QC-FIT EVALUATION OF CONNECTOR AND BOLT FAILURES
SUMMARY OF FINDINGS

Bureau of
Safety and
Environmental
Enforcement

Office of Offshore
Regulatory Programs

QC-FIT Report #2014-01
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EXECUTIVE SUMMARY

BACKGROUND

On December 18, 2012, while the Transocean Discoverer India was performing drilling operations at the Keathley Canyon (KC) KC-736 lease block in the Gulf of Mexico, the rig’s lower marine riser package (LMRP) separated from the blowout preventer (BOP) stack resulting in the release of approximately 432 barrels of synthetic-based drilling fluids into the Gulf of Mexico. Chevron, the designated operator, reported to the Bureau of Safety and Environmental Enforcement (BSEE) that the incident was the result of the failure of H4 connector bolts manufactured by GE Oil and Gas (formerly Vetco-Gray), on the LMRP.

Based on the initial analysis of the failure performed by Transocean, Chevron, and GE, GE sent replacement bolts for all known H4 connectors to customers worldwide. After learning of the December 18th incident, BSEE worked with GE to ensure that the company replaced any faulty bolts that were in use in equipment deployed on the Outer Continental Shelf (OCS), in a timely manner. This process resulted in the replacement of more than 10,000 bolts over a relatively short time frame and short-term disruption of related deepwater activities.

Verification of the structural integrity of a critical component like H4 connector bolts, which are currently deployed on the OCS and globally, is essential for both worker safety and the protection of the environment. Accordingly, in January 2013, BSEE tasked the Quality Control-Failure Incident Team (QC-FIT) to evaluate the possibility of additional bolt failures and make recommendations to mitigate potential risks of future failures, either domestically or internationally. BSEE charged the team, comprised of BSEE engineers and other technical personnel, with evaluating the currently available information including: (1) the Chevron/Transocean/GE root-cause analysis, (2) GE ’s connection design, manufacturing, and quality control processes, and (3) other information related to the performance of this equipment. During its inquiry, the QC-FIT was made aware of other offshore oil and gas failures related to bolts, studs, inserts and connectors, appearing to share similar contributing factors. BSEE management requested the QC-FIT to evaluate whether the causes of these other failures were related and whether evidence existed of an industry-wide issue.

The QC-FIT conducted visits with drilling contractors, equipment manufacturers, and a classification society; contacted BSEE’s counterparts in the International Regulators’ Forum (IRF); met with three operators- BP, Shell, and Chevron in the Gulf of Mexico; reviewed reports of similar incidents of bolt and connector failures in subsea environments; and researched technical documents and standards. These activities provided significant information on the material properties used in subsea applications, corrosion behaviors, manufacturing processes and protective coatings of bolts in environments similar to those of this application.

This report is based on the review of available data and input from various sources and was reviewed by an independent technical consultant.

KEY FINDINGS

- The failure of the GE H4 connector bolts was primarily caused by hydrogen induced stress corrosion cracking (SCC) due to hydrogen embrittlement, which led to the fracturing of the installed bolts. This finding is consistent with the conclusions of the Transocean/Chevron/GE root cause analysis.
- A GE subcontractor relied on an older 1998 version of the American Society for Testing and Materials (ASTM) B633 standard and therefore, the bolts did not receive the required post electroplating treatment. This finding is consistent with the Transocean/Chevron/GE submitted root cause analysis report.
- The GE quality management system (QMS) in place at the time, which met the industry standards and certification programs, qualified and audited only first-tier level suppliers (GE's contractors) and not others in the supply chain. In this incident, since a third-tier level supplier (subcontractor) performed the electroplating coating of the bolts, GE's QMS was unable to detect the issue. Neither Transocean nor Chevron in their management system assessment of contractor qualification, nor the programs that ensure the mechanical integrity of critical equipment detected this sub-tier supplier issue.
- An inadequate coat of paint on the portion of the bolt heads was determined to be a potential contributory factor. The GE inspection procedures, in place at the time, did not adequately address this potential issue.
- In 2003, a drilling riser bolt insert failure occurred in which the hardness of the inserts and cathodic protection systems were identified as areas of concern. Although the OEM and the Minerals Management Service (MMS) issued general cathodic protection guidelines in 2005 and several operators changed their internal specifications for the maximum hardness of bolts, there is no evidence of a successfully coordinated effort by industry to address the potential safety concerns associated with the issue. A more comprehensive incident and data sharing effort by industry over the past 10 years could possibly have flagged this issue earlier and resulted in the setting of consistent standards on the hardness of bolts/inserts or on the optimal applied voltage for cathodic protection on drillships.[1]
- Existing industry standards do not adequately address bolting/connector performance in subsea marine applications. For example, although API Specification 16A provides requirements for BOP connectors, it does not contain material property requirements for the connection bolting used for subsea applications. Furthermore, other industry standards that apply to subsea equipment have different maximum hardness limit requirements for bolts.

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[1] *To further demonstrate the need for the industry to comprehensively address the issues of design specifications, subcontractor oversight, and data sharing, prior to the completion of this report, the QC-FIT was notified of a connector failure involving a different OEM and drilling contractor wherein material hardness and heat treating appear to be contributing factors***.**

OPEN ISSUES

Areas of inquiry where the QC-FIT was unable to make conclusive findings:

- The QC-FIT noted that a number of incidents appeared to have occurred on Transocean owned rigs. The data set is too small to determine if this percentage is a statistical significant result that supports a conclusion that Transocean's operating or maintenance practices may be increasing the likelihood of a failure. However, there are some potential factors that could have played a role in these failures. The QC-FIT noted that either the lack of adequate cathode protection or the use of dissimilar metals near the H4 bolts could have caused accelerated corrosion of the bolts. QC-FIT also concluded that the information and issues regarding cathodic protection, operation, and maintenance need to be explored further.

- It remains unclear whether the material selection plating requirements for service class (SC) SC2 bolts are appropriate for the marine environment when these bolts are used per ASTM B633. GE maintains that this material selection is appropriate. GE also contends that API thickness restrictions would make a coating thickness beyond a SC2 specified thickness untenable. Further assessment of the appropriateness of this plating material needs to be performed and clarified in future editions of ASTM B633 as needed. BSEE suggests developing a joint industry technical forum to evaluate these issues.

KEY RECOMMENDATIONS

The QC-FIT formulated recommendations that BSEE should take (detailed in the body of this report) to mitigate the likelihood of future failures that could impact safety and/or the environment. These are:

1. *Improve industry standards*.
    - BSEE should encourage industry to develop a consistent set of standards for connections and connection fasteners used in all offshore subsea systems, including a requirement that allows tracking connection components during their service life. This should include clear and consistent guidance on material hardness, yield strength and ultimate tensile strength requirements. (The release of API Spec 20E; First Edition, August 2012 "Alloy and Carbon Steel Bolting for use in the Petroleum and Natural Gas Industries" should address some of the concerns regarding manufacture of bolts, studs, etc.)
    - BSEE should request that ASTM further revise its relevant standards to provide additional clarity related to the design and use of coatings for marine service.
    - BSEE should request that industry develop an improved quality management standard that addresses the use of subcontractors by manufacturers through multiple tiers in the manufacturing chain. The industry and BSEE should also review API RP75 (SEMS) and the BSEE SEMS regulation (Subpart S) to ensure that the sections on mechanical integrity and contractor qualification are sufficiently robust.

- BSEE should request that industry issue guidance or a standard on the optimal applied voltage limits for cathodic protection systems for use on drillships/modus.

2. *Initiate joint industry research initiatives*. BSEE should facilitate, support, and encourage specific studies that compare and contrast the connection and connection fastener design, material, maintenance, and quality specifications to identify potential requirement gaps and inconsistencies across the industry. The impact of cathodic protection systems on the performance of connectors should also be evaluated.

3. *Promote Failure Reporting.* BSEE should encourage industry to adopt a failure reporting system that allows data on failures and potential failures involving critical equipment to be collected, analyzed, and reported to the industry and BSEE. This information will better allow the industry and BSEE to identify trends and take corrective action before any injuries or impact to the environment occurs.

4. *Develop regulations that ensure specific design standards are met*. If necessary, BSEE should develop proposed regulations and/or notices to lessees to implement improved standards for connections and connection fasteners and cathodic protection systems.

BSEE remains interested in GE's and any others ongoing tests and may take further steps to address potential safety risks as indicated.

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PRELIMINARY FINDINGS

I. BACKGROUND ON CONNECTOR AND BOLT FAILURES

On December 18, 2012, while the Transocean Discoverer India was performing drilling operations at the Keathley Canyon (KC) KC-736 lease block in the Gulf of Mexico, the rig's lower marine riser package (LMRP) separated from the blowout preventer (BOP) stack resulting in the release of approximately 432 barrels of synthetic-based drilling fluids into the Gulf of Mexico. Chevron, the designated operator, reported to the Bureau of Safety and Environmental Enforcement (BSEE) that the incident was the result of the failure of H4 connector bolts manufactured by GE Oil and Gas (formerly Vetco-Gray), installed on the LMRP. Subsequent inspections and evaluations revealed fracture failures of the GE H4 connector bolts (approximately 9 inch (in.) long and 2 in. in diameter, 4340 grade steel) securing the BOP stack.

On January 25, 2013, GE advised their customers via a safety notice that manufacturing issues may have rendered H4 connector bolts susceptible to fracturing as a result of hydrogen embrittlement and provided the corresponding bolt lots/connector part numbers for a recall. The safety notice was issued to all customers and included a bolt inspection and torque test procedure. The purpose of the inspection and torque test procedure was to: (1) identify the bolts' marking identification and (2) evaluate the bolts' performance. GE requested that bolts identified by the recall be removed and returned to GE. Bolts with markings that were not listed on the recall list, and failed a "precautionary torque test," were also to be removed and replaced. All test data, results, and bolts were to be recorded and submitted to GE. GE issued replacement bolts as appropriate.

On January 29, 2013, GE issued a revised Safety Notice (SN) 13-001, Rev A with more details for all affected bolts and bolt lots. This revision expanded the bolts recall to a global effort. As a result of GE's Safety Notice, additional fractured bolts were discovered as a result of the inspection and testing process (see section titled *Documents and Related Technical Reference Articles*).

On January 29, 2013, BSEE's Gulf of Mexico Region issued Safety Alert Number 303 to industry (see section titled *Documents and Related Technical Reference Articles*). This alert was BSEE's initial notice providing preliminary information about the bolts and recommendations to operators to survey their contracted rig fleet on the Outer Continental Shelf (OCS) for identification of affected bolt lots referenced in GE's Safety Notices. This alert and subsequent information was shared by BSEE with other international regulators.

Due to GE's response, a total of 10,982 replacement bolts were provided by GE for the 361 LMRP connectors worldwide. GE reports that a total of 1,318 bolts were returned out of the approximately 10,000 that were "in-service" or "in inventory" as of August 1, 2013. Of the returned 1,318 bolts, 494 bolts were returned from the Gulf of Mexico (GOM) region.

After the mitigation measures were initiated, BSEE formed a Quality Control-Failure Incident Team (QC-FIT) to conduct an in-depth evaluation of the data and information and determine if there were other issues that required action by the industry or BSEE. During its inquiry, the QC-FIT became aware of other industry issues related to connectors, bolts, bolt inserts, or studs that also appear to involve either potential design or subcontractor issues. These included:

- In May 2003 a flanged riser failure occurred on Transocean's Discoverer Enterprise (TO-DE) drilling riser (BP-Thunderhorse). The bolts' inserts (nuts) that secure the drilling riser failed between joints 39 and 40. The inserts and the bolts' material was AISI 4340 with a material hardness of 34-38 HRC and yield strength of 145 ksi. The 2003 Combined RCA Report performed by TO, ExxonMobil and BP identified that the bolt inserts and bolts fractured due to severe, accelerated, environmentally assisted corrosion. The high material hardness, yield strength, bolt design, impressed current and thermal spray aluminum coating were identified as contributing factors for the failure.

- In November 2012, Transocean Discoverer India had blind shear ram (BSR)/shear ram (SR) bolts fracture during a 15,000 psi pressure test (stump test). The OEM issued a safety notice for this event. A similar failure also occurred on an ENSCO 8506 drilling riser. The bolts failed due to tensile overload and bolt hardness due to incorrect heat treatment. The initial identified contributing factor for the failure was QC issues with GE's subcontracted vendor regarding communication and improper heat treatment procedures for the raw bolt material.

- In July 2014, the QC-FIT was notified of a connector failure in a subsea stack involving a different OEM, drilling contractor and operator. Although the analysis has not been completed, the initial indication is that improper heat treatment and/or material hardness issues of the studs by a subcontractor contributed to and/or caused the failure. The OEM of the July 2014 reported incident issued a product advisory for the incident.

This list of incidents only includes connector and component failures that have been reported to BSEE in the development of this report. It is possible that there have been additional incidents worldwide involving other OEMs, drilling contractors and operators that have not been reported to regulators or to industry.

II. 2013 INDUSTRY ROOT CAUSE ANALYSIS REPORT OF BOLT FAILURES

On March 21, 2013, a combined root cause analysis (Combined RCA) was initiated by Chevron, Transocean, and GE for the incident on the Discoverer India. The resulting 2013 Combined RCA Report issued to BSEE had the following findings:

- The failure of the GE H4 connector bolts was primarily caused by stress corrosion cracking (SCC) due to hydrogen embrittlement, which led to the fracturing of the installed bolts.
- The bolts did not receive both pre- and post-electroplating heat treatment because a sub-contracted vendor used a 1998 version of ASTM B633 standard instead of

the 2007 edition. The 1998 edition did not require post-baking to reduce the risk for hydrogen embrittlement at the strength level of bolting used in H4 connections. The H4 bolts did receive pre-bake heat treatment. However, the updated 2007 ASTM B633 standard also requires a post baking treatment.

- Missing paint on the bolt heads facing the BOP was determined to be a potential underlying cause. GE's Operations and Maintenance manuals do not provide specific guidance, nor were there procedures to ensure complete paint coverage on bolt heads (2013 Combined RCA page 32). The failed bolt heads had evidence of corrosion on the side facing the LMRP connector body. These bolt heads did not have paint covering on the areas that faced the well bore. The missing paint coverage would leave the bolt heads exposed, making them susceptible to an increased current drawn from the CP anode on the BOP. Therefore, this would potentially yield an increased hydrogen charging rate on the exposed bolt surface.
    - The 2013 Combined RCA Report discounts the significance of jarring on the failure of the bolts. There were contradictory conclusions among GE, Chevron, and Transocean regarding the impact of the jarring operations on the bolts' fracture. All parties however, agreed that the jarring operations, coupled with the bolts' significant degraded corrosive condition, accelerated the separation of the connector. "Jarring, tripping, and pressure testing are routine operations in which separation of the connector would not have occurred if the bolts were not severely degraded (2013 Combined RCA Report page 45, not part of this report)."
    - The 2013 Combined RCA Report discounts cathodic protection, galvanic effects, and the presence of sulfides based on Stress Engineering Services Evaluation Report (Combined RCA Report page 226, not part of this report). The overall summary conclusion was unclear if additional amounts of hydrogen generated from cathodic protection, galvanic effects, or the presence of sulfides and chlorides in the water contributed to bolt cracking (Combined RCA Report page 226, not part of this report). The RCA also indicated that the origin of the bolt fractures, the fractures' proximity to the outside surfaces, and the potential of increased amount of hydrogen introduced to the bolts from the lack of post-bake after electroplating, were likely possible contributing factors (Combined RCA Report page 226, not part of this report).

