5]. This figure shows that oxygen concentration and pH trend similarly, decreasing with water depth to a minimum around 2000 ft and then increasing slightly, but not approaching surface values at 6500 ft depth. Temperature gradually degrees with depth, and salinity gradually increases, but neither linearly. A fifth variable, pressure, is not shown in the figure, but would tend to increase almost linearly with variations because of density changes. In terms of percentage change, oxygen concentration is the most significant, ranging from as low as about 0.3 ml/l at 2500 ft to 2.1 ml/l at 6500 ft or 5.9 ml/l at the surface and salinity. The pH varies significantly, too, ranging from slightly acidic at the surface to slightly basic over most of the depth range. One subsea component that must accommodate these variations would be a bolted riser assembly. In contrast, a piece of wellhead equipment at the sea floor, such as a BOP stack, has relatively constant conditions for most of the service period.

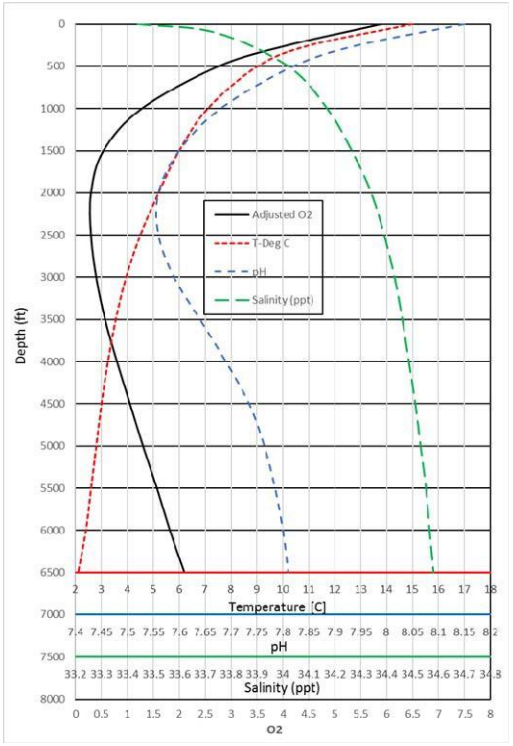

FIGURE 1 REPRESENTATIVE SEAWATER ENVIRONMENT WITH DEPTH

2.2 Exposure Testing in Ocean Conditions

For many decades, the U.S. Navy has endeavored to understand the effects of the ocean environment on metals. In the 70s, the Navy published test results for 475 different alloys at three depths (surface, 2500 ft, and 6000 ft) and from 123 to 1064 days. Some tests involved both

[5] Figure is derived from the Navy study: F. M. Reinhart, "Corrosion of Metals and Alloys in the Deep Ocean," Civil Engineering Laboratory, Naval Construction Battalion Center, Port Herneme, CA, Technical Report R-834, February, 1976.

coated and uncoated sample and various static stress loadings during the exposure. The study found that corrosion rates of steel at 2500 and 6000 ft depths decreased with increasing duration of exposure and were consistently lower than surface corrosion rates by a factor of approximately 3.

An important observation from the Navy study is the relatively low number of failures under load for AISI 4130 and AISI 4340 bolts[6]. These steel bolts were tested in a combination of conditions, including:

- Loading up to 30 to 75% of yield (American Iron and Steel Institute [AISI] Grade 4340)—30 samples at 30% yield strength, 22 samples at 35% yield, 56 samples at 50% yield, and 68 samples at 75% yield; and AISI 4130—18 samples at 30% yield, 15 samples at 50% yield, and 27 samples at 75% yield)
- Yield strength ranging from 170 ksi (AISI 4130) to 130–185 ksi (AISI 4340);
- No coatings;
- Cadmium, nickel, and copper coatings; and
- Exposures in the range of 197 to 751 days.

For the AISI 4130, there were 60 samples, and for AISI 4340, there were 176 samples (including different loadings as detailed above). While all the bolts corroded, there was only one failure out of the 236 sample combinations: a 4130 nickel-plated bolt stressed at 75% of yield. This failure occurred at 197 days, the shortest exposure period in 2340 ft of water. Notably, one failure among a relatively small number of tests does not support a conclusion that a particular number of bolts will fail in service under certain conditions. Independent of the number of tests failures can occur other than at the longest exposure or greatest depth. Possibly, this relates to another conclusion in the Navy findings that these coatings can cause decreases in mechanical properties after exposures on the order of 400 days at 2500 ft.[7]

In addition to low-alloy steels, the Navy study included several nickel alloy steels. For a range of nickel content between 1.5 to 9 % and between 400 to 1064 days of subsea exposure at 2500 or 6000 ft, the corrosion rate was nearly constant. However, the corrosion rate at the surface, while also nearly constant at 7 mils per year, was nearly seven times greater than at depth.[8] Most of the nickel alloy testing under load comparable to the low-alloy steel testing was conducted on 18%

[6] Both of these materials are referenced in API 20E (specifically including ASTM A320/A320M L7M, ASTM A320/A320M L43, and ASTM A540 B23)
[7] Paragraph 2.1.11 of the Navy study
[8] See Figure 7 and Paragraph 2.1.4 of the Navy study.

nickel, maraging[9] steel (electric furnace air melt, air cast, annealed, aged at 950°F for 3 hours, air-cooled surfaces) from a variety of special metals, military, and aerospace sources. More than 25% of these alloy specimens failed mostly at the highest depths.[10] Notably, this is a different alloy from alloy 718, which is about 50% nickel and used for subsea oil and gas service.

There is much more data on fastener performance in the literature since the Navy study. Comprehensive review and citation of such work is beyond the scope of this Argonne subsea bolt standards gap analysis.

[9] Maraging steels are a family of high nickel content materials in the range of 20%, cobalt (~10%), molybdenum (~4%), titanium (~1%), aluminum (~0.12%) and low carbon (0.03% maximum). They have both high tensile strength and fracture toughness achieved through age hardening (precipitation). They have numerous applications in the aircraft industry.

[10] See Figure 7 in the Navy study.

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3.0 Technical Approach and Early Observations of Gap Analysis

3.1 Approach Evolution and Standards Versions

At the onset of this study, January 2017, Argonne obtained and reviewed domestic oil and gas standards that pertained to drill-through equipment and were referenced in BSEE regulations. In general, these were standards published by API and had only minimal information about oil and gas industry subsea bolt manufacturing. Some, such as API 6A ("Specification for Wellhead and Christmas Tree Equipment"), have extensive information about bolting configuration (sizes, lengths, torqueing, clearances, thread engagement, etc.) but limited information about loading limits other than maximum tensile as percent of specified yield strength.

As a second and independent starting point for reviewing domestic standards, Argonne used a list of common ASTM standards mentioned in a BSEE workshop.[11] A review of this workshop collection and its references led to other domestic industries. Some of these domestic standards are recognized by organizations such as the ISO, and thus are both domestic and international. Additional international standards were identified from reference lists or were provided by BSEE staff based on their knowledge and experiences.

As this gap analysis process continued, certain types of standards were deemphasized or omitted. In general, the omitted standards did not pertain directly to the bolt life cycle[12] and concerned topics such as determining a measurement, preparing a sample, or conducting a specialized test.

To augment the standards collection described above, Argonne performed multiple word queries on ASTM standards subscription services and other reference databases. For standards concerning the domestic oil and gas industry, common and representative groups emerged that comprised our starting list. For purposes of discussion in this report, these groups are termed the **ASTM Core Group** and the **API Core Group**. Each group is a snapshot as of January 2017 and reflects the basis for this report.[13] These groups with edition and revisions are defined in Table 1 and Table 2 and appear with titles in the report discussions.

The oil and gas industry strives to use the latest standards, arguing that the latest or newest standards provide a higher level of safety. On a voluntary basis, the oil and gas industry adopts

[11] BSEE Workshop January 28, 2014.

[12] *Life cycle*, for the purposes of this study, is design, construction, operations, and maintenance, as shown in Appendix B.

[13] Argonne conducted standards collection and evaluations during the period of December 2016 through June 2017. International standards were collected and compiled mostly during the last 10 months of calendar year 2016.

and applies even standards that have not yet been incorporated into regulations. Two such prominent standards in use at the time of this study are API 20E ("Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries") and API 20F ("Corrosion-Resistant Bolting for Use in the Petroleum and Natural Gas Industries").

Note: ***There are other versions of the standards listed as the basis for this study. Some are more recent and may be in regular use by the oil and gas industry. Two of the standards in Table 2 are not the latest version that may have been available as of January 2017. These are API 16C ("Choke and Kill Equipment") and API 16Q ("Recommended Practice for Design, Selection, Operation, and Maintenance of Marine Drilling Riser Systems"). Only two of the standards in Table 1 and Table 2 appear to be incorporated by reference in current BSEE regulations at 30 CFR §250.198. Both precede the versions used for this study (API 6A, 19th edition instead of 20th edition, and API RP53, which is now API 53). Different standards versions than used for this gap analysis likely would not change the study's major conclusions substantially.***

3.2 Relating Normative References of Common Domestic ASTM Oil and Gas Bolt Standards

In this study, Argonne's first assessment strategy was to look at relationships between standards and identify common or unique references with the expectation that useful patterns and gaps would become evident.

This process began with the reference matrix shown in Appendix A, which includes all standards in the ASTM Core Group. A survey of the standards readily confirmed that ASTM A962/A962M ("Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range") was referenced in all the remaining standards of the ASTM Core Group, except for A1082/A1082M ("Standard Specification for High-Strength Precipitation—Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications"). This strategy readily illustrated differences in the uses of normative references concerning topics such as coatings. ASTM A962/A962M also lists normative standards on a range of topics.

Figure 2 is a graphical representation of the reference matrix in Appendix A. The right column lists specific referenced standards, from the ASTM Core Group (not including references in those references) that are shown on the left side of the figure. The referenced standards are sequenced from top to bottom by the frequency at which they are mentioned in the ASTM Core Group as a whole. The common standard (referenced to provide common requirement for all

other standards of the ASTM Core Group), ASTM A962/962M, has the most links to references. ASTM A540/A540M (“Standard

TABLE 1 ASTM STANDARDS IN ASTM CORE GROUP FOR PURPOSES OF STUDY DISCUSSIONS

Standard Designation	Edition	Bolt Standard Title
ASTM A193/A193M	2015	Standard Specification for Alloy Steel and Stainless Steel Bolting for High-Temperature or High-Pressure Service and Other Special Purpose Applications
ASTM A194/A194M	2015	Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both
ASTM A320/A320M	2015	Standard Specification for Alloy Steel and Stainless Steel Bolting for Low-Temperature Service
ASTM A453/A453M	2016	Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels
ASTM A540/A540M	2015	Standard Specification for Alloy Steel Bolting for Special Applications
ASTM A962/A962M	2015	Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range
ASTM A1082/1082M	2015	Standard Specification for High-Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications

TABLE 2 STANDARDS IN API CORE GROUP FOR PURPOSE OF STUDY DISCUSSIONS[14]

API Designation	Edition	Document Title[15]
API 16A	3rd ed. (reaffirmed 2016)	Specification for Drill-Through Equipment
API 16AR	1st ed. (2017)	Standard for Repair and Remanufacture of Drill-Through Equipment
API 16C	1st ed. (2001, and errata on 4 Feb. 2016)	Specification for Choke and Kill Equipment
API 16D	2nd ed. (reaffirmed 2013)	Specification for Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment
API 16F	1st ed. (Ad. 2, Nov. 2014)	Specification for Marine Drilling Riser Equipment
API 16Q	1st ed. (reaffirmed 2010)	Recommended Practice for Design, Selection, Operation, and Maintenance of Marine Drilling Riser Systems
API 53	4th ed. (Nov. 2012)	Blowout Prevention Equipment Systems for Drilling Wells
API 6A	20th ed. (Oct. 2011)	Specification for Wellhead and Christmas Tree Equipment

[14] These are selected standards pertaining to drill-through equipment that appear in the BSEE regulations at the time of this study. Notably, API 20E is not included in the current regulations, even though the industry has begun to use this standard. In February 2017, API released a 2nd edition of this standard.

[15] These standards are the first level of the BSEE regulatory tree regarding drill-through equipment. Unlike ASTM standards, some, but not all, have bolt design criteria and reference bolt standards.

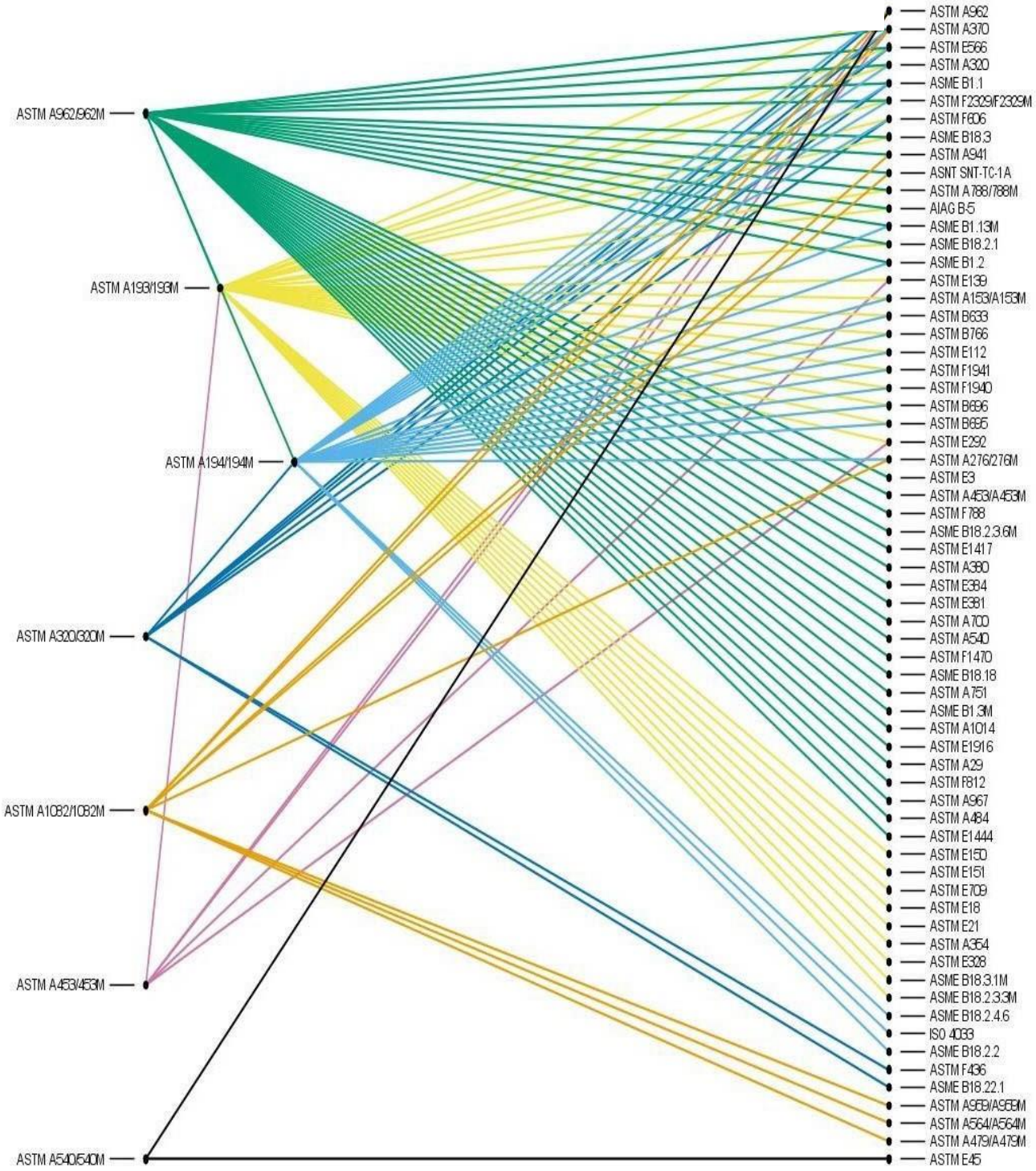

FIGURE 2 DOMESTIC OIL AND GAS STANDARDS: ASTM CORE GROUP RELATIONSHIP[16]

[16] Note: Titles for each of the listed standards documents in the right hand column appear in the top row of the table in Appendix A: Oil and Gas Standard Subset Matrix.

Specification for Alloy-Steel Bolting for Special Applications") has the fewest links, with references only to ASTM A962/A962M and ASTM E45 ("Standard Test Methods for Determining the Inclusion Content of Steel"). Notably, ASTM E45 is not referenced by any other standard in this group.

There are two coating standards in this reference list: ASTM B633 ("Standard Specification for Electroplated Coatings of Zinc on Iron and Steel") and ASTM F1941 ("Standard Specification for Electrodeposited Coatings on Mechanical Fasteners, Inch and Metric"). These standards appear only in two standards of the ASTM Core Group: ASTM A193/193M and ASTM A194/194M. Thus, if a manufacturer was not working with API 20E[17] voluntarily, there would be no standard requirements for coatings for several of the ASTM Core Group, and as such only the subset of materials specifications were taken from the ASTM Core Group. The first edition of API 20E treats coatings and plating as supplementary requirements that must be specified in the purchasing documents and there is a low-temperature baking requirement per ASTM B633 and ASTM B850 ("Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement"), as applicable. This first edition of API 20E allowed zinc coatings, and ASTM B850 provided a table of embrittlement-relief heat treatments that required experience with a particular alloy to select the proper class. The more recent version of API 20E disallows electroplated zinc coatings entirely for subsea use and incorporates coating requirements in the body of the specification and does not reference ASTM B633, which in turn references ASTM B849 ("Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement"), which is heat treating requirements to minimize hydrogen embrittlement. These API requirements include the baking of electroplated components within two hours after plating at 375–425°F for 8 hours minimum and testing to verify a sample does not fail within 200 hours at 75% of ultimate tensile strength. It also references ASTM A193/A193M and ASTM A194/A194M (which would get to ASTM B849 requirements through B633 reference). However, remaining alloys in API 20E (ASTM A320/A320M, ASTM A540/A540M, and proprietary) are outside the references to B633. Further, the content of the API 20E "record of qualification" does not mention coatings expressly. Apparently, whether or not the record includes coating information would depend on individual interpretation in category topics of the qualification record such as testing or processes.

[17] Note: technically, the 2nd edition was not available until February 2017, a month after the "snapshot" date of this study, but it was included nonetheless.

Relative to the ASTM Core Group, API 20E does not cover every grade of bolt possible. The standard only covers the following:

- ASTM A193/A193M (Grades B7 and B7M);
- ASTM A194/A194M (Grades 2H, 4, 7, 2HM, and 7M);
- ASTM A320/A320M (Grades L7, L7M, and L43);
- ASTM A540/A540M (Grades B22 and B23); and
- Equipment manufacturers' proprietary bolting specifications.

Notably, ASTM A453/A453M and A1082/A1082M are not included in API 20E.

3.3 Life Cycle Success Path Analysis

The second Argonne analysis strategy involved distributing requirements from standards into normal product life cycle success paths comprised of the following phases:

- Design;
- Construction;
- Operations; and
- Maintenance.

The strategy was applied to two standards from the ASTM Core Group: ASTM A540/A540M and ASTM A962/A962M. These success path charts are many pages tied together with reference markings and are provided in Appendix B: Life Cycle Success Path Examples.

This approach clarifies the scope and content of different standards and their offerings and roles in the overall life cycle. The ASTM bolting standards (ASTM Core Group) focus on standardizing manufacturing and bolt production topics such as thread patterns, materials of construction, materials condition, testing, marking, inspections, and testing. As a general rule, the ASTM Core Group standards mention little to nothing about design, use, or application. An exception is that the purchaser may elect to specify the anticipated application in some instances or that the standard is oriented toward a certain application. These applications appear in terms is defined succinctly. Thus, the analyst and presumably the parties involved in the actual manufacturing and acquisition process must define the performer roles. One important role and

responsibility is establishing the person or organization responsible for keeping records to establish traceability throughout the life cycle, especially if the bolt is used for a critical . Only one standard, ASTM A540/A540M, actually identifies a specific industry (nuclear).

TABLE 3 STATED APPLICATIONS FOR ASTM CORE GROUP STANDARDS

Oil and Gas Bolt Standard	Title	Scope
ASTM A193/A193M	Standard Specification for Alloy Steel and Stainless Steel Bolting for High-Temperature or High-Pressure Service and Other Special Purpose Applications	Alloy and stainless steel bolting materials and components for pressure vessels, valves, flanges, and fittings for high-temperature service or other special purpose applications.
ASTM A194/A194M	Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both	Nuts in size range of ¼ inch through 4 inch for high-pressure or high-temperature service or both.
ASTM A320/A320M	Standard Specification for Alloy Steel and Stainless Steel Bolting for Low-Temperature Service	Pressure vessels, valves, flanges, and fittings for low-temperature service.
ASTM A453/A453M	Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	Five grades and 12 classes for high-temperature service for bolting components such as bolts, screws, nuts, or studs for pressure vessel and valve flanges.
ASTM A540/A540M	Standard Specification for Alloy Steel Bolting for Special Applications	Regular and special quality alloy steel bolting materials and bolting components that may be used for nuclear and other special applications.
ASTM A1082/A1082M	Standard Specification for High-Strength Precipitation-Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	Special purpose applications such as pressure vessels. Application defines selection.
ASTM A962/A962M	Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	Applicable to any of the above specifications and applications.

A key observation for the success path phase of this project is: there is not defined traceability of critical bolts from manufacture to actual use. In the scopes of the ASTM Core Group direction concerning design criteria, shipping and handling, storage, operations, in-service inspections, and maintenance are left to the API system of specifications, including:

- API 20E;

- API 20F;
- API Q1 ("Specification for Quality Management System Requirements for Manufacturing Organizations for the Petrochemical and Natural Gas Industry");
- API Q2 ("Specification for Quality Management System Requirements for Service and Supply Organizations for the Petroleum and Natural Gas Industry"); and
- API 53.

The latter three API documents are generic and thus have no specificity regarding bolts, fasteners, and various components and parts of equipment. Standards API 20E and API 20F are not currently incorporated in BSEE regulations individually by reference and thus are only currently applicable in those instances where a standards is deemed acceptable or that standard expressly references those two API bolt standards.[18] Consequently, to the extent the two API bolt standards have not been incorporated into recent API standards updates, adoption by the oil and gas industry is voluntary or justified in the interest of safety, as many updates are not yet incorporated in the regulations.

The success path/life cycle process, as applied for this study, necessitates that the analyst pairs activities with the person(s) or organizations performing them. This proved to be a challenge with the chosen examples. The documents contain several terms for performers, such as the *manufacturer* or *original equipment manufacturer (OEM)*. At the same time, neither of these terms is defined succinctly. Thus, the analyst and presumably the parties involved in the actual manufacturing and acquisition process must define the performer roles. One important role and responsibility is establishing the person or organization responsible for keeping records to establish traceability throughout the life cycle, especially if the bolt is used for a critical application that might impact well control. Within the ASTM Core Group, there is the likelihood for inconsistency and even lost records. This is mitigated considerably if the parties involved in the situation are voluntarily applying API 20E and API 20F, which require a record of qualification (both API 20E editions). In both standards, this responsibility is assigned to the bolting manufacturer (defined in API 20E as the organization that, through the use of manufacturing equipment and processes appropriate for the bolting product form, transforms raw material into finished bolting, but not defined in 1st edition of API 20F. Records retention is specified as 10 years in both standards, but API 20F does not have a requirement (at paragraph 9 in API 20E) that the records be available for audit or the purchaser.

[18] Currently the very latest versions of few API standards do reference API 20E and API 20F such as API 17TR8 and API 16AR.

3.4 Topic Isolation and Sorting Analysis

While the two previous analysis methods (relationships and success paths) identified interesting points, they were insufficient to effectively isolate important topical areas that might be overlooked compared to standards in other industries and countries. Argonne proceeded to parse the collected standards based on the standardized topics as given in Table 4. This parsed information became the organization of the designed preliminary database. The following section describes the design and evolution of this database. During the development process, the database was a tool to create many of the tables and charts in this report and to confirm the major gaps of fatigue design basis and corrosion management areas (combination of coatings, cathodic protection, and hydrogen embrittlement mitigation measures). The gap in bolt traceability throughout the product life cycle became most apparent from the success path approach and from the recognition that much of this topic is missing from various standards. Most specifications have marking and, in some instances, shipping requirements, but do not provide traceability to the actual installation. Alternate technologies (as presented in Section 11.0) were also part of the study scope and were researched outside the database.

TABLE 4 TECHNICAL TOPICS AND DEFINITIONS

Technical Topic	Topic Definition
Acceptance Criteria	Conditions that a product must satisfy to be accepted by a user or customer
Adhesion	Having to do with the process or action of adhering
Apparatus	Technical equipment or machinery needed for a specific process or action
Bars	Long, solid, rolled or forged section with a relatively constant cross-section along its length
Bend Test	A test method for evaluating ductility
Bolts, Screws	Externally threaded fastener designed for insertion through holes in assembled parts; normally tightened or released via torque
Cathodic Protection	Reduction of corrosion by protecting the metal and making it the cathode through conduction via an applied direct current
Certification and Report	A certificate or report produced by the manufacturer as a means to confirm the required standards were satisfied and the product is adequate for its intended purposes
Charpy Impact Tests	A high strain-rate test used to determine the amount of energy a material absorbs while being fractured
Chemical Analysis	Study to determine the chemical composition and structure of a substance
Chemical Composition	A chemical substance's specific type, arrangement, and ratio of atoms in molecules
Classification	Grouping something in accordance to common qualities or characteristics
Cleaning	Ensure that every substance is free of dirt, marks, scratches, or contaminations through a process of washing, wiping, or brushing

TABLE 4 (CONT.)

Technical Topic	Topic Definition
Coatings	Insulating coverings bonded to a metal surface to protect against corrosion by preventing contact between the metal surface and electrolytes
Common Requirements	Requirements common to all industries and manufacturing processes related to subsea bolts
Control Systems	Special systems designed to control and ensure safe operation, such as BOPs
Cooling	Lowering the temperature of a substance for manufacturing or testing purposes
Corrosion	The interaction between a metal and its environment, resulting in alterations to the properties of the metal; often leads to impaired function of the metal, the environment, or the technical system
Creep Testing	A test meant to measure the tendency of a material under high stress to change its form relative to time
Decarburization	Loss of carbon from the surface of a fastener, usually due to heat treatment
Dimensions	Geometric characteristics, including, but not limited to, length, width, height, and thickness
Disposition of Nonconforming Lots	The removal of testing lots that failed to meet the acceptable criteria
Eddy Currents	Localized, electric currents induced in a conductor by a varying magnetic field
Electromagnetic Interference (EMI) Shielding	Protective measures taken to counter interference brought on by electronic and magnetic fields
Electroplating	Coating by electrolytic deposition using a metal such as chromium or silver
Electrostatic Discharge (ESD)	Abrupt flow of electricity between two electrically charged objects due to contact, an electrical short, or dielectric breakdown
Environment	The external conditions a material is subject to during any part of the bolt's life cycle
Environmental Law and Policy	Laws and policies pertaining to the environment
Environmentally Assisted Cracking	The cracking of a material due to tensile stress buildup caused by combinations of hazardous environmental conditions such as high pressures and concentrations of hydrogen
Explosion Testing	Subjecting a material to explosive conditions as a means to test its mechanical properties
Fatigue	Weakening of a metal caused by continuous and various stresses
Flanges and Fasteners	Flange—protruding rim, made to join pressure-bearing equipment together with another flange; fastener—a hardware device used to mechanically join or affix two or more objects together
Forging and Casting	Forging—to make or shape through a process of heating and then forming; casting—metal obtained at or near its finished shape by solidification of molten metal in a mold
Fouling	Polluting of a specimen
Fracture Toughness Test	Test to determine the ability of the material to resist fracture when subjected to strong impacts or high levels of instantaneous stress

TABLE 4 (CONT.)

Technical Topic	Topic Definition
Fueling Procedure	The procedure and method for fueling of an avionic vehicle
Gages	Marks used as indications to determine the length of some measurement
Grain Size	Number of grains per square inch at a given magnification
Hardness	Resistance of metal to plastic deformation
Heat Treatment	Heating or cooling a metal or alloy to obtain the desired properties
Hydrogen Embrittlement	Embrittlement caused by hydrogen induced into steel from external sources, such as sea water
Hydrostatic Test	Test pertaining to the equilibrium of liquids and the pressures exerted by a liquid at rest
Inclusion Content of Steel	Chemical compounds and nonmetals present in steel
Industry Resolution	Problem-solving process and solution to an industry obstacle
Infrastructure	Organizational structures and facilities needed for proper function of a society or enterprise
Inserts	Objects for the purpose of inserting
Inspection	Examination of test specimens to ensure they conform to industry standards
Installation	Process of installing crucial components for the function of a system
Interference	Altering of data or properties of a test specimen due to some external factor such as environment or magnetism
Keywords	Words of significance
Knoop Testing	Microhardness test using a very small indentation
Lateral Expansion	Expanse along the lateral direction of the material
Limits	Point or level beyond which something cannot exceed (such as stress, pressure, or time)
Liquid Penetrant Examination	Method of testing used to determine surface-breaking defects in nonporous metals
Locking	Fastening or securing via a lock or locking mechanism
Lubricants	Substances used to reduce friction
Macroetch	Process of etching deeply into a metal
Magnetic Particle Examination	A nondestructive form of testing as a means to detect surface and slight subsurface discontinuities in ferromagnetic materials
Magnetic Permeability	Ability of a material to support formation of a magnetic field within itself
Materials and Manufacturing	Description of the materials and their fabrication process
Melting Process	Description of the process to melt a material
Nondestructive Electric Test	Nondestructive tests done by inducing an electric current or magnetic field inside a material to observe its electromagnetic response
Notes	Noteworthy additions to the standards
Nuts and Washers	Components used to secure bolts as well as enhance circumference of applied pressure
Orbital Environments	An environment relating to orbital motion or orbit-like behavior
Ordering Information	Information pertaining to the ordering process of components necessary to the bolt procurement process
Packaging and Shipping	The packing and shipping of materials; specific, necessary procedures

TABLE 4 (CONT.)

Technical Topic	Topic Definition
Paint	Criteria having to do with the paint itself, as well as the painting and coating process
Polymeric Lining Materials	Materials composed of polymers for the purpose of lining and covering
Precision and Bias	Guarantee the highest degree of accuracy and impartial judgment
Preservation	Standards to preserve and maintain the quality of materials
Preventive Maintenance	Maintenance undertaken as a means of precaution so that issues do not arise later in the life of the bolt
Product Marking	Marking of products once they have been finished to display information like manufacturer, date, grade, and class
Proof Load and Cone Testing	Test to determine maximum tensile force that can be applied to a bolt before it is plastically deformed
Quality Control	System of maintaining standards in manufactured products by testing a sample lot against certain specifications
Radiographic Examination	Method of nondestructive testing to verify the internal structure and integrity of the specimen
Rejection and Repair	Determination of whether or not a material is inept and cannot perform properly; depending on the degree of failure, if the product can be repaired
Responsibility	Manufacturer's duty to accept repercussions and ownership of products
Retesting	Testing again if a specimen has failed to obtain more information or determine if there was another outside influencing factor
Safety	Making sure there is protection from unforeseen danger, risk, or injury
Sampling	Taking from a produced lot for testing at random to represent the lot as a whole
Screw Threads	Helical groove on a cylindrical or conical surface
Sealants	Material used for the purpose of sealing to make it air or water tight
Sensitivity Test	Test to determine the sensitivity of a material to external factors present in its intended environment
Shear Tests	Test to measure the shear strength properties and discontinuities of a material
Significance and Use	The intended use of a specific standard and how it is to be understood
Sign	A material used to convey a specific meaning or intention
Small Solid Rivet	Headed fastener with a shank used to pass through joint piles, while the unheaded end is upset to form a second head while pulling the joint heads together
Socket Cap, Set Screws, Hex Keys	Socket Cap - A flat, chambered top surface with smooth or knuckled cylindrical sides and a flat bearing surface; Set Screws - Screws threaded the entire length except for its length of point; Hex Keys - Screws with a hexagonal shaped indent for torqueing
Special Components	Component unique to a particular manufacturing process usually not applicable to other standards
Stress Relief	Tests involving the application of stresses to bolt or bolt materials as a means to measure mechanical properties

TABLE 4 (CONT.)

Technical Topic	Topic Definition
Surface Discontinuities	Inconsistencies found on the surface of a metal likely to be flaws that could impair mechanical performance
Tank System	Standards pertaining to the bolts used to maintain systems of tanks
Technical Provisions	Provisions taken to ensure effective production and adherence to important specifications
Tension Tests, Tensile Tests	Tests pertaining to putting specimens under tension and tensile strain to determine specific mechanical properties
Terminology and Definitions	Terms and definitions found throughout the standard necessary to understand and use the standard effectively
Test Specimen	Specific products taken and used for testing to determine characteristics of the manufactured lot as a whole
Torque	Twisting force applied to a bolt for the purpose of testing its torsional strength and simulating the process of tightening and loosing
Traceability	The ability to trace back certain steps of the manufacturing, procurement, and use process to a specific party
Training	Teaching of an aspect of the bolt process
Ultrasonic Examination	Nondestructive test based on the propagation of ultrasonic waves in the material tested
Vacuum Degassing	Process involving the exposure of molten steel to a low-pressure environment to remove gases
Welding	Joining together through heating of surfaces to the point of melting
Workmanship, Finish, and Appearance	Quality of work, the appearance of the final product, and the final touches needed to ensure the bolt meets all the necessary criteria
Yield Strength	Maximum strength the bolt can withstand unstill deformation begins

4.0 Preliminary Bolt Standards Database

4.1 Design Criteria

According to the study's work scope, Argonne was to "*review the industry codes and identify any existing standards or regulations with underlying failure mechanisms for subsea bolt technology.*" This review and literature survey needed to include:

- Design processes and procedures;
- Material specifications;
- Procurement (forging, manufacturing, coating, and heat treatment);
- Quality analysis/quality control;
- Assembly and makeup; and
- Best practices for other industries, such as refining, aerospace, nuclear, and military.

Argonne concluded that the best way to capture this information and make comparisons was a searchable database. Since ACCESS™ and EXCEL™ software are widely used at BSEE, Argonne, and most industrial organizations and since each has extensive built-in capability without requiring extensive custom coding, these were the software platforms used.

4.2 Additional Design Considerations

Argonne believed there needed to be common denominators for comparisons with standard definitions. This concept emerged from reviewing a broad sample of standards and creating topic definitions. Details of this are presented at greater length in Section 5.1.

Initially, Argonne's intent was to define industries and fit standards to those definitions. After a trial implementation, this approach proved cumbersome since many standards, including those of the ASTM Core Group, identify applicability, not specific industries. Therefore, Argonne identified industries based on the text of the standard only when clearly identified. This eliminated concern as to whether a particular standard was correctly characterized as belonging to an industry. In addition, some standards are used by multiple industries, and standards such as the ASME Boiler and Pressure Vessel Code (BPVC) are not only used in a wide range of industries, but are used worldwide. Therefore, instead of grouping standards by predetermined industry, Argonne extracted industries and purposes based on language in the standard.

From a technical perspective, if every standards detail (i.e., the full and exact text) appeared in a "survey and review" database, this would eliminate the need to purchase or own a standard. Such capture and compilation posed a potential copyright infringement issue. For this reason, Argonne chose to capture topics relative to best fit with predefined topic categories and to record where those topics appeared in a given standard. This preserved the need to buy and own standards of interest, yet provided common denominators to make comparisons and identify gaps. Further, this avoided the issue of whether an original subject or paragraph was interpreted exactly as a standards user might interpret it for a specific situation.

4.3 Standards Collection Principles

Standards and similar documents were identified as essential for the database and study when they fell into one of the following groups or categories:

- Specific to drill-through equipment and incorporated by reference in BSEE regulations found at 30 CFR 250.198 (referred to as the API Core Group in this report).
- Part of the ASTM group specified by the oil and gas industry and common to ASTM A962/A962M, referred to as the ASTM Core Group in this report.
- API 20E and API 20F, which were intended to be common to many API standards.
- ASME standards, including BPVC (defining both metric and U.S. thread systems and criteria for fasteners). ASME is a domestic organization, and the BPVC is used widely in many industrial sectors. The BPVC is available in many languages for worldwide applications.
- Oil- and gas-related foreign standards and regulations, where readily available in English.
- Pertaining to alloy steel bolts and fasteners primarily (for example, API 20F pertains to corrosion-resistant alloy bolts and fasteners).
- Covering non-oil and gas domestic industries (military, automotive, nuclear, chemical, aerospace, and marine).
- Listed as normative standard or reference and pertaining to manufacturing process (hot or cold rolling, casting, forging, cut threads, rolled threads, heat treating, annealing, coating processes, and marking).

The following types of standards tended to **not** be included:

- Non-English language.
- Restricted distribution. An issue here is that some countries protect technology through restrictions on the content of standards for export control or technology advantage situations. This occurred between the API and ISO a few years ago.
- Non-oil and gas drilling and industries outside the United States.

As with any study, there were monetary and time limitations. For this study and evaluation, Argonne sought to create a reasonable and representative sample to identify and understand key differences, particularly with regard to foreign oil and gas. Foreign standards are included in the database and study, but the depth of coverage is not as broad as for domestic standards. A full reference library of everything foreign and domestic would be costly unless a broad scope subscription was feasible and justifiable.

Once standards were identified, Argonne queried those standards to isolate the portions of greatest interest. When accessing large standards databases, we found major standards through simple word searches and through reading part or all of the text as appropriate. Routine fastener hardware terms related to these word searches were:

- "Bolt,"
- "Nut,"
- "Fastener,"
- "Thread,"
- "Screw" (or variant "Cap Screw" or "Socket" or "Hex"),
- "Washer," and
- "Stud."

Apart from the above subjects and technical topics appearing in Table 4, individual document and database searches concerned several stand-alone engineering and metallurgical topics of particular interest relating to fastener performance, including:

- "Fatigue;"
- "Corrosion;"

- “Coating;”
- “Cathodic;”
- “Stress;”
- “Tensile;”
- “Torque;”
- “Yield;”
- “Hydrogen;”
- “Embrittlement;”
- “Zinc;”
- “Cadmium;” and
- “Quality.”

These terms helped isolate pertinent standards’ paragraphs and identify whether a document even had useful information in these areas.

4.4 General Preliminary Database Capabilities

Argonne’s preliminary EXCEL™ database contains more than 24,000 specific records associated with more than 300 standards. (Section 14.0 contains the shorthand names, editions, and full titles of these standards.) Each record has seven fields. These are:

- Industry topic;
- Bolt standard identification;
- Paragraph where topic appears in the bolt standard;
- Description/keyword associated with the topic;
- Industry; and
- Region.

These records are replicated in an ACCESS™ database counterpart. In EXCEL™, details within each topic can be chosen in the pull-down menus. As filters are applied, choices in other columns are adjusted immediately to show only those remaining and available. For example, for "hardness," paragraph 8.1 in ASTM E10 is the only discussion of "method." This example also further confirms that some standards cross industries within other data fields and thus appear "generic."

Generally, sorting by paragraph number or description/keyword is not useful. While the organization system is similar for most standards, information and topics in paragraphs between standards vary drastically. Descriptions/keywords are generally unique to each section of a standard. Because of this, there are almost as many options as data entries. The paragraph number or description is, however, useful to locate information in more detail with a copy of the actual standard in hand.

Terminology between standards may or may not be consistent. Thus, the cross-referencing of definitions and terminology can be quite obscure and indecisive. For instance, Eddy currents are electrostatic charges that can disrupt the voltaic potential of the bolt metals. Within ASTM standards, the terms "eddy current" and "electromagnetic testing (ET)" often appear together. However, in ASME NQA-1 only ET appears as a nondestructive inspection technique. Such inconsistency complicates both the interpretation and the comparison of standards, especially in a database. Argonne attempts to bridge such terminology differences as much as possible. Eventually transitioning to a fully relational database form would dramatically improve the query capabilities and value of the compilation.

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5.0 Standards Reviewed and Analyzed

5.1 Key Topic Definitions

For this study, collecting subsea bolt and fastener data at the highest level of detail proved to be quite time consuming, did not enable ready identification of topics, and was not easily adaptable to a database structure. To enable database entry and logical organization, Argonne defined a common list of nearly 100 topics of interest, as mentioned above and listed with definitions in Table 5 Industries, Uses, and Definitions. Some can be traced to detailed breakdowns of the ASTM Core Group, normative references in the ASTM Core Group, and topics that appeared absent based on general engineering knowledge of failure mechanisms. Others were added after breaking down the content of non ASTM Core Group standards in the project's database. This structure enabled a user to find detail for each standard and isolate only those standards containing such topics.

5.2 Industries and Uses

As stated previously, this study began with assumptions about predetermined industries such as steel, automotive, aerospace, nuclear, and chemical. Sorting and compiling standards into these categories became too cumbersome, and Argonne recognized that most standards defined an intended applicable use. These uses, some of which were technically not "industries," were more accurate than judgmental assignments and thus became the use categorization for this study. The compiled list of these uses and industries, as used in this study, appear in Table 5 with appropriate definitions.

TABLE 5 INDUSTRIES, USES, AND DEFINITIONS

Industry or Use	Description of Industry or Use
Automotive	Standards related to the use of fasteners in the automotive industry
Aviation	Standards related to the use of fasteners in environments specific to the aircraft and aviation industry
Construction	Standards related to the use of fasteners in the construction industry; includes standards specific to construction in water-immersive environments
Corrosion Control	Standard specifications and guides related to corrosion control, hydrogen embrittlement, and cathodic protection; includes practices that define the paints and varnishes to be used as corrosion protection in different environments
Equipment	Standard guides related to equipment utilized in the testing of materials in different environments
Fasteners	Specific standards outlining terminology, practices, methods of testing, and methods of manufacturing for fasteners
Generic	Broad, unspecific standard practices that outline tests and testing methods utilized in various fastener and bolt industries
Hazardous Materials	Standard guides that outline hazardous materials for industry and laboratory use
Infrastructure	Standard specifications related to bolts, fasteners and studs utilized in the infrastructure industry; includes practices specific to anchor bolts and high-strength structural bolts
Maritime	Specific standards that outline practices and coatings for fasteners used in maritime environments; includes practices specific to bolts used in boats
Medical	Standards that outline specifications for bolts, screws, and other equipment used in the medical field
Metallurgy	Standard test methods specific to steel and the metallurgy industry
Metric Screw Threads	Standards specific to all metric screw threads; specifically, ASME standards encompassing metric screw threads
Military	Military standards specific to fasteners used in the U.S. military; includes test methods, corrosion prevention, screws, bolts, washers, and the application of equipment in the U.S. military
Navy	Navy standards specific to fasteners used in the U.S. Navy; includes cleaning and corrosion-prevention methods and materials used in the U.S. Navy
Nuclear	Nuclear industry standards that encompass topics such as safety, protective coatings, bolting applications, and test methods for fasteners used in nuclear power plants
Oil and Gas	Standards specific to the use of fasteners in the petroleum, natural gas, and oil industries; includes standards specific to offshore drilling environments
Piping	Broad and unspecific standards that outline practices and tests relevant to piping and pipeline industries
Pressure Vessels	Standards specific to the fasteners used in boilers and other pressure vessels
Railroad	Standards specific to bolts and nuts relevant to the railroad industry
Shipping	Broad and unspecific standard guides for the shipping, packaging, and marking of fasteners
Space	Standard practices for spacecraft materials, coatings, and testing methods; includes standards for materials specific to outer space environments

TABLE 5 (CONT.)