III. GE RESPONSE TO THE 2013 COMBINED RCA REPORT

GE did not sign off on the final 2013 Combined RCA Report because it believed that the true root cause for the bolts fracture and cause for synthetic-based mud spillage was not determined. GE believes the 2013 Combined RCA Report did not address effects of jarring operations on the wellbore or many of GE's technical and editorial concerns. GE is currently conducting additional research experiments, testing, and analyses.

GE’s representatives also stated that they are confident in the performance reliability of the replaced H4 connector bolts by reverting to the previously used zinc phosphate coating (with a post-bake period specified) for the following reasons:

- They report no previous issues or failures with the zinc phosphate coating,
- The bolts located on the lower H4 connector on the same BOP stack that were coated with the same previous zinc phosphate coating were completely intact without any identified fractures or cracks, and
- A third party reviewed and approved use of the replacement bolts.

IV. QC-FIT Evaluation

A. SCOPE

BSEE management tasked the QC-FIT to evaluate the potential for similar bolt-related failures throughout the Gulf of Mexico Region (GoMR) and globally, where similar connectors are used on critical drill through components. This concern was heightened by the fact that similar bolt designs were used in the H4 connectors both above the BOP stack in the lower marine riser connector and below the BOP stack at the well head. If a similar failure were to occur during or immediately following a loss of well control event, then the BOP assembly would likely fail and an environmental event of major consequence could result.

BSEE management also requested that the QC-FIT make recommendations to mitigate potential risks from future failures of connector bolts. During the QC-FIT’s inquiry, failures involving other OCS operators, OEMs, and drilling contractors, related to bolts, inserts, studs and connectors were discovered and appear to share similar contributing factors. BSEE management requested the QC-FIT to consider whether the causes of these events were related.

The QC-FIT conducted visits with drilling contractors, original equipment manufacturers, service providers and a classification society; contacted BSEE’s counterpart in the IRF; met with three operators- BP, Shell, and Chevron in the Gulf of Mexico; reviewed reports of similar incidents of bolt and connector failures in subsea environments; and researched technical documents and standards. These activities, especially the meetings with GE, provided significant information on the material properties used in subsea applications, corrosion behaviors, manufacturing processes and protective coatings of bolting in environments similar those of this application.

QC-FIT agrees with most of the findings of the 2013 Combined RCA Report, however does not agree that the lack of post-bake procedures is the sole root cause of the stress fracturing. The QC-FIT does agree with GE that the RCA is incomplete. The QC-FIT finds that the hydrogen-induced stress failure may be due to any combination of (1) the lack of post-bake procedure, (2) the bolts’ high material hardness, yield strength and ultimate tensile strength, (3) stray voltage, and (4) the use of coating class SC 2 in a marine environment as per application of ASTM B633.

Based on a review of the available information, the QC-FIT identified six areas of concern where additional information should be collected by BSEE and industry to better understand areas of concern and potential risk. These issues are bolt material hardness and strength; quality control systems/subcontractor controls; coatings; cathodic protection; paint coating; and installation torque procedures.

B. HARDNESS ISSUE

The GE H4 connector bolt is made with American Iron and Steel Institute (AISI) 4340 grade alloy metal with material hardness of Class 145 yield strength (145 ksi) and a minimum hardness of 34 Rockwell Hardness Scale C (HRC) and a maximum hardness of 38 HRC. According to GE, the specified high material hardness, yield strength, and ultimate tensile strength values are required to provide the strength needed to hold the two connector halves together and withstand the tensile, bending, and axial loads experienced on the connector during operation.

GE states that it recently began offering its customers an option of a new connector design that uses bolts with a hardness value of 34 HRC.

The QC-FIT found that bolt-hardness values above 34 HRC in a subsea environment remain an issue and should be the subject of additional testing. It should also be noted that the most recent incident was not the first time that the issue of material hardness had been implicated in the failure of connectors. A Vetco Gray connection failure occurred on May 21, 2003 on Transocean's Discoverer Enterprise (TO-DE) drilling riser (BP-Thunderhorse). The bolts' inserts (nuts) that secure the Vetco drilling riser failed between joints 39 and 40 resulting in the riser parting to approximately 3,200 feet below sea level. The 2003 RCA performed by BP and ExxonMobil characterized this failure as environmentally-assisted corrosion cracking of moderate- to high-strength steels with material hardness exceeding 34 HRC.

The suggested remedy for the 2003 Vetco Gray connector bolt failure was to redesign the bolts/bolt inserts material design specification requirements (i.e. lower the material hardness, yield strength and ultimate tensile strength), control the impressed current system voltage to -950 mv maximum, eliminate thermal spray aluminum coating, increase bolt diameter size, and reduce the load by approximately 10% on the bolts. These remedy solutions, presented to MMS, appear to have been implemented.

The QC-FIT notes that the 10,982 replacement bolts provided by GE for the H4 connectors had the same material hardness and strength values (yield strength and ultimate tensile strength) as the failed bolts. If the material hardness and strength of the bolts are contributing factors, then these bolts could have an increased risk of failing while in-service in some circumstances. GE reported that these bolts were reviewed by a third party and does not believe that these concerns are supported. This highlights the need for further analysis and study by the industry on the issue of material hardness, yield strength and ultimate tensile strength requirements.

The QC-FIT also notes that several of the industry standards related to bolting design for marine service generally, in other applications, require hardness and yield strength values below that of the GE replacement bolts. However, these standards are also inconsistent. Standards API 17A, NACE MR0175, and NORSOK M-001 Sections 5.6.1 and 5.6.3 require a maximum hardness of 32 HRC and minimum yield strength of 92,000 psi for subsea marine service. API Spec 6A, API

Spec 16F, and NORSOK M-001 for subsea equipment with cathodic protection require a hardness value of 35 HRC, which is lower than the GE specified maximum hardness value requirement of 38 HRC. The 2004 edition of API 16A, which is apparently the basis for the GE design, does not recommend a specific material hardness value for marine service. (Note: The QC-FIT did not evaluate the hardness requirements of other manufacturers of subsea equipment in this assessment). GE states that the current H-4 connector design (in use since 1994) has experienced no other similar issues.

Despite knowledge within the industry (the MMS, two major operators, one major drilling contractor, and one large OEM) of material hardness concerns involving marine service, there does not appear to have been any coordinated effort over the past 10 years to address the potential industry wide safety issue through the revision or adoption of new industry standards. API standards committees have recently begun looking at this fastener material properties requirement issue and as a result, have issued new standards (API Spec 20E released and Spec 20F finalized). However, a more comprehensive incident and data sharing effort by industry over the past 10 years might have highlighted this issue earlier and might have resulted in a more aggressive industry standards development response by the industry.

C. QUALITY CONTROL ISSUE

Prior to 2007, the H4 connector bolts were coated with a zinc phosphate based coating to increase shelf life in the offshore environment. After 2007, the material coating was changed from the zinc phosphate to zinc chromate to provide increased corrosion resistance to salt water when placed in a subsea application. The zinc chromate acts as a sacrificial anode, protecting the underlying steel bolt.

The technical specifications for properly coating materials with higher hardness values similar to the H4 connector bolts are addressed in the ASTM B633 plating standard. In 2007, this technical standard adopted more stringent requirements, which required a post-bake heat treatment procedure (post-bake). Therefore, beginning in 2007, the H4 connector bolts should have been put through a post-bake process.

The 2013 Combined RCA report concluded that GE’s third-tier sub-contracted coating vendor failed to follow the requirements of the 2007 edition of ASTM B633, which requires bolts with hardness values greater than 31 HRC or an ultimate tensile strength value greater than 1000 MPa (approximately 145 ksi), to be both pre- and post-baked. QC-FIT agrees with the RCA finding that the bolts did not receive the required post-bake heat treatment procedures and that this was a major factor in the failure of the bolts. The coating vendor apparently relied on the older 1998 version of the ASTM document that did not require this type of post heat treatment procedure.

GE’s quality management system, in use at the time, which meets current industry standards, qualified and audited only first tier suppliers. As a result, it did not detect that a third-tier contractor (IMF) was using an older version of a key ASTM document over a four year period. This inability of the system to maintain adequate controls throughout the supply chain was also not detected by (1) third party quality management certification groups such as API, or (2) either

Transocean or Chevron in their assessment of contractor qualifications, nor in the programs that ensure the mechanical integrity of critical equipment. As noted earlier in this report, a recent connector failure involving a different OEM, drilling contractor and operator was apparently the result of improper heat treatment of the studs by a subcontractor. This possibly suggests a more systemic problem involving the use and oversight of subcontractors by industry.

OEMs are currently using multiple tiers of international and domestic subcontractors in an attempt to keep up with the large demand for critical safety equipment. This trend is likely to increase in the future. Based on these incidents, it appears that industry quality management systems and certification programs may not have adjusted to this new reality and that further action may be needed to ensure, with certainty, that safety critical equipment in the future continues to perform in a safe and reliable manner (GE is now qualifying and auditing bolting, forging and heat treating by sub-tier suppliers).

D. COATINGS ISSUE

The H4 connector bolts that were manufactured from 2007 to 2012 were coated with ASTM B633 Type II, colored chromate coating finish for service class (SC) 2 moderate service conditions with a minimum coating thickness of 8 microns. As stated in both 1998 and 2007 versions of ASTM B633 in Appendix E, Table E.1 and section X2.2, the QC-FIT interprets ASTM B633 as recommending the SC 2 coating class for a moderate, mostly dry, indoor, occasional condensation service. Example applications for an SC 2 coating are given as: tools, zippers, pull shelves, machine parts. Based on the QC-FIT interpretation of ASTM B633, it remains uncertain whether the use of the SC 2 coating for marine service is appropriate for material design selection and application.

GE’s technical staff disagrees with the QC-FIT interpretation of ASTM B633 and believes that the charts relied upon by QC-FIT are only “examples of appropriate service conditions” and “non-mandatory.” In addition, GE states that proper application of relevant API standards does not permit use of coatings with thickness greater that SC 2 since the relevant assembly could not be accomplished to meet API requirements. Furthermore, GE believes that a review of all relevant industry standards supports its position that the bolts met the required specifications.

The fact that two groups differ on a provision within a key ASTM document suggests that the document needs to be clarified or a request for interpretation be submitted to ASTM. The QC-FIT recommends further examination of appropriate ASTM fastener standards for material coating selection for subsea applications. In particular, are the current standards suitable for the current marine environments where companies are now operating?

E. CATHODIC PROTECTION

The QC-FIT believes it is possible that there are operational issues that may be contributing to the accelerated corrosion degradation occurring with bolts on drilling rigs (see Appendix G table G.1 and Appendix H). The Combined RCA 2013 report contends the impressed current cathodic protection system (ICCP) had no effect on potentials below 3000 feet, based on the attenuation of cathodic potential down the riser (2013 Combined RCA Report page 42). However, readings taken and recorded in the earlier 2003 RCA indicated current levels at this point approach the values warned against in the Product Advisory issued by Vetco-Gray in 2005. More analysis is needed to determine whether existing cathodic protection systems have an impact on the corrosion degradation of bolts.

F. ABSENCE OF PAINT OR COATING

The 2013 Combined RCA Report discussed the impact of the absence of paint or coating on hydrogen generation on cathodically protected structures. The purpose of paint on subsea structures is to reduce the current required for cathodic protection by sealing and elimination of the available interface for cathodic reaction. Although it is impossible for a paint coating to form a complete hermitic seal, unpainted areas will result in increased current drawn from the CP anode system current, resulting in some amount of hydrogen generation. The more negative the CP value, the higher the potential for hydrogen charging (2013 Combined RCA Report pages 328-330). Therefore, hydrogen ion generation can possibly contribute to hydrogen embrittlement corrosion (GE states that their inspection program has been revised to include 100% visual and documentation for the H4 assembly prior to shipment). It is not known to what extent this contributed to the bolt incident in question here.

G. JARRING

The QC-FIT found that the available evidence was inconclusive regarding the impact of jarring operations on the bolt failures and therefore could not conclude whether this was or was not a contributing cause of the failure. Finite element analysis (FEA) of jarring operations loads on bolts is one of the outstanding RCA analyses that are being conducted by GE. Based on the QC-FIT's review of the remotely operated vehicle (ROV) video footage, the 2013 Combined RCA Report, the outstanding FEA analyses, the accuracy of jarring load conditions experienced on the H4 connector/bolts during operation, and the installation conditions' (equipment used, torque rating, loads, etc.) the impact of jarring on the bolts are unknown. The QC-FIT received GE's intermediate jarring analyses (September 3, 2013) with preliminary, non-conclusive FEA data and presentation on the magnitude of the jarring operations' impact on the bolt failures and integrity. Preliminary data suggests the bolts began to fail under loading due to hydrogen embrittlement. The continued side loads on the connector's upper body were likely incurred due to the jarring operations and caused an increase in loading and a bending moment on the bolts until the resulting fracture. As of the writing of this report, GE was still conducting FEA theoretical analyses, therefore the QC-FIT is unable to conclude the magnitude the jarring loads had on this particular bolt failure.

H. INSTALLATION AND TORQUE

Another possible contributing factor that should be reviewed is the potential additional loads incurred on the bolts during installation. Unfortunately, for this inquiry, installation procedures/reports, maintenance, operations and the applied torque(s) were not available on the connection in question. Therefore, it is not known if the installations conformed to the documented installation limits defined by GE. However, additional testing could identify if similar problems may be manifested if proper installation procedures are not followed. GE reports that additional testing showed no cracks detected when torque is applied above the 67% of recommended yield.

I. COUNTERFEIT BOLTS

At the time of the QC-FIT evaluation, there was discussion of possible global use of counterfeit bolts involving lower quality, non-approved metals and manufacturing procedures. The QC-FIT found no evidence that the failing bolts came from any source other than the GE.

V. QC-FIT RECOMMENDED ACTIONS

Based upon the findings of the QC-FIT, there are several actions that BSEE and the industry can undertake to help mitigate re-occurrence of these types of events. The suggested actions include:

- Encourage industry to adopt a component-level tracking system for bolts, studs and other fasteners during their specified service life and require that maintenance requirements include defined service intervals and service life expectations in the defined environments.
- Initiate a research project that compares and contrasts the bolting/fastener requirements of currently published specifications and standards (design, material, maintenance and quality specifications) to identify potential gaps and inconsistencies for presentation to standards bodies for consideration.
- Initiate a joint industry research initiative or use the Ocean Energy Safety Institute to investigate a) material properties requirements and alternative materials that may be used in the manufacturing of bolts/fasteners to address hydrogen embrittlement based corrosion during subsea operations and b) the relationships between these and other materials, and cathodic protection systems, and their respective performance~~s~~ in differing marine environments.
- Facilitate the creation of a failure and near-miss reporting and information sharing system to be used among offshore operators, equipment owners and manufacturers, and foreign regulatory authorities, such as through the International Regulators Forum (IRF) to track equipment failures.
- Monitor/follow-up with GE for the H4 connector and BSR bolts RCA's testing, analyses, results and reports. In addition, monitor/follow-up with Transocean, Chevron, and GE on the outstanding 2013 Combined RCA Report items.
- Consider promulgating regulations that incorporate desired standards for fastener material property requirements and respective specifications to require industry compliance with best practices, and best available technology for fasteners.
- BSEE should initiate, with industry, an information collection initiative that will allow the industry and BSEE to identify potential significant design issues that could affect the safety of offshore operations. Vetco Gray issued a safety alert related to TO vessels in 2005 (see

section titled *Documents and Related Technical Reference Articles*). If the results of the remedies taken in 2005 for this event had been adequately shared and recognized throughout the industry, more recent incidents may have been mitigated.

- BSEE should continue to work with operators and drilling contractors to determine if there may be inherent operational and maintenance issues that increase the risk of bolt failure.
- BSEE should initiate with industry a study of hydrogen embrittlement of bolts used in subsea operations (e.g., joint industry project (JIP)) to better understand the relationships and interaction of the following: bolt base alloy materials selection; optimal bolt material mechanical property values (material hardness, yield strength, tensile strength, ultimate strength); coating selection and processes; cathodic protection; and corrosion. Two separate research efforts (JIPs) should be committed to: (1) understanding the interaction of cathodic protection systems, anode alloy material, applied voltage on different critical drill-string components and (2) the impact of water salinity exposure in different waters (e.g., Black Sea and GOMR) on such equipment. These JIPs will help to ensure that the appropriate materials are selected for safe and environmentally sound operation.
- BSEE should consider using its regulatory authority to require operators, contractors and equipment manufacturers to be forthcoming with information on safety critical equipment that result in changes to equipment design or material specification. When this data is not readily available, BSEE and industry cannot effectively evaluate all relevant information, to determine the most significant lessons learned, and share the information to foster continuous safety improvement and reliability for the overall benefit of offshore oil and gas operations.
- BSEE should encourage operators to ensure that their SEMS programs cover contractors and subcontractors in a comprehensive manner to ensure a thorough review, assessment, and analysis of operational factors, maintenance, and environmental and operational conditions, including cathodic protection, for all safety critical elements and drilling vessels.
- BSEE should encourage industry to review industry standards: API 6A; API 16A; API 16F; API 17A; ASTM B633; ASTM B849; ASTM B850; ASTM F1941; ASTM F1137; NACE MR0175; and NORSOK-M001, which have different material property requirements for subsea operation. There needs to be a consistent approach toward addressing connector hardness, strength and coatings requirements and cathodic protection voltages in these documents.
- API should be requested to address, in Spec Q1, the issue of the audit and approval of the multiple tiers of subcontractors that are used in today’s manufacturing process for critical equipment.
- BSEE should encourage industry to work on developing standards and guidelines on the optimal applied voltage for cathodic protection systems on drillships.
- BSEE should request that ASTM revise its relevant standards to provide clarity related to the design and use of coatings for marine service.
- BSEE should continue their analysis to determine whether the hardness issue extends across the many types of connector fasteners being used on the OCS, especially in light of the recent connector stud failure made know to BSEE in mid-2014 and involving a different operator, drilling contractor, and connector OEM.

TIMELINE

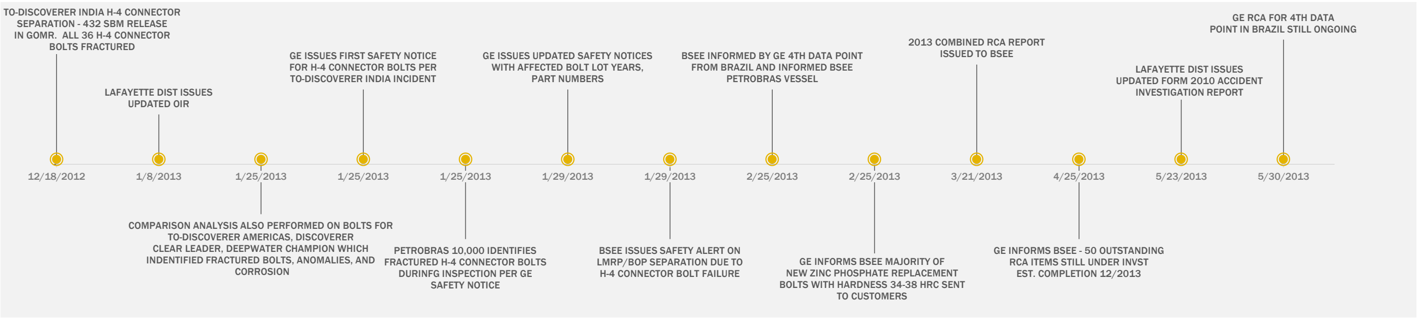
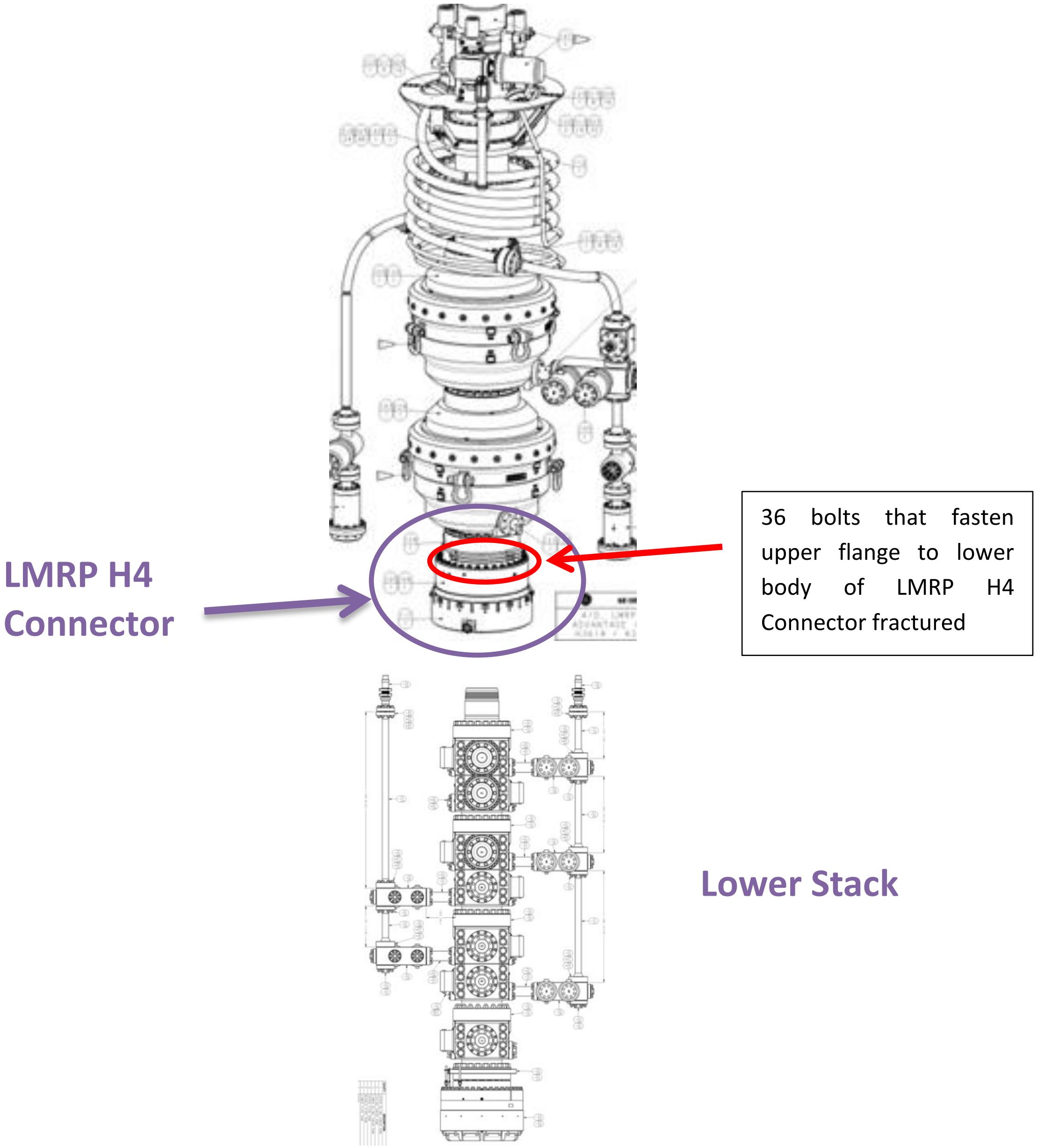


FIGURE 1: Accessibility to relevant documents, data, and facilities timeline



36 bolts that fasten upper flange to lower body of LMRP H4 Connector fractured

FIGURE 2 - SCHEMATIC OF LMRP H4 CONNECTOR AND MANDREL INDICATING LOCATION OF 36 CONNECTION BOLTS, DEPICTING SEPARATION (REF. 2013 GE PRESENTATION TO BSEE) GE COPYRIGHT, NON FOIA

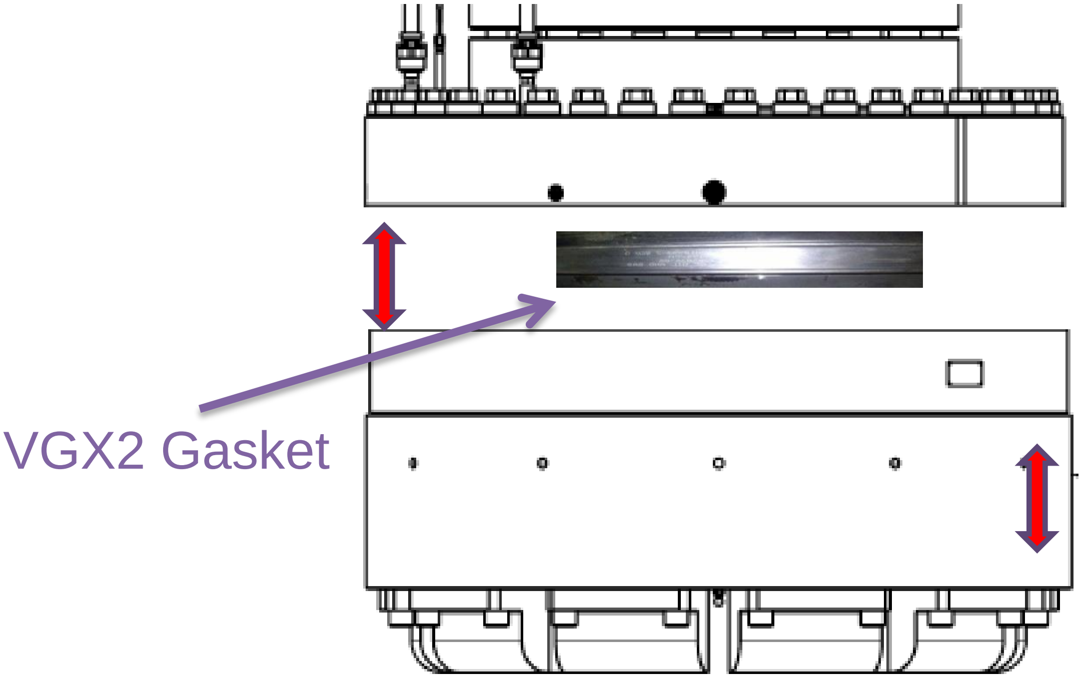


FIGURE 3 - SCHEMATIC DEPICTION OF LMRP H4 CONNECTOR SEPARATION. ALL 36 BOLTS THAT FASTEN THE CONNECTOR FAILED (REF. 2013 GE PRESENTATION TO BSEE) (GE COPYRIGHT, NON FOIA

APPENDIX A - ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Definition
ABS	American Bureau of Shipping
ADCP	Acoustic Doppler Current Profiler
AISI	American Iron and Steel Institute
Al	Chemical Nomenclature for Aluminum
API	American Petroleum Institute
aq	Aqueous
ASM	American Society for Materials
ASME	American Society for Mechanical Engineers
ASTM	American Society of Testing Materials
bbls	Barrels
BHA	Bottom Hole Assembly
BOP	Blow-out Preventer
BSEE	Bureau of Safety & Environmental Enforcement
BSR	Blind Shear Ram
^{o}C	Nomenclature for Degrees Celsius
CCU	Central Control Unit
CFR	Code of Federal Regulations
Cl	Chemical Nomenclature for Chloride (Chlorine)
Cl-SCC	Chloride-Stress Corrosion Cracking
COC	Certificate of Conformance
CONN	Connector
CP	Cathodic Protection
Cr	Chemical Nomenclature for Chromium (Chromate)

CVA	Certified Verification Agent
CVX	Chevron Corporation (NYSE Ticker Symbol)
DAS	Transocean Discoverer Americas Vessel
DCL	Transocean Discoverer Clear Leader Vessel
DI	Transocean Discoverer India Vessel
DNV	Det Norske Veritas
DOI	Department of the Interior
EDS	Energy Dispersive (X-ray) Spectroscopy
EMW	Estimated Mud Weight
ERA	Electric Riser Angle
^{o}F	Nomenclature for Degrees Fahrenheit
FMEA	Failure Mode Effect Analysis
FPSO	Floating Production Storage & Offloading Unit
GE	General Electric (Oil & Gas)
GMS	Global Management System
GOM	Gulf of Mexico
H^+	Hydrogen Cation
HE	Hydrogen Embrittlement
HPHT	High Pressure High Temperature
HPU	High Pressure Unit
HRC	Rockwell Hardness Scale C
HSE	Health and Safety Executive
IADC	International Association of Drilling Contractors
ICCP	Impressed Current Cathodic Protection
ID	Inner Diameter