Industry or Use	Description of Industry or Use
Steel Products	Standard specifications related to the manufacturing and fabrication of fasteners in the steel industry
Transmission Towers	Specific standards for fasteners and coatings important in transmission towers
Water Control	Standard practices related to water control and the temperature and flow control of ocean and on-line water supply

5.3 Domestic versus International Standards Samples

In addition to technical issues and industry sectors, the Argonne study sought to compare subjects across international borders and jurisdictions. This is complicated to some degree by the fact that certain domestic standards are international in scope. Therefore, in many instances, Argonne had to make a judgement as to whether a standard was international or domestic. Most of the conventions adopted for this study are associated with the publishing organization shown in Table 6, and a further level of detail can be found in the preliminary project database.

TABLE 6 STANDARDS DEVELOPMENT ORGANIZATIONS AND REGIONS IN PRELIMINARY DATABASE

Standard	Standard Organization	Region
API	American Petroleum Institute	Domestic
ASME	American Society of Mechanical Engineers	Domestic
ASTM	American Society for Testing and Materials	Domestic
BS	British Standards	International (Britain)
DNV-GL	Det Norske Veritas and Germanischer Lloyd	International (Norway, Germany)
EPRI	Electric Power Research Institute	Domestic
ET	Petrobras Standards	International (Brazil)
FF	Federal Specifications	Domestic
IBECA	IBECA Technologies	International (Canada)
IFI	International Fasteners Institute	Domestic
ISO	International Organization for Standardization	International (Switzerland)
MIL	U.S. Military	Domestic
NACE	National Association of Corrosion Engineers	Domestic
NASA	National Aeronautics and Space Administration	Domestic
NAVAIR	U.S. Navy	Domestic
NORSOK	Norsk Sokkels Konkuranseposisjon	International (Norway)
NRC	U.S. Nuclear Regulatory Commission	Domestic
TT	Federal Specifications	Domestic
USCAR	U.S. Council for Automotive Research	Domestic
USCG	U.S. Coast Guard	Domestic

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6.0 Comparisons of All Standards Sampled

6.1 Oil and Gas versus Other Industries

The scope and technical content of standards varies considerably. For example, oil and gas industry bolting- and fastener-related ASTM standards tend to focus on the technical subjects related to manufacturing and do not address design or maintenance subjects. The ASTM Core Group standards (as commonly used by, but not expressly identified for, the oil and gas industry) do define certain quality assurance actions, as do the API standards, but there is not a universal outline of subjects addressed by these two organizations. In some instances, one standard parallels other standards with virtually identical outlines. A good example of this is API 20E and API 20F since both concern bolting, but one provides guidance for low-alloy steel products and the other provides guidance for corrosion-resistant alloy products. However, when looking at bolting standards published by multiple organizations representing many industries, even though common subjects are likely there is an expectation of scope differences because of industry specific needs.

The Venn diagram in Figure 3 presents the scopes of standards (standards are listed in Section 14.0), comparing industry topics (as listed in Table 4 above), other industries, or some combination of the two. From the diagram, oil and gas only has one unique topic—control systems—but shares a variety of topics with other industries. As shown in the right portion of the figure, many subjects are apparently not covered by oil and gas standards for bolting. This is because industries are not clearly defined in the documents. As explained previously, rather than assign an industry to a standard subjectively, industry association for purposes of data compilation was limited to the language in the standards documents. For instance, API 20E references ASTM A193/A193M, ASTM A194/A194M, ASTM A320/A320M, and ASTM A540/A540M. Although API 20E is clearly an industry standard, the scope section of each of these particular references lacks any link to an industry other than nuclear in ASTM A540/A540M. Instead, the applicability relates to service circumstances such as pressure vessels and temperatures. Therefore, Figure 3 is a perspective based on actual language in the documents and does not reflect referenced content or actual practice, such as the API 20E situation. In practice, most of the topics in the right-hand cell appear in referenced documents even though those documents do not declare association with the oil and gas industry.

Additional notes about topics shown in the right hand portion of Figure 3 include:

- Bend test,[19] which does appear in API 6A and API 53, but not expressly for bolts;[20]
- Creep testing (for low-alloy steels) does not appear in API 20E or ASTM A962/A962M;
- Electroplating (zinc electroplating not permitted in API 20E);
- Fracture toughness, not to be confused with Charpy only;
- Grain size, as size is specified for non-CRA steels, appears in ASTM A193/A193M, but does mention uniformity;
- Radiographic examination—API 53 mentions the NDE process with no details; and
- Vacuum degassing is mentioned in API 6A, but not specifically tied to bolts. Vacuum induction furnace is in A193/A193M and A962/A962M as a vacuum treating option.

A possible explanation for some of these omissions is that usually drill-through equipment is not necessarily subject to life cycles of two or more decades, as is equipment in other industries or even subsea oil and gas production hardware and equipment.

An interesting observation from the collection of bolt standards is that the transportation industry (automobile, aviation, and heavy trucks) tends to use fasteners per Society of Automotive Engineers (SAE) standards rather than just ASTM specifications. Standard SAE J429 ("Mechanical and Material Requirements for Externally Threaded Fasteners"),[21] for example, is similar in scope to the ASTM Core Group and defines tensile strength minimums, hardness, elongation minimums, and tempering temperature along with four grade levels (1, 2, 5, and 8) that are roughly equivalent to ASTM A307 ("Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60,000 psi Tensile Strength"), A449 ("Standard Specification for Hex Cap Screws, Bolts and Studs, Steel, Heat Treated, 120/105/90 ksi Minimum Tensile Strength, General Use"), or A354 ("Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners") for sizes larger than 1.5 inches. These bolt standards are not commonly used for oil and gas subsea applications. Further, some automotive bolts are zinc plated per ASTM F1941 and F2329 ("Standard Specification for Zinc Coating, Hot-Dip, Requirements for Application to Carbon and Alloy Steel Bolts, Screws, Washers, Nuts,

[19] Bend tests are a measure of ductility.

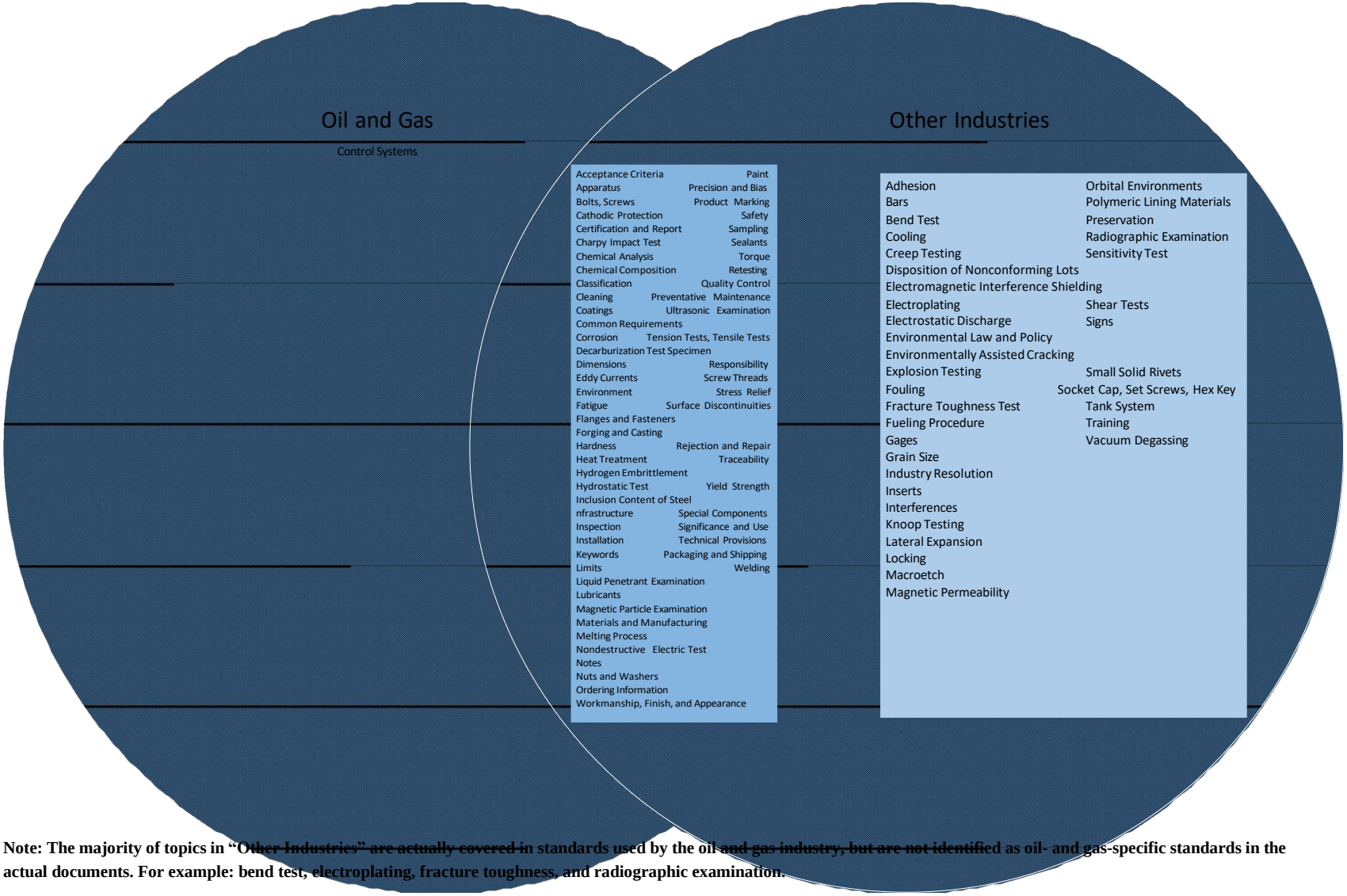
[20] Comparisons based on ASTM A193/193M, ASTM A194/A194M, ASTM A320/A320M, ASTM A453/A453M, ASTM A540/A540M, ASTM A962/A962M, ASTM A1082/A1082M, API 6A, API 16D, API 20E, and API 53. All are latest editions.

[21] http://www.portland bolt.com/technical/specifications/sae-J429.

and Special Threaded Fasteners”). Zinc electroplated coating is disallowed in the latest API 20E in paragraph 5.4.8.3.

6.2 Domestic versus International

The previous section looked at scope variations between oil and gas and other industries based on the standardized topic definitions that actually appear in the standard (which would not capture a normative reference content). This section looks at the same standards group comparing domestic and international. The Venn diagram in Figure 4 characterizes this comparison. With the exception of the nondestructive electric test (being the only subject not addressed domestically), all topics are represented across all industries sampled.



Note: The majority of topics in "Other Industries" are actually covered in standards used by the oil and gas industry, but are not identified as oil- and gas-specific standards in the actual documents. For example: bend test, electroplating, fracture toughness, and radiographic examination.

FIGURE 3 ALL SAMPLED BOLT STANDARDS TOPICS: OIL AND GAS (AS IDENTIFIED IN EACH STANDARD) VERSUS OTHER INDUSTRIES

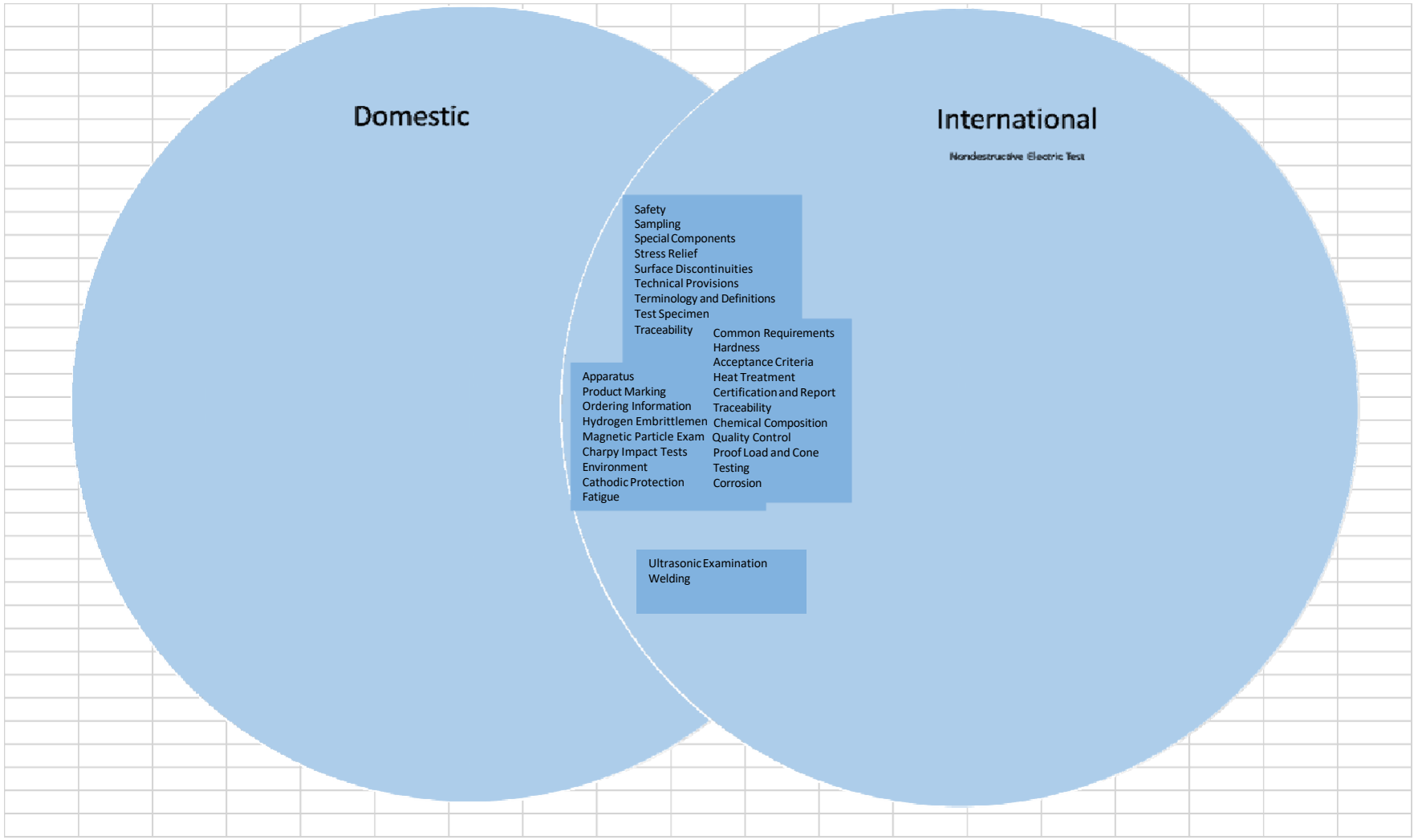


FIGURE 4 TOPICAL COMPARISONS OF ALL STANDARDS SAMPLED: DOMESTIC VERSUS INTERNATIONAL

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7.0 ASTM and API Core Group Gaps

7.1 Overview

Initially, subject gaps were identified primarily through the recognition that certain topics were not present or were only partially addressed. Often, these gaps (fatigue, corrosion areas, and traceability aspects) were consistent with the anticipated scope of the document relative to the document's issuing organization and purpose. For example, an ASTM standard for bolt manufacturing would not establish design stress limits, and a quality program requirements document such as from ASME or API would not normally be expected to cite bolts or fasteners. Part of this identification also emerged from macroscopic comparisons, such as those presented in Section 3.0. An original objective was to identify entire discontinuities. However, later in the project, technology gaps emerged in degrees rather than entireties. Key topics such as allowable bolt tensile stress, coating requirements, and cathodic protection guidance appear in standards documents, but not to the same levels of detail. Table 7 illustrates this reality; cases of partial treatment are mixed with a clear presence or none at all.

Graded categories of topic coverage level for Table 7 are as follows:

- Yes: Topic or subject exists in document or group of documents.
- Yes, partial: Subject appears, but is not consistently addressed in document or group of documents.
- No: Topic does not appear in document or group of documents.
- No, incomplete: Document mentions subject, but there is not a full treatment of the details expected.
- N/A: Not applicable because standard would not be expected to address the topic.

Each block has a different color because of the mix of groups and standards. More thorough impact and significance assessment should consider both the group and intent of the standard.

There is a number of qualifying and clarifying statements associated with the figure. These appear in the following subsections of Section 7. All the standards in the figure pertain to bolts and fasteners for subsea applications.[22] NACE MR0175/ISO-15156-3 ("Petroleum and Natural

[22] API Q1 and Q2 are generic quality systems covering manufacturing and servicing phases of the life cycle that includes the use of fasteners in equipment and systems.

Gas Industries—Materials for Use in H2S-Containing Environments in Oil and Gas Production") does not refer to bolts, but instead refers to "threaded items."

TABLE 7 OVERVIEW OF CORE GROUPS AND SELECTED INDIVIDUAL STANDARDS TOPIC COVERAGE

Subject	ASTM Core Group	Regulatory Core Group	API Q1	API Q2	API 20E	NACE MRO 175-3 (15156-3)
Term **bolt, screw, nut, and/or stud in document**	Yes	Yes	N/A	No	Yes	Yes, partial
Bolt fatigue	No	No, incomplete	N/A	N/A	No	N/A
Bolt tensile stress limit	N/A	Yes	N/A	No	No	N/A
Cathodic protection	No	Yes, partial	N/A	N/A	No	N/A
Hydrogen embrittlement	Yes, partial	Yes, partial	N/A	N/A	Yes	No, incomplete
Coatings	Yes, partial	Yes, partial	N/A	N/A	Yes, partial	Yes, partial
Traceability (for life cycle)	Yes, partial	Yes, partial	Yes, partial	No, incomplete	Yes, partial	Yes, partial
Maintenance specifies bolts	N/A	No	N/A	No, incomplete	N/A	N/A
Hardness	Yes	Yes, partial	No	N/A	N/A	N/A

7.2 ASTM Core Group Gap Characterizations

7.2.1 Bolt Fatigue

Bolt fatigue criteria are not found in any of the ASTM Core Group standards (note that the ASTM Core Group does not include API standard content, which appears in Section 7.3. Based on the standards' scope, this is expected. The common standard ASTM A962/A962M has optional considerations for dynamic service (S54). These requirements are for examining surface discontinuities, decarburization, thread lap inspection, quench cracks, folds at junction of head and shank, microscope examination, and micro-hardness measurement. However, this dynamic service option is at the discretion of the purchaser.

7.2.2 Cathodic Protection

Cathodic protection requirements are not mentioned in the ASTM Core Group. This is consistent with the expected scope of the standard, since this type of protection is not something that can be readily done at the bolt level.

7.2.3 Hydrogen Embrittlement and Coatings in ASTM Core Group

Within the ASTM Core Group, hydrogen embrittlement is only specifically mentioned in ASTM A193/A193M and A194/A194M. The remaining standards in the group, including ASTM A962/A962M, do not address this subject. However, referenced standards in those standards do mention hydrogen embrittlement, including

- ASTM B633;
- ASTM B849;
- ASTM B850; and
- ASTM F1941.

Details on which ASTM Core Group standard references each of these standards are shown in Figure 2 and in the table in Appendix A: Oil and Gas Standard Subset Matrix. Related information also appears in Table . Neither B849 nor B850 is referenced in the ASTM Core Group.

7.2.4 Traceability

Traceability is largely a quality assurance function, but is not comprehensibly defined in one place and certainly not in the ASTM Core Group. All of the primary bolting standards defer to ASTM A962/A962M, which defines the closest thing: a certification report. Unfortunately, that report is elective for the purchaser. Therefore, compliance in the context of

- ASTM A193/A193M,
- ASTM A194/A194M,
- ASTM A320/A320M,
- ASTM A453/A453M,

- ASTM A540/A540M, and
- ASTM A1082/A1082M

means little if this option is not required. API 20E and API 20F require a "record of qualification." This documentation is similar to ASTM certification, but specifically does not include coatings. At this time, use of API 20E and API 20F is voluntary because the standard is not incorporated by reference in BSEE regulations and has yet to be fully implemented in all of the API system of standards for subsea drill-through equipment.

7.3 API Core Group Gap Characterizations

7.3.1 Fatigue

Fatigue is addressed in the API Core Group, but not with consistency and substantial depth of detail for bolting. The standards API 16A and 16F have significant criteria applicable to the component or vessel, but bolt and fastener design limits are not explicitly covered. API 53 includes several bolting requirements, such as for torqueing and visual inspection, but defers design related issues to API 6A, API 16A, and API 17D ("Design and Operation of Subsea Production Systems-Subsea Wellhead and Tree Equipment"). API 16Q, which relates to life cycle (design, selection, operation, and maintenance), provides cyclic design criteria without mentioning bolts. Consequently, *some analysts may evaluate bolt fatigue for a critical application, while others may not* since there is not absolute specificity regarding whether the bolts are or are not "equipment."

7.3.2 Tensile Stress Limit

Three of the API standards have criteria limiting bolt tensile stress[23]:

- API 16C, and API 6A, designating membrane stress at 83% of minimum yield strength;
- API 16A, which includes an additional criteria for membrane plus bending at 100% of yield strength. Yield strength is defined at 0.2% offset (from actual linearized stress strain plot) consistently. This situation results in some potential inconsistency, while the other

[23] Note: these and other standards cited in this report may or may not be the latest versions at publication time. The report is a snapshot of standards at the time comparisons were done.

standards in the grouping are silent on the design stress guidance. These are: API 16Q, 16D, 16F, 53, and 16AR.

7.3.3 Cathodic Protection

Cathodic protection is addressed in two standards of the group: API 16F and 16D. Essentially, API 16F recognizes the issue with a general statement that bolting must have low susceptibility to hydrogen embrittlement. The standard API 16D requires cathodic protection per NACE RP-0176 (“Corrosion Control of Steel Fixed Offshore Structures Associated with Petroleum Production”). The remaining standards of the API Core Group do not mention the subject, and none have specificity. These are

- API 16A,
- API 16AR,
- API 16C,
- API 16Q,
- API 53, and
- API 6A.

7.3.4 Hydrogen Embrittlement

There is considerable inconsistency concerning standard treatment of hydrogen embrittlement. The drill-through equipment standard API 16A, Section 4.3.3.2.1, links alloy and carbon steel bolts to a maximum hardness of 34 HRC for hydrogen embrittlement concerns. The riser equipment standard, API 16F, includes ASTM B850 in the normative references. Standard API 53 introduces the subject as a caution for equipment modifications.

7.3.5 Coatings

For drill-through equipment, API 16A calls for the OEM to follow NACE MR0175/ISO 15156. This appears to be based on concern for dimensions (and clearances). As mentioned in Section 7.3.4, there is reference to ASTM B850 regarding post-coating treatment for hydrogen embrittlement control.

7.3.6 Traceability

Traceability is mostly a quality control function, but standards do sometimes include this aspect. Just as this is important for newly manufactured items, API 16AR does mention the creation and maintenance of records through the "Certificate of Service" by a competent authority. From context, this appears to be limited to pressure-retaining parts, and the definition continues to include ram door bolting as an example. Responsibility for the certificate is assigned to the manufacturer, remanufacturer, or other technical authority. Concise definitions for these named entities are not given.

7.3.7 Maintenance

The maintenance and inspection section of API 16D calls out "mechanical components," but not expressly bolt condition. This is indefinite, as some would interpret it one way, and others another way. API 53 does call for visual inspection of bolts to confirm tightness and surface condition as part of a preventive maintenance program.[24] The remainder of the standards in this API Core Group is silent with regard to bolt maintenance or inspection. These are:

- API 16A,
- API 16AR,
- API 16C,
- API 16F,
- API 16Q, and
- API 6A.

7.3.8 Hardness

7.3.8.1 Low Alloy Steel Bolting

As shown Table 8, bolt hardness is dependent on the specification or even proprietary practices as mentioned in API 20E. The hardness requirements can be diameter dependent, but there is a possible inconsistency between API 20E and the ASTM relative to maximum hardness. As

[24] At section 4.3.4 but without concise definition of preventive maintenance program elements.

shown for the grades specified in API 20E (near the bottom of the table and denoted by a blue block adjacent to the particular grade or class cited in API 20E), the not-to-exceed (maximum) is 34 HRC compared to the ASTM standard, which is as high as 35 HRC. ASTM A453/A453M and A1082/A1082M are not referenced in API 20E, but grade 660 Class D is referenced in API 20F. As shown in the table, some API 20E classes and grades can be as low as 24 HRC, and API 20E does not include all grades and classes in the ASTM Core Group. An interesting variation in all this appears in the common specification, ASTM A962/A962M. As listed in the table, paragraph 9.2 allows tensile tests to prevail over hardness tests relative to minimum strength, unless specified otherwise in the product specification.

7.3.8.2 Corrosion Resistant Alloy Bolting

Table 8 summarizes hardness requirements defined in API 20F. This version only references one ASTM grade—ASTM A453/A453M-660 Class D—and API 6A-718 ("Nickel Base Alloy 718 [UNS N07718] for Oil and Gas Drilling and Production Equipment"[25]) generally. Hardness requirements are deferred to ASTM A453 or API 6A718. In that ASTM standard, "approximate" hardness is a range of 24 to 35 HRC, and as described above, the caveat in the common standard ASTM would allow tensile testing to prevail unless limited otherwise.

[25] This standard has been replaced with API 6ACRA ("Age-Hardened Nickel-Based Alloys for Oil and Gas Drilling and Production Equipment").

TABLE 8 SELECTED ASTM CORE GROUP AND API BOLTING STANDARDS' REQUIREMENTS IN THE HRC RANGE [26]

Standards and Bolt Grades/Classes/Type		HRC (lower or minimum)	HRC (upper or maximum)	Notes
ASTM A193/A193M-15a (From Table 2, metric products similar in Table 3)				
	B6X, 13 Cr		26	Up to 4 in diameter, max. hardness
B7[27]	B7, Cr-Mo		35	Up to 7 in diameter, max. hardness
	Classes 1C and 1D: B8R, (carbon solution treated), Class 1C: B8RA (carbon solution treated in finished condition), Class 1C and 1D: B8SA (carbon solution treated) and Class 1C:B8SA (carbide solution treated in the finished condition)		28	All diameters, max. hardness
	Class 2: B8, B8C, B8P, B8T, B8N (carbide solution treated and strain hardened)		35	Up to 1.5 in diameter, max. hardness
	Class 2: B8M, B8MN, B8MLcuN (carbide solution treated and strain hardened)		35	Up to 1.5 in diameter, max. hardness
	Class 2B: B8, B8M2 (carbide solution treated and strain hardened)		35 (at half radius) over 1.5 in)	Up to 3 in diameter, max. hardness
	Class 2C: B8M3 (carbide solution treated and strain hardened)		35 (at half radius over 1.5 in)	Up to and above 2 in diameter, max. hardness
ASTM A194/A194M-15a (From Table 2)				
	2H to 1.5 in or M36, incl.	24	35	Hardness range to 1.5 in
2H	2H over 1.5 in or M36		35	Max hardness
4,7	3,4,7 and 16	24	35	
	8, 8C, 8CLN, 8M, 8T, 8F, 8P, 8N, 8Mn, 8LN, 8MLN, 8MLCuN, 8ML4CuN, and 9C		32	Max hardness
	8R, 8RA, 8S, and 8SA		25	Max hardness

[26] Note: This table is intended for approximate comparisons only. The actual standard should be used for a detailed situation.

[27] Denotes specific grades, types, or classes cited in API 20E.

TABLE 8 (CONT.)

Standards and Bolt Grades/Classes/Type		HRC (lower or minimum)	HRC (upper or maximum)	Notes
ASTM A320/A320M-15a (Table 1)				
	L7, L7A, L7B, L7C, L70, L71, L72, L73 (quenched and tempered)		35	Max. hardness, 2.5 in diameter and under
	L43 (quenched and tempered)		35	Max. hardness, 4 in diameter and under
	Class 2: B8, B8C, B8P, B8F, B8T (carbide solution treated and strain hardened)		35	Up to 1.5 in diameter, max. hardness
	L7		35	Up to 1.5 in diameter, max. hardness
ASTM A453/A453M-15 L43 *(Table 5: all hardness values are approximate range with maximum)*				
		24	*37*	
	660, Class D	*24*	*35*	
	662, Class A and B	*24*	*35*	
	665, Class A and B	*32*	*41*	
	668, Class A and B	*24*	*37*	
ASTM A540/A540M-15 (Table 2, higher strength only unless cited in API 20E, converted from Brinnell, all surface hardness, metric similar)				
	B21, Class 2 (Cr-Mo-V, 155 ksi)	~33 (311 B)	~43 (401 B	To 4 in diameter
	B21, Class 1 (Cr-Mo-V, 165 ksi)	~34 (321 B)	~46 (429 B)	To 4 in diameter
B22	B22, Class 5 (4142 H, 105 ksi)	~24(248 B)	~31(293 B)	To 2 in, larger different (harder)
B22	B22, Class 4 (4142 H, 120 ksi)	~28(269 B)	~37(341 B	To 1 in, larger different (harder)
B22	B22, Class 3 (4142 H, 130 ksi)	~31(293 B)	~39(363 B)	To 2 in, larger different (harder)
B22	B22, Class 2 (4142 H, 140 ksi)	~33 (311 B)	~43 (401 B)	To 3 in incl.
B22	B22, Class 1 (4142 H, 150 ksi)	~34 (321 B)	~43 (401 B)	To 1.5 incl.
B23	B23, Class 5 (E-4340-H, 105 ksi)	(248 B)	~33 (311 B)	To 6 in, larger harder
B23	B23, Class 4 (E-4340-H, 120 ksi)	~28 (269 B)	~37 (341 B)	To 3 in, larger different (harder)
B23	B23, Class 3 (E-4340-H, 130 ksi)	~31 (293 B)	~39 (363 B)	To 3 in, larger different (harder)
B23	B23, Class 2 (E-4340-H, 140 ksi)	~33 (311 B)	~42 (389 B)	To 3 in (larger to 8 in different hardness limits)

TABLE 8 (CONT.)

	Standards and Bolt Grades/Classes/Type	HRC (lower or minimum)	HRC (upper or maximum)	Notes
B23	B23, Class 1 (E-4340-H, 150 ksi)	~34 (321 B)	~44.5 (415 B)	To 3 in, larger different (harder)
	B24, Class 2 (4340 Mod, 155 ksi)	~33 (311 B)	~43 (401 B)	To 7 in diameter, larger to 8 in different)
	B24, Class 1 (4340 Mod, 165 ksi)	~35.5 (331 B)	~46 (429 B)	To 6 in diameter, larger to 8 in different
	B24V, Class 2 (4340V-Mod, 140 KSI)	~33 (311 B)	~42 (388 B)	To 4 in, up to 11 in different
	B24V, Class 1 (4340 V-Mod, 150 ksi)	~34 (321 B)	~44.5 (415 B)	To 4 in incl., up to 11 in different
ASTM A1082/A1082M-15 (Table 2: stainless steel precipitation-hardening solution treatment condition)				
	Type 630 (cool to below 90°F)		38	1.5 in and smaller
	Type 635 (air cool)		32	1.5 in and smaller
ASTM A962/A962M-15 (Common ASTM requirements to all above ASTM bolt standards)				
	Hardness per product specification at paragraph 9.1			At 9.2: "*Tensile tests prevail over hardness tests in the event a conflict exists relative to minimum strength unless otherwise specified in the product specification*"
API 20E (Section 5.9.2.2.1, ASTM A193, A194, A320, A540, or proprietary manufacturers' specifications)				
	Hardness per product specification and all measurements to be within 3 HRC (paragraph 5.9.2.3.1)		34	Not to exceed 34 HRC specific per paragraph 5.9.2.2.1
API 20F (1st Edition) (Reference in paragraph 4.3.2)				
	General reference to ASTM A453 in BSL definition and, for materials, grade 660 Class D (not ASTM A453/A453M or specific version); also API 6A718	32	40	Per ASTM A453 or 6A718, Sections 4.5 and 5.9 (not Section 5.9.1 as shown in Table 1)

8.0 Other Pertinent Standards, Quality, API 20E, and API 20F

8.1 API Q1

Overall, the scopes of API Q1 *do* contain guidance on traceability and records. Logically, this coverage should include bolts and fasteners for covered equipment. However, API 20E and API 20F are generic and only cover the manufacturing and service industry portions of the life cycle. Thus, to establish full traceability, the owner or operator must implement other quality systems. In API Q2, there are provisions for exclusions, yet traceability is required on critical service products. This appears to be a preventive measure intended to establish traceability back to the original manufacturer. Traceability is delegated to the "organization" without clarification as to how records continuity should occur. Further, the word *critical* is not linked to well control for bolts and fasteners and there is not a definition for "critical service" in the standards definitions in Section 3.

8.2 API 20E

Specification API 20E bridges and amends aspects of the API Core Group for low-alloy steel materials with the exceptions of ASTM A453/A453M and A1082/A1082M. API 20F is a companion standard to API 20E, which does reference ASTM A453/A453M.[28] The required "record of qualification" in both these standards is similar to optional certification in the ASTM Core Group, but is not optional. However, there is not a requirement in API 20F for the record to be available and auditable to the purchaser as there is in API 20E.

Unfortunately, the topics in API 20E do not include full details on standardized coatings (of any kind), the application of those coatings, and corrosion control measures in general. The coating omission appears to be an approach to not require disclosing proprietaryprocesses. Other technical topics could likewise be proprietary, and the documents could be marked accordingly to address this aspect.[29] With references to ASTM B850 and F519 ("Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments"), the hydrogen embrittlement topic is addressed within the standards arena. The

[28] The notation with regard to referencing the ASTM Core Group in the entirety of both API 20E and API 20F does not include the metric aspect or the full ASTM designation (example: ASTM A193 instead of the full designation ASTM A193/A193M).

[29] Note: Information provided to the U. S. government can be marked as "Proprietary" and be exempted from public disclosure though the Freedom of Information Act.

document (API 20E) does call for baking within two hours following plating and disallows the use of zinc coating.

A common issue with API 20E and API 20F and with the ASTM Core Group is identifying the performer(s) of certain quality function(s). For example, in the course of defining "record of qualification" in API 20E, the responsibility remains less than clear. Another example is in API 20F, where there is not a definition for "bolting manufacturer," yet roles appear elsewhere. This all appears to give the eventual owner flexibility over procured items and how or who should establish and maintain quality records. Another interesting observation is that API specification Q1 is a normative reference in API 20E, but not in API 20F, even though the two standards' outlines are nearly identical.

8.3 NACE MR0175-3 Petroleum and Natural Gas Industries — Materials for Use in H2S-Containing Environments in Oil and Gas Production

The NACE MR0175/ISO-15156-3 standard refers to threaded items without using the word "bolt" and similar common terms. Further, the standard only addresses materials, even though there are prescribed record-keeping requirements.

9.0 Domestic Industry Standards Observations

9.1 Cross-Cutting Standards and Codes

Bolt-related standards are not necessarily specific to a particular industry on the basis of the scope statements included. Aspects, such as thread forms, head and nut dimensions, head types, drive interfaces, shank sizes, and lengths, are highly standardized nationally and internationally to the extent that ordinary products are available as replacements from many sources. Such products are produced and distributed in bulk, whereas different grades and strengths are based on standard markings per organizations such as ASME, ASTM, and SAE. However, as bolt or threaded fastener requirements become more specialized and demanding, such bolts become a specialty item not readily available off the shelf, and in some cases, are only available from the manufacturer of the item. Quality requirements also change, and this is evident from the ASTM Core Group standards and API 20E. A bolt for a critical application needs to be procured specific to the application, with a good deal of assurance the correct bolt is obtained, placed into proper service, and maintained.

9.1.1 ASME Boiler and Pressure Vessel Code Used Across Multiple Industries

The ASME BPVC applies across many industries and interests and is available in a variety of languages other than English for use worldwide. Two categories demonstrate this diversity of application: fired and unfired pressure vessels, both of which occur in many industries. These vessel standards reach beyond heavy industry and even include consumer propane tanks and air compressor receivers. Many states and jurisdictions formally ban non-coded vessels for safety reasons. Of course, ASME BPVC, Section III (“Rules for Construction of Nuclear Facility Components,” including nuclear power plants), is also a major part of the BPVC, along with Section XI (“Rules for In-service Inspection of Nuclear Power Plant Components”), which addresses in-service inspection for nuclear plants. The related ASME NQA-1 (“Quality Assurance Requirements for Nuclear Facility Applications”) is a quality system that parallels the criteria set forth by the U.S. Nuclear Regulatory Commission for nuclear plant owners. This nuclear quality assurance (QA) system follows a graded approach, wherein more attention is directed toward critical equipment, including more comprehensive traceability. ASME also publishes standards on thread forms and head details separate from the BPVC. These specific standards are heavily referenced throughout ASTM bolt manufacturing standards.

9.1.2 ASTM A962/962M Applications beyond the ASTM Core Group

ASTM A962/A962M is often referenced in other ASTM standards, as shown in Figure 2 and is referenced in API 20E and API 20F, but is not heavily (not at all in the Argonne sample) referenced in NACE, ASME, or military standards. Figure 5 illustrates what some other standards reference instead of ASTM A962/A962M. The standard ASME SA320 (Specification for Alloy Steel Bolting Materials for Low Temperature Service) is supposed to be comparable to ASTM A320/A320M-99. However, as shown in the figure ASTM A320/A320M (2015) references ASTM A962/A962M, while ASME SA320 does not.

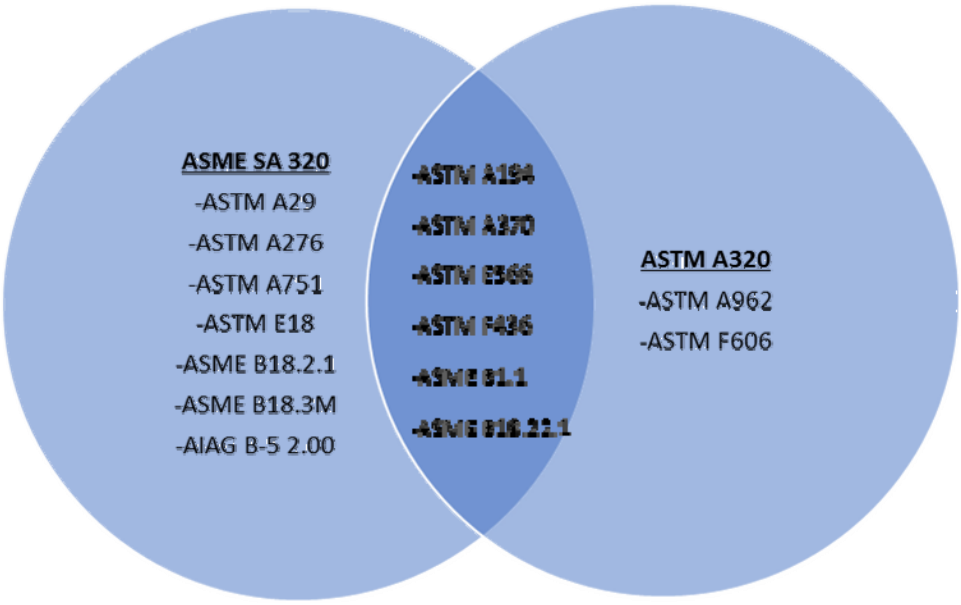


FIGURE 5 SOME REFERENCES TO "EQUIVALENT" STANDARDS (ASME SA 320 AND ASTM A320/A320M)

Both ASME SA320 and ASTM A962/A962M reference ASME B18.2.1 ("Square, Hex, Heavy Hex, and Square Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head, and Lag Screws [Inch Series]") and B18.3 ("Socket Cap, Shoulder, Set Screws, and Hex Keys [Inch Series]") for the mechanical details of threaded products. MIL-DTL-1222J ("Detail Specification: Studs, Bolts, Screws and Nuts for Application Where a High Degree of Reliability Is Required") also references ASME B18.2.1 and B18.3. NACE does not appear to be referenced in these standards and thus appears to be a standalone standard relative to subsea bolting.

9.1.3 Cross-Cutting Quality Assurance Standards Scope Comparisons

ASME B18.18 ("Quality Assurance for Fasteners") is a general quality assurance standard for the fastener industry. This standard complements a handful of other standards referenced in a variety of general industry standards (such as ASME B1.1, "Unified Inch Screw Threads-UN and UNR Thread Form," and B18.2.1). Standard B18.18 appears in the normative references of ASTM A962/962M, but not in any of the remaining ASTM Core Group standards. The first edition of API 20E includes A962/962M as a normative reference, and while defining bolt service levels (BSLs), does not list a full life cycle quality system. The second edition of API 20E lists API Q1 as well as A962/A962M. Along with BSLs, API 20E has a revised list of records criteria. For record of qualification[30] criteria, scope only covers the fastener life cycle up to shipment from the manufacturer. In any event, API bolts even for critical applications appear to not have full life cycle quality assurance unless the owner elects to do so.

9.2 Fatigue in ASME BPVC

Design requirements for bolt fatigue appear in hundreds of places throughout the entire ASME BPVC (All sections). Most of these requirements are nuclear related and are found in ASME BPVC Section III. However, there are a good number of technical requirements related to fatigue in Sections II, XI, and VII, and the ASME fitness for service requirements (titles in Table 9). Table lists a sampling of the nonnuclear references and details. This is a mix of interpretations, material specifications, and samples from the BPVC text.

TABLE 9 SAMPLING OF BOLT FATIGUE REFERENCES IN THE ASME BPVC[31]

ASME BPVC Section	Cited Portion	Content and Relevant Wording
ASME BPVC, Section VIII, Division 3	Article KD-3, Figure KD-320.5	Fatigue requirements and "the designer" shall consider that corrosion effects on a bolted connection can reduce bolt fatigue life.
ASME FFS-1 ("Fitness for Service")	Figure 14B.8	*Fatigue Curve for High-Strength Bolting For Temperatures Not Exceeding 700°F – Maximum Nominal Stress ≤ 2.7S.*

[30] Section 4.5, API Specification 20E.
[31] From the Engineering Workbench for the 2015 version of ASME BPVC.

TABLE 9 (CONT.)

ASME BPVC Section	Cited Portion	Content and Relevant Wording
ASME BPVC, Section XI ("In-service Inspection of Nuclear Power Plant Components")	Interpretations Volume 36-Section XI	*Preservice Examination […] component supports [...] edition of Section V [...] exemptions - gasket replacements [...] integrally cast steam generator nozzle [...] limited to [...] of Class 2 vessel [...] of manways – bolting [...] piping, pumps, and valves – hydrostatic testing [...] pumps and valves - VT-3 prior to service [...] ultrasonic examination - acceptance standards.*
ASME BPVC, Section VIII, Division 1 ("Rules for Construction of Pressure Vessels-Division 1)	VIII-1-83-42. BC82-416. 26	Bolting fatigue
ASME BPVC Section II-A-1 ("Materials-Part A-Ferrous Materials Specifications")	Section IIA Ferrous Material Specification (beginning to SA-450) Materials	Fatigue data
ASME BPVC, Section VIII, Division 3 ("Rules for Construction of Pressure Vessels Division 3-Alternative Rules for Construction of High Pressure Vessels")	Case 2514-1	*FIG. 1M DESIGN FATIGUE CURVE FOR 21/4Cr-1Mo-V STEEL FOR TEMPERATURES NOT EXCEEDING 800°F (427°C) AND 850°F (454°C) 3 (2514-1) SUPP. [...] The average primary stress intensity in bolts shall be based on the thread root diameter and shall not exceed the maximum allowable stress values of Sin in Table 3 of Section II, Part D.*

9.3 Cathodic Protection and Other Failure-Mitigation and Corrosion-Control Practices

ASME (including ASME B31.1, "Power Piping"; ASME Code for "Pressure Piping"; and ASME B31.8, "Gas Transmission and Distribution Piping Systems") and ASME BPVC (including Section VIII, "Rules for Construction of Pressure Vessels"; Division 3, "Alternative Rules for Construction of High Pressure Vessels"; Section II, "Materials"; and ASME BPVC.II.D.C) require cathodic protection. Most applications of the cited standards are buried pipelines or tanks. A basic requirement is thickened walls for corrosion allowance. A similar provision appears in the pressure vessel standards, depending on materials and other factors. Added thickness is often not credited in vessel strength design, as the assumption is that eventually the material will not be present.

9.3.1 Electrodeposited Coatings

The most commonly referenced electrodeposited coatings in the Argonne sample are ASTM B633 and ASTM F1941. Both ASTM A193/A193M and A194/A194M reference these electrodepositing standards. As shown in Table 10, B633 is directly referenced by several military standards, and F1941 is directly referenced by ASME standards. These electrodepositing standards are often secondary references (usually through ASME B18.2.1 or ASTM A193/A193M), with the exception of NACE. Of the NACE standards collected, only NACE SP0387 ("Metallurgical and Inspection for Cast Galvanic Anodes for Offshore Applications") references ASTM B633. However, NACE SP0492 references BS1706 (British Standard "Method for Specifying Electroplated Coatings of Zinc and Cadmium on Iron and Steel").

TABLE 10 COATING STANDARDS REFERENCED BY SOME ASTM, ASME, AND MILITARY STANDARDS.

Standard Title	ASTM B633	ASTM F1941
ASTM A193/A193M	x	x
ASTM A194/A194M	x	x
ASTM F2437-14, "Standard Specification for Carbon and Alloy Steel Compressible-Washer-Type Direct Tension Indicators for Use with Cap Screws, Bolts, Anchors, and Studs"	x	x
IFI Hydrogen Embrittlement	x	x
ASME B18.2.1, 2013		x
ASME B18.2.3.3M, "Metric Heavy Hex Screws," 2007		x
ASME B18.3, 2012		x
ASTM B633, 2015	N/A	x
ASTM F1940, "Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners," 2007a		x
ASTM F1476, "Standard Specification for Performance of Gasketed Mechanical Couplings for Use in Piping Applications," 2007	x	
FF-N-836E, "Federal Specification: Nut, Square, Hexagon, Cap, Slotted, Castle, Knurled, Welding and Single Ball Seat"	x	
MIL-DTL-12133E, "Detail Specification: Washer, Spring Tension, General Specification for"	x	
MIL-DTL-21338B, "Detail Specification: Washer, Key Retaining, Ball and Rover Bearings"	x	
MIL-DTL-1222J, "Detail Specification: Studs, Bolts, Screws and Nuts for Application Where a High Degree of Reliability is Required"	x	
MIL-W-12133D, "Military Specification: Washer, Spring Tension, General Specification for Department of Defense"	x	
NACE SP0387"Metallurgical and Inspection for Cast Galvanic Anodes for Offshore Applications"	x	

9.3.2 ASTM General Cathodic Protection Standards

Many ASTM standards about cathodic protection discuss measurements and testing rates of corrosion, but do not discuss recommended practices specifically for offshore structures (some standards that reference these ASTM standards about cathodic protection appear in Table 11). Notably, standards API 16D and DNV-RP-B401 ("Cathodic Protection Design") both reference NACE RP0176 ("Corrosion Control of Steel-Fixed Offshore Structures Associated with Petroleum Production"). Further, bolt standards ASTM A193/A193M and ASTM A194/A194M reference ASTM F1940, but the remainder of the ASTM Core Group does not reference such standards.

TABLE 11 ASTM CATHODIC/GALVANIC PROTECTION STANDARDS THAT APPEAR IN NORMATIVE REFERENCES IN THE ASTM BOLT-RELATED STANDARDS

Standard Title	ASTM B418[a]	ASTM F1940	ASTM G116	ASTM G8[b]	ASTM G82[c]	ASTM G96[d]	ASTM F722[e]
ASTM G215, "Standard Guide for Electrode Potential Measurement," 2017					x	x	
NACE TM0169/G31, "Standard Guide for Laboratory Immersion Corrosion Testing of Metals," 2012a			x		x		
ASTM F2660, "Standard Test Method for Qualifying Coatings for Use on A490 Structural Bolts Relative to Environmental Hydrogen Embrittlement," 2013					x		
ASTM G116, "Standard Practice for Conducting Wire-on-Bolt Test for Atmospheric Galvanic Corrosion," 1999					x		
ASTM D6577, "Standard Guide for Testing Industrial Protective Coatings," 2015				x			
DNV-RP-B401				x			
MIL-PRF-23236D, "Performance Specification: Coating Systems for Ship Structures"				x			
NACE SP0169, "Control of External Corrosion on Underground or Submerged Metallic Piping Systems"				x			
NACE TM0204, "Exterior Protective Coatings for Seawater Immersion Service"				x			
ASTM A193/A193M		x					
ASTM A194/A194M		x					
ASTM F1136/F1136M, "Standard Specification for Zinc/Aluminum Corrosion Protective Coatings for Fasteners," 2011		x					
ASTM F1941/F1941M, Section 15		x					
ASTM F2833, "Standard Specification for Corrosion Protective Fastener Coatings with Zinc Rich Base Coat and Aluminum Organic/Inorganic Type," 2011		x					

TABLE 11 (CONT.)

Standard Title	ASTM B418[a]	ASTM F1940	ASTM G116	ASTM G8[b]	ASTM G82[c]	ASTM G96[d]	ASTM F722[e]
ASTM F3019, "Standard Specification for Chromium Free Zinc-Flake Composite, with or without Integral Lubricant, Corrosion Protective Coatings for Fasteners," 2014		x					
ASTM F3125, "Standard Specification for High-Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 Mpa), Minimum Tensile Strength, Inch and Metric Dimensions," 2015a		x					
ICEBA Hydrogen Embrittlement- 2006		x					
IFI Hydrogen Embrittlement		x					
NACE RP0176, "Corrosion Control of Steel-Fixed Offshore Structures Associated with Petroleum Production"	x						
NACE SP0176, "Corrosion Control of Submerged Areas of Permanently Installed Steel Offshore Structures Associated with Petroleum Production"	x						
ASTM F1155, "Standard Practice for Selection and Application of Piping System Materials," 2010							x

[a] "Standard Specification for Cast and Wrought Galvanic Zinc Anodes."
[b] "Standard Test Methods for Cathodic Disbonding of Pipeline Coatings."
[c] "Standard Guide for Development and Use of a Galvanic Series for Predicating Galvanic Corrosion Performance."
[d] "Standard Guide for Online Monitoring of Corrosion in Plant Equipment (Electrical and Electrochemical Methods)."
[e] "Standard Specification for Welded Joints for Shipboard Piping Systems."

9.4 Traceability

Traceability is important when subsea bolts used in critical applications fail and compromise a safety barrier. The domestic oil and gas industry follows QA program standards, but apparently does not have a unified full life cycle system standard even though the API quality standards have broadened with each new edition. In contrast, the U.S. nuclear industry does have such a system, as defined in the Code of Federal Regulations at Title 10, Appendix B to Part 50 for the NRC. Part of the specific criteria for each applicant's (usually owner organization) quality system, as conveyed through the NRC licensing track, is as follows[32]:

"Measures shall be established for the identification and control of materials, parts, and components, including partially fabricated assemblies. These measures shall assure that identification of the item is maintained by heat number, part number, serial number, or other appropriate means, either on the item or on records traceable to the item, as required throughout fabrication, erection, installation, and use of the item. These identification and

[32] Paragraph VIII. Link to U.S. Nuclear Regulatory Commission is: *https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appb.html*

control measures shall be designed to prevent the use of incorrect or defective material, parts, and components."

ASME BPVC, Section III, is the basis of nuclear steam supply system design, and the associated quality system is ASME NQA-1.[33]

For practical reasons, quality management should be implemented as a graded approach, wherein greater requirements apply to items of greater safety significance (much like the intent of bolt service level provisions in API 20E, and elsewhere in the API standards systems). Quality requirements of a properly approved plan in the NRC system and API (now) are in turn required of sub-tier suppliers and service providers. Such a broad system enables technical assessments of failures and enables lessons learned to be incorporated across the industry.

ASME B18.18 is a quality assurance outline for special purpose fasteners and is theoretically part of the API approach through API 20E and ASTM A962/962M. The ASME document covers sampling, inspection frequency, control procedures, and records/recordkeeping. According to the abstract,[34] the producer has the role of creating and maintaining process and inspection records. **Therefore BSEE's expectations should be that those using API 20E must apply this approach.**

[33] Quality Assurance Requirements for Nuclear Facility Applications (An American National Standard), ASME NQA-1-20154, American Society of Mechanical Engineers, 2015.

[34] https://ewb.ihs.com/#/document/TOSSJBAAAAAAAAAA?qid=63641687722279587 5&sr=as-9-20&kbid=4%7C20027&docid=940065478#hfe8b0e61

10.0 International Oil and Gas Industry Observations

10.1 Fatigue

One international fatigue-specific standard is DNVGL-RP-0005 (“Fatigue Design of Offshore Steel Structures”). This standard references other fatigue standards, including:

- ISO 12107 (“Metallic Materials—Fatigue Testing—Statistical Planning and Analysis of Data”),
- ISO 19902, (“Petroleum and Natural Gas Industries—Fixed Steel Offshore Structures”),
- ISO 2394 (“General Principles on Reliability for Structures”),
- ISO 5817 (“Welding—Fusion-welded joints in steel, nickel, titanium and their alloys [beam welding excluded]—Quality levels for imperfections”),
- BS 7910 (“Guide to Methods for Assessing the Acceptability of Flaws in Metallic Structures”), and
- NORSOK N-006 (“Assessment of Structural Integrity for Existing Offshore Load-Bearing Structures”).

Most references from this standard (DNVGL-RP-0005) that mention fatigue tests are articles or other papers written by Inge Lotsberg. From this, Inge Lotsberg seems to be a key fatigue specialist supporting the DNV standards. Some other standards that include fatigue test methods or terminology are ASTM E1823 (“Terminology”), ASTM E466 (“Axial Fatigue Test”), ASTM E606 (“Strain-Controlled Fatigue Testing”), ASTM E647 (“Standard Test Method for Measurement of Fatigue Crack Growth Rates”), ASTM G168 (“Standard Practice for Making and Using Precracked Double Beam Stress Corrosion Specimens”), and DNV-RP-C206 (“Fatigue Methodology”).

Table 12 shows standards that reference the above list of fatigue standards. DNVGL-RP-0005 is an international fatigue test standard that does not appear to have a domestic equivalent.

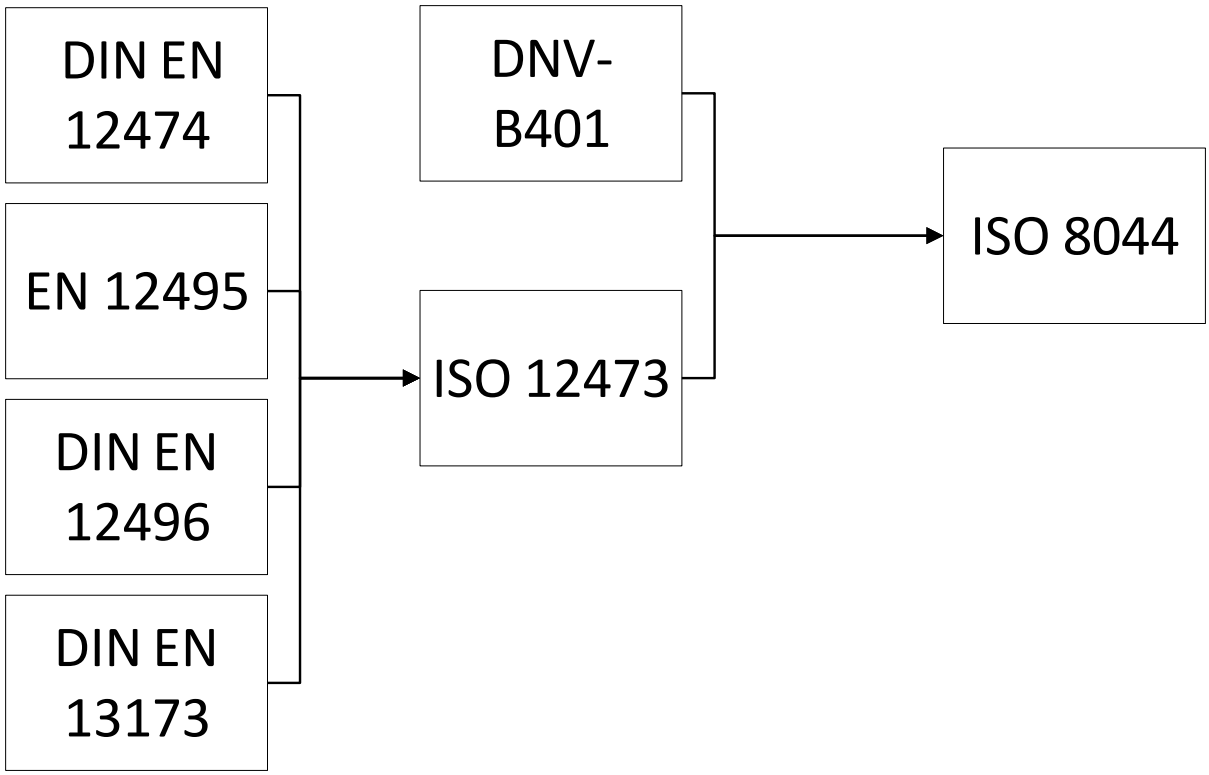
TABLE 12 PROMINENT INTERNATIONAL STANDARDS FATIGUE REFERENCES

Standard Title	ASTM E1823	BS 7910:2005	BS 7910	ISO 12107	ISO 19902	ISO 2394	ISO 5817	NORSOK N-006	ASTM E606	ASTM E466	ASTM E647
DNVGL-RP-0005, 2006		x		x	x	x	x				
DNVGL-ST-0035, "Subsea Equipment and Components," 2008					x						
DNVGL-OS-C101, "Design of Offshore Steel Structures, General-LFRD Method"			x								
DNVGL-RP-0002, "Integrity Management of Subsea Production Systems"			x					x			
ASTM E1681, "Standard Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials, 2008	x										x
ASTM E23, "Standard Test Methods for Notched Bar Impact Testing of Metallic Materials," 2016b	x										
ASTM E6, "Standard Terminology Relating to Methods of Mechanical Testing," 2015	x										
ASTM F1940, Section 07A	x										
ASTM F519, Section 13	x										
ASTM G168, 2000	x										
ASTM E1012, "Standard Practice for Verification of Testing Frame and Specimen Alignment under Tensile and Compressive Axial Force Application," 2014									x	x	

10.2 Corrosion Control, Cathodic Protection, and Other Failure-Mitigation Practices

There is not consistency between the ASTM Core Group and NORSOK concerning ASTM bolt standards. NORSOK M-001 (“Materials Selection”), Section 5.11.2, Table 9 (or the standard), lists only ASTM A320 Grade L7, L7M and L43; A193 Grade B8M (Class 1 and 2); A453 Grade 660 Class D, A1014 Grade API 6A 718; and ASTM F468 Grade Ni 625, Ni 625, Ni59, and Ni 686 as acceptable subsea fasteners with specific grades of either A194, A453, or F467 heavy hex nuts. Fasteners per ASTM A320/A320M, A540/A540M, and A1082/A1082M are part of the U.S. ASTM Core Group, but are not listed in NORSOK. The NORSOK table also has standards that are not in the ASTM Core Group, such as ASTM A1014 (“Standard Specification for Precipitation-Hardening Bolting [UNS N07718] for High-Temperature Service”), F467 (“Standard Specification for Nonferrous Nuts for General Use”), and F468 (“Standard Specification for Nonferrous Bolts, Hex Cap Screws, Socket Head Cap Screws, and Studs for General Use”), which relate to API 6A718 (“Nickel Base Alloy 718 [UNS N07718] for Oil and Gas Drilling and Production Equipment”). ASTM F468 Grade Ni 625 bolts are specifically deemed suitable for service in a non-cathodic protection environment at ambient temperatures, and all fasteners are required to be delivered with material certifications in accordance with EN 10204 Type 3.1 or ISO 10474 Type 3.1 (“Steel and Steel Products—Inspection Documents”). Maximum hardness is 35 HRC, much akin to information about U.S. practices, as shown in Section 7.3.8. NORSOK M-001’s scope is guidance for hydrocarbon production systems with 20-year design life, rather than upstream applications that have shorter design lives.

Some international standards do have recommended practices for cathodic protection in seawater. For example, ISO 12473 (“General Principles of Cathodic Protection in Sea Water”), DNV-RP-B401, and DIN EN 12496 all address cathodic protection. Standards API 16D and DNV-RP-B401 both reference NACE RP0176. Figure 6 illustrates the reference structure for this group.



Standards Titles
DIN EN 12474: “Cathodic Protection for Submarine Pipelines” Also known as British Standard 12474
DIN EN 12495: “Cathodic Protection for Fixed Steel Offshore Structures”
DIN EN 12496 “Galvanic Anodes for Cathodic Protection in Seawater”
DIN EN 13173: “Cathodic Protection for Steel Offshore Floating Structures”
DNV 8401: Cathodic Protection Design-Rules and Standards
ISO 12473 “general Principles of Cathodic Protection in Seawater”
ISO 8044: Corrosion of Metals and Alloys - Basic Terms and Definitions
Interpretation: Standards in left column reference ISO 12473 which reference ISO 8044.
I

FIGURE 6 CATHODIC PROTECTION REFERENCE STRUCTURE FOR ISO AND DIN STANDARDS

10.3 Traceability

Components and fasteners, especially those used for critical applications where failure risks injury to life and the environment, deserve more attention to quality assurance than ordinary fasteners used for a noncritical application. Logically, one might expect graded and continuous quality assurance during the bolt’s life cycle to minimize the likelihood of failure from such aspects as

- Improper manufacturing;
- Incorrect or out-of-specification materials;
- Origin from unintended sources;

- Improper handling during shipping or storage;
- Incorrect labelling;
- Misapplication or misuse; and
- Sustained in-service integrity.

A common quality system referenced in the international oil and gas context (as well as the domestic API standard 20E) is ISO 9000 ("Quality Management Systems—Requirements"). However, like the API Q1 and Q2, the ISO quality standard is mostly directed at the organization providing products and services. This appears to neglect the service phase of the life cycle.

In the case of DNV's service specification for certification of subsea components[35], there is a general requirement to maintain retrievable documentation for the life cycle of a product. Per Appendix A, this should include inspection and testing. Unfortunately, per Table 3-1, a bolt in a Category I subsea tree may be accepted in a non-safety category if compliant with the original referenced standard. In this instance, apparently, bolts are not afforded the same scrutiny as in the remainder of a subsea tree.

[35] Service Specification, Certification of subsea equipment and components, DNVGL-SE-045:2014-08 at Section 3.2.1.5

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11.0 Alternative Fastener Technology

11.1 Alternatives to Bolts

A rational reaction to any failure, bolt or general fastener, is to seek alternative means to perform the same function. From a practical engineering perspective, despite occasional failures, conventional bolting is a compact and straightforward means way to fasten parts together when periodic disassembly is needed. However, a recent paper from Offshore Technology Conference (OTC) 2018[36], describes a riser system (Referred to as Hands Free Riser System (HRFe)) that does not require bolts to connect the sections yet can be disassembled and reassembled. This new system uses a split ring that bridges the gap between riser sections. The inside bore of the ring segments has projections that mate with grooves on the ends of both riser tubular sections. The mating components lock in position with secondary lock rings and a cam ring. These locking rings move axially and keep the split rings in the grooves. The entire joint make-up or break-out operation is performed on a special remotely controlled and automated spider system that also supports the weight of the drill string as riser sections are added or removed.

The HRFe is deemed to be a step forward in riser design in terms of performance, safety, reduced risk, and increased operating efficiencies. Specific claims are:

- Personnel do not need to be on the rig floor for riser make-up and break out operations,
- String run time can be reduced (claim is 80% reduction compared to conventional risers),
- Only one person needed to operate system at safe distance,
- Reduces human error,
- Improves structural load distributions, and
- Improves fatigue performance.

According to the developer, the system also reduces riser weight by loading the choke and kill lines. Overall, the system is innovative and does eliminate the need for a large number of bolts (possibly as many as several hundred- 800 assuming 100 riser joints/8 bolts per flange) compared to conventional bolted risers.

[36] Sandman, Colton, Drew Plichta, Darren Mills, and Jim Kaculi (Drill Quip, Inc), "*HPHT Hands Free Drilling Riser System with Superior Fatigue Performance," OTC-28869-MS, Offshore Technology Conference held in Houston, Texas April 30-May 3, 2018.*

11.2 Torque Indicating Crush Washer Standards and Technology

The oil and gas subsea industry uses many means to obtain the proper loading and closure pressure from bolts and fasteners. The usefulness of each depends on physical circumstance and operational considerations. Each has advantages, disadvantages, and varying levels of certainty. These means include:

- Torque wrench (various levels and means of calibration, control of thread lubricants, and strain-based measurements on equivalent situations as benchmarks);
- Measurements of strain across entire bolt (top of head to end with micrometer);
- Strain measurement in precision hole in center of bolt along loaded length;
- Ultrasonic length measurement; and
- Hydraulic loading and tightening.

One method not often mentioned is direct tension indicating (DTI) washers. There are two ASTM standards on this topic. These standards are:

- ASTM F959 ("Standard Specification for Compressible Washer-Type Direct Tension Indicators for Use with Structural Fasteners") and
- ASTM F2437.

The first of these standards discusses structural applications and situations, including corrosion issues, as the products may have carbon, manganese, phosphorus, sulfur, silicon, chromium, nickel, and copper content. There is a corrosion index reference, and the purchaser has some flexibility regarding chemical composition. The maximum nominal diameter is 1.5 in with loads up to 178,000 lbs (equivalent to M36 diameter and 684 kNewtons for metric items).

The second standard involves the same ASTM subcommittee (F16 on fasteners) and is specific to carbon and alloy steel compressible type washers. There are similar chemical contents provisions, and mean compression loads are as high as 419,000 lbs for 2.5-in nominal diameter shanks (cap screws, anchors, and studs). The standard is specific to dimensions and shape.

Neither standard provides significant information about statistical variation and precision such as would be addressed if complying with a standard similar to ASTM E2566 ("Standard Guide for Reporting Uncertainty of Test Results and Use of the Term Measurement Uncertainty in ASTM Test Methods").[37] The washers are single use and would need to be discarded each time there is assembly. The chemical and cathodic protection environment subsea might also complicate their application.

The SAE also has standards for similar torque indicating devices. Likely, these mandate much smaller sizes than the maximums cited in the prior paragraphs.

[37] ASTM offers hundreds of publications and standards about measurement uncertainty covering a broad range of subjects ranging from coating thickness to calibrations and radioactivity measurements.

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12.0 Major Gaps and Recommendations

12.1 General

The major gaps identified during this study arise for several reasons. Infrequently, a topic is not covered in the network of standards and their references. Most of the time, users could interpret the standard to include a topic, but language is broadly written with little detail or guidance. In this situation, the exact approach to a subject is decided according to principles such as competent engineering and prudent practice. Requirement gaps also can occur because a standard (in the BSEE situation) is not incorporated by reference in the regulations, or there is a newer standard version available with more specific guidance. One example of this is the latest revision (2nd edition) of API 20E; this standard is not in the current BSEE regulations, but the industry is voluntarily implementing it because there is guidance in two important areas: eliminating electroplated zinc as a coating and improving the mandated "record of qualification" documentation. Further, there can be an assembly of new and older equipment built according to different standards. Because of the continuous publication cycle for new standards, this gap analysis can only be a snapshot in time. The following paragraphs summarize specific gaps Argonne identified and present recommendations.

12.2 Fatigue

Overall, fatigue criteria appear in many standards for components, but are only addressed in a few API Core Group standards, specifically with regard to bolts (or equivalent fastener terms) or even specifically bolts used in critical applications (see Sections 7.3.1 and 7.3.2). First, there is not an apparent uniform definition equivalent to "critical application" that triggers quality measures such as higher levels of inspection and testing, better materials control, recordkeeping, and design for fatigue loading. Secondly, the design criteria in the API Core Group for bolts are generally limited to tensile membrane stress, and in one case, membrane plus bending, without specific criteria for fatigue and cyclic loading. Cyclic stress could be included or not included, depending on the owner's internal policy. Fatigue is not a scope normally undertaken by ASTM, but does appear in some foreign subsea oil and gas standards as described for NORSOK in Section 10.1

Recommendations:

- **API standards should consistently recognize bolts and bolt design principles as part of assemblies and components throughout the API portfolio of subsea drill-through equipment standards, specifications, and/or practices.**

- **API should consider adding definite fatigue requirements for bolting to drill-through standards for critical applications. Such criteria should correlate with bolt service levels.**

12.3 Systems Approach to Cathodic Protection and Other Corrosion-Related Failure-Mitigation Practices

Numerous standards address cathodic protection, coatings, and hydrogen embrittlement for marine environments as standalone topics. For situations that do not involve dissimilar metals and electrical equipment, a standalone standards approach can be effective. However, oil and gas equipment in the marine environment involves considerable electrical equipment in a marine environment and many possibilities for different metals, and even coating materials. Logically, such a complex situation should lead to a systems approach to corrosion management that assures one action or situation does not conflict with other. Without doubt, this is occurring voluntarily in many responsible organizations over the various phases of the equipment life cycle, but the systems concept is not emphasized in the standards. Cathodic protection is mentioned as a cautionary note in a few standards in the API Core Group. Based on such guidance, designers' and operators' functions could or could not consider all technical details. Effective corrosion management must consider all subsea equipment as a system.

Recommendation:

The standards organizations should consider systems-focused corrosion management for oil and gas drill-through equipment. A first step, if not already completed, would be for the standards organizations to achieve consistency and clarity of application regarding coating and hydrogen embrittlement topics within ASTM B633, ASTM B849, ASTM B850, and ASTM F1941.

12.4 Traceability

Traceability as a quality control measure appears in fragments within the U.S. oil and gas industry standard system, likely because practices have evolved over decades. Various quality requirements are scattered throughout the ASTM Core Group, the API Core Group, API Q1, API Q2, and the most recent API 20E and API 20F. Based on the standards, there is also an apparent industry convention that bolts and fasteners are inferred to be part of all maintenance requirements spread throughout different API documents pertaining to operations and maintenance. In some cases, there are specific requirements such as in API 53, but without much differentiation on the bolt's purpose. Some bolts and fasteners should be subject to more

stringent requirements than others, and API 20E and API 20F establish bolt service levels. However, these standards do not positively link applications to the service level. Further, API 20E is not referenced in all key industry standards pertaining to drill-through equipment,[38] nor are API 20E and API 20F incorporated by reference in BSEE regulations. In the case of API 20F, details on manufacturing processes are vital to satisfactory reliability and performance.

Recommendations:

- **Standards organizations should should clarify roles and responsibilities regarding records retention requirements, particularly those associated with traceability for bolts used in critical applications over their entire life cycles. Records should include detailed information about coatings, all materials processes, supply chain performers, and quality assurance documents.**
- **To facilitate implementation of the record of qualification API should continue incorporating API 20E and API 20F into API's offshore equipment standards. Each standards committee (including the API 6A committee) should evaluate API 20E and API 20F for the particular situations of each standard, but deviations from the standards should be minimal.**

[38] This is as of summer 2017. Argonne understands there is an API effort underway to cite API 20 in more and more API documents as part of the normal review and revision/affirmation cycle specific to each particular standard.

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13.0 Miscellaneous Observations and Recommendations from GAP Standard Analyses

Several topical areas in the U.S. oil and gas standards system for bolts have inconsistencies, differences, or minor gaps. Many of these arise from the fact different organizations and committees are involved in preparing and publishing the documents. The most notable of these differences, as identified from the gap analysis of this study, are discussed in the following paragraphs together with recommended actions. These paragraphs are arranged to group recommendations for specific organizations together. The sequence is:

- BSEE (Sections 13.1 through Section 13.5),
- API (Sections 13.6 through Section 13.11),
- ASTM (Sections13.12), and
- General Standards Development Organizations (Section 13.13).

13.1 Proprietary Bolting Material Specifications in API 20E (BSEE)

13.1.1 Materials Grade Equivalency in API 20E

Thirteen specific bolt material grades appear in API 20E (2nd edition). All but one appear in four ASTM standards used in the oil and gas industry. The last grade in Section 4.3.1 of API 20E is "equipment manufacturer's proprietary bolting material specification." Clearly, there should always be opportunities and incentives for the industry to innovate and advance technology for improved performance and better economics. Undoubtedly, the industry does strive for improvements in most instances but a standard such as API 20E should not allow diminished bolt performance compared to the proven and well defined bolting of the present ASTM standards. The API 20E does define new requirements for all ASTM grades and requirements in Section 4.3.2 extend these to the proprietary grade. However, even with added requirements, there is not a defined performance baseline or acceptance criteria for the proprietary grade.

13.1.2 ASTM Technical Variations Reduced

The ASTM family of seven subsea oil and gas bolt standards is built around ASTM A962/A962M which contains common requirements. This structure is preferable to seven standards pursuing the same subjects. However, as such, there are over 20 optional supplementary requirements in this common standard covering a range of topics from nondestructive testing to marking, inspection, and process control. No doubt, these were defined to cover as many variations as possible consistent with bolting manufactured for the subsea oil and gas industry. However, when taken together with the supplementary requirements in the seven referencing standards, there would seem to be almost endless combinations and variations. While some additional requirements are added in API 20E and API 20F, these API documents reduce the number of ASTM bolt grades and certain supplementary requirements are no longer optional. If API 20E is implemented broadly, the specification takes precedence to the ASTM series' requirements.

13.1.3 Recommended BSEE Action on API 20E Proprietary Bolting Provision

- **BSEE should track API action on amending the proprietary fastener grade in API 20E to include an acceptance criteria. The proprietary grade must be equivalent or better than the most appropriate ASTM grade in the standard for the application.**

13.2 BSL Requirements Defined in API 20E and API 20F (BSEE)

13.2.1 Linking BSL to Service Application

The API 20E specification defines graded requirements for three service levels, and API 20F defines two service levels coincident with API 20E. Generally, these are process steps and quality assurance actions that are intended to result in fasteners appropriate for the challenges of the application. Notably, service level applications are left undefined in both documents, although in Table 2 (concerning microstructure requirements in API 20E), the term "severity level" is used but undefined. Apparently, service level choice is left to equipment manufacturers or purchasers in both specifications.

13.2.2 Recommended BSEE Action on API 20E and API 20F Evaluation and API Action on Proprietary Fastener Provision

- **BSEE should evaluate bolting service levels and record of qualification requirements in API 20E and API 20F in terms of safety and regulatory value. One specific consideration is whether all critical applications should require BSL-3 or whether BSL-2 is sufficient for some. Another consideration is whether the two standards, including any needed modifications, should be incorporated in regulations recognizing that API is currently incorporating the two standards into other standards on a case by case basis.**

13.3 ASTM Coating Requirement's Clarification (BSEE)

13.3.1 Inconsistent Coating Requirements

As mentioned in the recommendation from paragraph 13.1, there are requirement inconsistencies between ASTM B633, ASTM B849, ASTM B850, and ASTM F1941 and references from the ASTM Core Group.

13.3.2 Recommended BSEE Action on Monitoring ASTM Progress Relative to Clarifying Coating Requirements

BSEE should monitor ASTM progress on changes to ASTM B633, ASTM B849, ASTM B850, ASTM F1941, and other ASTM standards to clarify coating requirements applicable to subsea bolting and fasteners.

13.4 Graded Requirements in Standards ("Shall" and "Should") (BSEE)

13.4.1 "Should" and "Shall" Definitions in ASTM Standards.

Within the ASTM Core Group standards, the terms "should" and "shall" appear throughout, although the latter is most common. Unlike most API standards and specifications, there are not definitions in the ASTM standards for each term. Likely, a user would adopt a definition close to that in API documents ("shall" is a minimum requirement, or "must" is a definite requirement). The ASTM standards use the term "should" in the standards, but in most cases not as often as the

term “shall.” Among the ASTM standards applicable to oil and gas bolts and fasteners, there are not stated limitations on use in terms of engineering, business, or scientific judgement.

13.4.2 “Should” and “Shall” Definitions in API Documents

Ideally, an API standard should be written in the interest of consistency as to whether a requirement is optional or required at some minimum level. For standards in the API Core Group, this appears to be true regarding most bolt requirements. These standards’ forwards define “shall” as a minimum requirement and “should” as a recommendation that is advised, but not required. However, in the case of API 16D, there is not such defining language, even though several paragraphs in, that standard does use the terms “shall,” “should,” and “minimum.” The API standards caveat requirements with boilerplate language that engineering, scientific, and business judgment should never be neglected. Standard API 20E goes beyond “shall” and “should” with defined interpretations of “may” and “can.”

13.4.3 Recommended BSEE Action on “Shall” Clarification

BSEE should consider revising regulations to clarify the meaning of “shall” for referenced documents pertaining to bolting. While interpretation of “shall” is nearly universal in API bolting-related standards, interpretation varies considerably among ASTM bolt-related standards. In the regulatory text at 250.198, (Code of Federal Regulations Title 30 Mineral Resources) regulations define “should” as a “must” requirement when appearing in referenced documents, but do not appear to address “shall.” ASTM bolt-related standards are not currently and specifically referenced in the regulations at 250.198, nor are API 20E or API 20F. BSEE should also consider clarifying “shall” and “should” interpretations relative to ASTM standards, including those that are followed because of normative reference status.

13.5 Current BSEE Regulations on Bolts (BSEE)

13.5.1 Scattered Bolt and Fastener Requirements

Several API standards and specifications related to drill-through subsea equipment do have bolting requirements. For example, in API 6A, there is extensive guidance on flanges and associated fasteners. As stated elsewhere in this report, design criteria are limited primarily to the 83% of minimum specified material yield strength. In addition, there are scattered references to

various ASTM bolting standards, including ASTM A193/A193M, A194/A194M, A320/A320M, A453/A453M, and (by reference) A962/A962M. There are also stipulations to apply NACE standards for corrosive environments, but there is no reference to API 20E or the counterpart for more corrosion-resistant materials, API 20F.

API 53 references API 6A, API 16A, and API 17D for fastener requirements and does include some additional criteria, such as BOP bolting being part of a preventive maintenance program for the system (Section 4.3.4). Like API 6A, there is not a reference to API 20E or to API 20F.

The missing references to API 20E and API 20F are related to when these were published relative to the normal updating cycle of other API standards and specifications. There has not been adequate time to incorporate them throughout the API standards and specifications system. In addition, they do not yet appear in the BSEE regulations.

13.5.2 Recommended BSEE Action on Current API 20E and API 20F Implementation

For the present, BSEE should support continued inclusion of API 20E and API 20F in the API drill-through equipment standards system.

13.6 Proprietary Bolting Material Specifications in API 20E (API)

13.6.1 Materials Grade Equivalency in API 20E

As outlined in paragraph 13.1, API 20 E lacks a defined performance baseline or acceptance criteria for the proprietary grade.

13.6.2 Recommended API Action on API 20E Proprietary Bolting Provision

- **API should amend the proprietary fastener grade in API 20E to include an acceptance criteria. The proprietary grade needs to be equivalent or better than the most appropriate ASTM grade in the standard for the application.**

13.7 Conflicts, Contradictions, and Resolution Process (API)

13.7.1 ASTM Approach to Conflicts in Standards

The ASTM Core Group of oil and gas bolt/fastener standards clearly stipulates that, in the event of a technical requirement conflict between a base standard and the common requirements in ASTM A962/A962M, the latter shall prevail. This appears in a “Common Requirements” paragraph in each of these referencing standards. While this covers many potential conflicts, there is not a defined practice should there be technical conflicts between a referenced standard and another referenced standard within the same standard. Presumably, this would be addressed through a technical inquiry to ASTM.

13.7.2 API 20E and API 20F on Technical Conflicts

The API bolting specifications, API 20E and API 20F, provide guidance on how to address conflicts between ASTM and API 20E. In both standards, API requirements supersede the ASTM requirements and both API standards define certain grades or types from the ASTM Core Group bolt standards. The standards and bolting material grades covered by API 20E are part of the ASTM Core Group list and appear in Section 4.3.1 as follows (from the API document):

- ASTM A193/A193M[39] Grades B7 and B7M;
- ASTM A194/A194M Grades 2H, 4, 7, 2HM, and 7M ("Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High-Pressure or High-Temperature Service or Both");
- ASTM A320/A320M Grades L7, L7M, and L43; and
- ASTM A540/A540M Grades B22 and B23.

The counterpart ASTM standards in API 20F appear in Section 4.3.1 (of the API document) and are limited to precipitation-hardened austenitic iron-based A453 Grade 660 Class D. The API 20F also includes material, API 6A718 precipitation-hardened nickel-based alloys in accordance with API 6A718 (which has been replaced by API 6ACRA, "Nickel-Base Alloy 718 [UNS N07718] for Oil and Gas Drilling and Production Equipment").

Taken together, API 20E and API 20F isolate specific grades and types of bolts for the ASTM Core Group base standards. An addition to API 20E is that an "equipment manufacturer's proprietary bolting material specification" is allowed standard, but the same category does not appear in API 20F. ASTM A1082/A1082M standards, while part of the ASTM Core Group fasteners considered in the study, are not included in API 20E or 20F, nor are grades or types not listed from the above standards.

Comparing API 20E to API 6A, the latter list of references does not include ASTM A540/A540M, but does include ASTM A453/A453M. The second edition, addendum 4 of API 20E, is dated June 2017, and the 20th edition of API 6A (Addendum 4) is dated June 2016, which may be a reason for the differences. There are other inconsistencies between API 20E and API 6A, such as bolting materials properties in API 6A taking precedence over those in the ASTM standards. These differences are presumed to properly reflect nuances appropriate to the oil and gas industry.

A particularly notable omission in API 20F is API Q1 ("Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry"). Another difference between API 20E and API 20F is the reference to ASTM A962/A962M. For some reason, API 20F references the 2014 version, yet in API 20E, the version is the latest. Still another difference between the two API bolting standards is the requirement for the record of qualification to be available and auditable to the purchaser. This is not part of API 20F.

[39] Note that the actual reference in the standard does not include the conventional metric designation. It is not clear whether this is intended to mean the standard is for inch-sized bolting.

13.7.3 Recommended API Actions on Record of Qualification and Standards Precedence

- **API should achieve consistency between API 20E and API 20F with regard to the auditable and traceable requirement for record of qualification and content of the records.**
- **To the extent possible, API standards committees should define in each standard which standards or requirements take precedence in the event of technical conflicts.**

13.8 Important Definitions/Roles and Responsibilities (API)

13.8.1 Manufacturer Definition

Many key bolt-related standards do not define the manufacturer. While not necessarily an easy term to define, including such a definition would more positively associate roles and responsibilities to entities and reduces variability of interpretations. Bolt/fastener-related standards, both API and ASTM,[40] use the term in the text, but lack a clear definition of the term. Noted standards are:

- API 6A,
- API 16D,
- API 53,
- API Q1,
- ASTM A193/A193M-15A,
- ASTM A194/A194M-15a,
- ASTM A320/A320M-15a,
- ASTM A453/A453M-15,

[40] Among the ASTM standards listed here, ASTM A193/A193M, A320/A320M, and A540/A540M do not have a terminology section in their text. The remainders do have such a section, but do not define manufacturer.

- ASTM A540/A540M-15, and
- ASTM A1082/A1082M-15.

The API specification 20E does define a "bolt manufacturer" in Section 3.1.2 as "*an organization that, through the use of manufacturing equipment and processes appropriate for the product form, transforms raw material into finished bolting*." The term *bolting* in this definition includes most, if not all, fasteners. There is still a potential gap if several manufacturing organizations are involved in the creation of fastener, in which case one organization should be designated to take a lead manufacturing role (such as for preparing the record of qualification). In contrast, API 20F has no definition for "bolt manufacturer."

Specification API 16D does introduce the concept of a commodity item as a purchased, manufactured product for part of the larger system. In API Q1 and API 20E, the monogram program does link a product to a specification or standard, as the product manufacturer must have a valid license to use the API monogram.

ASTM A962/A962M does define a "certifying organization or association," which has the primary responsibility to certify conformance and marking of the product to the specification used. Since compliance with this specification is a requirement in the other ASTM bolt standards shown here, this mitigates much of the impact of the missing definition. At the same time, this creates a point of confusion with regard to how API 20E is coordinated with the ASTM bolting series.

13.8.2 Original Equipment Manufacturer (OEM) Definition

With some exceptions, the definition situation for OEM closely parallels that for the manufacturer definition as discussed in Section 13.8.1.