IMF	Industrial Metal Finishing Plating Company
IMP	Inspection Maintenance & Procedure
IPT	Integrated Pressure Testing
In	Chemical Nomenclature for Indium
in	Abbreviation for inch
IRF	International Regulators Forum
JIP	Joint Industry Project
K	1,000
KC	Keathley Canyon Lease Block
kips	1,000 pound force
ksi	Kilo pound per square inch
lb	Pounds
LMRP	Lower Marine Riser Package
LOT	Leak Off Test
LWD	Logging While Drilling
µm	Micrometer length unit
MD	Measured Depth
MDDM	Modular Derrick Drilling Machine
MMS	Minerals Management Service
MPa	Mega Pascal
MPI	Magnetic Particle Inspection
MTR	Materials Trace Record
MWD	Measurement While Drilling
NACE	National Association of Corrosion Engineers
NDE	Non-Destructive Examination
NHR	GE North Houston Rosslyn Center

NORSOK	Norsk Sokkels Konkuranseposisjon Norwegian Petroleum Industry Standard
O	Chemical Nomenclature for Oxygen
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
OD	Outer Diameter
OEM	Original Equipment Manufacturer
OH^-	Chemical Nomenclature for Hydroxyl Group Anion
P	Chemical Nomenclature for Phosphate (Phosphor)
P-10K	Petrobras 10,000 vessel
PM	Preventive Maintenance
P/N	Part Number
ppg	Pounds per Gallon
ppm	Parts per million
psi	Pounds per square inch
QA	Quality Assurance
QC	Quality Control
QMS	Quality Management System (GE)
RCA	Root Cause Analysis
ROP	Rate of Penetration
ROV	Remotely Operated Vehicle
S	Chemical Nomenclature for Sulfur (Sulfide)
σ	Greek letter sigma, stress
SBM	Synthetic Based Mud

SC	Service Class
SEM	Scanning Electron Microscope (Microscopy)
SES	Stress Engineering Services
SN	Safety Notice
S-SCC	Sulfide-Stress Corrosion Cracking
SCC	Stress Corrosion Cracking
SR	Shear Ram
SSRT	Slow Strain Rate Tensile (Test)
TLP	Tension Leg Platform
TO	Transocean
TO-DAS	Transocean Discoverer Americas
TO-DCL	Transocean Discoverer Clear Leader
TO-DE	Transocean Discoverer Enterprise
TO-DI	Transocean Discoverer India vessel
TO-P	Transocean Discoverer Pathfinder
TOP-SET®	Technology, Organization, People, Similar Events, Environment and Time
TVD	True Vertical Depth
UTS	Ultimate Tensile Strength
Wt.	Weight
YS	Yield Strength
Zn	Chemical Nomenclature for Zinc
ZnCr	Zinc Chromate Coating
ZnP	Zinc Phosphate Coating

APPENDIX B - QC-FIT SITE VISITS AND MEETINGS

The QC-FIT participated in the following facility site visits, tours, meetings, and teleconferences with the operators; contractor service providers; vendors; and original equipment manufacturers.

Site Visits and Facility Tours

1. **STRESS ENGINEERING SERVICES (SES)**
    - SES was the third-party laboratory that performed the metallurgical root cause analyses of the subject bolts.
    - The QC-FIT toured and inspected SES's test facility, inspected the failed H4 connector bolts, and held a meeting, including a presentation by SES of preliminary data and findings.

2. **US BOLT**
    - US Bolt is the original manufacturer of the H4 connector bolts.
    - The QC-FIT toured and inspected US Bolt's manufacturing facilities and operations and held a meeting to discuss their manufacturing, inspection, and QA/QC processes and procedures.

3. **INDUSTRIAL METAL FINISHING (IMF) PLATING COMPANY**
    - IMF was the vendor who applied the zinc chromate (Zn-Cr) coating to the H4 connector bolts involved in the bolt failure.
    - The QC-FIT toured IMF's plating facilities and operations and held a meeting to discuss the QA/QC procedures and Zn-Cr electro-plating process.

4. **S&S PLATING COMPANY (S&S)**
    - S&S is the new vendor (replacing IMF) for the zinc phosphate coating to the replacement H4 connector bolts.
    - The QC-FIT toured and inspected S&S's plating facilities and operations and held a meeting to discuss process, procedures and standards, for comparison to IMF operations.

5. **GE, VETCO GRAY**
    - Vetco Gray assembled the original H4 connectors that utilized the subject bolts.
    - The QC-FIT toured Vetco Gray's facility and inspected the failed H4 connector.

MEETINGS AND TELECONFERENCES WITH INDUSTRY

Meetings and teleconferences were held to 1) gain an in-depth understanding of the events leading up to and surrounding the H4 connector bolt failure and 2) hear from others in industry regarding their experiences and knowledge of the issues in relation to QC-FIT's inquiry, as follows:

1. Combined meeting: Transocean (TO), Chevron (CVX), GE
2. GE (separate meetings, teleconferences in addition to combined TO-CVX-GE meeting)
3. Shell (Meeting)
4. ABS (Meetings & Teleconferences)
5. BP (Teleconference)

APPENDIX C – GLOSSARY OF TECHNICAL TERMS

Technical Term	Definition
Brittle Fracture	Fracture mechanism that occurs in brittle, jagged manner, the fracture occurs at rapid rate. This type of fracture commonly occurs under tensile load conditions.
Cathodic Protection	System utilized to control corrosion of a metal by using it as the cathode of an electrode chemical cell containing both a cathode and anode. This system is used in potential corrosive environments to prevent stress corrosion cracking.
Electroplating	The process of applying an adherent layer of a metallic coating to a different substrate surface by electro-deposition process.
Environmentally Assisted Corrosion Cracking (EAC)	Corrosion based cracking mechanism that occurs due to environmental factors, primarily in the presence of hydrogen ions (atomic, free elemental hydrogen).
Ductile Fracture	Fracture mechanism that occurs in a ductile cup and cone manner, the material deforms elastically before final fracture.
Fractography	The scientific methodology that interprets fracture surface features, in relation to causative stresses.
Galling	Wear that is caused by friction of close contact, adhesion, or rubbing of more than one dissimilar metal; characterized by the deposits of material from one surface to another.
Galvanic Corrosion	This is also called dissimilar metal corrosion. This occurs when dissimilar metals are in close proximity. For galvanic corrosion to occur three conditions must be present: 1-electrochemically dissimilar metals must be present, 2-the metals must be in electrical contact, 3-the metals must be exposed to an electrolyte bath type solution.
Hydrogen Embrittlement (Hydrogen cracking)	Corrosion based embrittlement, cracking (fracture) of a material or component in the presence of hydrogen under stress load conditions.
Magnetic Particle Inspection	Non-destructive testing procedure for identification of surface and sub-surface defects, cracks, imperfections, or flaws in a material/component.
pH	A measure of hydrogen ion concentration. Determines the salinity level of a solution.
Stress Corrosion Cracking (SCC)	A fracture resulting from the growth of cracks in a corrosive environment under tensile stress loads. This can occur in the presence of: sulfide, chlorides, and hydrogen.
Sulfide-Stress Corrosion Cracking (S-SCC)	SCC in the presence of sulfur.
Chloride-Stress Corrosion Cracking (Cl-SCC)	SCC in the presence of chloride.

Appendix D - GENERAL LIST OF STANDARDS

Many industry standards were of interest to the QC-FIT inquiry. Of those, many are not incorporated by reference into regulation. Those that are incorporated are only done so in-part and do not contain specific enforceable material requirements.

The documents listed below are incorporated, in-part, by reference:

1. API SPEC 6A – “Specification for Wellhead and Christmas Tree Equipment, Nineteenth Edition” (under 250.806, 250.1002, and 250.198 (2013)).
2. NACE MR0175 – “Metals for Sulfide Stress Cracking and Stress Corrosion Cracking Resistance in Sour Oilfield Environments, 2003 Edition” (under 250.490, 250.901, and 250.198 (2013)).

The documents listed below are not incorporated by reference:

3. API 16A – “Specification for Drill Through Equipment, Thud Edition”
4. API 16F – “Specification for Marine Drilling Riser Equipment, First Edition”
5. API 17A – “Design and Operation of Subsea Production Systems – General Requirements and Recommendations, Fourth Edition”
6. API 20E – "Alloy and Carbon Steel Bolting for use in the Petroleum and Natural Gas Industries, August 2012 First Edition”; applies when required or invoked by other standards.
7. ASTM A370 – “Standard Test Methods and Definitions for Mechanical Testing of Steel Products, 2013 Edition”
8. ASTM B633 – “Standard Specification of Electrodeposited Coatings of Zinc on Iron or Steel, 2013 Edition”
9. ASTM B849 – “Standard Specification of Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement, 2013 Edition”
10. ASTM B850 – “Standard Guide for Post-Coating Treatments of Steel for Reducing Risk of Hydrogen Embrittlement, 2009 Edition”
11. ASTM E18 – “Standard Test Methods for Rockwell Hardness of Metallic Materials, 2014 Edition”
12. ASTM E45 – “Standard Test Methods for Determining the Inclusion Content of Steel, 2011 Edition”
13. ASTM F1137 – “Standard Specification for Phosphate/Oil Corrosion Protective Coatings for Fasteners, 2011 Edition”
14. ASTM F1470 – “Standard Practice for Fastener Sampling for Specified Mechanical Properties and Performance Inspection, 2012 Edition”
15. ASTM F1940 – “Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners, 2007 Edition”
16. ASTM F1941 – “Standard Specification for Electrodeposited Coatings on Threaded Fasteners”
17. NORSOK M-001 – “Materials selection, 2004 Edition”

APPENDIX E - RELEVANT INDUSTRY STANDARDS

Several industry standards apply to the design, selection, and manufacture of connector bolts. These relevant industry standards include the following: API Spec 16A-Specification for Drill-Through Equipment; ASTM B633-Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel; ASTM B849 Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement; ASTM B850-Standard Post-Coating Treatment of Steel for Reducing the Risk of Hydrogen Embrittlement.

API 16A

The connector and the bolts were designed and manufactured per the hydraulic connector requirements outlined in the 2004 edition of API Spec 16A. This standard does not require nor indicate specific material properties value requirements; particularly material hardness, yield strength and ultimate tensile strength values for operation in a subsea environment(s). Since the connector was designed per API Spec 16A, which invokes manufacturer requirements for flanged connectors, there were no specific material hardness and strength value requirements, other than the manufacturer's design standards. This points to the need to add material properties requirements in API 16A.

API 20E

Specifies requirements for the qualification, production and documentation of alloy and carbon steel bolting used in the petroleum and natural gas industries. This standard establishes requirements for three bolting specification levels (BSL). These three BSL designations define different levels of technical, quality and qualification requirements, BSL-1, BSL-2, and BSL-3. The BSLs are numbered in increasing levels of severity in order to reflect increasing technical, quality and qualification criteria. This standard covers the following finished product forms, processes, and sizes:

- machined studs;
- machined bolts, screws and nuts;
- cold formed bolts, screws, and nuts (BSL-1 only);
- hot formed bolts and screws < 1.5 in. (38.1 mm) nominal diameter;
- hot formed bolts and screws > or = 1.5 in. (38.1 mm) nominal diameter;
- roll threaded studs, bolts, and screws < 1.5 in. (38.1 mm) diameter;
- roll threaded studs, bolts, and screws > or = 1.5 in. (38.1 mm) diameter;
- hot formed nuts < 1.5 in. (38.1 mm) nominal diameter; and
- hot formed nuts > or = 1.5 in. (38.1 mm) nominal diameter.

ASTM B633

This standard outlines different thickness classes with required salt spray test verification durations (See Appendix E, Table E.1 for coating finish types; ref. ASTM B633, 1998, 2007).

Table E.2 specifies coating thickness classes based on the service condition (Ref. ASTM B633, 1998, 2007, 2011). Section 6.4 recommends base metal alloys with an UTS value greater than 1700 MPa (247 ksi) should not be coated with zinc coating. The QC-FIT identified a concern about the manner that standards are applied within the supplier and manufacturer chains throughout industry.

Table E.1 – ASTM B 633 Coating Finish Types (ref ASTM B633 1998, 2007, 2011 editions)		
Type	**Description**	**Minimum Salt Spray Test Time (hrs)** (2007, 2011 ed)
I	As-plated without supplementary treatment	-
II	With colored chromate conversion coatings	96
III	With colorless chromate conversion coatings	12
IV	With phosphate conversion coatings	-
V (2007,2011 ed)	With colorless passivate	72
VI (2007,2011 ed)	With colored passivate	120

Table E.2 – ASTM B 633 Thickness Classes for Coatings (1998, 2007, 2011 editions)		
Classification[A] Number and Conversion Coating Suffix	**Service Condition [B, C]**	**Thickness minimum μm**
Fe/Zn 25	SC 4 (very severe)	25
Fe/Zn 12	SC 3 (severe)	12
Fe/Zn 8	SC 2 (moderate)	8
Fe/Zn 5	SC 1 (mild)	5
[A] Iron or steel with zinc electroplate. Number indicates thickness in micrometers [B] See ASTM B633 Appendix X2 [C] When service conditions are valid only for coatings with chromate conversion type II for SC 4 and SC 3 and Type III for SC 2 and SC 1.		

Table E.3 summarizes ASTM B633, the SC descriptions, and appropriate service conditions for each class (ASTM B633, 1998, 2007, 2011). The coating for the 2012 failed bolts manufactured 2007 – 2009 is a SC 2 class. SC 2 is for a moderate service condition, exposed mostly to indoor atmospheres, occasional condensation with minimum wear or abrasion. The recommended parts are tools, zippers, pull shelves and machine parts. The H4 connector bolts were coated to an SC 2 class and are used in marine subsea service blowout preventer (BOP) applications. According to GE, relevant API standards cannot be applied if a coating thicker than SC 2 is used.

Table E.3 – Summary of ASTM B633 Coatings Service Class, Service Conditions, Description of Service Condition (ref. ASTM B633 1998, 2007, 2011 editions)

Class	Service Condition	Service Condition Description
SC 1	Mild	Exposure to indoor atmospheres with rare condensation and subject to minimum wear or abrasion. Examples: buttons, wire goods, fasteners.
SC 2	Moderate	Exposure mostly to dry indoor atmospheres but subject to occasional condensation, wear, or abrasion. Examples: tools, zippers, pull shelves, machine parts.
SC 3	Severe	Exposure to condensation, perspiration, infrequent wetting by rain, and cleaners. Examples are: tubular furniture, insect screens, window fittings, builder's hardware, military hardware, washing machine parts, bicycle parts.
SC 4	Very Severe	Exposure to harsh conditions, or subject to frequent exposure to moisture, cleaners and saline solution, plus likely damage by denting, scratching or abrasive wear. Examples are: plumbing fixtures, pole line hardware.