Some key standards using the term OEM without a definition are:

- API 16D and
- API Q1.

Standards ***without*** the term OEM, but with numerous references to manufacturing, are:

- API 6A,
- API 20E;
- ASTM A193/A193M-15A,

- ASTM A194/A194M-15a,
- ASTM A320/A320M-15a,
- ASTM A453/A453M-15,
- ASTM A540/A540M-15,
- ASTM A962/A962M-15 (“Standard Specification for Common Requirement for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range”), and
- ASTM A1082/A1082M-15.

None of the ASTM Core Group bolting standards use the OEM term.

Standard API 53 defines the OEM as “design owner or manufacturer of the traceable assembled equipment, single equipment unit, or component part.” This is a useful definition if the part is traceable. Obviously, traceability could be interpreted in many degrees from something such as a manufacturer’s plate markings or more positive identification up to and including quality-management-based tracking with unique identifiers and life cycle records.

13.8.3 Recommended API Action on Defining Manufacturer and OEM

- **API should adopt and implement a common definition of “manufacturer” and “OEM” to lessen confusion about organizational roles and responsibilities. This is important to certifying compliance with specifications and especially a documentation trail for critical application bolting. The definition in API 53 and the linkage to traceable equipment might be the precedent.**

13.9 Critical Application Definition (API)

13.9.1 Critical Application Term in API Standards

Throughout many of the API standards, guidance, and specifications reviewed for this study, the term “critical application” is used, as for BSLs in API 20E and API 20F. From the context, the definition appears to be something linking potential failure to loss of well control. The most applicable definition found during the study appears in API 17TR8 (“High-pressure High-temperature Design Guidelines”) at paragraph 3.1.11. “Critical bolting is defined as “*threaded fasteners and closure bolting, identified as high risk components (i.e., loss of structural integrity*

or pressure containment)." A similar definition is not provided in standards of the API Core Group of this sturdy, API 20E, or API 20F.

13.9.2 Recommended API Action

API should consider adopting and applying a common stated definition of "Critical Application," at least for subsea bolting and fasteners, to improve consistency on BSL requirements and applications.

13.10 Designs with Tapped Holes or Inserts for Bolting (API)

13.10.1 ASTM Criteria

Generally, ASTM bolt standard scope is limited to manufacturing topics rather than design parameters such as stress limits. Typical manufacturing topics concern compliance with thread dimensions, material chemistry, mechanical properties, heat treatment, and batch versus continuous casting. Some of the ASTM Core Group oil and gas standards reference ASME dimension standards and some do not. However, the common standard, ASTM A962/A962M, does reference several ASME dimension standards for standardized thread series and bolting dimensions, such as minimum and maximum thread lengths. At the same time, there appears to be nothing about thread engagement length beyond the sizes for nuts. This seems consistent with the normal scope for the ASTM standards.

13.10.2 API Criteria

API 6A has some criteria that appear to recognize that occasionally bolting is threaded into tapped holes, some of which may be different material. The criteria at Section 4.4.3.1.2 are that thread engagement for a stud shall be a minimum of the outside diameter of the stud. This is consistent with ordinary bolting practices for a bolt and nut of similar material, but is not necessarily appropriate for differing materials. A subparagraph of that section entitled "Other Bolts" specifies "*The stud thread-anchoring means shall be designed to sustain a tensile load equivalent to the load that can be transferred to the stud through a fully engaged nut.*" This is sensible, although technically, there would appear to be a slight gap if the bolting is a stud (not other bolting), if the tapped material is a lesser strength than the bolt, and if the equipment design

does not consider the difference. The tapped threads for other bolts could be too weak for the load. There appears to be no criteria in API 20E or API 20F concerning this particular situation. Possibly, this subject is better addressed in standards and specifications with more design guidance such as API 6A.

13.10.3 Recommended API Action on Threaded Insets and Tapped Holes

API should clarify criteria for tapped holes and tapped inserts in the standards system, including accommodations for different materials.

13.11 Coatings as Part of Record of Qualification (API)

13.11.1 Observation on Enhancing Record of Qualification in API 20E and 20F

API 20E and API 20F each have a bullet list defining the content of the "record of qualification." Neither of the lists specifically includes information about any coatings applied to the bolt or expressly about hydrogen embrittlement mitigation. These omissions are more significant for API 20E.

13.11.2 Recommended API Action on Coatings in Record of Qualification

- **API should add coatings to the lists for "record of qualification" for API 20E and consider same for API 20F, if applicable.**
- **API should add hydrogen embrittlement and other special corrosion control processes to the record of qualification' for API 20E to the extent this is not captured in materials or process specifications.**

13.12 Reference Conventions (ASTM)

13.12.1 ASTM Reference Practices

With the exception of ASTM A962/A962M, the common convention for the balance of oil and gas ASTM Core Group standards is to not specify version, date, or even whether the "latest" is applicable. When a standard is withdrawn, the user is referred to an ASTM catalog to identify the latest version. In the case of ASTM A962, the standard establishes that all references should be the latest versions without identifying them succinctly. However, as an example, ASTM A320/A320M references ASTM F436 ("Standard Specification for Hardened Steel Washers Inch and Metric Dimensions"), but lacks guidance on the version. This particular example does not appear in the ASTM A962/A962M reference list that has guidance to use the "latest version." Not considering that versions could change during the time of an active purchase, there is inconsistency on which version to use if this is the situation, so a purchase should be specific on versions.

13.12.2 API Reference Practices

Within the API standards group sampled as having relevance to subsea bolts and fasteners, there is inconsistent guidance on referenced standard versions. Most API standards and specifications stipulate that the latest edition of undated references should be used at the beginning of the normative reference section. At the same time, some references list an edition rather than a date, but provide guidance to include the latest amendments. An exception to this convention among the API documents sampled is API 16D. This particular normative references section provides no general guidance on edition, instead leaving this to appear in the text each time a reference is cited. This introduces the possibility that such is omitted (intentionally or unintentionally). One example is standard AWS D1.1 in paragraph a of Section 8.2 of API 16D, which, instead of defining version, introduces the "equivalent recognized international standard." Apparently, API did not implement a standardized template/format for this particular standard (API 16D).

13.12.3 Recommended ASTM Action on Referenced Standards

ASTM should clarify the apparently inconsistent guidance on referenced standards versions in their oil and gas bolting standards. Different criteria appears in the common

standard (ASTM A962/A962M) than in some standards that reference that common document.

13.13 Issue and Effective Dates (Standards Development Organizations)

13.13.1 ASTM Practice on Effective Document Dates

ASTM bolt standards, such as A193/A193M-15a, contain an approval date (November 1, 2015), a publication date (December 2015), and the original approval date (1936). This particular example mentions a previous version, 15, which was approved in 2015 and refers to ASME BPVC specifications (paragraph SA-193 in Section II, for the example[41]) for ASME BPVC applications. Notably, there is not language indicating that the version supersedes previous versions, nor is there specificity on when the standard should or must be implemented. Notably, this standard, as well as the remainder of the individual ASTM Core Group standards (except ASTM A962/A962M, which is referenced by all the ASTM Core Group standards), are approved for use by agencies of the U.S. Department of Defense.

13.13.2 API Practice on Effective Document Dates

The API standards[42] contain a statement in the document's forward indicating that the current edition cancels and replaces a prior edition. The covers edition, errata, and addendum information with an effective date. There are also special notes with cautions about the use of the standard, one being that the standards are not intended to replace sound engineering, science, and business practice and judgement.

13.13.3 Recommended Standards Organization Action on Standard Effective Dates

There is inconsistency between ASTM and API on implementation of standards and specifications. The API process is much more succinct and even provides for voluntary use of a new version between the release date and effective date. This situation is much more indefinite for ASTM standards versions.

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[41] Paragraph SA 194 for ASTM A194/A194M, paragraph SA-194 for ASTM A320/A320M-14, paragraph SA-540 in ASTM A540/540M-15a, and paragraph SA-453 for ASTM A453/A453M-15. There is no such ASME paragraph reference in ASTM A1082/A1082M-15 or ASTM A962/A962M-15.

[42] Paragraph specific to API 6A, API 16D, API 53, and API 20E.

Standards organizations should strengthen date and version criteria at the normative reference level to assure consistency of technical requirements occurring through standards. Current criteria at §250.198 (found in Code of Federal Regulations- Title 30 Mineral Resources) pertain to the edition of the particular publication cited, although part (2)I does make provisions in the interest of safety, new technology, and absence of undue costs. However, from plain language a standard incorporated by reference in a publication may in turn be the "latest version" in a normative standards list. (For example, the API 6A heading for the normative references is "For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document [including any amendments] applies."). Thus, a regulation reference may be subject to some changes since in this example there is no date associated with ASTM A193/A193M in the normative references list. The regulations do not appear to address this sub-tier reference issue even though the regulation does say, "future amendments or revisions of the document are not included."

14.0 Preliminary Database References

The following table lists the standards reviewed to create this document and the preliminary database.

Standard Shorthand [43]	Standard Title	Edition
A-A-55625	Commercial Item Description: Nut, Plain, Plate	1997
A-A-55628A	Commercial Item Description: Nut, Plain, Cap, High Crown UNC-2B and UNF-2B	1998
A-A-55629	Commercial Item Description: Nut, Plain, Cap, Low Crown UNC-2B and UNF-2B	1997
A-A-59441	Commercial Item Description: Vapor Corrosion Inhibitors	2004
A-A-59817	Commercial Item Description: U-Nut, Wide Panel Range, 3/8-Inch Diameter, Coarse Unified Inch Screw Threads	2008
ANSI/AISC 360-05	Specification for Structural Steel Buildings	2005
API 16A	Specification for Drill-Through Equipment	3rd ed. 2004 (reaffirmed 2016)
API 16A	Specification for Drill-Through Equipment	4th ed. 2017
API 16AR	Standard for Repair and Remanufacture of Drill-Through Equipment	1st ed. 2017
API 16C	Specification for Choke and Kill Systems	1st ed. 1993 (reaffirmed 2001)
API 16C	Choke and Kill Equipment	2nd ed. 2015
API 16D	Specification for Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment	2nd ed. 2005 (reaffirmed 2013)
API 16F	Specification for Marine Drilling Riser Equipment	1st ed. 2004 (reaffirmed 2014)
API 16Q	Recommended Practice for Design, Selection, Operation, and Maintenance of Marine Drilling Riser Systems	1st ed. 1993 (reaffirmed 2010)
API 17A	Design and Operation of Subsea Production Systems - General Requirements and Recommendations	4th ed. 2006 (reaffirmed 2011)
API 20E	Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries	1st ed. (August 2012)
API 20E	Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries	2nd ed. 2017
API 20F	**Corrosion-Resistant Bolting for Use in the Petroleum and Natural Gas Industries**	1st ed. 2015
API 2SC	Manufacture of Structural Steel Casting for Primary Offshore Applications	1st ed. 2010 (reaffirmed 2015)
API 53	Blowout Prevention Equipment Systems for Drilling Wells	4th ed. (November 2012)
API 5SI	Recommended Practice for Purchaser Representative Surveillance and/or Inspection at the Supplier	1st ed. 2006 (reaffirmed 2012)
API 6A	Specification for Wellhead and Christmas Tree Equipment	20th ed. (October 2011)
API 6A	Specification for Wellhead and Christmas Tree Equipment	20th ed. 2011

[43] Where a specific section or item is mentioned in this report, details are either included in text or a footnote.

Standard Shorthand [43]	Standard Title	Edition
API 6AV1	Specification for Verification Test of Wellhead Surface Safety Valves and Underwater Safety Valves for Offshore Service	1st ed. 1996 (reaffirmed 2008)
API 6AV1	Specification for Validation of Wellhead Surface Safety Valves and Underwater Safety Valves for Offshore Service	2nd ed. 2013
API Bul 91	Planning and Conducting Surface Preparation and Coating Operations for Oil and Natural Gas Drilling and Production Facilities in a Marine Environment	1st ed. 2007
API Q1	Specification for Quality Programs for the Petroleum, Petrochemical, and Natural Gas Industry	8th ed. 2010
API Q1	Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry	9th ed. 2014
API Q2	Specification for Quality Management System Requirements for Service Supply Organizations for the Petroleum and Natural Gas Industries	1st ed. 2011
API TR 6AF1	Technical Report on Temperature Derating on API Flanges Under Combination of Loading	2nd ed. 1998
API TR 6AF2	Technical Report on Capabilities of API Integral Flanges Under Combination of Loading—Phase II	5th ed. 2013
ASME B1.1	Unified Inch Screw Threads (UN and UNR Thread Form)	2003 (reaffirmed 2008)
ASME B1.13M	Metric Screw Threads: M Profile	2005 (reaffirmed 2015)
ASME B1.2	Gages and Gaging for Unified Inch Screw Threads	1983 (reaffirmed 2007)
ASME B18.1.3M	Metric Small Solid Rivets	1983 (reaffirmed 2016)
ASME B18.2.1	Square, Hex, Heavy Hex, and Askew Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head, and Lag Screws (Inch Series)	2012
ASME B18.2.3.3M	Metric Heavy Hex Screws	2007 (reaffirmed 2014)
ASME B18.3	Socket Cap, Shoulder, Set Screws, and Hex Keys (Inch Series)	2012
ASME SA-320/SA-320M	Specification for Alloy Steel Bolting Materials for Low-Temperature Service	2007
ASTM A1014/A1014M	Standard Specification for Precipitation-Hardening Bolting (UNS N07718) for High-Temperature Service	2016
ASTM A1058	Standard Test Methods for Mechanical Testing of Steel Products – Metric	2014
ASTM A1059/A1059M	Standard Specification for Zinc Alloy Thermo-Diffusion Coatings (TDC) on Steel Fasteners, Hardware, and Other Products	2008 (reapproved 2013)
ASTM A106/A106M	Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service	2015
ASTM A1082/A1082M	Standard Specification for High-Strength Precipitation-Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	2015
ASTM A123/A123M	Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products	2015
ASTM A143/A143M	Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement	2007 (reapproved 2014)
ASTM A153/A153M	Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware	2016a
ASTM A183	Standard Specification for Carbon Steel Track Bolts and Nuts	2014

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ASTM A193/A193M	Standard Specification for Alloy-Steel and Stainless Steel Bolting for High-Temperature or High-Pressure Service and Other Special Purpose Applications	2015a
ASTM A194/A194M	Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both	2015a
ASTM A276/276M	Standard Specification for Stainless Steel Bars and Shapes	2017
ASTM A29/A29M	Standard Specification for General Requirements for Steel Bars, Carbon and Alloy, Hot-Wrought	2016
ASTM A307	Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 PSI Tensile Strength	2014
ASTM A320/A320M	Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	2015a
ASTM A320/A320M	Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	2015a
ASTM A325	Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength	2014
ASTM A354	Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners	2011
ASTM A370	Standard Test Methods and Definitions for Mechanical Testing of Steel Products	2017
ASTM A380/A380M	Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems	2013
ASTM A384/A384M	Standard Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies	2007 (reapproved 2013)
ASTM A385/A385M	Standard Practice for Providing High-quality Zinc Coatings (Hot-Dip)	2015
ASTM A394	Standard Specification for Steel Transmission Tower Bolts, Zinc-Coated and Bare	2008 (reapproved 2015)
ASTM A437/A437M	Standard Specification for Stainless and Alloy-Steel Turbine-Type Bolting Specially Heat Treated for High-Temperature Service	2015
ASTM A449	Standard Specification for Hex Cap Screws, Bolts and Studs, Steel, Heat Treated, 120/105/90 ksi Minimum Tensile Strength, General Use	2014
ASTM A453/A453M	Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	2016
ASTM A453/A453M	Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	2016
ASTM A479/A479M	Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels	2017
ASTM A484/A484M	Standard Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings	2016
ASTM A490	Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength	2014a

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ASTM A490M	Standard Specification for High-Strength Steel Bolts, Classes 10.9 and 10.9.3, for Structural Steel Joints (Metric)	2014a
ASTM A540/A540M	Standard Specification for Alloy-Steel Bolting for Special Applications	2015
ASTM A563	Standard Specification for Carbon and Alloy Steel Nuts	2015
ASTM A564/A564M	Standard Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes	2013
ASTM A574	Standard Specification for Alloy Steel Socket-Head Cap Screws	2017
ASTM A684/A684M	Standard Specification for Steel, Strip, High-Carbon, Cold-Rolled	2017
ASTM A700	Standard Guide for Packaging, Marking, and Loading Methods for Steel Products for Shipment	2014
ASTM A747/A747M	Standard Specification for Steel Castings, Stainless, Precipitation Hardening	2016a
ASTM A751	Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products	2014a
ASTM A780/A780M	Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings	2009 (reapproved 2015)
ASTM A788/A788M	Standard Specification for Steel Forgings, General Requirements	2016
ASTM A896/A896M	Standard Practice for Conducting Case Studies on Galvanized Structures	2009 (reapproved 2014)
ASTM A941	Standard Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys	2016
ASTM A959	Standard Guide for Specifying Harmonized Standard Grade Compositions for Wrought Stainless Steels	2016
ASTM A962/A962M	Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	2015
ASTM A968/A968M	Standard Specification for Chromium, Chromium-Nickel, and Silicon Alloy Steel Bars and Shapes for Corrosion and Heat-Resisting Service	1996 (reapproved 2014)
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	2016
ASTM B194	Standard Specification for Copper-Beryllium Alloy Plate, Sheet, Strip, and Rolled Bar	2015
ASTM B418	Standard Specification for Cast and Wrought Galvanic Zinc Anodes	2016a
ASTM B487	Standard Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of Cross Section	1985 (reapproved 2013)
ASTM B633	Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel	2015
ASTM B695	Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel	2004 (reapproved 2016)
ASTM B696	Standard Specification for Coatings of Cadmium Mechanically Deposited	2000 (reapproved 2015)
ASTM B766	Standard Specification for Electrodeposited Coatings of Cadmium	1986 (reapproved 2015)
ASTM B843	Standard Specification for Magnesium Alloy Anodes for Cathodic Protection	2013
ASTM B849	Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement	2002 (reapproved 2013)
ASTM B850	Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement	1998 (reapproved 2015)

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ASTM C1562	Standard Guide for Evaluation of Materials Used in Extended Service of Interim Spent Nuclear Fuel Dry Storage Systems	2010
ASTM C1725	Standard Guide for Hot Cell Specialized Support Equipment and Tools	2010
ASTM D1141	Standard Practice for the Preparation of Substitute Ocean Water	1998 (reapproved 2013)
ASTM D3911	Standard Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions	2008
ASTM D3951	Standard Practice for Commercial Packaging	2015
ASTM D5144	Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants	2008
ASTM D5540	Standard Practice for Flow Control and Temperature Control for On-Line Water Sampling and Analysis	2013
ASTM D5648	Standard Test Method for Torque-Tension Relationship of Adhesives Used on Threaded Fasteners (Lubricity)	2001 (reapproved 2014)
ASTM D5649	Standard Test Method for Torque Strength of Adhesives Used on Threaded Fasteners	2015
ASTM D5657	Standard Test Method for Fluid Tightness Ability of Adhesives Used on Threaded Fasteners	2007 (reapproved 2014)
ASTM D5969	Standard Test Method for Corrosion-Preventive Properties of Lubricating Greases in Presence of Dilute Synthetic Sea Water Environments	2011 (reapproved 2016)
ASTM D6577	Standard Guide for Testing Industrial Protective Coatings	2015
ASTM D7230	Standard Guide for Evaluating Polymeric Lining Systems for Water Immersion in Coating Service Level III Safety-Related Applications on Metal Substrates	2006 (reapproved 2013)
ASTM E10	Standard Test Method for Brinell Hardness of Metallic Materials	2017
ASTM E1012	Standard Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application	2014
ASTM E112	Standard Test Methods for Determining Average Grain Size	2013
ASTM E139	Standard Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials	2011
ASTM E140	Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness	2012b
ASTM E1417/E1417M	Standard Practice for Liquid Penetrant Testing	2016
ASTM E1444/E1444M	Standard Practice for Magnetic Particle Testing	2016
ASTM E1681	Standard Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials	2003 (reapproved 2013)
ASTM E18	Standard Test Methods for Rockwell Hardness of Metallic Materials	2016
ASTM E1997	Standard Practice for Selection of Spacecraft Materials	2015
ASTM E21	Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials	2009
ASTM E220	Standard Test Method for Calibration of Thermocouples by Comparison Techniques	2013
ASTM E23	Standard Test Methods for Notched Bar Impact Testing of Metallic Materials	2016b

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ASTM E2681	Standard Guide for Environmental Management of Underground Storage Tank Systems Storing Hazardous Substances or Petroleum	2013
ASTM E29	Standard Practice for Using Significant Digits in Test Data to Determining Conformance with Specifications	2013
ASTM E292	Standard Test Methods for Conducting Time-for-Rupture Notch Tension Tests of Materials	2009
ASTM E3	Standard Guide for Preparation of Metallographic Specimens	2011
ASTM E328	Standard Test Methods for Stress Relaxation for Materials and Structures	2013
ASTM E381	Standard Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings	2001 (reapproved 2012)
ASTM E384	Standard Test Method for Microindentation Hardness of Materials	2016
ASTM E4	Standard Practices for Force Verification of Testing Machines	2016
ASTM E45	Standard Test Methods for Determining the Inclusion Content of Steel	2013
ASTM E566	Standard Practice for Electromagnetic (Eddy Current) Sorting of Ferrous Metals	2014
ASTM E6	Standard Terminology Relating to Methods of Mechanical Testing	2015
ASTM E633	Standard Guide for Use of Thermocouples in Creep and Stress-Rupture Testing to 1800 F (1000 C) in Air	2013
ASTM E647	Standard Test Method for Measurement of Fatigue Crack Growth Rates	2015
ASTM E691	Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method	2016
ASTM E709	Standard Guide for Magnetic Particle Testing	2015
ASTM E77	Standard Test Method for Inspection and Verification of Thermometers	2014
ASTM E8/E8M	Standard Test Methods for Tension Testing of Metallic Materials	2016a
ASTM E92	Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials	2017
ASTM F1130	Standard Practice for Inspecting the Coating System of a Ship	1999 (reapproved 2014)
ASTM F1136/F1136M	Standard Specification for Zinc/Aluminum Corrosion Protective Coatings for Fasteners	2011
ASTM F1137	Standard Specification for Phosphate/Oil Corrosion Protective Coatings for Fasteners	2011
ASTM F1155	Standard Practice for Selection and Application of Piping System Materials	2010 (reapproved 2015)
ASTM F1182	Standard Specification for Anodes, Sacrificial Zinc Alloy	2007 (reapproved 2013)
ASTM F1428	Standard Specification for Aluminum Particle-Filled Basecoat/Organic or Inorganic Topcoat, Corrosion Protective Coatings for Fasteners	1992 (reapproved 2011)
ASTM F1469	Standard Guide for Conducting a Repeatability and Reproducibility Study on Test Equipment for Nondestructive Testing	2011
ASTM F1470	Standard Practice for Fastener Sampling for Specified Mechanical Properties and Performance Inspection	2012
ASTM F1476	Standard Specification for Performance of Gasketed Mechanical Couplings for Use in Piping Applications	2007 (reapproved 2013)
ASTM F1554	Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength	2015
ASTM F1789	Standard Terminology for F16 Mechanical Fasteners	2016

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ASTM F1940	Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners	2007a (reapproved 2014)
ASTM F1941/F1941M	Standard Specification for Electrodeposited Coatings on Mechanical Fasteners, Inch and Metric	2016
ASTM F2280	Standard Specification for "Twist Off" Type Tension Control Structural Bolt/Nut/washer Assemblies, Steel, Heat Treated, 150 ksi Minimum Tensile Strength	2014
ASTM F2281	Standard Specification for Stainless Steel and Nickel Alloy Bolts, Hex Cap Screws, and Studs, for Heat Resistance and High Temperature Applications	2004 (reapproved 2012)
ASTM F2282	Standard Specification for Quality Assurance Requirements for Carbon and Alloy Steel Wire, Rods, and Bars for Mechanical Fasteners	2015
ASTM F2328M	Standard Test Method for Determining Decarburization and Carburization in Hardened and Tempered Threaded Steel Bolts, Screws, Studs, and Nuts (Metric)	2014
ASTM F2329/F2329M	Standard Specification for Zinc Coating, Hot-Dip, Requirements for Application to Carbon and Alloy Steel Bolts, Screws, Washers, Nuts, and Special Threaded Fasteners	2015
ASTM F2437/F2437M	Standard Specification for Carbon and Alloy Steel Compressible-Washer-Type Direct Tension Indicators for Use with Cap Screws, Bolts, Anchors, and Studs	2017
ASTM F2482	Standard Specification for Load-Indicating Externally Threaded Fasteners	2008 (reapproved 2015)
ASTM F2660	Standard Test Method for Qualifying Coatings for Use on A490 Structural Bolts Relative to Environmental Hydrogen Embrittlement	2013
ASTM F2833	Standard Specification for Corrosion-Protective Fastener Coatings with Zinc Rich Base Coat and Aluminum Organic/Inorganic Type	2011
ASTM F3019/F3019M	Standard Specification for Chromium Free Zinc-Flake Composite, With or Without Integral Lubricant, Corrosion-Protective Coatings for Fasteners	2014
ASTM F3042	Standard Specification for Nonferrous Hex Socket, Slotted Headless, and Square Head Set Screws	2013
ASTM F3043	Standard Specification for "Twist Off" Type Tension Control Structural Bolt/Nut/Washer Assemblies, Alloy Steel, Heat Treated, 200 ksi Minimum Tensile Strength	2015
ASTM F3111	Standard Specification for Heavy Hex Structural Bolt/Nut/Washer Assemblies, Alloy Steel, Heat Treated, 200 ksi Minimum Tensile Strength	2016
ASTM F3114	Standard Specification for Structures	2015
ASTM F3125/F3125M	Standard Specification for High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 Mpa) Minimum Tensile Strength, Inch and Metric Dimensions	2015a
ASTM F3148	Standard Specification for High Strength Structural Bolt Assemblies, Steel and Alloy Steel, High Treated, 144ksi Minimum Tensile Strength, Inch Dimensions	2017a
ASTM F432	Standard Specification for Roof and Rock Bolts and Accessories	2013
ASTM F436/F436M	Standard Specification for Hardened Steel Washers Inch and Metric Dimensions	2016
ASTM F467M	Standard Specification for Nonferrous Nuts for General Use (Metric)	2006a (reapproved 2012)

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ASTM F468	Standard Specification for Nonferrous Bolts, Hex Cap Screws, Socket Head Cap Screws, and Studs for General Use	2016
ASTM F519	Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments	2013
ASTM F541	Standard Specification for Alloy Steel Eyebolts	2012
ASTM F543	Standard Specification and Test Methods for Metallic Medical Bone Screws	2017
ASTM F593	Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs	2017
ASTM F594	Standard Specification for Stainless Steel Nuts	2009 (reapproved 2015)
ASTM F606/F606M	Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets	2016
ASTM F722	Standard Specification for Welded Joints for Shipboard Piping Systems	1982 (reapproved 2014)
ASTM F788	Standard Specification for Surface Discontinuities of Bolts, Screws, and Studs, Inch and Metric Series	2013
ASTM F812	Standard Specification for Surface Discontinuities of Nuts, Inch and Metric Series	2012
ASTM F835	Standard Specification for Alloy Steel Socket Button and Flat Countersunk Head Cap Screws	2016
ASTM F836M	Standard Specification for Style 1 Stainless Steel Metric Nuts (Metric)	2002 (reapproved 2015)
ASTM F837M	Standard Specification for Stainless Steel Socket Head Cap Screws (Metric)	2013
ASTM F844	Standard Specification for Washers, Steel, Plain (Flat), Unhardened for General Use	2007a (reapproved 2013)
ASTM F879M	Standard Specification for Stainless Steel Socket Button and Flat Countersunk Head Cap Screws (Metric)	2016
ASTM F880	Standard Specification for Stainless Steel Socket, Square Head, and Slotted Headless Set Screws	2012
ASTM F901	Standard Specification for Aluminum Transmission Tower Bolts and Nuts	2001 (reapproved 2012)
ASTM F912	Standard Specification for Alloy Steel Socket Set Screws	2011 (reapproved 2017)
ASTM F945	Standard Test Method for Stress-Corrosion of Titanium Alloys by Aircraft Engine Cleaning Materials	2012
ASTM F959	Standard Specification for Compressible Washer-Type Direct Tension Indicators for Use with Structural Fasteners	2015
ASTM G101	Standard Guide for Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels	2004 (reapproved 2015)
ASTM G116	Standard Practice for Conducting Wire-on-Bolt Test for Atmospheric Galvanic Corrosion	1999 (reapproved 2015)
ASTM G168	Standard Practice for Making and Using Precracked Double Beam Stress Corrosion Specimens	2000 (reapproved 2013)
ASTM G192	Standard Test Method for Determining the Crevice Repassivation Potential of Corrosion Resistant Alloys Using a Potentiodynamic- Galvanostatic-Potentiostatic Technique	2008 (reapproved 2014)
ASTM G215	Standard Guide for Electrode Potential Measurement	2017
ASTM G38	Standard Practice for Making and Using C-Ring Stress-Corrosion Test Specimens	2001 (reapproved 2013)
ASTM G39	Standard Practice for Preparation and Use of Bent-Beam Stress-Corrosion Test Specimens	1999 (reapproved 2016)

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ASTM G4	Standard Guide for Conducting Corrosion Tests in Field Applications	2001 (reapproved 2014)
ASTM G48	Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution	2011 (reapproved 2015)
ASTM G49	Standard Practice for Preparation and Use of Direct Tension Stress-Corrosion Test Specimens	1985 (reapproved 2011)
ASTM G75	Standard Test Method for Determination of Slurry Abrasivity (Miller Number) and Slurry Abrasion Response of Materials (SAR Number)	2015
ASTM G78	Standard Guide for Crevice Corrosion Testing of Iron-Base and Nickel-Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments	2015
ASTM G8	Standard Test Methods for Cathodic Disbonding of Pipeline Coatings	1996 (reapproved 2010)
ASTM G82	Standard Guide for Development and Use of a Galvanic Series for Predicating Galvanic Corrosion Performance	1998 (reapproved 2014)
ASTM G96	Standard Guide for Online Monitoring of Corrosion in Plant Equipment (Electrical and Electrochemical Methods)	1990 (reapproved 2013)
BS 7371_12	Coatings on metal fasteners - Part 12: Requirements for imperial fasteners	2008
BS 7371_3	Coatings on metal fasteners - Part 3: Specifications for electroplated zinc coatings	2009
BS 7371_7	Coatings on metal fasteners - Part 7: Specification for mechanically applied zinc and zinc-based coatings	2010
BS EN 13173	Cathodic protection for steel offshore floating structures	2001
BS EN 50162	Protection against corrosion by stray current from direct current systems	2004
DNVGL-OS-B101	Metallic Materials	2015
DNVGL-OS-C101	Design of Offshore Steel Structures, General - LRFD Method	2015
DNVGL-RP-0002	Integrity Management of Subsea Production Systems	2014
DNVGL-RP-0005: 2014-06	RP-C203: Fatigue Design of Offshore Steel Structures	2014
DNVGL-SE-0045:2014-08	Certification of Subsea Equipment and Components	2014
DNVGL-ST-0035: 2014-08	Subsea Equipment and Components	2014
DNV-RP-0034	Steel Forgings for Subsea Applications	2015
DNV-RP-B401	Cathodic Protection Design	2010
DNV-RP-C201	Buckling Strength of Plated Structures	2010
DNV-RP-C205	Environmental Conditions and Environmental Loads	2014
DNV-RP-E102	Recertification of Blowout Preventers and Well Control Equipment for the U.S. Outer Continental Shelf	2010
DNV-RP-F112	Design of Duplex Stainless Steel Subsea Equipment Exposed to Cathodic Protection	2008
EPRI NP-6316	Guidelines for Threaded-Fastener Applications in Nuclear Power Plants	1989
ET-3000.00-1500-251-PAZ-001	Technical Specification: High Resistance Steel Fixers for Underwater Use	2011
FF-N-836E	Federal Specification: Nut, Square, Hexagon, Cap, Slotted, Castle, Knurled, Welding and	1994

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	Single Ball Seat	
FF-N-845D	Federal Specification: Nut, Plain, Wing, Inch and Metric	1981
IBECA-H-E	Hydrogen Embrittlement in Coated Steel Fasteners	2006
IBECA-H-S-F	Integrity of High Strength Fasteners for Aircraft Structures	2007
IFI-H-E	Fundamentals of Hydrogen Embrittlement In Steel Fasteners	2014
ISO 12473	General principles of cathodic protection in sea water	2006
ISO 12944-1	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 1: General Introduction	1998
ISO 12944-2	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 2: Classification of environments	1998
ISO 12944-3	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 3: Design Considerations	1998
ISO 12944-5	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 5: Protective Paint Systems	2007
ISO 12944-7	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 7: Execution and Supervision of Paint Work	1998
ISO 13625	Petroleum and natural gas industries - Drilling and production equipment - Marine drilling riser couplings	2002
ISO 14713-1	Zinc coatings - Guidelines and recommendations for the protection against corrosion of iron and steel in structures - Part 1: General principles of design and corrosion resistance	2009
ISO 14713-2	Zinc coatings - Guidelines and recommendations for the protection against corrosion of iron and steel in structures - Part 2: Hot dip galvanizing	2009
ISO 2081	Metallic and other inorganic coatings - Electroplated coatings of zinc with supplementary treatments on iron or steel	2008
ISO 21457	Petroleum, petrochemical and natural gas industries - Materials selection and corrosion control for oil and gas production systems	2010
ISO 3506-1	Mechanical properties of corrosion-resistant stainless steel fasteners- Part 1: Bolts, screws and studs	2009
ISO 4520	Chromate conversion coatings on electroplated zinc and cadmium coatings	1981
ISO 9717	Metallic and other inorganic coatings - Phosphate conversion coatings of metals	2010
MIL-DTL-12133E	Detail Specification: Washer, Spring Tension, General Specification For	2015
MIL-DTL-1222J	Detail Specification: Studs, Bolts, Screws and Nuts for Application Where a High Degree of Reliability is Required; General Specification For	2000
MIL-DTL-13924D	Detail Specification: Coating, Oxide, Black, for Ferrous Metals	1999
MIL-DTL-21338B	Detail Specification: Washer, Key Retaining, Ball and Rover Bearings	2014
MIL-DTL-32258	Detail Specification: Nut, Self-locking (Ring Type Non-Metallic Insert), Heavy Hex, Controlled Root Radius, Nickel-Copper Alloy	2007
MIL-HDBK-729	Military Standardization Handbook: Corrosion and Corrosion Prevention Metals	1983

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MIL-N-45913B	Military Specification: Nuts, Self-Locking, Hexagon, Prevailing Torque	1970
MIL-PRF-23236D	Performance Specification: Coating Systems for Ship Structures	2009
MIL-STD-1251A	Military Standard: Screws and Bolts Preferred for Design Listing of Department of Defense	1981
MIL-STD-1312-1	Military Standard: Fastener Test Methods	1984
MIL-STD-1515A	Military Standard: Fastener Systems for Aerospace Applications	1978
MIL-W-12133D	Military Specification: Washer, Spring Tension, General Specification for Department of Defense	1994
MS19070B	Detail Specification Sheet: Washer, Key Retaining, Ball and Roller Bearing, Regular Series	2011
MS20500G	Detail Specification Sheet: Nut, Self Locking, Hexagon 1200F, 125 KSI FTU	2012
MS25081K	MS Specification Sheet: Washer, Key	2004
MS25081L	Detail Specification Sheet: Washer, Key	2011
MS25082P	Military Specification Sheet: Nut, Plain, Hexagon Electrical - Thin	1996
MS25082P - Amendment 1	Military Specification: Nut, Plain, Hexagon Electrical - Thin	2004
MS25082P - Amendment 2	Detail Specification Sheet: Nut, Plain, Hexagon Electrical - Thin	2011
MS35335G	MS Specification Sheet: Washer, Lock, Flat-External Tooth	2004
MS35690F	Detail Specification Sheet: Nut, Plain, Hexagon, UNC-2B and UNF-2B	2005
MS9090D	Detail Specification Sheet: Bolt Machine, Drilled 12 Point Head, Steel, .3125-24 UNF-3A	2011
NACE MR0175/ISO-15156-1	Petroleum and natural gas industries - Materials for use in H2S-containing Environments in oil and gas production - Part 1: General Principles for selection of cracking-resistant materials	1st ed. (2003)
NACE MR0175/ISO-15156-1	Petroleum and natural gas industries - Materials for use in H2S-containing environments in oil and gas production - Part 1: General Principles for selection of cracking-resistant materials	2nd ed. (2009)
NACE MR0175/ISO-15156-2	Petroleum and natural gas industries - Materials for use in H2S-containing environments in oil and gas production - Part 2: Cracking-resistant carbon and low alloy steels, and the use of cast irons	1st ed. (2003)
NACE MR0175/ISO-15156-3	Petroleum and natural gas industries - Materials for use in H2S-containing environments in oil and gas production - Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys	1st ed. (2003)
NACE MR0175/NACE MR0175 2003	Standard Material Requirements: Metals for Sulfide Stress Cracking and Stress Corrosion Cracking Resistance in Sour Oilfield Environments	2003
NACE MR0175-2002	Standard Material Requirements: Sulfide Stress Cracking Resistant Metallic Materials for Oilfield Equipment	1st ed. (2002)
NACE No. 12/AWS C2.23M/SSPC-CS 23.00	Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloy and Composites for the Corrosion Protection of Steel	2003
NACE SP0169	Control of External Corrosion on Underground or Submerged Metallic Piping Systems	1969 (reaffirmed 2007)

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NACE SP0176	Corrosion Control of Submerged Areas of Permanently Installed Steel Offshore Structures Associated with Petroleum Production	1976 (reaffirmed 2007)
NACE SP0192	Monitoring Corrosion in Oil and Gas Production with Iron Counts	2012
NACE SP0387	Metallurgical and Inspection for Cast Galvanic Anodes for Offshore Applications	2014
NACE SP0492	Metallurgical and Inspection Requirements for Offshore Pipeline Bracelet Anodes	1992 (reaffirmed 2006)
NACE SP0499	Corrosion Control and Monitoring in Seawater Injection Systems	1999 (reaffirmed 2012)
NACE SP0775	Preparation, Installation, Analysis, and Interpretation of Corrosion Coupons in Oilfield Operations	1975 (reaffirmed 2012)
NACE TM0169/G31	Standard Guide for Laboratory Immersion Corrosion Testing of Metals	2012a
NACE TM0177	Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H2S Environments	2005
NACE TM0198	Slow Strain Rate Test Method for Screening Corrosion-Resistant Alloys for Stress Corrosion Cracking in Sour Oilfield Service	2011
NACE TM0204	Exterior Protective Coatings for Seawater Immersion Service	2004
NACE TM0284	Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking	2003
NASA-RP-1228	Fastener Design Manual	1990
NAVAIR 01-1A-509-1 TM 1-1500-322-23-1 to 1-1-689-1	Cleaning and Corrosion Control - Volume I: Corrosion Program and Corrosion Theory	2005
NAVAIR 01-1A-509-2 TM 1-1500-344-23-2	Cleaning and Corrosion Control - Volume II: Aircraft	2005
NAVAIR 01-1A-509-3 TM 1-1500-433-23-3 to 1-1-689-3	Cleaning and Corrosion Control - Volume III: Avionics and Electronics	2005
NAVAIR 01-1A-509-4 TM 1-1500-344-23-4	Cleaning and Corrosion Control - Volume IV: Consumable Materials and Equipment for Aircraft and Avionics	2005
NAVAIR 01-1A-509-5 TM 1-1500-344-23-5 to 1-1-689-5	Cleaning and Corrosion Control - Volume V: Consumable Materials and Equipment for Aircraft and Avionics	2005
NAVAIR 16-1-541 to 1-1-689 TM 1-1500-343-23	Avionics Cleaning and Corrosion Prevention/Control	2000
NAVFAC MO-307	Corrosion Control	1992
NAVSEA HY-80 100 130 HSLA-80 100	Base Materials for Critical Applications: Requirements for Low Alloy Steel Plate, Forgings, Castings, Shapes, Bars, and Heads of HY-80/100/130 and HSLA-80/100	Rev. 2 (2012)
NORSOK M-001	Materials Selection	5th ed. (2014)
NRC NUREG-1339	Resolution of Generic Safety Issue 29: Bolting Degradation or Failure in Nuclear Power Plants	1990

Standard Shorthand [43]	Standard Title	Edition
NUREG-1801	Generic Aging Lessons Learned (GALL) Report	Rev. 2
RP O401	Safety and Reliability of Subsea Systems	1985
TT-C-490E	FEDERAL SPECIFICATION CHEMICAL CONVERSION COATINGS AND PRETREATMENTS FOR FERROUS SURFACES (BASE FOR ORGANIC COATINGS)	2002
USCAR UHSFG 1416U	USCAR – IFI GUIDE for Ultra-high Strength Externally Threaded Fasteners	2014
USCG M10360.3B	1997	2001

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Appendices
A: Oil and Gas Standard Subset Matrix

The following table in this appendix is a matrix of the domestic oil and gas group of ASTM standards and more than 60 normative references for each. One standard, ASTM A962/A962M, is a normative reference in all of the other bolt standards in the group.

There is inconsistency in the references for each use. For example, concerning coatings, the following is apparent:

- ASTM B633 is only referenced in ASTM A193/193M and ASTM A194/194M.
- ASTM F 1941, is only referenced in ASTM A193/193M.
- Neither ASTM B633 nor ASTM F1941 appears in the remainder of the ASTM oil and gas group: ASTM A320/A320M, A453/A453M, A540/A540M, A962/A962M, or A1082/A1082M.

Two ASTM Standards pertain to electrodeposited coatings on fasteners. These are:

- ASTM B633-15; and
- ASTM F1941/F1941M-15.

ASTM B633 is only referenced in ASTM A193/193M, and ASTM F1941 was prepared by a different ASTM subcommittee. Specification B633 is under the jurisdiction of ASTM Committee B08 on Metallic and Organic Coatings and is the direct responsibility of Subcommittee B08.06 on Soft Metals. The second specification is more extensive, is under the jurisdiction of ASTM Committee F16 on Fasteners, and is the direct responsibility of Subcommittee F16.03 on Coatings on Fasteners.

In terms of scope, at paragraph 1.5, specification B633-15 “may be used for fasteners,” but defers to F1941-15 when the latter is “more applicable” (with the note that the F1941/F1941M-2015 version has been withdrawn).