ASTM B633 PRE-BAKE HEAT TREATMENT REQUIREMENTS

Pre-bake heat treatment is recommended to remove any residual hydrogen from the base substrate. All editions of ASTM B633 recommend if the customer does not specify an exception, then the coating vendor should pre-bake according to thickness classes per Table E.1 in the standard (ref ASTM B633 1998, 2007, 2011). Table E.4 is a comparison chart of the different material property value requirements for pre-bake heat treatments for 1998, 2007, 2011 editions. The 1998 edition of ASTM B633 does not specify a material hardness for pre-bake requirement, however, recommends pre-baking for base alloys with an ultimate tensile strength greater than 174 ksi. Therefore, per the 1998 edition, the H4 connector bolts were not required to have a pre-bake procedure. However, per the 2007 and 2011 editions, the bolts would have been required to be pre-baked.

TableE.4 –Comparison of Material Properties Requirements for Pre-Bake Heat Treatment Stress Relief 1998, 2007 & 2011 editions ASTM B633

	Hardness HRC	Ultimate Tensile Strength MPa (ksi)
1998 Edition	No specified requirement	1000+ (174+)
2007 Edition	31	1000+ (145+)
2011 Edition	31	1000+ (145+)

ASTM B633 POST-BAKE REQUIREMENTS

The QC-FIT identified similar concerns about the need for improved industry wide communication regarding applicable standards requirements for post-bake procedures. A post-bake "hydrogen embrittlement relief" procedure is recommended after electroplating the base metal with zinc coating to reduce susceptibility to hydrogen embrittlement (ref. Section 6.6 in 1998 edition, Section 6.5 in 2007 and 2011 editions). The ASTM B633 (1998 edition) specifies for parts with an UTS greater than 1200 MPa (174 ksi equivalent) to be post-baked. However, a specific material hardness value requirement is not indicated in the actual standard (ref. ASTM B633, 1998 edition). The table provided in the combined 2007 and 2011 editions requires post-bake heat treatment stress relief for metals with a hardness value of 31 HRC and UTS greater than 1000 MPa (145 ksi). Per the material hardness and strength values in the 2007, 2011 edition of ASTM B633, the bolts would have needed to be post-baked. However, per the 1998 edition ASTM B633, the bolts would not needed to be post-baked. As outlined in Table E.5 are the different material property values requirements for post-bake for ASTM B633 1998, 2007, and 2011 editions. Therefore, prior to the release of the latest edition of ASTM B633 2007 edition, the IMF plating company had to rely upon the requirement for UTS because the standard did not have a specified hardness requirement.

The connector bolts manufactured from 2007 to 2009 were coated with a Type II, colored chromate coating finish for SC 2 moderate service condition with a minimum thickness of 8 microns. From 2007 to 2009, the subcontracted vendor followed the ASTM B633 1998 edition for coating the connector bolts with zinc chromate. As specified by the manufacturer’s bolt design specification, the required a minimum UTS value of 160 ksi. Therefore, according to the 1998 edition, bolts did not require a post-bake procedure. However, according per the 2007 and 2011 editions, a post-bake procedure was required (see Table E.5).

Table E.5 – Comparison of Post-Bake Hydrogen Embrittlement Stress Relief Requirements for ASTM B633 1998, 2007, 2011 Editions

	Hardness HRC	**Ultimate Tensile Strength MPa (ksi)**
1998 Edition	N/A	1200+ (174+)
2007 Edition	31	1000+ (145+)
2011 Edition	31	1000+ (145+)

ASTM B849

ASTM B849 provides recommended guidance for stress relief, pre-bake heat duration of metals prior to electroplating. Table E.6 is an overview of recommended pre-bake durations and temperatures for high strength steels based on tensile strength (to be provided by customer) (Ref. 2007 ASTM B849). As seen in Table E.6, classes are based on the UTS values.

Table E.6 – Stress Relief Requirements for High Strength Steel (Ref. ASTM B849, 2007 edition)

Class	**Tensile Strength**		**Temperature ^{o}C**	**Time, mins.**
	MPa	**Ksi**		
SR-0	N/A	N/A	N/A	N/A
SR-1	1800+	261+	200-230	24
SR-2	1800+	261+	190-220	24
SR-3	1401 – 1800	203 – 261	200-230	18
SR-4	1450 - 1800	210 -261	190-220	18
SR-5	1034+	150+	177-205	3
SR-6	1000 - 1400	145 – 203	200-230	3
SR-7	1050 - 1450	152 – 210	190-220	1
SR-8	Surface hardened parts ≤ 1400	Surface hardened parts ≤ 203	130-160	8

ASTM B850

ASTM B850 provides procedural guidance for post-baking, heat treatment duration for hydrogen stress relief of metals subjected to electroplating coating processes. Post-bake heat treatment is recommended for metals with a hardness value greater than >31 HRC and an UTS >145 ksi. The bolt design specification required a material hardness of 34-38 HRC, and a minimum UTS value of 145 ksi (ref. 2009 US Bolt MTR in 2013 Combined RCA Report, Appendix R page 335). Therefore per the 1998 edition for ASTM B850, the bolts were required to be post-baked from 2007 to 2009. If the design specification had clearly referenced ASTM B850, then the post-bake requirements would have been clear.

ASTM F1941

This specification covers application, performance and dimensional requirements for electrodeposited coatings on threaded fasteners with unified inch screw threads. It specifies coating thickness, supplementary hexavalent chromate or trivalent chromite finishes, corrosion resistance, precautions for managing the risk of hydrogen embrittlement and hydrogen embrittlement relief for high-strength and surface-hardened fasteners. The electrodeposited coating as ordered shall cover all surfaces and shall meet the requirements prescribed. Coated fasteners, when tested by continuous exposure to neutral salt spray shall show neither corrosion products of coatings (white corrosion) nor basis metal corrosion products (red rust) at the end of the test period. The coating thickness, embrittlement, corrosion resistance, and trivalent chromite finish shall be tested to meet the requirements prescribed.

APPENDIX F- INDUSTRY STANDARDS ON MATERIAL HARDNESS, STRENGTH, AND COMPATIBILITY

Although NORSOK M-001 and 16F standards were not followed for the manufacture, design and material selection for the connector bolts, they are appropriate because recommended material hardness, yield strength and UTS requirements are specified for effective subsea operation. These references show industry has considered the issue of ensuring that hardness values do not exceed 32-35 HRC for subsea environment operations. However, QC-FIT identified the need for consistency and the general principle of ensuring proper material selection should be applied for other subsea equipment. Therefore other standards should be reevaluated, as well.

NORSOK M-001 – MATERIALS SELECTION

NORSOK M-001 specifies materials design selection requirements, guidance, and recommendations for equipment design for specific operating environment specifications. Further, NORSOK M-001 provides guidance for the material selection, manufacture, ideal materials' properties for the operating environment and potential corrosion conditions, and design limitations of candidate materials for the proposed subsea operating environment. Some applicable equipment for NORSOK M-001 include: bolting materials (fasteners), drilling equipment, structural materials, well completion, pipelines, and chains and moorings for FPSO's.

Specific sections of interest in the NORSOK M-001 standard relevant to this inquiry include:

- Section 5.6.1 recommends that for bolts used for subsea applications, the material should have a maximum hardness on Rockwell Scale C (HRC) of 32. The manufactured bolts' material hardness should be verified by spot testing for each delivery, lot, batch, and bolts' used for subsea applications.

- Section 5.6.3 recommends for submerged bolt materials used for structural applications, the material strength class should not exceed ISO 898 class 8.8 and the maximum hardness per section 5.6.1, 32 HRC. ISO 898 class 8.8 bolts materials that are quenched and tempered should have a minimum ultimate tensile strength of 120,000 psi and minimum yield strength of 92,000 psi. These material mechanical strength properties values are recommended to ensure effective material performance in subsea applications and reduce susceptibility to corrosion (hydrogen embrittlement and stress corrosion cracking (sulfide and chloride)). The yield and ultimate tensile strength properties values are important to verify the appropriate resulting microstructure in addition to the heat treatment.

- Section 6.1 recommends that for submerged equipment parts that may be exposed to CP, the material hardness for austenitic stainless steels are not to exceed 35 HRC. QC-FIT identified that broad use of AISI 4340 alloy with material hardness specification of 34-38 HRC, yield strength: 145,000 psi minimum; tensile strength: 160,000 psi minimum may not be appropriate. .

NORSOK also recommends alternative bolt materials for "submerged" structural applications. For bolts screwed into component bodies, the material should be compatible to prevent galling and have the improved capability for disassembly. Selection of compatible materials should be considered to reduce the risk of galvanic corrosion, thermal coefficient, and effect of cathodic protection.

QC-FIT compared material properties specifications and actual material properties' values and found significant concerns. QC-FIT finds it is important not to assume that the values for an alloy are acceptable in all cases.

APPENDIX G - RECENT IMPACTED VESSELS & RELATED FAILURE EVENTS

TRANSOCEAN VESSELS

As a result of the TO-DI H4 connector bolt failures, bolts from other TO vessels were inspected, tested. During these inspections, fractured H4 connector bolts were identified on January 5, 2013 on TO-DAS.

Currently TO have four identified vessels with related bolt failures:

- TO-DI – December 18, 2012 original identified failure notified BSEE of H4 Connector Failure Event.
- TO – DAS – In response to GE Safety Notice SN 13-001 request for bolt inspection, anomalies identified during inspection and torque test procedure. Bolts were rejected.
- TO-Discoverer Clear Leader – bolts were rejected during magnetic particle inspection (MPI)
- TO-Deepwater Champion – corrosion products identified on bolts during inspection.

OTHER POTENTIAL VESSELS

PETROBRAS VESSELS

Fractured bolts were identified during inspection and torque testing per the OEM Safety Notice of the (P-10K) vessel operating in the GOMR on the OCS on January 25, 2013. The P-10K was approximately 2.5 years in-service, when fractured bolts due to corrosion and possible similar hydrogen embrittlement were identified.

Petrobras had 56 drilling rigs and 27 wells with BOPs on subsurface that required bolt repair in Brazil.

SHELL VESSELS

The QC-FIT met with Shell who had six impacted vessels, three in the GOMR OCS, one each in the North Sea, Australia, and Nigeria. The three GOMR rigs were: the Jim Thompson, Globe Trotter 1, and Driller. All of Shell’s wellheads have H4 connectors and a LMRP connector; there’s a Cameron connector at the BOP. All retrieved bolts had no identified damage to-date. Any fractured H4 connector bolts will be replaced.

BP VESSELS

BP has five impacted rigs in GOMR. BP is currently performing inspections by remote operating vehicle (ROV).

GLOBAL IMPACT

GE informed the QC-FIT during meetings they had customers impacted globally. GE was working hard to retrieve affected bolt lots from their global customers. GE indicated to the QC-FIT any assistance from BSEE would be helpful with the bolt recovery efforts.

Table G.1 - OVERVIEW OF VESSELS WITH BOLT FAILURES 2003 - 2013

			2003	2011	2012-2013
		GOMR - OCS			
1	**TO-Discoverer India**			2011-2013 Blind Shear Ram bolt failure lower mechanical strength values.	H4 Connector Bolt & Blind Shear Ram Bolt failures. H4 bolts due to hydrogen embrittlement corrosion, fracture. High Material hardness, coating issues. Blind Shear Ram bolt failure lower mechanical strength values. In 2011-2013
2	**TO – Discoverer Americas**				H4 Connector Bolt due to hydrogen embrittlement corrosion fracture.
3	**TO – Discoverer Clear Leader**				H4 Connector Bolts failed inspection, were rejected.
4	**TO- Deepwater Champion**				H4 Connector Bolts had significant corrosion products, fractures
5	**P-10K**				H4 Connector Bolt due to hydrogen embrittlement corrosion, fracture.
6	**TO – Discoverer Enterprise 2003 BP Thunderhorse Riser bolt/bolt insert failure**		Riser Bolt Inserts (nuts) & Bolt fractures due to environmentally assisted cracking, hydrogen embrittlement. Corrosion brittle fracture. High material hardness, coating/material compatibility issues, strength loading		
7	**TO-Pathfinder 2003 BP Thunderhorse Riser bolt/bolt insert failure**		Riser Bolt Inserts (nuts) & Bolt fractures due to environmentally assisted cracking, hydrogen embrittlement. Corrosion brittle fracture. High material hardness, coating/material compatibility issues, strength loading.		
8	**TO-Horizon 2003 BP Thunderhorse Riser bolt/bolt insert failure**		Identified Riser Bolt Inserts (nuts) & Bolt fractures due to environmentally assisted cracking, hydrogen embrittlement. Corrosion brittle fracture. High material hardness, coating/material compatibility issues, strength loading		
9	**TO-Millennium 2003 BP Thunderhorse Riser bolt/bolt insert failure**		Identified Riser Bolt Inserts (nuts) & Bolt fractures due to environmentally assisted cracking, hydrogen embrittlement. Corrosion brittle fracture. High material hardness,		

			coating/material compatibility issues, strength loading		
10	**TO – Deepseas 2003 BP Thunderhorse Riser bolt/bolt insert failure**		Identified Riser Bolt Inserts (nuts) & Bolt fractures due to environmentally assisted cracking, hydrogen embrittlement. corrosion brittle fracture. High material hardness, coating/material compatibility issues, strength loading		
Brazil Received through IRF					
11	**Petrobras Vessel**	Severe corrosion fractured failed H4 connector bolts			
12	**Noble –Paul Wolf**	Fractured bolts identified during leak during pressure test			
13	**BP vessel**	Connector bolts were changed			
Norway (Recent news article information)					
13	**Vessel (BP Operator)**	Chloride Stress Corrosion Cracking (Cl-SCC) fracture failure of bolts for valve. Likely same alloy material as H4 connector bolt			

APPENDIX H - POTENTIALLY RELATED EARLIER BOLT INSERT FAILURES

2003 TO 2005 TRANSOCEAN - DISCOVERER ENTERPRISE - BP THUNDERHORSE & RCA

A bolt insert failure occurred on May 21, 2003 on Transocean's Discoverer Enterprise (TO-DE) drilling riser (BP-Thunderhorse) (see Figure H.1 for overview detail of TO-Discoverer Enterprise Bolt Event Timeline). The bolts' inserts (nuts) that secure the drilling riser failed between joints 39 and 40 resulting in the riser parting to approximately 3,200 feet below sea level and the release of 2,450 bbl of Accolade synthetic based drilling fluid. The bolt insert and bolt fractured due to severe, accelerated, environmentally assisted corrosion. The 2003 TO-DE bolt insert/bolt failure impacted five TO rigs: Discoverer Enterprise, Pathfinder, Horizon, Millennium, and Deepseas.

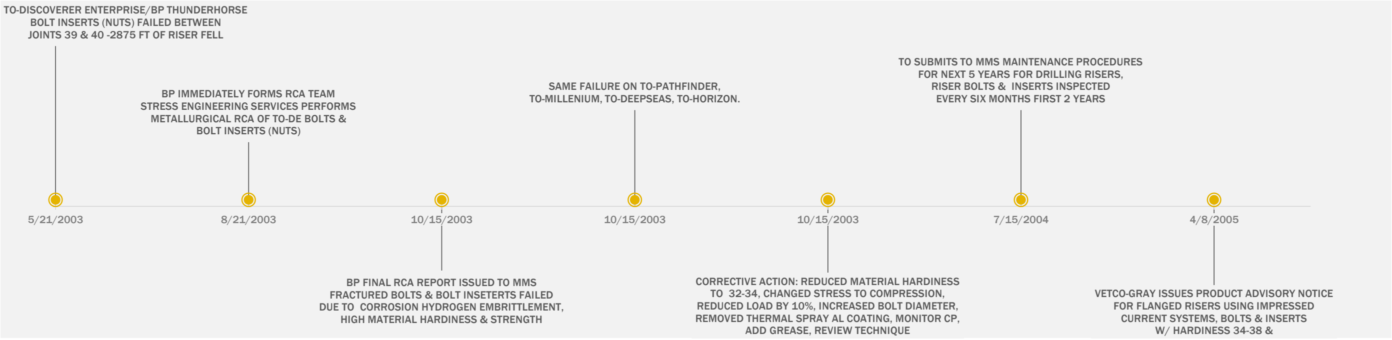


Figure H.1 - 2003-2005 Transocean–Discoverer Enterprise/BP Thunderhorse and Affected Vessels Timeline

On October 15, 2003, an RCA report on the TO-DE riser inserts (and bolts) failure was issued to the Minerals Management Service (MMS). A third party performed the metallurgical RCA for the inserts and the bolts that were also AISI 4340 with a material hardness design specification 34-38 HRC. The inserts and bolts for TO-DE and TO-Discoverer Pathfinder (examined for comparison) had yield strength values of 135 ksi for inserts and 145 ksi for bolts. The material hardness values were in the range of 34-40 HRC for the inserts and 34-38 HRC for the bolts that did not fail. For the failed inserts the hardness values were 34-39 HRC, and 35-37 HRC for the failed bolts. The RCA stated the immediate cause for failure was due to the identified failure mechanism of environmentally assisted cracking fracture of the AISI 4340 inserts. This report also identified several factors as potential correlated factors contributing to the cause of hydrogen-related failure, as follows: high material hardness, high material yield strength of the inserts (and bolts), seawater salinity, fluid, thermal spray aluminum coating, potential stray direct current (DC) induced electrical currents, type of cathodic protection system, material compatibility (use of dissimilar metals in close proximity), and combined charging effects.

In 2003, four other TO rigs: TO-Millennium, TO-Horizon, TO-Deepseas, and TO-Pathfinder bolt inserts failed in the same brittle corrosion fracture manner as the 2003 TO-DE and the 2012-2013 H4 connector bolt failures of TO-DI, TO-DAS, TO-Deepwater Champion and P-10K. The same third laboratory performed the RCA for both of the 2003 and recent 2012-2013 bolt failures.

On April 8, 2005, Vetco-Gray issued an urgent product advisory notice (see section titled *Documents and Related Technical Reference Articles*) to its customers using flanged marine drilling risers cathodically protected with an impressed current system (ICS). The notice referenced the 2003 TO-DE BP Thunderhorse drilling riser separation due to bolt insert failure from environmentally assisted cracking with other contributing factors. The notice also advised there was data to show the strong correlation to an unusually high rate of accelerated corrosion incidents and the combination of the following: thermal spray aluminum (TSA) coating; an ICS; and bolt material hardness. These incidents were characterized as environmentally assisted corrosion cracking of moderate to high strength steels with material hardness exceeding 34 HRC. A recommended in-service inspection procedure was advised. The lessons learned from these incidents were not implemented expediently through industry standards.

The 2003 RCA suggested the remedy for the 2003 bolt insert failures was to redesign the TO-DE bolts/bolt inserts material design specification requirements (lower the material hardness, yield strength and ultimate tensile strength), maintain ICCP voltage to no more than -950 mv, eliminate thermal spray aluminum coating, increase bolt diameter size, and reduce the load by approximately 10% on the bolts. However, the 2012-2013 bolt failures vessels' bolt material specification requirements were not modified. GE reports that the remedial corrective actions were deployed on fourteen (14) rigs.

REFERENCES

Listed below are documents, regulations, Industry standards, organizations, refereed technical papers, and the names of subject matter experts consulted during QC-FIT inquiry.

API Specification 6A (2010) – Specification for Wellhead and Christmas Tree Equipment – Twentieth Edition (Referenced Standard for Material Properties Requirements)

API Spec 16A (2004) **-** Specification for Drill Through Equipment

API Specification 16F (2004) – Specification for Marine Drilling Riser Equipment (Referenced Standard for Material Properties Requirements)

API RP 17A (2010, 2006) – Design and Operation of Subsea Production Systems – General Requirements and Recommendations – Fourth Edition (Referenced Standard for Material Properties Requirements)

ASTM B633 (2011, 2007, 1998) **-** Standard Specification of Electrodeposited Coatings of Zinc on Iron or Steel

ASTM 849 (2007) - Standard Specification of Pre-treatment of Iron or Steel for Reducing Risk of Hydrogen Embrittlement

ASTM 850 (2009, 2004, 1998) - Standard Guide for Post Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement

ASTM F1940 (2007) - Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners

ASTM F1941 (2010, 2007) **-** Standard Specification for Electrodeposited Coatings on Threaded Fasteners

NACE MR0175 (2011, 2009, 2003) - Metals for Sulfide Stress Cracking and Stress Cracking Resistance Environments (Corrosion Standard for Materials for Use in H_2S Containing Environments in Oil and Gas Production-2003 edition)

NORSOK M-001 – (2004) Materials Standard

Brahimi, S., & Yue, S. (n.d.). Effecto of Surface Processing Variables and Coating Characteristics on Hydrogen Embrittlement of Steel Fasteners. Montreal, Canada: IBECA Technologies Corp; McGill University.

Bauccio, M. (1998) ASM Metals Reference Book, Third Edition. Materials Park, OH: ASM International.

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Hillier, E., & Robinson, M. (2004). Hydrogen Embrittlement of High Strength Steel Electroplated with Zinc-Cobalt Alloys. *Corrosion Science*, 715-727.

Jones, D. A. (1996). Principles and Prevention of Corrosion. Upper Saddle River, NJ: Prentice Hall.

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McEvily, Jr. A.G. (1990) Atlas of Stress-Corrosion and Corrosion Fatigue Curves. Materials Park, OH: ASM International.
Ohring, M. (1992) The Materials Science of Thin Films. San Diego, CA: Academic Press.

Raymond, L. (1998). The Susceptibility of Fasteners to Hydrogen Embrittlement and Stress Corrosion Cracking. In Handbook of Bolts and Bolted Joints (pp. Chapter 39, page 723). New York, NY: Marcel Decker, Inc.

Shreir, L.L. (1980) Corrosion Volume 2 – Corrosion Control. Boston, MA: Newnes-Butterworths.

Smith, W.F. (1993) Structure and Properties of Engineering Alloys. Newell. York: NY: McGraw Hill.

Van Droffelaar, H. & Atkinson, J.T.N. (1995) Corrosion and Its Control. Houston, TX: NACE International.

Vossen, J. & Werner, K. (1978). Thin Film Processes. Orlando, FL: Academic Press.

http://www.industrytoday.com/article_view.asp?ArticleID=719, ABB Vetco Gray Through Modern Machines Vol. 6 No. 3

2012 GE Oil & Gas H4 Subsea Connectors Brochure.

DOCUMENTS AND RELATED TECHNICAL REFERENCE ARTICLES

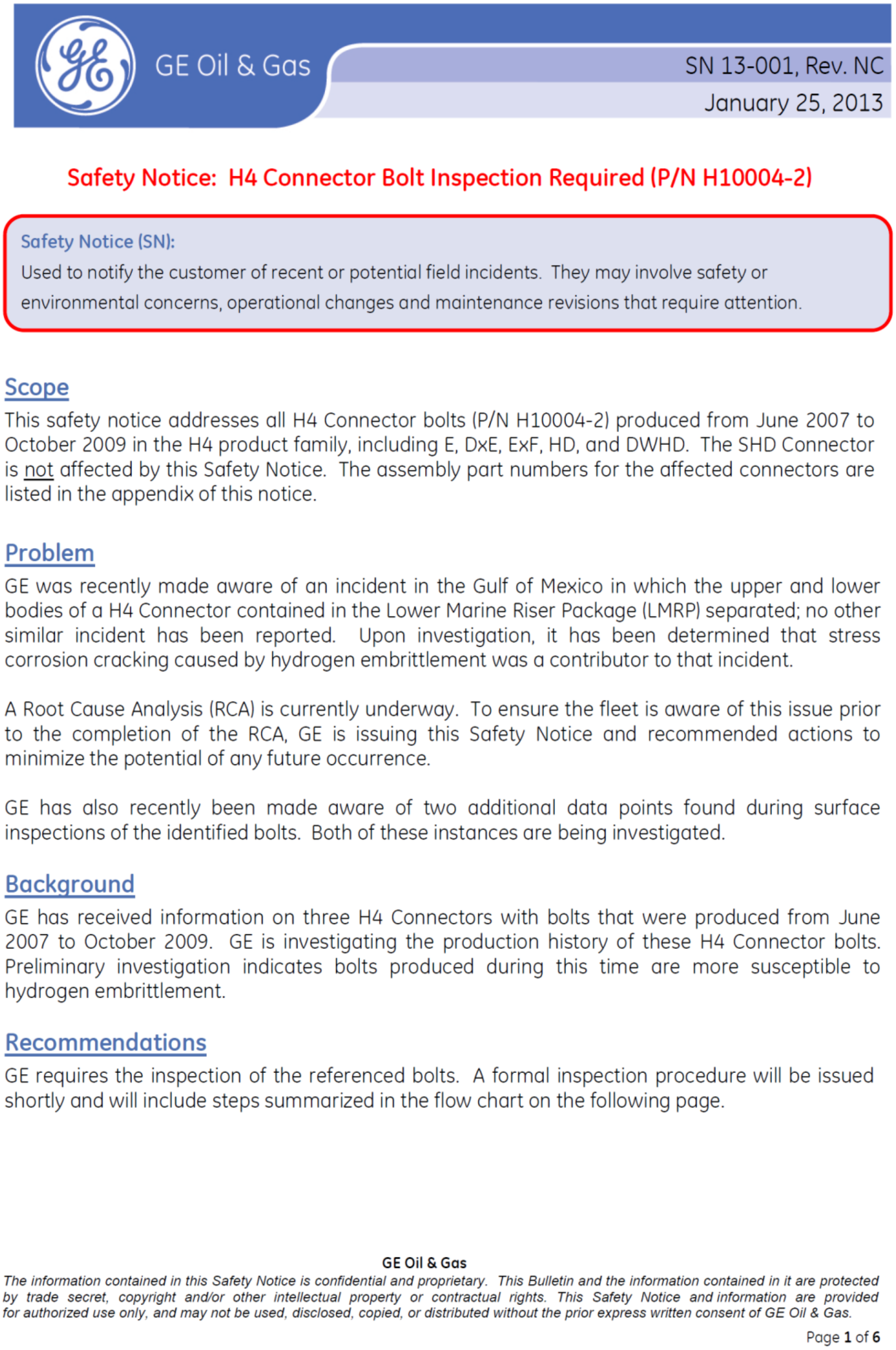
GE SAFETY NOTICE SN 13-001, REV. NC H4 CONNECTOR BOLT INSPECTION

BSEE SAFETY ALERT NO. 303 LMRP CONNECTOR FAILURE

CAMERON PRODUCT ADVISORY 29432FAILED STUDS IN COLLET

VETCO GRAY PRODUCT ADVISORY

GE Safety Notice SN 13-001, Rev. NC H4 Connector Bolt Inspection



GE Oil & Gas

SN 13-001, Rev. NC
January 25, 2013

Safety Notice: H4 Connector Bolt Inspection Required (P/N H10004-2)

Safety Notice (SN):
Used to notify the customer of recent or potential field incidents. They may involve safety or environmental concerns, operational changes and maintenance revisions that require attention.

Scope

This safety notice addresses all H4 Connector bolts (P/N H10004-2) produced from June 2007 to October 2009 in the H4 product family, including E, DxE, ExF, HD, and DWHD. The SHD Connector is not affected by this Safety Notice. The assembly part numbers for the affected connectors are listed in the appendix of this notice.

Problem

GE was recently made aware of an incident in the Gulf of Mexico in which the upper and lower bodies of a H4 Connector contained in the Lower Marine Riser Package (LMRP) separated; no other similar incident has been reported. Upon investigation, it has been determined that stress corrosion cracking caused by hydrogen embrittlement was a contributor to that incident.

A Root Cause Analysis (RCA) is currently underway. To ensure the fleet is aware of this issue prior to the completion of the RCA, GE is issuing this Safety Notice and recommended actions to minimize the potential of any future occurrence.

GE has also recently been made aware of two additional data points found during surface inspections of the identified bolts. Both of these instances are being investigated.

Background

GE has received information on three H4 Connectors with bolts that were produced from June 2007 to October 2009. GE is investigating the production history of these H4 Connector bolts. Preliminary investigation indicates bolts produced during this time are more susceptible to hydrogen embrittlement.

Recommendations

GE requires the inspection of the referenced bolts. A formal inspection procedure will be issued shortly and will include steps summarized in the flow chart on the following page.

GE Oil & Gas

Inspection and Data Collection (all bolts)

- Remove coating/paint from bolt heads.
- Use bolt data collection template to record data for each bolt, including location, serial number, and batch.
- If bolts have markings that match any bolt listed on website (see link for bolts affected), please remove these bolts for disposition.
- If bolts have markings <u>not</u> found at website, perform a precautionary 'torque test' to ensure the integrity of all installed bolts (see procedure in appendix).
- If bolt does <u>not</u> pass the 'torque test', remove the bolt for disposition.

Disposition and Containment (identified bolts)

- Using a properly calibrated torque tool, mark the bolt's location on the head of the bolt and remove the bolt.
- Record the break-out torque required for each identified bolt, as well as the general appearance of each bolt on the supplied data collection template (see appendix).
- GE will supply new bolts as appropriate.

Corrective and Preventative Actions

- GE will update the fleet with pertinent developments.

Please go to the Bolt Support Link (see Contact section) to obtain the procedure and template for bolt data collection. Return the data collection template to the e-mail address provided (see Contact section) at your earliest opportunity. As appropriate, return the identified bolts to the GE address (see Contact section) at your earliest opportunity and contact the H4 Connector Bolt team for bolt replacements.