Within the group of common ASTM bolt standards used in oil and gas—ASTM A193/A193M, ASTM A194/A194M, ASTM A320/A320M, ASTM A453/A453M, ASTM A540/A540M, ASTM A962/A962M, and ASTM A1082/A1082M —only B633 is mentioned in ASTM A193/A193M and ASTM A194/A194M. Therefore, unless specified otherwise (not considering the withdrawal), a bolt vendor could follow either standard.

One noted difference between the two standards is baking requirements. In ASTM B633 (paragraph 6.5), surfaced hardened parts and electroplated steel parts above 31 HRC shall be baked before treatments and within 4 hours of removal from the last process to reduce the risk of hydrogen embrittlement. In Table 4 in ASTM F1941, for a specified core hardness greater than 39 HRC and up to 44 HRC ("Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel"), baking temperature (375 to 425 F) and a minimum time of 14 hours are specified. Further, in ASTM F1941, hydrogen embrittlement testing is mandatory for case-hardened screws with additional baking required if there are test failures. In ASTM B633, hydrogen embrittlement relief testing is determined in the contract or purchase order (paragraph 10.4). Argonne understands that ASTM is seeking to mitigate these apparent contradictions.

TABLE A-1 MATRIX OF NORMATIVE STANDARDS FOR COMMON DOMESTIC OIL AND GAS STANDARDS

		02.00 Primary Metals Identification Tag Application Standard	Screw Threads	Metric Screw Threads	Gages and Gaging for Unified Screw Threads	Screw Thread Gaging Systems for Dimenstional Acceptability of Metric Screw Threads	Quality Assurance for Fasteners
Title		**AIAG B-5**	**ASME B1.1**	**ASME B1.13M**	**ASME B1.2**	**ASME B1.3M**	**ASME B18.18**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M	x					
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M		x	x	x		
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M		x				
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M						
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M						
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M	x	x	x	x	x	x
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M						

		Square and Hex Bolts and Screws	Square and Hex Nuts	Metric Heavy Hex Screws	Metric Heavy Bolts
Title		**ASME B18.2.1**	**ASME B18.2.2**	**ASME B18.2.3.3M**	**ASME B18.2.3.6M**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M	**x**		**x**	
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M		**x**		
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M				
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M				
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M				
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M	**x**			**x**
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M				

		Metric Heavy Hex Nuts	Plain Washers	Hexagon Socket and Spline Socket Screws	Metric Socket Head Cap Screws	Recommended Practice
Title		**ASME B18.2.4.6**	**ASME B18.22.1**	**ASME B18.3**	**ASME B18.3.1M**	**ASNT SNT-TC-1A**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M			**x**	**x**	
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M	**x**				
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M		**x**			
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M					
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M					
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M			**x**		**x**
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M					**x**

		Specification for Precipitation-Hardening Bolting for high Temperature service	Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware	Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both
Title		**ASTM A1014**	**ASTM A153/A153M**	**ASTM A193/193M**	**ASTM A194/194M**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M		**x**		**x**
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M		**x**		
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M				**x**
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M			**x**	
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M				
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M	**x**		**x**	**x**
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M				

		Specification for Stainless Steel Bars and Shapes	Specification for General Requirements for Steel Bars, Carbon and Alloy, Hot-Wrought	Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners	Test Methods and Definitions for Mechanical Testing of steel Products
Title		**ASTM A276/276M**	**ASTM A29**	**ASTM A320**	**ASTM A354**	**ASTM A370**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M			x	x	
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M	x		x		x
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M					X
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M					x
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M					
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M		x	x		x
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M	x				x

		Practice for Cleaning, Descaling, and Passivation of stainless Steel Parts, Equipment and Systems	Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels	Speficication for General Requirements for Stainless steel Bars, Billets and Forgings	Standard Specification for Alloy-Steel Bolting for Special Applications
Title		**ASTM A380**	**ASTM A453/A453M**	**ASTM A479/A479M**	**ASTM A484**	**ASTM A540**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M					
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M					
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M					
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M					
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M					
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M	**x**	**x**		**x**	**x**
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M			**x**		

		Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes	Guide for Packing, Marking, and loading methods for steel Products for Shipment	Test Methods, Practices and Terminology for Chemical Analysis of Steel Products	Standard Specification for Steel Forgings, General Requirements
Title		**ASTM A564/A564M**	**ASTM A700**	**ASTM A751**	**ASTM A788/788M**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M				**x**
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M				
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M				
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M				
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M				
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M		**x**	**x**	**x**
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M	**x**			

		Terminology Relating to Steel, Stainless Steel, Related Alloys and Ferroalloys	Guide for Specifying Harmonized Standard Grade Compostitions for Wrought Stainless steels	Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	Specification for Chemical Passivation Treatments for Stainless Steel Parts	Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel
Title		**ASTM A941**	**ASTM A959/A959M**	**ASTM A962**	**ASTM A967**	**ASTM B633**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M			x		x
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M			x		x
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M			x		
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M			x		
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M			x		
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M	x			x	
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M	x	x	x		

		Standard Specification for coatings of Zinc Mechanically Depostied on Iron and Steel	Standard Speficitation for Coatings of Cadmium Mechanically Deposited	Standard Specification for Electrodeposited Coatings of Cadmium	Test Methods for Determning Average Grain Size	Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tension tests of Metallic Materials	Practice for Liquid Penetrant Testing
Title		**ASTM B695**	**ASTM B696**	**ASTM B766**	**ASTM E112**	**ASTM E139**	**ASTM E1417**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M	x	x	x	x	x	
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M	x	x	x	x		
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M						
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M					x	
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M						
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M						x
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M						

		Practice for Magnetic Particle Testing	Recommended practice for Conducting Creep and Creep-Rupture Tension Tests of Metallic materials Under Conditions of Rapid Heating and Short Times	Recommended Practice for Tension Tests of Metallic Materials at Elevated Temperatures with Rapid Heating and Conventional or Rapid Strain Rates	Test Methods for Rockwell Hardness of metallic Materials	Guide for Identirication of Mixed Lots of Metals
Title		**ASTM E1444**	**ASTM E150**	**ASTM E151**	**ASTM E18**	**ASTM E1916**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M		**x**	**x**	**x**	
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M					
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M					
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M					
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M					
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M	**x**				**x**
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M					

		Test Methods for Elevated Temperature Tension Tests of Metallic Materials	Test Methods for Conducting Time-for-Rupture Notch Tension Tests of Materials	Guide for Preparation of Metallographic Specimens	Test Methods for Stress Relaxation for Materials and structures	Method of Macroetch Testing Steel Bars, Billets, Blooms and Forgings	Test Method for Knoop and Vickers Hardness of Materials
Title		**ASTM E21**	**ASTM E292**	**ASTM E3**	**ASTM E328**	**ASTM E381**	**ASTM E384**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M	x	x		x		
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M						
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M						
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M		x				
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M						
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M			x		x	x
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M						

		Test Methods for Determining the Inclusion Content of Steel	Practice for Electromagnetic (Eddy Current) Sorting of Ferrous Metals	Guide for Magnetic Particle Testing	Standard Practice for Fastener sampling for Specified mechanical Properties and Performance Inspection	Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners	Standard Specification for Electrodeposited Coatings on Mechanical Fasteners, Inch and Metric
Title		**ASTM E45**	**ASTM E566**	**ASTM E709**	**ASTM F1470**	**ASTM F1940**	**ASTM F1941**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M		x	x		x	x
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M		x			x	x
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M		x				
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M						
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M	x					
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M		x		x		
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M						

		Standard Specification for Zinc Coating, Hot-Dip, Requirements for Application to carbon and Alloy Steel Bolts, Screws, Washers, Buts and special Threaded Fasteners	Specification for Hardened Steel Washers	Standard Test Methods for determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct tnesion Indicators, and Rivets	Standard Specification for Surface Discontinuties for Bolts, Screws, and Studs, Inch and Metric Series
Title		**ASTM F2329/F2329M**	**ASTM F436**	**ASTM F606**	**ASTM F788**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M	**x**		**x**	
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M	**x**		**x**	
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M		**x**	**x**	
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M				
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M				
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M	**x**			**x**
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M				

		Standard Specification for Surface Discontinuities of Nuts, Inch and Metric Series	Hexagon High Nuts
Title		**ASTM F812**	**ISO 4033**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications	ASTM A193/193M		
Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both	ASTM A194/194M		**x**
Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service	ASTM A320/320M		
Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels	ASTM A453/453M		
Standard Specification for Alloy-Steel Bolting for Special Applications	ASTM A540/540M		
Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range	ASTM A962/962M	**x**	
Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications	ASTM A1082/1082M		

B: Life Cycle Success Path Examples

Argonne constructed success trees on two standards from the domestic bolts standards core group: ASTM A540/A540M and ASTM A962/A962M. These are considered representative of the balance of the group based on a detailed reading of each, since the first is a basic bolting standard from a group and the latter is common to all in that group.

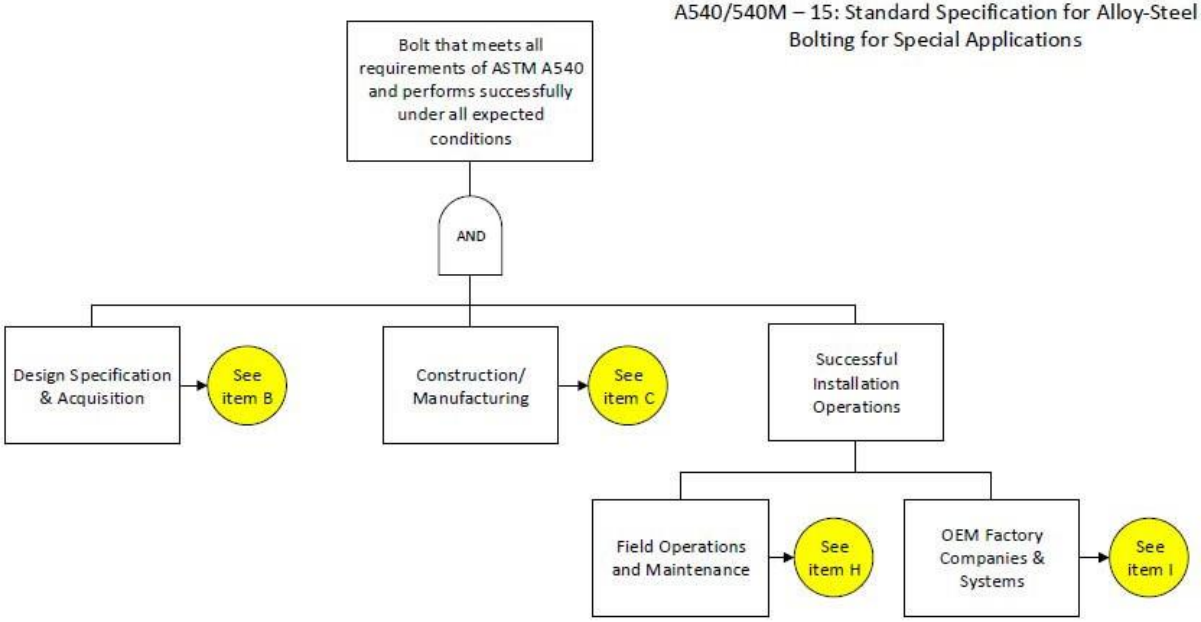
ASTM A540/540M Success Tree

The following figure is a success tree for ASTM A540/A540M-15. The structure at the outline level shows design, construction, operations, and maintenance. Subsection topics are based on the headings in the standard and, are in some cases, abbreviated. Numbers shown in parentheses refer to the paragraph numbering system in the standard.

The primary finding from this tree is that the ASTM specifications mostly focus on the "construction" phase of the bolt. Further, there are marking requirements defined that help establish some information useful to establish bolt history, but by no means are these a comprehensive approach. While there are many details about materials, heat treating, and forming, there are little criteria about mechanical design and the operations and maintenance phase of the life cycle. Thus, for subsea applications, these missing subjects in the ASTM systems are expected to appear in the API guidance system.

Item A

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



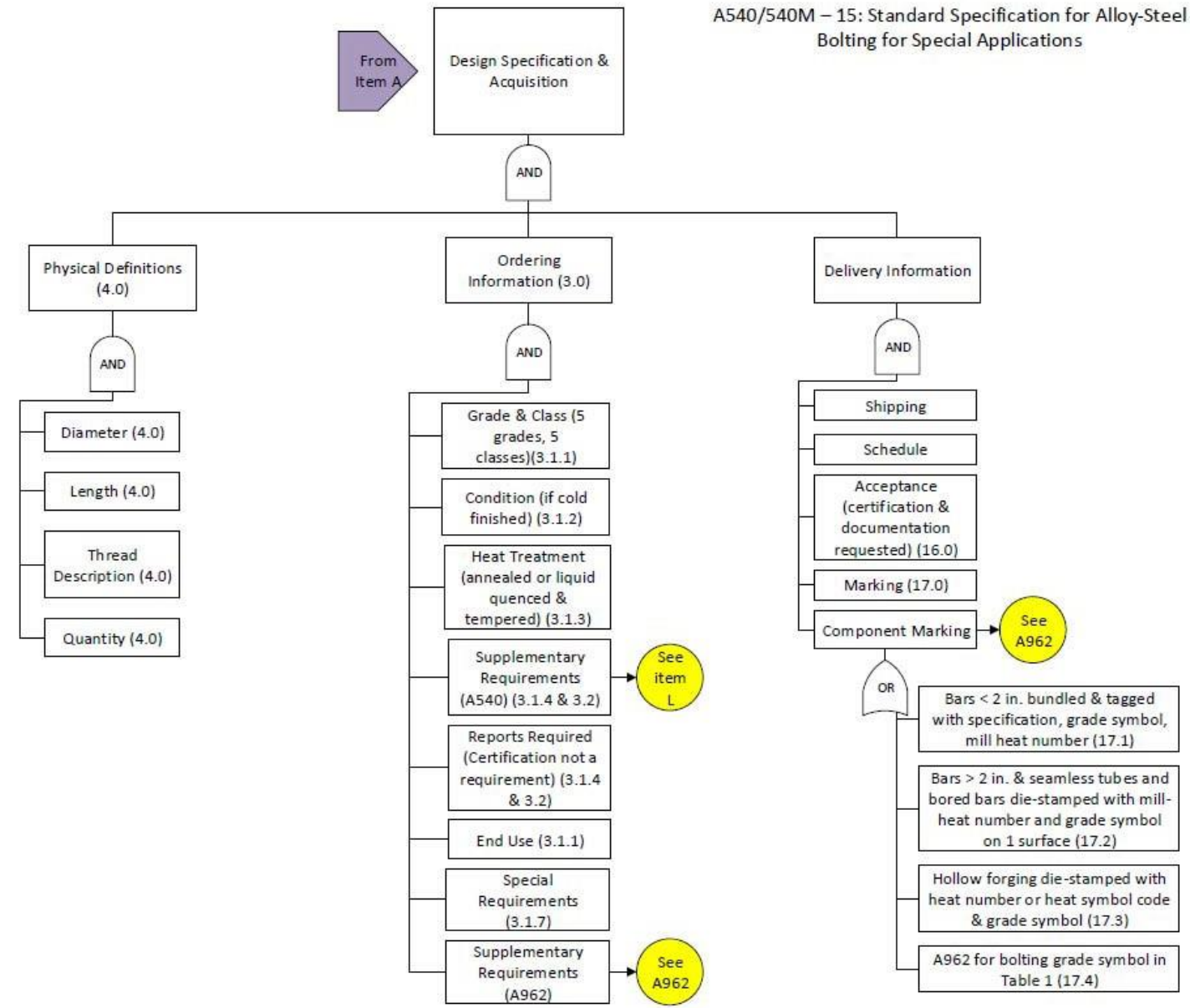
Controlling Entity:

Purchaser (one or several "ownders")

Bolt Manufacturer

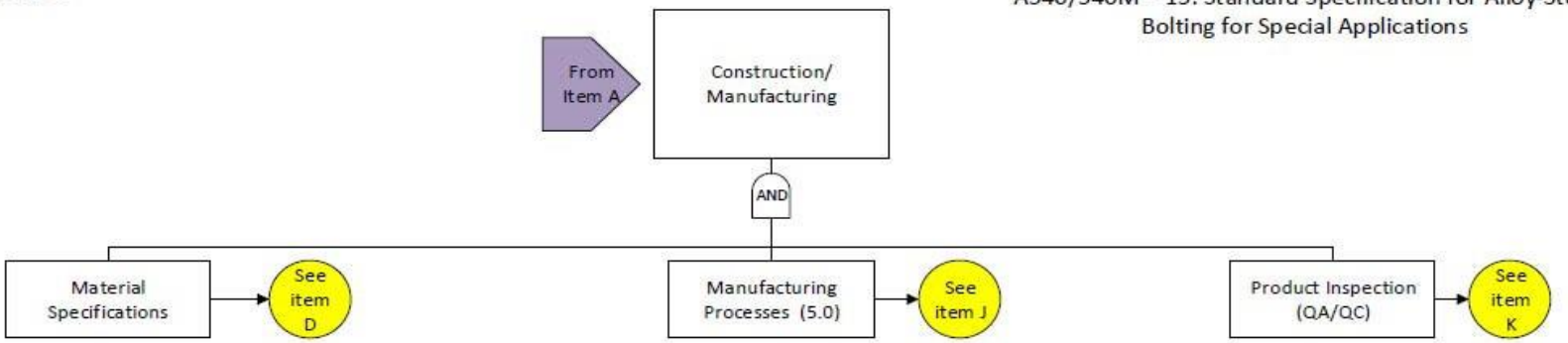
Owners

Item B


A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications
From Item A
Design Specification & Acquisition
AND
Physical Definitions (4.0)
AND
Diameter (4.0)
Length (4.0)
Thread Description (4.0)
Quantity (4.0)
Ordering Information (3.0)
AND
Grade & Class (5 grades, 5 classes)(3.1.1)
Condition (if cold finished) (3.1.2)
Heat Treatment (annealed or liquid quenced & tempered) (3.1.3)
Supplementary Requirements (A540) (3.1.4 & 3.2)
See item L
Reports Required (Certification not a requirement) (3.1.4 & 3.2)
End Use (3.1.1)
Special Requirements (3.1.7)
Supplementary Requirements (A962)
See A962
Delivery Information
AND
Shipping
Schedule
Acceptance (certification & documentation requested) (16.0)
Marking (17.0)
Component Marking
See A962
OR
Bars < 2 in. bundled & tagged with specification, grade symbol, mill heat number (17.1)
Bars > 2 in. & seamless tubes and bored bars die-stamped with mill-heat number and grade symbol on 1 surface (17.2)
Hollow forging die-stamped with heat number or heat symbol code & grade symbol (17.3)
A962 for bolting grade symbol in Table 1 (17.4)

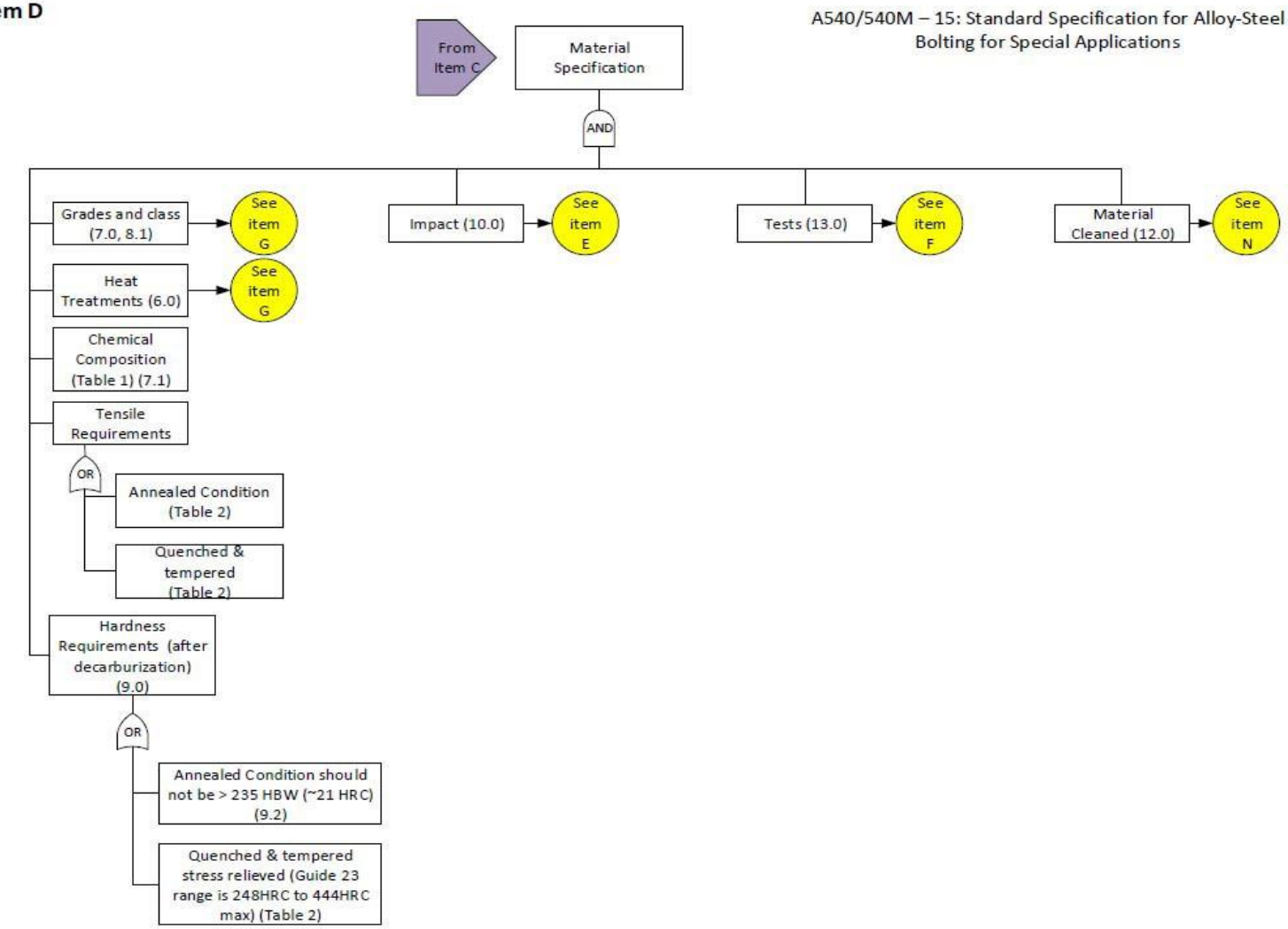
Item C

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



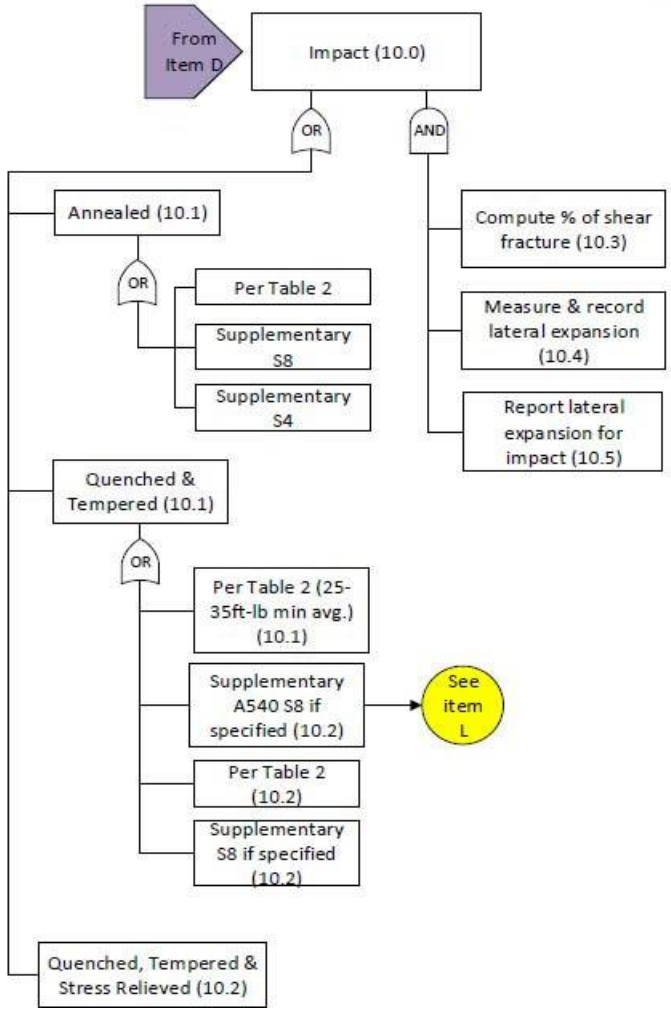
Item D

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



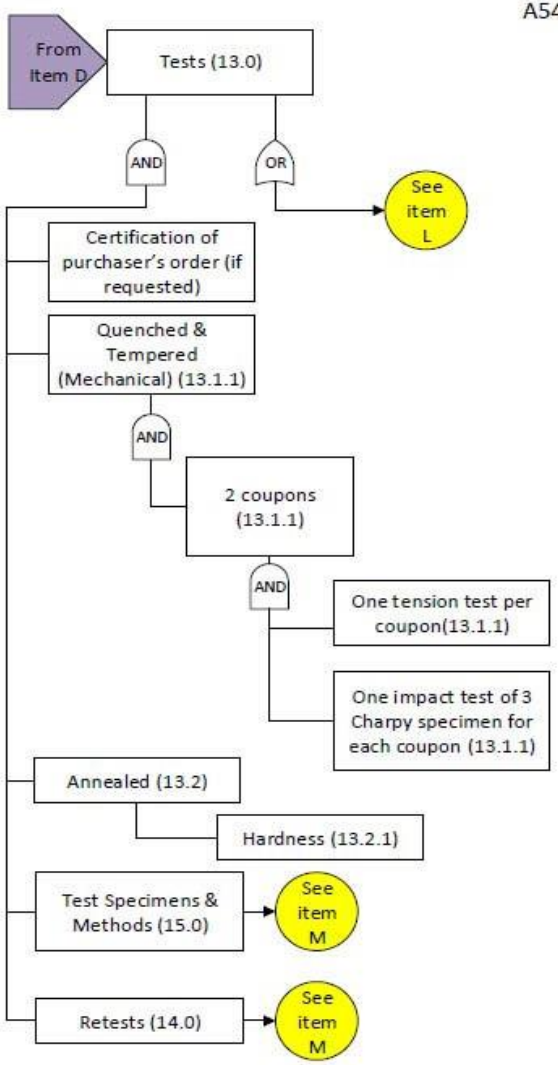
Item E

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



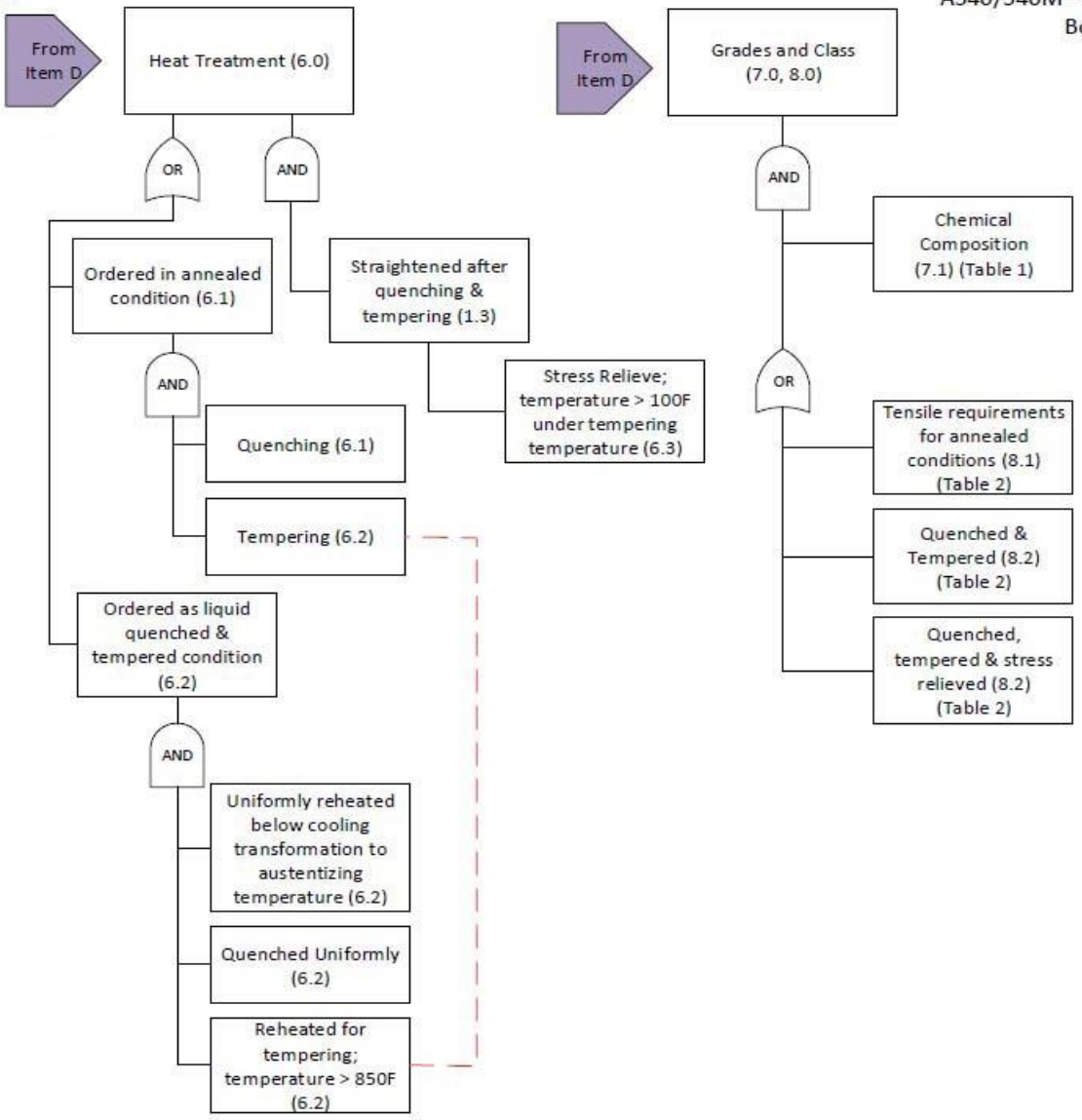
Item F

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



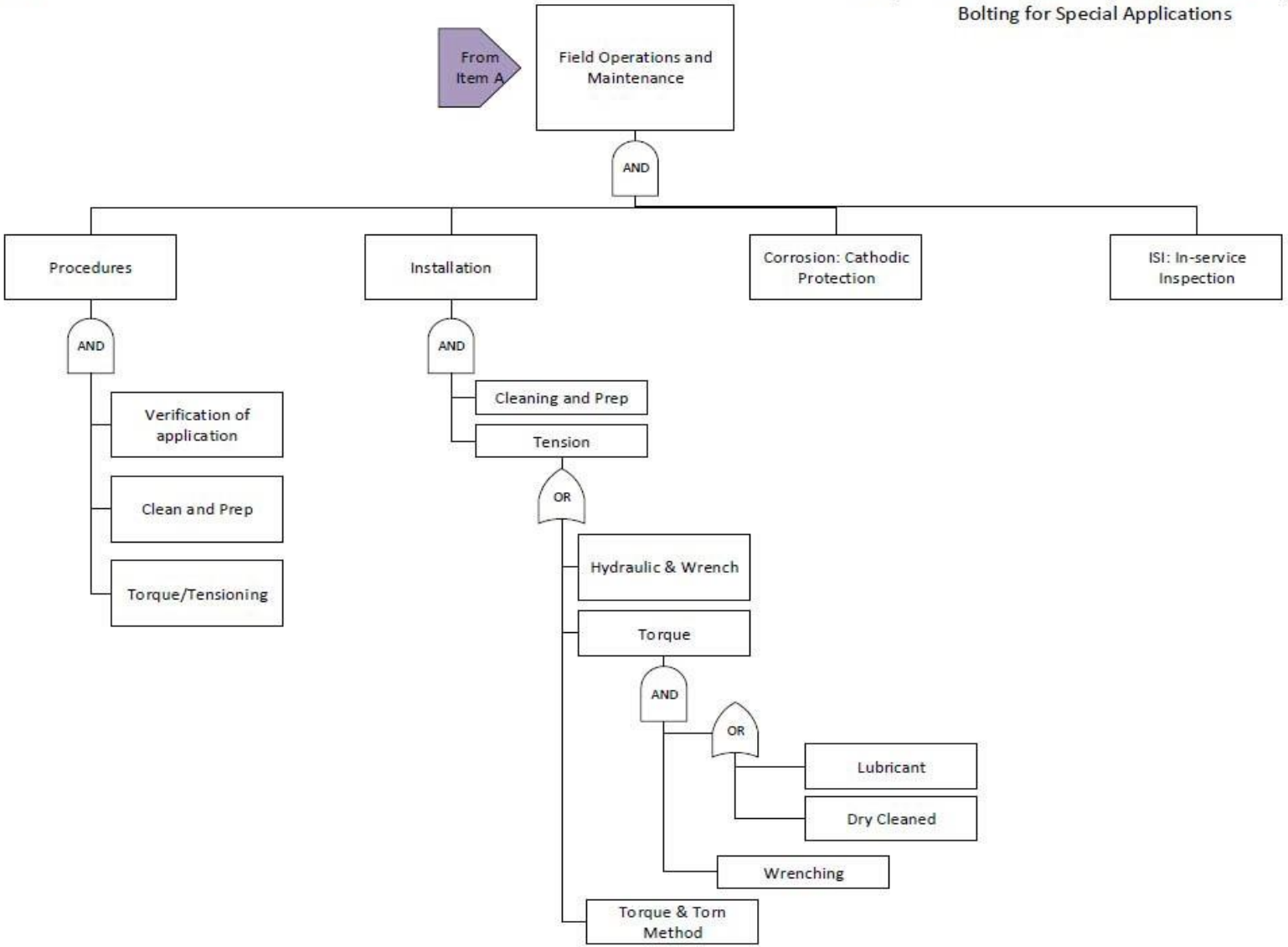
Item G

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



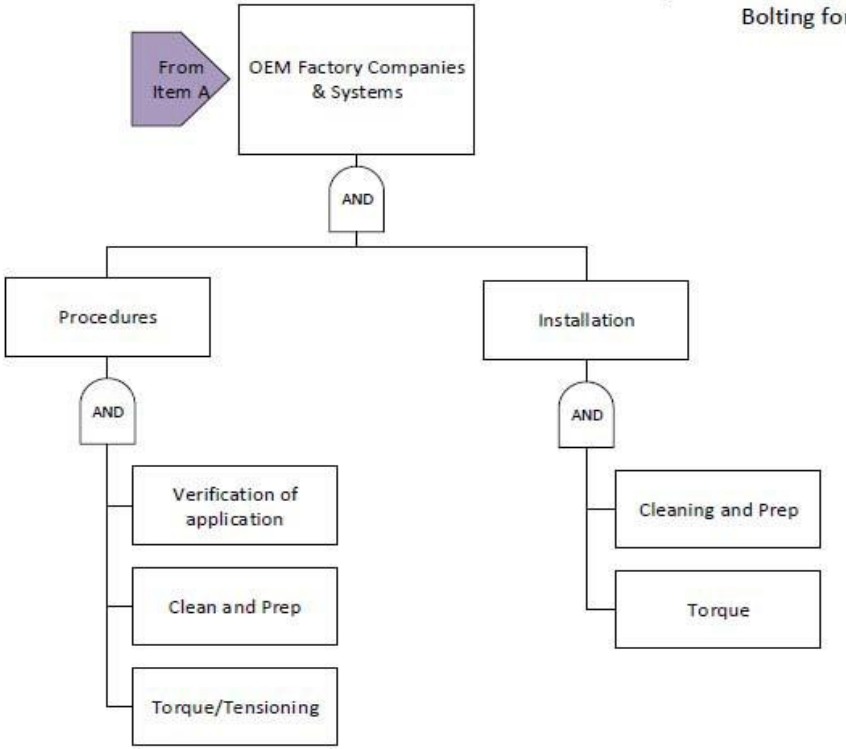
Item H

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



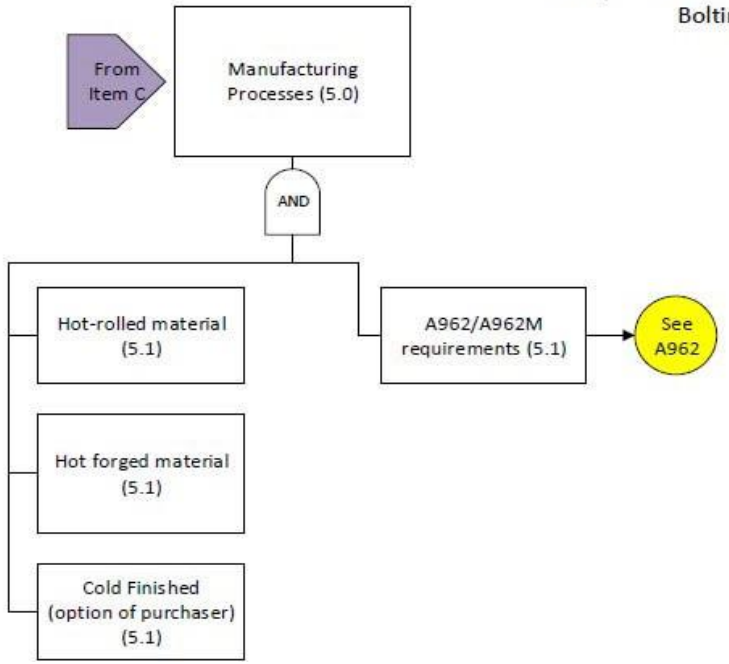
Item I

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



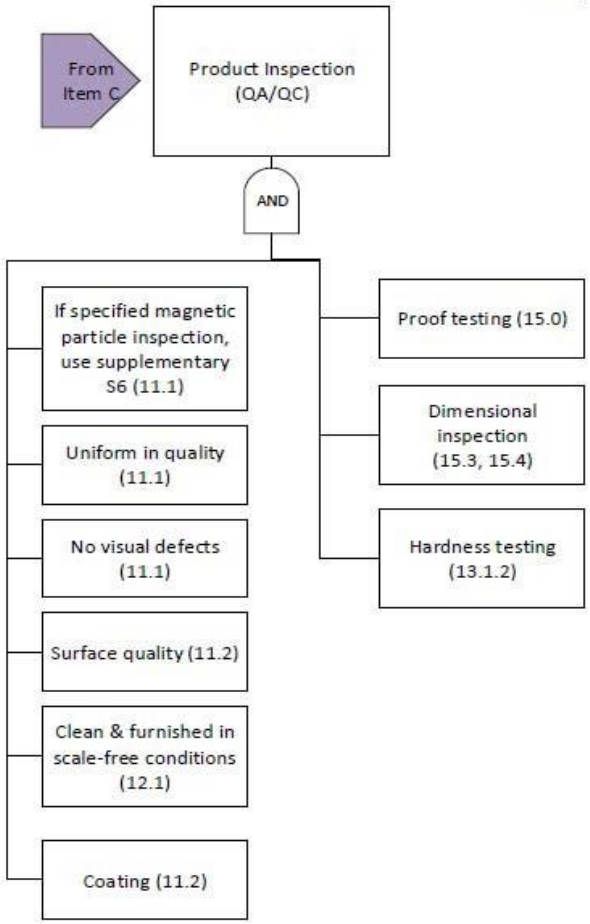
Item J

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications

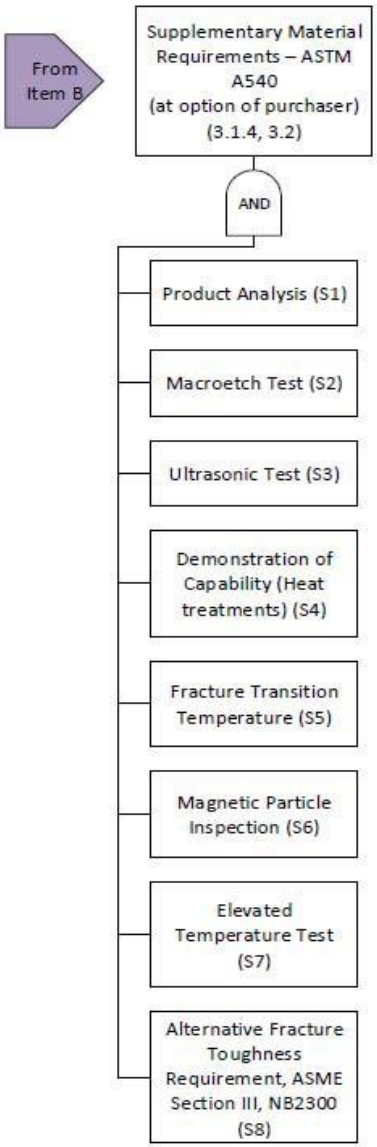


Item K

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



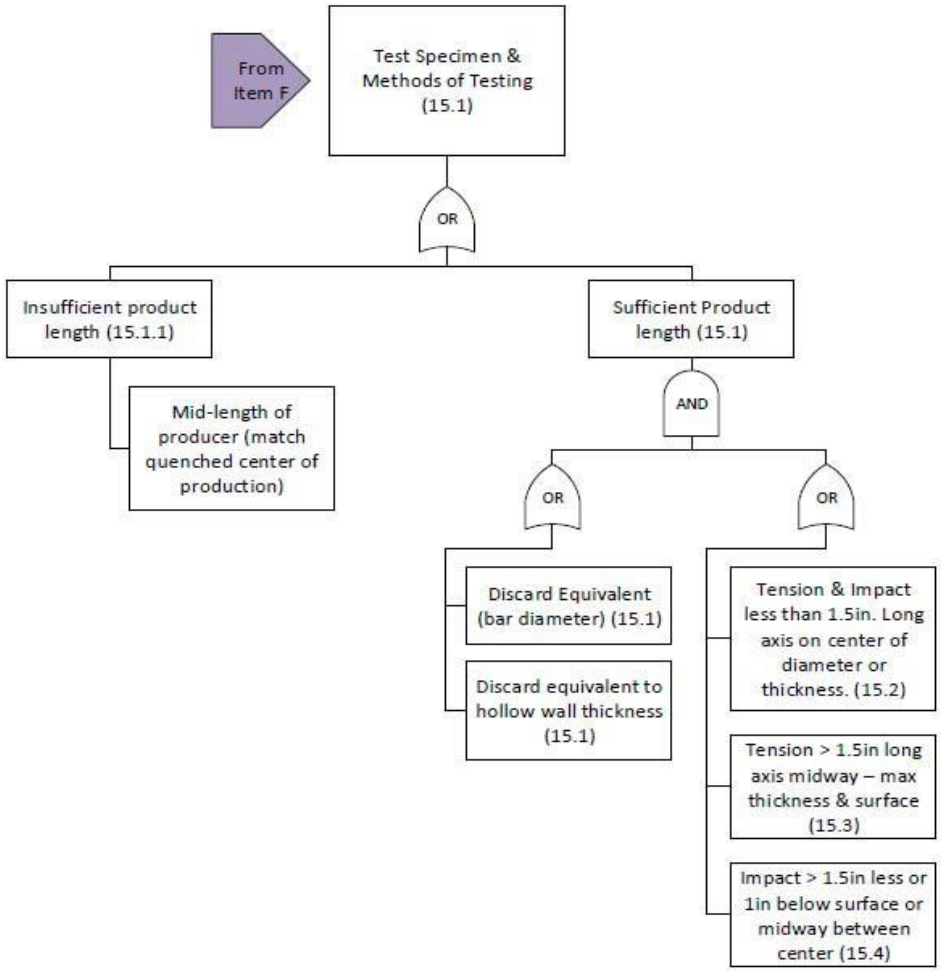
Item L

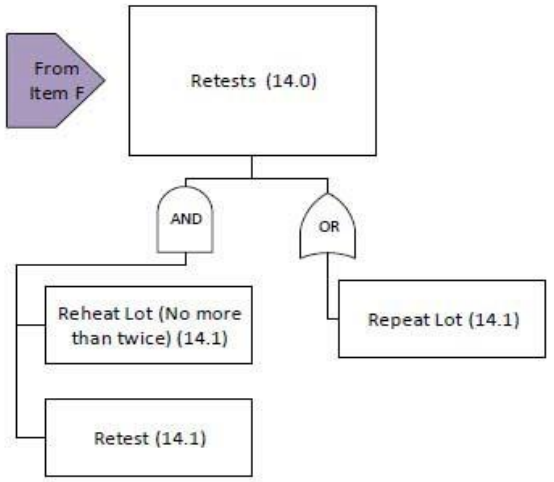


A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications

Item M

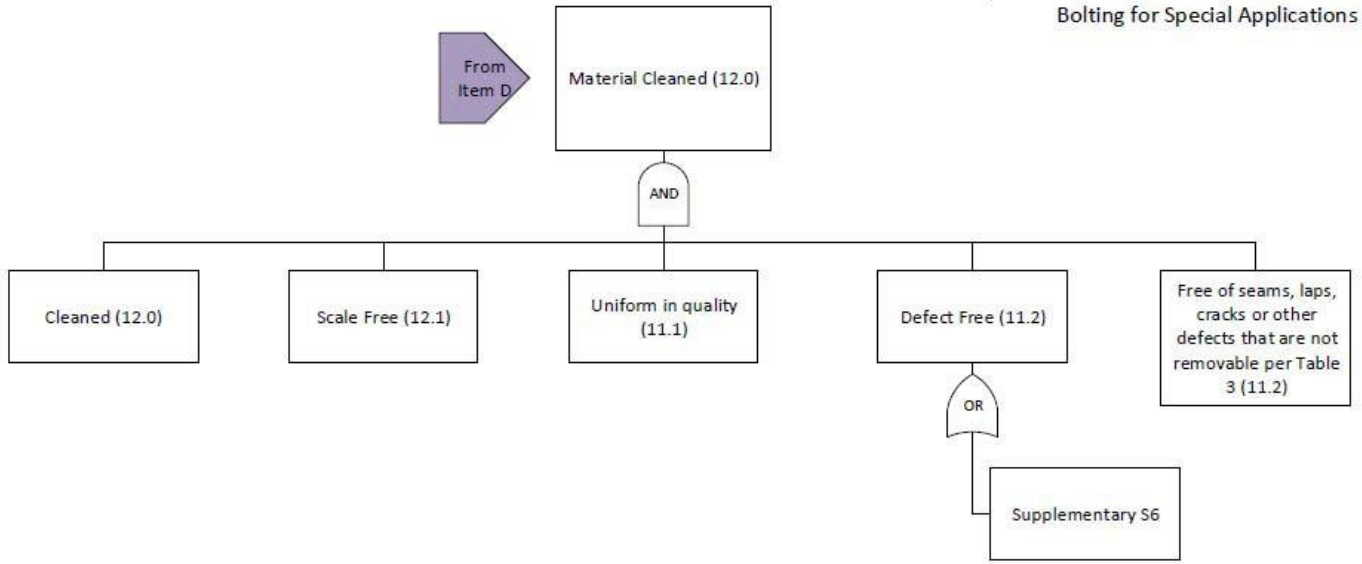
A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications





Item N

A540/540M – 15: Standard Specification for Alloy-Steel Bolting for Special Applications



ASTM A962/A962M Success Tree

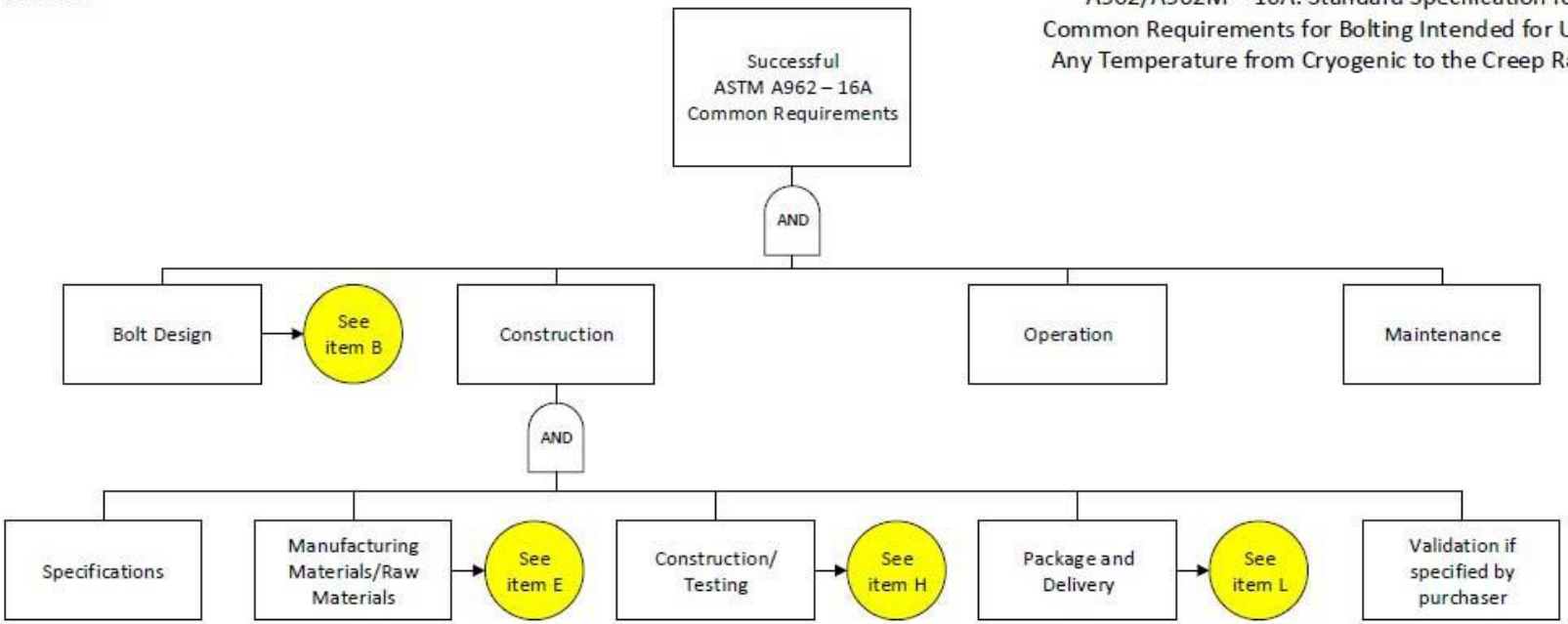
The following figure is a success tree for ASTM A962/A962M-16A. As with the previous ASTM A540 success path figure, the general structure at the first level shows design, construction, operations, and maintenance. Subsection topics are based on the headings in the standard. Numbers shown in parentheses refer to the paragraph numbering system in the standard.

The notable findings from this tree are the following:

- Standard defines materials, manufacturing, and testing.
- Standard does not define design criteria, such as is done in the ASME BPVC.
- Standard does contain information about operations and maintenance.
- Standard is common reference for entire oil and gas ASTM Core Group of bolting standards.

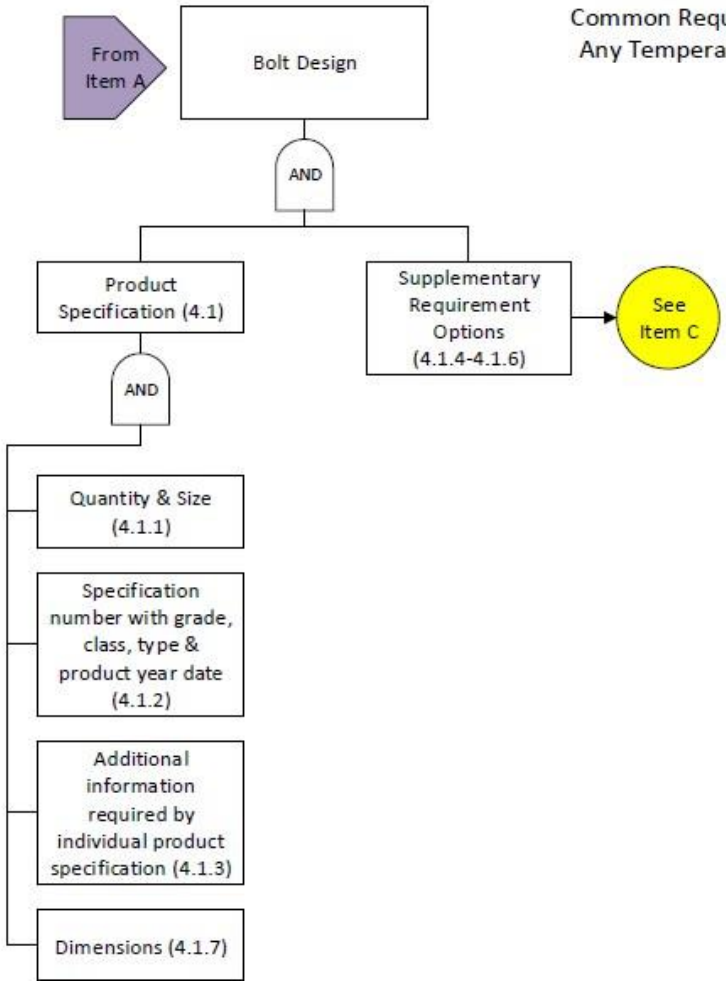
Item A

A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range



Item B

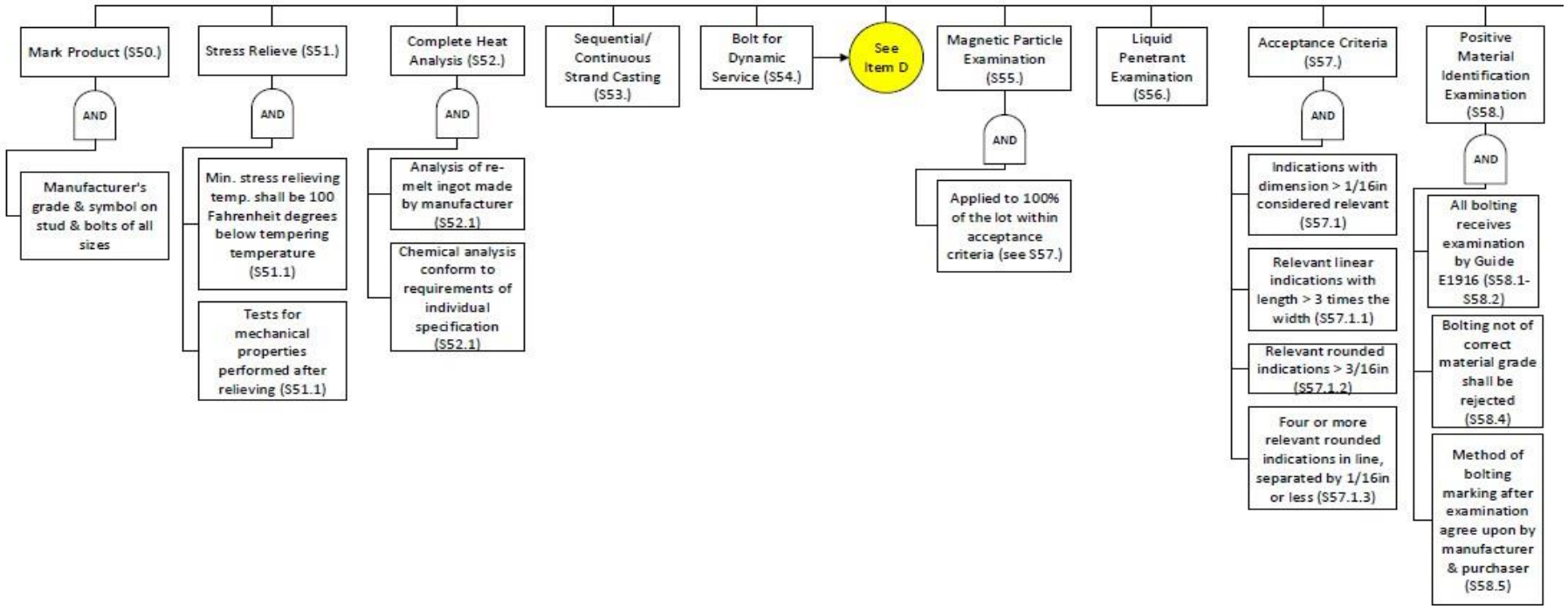
A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range



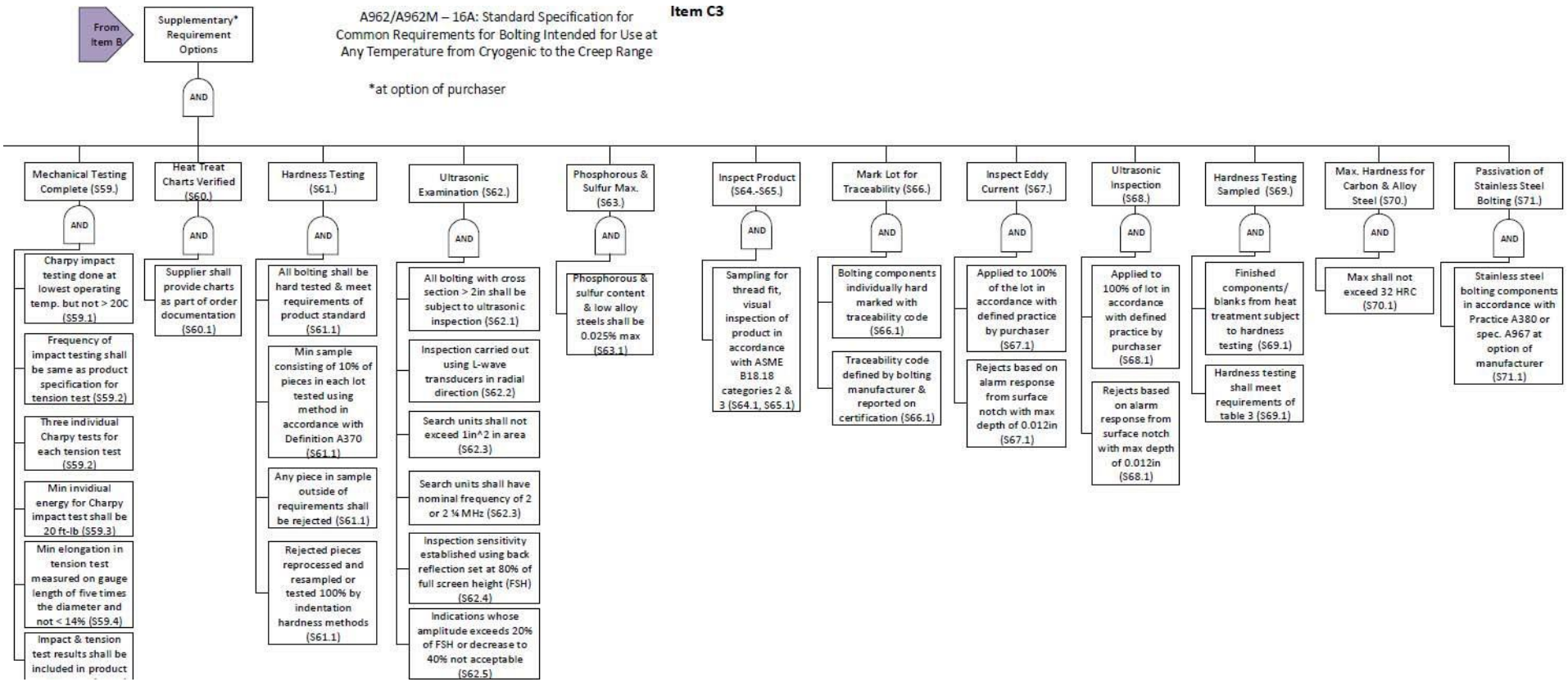
Note: This sheet is too wide for the paper format and has been divided into a left and right portion for legibility. This is the left portion.

Item C1

Item C2

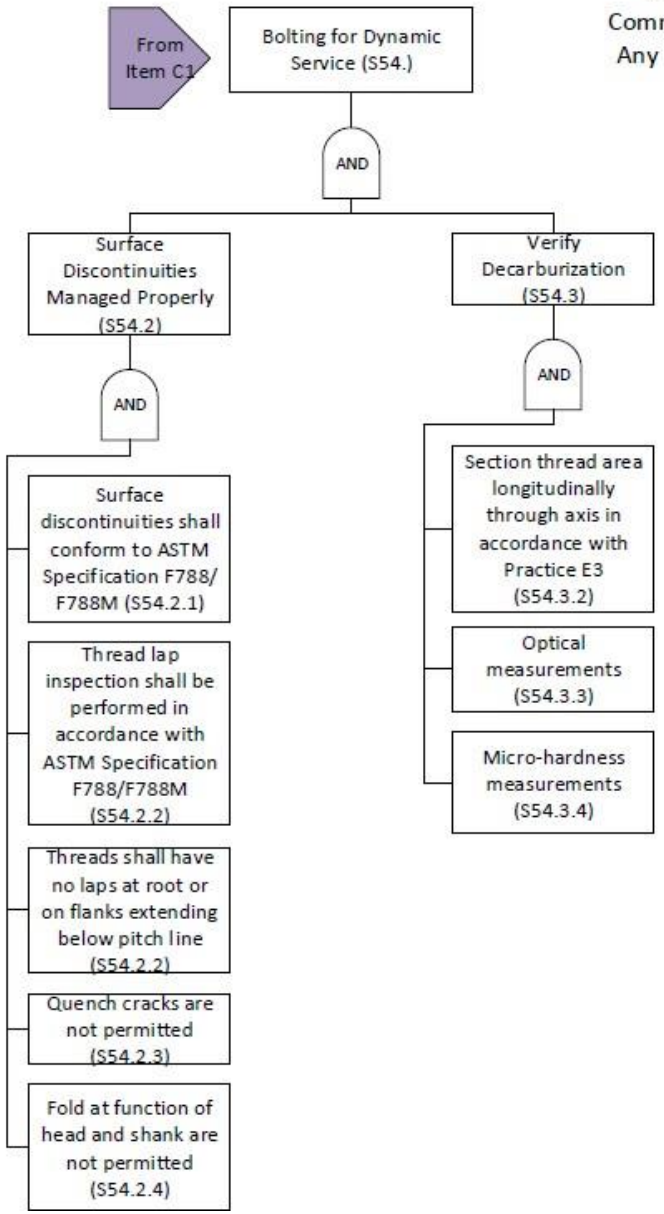


Note: This sheet is too wide for the paper format and has been divided into a left and right portion for legibility. This is the right portion.



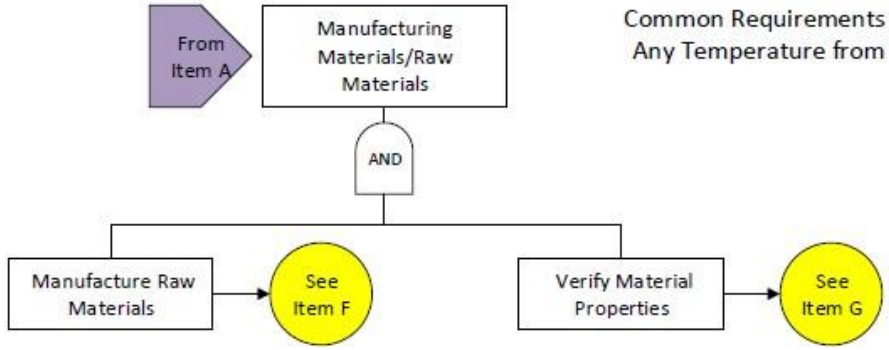
Item D

A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range



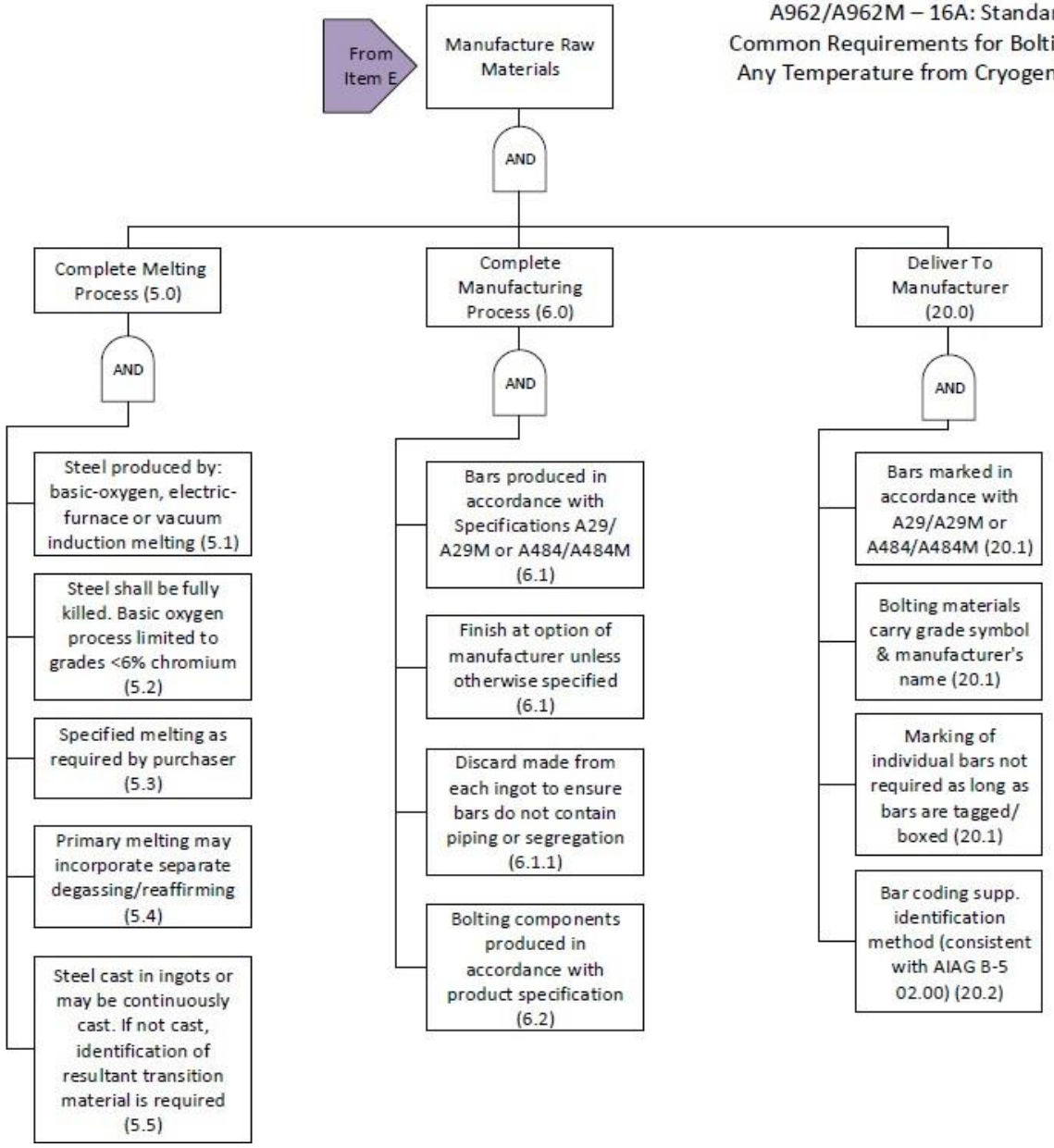
Item E

A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range

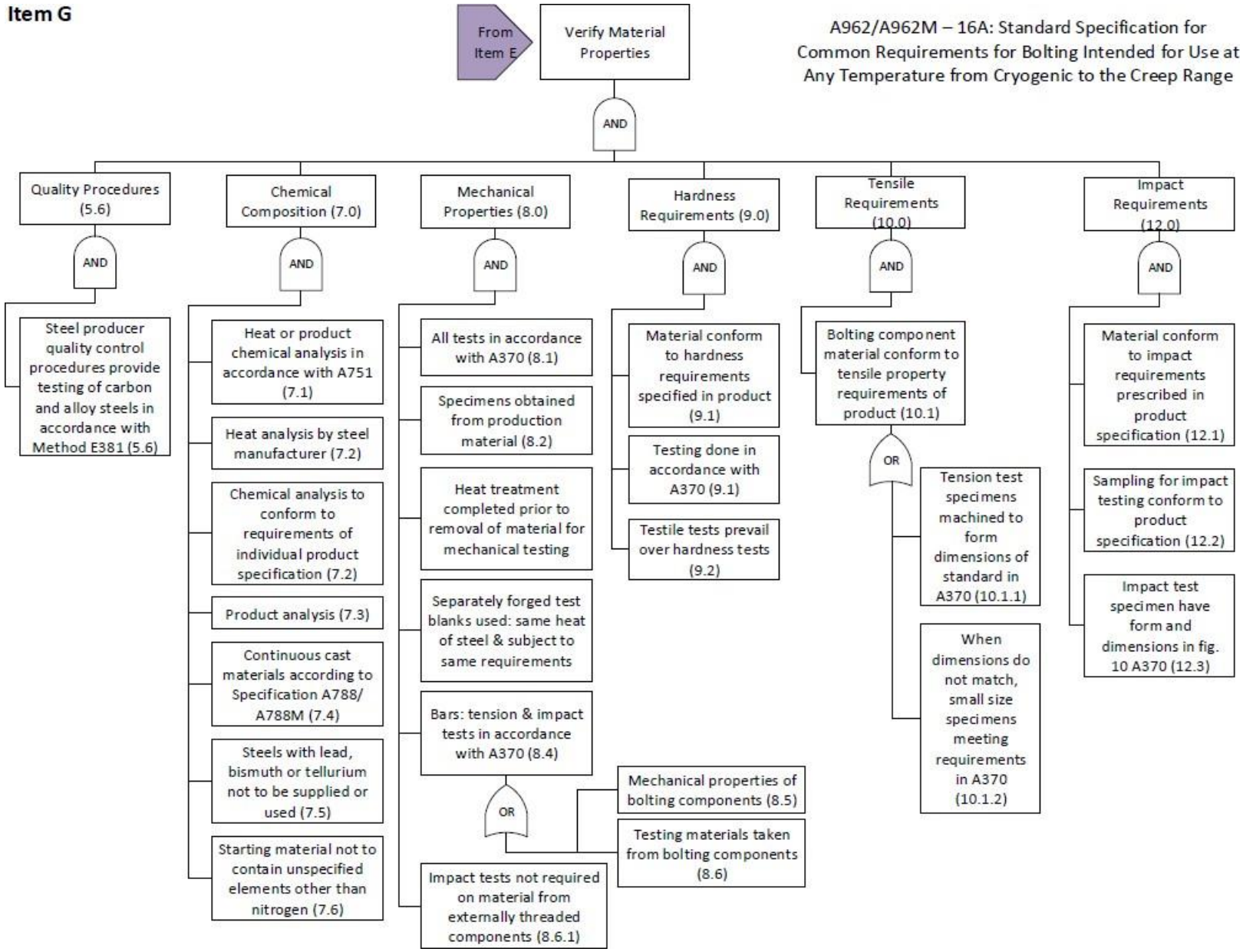


Item F

A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range

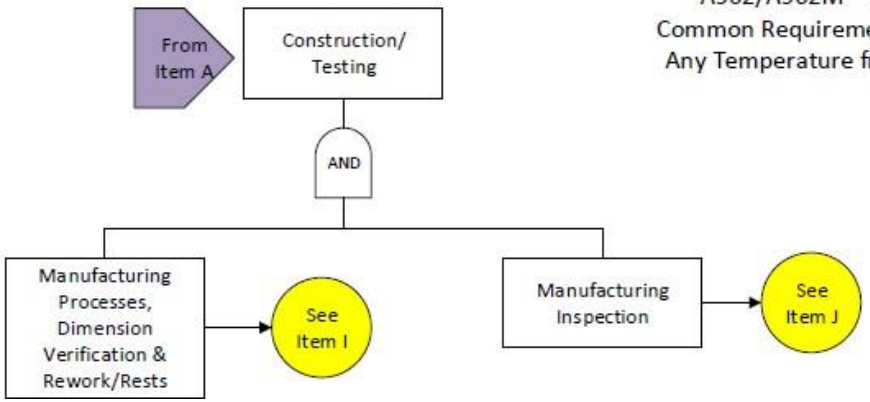


Item G

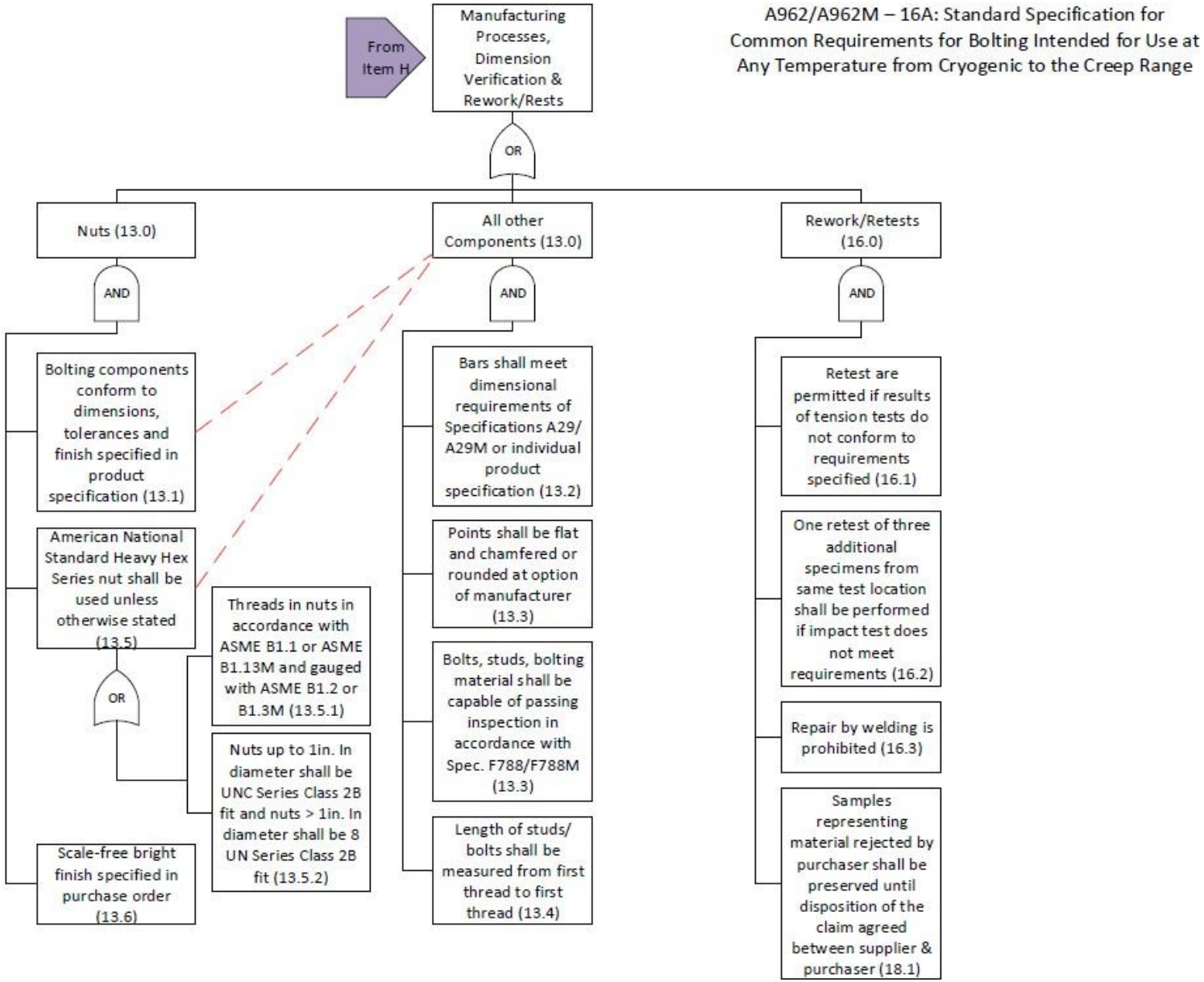

From Item E
Verify Material Properties
A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range
AND
Quality Procedures (5.6)
Chemical Composition (7.0)
Mechanical Properties (8.0)
Hardness Requirements (9.0)
Tensile Requirements (10.0)
Impact Requirements (12.0)
Steel producer quality control procedures provide testing of carbon and alloy steels in accordance with Method E381 (5.6)
Heat or product chemical analysis in accordance with A751 (7.1)
Heat analysis by steel manufacturer (7.2)
Chemical analysis to conform to requirements of individual product specification (7.2)
Product analysis (7.3)
Continuous cast materials according to Specification A788/ A788M (7.4)
Steels with lead, bismuth or tellurium not to be supplied or used (7.5)
Starting material not to contain unspecified elements other than nitrogen (7.6)
All tests in accordance with A370 (8.1)
Specimens obtained from production material (8.2)
Heat treatment completed prior to removal of material for mechanical testing
Separately forged test blanks used: same heat of steel & subject to same requirements
Bars: tension & impact tests in accordance with A370 (8.4)
OR
Mechanical properties of bolting components (8.5)
Testing materials taken from bolting components (8.6)
Impact tests not required on material from externally threaded components (8.6.1)
Material conform to hardness requirements specified in product (9.1)
Testing done in accordance with A370 (9.1)
Testile tests prevail over hardness tests (9.2)
Bolting component material conform to tensile property requirements of product (10.1)
OR
Tension test specimens machined to form dimensions of standard in A370 (10.1.1)
When dimensions do not match, small size specimens meeting requirements in A370 (10.1.2)
Material conform to impact requirements prescribed in product specification (12.1)
Sampling for impact testing conform to product specification (12.2)
Impact test specimen have form and dimensions in fig. 10 A370 (12.3)

Item H

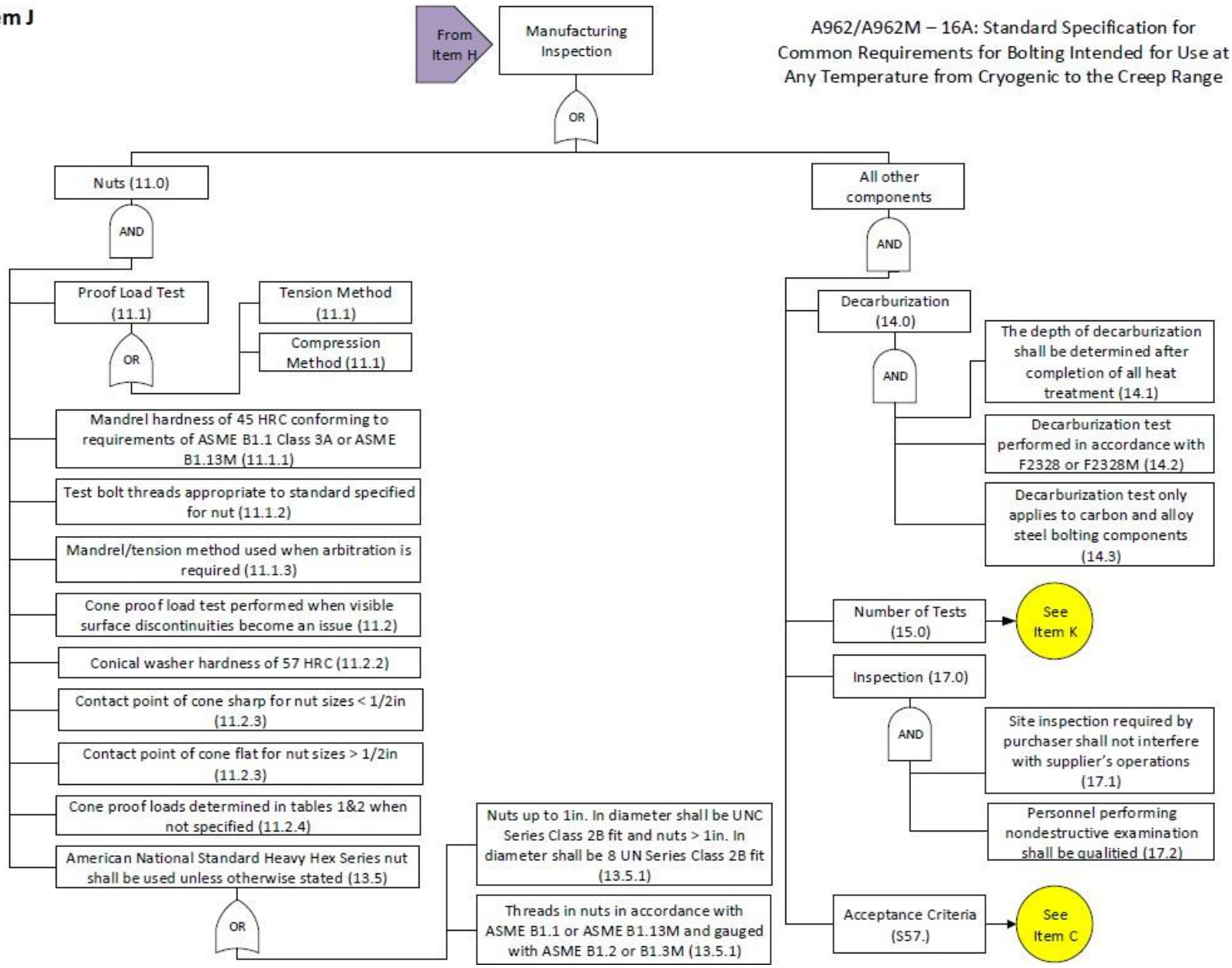
A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range



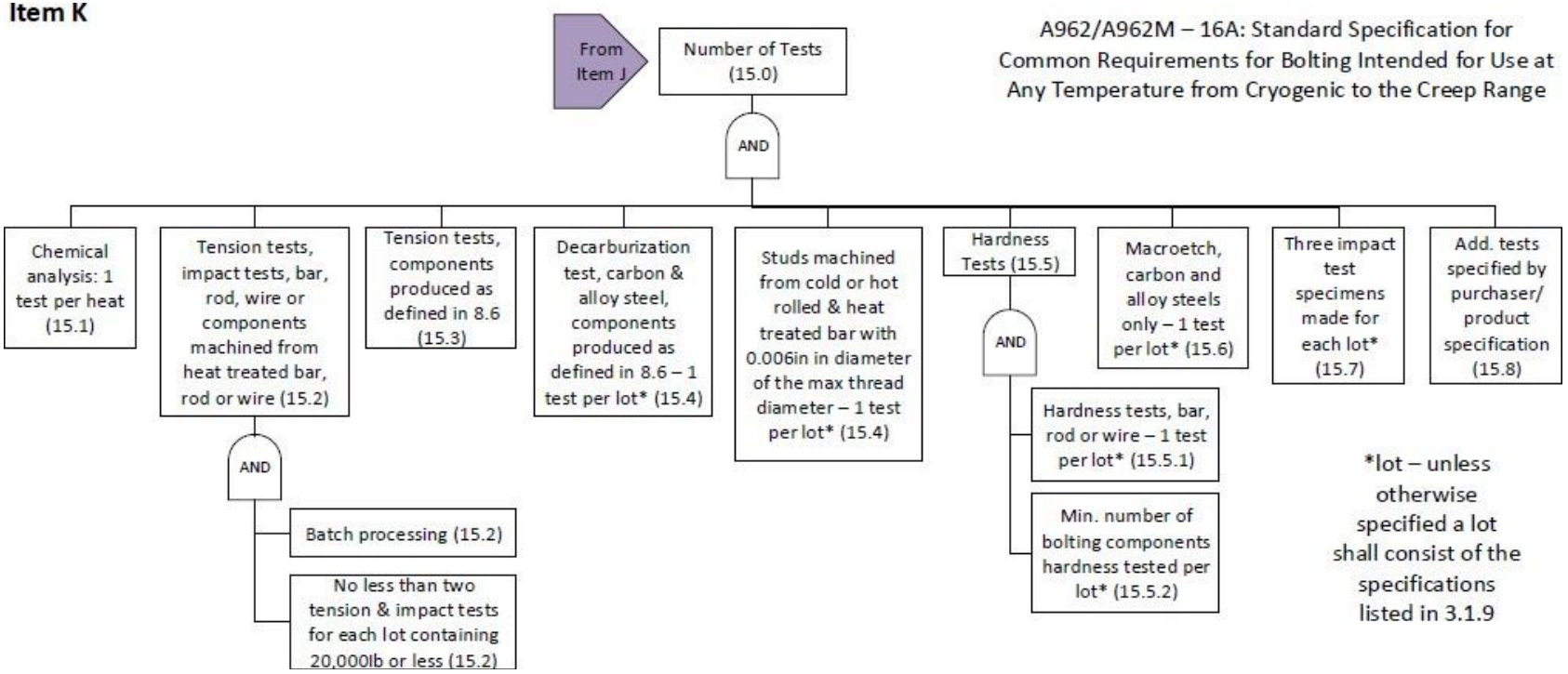
Item I


A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range
From Item H
Manufacturing Processes, Dimension Verification & Rework/Rests
OR
Nuts (13.0)
All other Components (13.0)
Rework/Retests (16.0)
AND
AND
AND
Bolting components conform to dimensions, tolerances and finish specified in product specification (13.1)
American National Standard Heavy Hex Series nut shall be used unless otherwise stated (13.5)
OR
Threads in nuts in accordance with ASME B1.1 or ASME B1.13M and gauged with ASME B1.2 or B1.3M (13.5.1)
Nuts up to 1in. In diameter shall be UNC Series Class 2B fit and nuts > 1in. In diameter shall be 8 UN Series Class 2B fit (13.5.2)
Scale-free bright finish specified in purchase order (13.6)
Bars shall meet dimensional requirements of Specifications A29/ A29M or individual product specification (13.2)
Points shall be flat and chamfered or rounded at option of manufacturer (13.3)
Bolts, studs, bolting material shall be capable of passing inspection in accordance with Spec. F788/F788M (13.3)
Length of studs/ bolts shall be measured from first thread to first thread (13.4)
Retest are permitted if results of tension tests do not conform to requirements specified (16.1)
One retest of three additional specimens from same test location shall be performed if impact test does not meet requirements (16.2)
Repair by welding is prohibited (16.3)
Samples representing material rejected by purchaser shall be preserved until disposition of the claim agreed between supplier & purchaser (18.1)