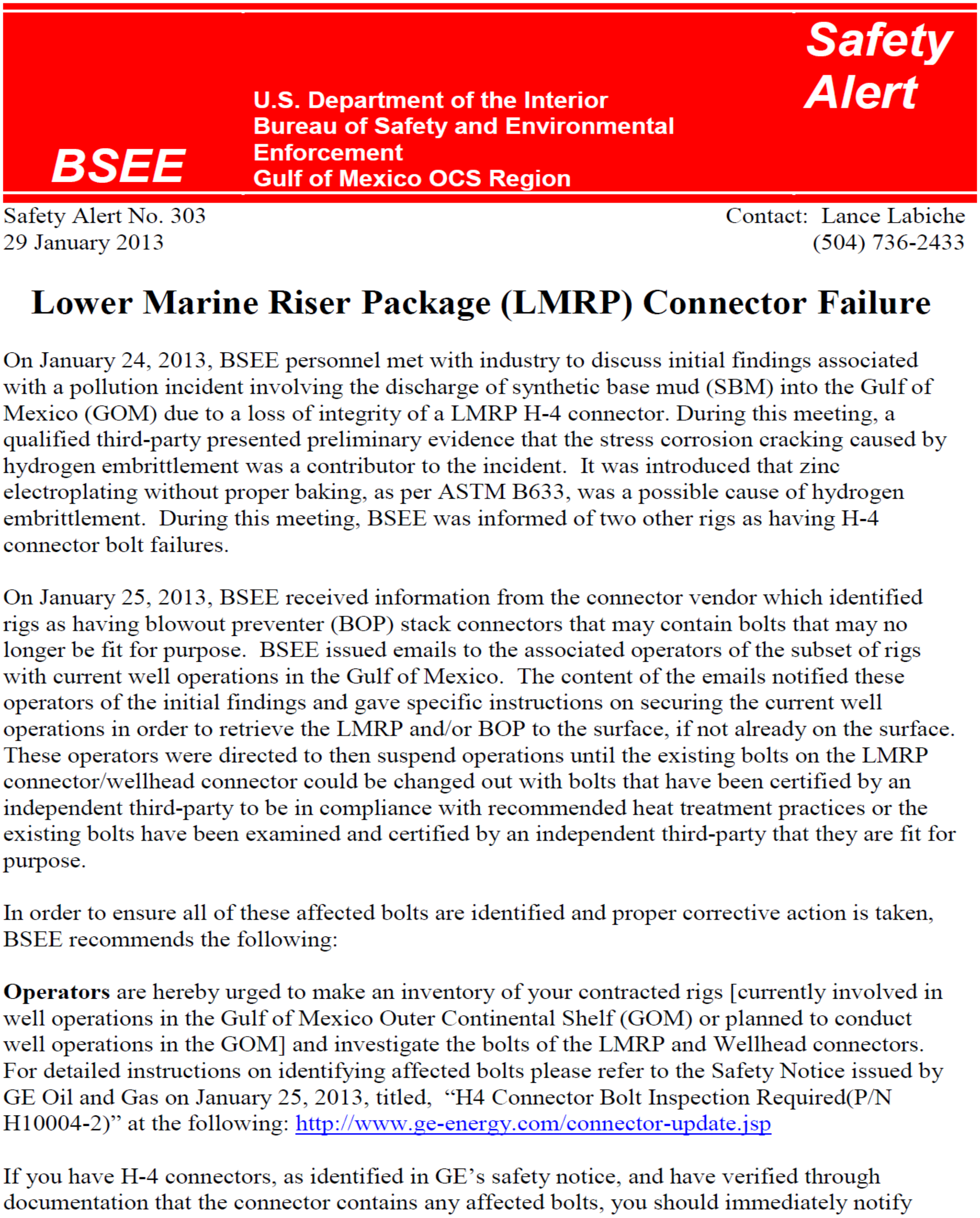
Parts Affected

Part number: H10004-2, including bolt kit numbers H125004-5, H125004-6, H125004-7

H4 assembly part numbers: see appendix

Link to identified H4 bolts (P/N H10004-2): http://www.ge-energy.com/connector-update.jsp

BSEE SAFETY ALERT NO. 303 LMRP CONNECTOR FAILURE



BSEE

U.S. Department of the Interior
Bureau of Safety and Environmental Enforcement
Gulf of Mexico OCS Region

Safety Alert

Safety Alert No. 303
29 January 2013

Contact: Lance Labiche
(504) 736-2433

Lower Marine Riser Package (LMRP) Connector Failure

On January 24, 2013, BSEE personnel met with industry to discuss initial findings associated with a pollution incident involving the discharge of synthetic base mud (SBM) into the Gulf of Mexico (GOM) due to a loss of integrity of a LMRP H-4 connector. During this meeting, a qualified third-party presented preliminary evidence that the stress corrosion cracking caused by hydrogen embrittlement was a contributor to the incident. It was introduced that zinc electroplating without proper baking, as per ASTM B633, was a possible cause of hydrogen embrittlement. During this meeting, BSEE was informed of two other rigs as having H-4 connector bolt failures.

On January 25, 2013, BSEE received information from the connector vendor which identified rigs as having blowout preventer (BOP) stack connectors that may contain bolts that may no longer be fit for purpose. BSEE issued emails to the associated operators of the subset of rigs with current well operations in the Gulf of Mexico. The content of the emails notified these operators of the initial findings and gave specific instructions on securing the current well operations in order to retrieve the LMRP and/or BOP to the surface, if not already on the surface. These operators were directed to then suspend operations until the existing bolts on the LMRP connector/wellhead connector could be changed out with bolts that have been certified by an independent third-party to be in compliance with recommended heat treatment practices or the existing bolts have been examined and certified by an independent third-party that they are fit for purpose.

In order to ensure all of these affected bolts are identified and proper corrective action is taken, BSEE recommends the following:

Operators are hereby urged to make an inventory of your contracted rigs [currently involved in well operations in the Gulf of Mexico Outer Continental Shelf (GOM) or planned to conduct well operations in the GOM] and investigate the bolts of the LMRP and Wellhead connectors. For detailed instructions on identifying affected bolts please refer to the Safety Notice issued by GE Oil and Gas on January 25, 2013, titled, “H4 Connector Bolt Inspection Required(P/N H10004-2)” at the following: http://www.ge-energy.com/connector-update.jsp

If you have H-4 connectors, as identified in GE’s safety notice, and have verified through documentation that the connector contains any affected bolts, you should immediately notify

BSEE. You should also consult with your contractors and subcontractors to determine the appropriate inspection, disposition and/or corrective actions. BSEE will require an independent third-party certification that confirms proper inspection and refurbishment processes were completed prior to reinstallation of any affected bolts.

Operators should review the QA/QC programs for all equipment vendors (contracted and sub-contracted) to ensure that all equipment is being manufactured to the required specifications. Special attention should be given to ensure proper heat treating has taken place in accordance with the specifications.

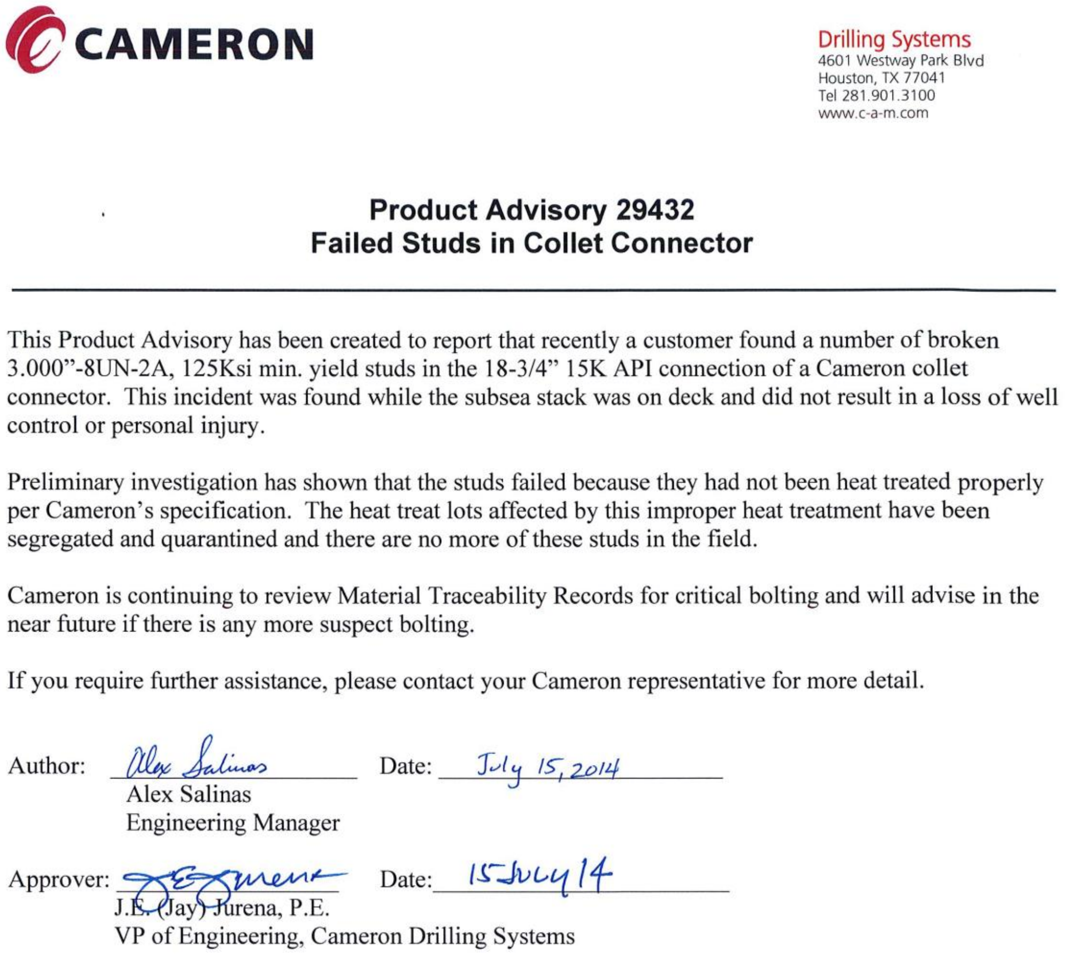
Upper half of failed LMRP Connector

Lower half of failed LMRP Connector

--BSEE--GOMR--
www.bsee.gov

A **Safety Alert** is a tool used by BSEE to inform the offshore oil and gas industry of the circumstances surrounding an accident or a near miss. It also contains recommendations that should help prevent the recurrence of such an incident on the Outer Continental Shelf.

Cameron Product Advisory 29432Failed Studs in Collet Connector



CAMERON

Drilling Systems
4601 Westway Park Blvd
Houston, TX 77041
Tel 281.901.3100
www.c-a-m.com

Product Advisory 29432
Failed Studs in Collet Connector

This Product Advisory has been created to report that recently a customer found a number of broken 3.000"-8UN-2A, 125Ksi min. yield studs in the 18-3/4" 15K API connection of a Cameron collet connector. This incident was found while the subsea stack was on deck and did not result in a loss of well control or personal injury.

Preliminary investigation has shown that the studs failed because they had not been heat treated properly per Cameron's specification. The heat treat lots affected by this improper heat treatment have been segregated and quarantined and there are no more of these studs in the field.

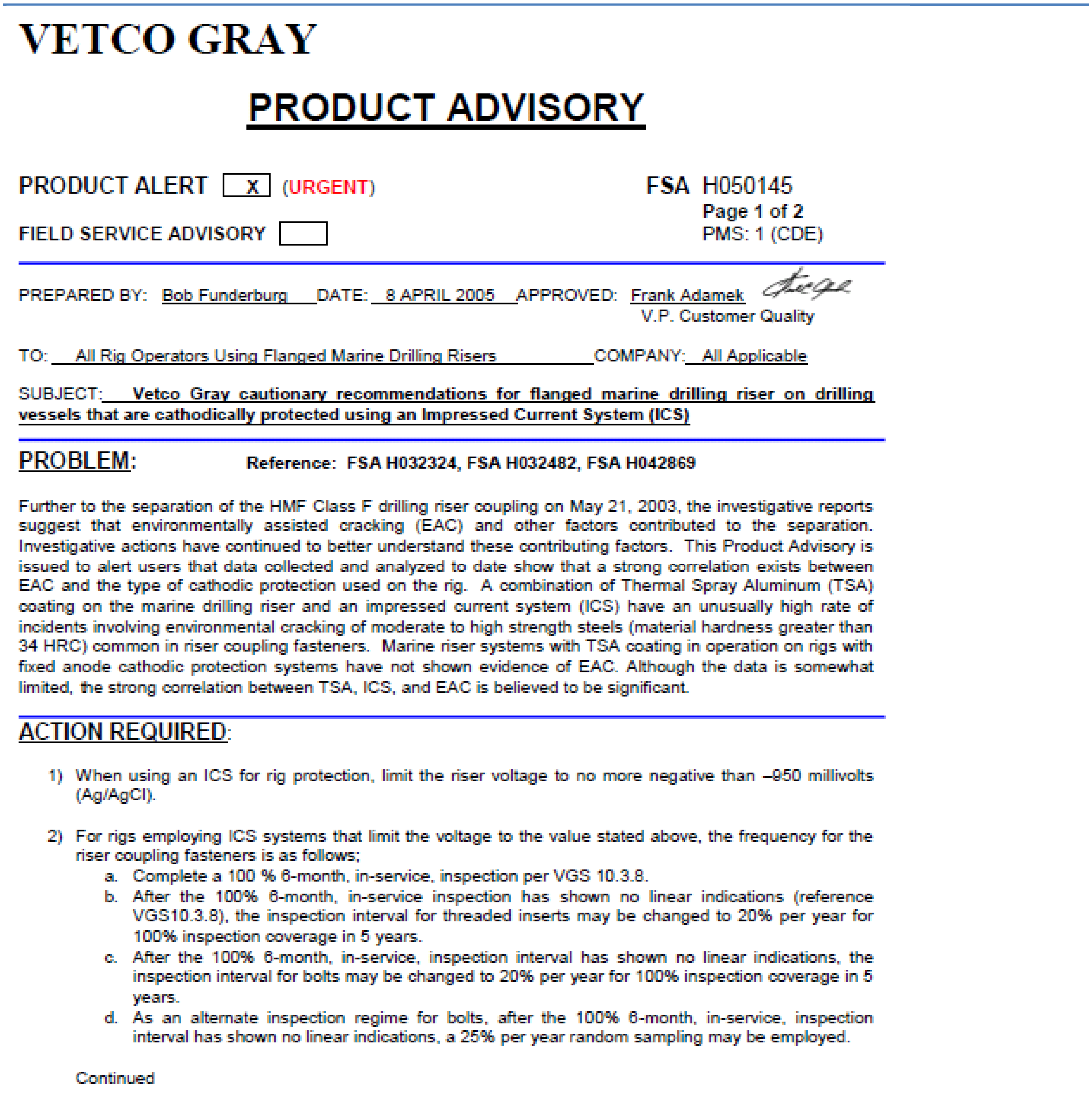
Cameron is continuing to review Material Traceability Records for critical bolting and will advise in the near future if there is any more suspect bolting.