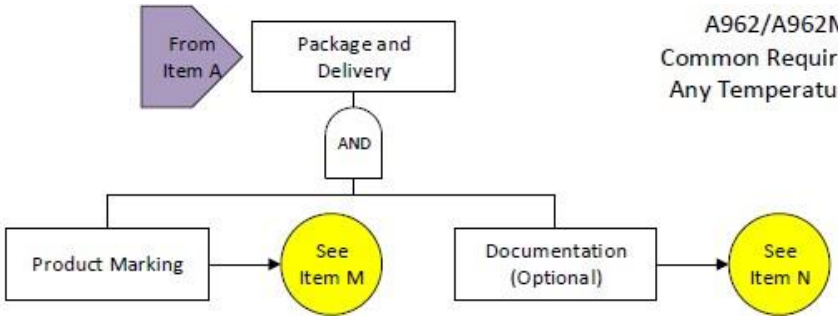
Item J


From Item H
Manufacturing Inspection
A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range
OR
Nuts (11.0)
AND
Proof Load Test (11.1)
OR
Tension Method (11.1)
Compression Method (11.1)
Mandrel hardness of 45 HRC conforming to requirements of ASME B1.1 Class 3A or ASME B1.13M (11.1.1)
Test bolt threads appropriate to standard specified for nut (11.1.2)
Mandrel/tension method used when arbitration is required (11.1.3)
Cone proof load test performed when visible surface discontinuities become an issue (11.2)
Conical washer hardness of 57 HRC (11.2.2)
Contact point of cone sharp for nut sizes < 1/2in (11.2.3)
Contact point of cone flat for nut sizes > 1/2in (11.2.3)
Cone proof loads determined in tables 1&2 when not specified (11.2.4)
American National Standard Heavy Hex Series nut shall be used unless otherwise stated (13.5)
OR
Nuts up to 1in. In diameter shall be UNC Series Class 2B fit and nuts > 1in. In diameter shall be 8 UN Series Class 2B fit (13.5.1)
Threads in nuts in accordance with ASME B1.1 or ASME B1.13M and gauged with ASME B1.2 or B1.3M (13.5.1)
All other components
AND
Decarburization (14.0)
AND
The depth of decarburization shall be determined after completion of all heat treatment (14.1)
Decarburization test performed in accordance with F2328 or F2328M (14.2)
Decarburization test only applies to carbon and alloy steel bolting components (14.3)
Number of Tests (15.0)
See Item K
Inspection (17.0)
AND
Site inspection required by purchaser shall not interfere with supplier's operations (17.1)
Personnel performing nondestructive examination shall be qualitied (17.2)
Acceptance Criteria (S57.)
See Item C

Item K

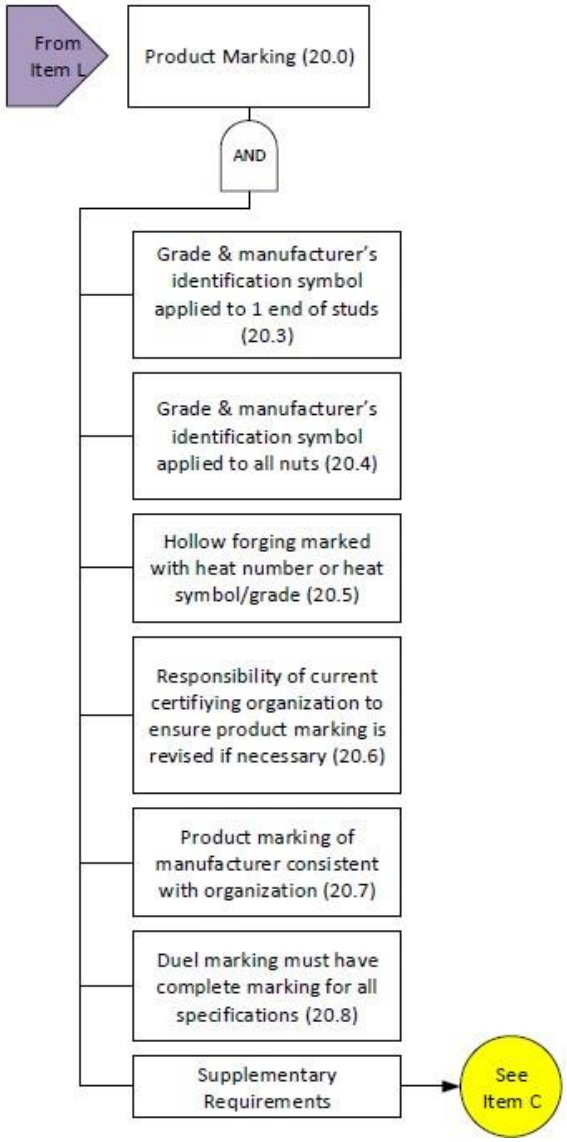

From Item J
Number of Tests (15.0)
AND
Chemical analysis: 1 test per heat (15.1)
Tension tests, impact tests, bar, rod, wire or components machined from heat treated bar, rod or wire (15.2)
AND
Batch processing (15.2)
No less than two tension & impact tests for each lot containing 20,000lb or less (15.2)
Tension tests, components produced as defined in 8.6 (15.3)
Decarburization test, carbon & alloy steel, components produced as defined in 8.6 – 1 test per lot* (15.4)
Studs machined from cold or hot rolled & heat treated bar with 0.006in in diameter of the max thread diameter – 1 test per lot* (15.4)
Hardness Tests (15.5)
AND
Hardness tests, bar, rod or wire – 1 test per lot* (15.5.1)
Min. number of bolting components hardness tested per lot* (15.5.2)
Macroetch, carbon and alloy steels only – 1 test per lot* (15.6)
Three impact test specimens made for each lot* (15.7)
Add. tests specified by purchaser/ product specification (15.8)
A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range
*lot – unless otherwise specified a lot shall consist of the specifications listed in 3.1.9

Item L



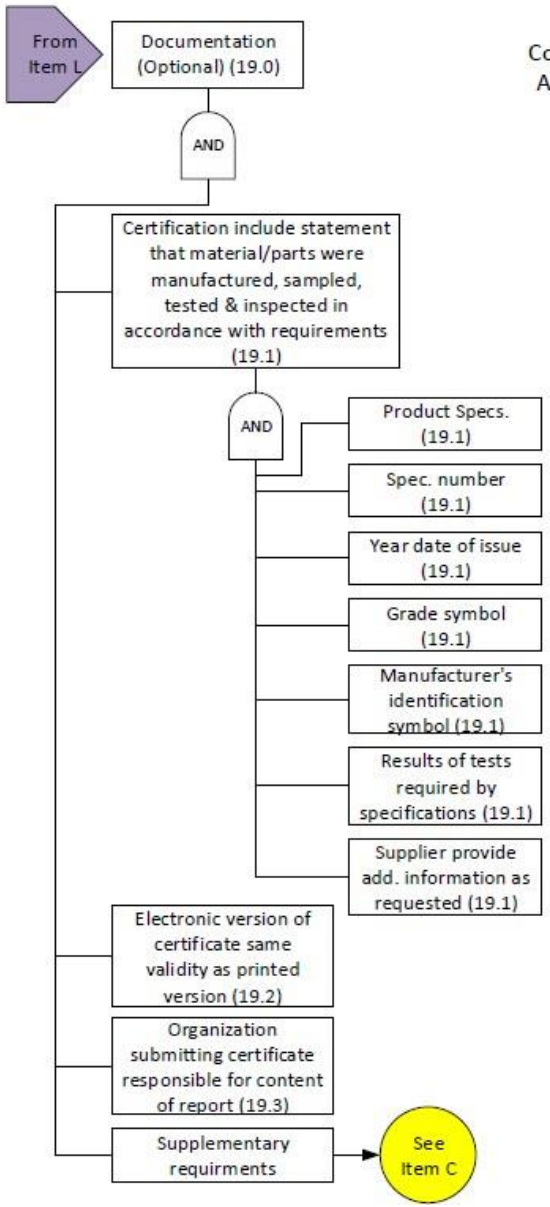
A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range

Item M



A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range

Item N



A962/A962M – 16A: Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range

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C: API Meeting Summary

During the study, BSEE requested that Argonne present preliminary findings to a group assembled by API. This presentation and discussion was a telecom on June 2, 2017.

Preliminary findings presented and discussed:

- Fatigue criteria is missing in key U.S. oil and gas bolting standards, but appears in some foreign oil and gas standards, as well as in the ASME BPVC (which is itself an internally applied code).
- Cathodic protection requirements are not well characterized and standardized in the U.S. oil and gas industry bolting standards.
- Quality assurance provisions now applied to the oil and gas industry bolting do not have comprehensive tracking requirements for critical bolting.
- API 20E and API 20F are both positive steps on the part of API to more tightly specify bolting requirements for subsea applications. These includes definitions of three bolt service levels.
- Coating requirements between B633 and F1941 are not consistent and are not part of the entire ASTM oil and gas bolting standards group. The technical difference concerning baking time after a coating is applied.

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D: Bolt Standards Appearing in Preliminary Database

Table D-1 lists more than 300 bolt-related standards covered in the preliminary project database that contains topics from most (but not all) of the standards discussed in this study. The first column lists the name of the standard, the second column lists the edition, and the third column lists the title. In some cases, the entire standard pertains to some feature about bolts and fasteners, such as is the case with ASME B1.1 on thread form. In other cases, bolting and fasteners are mentioned in the standard, but are a minor part of the standard or specification as a whole. This occurs with API 16A. In still other cases, fasteners are not specifically mentioned, yet are subject to that standard, such as occurs and is appropriate with a quality control system as defined in API Q1. Few standards documents address every aspect of bolting since the typical standard references several other standards, including other standards that organization publishes as well as those of other standards development organizations. Such normative references are detailed in Appendix E: Normative References from Preliminary Database Bolt Standards

As mentioned elsewhere in this report, quality assurance in the API family of standards tends to focus on only part of the life cycle of a component or bolt. In contrast, ASME NQA-1, which is published by the ASME, provides requirements and guidelines for the establishment and execution of quality assurance programs during siting, design, construction, operation, and decommissioning. Another commonly referenced quality standard, ISO 9001 ("Quality Management Systems—Requirements"), specifies requirements for a quality management system to demonstrate the ability to provide product conformity to the specification of customers.[44] In addition, there are stipulations in the respective standard regarding use. For NQA-1, some important considerations are the following:

- Can be used by regulatory authorities to set requirements
- Can be invoked by contract, adopted voluntarily, or used as the basis for assessing a management system or a quality assurance program
- Requires responsibility for the quality assurance system (NQA-1)/management system and work carried out to be retained by the organization
- Fosters grading in the application of requirements consistent with the relative importance of the item or activity
- Requires records for the control of purchased items and services

[44] From Jeannot P. Boogaard, Comparison between GS-R-# and the ASME NQA-1-2008 and ISO 9001 Requirements. July 2012.

- Specifically requires inspection during operations and inspection records

Like API Q1, ISO 9001 does not cover the entire life cycle of a component since the emphasis of both is the interface between a provider and customer.

TABLE D-1 BOLT-RELATED STANDARDS INCLUDED IN PRELIMINARY PROJECT DATABASE

Standard Shorthand Name	Edition	Standard Title
A-A-55625	1997	Commercial Item Description: Nut, Plain, Plate
A-A-55628A	1998	Commercial Item Description: Nut, Plain, Cap, High Crown UNC-2B and UNF-2B
A-A-55629	1997	Commercial Item Description: Nut, Plain, Cap, Low Crown UNC-2B and UNF-2B
A-A-59441	2004	Commercial Item Description: Vapor Corrosion Inhibitors
A-A-59817	2008	Commercial Item Description: U-Nut, Wide Panel Range, 3/8-Inch Diameter, Coarse Unified Inch Screw Threads
ANSI/AISC 360-05	2005	Specification for Structural Steel Buildings
API 16A	3rd ed. (06/2004)	Specification for Drill-Through Equipment
API 16A	4th ed. (2017)	Specification for Drill-Through Equipment
API 16AR	1st ed. (2017)	Standard for Repair and Remanufacture of Drill-Through Equipment
API 16C	1st ed. (1993)	Specification for Choke and Kill Systems
API 16C	2nd ed. (2015)	Choke and Kill Equipment
API 16D	2nd ed. (2005)	Specification for Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment
API 16F	1st ed. (2004 ad 2 Nov 2014)	Specification for Marine Drilling Riser Equipment
API 16Q	1st ed. (2010)	Recommended Practice for Design, Selection, Operation, and Maintenance of Marine Drilling Riser Systems
API 17A	4th ed. (2011)	Design and Operation of Subsea Production Systems - General Requirements and Recommendations
API 20E	1st ed. (08/2012)	Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries
API 20E	2nd ed. (2017)	Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries
API 20F	1st ed. (2015)	Corrosion-Resistant Bolting for Use in the Petroleum and Natural Gas Industries
API 2SC	1st ed. (2010)	Manufacture of Structural Steel Casting for Primary Offshore Applications
API 53	4th ed. (11/2012)	Blowout Prevention Equipment Systems for Drilling Wells
API 5SI	1st ed. (2006)	Recommended Practice for Purchaser Representative Surveillance and/or Inspection at the Supplier
API 6A	19th ed. (2005)	Specification for Wellhead and Christmas Tree Equipment
API 6A	20th ed. (10/2011)	Specification for Wellhead and Christmas Tree Equipment
API 6AV1	1st ed. (1996)	Specification for Verification Test of Wellhead Surface Safety Valves and Underwater Safety Valves for Offshore Service
API 6AV1	2nd ed. (2013)	Specification for Validation of Wellhead Surface Safety Valves and Underwater Safety Valves for Offshore Service
API Bulletin 91	1st ed. (2007)	Planning and Conducting Surface Preparation and Coating Operations for Oil and Natural Gas Drilling and Production Facilities in a Marine Environment
API Q1	8th ed. (2010)	Specification for Quality Programs for the Petroleum, Petrochemical and Natural Gas Industry

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Standard Shorthand Name	Edition	Standard Title
API Q1	9th ed. (2014)	Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry
API Q2	1st ed. (2011)	Specification for Quality Management System Requirements for Service Supply Organizations for the Petroleum and Natural Gas Industries
API TR 6AF1	2nd ed. (1998)	Technical Report on Temperature Derating on API Flanges Under Combination of Loading
API TR 6AF2	5th ed. (2013)	Technical Report on Capabilities of API Integral Flanges Under Combination of Loading—Phase II
ASME B1.1	2003 (reaffirmed 2008)	Unified Inch Screw Threads (UN and UNR Thread Form)
ASME B1.13M	2005 (reaffirmed 2015)	Metric Screw Threads: M Profile
ASME B1.2	1983 (reaffirmed 2007)	Gages and Gaging for Unified Inch Screw Threads
ASME B18.1.3M	1983 (reaffirmed 2016)	Metric Small Solid Rivets
ASME B18.2.1	2012	Square, Hex, Heavy Hex and Askew Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head, and Lag Screws (Inch Series)
ASME B18.2.3.3M	2007	Metric Heavy Hex Screws
ASME B18.3	2012	Socket Cap, Shoulder, Set Screws, and Hex Keys (Inch Series)
ASME SA-320/SA-320M	2007	Specification for Alloy Steel Bolting Materials for Low-Temperature Service
ASTM A1014/A1014M	2016	Standard Specification for Precipitation-Hardening Bolting (UNS N07718) for High Temperature Service
ASTM A1058	2014	Standard Test Methods for Mechanical Testing of Steel Products - Metric
ASTM A1059/A1059M	2008 (reapproved 2013)	Standard Specification for Zinc Alloy Thermo-Diffusion Coatings (TDC) on Steel Fasteners, Hardware and Other Products
ASTM A106/A106M	2015	Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service
ASTM A1082/A1082M	2015	Standard Specification for High-Strength Precipitation-Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications
ASTM A123/A123M	2015	Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
ASTM A143/A143M	2007 (reapproved 2014)	Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement
ASTM A153/A153M	2016a	Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
ASTM A183	2014	Standard Specification for Carbon Steel Track Bolts and Nuts
ASTM A193/A193M	2015	Standard Specification for Alloy Steel and Stainless Steel Bolting for High-Temperature or High-Pressure Service and Other Special Purpose Applications

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Standard Shorthand Name	Edition	Standard Title
ASTM A194/A194M	2015	Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both
ASTM A276/276M	2017	Standard Specification for Stainless Steel Bars and Shapes
ASTM A29/A29M	2016	Standard Specification for General Requirements for Steel Bars, Carbon and Alloy, Hot-Wrought
ASTM A307	2014	Standard Specification for Carbon Steel Bolts, Studs and Threaded Rod 60000 PSI Tensile Strength
ASTM A320/A320M	2014	Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service
ASTM A320/A320M	2015	Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service
ASTM A325	2014	Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength
ASTM A354	2011	Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners
ASTM A370	2017	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A380/A380M	2013	Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems
ASTM A384/A384M	2007 (reapproved 2013)	Standard Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies
ASTM A385/A385M	2015	Standard Practice for Providing High-Quality Zinc Coatings (Hot-Dip)
ASTM A394	2008 (reapproved 2015)	Standard Specification for Steel Transmission Tower Bolts, Zinc-Coated and Bare
ASTM A437/A437M	2015	Standard Specification for Stainless and Alloy Steel Turbine-Type Bolting Specially Heat Treated for High-Temperature Service
ASTM A449	2014	Standard Specification for Hex Cap Screws, Bolts and Studs, Steel, Heat Treated, 120/105/90 ksi Minimum Tensile Strength, General Use
ASTM A453/A453M	2015	Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels
ASTM A453/A453M	2016	Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels
ASTM A479/A479M	2017	Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels
ASTM A484/A484M	2016	Standard Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings
ASTM A490	2014a	Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength
ASTM A490M	2014a	Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength
ASTM A540/A540M	2015	Standard Specification for Alloy Steel Bolting for Special Applications
ASTM A563	2015	Standard Specification for Carbon and Alloy Steel Nuts
ASTM A564/A564M	2016	Standard Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings
ASTM A574	2017	Standard Specification for Alloy Steel Socket-Head Cap Screws

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Standard Shorthand Name	Edition	Standard Title
ASTM A684/A684M	2017	Standard Specification for Steel, Strip, High-Carbon, Cold-Rolled
ASTM A700	2014	Standard Guide for Packaging, Marking, and Loading Methods for Steel Products for Shipment
ASTM A747/A747M	2016a	Standard Specification for Steel Castings, Stainless, Precipitation Hardening
ASTM A751	2014a	Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
ASTM A780/A780M	2009 (reapproved 2015)	Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
ASTM A788/A788M	2016	Standard Specification for Steel Forgings, General Requirements
ASTM A896/A896M	2009 (reapproved 2014)	Standard Practice for Conducting Case Studies on Galvanized Structures
ASTM A941	2016	Standard Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys
ASTM A959/A959M	2016	Standard Guide for Specifying Harmonized Standard Grade Compositions for Wrought Stainless Steels
ASTM A962/A962M	2015	Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range
ASTM A968/A968M	1996 (reapproved 2014)	Standard Specification for Chromium, Chromium-Nickel, and Silicon Alloy Steel Bars and Shapes for Corrosion and Heat-Resisting Service
ASTM B117	2016	Standard Practice for Operating Salt Spray (Fog) Apparatus
ASTM B194	2015	Standard Specification for Copper-Beryllium Alloy Plate, Strip and Rolled Bar
ASTM B418	2016a	Standard Specification for Cast and Wrought Galvanic Zinc Anodes
ASTM B487	1985 (reapproved 2013)	Standard Test Method for Measurement of Metal and Oxide coating Thickness by Microscopical Examination of Cross Section
ASTM B633	2015	Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel
ASTM B695	2015	Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel
ASTM B696	2015	Standard Specification for Coatings of Cadmium Mechanically Deposited
ASTM B766	2015	Standard Specification for Electrodeposited Coatings of Cadmium
ASTM B843	2013	Standard Specification for Magnesium Alloy Anodes for Cathodic Protection
ASTM B849	2002 (reapproved 2013)	Standard Specification for Pre-Treatments of Iron or steel for Reducing Risk of Hydrogen Embrittlement
ASTM B850	1998 (reapproved 2015)	Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement
ASTM C1562	2010	Standard Guide for Evaluation of Materials Used in Extended Service of Interim Spent Nuclear Fuel Dry Storage Systems
ASTM C1725	2010	Standard Guide for Hot Cell Specialized Support Equipment and Tools
ASTM D1141	1998 (reapproved 2013)	Standard Practice for the Preparation of Substitute Ocean Water

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Standard Shorthand Name	Edition	Standard Title
ASTM D3911	2008	Standard Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions
ASTM D3951	2015	Standard Practice for Commercial Packaging
ASTM D5144	2008	Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants
ASTM D5540	2013	Standard Practice for Flow Control and Temperature Control for On-Line Water Sampling and Analysis
ASTM D5648	2001 (reapproved 2014)	Standard Test Method for Torque-Tension Relationship of Adhesives Used on Threaded Fasteners (Lubricity)
ASTM D5649	2015	Standard Test Method for Torque Strength of Adhesives Used on Threaded Fasteners
ASTM D5657	2007 (reapproved 2014)	Standard Test Method for Fluid Tightness Ability of Adhesives Used on Threaded Fasteners
ASTM D5969	2011 (reapproved 2016)	Standard Test Method for Corrosion-Preventive Properties of Lubricating Greases in Presence of Dilute Synthetic Sea Water Environments
ASTM D6577	2015	Standard Guide for Testing Industrial Protective Coatings
ASTM D7230	2006 (reapproved 2013)	Standard Guide for Evaluating Polymeric Lining Systems for Water Immersion in Coating Service Level III Safety-Related Applications on Metal Substrates
ASTM E10	2017	Standard Test Method for Brinell Hardness of Metallic Materials
ASTM E1012	2014	Standard Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
ASTM E112	2013	Standard Test Methods for Determining Average Grain Size
ASTM E139	2011	Standard Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials
ASTM E140	2012b	Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness and Leeb Hardness
ASTM E1417/E1417M	2016	Standard Practice for Liquid Penetrant Testing
ASTM E1444/E1444M	2016	Standard Practice for Magnetic Particle Testing
ASTM E1681	2003 (reapproved 2013)	Standard Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials
ASTM E18	2016	Standard Test Methods for Rockwell Hardness of Metallic Materials
ASTM E1997	2015	Standard Practice for Selection of Spacecraft Materials
ASTM E21	2009	Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials
ASTM E220	2013	Standard Test Method for Calibration of Thermocouples by Comparison Techniques
ASTM E23	2016b	Standard Test Methods for Notched Bar Impact Testing of Metallic Materials
ASTM E2681	2013	Standard Guide for Environmental Management of Underground Storage Tank Systems Storing Hazardous Substances or Petroleum
ASTM E29	2013	Standard Practice for Using Significant Digits in Test Data to Determining Conformance with Specifications

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Standard Shorthand Name	Edition	Standard Title
ASTM E292	2009	Standard Test Methods for Conducting Time-for-Rupture Notch Tension Tests of Materials
ASTM E3	2011	Standard Guide for Preparation of Metallographic Specimens
ASTM E328	2013	Standard Test Methods for Stress Relaxation for Materials and Structures
ASTM E381	2001 (reapproved 2012)	Standard Method of Macro-etch Testing Steel Bars, Billets, Blooms, and Forgings
ASTM E384	2016	Standard Test Method for Micro-Indentation Hardness of Materials
ASTM E4	2016	Standard Practices for Force Verification of Testing Machines
ASTM E45	2013	Standard Test Methods for Determining the Inclusion Content of Steel
ASTM E566	2014	Standard Practice for Electromagnetic (Eddy Current) Sorting of Ferrous Metals
ASTM E6	2015	Standard Terminology Relating to Methods of Mechanical Testing
ASTM E633	2013	Standard Guide for Use of Thermocouples in Creep and Stress-Rupture Testing to 1800F (1000C) in Air
ASTM E647	2015	Standard Test Method for Measurement of Fatigue Crack Growth Rates
ASTM E691	2016	Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
ASTM E709	2015	Standard Guide for Magnetic Particle Testing
ASTM E77	2014	Standard Test Method for Inspection and Verification of Thermometers
ASTM E8/E8M	2016a	Standard Test Methods for Tension Testing of Metallic Materials
ASTM E92	2017	Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials
ASTM F1130	1999 (reapproved 2014)	Standard Practice for Inspecting the Coating System of a Ship
ASTM F1136/F1136M	2011	Standard Specification for Zinc/Aluminum Corrosion Protective Coatings for Fasteners
ASTM F1137	2011	Standard Specification for Phosphate/Oil Corrosion Protective Coatings for fasteners
ASTM F1155	2010 (reapproved 2015)	Standard Practice for Selection and Application of Piping System Materials
ASTM F1182	2007 (reapproved 2013)	Standard Specification for Anodes, Sacrificial Zinc Alloy
ASTM F1428	1992 (reapproved 2011)	Standard Specification for Aluminum, Particle-Filled Basecoat/Organic or Inorganic Topcoat, Corrosion Protective Coatings for Fasteners
ASTM F1469	2011	Standard Guide for Conducting a Repeatability and Reproducibility Study on Test Equipment for Nondestructive Testing
ASTM F1470	2012	Standard Practice for Fastener Sampling for Specified Mechanical Properties and Performance Inspection
ASTM F1476	2007 (reapproved 2013)	Standard Specification for Performance of Gasketed Mechanical Couplings for Use in Piping Applications
ASTM F1554	2015	Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength
ASTM F1789	2017	Standard Terminology for F16 Mechanical Fasteners

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Standard Shorthand Name	Edition	Standard Title
ASTM F1940	2007 (reapproved 2014)	Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners
ASTM F1941/F1941M	2015	Standard Specification for Electrodeposited Coatings on Mechanical Fasteners, Inch and Metric
ASTM F2280	2014	Standard Specification for "Twist Off" Type Tension Control Structural Bolt/Nut/Washer Assemblies, Steel, Heat Treated, 150 ksi Minimum Tensile Strength
ASTM F2281	2004 (reapproved 2012)	Standard Specification for Stainless Steel and Nickel Alloy Bolts, Hex Cap Screws, and Studs, for Heat Resistance and High Temperature Applications
ASTM F2282	2015	Standard Specification for Quality Assurance Requirements for Carbon and Alloy Steel Wire, Rods, and Bars for Mechanical Fasteners
ASTM F2328	2014	Standard Test Method for Determining Decarburization and Carburization in Hardened and Tempered Threaded Steel Bolts, Screws, Studs, and Nuts
ASTM F2329/F2329M	2015	Standard Specification for Zinc Coating, Hot-Dip, Requirements for Application to Carbon and Alloy Steel Bolts, Screws, Washers, Nuts, and Special Threaded Fasteners
ASTM F2437/F2427M	2017	Standard Specification for Carbon and Alloy Steel Compressible-Washer-Type Direct Tension Indicators for Use with Cap Screws, Bolts, Anchors, and Studs
ASTM F2482	2008 (reapproved 2015)	Standard Specification for Load-Indicating Externally Threaded Fasteners
ASTM F2660	2013	Standard Test Method for Qualifying Coatings for Use on A490 Structural Bolts Relative to Environmental Hydrogen Embrittlement
ASTM F2833	2011	Standard Specification for Corrosion Protective Fastener Coatings with Zinc Rich Base Coat and Aluminum Organic/Inorganic Type
ASTM F3019/F3019M	2014	Standard Specification for Chromium Free Zinc-Flake Composite, with or without Integral Lubricant, Corrosion Protective Coatings for Fasteners
ASTM F3042	2013	Standard Specification for Nonferrous Hex Socket, Slotted Headless, and Square Head Set Screws
ASTM F3043	2015	Standard Specification for "Twist Off" Type Tension Control Structural Bolt/Nut/washer Assemblies, Alloy Steel, Heat Treated, 200 ksi Minimum Tensile Strength
ASTM F3111	2016	Standard Specification for Heavy Hex Structural Bolt/Nut/washer Assemblies, Alloy Steel, Heat Treated, 200 ksi Minimum Tensile Strength
ASTM F3114	2015	Standard Specification for Structures
ASTM F3125/F3125M	2015a	Standard Specification for High-Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength, Inch and Metric Dimensions
ASTM F3148	2017a	Standard Specification for High Strength Structural Bolt Assemblies, Steel and Alloy Steel, High Treated, 144 ksi Minimum Tensile Strength, Inch Dimensions
ASTM F432	2013	Standard Specification for Roof and Rock Bolts and Accessories

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Standard Shorthand Name	Edition	Standard Title
ASTM F436/F436M	2016	Standard Specification for Hardened Steel Washers Inch and Metric Dimensions
ASTM F467M	2006a (reapproved 2012)	Standard Specification for Nonferrous Nuts for General Use (Metric)
ASTM F468	2016	Standard Specification for Nonferrous Bolts, Hex Cap Screws, Socket Head Cap Screws, and Studs for General Use
ASTM F519	2013	Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments
ASTM F541	2012	Standard Specification for Alloy Steel Eyebolts
ASTM F543	2017	Standard Specification and Test Methods for Metallic Medical Bone Screws
ASTM F593	2017	Standard Specification for Stainless Steel Bolts, Hex Cap Screws and Studs
ASTM F594	2009 (reapproved 2015)	Standard Specification for Stainless Steel Nuts
ASTM F606/F606M	2016	Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets
ASTM F722	1982 (reapproved 2014)	Standard Specification for Welded Joints for Shipboard Piping Systems
ASTM F788	2013	Standard Specification for Surface Discontinuities of Bolts, Screws, and Studs, Inch and Metric Series
ASTM F812	2012	Standard Specification for Surface Discontinuities of Nuts, Inch and Metric Series
ASTM F835	2016	Standard Specification for Alloy Steel Socket Button and Flat Countersunk Head Cap Screws
ASTM F836M	2016	Standard Specification for Style 1 Stainless Steel Metric Nuts (Metric)
ASTM F837M	2016	Standard Specification for Stainless Steel Socket Head Cap Screws (Metric)
ASTM F844	2007a (reapproved 2013)	Standard Specification for Washers, Steel, Plain (Flat), Unhardened for General Use
ASTM F879M	2016	Standard Specification for Stainless Steel Socket Button and Flat Countersunk Head Cap Screws (Metric)
ASTM F880	2012	Standard Specification for Stainless Steel Socket, Square Head, and Slotted Headless Set Screws
ASTM F901	2001 (reapproved 2012)	Standard Specification for Aluminum Transmission Tower Bolts and Nuts
ASTM F912	2011 (reapproved 2017)	Standard Specification for Alloy Steel Socket Set Screws
ASTM F945	2012	Standard Test Method for Stress-Corrosion of Titanium Alloys by Aircraft Engine Cleaning Materials
ASTM F959	2015	Standard Specification for Compressible Washer-Type Direct Tension Indicators for Use with Structural Fasteners

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Standard Shorthand Name	Edition	Standard Title
ASTM G101	2004 (reapproved 2015)	Standard Guide for Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels
ASTM G116	1999 (reapproved 2015)	Standard Practice for Conducting Wire-on-Bolt Test for Atmospheric Galvanic Corrosion
ASTM G168	2000 (reapproved 2013)	Standard Practice for Making and Using Precracked Double Beam Stress Corrosion Specimens
ASTM G192	2008 (reapproved 2014)	Standard Test Method for Determining the Crevice Repassivation Potential of Corrosion Resistant Alloys Using a Potentiodynamic- Galvanostatic-Potentiostatic Technique
ASTM G215	2017	Standard Guide for Electrode Potential Measurement
ASTM G38	2001 (reapproved 2013)	Standard Practice for Making and Using C-Ring Stress-Corrosion Test Specimens
ASTM G39	1999 (reapproved 2016)	Standard Practice for Preparation and Use of Bent-Beam Stress-Corrosion Test Specimens
ASTM G4	2001 (reapproved 2014)	Standard Guide for Conducting Corrosion Tests in Field Applications
ASTM G48	2011 (reapproved 2015)	Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution
ASTM G49	1985 (reapproved 2011)	Standard Practice for Preparation and Use of Direct Tension Stress-Corrosion Test Specimens
ASTM G75	2015	Standard Test Method for Determination of Slurry Abrasivity (Miller Number) and Slurry Abrasion Response of Materials (SAR Number)
ASTM G78	2015	Standard Guide for Crevice Corrosion Testing of Iron-Base and Nickel-Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments
ASTM G8	1996 (reapproved 2010)	Standard Test Methods for Cathodic Disbonding of Pipeline Coatings
ASTM G82	1998 (reapproved 2014)	Standard Guide for Development and Use of a Galvanic Series for Predicating Galvanic Corrosion Performance
ASTM G96	1990 (reapproved 2013)	Standard Guide for Online Monitoring of Corrosion in Plant Equipment (Electrical and Electrochemical Methods)
BS 7371_12	2008	Coatings on metal fasteners - Part 12: Requirements for imperial fasteners
BS 7371_3	2009	Coatings on metal fasteners - Part 3: Specifications for electroplated zinc coatings
BS 7371_7	2010	Coatings on metal fasteners - Part 7: Specification for mechanically applied zinc and zinc based coatings
BS EN 13173	2001	Cathodic protection for steel offshore floating structures
BS EN 50162	2004	Protection against corrosion by stray current from direct current systems

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Standard Shorthand Name	Edition	Standard Title
DNVGL-OS-B101	2015	Metallic Materials
DNVGL-OS-C101	2015	Design of Offshore Steel Structures, General - LRFD Method
DNVGL-RP-0002	2014	Integrity Management of Subsea Production Systems
DNVGL-RP-0005: 2014-06	2014	RP-C203: Fatigue Design of Offshore Steel Structures
DNVGL-SE-0045:2014-08	2014	Certification of Subsea Equipment and Components
DNVGL-ST-0035: 2014-08	2014	Subsea Equipment and Components
DNV-RP-0034	2015	Steel Forgings for Subsea Applications
DNV-RP-B401	2010	Cathodic Protection Design
DNV-RP-C201	2010	Buckling Strength of Plated Structures
DNV-RP-C205	2014	Environmental Conditions and Environmental Loads
DNV-RP-E102	2010	Recertification of Blowout Preventers and Well Control Equipment for the U.S. Outer Continental Shelf
DNV-RP-F112	2008	Design of Duplex Stainless Steel Subsea Equipment Exposed to Cathodic Protection
EPRI NP-6316	1989	Guidelines for Threaded-Fastener Applications in Nuclear Power Plants
ET-3000.00-1500-251-PAZ-001	2011	Technical Specification: High Resistance Steel Fixers for Underwater Use
FF-N-836E	1994	Federal Specification: Nut, Square, Hexagon, Cap, Slotted, Castle, Knurled, Welding and Single Ball Seat
FF-N-845D	1983	Federal Specification: Nut, Plain, Wing, Inch and Metric
IBECA-H-E	2006	Hydrogen Embrittlement in Coated Steel Fasteners
IBECA-H-S-F	2007	Integrity of High Strength Fasteners for Aircraft Structures
IFI-H-E	2015	Fundamentals of Hydrogen Embrittlement In Steel Fasteners
ISO 12473	2006	General principles of cathodic protection in sea water
ISO 12944-1	1998	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 1: General Introduction
ISO 12944-2	1998	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 2: Classification of environments
ISO 12944-3	1998	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 3: Design Considerations
ISO 12944-5	2007	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 5: Protective Paint Systems
ISO 12944-7	1998	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 7: Execution and Supervision of Paint Work

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Standard Shorthand Name	Edition	Standard Title
ISO 13625	2002	Petroleum and natural gas industries - Drilling and production equipment - Marine drilling riser couplings
ISO 14713-1	2009	Zinc coatings - Guidelines and recommendations for the protection against corrosion of iron and steel in structures - Part 1: General principles of design and corrosion resistance
ISO 14713-2	2009	Zinc coatings - Guidelines and recommendations for the protection against corrosion of iron and steel in structures - Part 2: Hot dip galvanizing
ISO 2081	2008	Metallic and other inorganic coatings - electroplated coatings of zinc with supplementary treatments on iron or steel
ISO 21457	2010	Petroleum, petrochemical and natural gas industries - Materials selection and corrosion control for oil and gas production systems
ISO 3506-1	2008	Mechanical Properties of Corrosion-resistant stainless steel fasteners. Part 1: Bolts, Screws and Studs
ISO 4520	1981	Chromate conversion coatings on electroplated zinc and cadmium coatings
ISO 9717	2010	Metallic and other inorganic coatings - Phosphate conversion coatings of metals
MIL-DTL-12133E	2015	**Detail Specification: Washer, Spring Tension, General Specification For**
MIL-DTL-1222J	1986	Detail Specification: Studs, Bolts, Screws and Nuts for Application Where a High Degree of Reliability is Required
MIL-DTL-13924D	1980	Detail Specification: Coating, Oxide, Black, for Ferrous Metals
MIL-DTL-21338B	2014	Detail Specification: Washer, Key Retaining, Ball and Rover Bearings
MIL-DTL-32258	2007	Detail Specification: Nut, Self-locking (ring type non-metallic insert), Heavy Hex, Controlled Root Radius, Nickel-Copper Alloy
MIL-HDBK-729	1965	Military Standardization Handbook: Corrosion and Corrosion Prevention
MIL-N-45913B	1968	Military Specification: Nuts, Self-Locking, Hexagon, Prevailing Torque
MIL-PRF-23236D	2003	Performance Specification: Coating Systems for Ship Structures
MIL-STD-1251A	1975	Military Standard: Screws and Bolts Preferred for Design Listing of Department of Defense
MIL-STD-1312-1	1967	Military Standard: Fastener Test Methods
MIL-STD-1515A	1972	Military Standard: Fastener Systems for Aerospace Applications
MIL-W-12133D	1984	Military Specification: Washer, Spring Tension, General Specification for Department of Defense
MS19070B	2011	Detail Specification Sheet: Washer, Key Retaining, Ball and Roller Bearing, Regular Series
MS20500G	2012	Detail Specification Sheet: Nut, Self-Locking Hexagon 1200F, 125 ksi FTU
MS25081K	2004	MS Specification Sheet: Washer, Key
MS25081L	2011	Detail Specification Sheet: Washer, Key
MS25082P	1996	Military Specification Sheet: Nut, Plain, Hexagon Electrical - Thin
MS25082P – Amendment 1	2004	Military Specification: Nut, Plain, Hexagon Electrical - Thin
MS25082P –	2011	Detail Specification Sheet: Nut, Plain, Hexagon Electrical - Thin

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Standard Shorthand Name	Edition	Standard Title
Amendment 2		
MS35335G	2004	MS Specification Sheet: Washer, Lock, Flat-External Tooth
MS35690F	2005	Detail Specification Sheet: Nut, Plain, Hexagon, UNC-2B and UNF-2B
MS9090D	2011	Detail Specification Sheet: Bolt Machine, Drilled 12 Point Head, Steel, .3125-24 UNF-3A
NACE MR0175/ISO-15156-1	1st ed. (2003)	Petroleum and natural gas industries - Materials for use in H2S-containing environments in oil and gas production - Part 1: General Principles for selection of cracking-resistant materials
NACE MR0175/ISO-15156-1	2nd ed. (2009)	Petroleum and natural gas industries - Materials for use in H2S-containing environments in oil and gas production - Part 1: General Principles for selection of cracking-resistant materials
NACE MR0175/ISO-15156-2	1st ed. (2003)	Petroleum and natural gas industries - Materials for use in H2S-containing environments in oil and gas production - Part 2: Cracking-resistant carbon and low alloy steels, and the use of cast irons
NACE MR0175/ISO-15156-3	1st ed. (2003)	Petroleum and natural gas industries - Materials for use in H2S-containing environments in oil and gas production - Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys
NACE MR0175/NACE MR0175 2003	2003	Standard Material Requirements: Metals for Sulfide Stress Cracking and Stress Corrosion Cracking Resistance in Sour Oilfield Environments
NACE MR0175-2002	1st ed. (2002)	Standard Material Requirements: Sulfide Stress Cracking Resistant Metallic Materials for Oilfield Equipment
NACE No. 12/AWS C2.23M/SSPC-CS 23.00	2003	Specification for the Application of Thermal Spray coatings (Metallizing) of Aluminum, Zinc, and Their Alloy and composites for the Corrosion Protection of Steel
NACE SP0169	2007	Control of External Corrosion on Underground or Submerged Metallic Piping Systems
NACE SP0176	2007	Corrosion Control of Submerged Areas of Permanently Installed Steel Offshore Structures Associated with Petroleum Production
NACE SP0192	2012	Monitoring Corrosion in Oil and Gas Production with Iron Counts
NACE SP0387	2014	Metallurgical and Inspection for Cast Galvanic Anodes for Offshore Applications
NACE SP0492	2006	Metallurgical and Inspection Requirements for Offshore Pipeline Bracelet Anodes
NACE SP0499	2012	Corrosion Control and Monitoring in Seawater Injection Systems
NACE SP0775	2012	Preparation, Installation, Analysis and Interpretation of Corrosion Coupons in Oilfield Operations
NACE TM0169/G31	2012a	Standard Guide for Laboratory Immersion Corrosion Testing of Metals
NACE TM0177	2005	Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H2S Environments
NACE TM0198	2004	Slow Strain Rate Test Method for Screening Corrosion-Resistant Alloys for Stress Corrosion Cracking in Sour Oilfield Service
NACE TM0204	2004	Exterior Protective Coatings for Seawater Immersion Service
NACE TM0284	2003	Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking
NASA-RP-1228	1990	Fastener Design Manual
NAVAIR 01-1A-509-1	2005	Cleaning and Corrosion Control - Volume I: Corrosion Program and Corrosion Theory

TABLE D-1 (CONT.)

Standard Shorthand Name	Edition	Standard Title
TM 1-1500-322-23-1 to 1-1-689-1		
NAVAIR 01-1A-509-2 TM 1-1500-344-23-2	2005	Cleaning and Corrosion Control - Volume II: Aircraft
NAVAIR 01-1A-509-3 TM 1-1500-433-23-3 to 1-1-689-3	2005	Cleaning and Corrosion Control - Volume III: Avionics and Electronics
NAVAIR 01-1A-509-4 TM 1-1500-344-23-4	2005	Cleaning and Corrosion Control - Volume IV: Consumable Materials and Equipment for Avionics
NAVAIR 01-1A-509-5 TM 1-1500-344-23-5 to 1-1-689-5	2005	Cleaning and Corrosion Control - Volume V: Consumable Materials and Equipment for Aircraft and Avionics
NAVAIR 16-1-541 to 1-1-689 TM 1-1500-343-23	2000	Avionics Cleaning and Corrosion Prevention/Control
NAVFAC MO-307	1992	Corrosion Control
NAVSEA HY-80 100 130 HSLA-80 100	Rev. 2 (2012)	Base Materials for Critical Applications: Requirements for Low Alloy Steel Plate, Forgings, Castings, Shapes, Bars, and Heads of HY-80/100/130 and HSLA-80/100
NORSOK M-001	5th ed. (2014)	Materials Selection
NRC NUERG-1339	1990	Resolution of Generic Safety Issue 29: Bolting Degradation or Failure in Nuclear Power Plants
NUREG-1801	Rev. 2	Generic Aging Lessons Learned (GALL) Report
RP O401	1985	Safety and Reliability of Subsea Systems
TT-C-490E	1993	Federal Specification: Chemical Conversion Coatings and Pretreatments for Ferrous Surfaces (Base for Organic Coatings)
USCAR UHSFG 1416U	2014	USCAR - IFI Guide for Ultra-High Strength Externally Threaded Fasteners
USCG M10360.3B	2001	Coatings and Color Manual - 2001
USCG M10360.3C	2005	Coatings and Color Manual - 2005

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E: Normative References from Preliminary Database Bolt Standards

Table E-1 lists the normative references appearing in the database of bolt related standards. These are listed by alphabetical order of the standard shorthand. Some, but not all, appear in the preliminary bolt database.

Bolt-Related Standard	Normative References
A-A-55625	ASTM A109, QQ-P-416, ASTM B766, ASTM B633, FED-STD-H28/2
A-A-55628A	QQ-P-416, ASTM B633, QQ-N-290, MIL-F-495, ASME B1.1, ASME B1.3M, SAE J483, ASME Y14.5M
A-A-55629	ASTM D4066, QQ-P-416, ASTM B633, ASTM A967, QQ-N-290, MIL-F-495
A-A-59441	No Normative References
A-A-59817	ASTM F1137, ASME B1.1
ANSI/AISC 360-05	ACI 318-02, ACI 318M-02, AISC 303-05, ANSI/AISC 341-05, ANSI/AISC N690-1994(R2004), ANSI/AISC N690L-03, SEI/ASCE 7-02, ASCE/SFPE 29-99, ASME B18.2.6-96, ASME B46.1-95, ASTM A6/A6M-04a, ASTM A36/A36M-04, ASTM A53/A53M-02, ASTM A193/A193M-04a, ASTM A194/A194M-04, ASTM A216/A216M-93(2003), ASTM A242/A242M-04, ASTM A283/A283M-03, ASTM A307-03, ASTM A325M-04, ASTM A354-03a, ASTM A370-03a, ASTM A449-04, ASTM A490-04, ASTM A500-03a, ASTM A501-01, ASTM A502-03, ASTM A514/A514M-00a, ASTM A529/A529M-04, ASTM A563-04, ASTM A563M-03, ASTM A568/A568M-03, ASTM A572/A572M-04, ASTM A588/A588M-04, ASTM A606-04, ASTM A618/A618M-04, ASTM A668/A668M-04, ASTM A673/A673M-04, ASTM A709/A709M-04, ASTM A751-01, ASTM A847-99a(2003), ASTM A852/A852M-03, ASTM A913/A913M-04, ASTM A992/A992M-04, ASTM A1011/A1011M-04, ASTM C33-03, ASTM C330-04, ASTM E119-00a, ASTM E709-01, ASTM F436-03, ASTM F959-02, ASTM F1554-99, ASTM F1852-04, AWS D1.1/D1.1M-2004, AWS A5.1-2004, AWS A5.5-96, AWS A5.17/A5.17M-97, AWS A5.18:2001, AWS A5.20-95, AWS A5.23/A5.23M-97, AWS A5.25/A5.25M-97, AWS A5.26/A5.26-97, AWS A5.28-96, AWS A5.29:1998, ASTM A325, ASTM A490
API 16A – 3rd ed.	ISO 2859-1:1989, ISO 6506-1, ISO 6507-1, ISO 6508-1, ISO 6892, ISO 10423:2001, ISO 11961:1996, ISO 13665, API 6AF, ASME Boiler and Pressure Vessel Code, ASTM A193:1999, ASTM A320/A320M:1999, ASTM A370: 1997, ASTM A453/A453M:1999, ASTM D395:1998, ASTM D412:1998, ASTM D471:1998, ASTM D1414:1994, ASTM D1415:1994, ASTM D1418:1999, ASTM D2240:1997, ASTM E94:1993, ASTM E140: 1999, ASTM E165:1995, ASTM E569:1997, ASTM E747:1997, ASNT-SNT-TC-1A:1992, NACE NR0175-2000, SAE AMS-G-6875A:1998
API 16A – 4th ed.	API CT, API 5DP, API 6A, API 6AF2, API 6X, API 7-1, API 20E, API 20F, API TR 6MET, ASME Boiler and Vessel Code, ASTM A388, ASTM D412, ASTM D471, ASTM D1414, ASTM D1415, ASTM D1418, ASTM D2240, ASTM E10, ASTM E18, ASTM E94, ASTM E110, ASTM E140, ASTM E165/E165M, ASTM A370, ASTM E384, ASTM D395, ASTM E428, ASTM E569, ASTM E709, ASTM E747, ASNT-SNT-TC-1A, AWS D17.1/D17.1M, AWS QC1, CSWIP-WI-6-92, ISO 2859-1, ISO 6506-1, ISO 6507-1, ISO 6508-1, ISO 6892, ISO 9712, ISO 18265, NACE MR0175/ISO15156, SAE AMS2750

Bolt-Related Standard	Normative References
API 16AR	API 5DP, API 6A, API 16A, API 20E, API 20F, API Q1, ANSI/ASME B31.1, ASME Boiler and Pressure Vessel Code, ANST-SNT-TC-1A, ASTM A370, ASTM A388/A388M, ASTM A967/A967M, ASTM D395, ASTM D412, ASTM D471, ASTM D1414, ASTM D1415, ASTM D2240, ASTM E10, ASTM E18, ASTM E94, ASTM E110, ASTM E140, ASTM E165/A165M, ASTM E384, ASTM E165/E165M, ASTM E384, ASTM E428, ASTM E569/E569M, ASTM E709, AWS A4.2M, ASTM E709, AWS QC1, CSWIP-WI-6-92, ISO 6506-1, ISO 6507-1, ISO 6508, ISO 6892, ISO 9712, ISO 18265, NACE MR0175/ISO 15156, SAE AMS 2750E, SAE AMS-G-6875B
API 16C, 1st ed.	ANSI/ASME B31.3, API 5B, API 6A, API 16A, API 16C, API RP-53, ASME Boiler and Pressure Vessel Code, ASTM A370, ASTM A388, ASTM A609, ASTM D975, ASTM D1415, ASTM D1418, ASTM D2240, ASTM E10, ASTM E18, ASTM E92, ASTM E94, ASTM E140, ASTM E165, ASTM E168, ASTM E280, ASTM E428, ASSTM E446, ASTM E709, ASTM E747, ASTM D975, MIL-H-6875F, MIL-STD-105D, NACE MR1075-91, SAE J517, SNT-TC-1A
API 16C, 2nd ed.	API 5, API 5CT, API 5L, API 6A, API 16A, API 6X, API 53, API 500, API 505, ASME Boiler and Pressure Vessel Code, ASME B1.1, ASME B1.2, ASME B31.3, ANST SNT-TC-1A, ASQ Z1.4, ASME A370, ASTM A388, ASTM A609, ASTM D1415, ASTM D2240, ASTM E10, ASTM E18, ASTM E94, ASTM E140, ASTM E165, ASTM E384, ASTM E428, ASTM E709, ASTM E747, AWS A.5.1, CSWIP-WI-6-92, ISO 6506-1, ISO 6507-1, ISO 6508-1, ISO 9712, NACE MR0175/ISO 15156, NFPA 496, SAE J 517
API 16D	API RP 14F, API RP 500, ANSI Y32.10, ASME B31.1, ASME B31.3, AWS A2.4-86, AWS D1.1, ISO/IEC IEC 529, ISO 1219, ISO 13628-8, API RP 17H, ISO 14224, BS-5500, DOT Spec 3AA2015, NEMA 4X
API 16F	API RP 2RD, API Bull 5C3, API 5L, API 6A, API TR 6AM, API 8C, API 9A, API RP 9B, API 16A, API 16C, API 16D, API RP 16Q, API 16R, API RP 64, ANSI/AWS D1.1, ASME B31.1, ASME B31.3, ANST No. SNT-TC1A, ASTM A370, ASTM A703, ASTM D2240, ASTM B850, ASTM E8, ASTM E10, ASTM E18, ASTM E23, ASTM E140, ASTM E165, ASTM E399, ASTM E709, ASTM E1290, IEC 61892, ISO 13625, NACE MR-01-75/ISO 15156, UL 94
API 16Q	API RP 2R
API 17A	ISO 3506-1, ISO 3506-2, ISO 10423, ISO 13535, ISO 13628-4, ISO 13628-5, ISO 13628-6, ISO 13628-7, ISO 13628-8, ISO 13628-9, API RP 2A, DNV2.7-1
API 20E, 1st ed.	API 6A, ASTM A29/A29M, ASTM A193/A193M, ASTM A193/A193M, ASTM A320/A320M, ASTM A370, ASTM A540/A540M, ASTM A751, ASTM A941, ASTM A962/A962M, ASTM B633, ASTM B860, ASTM E10, ASTM E18, ASTM E45, ASTM E112, ASTM E1268, ASTM F606, ASTM F1470, ANSI/NCSL Z540.3, SAE-AMS 2750, SAE AMS H-6875
API 20E, 2nd ed.	API Q1, API 6A, API 6HT, ASTM A29/A29M, ASTM A193/A193M, ASTM A193/A193M, ASTM A320/A320M, ASTM A370, ASTM A540/A540M, ASTM A751, ASTM A941, ASTM A962/A962M, ASTM B850-98(15), ASTM E10, ASTM E18, ASTM E45, ASTM E112, ASTM E381, ASTM E384, ASTM E1268, ASTM F519, ASTM F606, ASTM F1470-12, ANSI/NCSL Z540.3, ISO 17025, SAE AMS2750, SAE AMSH6875
API 20F	API 6A, API 6A718, ANSI/NCSL Z540.3, ASTM A453/A453M, ASTM A751, ASTM A962/A962M, ASTM E10, ASTM E18, ASTM E1476, ASTM F788, ASTM E812, SAE AMS 2750, SAE AMS H-6875
API 2SC	ASME Boiler and Pressure Vessel Code, ANST SNT-TC-1A, ASTM A609, ASTM A703, ASTM E10, ASTM E23, ASTM E92, ASTM E110, AWS A4.3, AWS A5.01, AWS D1.1:2008, BSI BS 2M 54, BSI BS 7363, BSI BS EN 1043-1, ISO 3690, ISO 6507-1, ISO 10474, MIL-STD-1684, MSS SP-53, MSS SP-54, MISS SP-55

Bolt-Related Standard	Normative References
API 53	API 5L, API 6A, API 16A, API 16C, API 16D, API 17D, API 17H, API RP 75, API RP 500, API RP 505. ASME B1.20.1, ASME B31.3, ASME Boiler and Pressure Vessel Code, NACE MR 0175/ISO 15156
API 5SI	API 5L, API RP 5L9
API 6A, 19th ed.	ISO 31, ISO 10419, ISO 10433, ISO 13628-3, API Bul 5A, API 5CT, API A, API TR 6AF, API TR 6AF1, API TR 6AF2, API 6AC1, API 6FA, API 14D, API RP 14H, ASME B1.5, ASME B16.5, ASME B16.34, ASME B18.2.2, ASME SPPE 1, ASTM E21
API 6A, 20th ed.	ISO 31-0, ISO 148, ISO 2859-1:1999, ISO 6506, ISO 6507, ISO 6508, ISO 6892-1, ISO 9712, ISO 10414-1, ISO 10424-1:2004, ISO 11960, ISO 13533, ISO 1368-4, ISO 13678, ISO 15156, ISO 18265, API 5B, API 7:2001, API RP 14F, ASME B1.1, ASME B1.2, ASME B1.3, ASME B1.5, ASME B1.20.1, ASME Boiler and Vessel Code, ASNT SNT-TC-1A, ASTM A194/A194M, ASTM A193/A193M, ASTM A320/A320M, ASTM A370, ASTM A388/A388M, ASTM A453/A453M, ASTM A703/A703M-08a, ASTM D395, ASTM D412, ASTM D1414, ASTM D1415, ASTM D1418, ASTM D2240, ASTM E10, ASTM E18, ASTM E92, ASTM E94, ASTM E140, ASTM E165, ASTM E428, ASTM E709, ASTM E747, EN 473, MISS SP-55, SAE AMS-G-6875, SAE AS 568A:1974
API 6AV1, 1st ed.	API 6A, API 6D, API Bul 6AM, API RP 6AR, API Bul 6AF, API Bul 6AF1, API Bul 6AF2, API 6FA, API 6FB, API 6FC, API 6FD, API Bul 6F1, API Bul 6F2, API 6H, API Bul 6J, API Bul 6RS
API 6AC1, 2nd ed.	API 6A, API 13B-1
API Bul 91	API RP 54, API RP 74
API Q1, 8th ed.	ISO 9000:2005, ISO 9001:2008
API Q1, 9th ed.	ISO 9000
API Q2	ISO 9000:2005
API TR 6AF1	PRAC 89-21, PRAC 86-21, API 6A, API 6AF, API Bul 6AF2, ASME Boiler and Pressure Vessel Code, ANSI B1.1
API TR 6AF2	API 6A, API 6AF
ASME B1.1	ASME B1.2, ASME B1.3, ASME B1.7, ASME B1.30, ASME B47.1, ASME B94.11, ASME Y14.5, ISO 68
ASME B1.13M	ASME B1.3, ASME B1.7M, ASME B1.21M, ASME B1.30, ASME B47.1, ASME Y14.5, ASTM F568M, ISO 3, ISO 68-1, ISO 261, ISO 724, ISO 898-1, ISO 965-1, SAE J1199
ASME B1.2	ANSI B1.1, ANSI B1.3, ANSI B1.7, ANSI B46.1, ANSI B47.1, ANSI B89.1.9, ANSI B89.3.1
ASME B18.1.3M	ANSI Y14.5, ANSI B18.12. ISO R1051-1969E
ASME B18.2.1	ASME B1.1, ASME B1.2, ASME B1.3, ASME B18.2.6, ASME B18.2.8, ASME B18.2.9, ASME B18.12, ASME B18.18, ASME B18.24, ASME B94.11M, ASME Y14.5, ASTM A193/A193M, ASTM A307, ASTM A320/A320M, ASTM A354, ASTM A449, ASTM F468, ASTM F593, ASTM F788/F788M, ASTM F1941, MIL-F-18240, MS15981, SAE J429
ASME B18.2.3.3M	ASME B1.3M, ASME B1.13M, ASME B18.2.8, ASME B18.12, ASME B18.18.1, ASME B18.24, ASME Y14.5M, ASTM F468M, ASTM F568M, ASTM F738M, ASMT F1941M,
ASME B18.3	ASME B1.1, ASME B1.3, ASME B18.2.9, ASME B18.12, ASME B18.18, ASME B18.24, ASME B46.1, ASME B47.1, ASME Y14.5, ASME Y14.6, ASTM A574, ASTM F835, ASTM F837, ASTM F879, ASTM F880, ASTM F912, ASTM F1941
ASME SA-320/SA-320M	ASTM A29/A29M, ASTM A194/A194M, ATM A276, ASTM A370, ASTM A751, ASTM E18, ASTM E566, ASTM F436, ANSI B1.1, ANSI B18.2.1, ANSI B18.3, ANSI B18.22.1, AIAG B-5

Bolt-Related Standard	Normative References
ASTM A1014/A1014M	ASTM A962/A962M, ASTM B637, ASTM B880, ASTM E112, ASTM E292, ASME B1.1, SAE AS 7467
ASTM A1058	ASTM A833, ASTM A956, ASTM A1038, ASTM E8/E8M, ASTM E10, ASTM E18, ASTM E29, ASTM E110, ASTM E190, ASTM E290, ASME Boiler and Pressure Vessel Code, ISO 148-1, ISO 148-2, ISO 2566-1, ISO 2566-2, ISO 6506-1, ISO 6508-1, ISO 6892-1, ISO 6892-1, ISO 7438, ISO 8491, ISO 17025, JIS B7722, JIS Z2201, JIS Z2241, JIS Z2242, JIS Z2243, JIS Z2245, JIS Z2248
ASTM A1059/A1059M	ASTM A90/A90M, ASTM A385, ASTM A700, ASTM A902, ASTM B487, ASTM D521, ASTM D6386, ASTM E376, ASTM F1789, ASTM F2329, ASTM F2674
ASTM A106/A106M	ASTM A530/A530M, ASTM E213, ASTM E309, ASTM E381, ASTM E570, ASME B36.10M, MIL-STD-129, MIL-STD-163, FED. STD. NO. 123, FED. STD. NO. 183, SSPC-SP 6
ASTM A1082/A1082M	ASTM A276/A276M, ASTM A370M, ASTM A479/A479M, ASTM A564/A564M, ASTM A959/A959M, ASTM A962/A962M, ASNT SNT-TC-1A
ASTM A123/A123M	ASTM A47/A47M, ASTM A90/A90, ASTM A143/A13M, ASTM A153/A153M, ASTM A384/A384M, ASTM A385, ASTM A767/A767M, ASTM A780, ASTM A902, ASTM B6, ASTM B487, ASTM B602, ASTM B960, ASTM D6386, ASTM D7803, ASTM E376
ASTM A143/A143M	ASTM F606
ASTM A153/A153M	ASTM A90/A90M, ASTM A143/A143M, ASTM A780, ASTM A902, ASTM B6, ASTM B487, ASTM B960, ASTM E376, ASTM F1470, ASTM F1789, ASTM F2329/F2329M
ASTM A183	ASTM A700, ASTM F606, ASME B1.1, ASME B18.10
ASTM A193/A193M	ASTM A153/A153M, ASTM A194/A194M, ASTM A320/A320M, ASTM A354, ASTM A788/A788M, ASTM A962/A962M, ASTM B633, ASTM B695, ASTM B696, ASTM B766, ASTM E18, ASTM E21, ASTM E112, ASTM E139, ASTM E150, ASTM E151, ASTM E292, ASTM E328, ASTM E566, ASTM E709, ASTM F606, ASTM F1940, ASTM F1941, ASTM F2329, ASME B18.2.1, ASME B18.2.3.3M, ASME B18.3, ASME B18.3.1M, AIAG B-5
ASTM A194/A194M	ASTM A153/A153M, ASTM A276, ASTM A320/A320M, ASMT A370, ASTM A962/A962M, ASMT B633, ASTM B695, ASTM B696, ASTM B766, ASTM E112, ASTM E566, ASTM F606, ASTM F1940, ASTM F1941, ASTM F2329, ASME B1.1, ASME B1.2, ASME B1.1.13M, ASME B18.2.2, ASME B18.2.4.6M, ISO 4033
ASTM A276/276M	ASTM A314, ASTM A370, ASTM A484/A484M, ASTM A582/A582M, ASTM A751, ASTM A1058, ASTM E527, SAE J 1086
ASTM A29/A29M	ASTM A108, ASTM A304, ASTM A311/A311M, ASTM A321, ASTM A322, ASTM A370, ASTM A434/A434M, ASTM A499, ASTM A575, ASTM A576, ASTM A663/A633M, ASTM A675/A675M, ASTM A689, ASTM A696, ASTM A700, ASTM A739, ASTM A751, ASTM AE29, ASTM E112, FED. STD NO. 123, FED. STD. NO. 183, MIL-STD-163, AIAG B-1, AIAG B-5
ASTM A307	ASTM A563, ASTM A706/A706M, ASTM A751, ASTM B695, ASTM F606, ASTM F788/F788M, ASTM F1470, ASTM F1554, ASTM F1789, ASTM F2329, ASME B1.1, ASME B18.2.1, ASME B18.24, ASME B18.31.3
ASTM A320/A320M	ASTM A194/A194M, ASTM A370, ASTM A962/962M, ASTM E566, ASTM F436, ASTM F606, ASME B1.1, ASME B18.22.1
ASTM A320/A320M-14	ASTM A194/A194M, ASTM A370, ASTM A962/A962M, ASTM E566, ASTM F436, ASTM F606, ASME B1.1, ASME B18.22.1

Bolt-Related Standard	Normative References
ASTM A325	ASTM A194/A194M, ASTM A325M, ASTM A449, ASTM A751, ASTM B695, ASTM D3951, ASTM F436, ASTM F606, ASTM F788/F788M, ASTM F959, ASTM F1136, ASTM F1470, ASTM F1789, ASTM F2329, ASTM G101, ASME B1.1, ASME B18.2.6, ASME N18.24
ASTM A354	ASTM A193/A193M, ASTM A490, ASTM A563, ASTM A751, ASTM B695, ASTM D3951, ASTM F436, ASTM F606, ASTM F788/F788M, ASTM F1470, ASTM F1789, ASTM F2329, ASME B1.1, ASME B18.2.1, ASME B18.24
ASTM A370	ASTM A623, ASTM A623M, ASTM A833, ASTM A956, ASTM A1038, ASTM A1058, ASTM A1061/A1061M, ASTM E4, ASTM E6, ASTM E8/E8M, ASTM E10, ASTM E18, ASTM E23, ASTM E29. ASTM E83, ASTM E110, ASTM E190, ASTM E290, ASTM Boiler and Pressure Vessel Code, ISO/IEC 17025
ASTM A380/A380M	ASTM A967, ASTM F21, ASTM F22, FED. STD. NO. 209E
ASTM A384/A384M	ASTM A143/A143M, ASTM A385, ASTM A780
ASTM A385/A385M	ASTM A123/A123M, ASTM A143/A143M, ASTM A153/A153M, ASTM A384/A384M, ASTM A563
ASTM A394	ASTM A563, ASTM D3951, ASTM F436, ASTM F606/F606M, ASTM F788/F788M, ASTM F1470, ASTM F1789, ASTM F2329, ASTM G101, ASME B1.1, ASME B18.2.1, ASME B18.24
ASTM A437/A437M	ASTM A962/A962M, ASTM E292, ASTM E112
ASTM A449	ASTM A563, ASTM A751, ASTM B695, ASTM F436, ASTM F606, ASTM F788/F788M, ASTM F1470, ASTM F1789, ASTM F2329, ASTM G101, ASME B1.1, ASME B18.2.1, ASME B18.24
ASTM A453/A453M	ASTM A193/A193M, ASTM A962M/A962M, ASTM E139, ASTM E292
ASTM A453/A453M-16	ASTM A193/A193M, ASTM A962A/962M, ASTM E139, ASTM E292
ASTM A479/A479M	ASTM A262, ASTM A370, ASTM A484/A484M, ASTM A751, ASTM E112, ASTM E527, SAE J 1086
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ASTM A490	ASTM A194/A194M, ASTM A325, ASTM A354, ASTM A490M, ASTM A563, ASTM A751, ASTM D3951, ASTM E384, ASTM E709, ASTM E1444, ASTM F436, ASTM F606, ASTM F788/F788M, ASM F959, ASTM F1136, ASTM F1470, ASTM F1789, ASTM F2328, ASTM F2833, ASTM G101, ASME B1.1, ASME B18.2.6, ASME B18.24, IFI 144
ASTM A492M	ASTM A194/A194M, ASTM A325, ASTM A354, ASTM A490M, ASTM A563, ASTM A751, ASTM D3951, ASTM E384, ASTM E709, ASTM E1444, ASTM F436, ASTM F606, ASTM F788/F788M, ASTM F959, ASTM F1136, ASTM F1470, ASTM F1789, ASTM F2328, ASTM F2833, ASTM G101, ASME B1.1M, ASME B18.2.6, ASME B18.24, IFI 144
ASTM A540/A540M	ASTM A962/A962M, ASTM E45
ASTM A563	ASTM A194/A194M, ASTM A242/A242M, ASTM A307, ASTM A325, ASTM A354, ASTM A394, ASTM A449, ASTM A490, ASTM A563M, ASTM A588/A588M, ASTM A687, ASTM A709/A709M, ASTM A751, ASTM B695, ASTM D3951, ASTM F606, ASTM F812/F812M, ASTM F1789, ASTM F2329, ASTM G101, ANSI B1.1, ANSI B18.2.2
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ASTM E139	ASTM E4, ASTM E6, ASTM E8, ASTM E21, ASTM E29, ASTM E74, ASTM E83, ASTM E177, ASTM E220, ASTM E292, ASTM E633, ASTM E1012
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ASTM F1469	No Normative References
ASTM F1470	ASTM F1789, ASTM F788/F788M, ASTM F812/F812M, ASTM F2688, ASME B18.18.1, ASME B18.18.2M, ASME B18.18.3M, ASME B18.18.5M, ASME B18.186M, ASQ Q9001, ISO 9001, ISO/TS 16949
ASTM F1476	ASTM A47/A47M, ASTM A53/A53M, ASTM A135, ASTM A153/A153M, ASTM A183, ASTM A193/A193M, ASTM A194/A194M, ASTM A325, ASTM A395/A395M, ASTM A536, ASTM A563, ASTM A574, ASTM A743/A743M, ASTM B26/B26M, ASTM B88, ASTM B580, ASTM B633, ASTM D2000, ASTM F837, ANSI B36.10, ANSI B36.19, ANSI C151/A21.51, ANSI C606, ANSI Z1.4, ANSI Z540.1, NFPA 13, BS 1706, BS 2494, BS 5781, BS 6104, BS 6105
ASTM F1554	ASTM A6/A6M, ASTM A194/A194M, ASTM A370, ASTM A563, ASTM A673, A673M, ASTM A751, ASTM B695, ASTM F436, ASTM F606/F606M, ASTM F1789, ASTM F2329/F2329M, ASME B1.1, ASME B1.2 ASME B18.2.1, ASME B18.2.2, ASME B18.18
ASTM F1789	ASTM A563, ASTM E456, ASTM F432, ASTM F2428, ANSI/ASME B18.12, IFI-139, IFI-140, SAE J412, ISO/IEC 17011, ISO/IEC 17025
ASTM F1940	ASTM D1193, ASTM E4, ASTM E8/E8M, ASTM E18, ASTM E29, ASTM E177, ASTM E399, ASTM E691, ASTM E1823, ASTM F519, ASTM F1137, ASTM F1941, ASTM G5, AMS 2759, AMS 3078, AMS 6415

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ASTM F1941/F1941M	ASTM B117, ASTM B487, ASTM B499, ASTM B504, ASTM B567, ASTM B568, ASTM B659, ASTM D6492, ASTM E376, ASTM F519, ASTM F606/F606M, ASTM F788, ASTM F1470, ASTM F1624, ASTM F1489, ASTM F1940, ASTM F2078, ASME B1.1, ASME B1.2 ASME B1.16M, ASME B18.6.3, NASM-1312-5, IFI-142, ISO 965-1, ISO 965-2, ISO 965-3, ISO 4042
ASTM F2280	ASTM A490, ASTM A563, ASTM A751, ASTM E709, ASTM E1444, ASTM F436, ASTM F606, ASTM F788/F788M, ASTM F1470, ASTM F1789, ASTM F2328, ASTM G101, ASME B1.1, ASME B1.3M, ASME B18.2.6
ASTM F2281	ASTM A262, ASTM A276, ASTM A342/A342M, ASTM A380, ASTM A484/A484M, ASTM A493, ASTM A564/A564M, ASTM A582/A582M, ASTM A751, ASTM B637, ASTM B880, ASTM D3951, ASTM E21, ASTM E29, ASTM E76, ASTM E139, ASTM E292, ASTM E353, ASTM E354, ASTM E606, ASTM F788/F788M, ASMT F1470, ASME B1.1, ASME B18.2.1
ASTM F2282	ASTM A29/A29M, ASTM A370, ASTM A700, ATM A751, ASTM E4, ASTM E10, ASTM E29, ASTM E112, ASTM E381, ASTM E407, ASTM E1077, ASTM F1470, ASTM F1789, AIAG B-5, IFI-140, SAE J403, SAE J404, SAE J406, SAE J415
ASTM F2328	ASTM E3, ASTM E384, ASTM F1789
ASTM F2329/F2329M	ASTM A153/A153M, ASTM A394, ASTM A563, ASTM A563M, ASTM A780/A780M, ASTM B487, ASTM E376, ASTM F606/F606M, ASTM F1470, ASTM F1789
ASTM F2437/F2427M	ASTM A193/A193M, ASTM A194/A194M, ASTM A307, ASTM A354, ASTM A449, ASTM A563, ASTM B695, ASTM F436/F436M, ASTM F606/F606M, ASTM F1470, ASTM F1554, ASTM F1789, ASTM F1491/F1491M, ASME B18.2.1, ASME B18.2.2, ASME B18.2.8, SAE J429, SAE J995, ISO 887, ISO 898-1, ISO 898-2, ISO 4014, ISO 4032, ISO 7089
ASTM F2482	ASTM A193/A193M, ASTM A325, ASTM A354, ASTM A449, ASTM A490, ASTM E4, ASTM E1685, ASTM E1470, ASTM F1789
ASTM F2660	ASTM A490, ASTM E4, ASTM E8/E8M, ASTM F519, ASTM F606, ASTM F1624, ASTM F1789, ASTM F2078, ASTM G3, ASTM G15, ASTM G44, ASTM G82, ISO 17025
ASTM F2833	ASTM B117, ASTM D610, ASTM D3359, ASTM F606, ASTM F606M, ASTM F1624, ASTM F1470, ASTM F1624, ASTM F1789, ASTM 1940
ASTM F3019/F3019M	ASTM B117, ASTM B487, ASTM B499, ASTM B568, ASTM D610, ASTM D3359, ASTM E376, ASTM F606, ASTM F606M, ASTM F788, ASTM F1470, ASTM F1624, ASTM F1789, ASTM F1940, ISO 16047
ASTM F3042	ASTM B154, ASTM E18, ASTM E29, ASTM E53, ASTM E54, ASTM E55, ASTM E62, ASTM E75, ASTM E76, ASTM E120, ASTM E165, ASTM E350, ASTM E354, ASTM E478, ASTM E1409, ASTM F788/F788M, ASTM F1470, ASME B1.1, ASME B18.3, ASME B18.6.2, SAE AMS2485, SAE AMS2487, SAE AMS2488, SAE J2656, QQ-N-286
ASTM F3043	ASTM A751, ASTM E709, ASTM E1444/E1444M, ASTM F606/F606M, ASTM F788, ASTM F812, ASTM F1470, ASTM F1789, ASTM F2328, ASME B1.3, ASME B1.15, ASME B18.2.6
ASTM F3111	ASTM A751, ASTM E709, ASTM E1444/E1444M, ASTM F606/F606M, ASTM F788, ASTM F812, ASTM F1470, ASTM F1789, ASTM F2328, ASME B1.3, ASME B1.15, ASME B18.2.6
ASTM F3114	ASTM F3060, ASTM F3061, ASTM F3083, ASTM F3093, ASTM F3115, ASTM F3116
ASTM F3125/F3125M	ASTM A194/A194M, ASTM A354,ASTM A449, ASTM A563, ASTM A563M, ASTM A751, ASTM B695, ASTM E709, ASTM E1444/E1444M, ASTM F436, ASTM F436M, ASTM F606/F606M, ASTM F788, ASTM F1136/F1136M, ASTM F1470, ASTM F1789, ASTM F1940, ASTM F2328, ASTM F2328M, ASTM F2329, ASTM F2660, ASTM F2833, ASTM G101, ASME B1.1, ASME B1.13M, ASME B18.18, ASME B18.2.6, ASME 18.2.6M

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ASTM F432	ASTM A29/A29M, ASTM A47/A47M, ASTM A194/A194M, ASTM A320/A320M, ASTM A370, ASTM A416/A416M, ASTM A536, ASTM A563, ASTM A615/A615M, ASTM A882/A882M, ASTM A1011/A1011M, ASTM A751, ASTM D6637, ASTM D1428, ASTM F436, ASTM F606, ASME B1.1, ASME B1.3M, ASME B18.2.2
ASTM F436/F436M	ASTM A354, ASTM A588/A588M, ASTM A751, ASTM B695, ASTM F606/F606M, ASTM F1136/F1136M, ASTM F1470, ASTM F1789, ASTM F2329, ASTM F3125, ASTM G101
ASTM F467M	ASTM B154, ASTM B574, ASTM D3951, ASTM E18, ASTM E29, ASTM E34, ASTM E38, ASTM E53, ASTM E54, ASTM E55, ASTM E62, ASTM E75, ASTM E76, ASTM E92, ASTM E101, ASTM E120, ASTM E165, ASTM E227, ASTM E354, ASTM E478, ASTM E1409, ASTM F468M, ASTM F606M, ASTM F1470, ASME B1.13M, ASME B18.2.4.1M
ASTM F468	ASTM B154, ASTM B193, ASTM B211, ASTM B565, ASTM B574, ASTM D3951, ASTM E8/E8M, ASTM E18, ASTM E29, ASTM E34, ASTM E38, ASTM E53, ASTM E54, ASTM E55, ASTM E62, ASTM E75, ASTM E76, ASTM E92, ASTM E101, ASTM E120, ASTM E165/E165M, ASTM E227, ASTM E354, ASTM E478, ASTM E1409, ASTM E467, ASTM F606/F606M, ASTM F788, ASTM F1470, ASME B1.1, ASME B1.3, ASME B18.2.1, ASME B18.3, ASME H35.1, QQ-N-286
ASTM F519	ASTM B374, ASTM B851, ASTM D1193, ASTM E4, ASTM E8/E8M, ASTM E18, ASTM E29, ASTM E292, ASTM E691, ASTM E709, ASTM E1417, ASTM E1444, ASTM E1823, ASTM F1459, ASTM F1624, ASTM F2078, ASTM G5, ASTM G38, AMS 2430, AMS 2759/2, AMS 2759/11, AMS 6360, AMS-QQ-P-416, AMS-S-5000, MIL-PRF-16173
ASTM F541	ASTM A370, ASTM A574, ASTM A751, ASTM E10, ASTM E18, ASTM E112, ASTM E340, ASTM E709, ASTM F606, ASTM F1470, ASME B1.1, ASME B18.15, ASME B18.24
ASTM F543	ASTM E4, ASTM E6, ASTM E8, ASTM E122, ASTM F67, ASTM F86, ASTM F116, ASTM F136, ASTM F138, ASTM F565, ASTM F620, ASTM F799, ASTM F983, ASTM F1295, ASTM F1314, ASTM F1472, ASTM F1537, ASTM F1586, ASTM F1713, ASTM F1813, ASTM F1839, ASTM F2066, ASTM F253, ISO 5835, ISO 6475, ISO 8319-1, ISO 8319-2, ISO 9268, ISO 10664
ASTM F593	ASTM A262, ASTM A276, ASTM A342/A342M, ASTM A380, ASTM A484/A484M, ASTM A493, ASTM A555/A555M, ASTM A564/A564M, ASTM A582/A582M, ASTM A751, ASTM A967, ASTM D3951, ASTM E29, ASTM F594, ASTM F606/F606M, ASTM F1470, ASME B1.1, ASME B18.2.1, JIS G4309
ASTM F594	ASTM A262, ASTM A342/A342M, ASTM A380, ASTM A493, ASTM A555/A555M, ASTM A564/A564M, ASTM A582/A582M, ASTM A751, ASTM D3951, ASTM E29, ASTM F593, ASTM F606, ASTM E1470, ASME B1.1, ASME B18.2.2
ASTM F606/F606M	ASTM A394, ASTM E4, ASTM E8/E8M, ASTM E10, ASTM E18, ASTM E83, ASTM E92, ASTM E384, ASTM F436/F436M, ASTM F959, ASTM F1624, ASTM F2328, ASTM F2328M, MIL-STD-1312
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ASTM F788	ASTM E340, ASTM E1470, ASTM F1789, ISO 1615/I
ASTM F812	ASTM F606, ASTM F606M, ASTM F1470, SATM F1789, ISO/DIS 6157/II
ASTM F835	ASTM A751, ASTM D3951, ASTM E3, ASTM E18, ASTM E112, ASTM E384, ASTM F606/F606M, ASTM F788, ASME B18.3, ASME B18.24

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ASTM F837M	ASTM A262, ASTM A342/A342M, ASTM A380, ASTM A493, ASTM A555/A555M, ASTM A751, ASTM A967, ASTM D3951, ASTM E18, ASTM E92, ASTM E384, ASTM F606, ASTM F788/788M, ASTM F1470, ASME B18.3, JIS G 4311
ASTM F844	ASTM A29/A29M, ASTM A568/A568M, ASTM A751, ASTM B633, ASTM B695, ASTM D3951, ASTM F436, ASTM F436M, ASTM F606, ASTM F1470, ASTM F2329, ASME B18.22.1, ASME B18.24, DOD-P-16232, QQ-P-416
ASTM F879M	ASTM A262, A342/A342M, ASTM A380/A380M, ASTM A555/A555M, ASTM A751, ASTM A967/A967M, ASTM D3951, ASTM E18, ASTM E92, ASTM E384, ASTM F593, ASTM F606/F606M, ASTM F788, ASTM F1470, ASME B18.3, JIS G 4309
ASTM F880	ASTM A262, ASTM A342/A342M, ASTM A380, ASTM A555/A555M, ASTM A751, ASTM A967, ASTM D3951, ASTM E18, ASTM F593, ASTM F788/F788M, ASTM F1470, ASME B18.3, ASME 18.6.2
ASTM F901	ASTM B565, ASTM D3951, ASTM E29, ASTM E34, ASTM E55, ASTM E101, ASTM E227, ASTM F606, ASTM F1470, ASME B1.1, ASME B18.2.1, ASME B18.2.2, MIL-STD-A-8625
ASTM F912	ASTM A751, ASTM E3, ASTM E112, ASTM E384, ASTM F606/F606M, ASTM F788, ASTM F1470, ASTM F2328, ASME B18.3, ASME B18.24
ASTM F945	ASTM D740, ASTM D841, ASTM D1193, AMS 4911, AMS 4916
ASTM F959	ASTM A325, ASTM A325M, ASTM A490, ASTM A490M, ASTM B695, ASTM F436, ASTM F436M, ASTM F606/F606M, ASTM F1470, ASTM F1789, ASTM F1852, ASTM F2280, ASTM G101, ASME B18.2.6, ASME B18.2.6M
ASTM G101	ASTM A242/A242M, ASTM A588/A588M, ASTM A606, ASTM A709/A709M, ASTM A852/A852M, ASTM A871/A871M, ASTM G1, ASTM G16, ASTM G50
ASTM G116	ASTM G1, ASTM G3, ATM G15, ASTM G16, ASTM G50, ASTM G82, ASTM G84, ASTM G91, ASTM G92, ASTM G104
ASTM G168	ASTM D1193, ASTM E399, ASTM E1823, ASTM G15, ASTM G35, ASTM G36, ASTM G37, ASTM G41, ASTM G44, ASTM G49, ASTM G50
ASTM G192	ASTM B575, ASTM D1193, ASTM E691, ASTM G1, ASTM G5, ASTM G15, ASTM G48, ASTM G61, ASTM G78
ASTM G215	ASTM C876, ASTM F746, ASTM F2129, ASTM F3044, ASTM G3, ASTM G5, ASTM G59, ASTM G61, ASTM G69, ASTM G71, ASTM G82, ASTM G96, ASTM G97, ASTM G102, ASTM G106, ASTM G150, ASTM G193, NACE TM0479-2012, NACE TM0101-2012, NACE TM0108-2012, NACE TM0109-2012, NACE 0109-2009, ASTM TM0190-2012, ASTM TM0211-2011, ASTM TM0331-2013
ASTM G38	NACE TM0177-96
ASTM G39	ASTM D1141, ASTM G30, ASTM G36, ASTM G44, ASTM G50, ASTM G85, NACE TM0177-96
ASTM G4	ASTM A262, ASTM E3, ASTM G1, ASTM G15, ASTM G16, ASTM G30, ASTM G36, ASTM G37, ASTM G41, ATM G44, ASTM G46, ASTM G47, ASTM G58, ATSTM G78, NACE RP0497
ASTM G48	ASTM A262, ASTM D1193, ASTM E691, ASTM E1338, ASTM G1, ASTM G15, ASTM G46, ASTM G107
ASTM G49	ASTM E8, ASTM G35, ASTM G36, ASTM G37, ASTM G44
ASTM G75	ASTM G40, MIL-R-6855C
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DNV-RP-B401	ASTM G8, ASTM D1141, DNV-RP-F103, EN 10204, NORSOK M-501, ISO 3506, ISO 8044, ISO 8501-1, ISO 10005, ISO 17474, NACE RP076, NACE RP0387
DNV-RP-C201	DNV-RP-C201
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USCAR UHSFG 1416U	ISO 898-1, VDA 235-205, Fundamentals of Hydrogen Embrittlement in Steel Fasteners, SAE J403

Bolt-Related Standard	Normative References
USCG M10360.3B	FED-STD-595, TT-P-28, TT-R-248, TT-E-489, TT-S-711, A-A-1800, MIL-C-16173, MIL-D-17951, MIL-R-19907, MIL-T-22361, MIL-PRF-23236, DOD-PRF-24176, MIL-PRF-24596, DOD-E-24607, MIL-PRF-24635, MIL-PRF-24647, DOD-P-24648, MIL-PRF-24667, A-A-50598, MIL-C-81309
USCG M10360.3C	FED-STD-595, FED SPEC TT-P-28, FED SPEC TT-R-248, FED SPEC TT-F-340, FED SPEC TT-S-711, CID A-A-1800 SPAR, MIL-PRF-16173, MIL-D-17951, MIL-R-19907, MIL-PRF-23236, DOD-PRF-24176, MIL-PRF-24596, DOD-E-24607, MIL-PRF-24635, MIL-PRF-24647, DOD-PRF-24648, MIL-PRF-24667, CID A-A-59313, MIL-C-81309

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