If you require further assistance, please contact your Cameron representative for more detail.

Author: Alex Salinas Date: July 15, 2014
Alex Salinas
Engineering Manager

Approver: Date: 15 JULY 14
J.E. (Jay) Jurena, P.E.
VP of Engineering, Cameron Drilling Systems

VETCO GRAY ADVISORY NOTICE



VETCO GRAY

PRODUCT ADVISORY

PRODUCT ALERT ☒ (URGENT)

FIELD SERVICE ADVISORY ☐

FSA H050145
Page 1 of 2
PMS: 1 (CDE)

PREPARED BY: Bob Funderburg DATE: 8 APRIL 2005 APPROVED: Frank Adamek
V.P. Customer Quality

TO: All Rig Operators Using Flanged Marine Drilling Risers COMPANY: All Applicable

SUBJECT: **Vetco Gray cautionary recommendations for flanged marine drilling riser on drilling vessels that are cathodically protected using an Impressed Current System (ICS)**

PROBLEM:

Reference: FSA H032324, FSA H032482, FSA H042869

Further to the separation of the HMF Class F drilling riser coupling on May 21, 2003, the investigative reports suggest that environmentally assisted cracking (EAC) and other factors contributed to the separation. Investigative actions have continued to better understand these contributing factors. This Product Advisory is issued to alert users that data collected and analyzed to date show that a strong correlation exists between EAC and the type of cathodic protection used on the rig. A combination of Thermal Spray Aluminum (TSA) coating on the marine drilling riser and an impressed current system (ICS) have an unusually high rate of incidents involving environmental cracking of moderate to high strength steels (material hardness greater than 34 HRC) common in riser coupling fasteners. Marine riser systems with TSA coating in operation on rigs with fixed anode cathodic protection systems have not shown evidence of EAC. Although the data is somewhat limited, the strong correlation between TSA, ICS, and EAC is believed to be significant.

ACTION REQUIRED:

1) When using an ICS for rig protection, limit the riser voltage to no more negative than –950 millivolts (Ag/AgCl).

2) For rigs employing ICS systems that limit the voltage to the value stated above, the frequency for the riser coupling fasteners is as follows;
    a. Complete a 100 % 6-month, in-service, inspection per VGS 10.3.8.
    b. After the 100% 6-month, in-service inspection has shown no linear indications (reference VGS10.3.8), the inspection interval for threaded inserts may be changed to 20% per year for 100% inspection coverage in 5 years.
    c. After the 100% 6-month, in-service, inspection interval has shown no linear indications, the inspection interval for bolts may be changed to 20% per year for 100% inspection coverage in 5 years.
    d. As an alternate inspection regime for bolts, after the 100% 6-month, in-service, inspection interval has shown no linear indications, a 25% per year random sampling may be employed.

Continued

3) For rigs employing ICS systems that do not limit the voltage as stated above, the inspection frequency for both riser coupling bolts and threaded inserts is as follows;
    a. Continue to inspect 100% at 6-month, in-service intervals per VGS 10.3.8.
    b. After the second 6-month, in-service inspection interval has shown no linear indications (reference VGS 10.3.8), the inspection interval may be increased to 12 months in-service. After the 12-month, 100% inspection interval has shown no linear indications, the inspection interval may be increased to 24 months in-service and every 24 months in-service thereafter.

4) Should the riser voltage level be more negative than –950 millivolts for a period exceeding 24 hours, additional inspection may be required. Contact Vetco Gray for direction and recommendations.

5) If material defects are detected in the bolts or threaded inserts during any inspection, contact Vetco Gray immediately for direction and recommendations.

Testing and data collection continues. As additional information is gathered and conclusions drawn, further recommendations may be forthcoming.

If you have any questions, please contact:

Robert (Bob) Funderburg, Jr. P.E.
CDE Engineering Manager
Phone: 1-281-878-5103
Fax: 1-281-878-3403
E-Mail: bob.funderburg@vetcogray.com

RECEIPT ACKNOWLEDGMENT

RECEIVED BY: ______________________________ **FSA** H050145

SIGNATURE: ____

PRINTED NAME: ______________________ DATE: __________

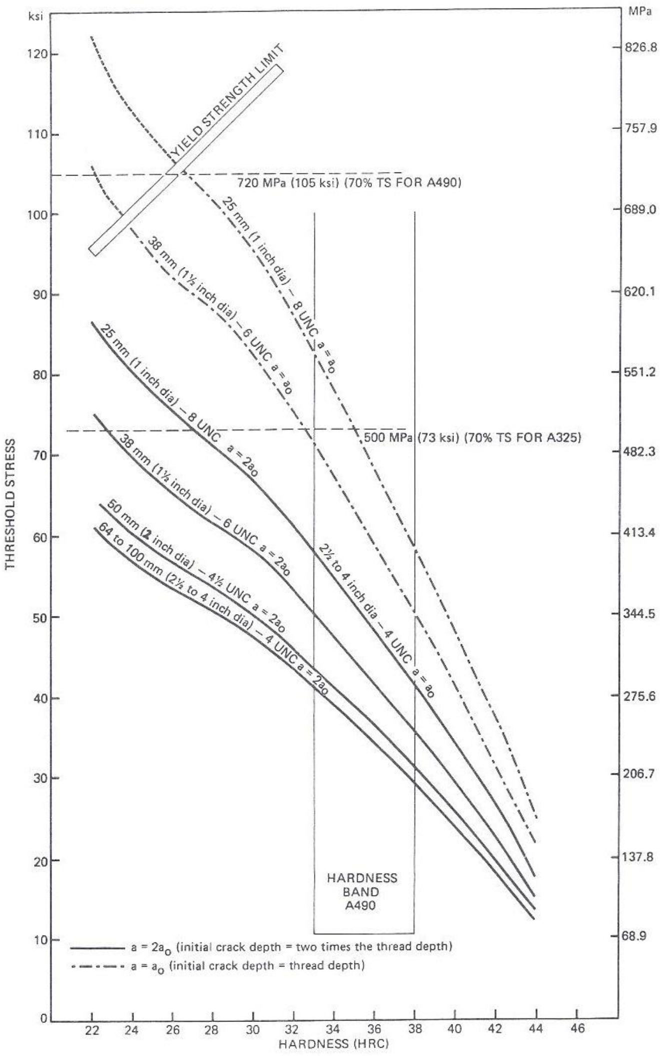
COMPANY: __________________________ POSITION: ________

Please acknowledge receipt of this document by returning a signed copy within 14 days of receipt to Vetco Gray (to the attention of the document author).

HYDROGEN EMBRITTLEMENT TECHNICAL REFERENCE ARTICLES

GENERAL OVERVIEW OF THRESHOLD STRESS FOR STRESS CORROSION CRACKING IN LOW ALLOY BOLTS BASED ON HYDROGEN CONTENT FOR 4340 STEEL

Low-Alloy Bolts: Threshold Stress for Stress-Corrosion Cracking



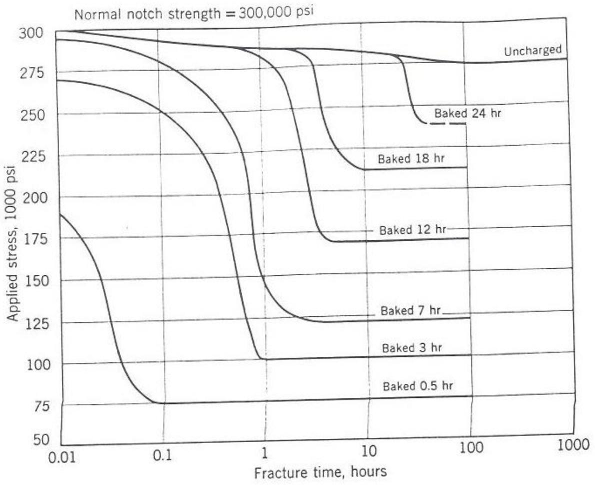
Plot of threshold stresses for stress-corrosion cracking in low-alloy quenched and tempered bolting materials with different hardness levels. Note: UNC denotes unified coarse thread.

Reference: Atlas of Stress Corrosion & Stress Corrosion Fatigue Curves, 1990.

QC-FIT SYNOPSIS OF THRESHOLD YIELD STRESS LEVEL BEFORE SCC FRACTURE BASED ON HARDNESS FOR LOW ALLOY BOLTS

Based on curve above, when bolts are subjected to stresses in the range of approximately 28,000 to 35,000 psi with diameters in the range of 2.5-4 inches, and hardness 34-38 HRC, they will likely fracture due to stress corrosion cracking. For example, bolts with a hardness of 34 HRC, will likely fracture due to stress corrosion cracking (SCC) at approximately 35,000 psi. When subjected to an applied stress of approximately 28,000 psi. Bolts with a material hardness value greater than 38 HRC, will likely fracture due to SCC. Therefore, the higher the bolts' material hardness value, the lower threshold stress they can withstand before fracturing due to SCC. The lower the bolts' material hardness (more ductile its material strength properties), the higher the threshold stress they can withstand before fracturing due to SCC.

4340 Alloy Steel: Fracture Time as a Function of Hydrogen Content



Delayed fracture times and minimum stress for cracking of 0.4% carbon steel as a function of hydrogen content. Specimen initially charged cathodically, baked at 150 °C for varying times to reduce hydrogen content.

Reference: Atlas of Stress Corrosion & Stress Corrosion Fatigue Curves, 1990.

The graph above depicts the stress corrosion fracture time for AISI 4340 alloy (connector bolt material) as a function of its hydrogen content. Based on the graph, bolts without post-bake, would likely fracture or incur cracks, virtually instantly with minimal applied stress. Also, for a bolt that has been baked for 30 minutes (0.5 hour), fracture will likely occur within approximately 10 minutes.

Hydrogen Embrittlement

by:
Daniel H. Herring
“The Heat Treat Doctor”®, President
The HERRING GROUP, Inc.
P.O. Box 884
Elmhurst, IL 60126-0884 USA
www.heat-treat-doctor.com

Although many of the most severe hydrogen embrittlement problems have occurred in aircraft applications, it should be remembered “that it doesn’t have to fly in order to die”.

Embrittlement is a phenomenon that causes loss of ductility in a material, thus making it brittle. There are a number of different forms including:

- Environmentally Induced Cracking.
- Stress Corrosion Cracking.
- Hydrogen Embrittlement.
- Corrosion Fatigue.
- Liquid Metal Embrittlement.

Of these, hydrogen embrittlement is responsible for a surprising number of delayed failures and problems with products produced from wire, especially if they undergo secondary processing operations such as plating. The factors (see **Figure 1**) responsible for this type of failure include having a susceptible material, an environment conductive to attack and the presence of stress (internal or applied). Once two of these three factors are present, failure is inevitable.

Hydrogen embrittlement is also known as hydrogen induced cracking or hydrogen attack. Materials that are most vulnerable include high-strength steels, titanium and aluminum alloys and electrolytic tough pitch copper. Hydrogen embrittlement mechanisms (see **Figure 2**) can be aqueous or gaseous and involve the ingress of hydrogen into the metal, reducing its ductility and load bearing capacity. Stress below the yield stress of the susceptible material then causes subsequent cracking and catastrophic brittle failures (see **Figure 3**).

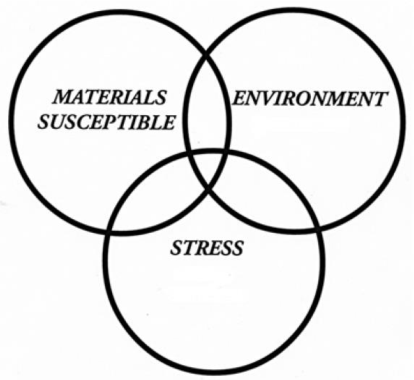
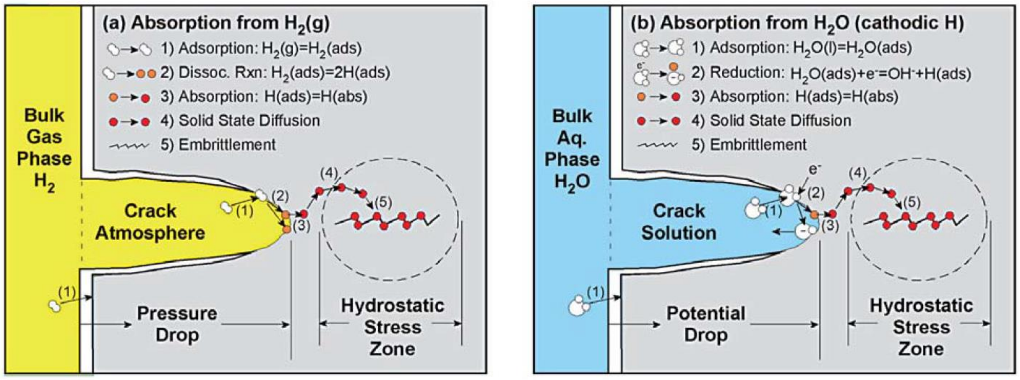


Fig. 1 — Factors contributing to hydrogen embrittlement.

How Hydrogen Gets In

It is generally agreed that hydrogen, in atomic form, will enter and diffuse through a metal surface whether at elevated temperatures or ambient temperature. Once absorbed, dissolved hydrogen may be present either as atomic or molecular hydrogen or in combined molecular form (e.g., methane). Since these molecules are too large to diffuse through the metal, pressure builds at crystallographic defects (dislocations and vacancies) or discontinuities (voids, inclusion/matrix interfaces) causing minute cracks to form. Whether this absorbed hydrogen causes cracking or not is a complex


(a) Absorption from $H_2(g)$

(b) Absorption from H_2O (cathodic H)

Fig. 2 — Hydrogen embrittlement mechanisms.

interaction of material strength, external stresses and temperature.

Sources of hydrogen include heat treating atmospheres, breakdown of organic lubricants, the steelmaking process (e.g., electric arc melting of damp scrap), the working environment, arc welding (with damp electrodes), dissociation of high pressure hydrogen gas and even grinding (in a wet environment).

Parts that are undergoing electrochemical surface treatments such as etching, pickling, phosphate coating, corrosion removal, paint stripping and electroplating are especially susceptible. Of these, acid cleaning is the most severe, followed by electroplating at high current (these are less efficient and create more hydrogen even though they produce a better plated structure), electrolysis plating and conversion coatings.

Nature & Effect of Hydrogen Attack

Although the precise mechanism(s) is the subject of active investigation, the reality is that components fail due to this phenomenon. It is generally believed that all steels above 30 HRC are vulnerable, as are materials such as copper, whether tough pitch or oxygen-free, titanium and titanium alloys, nickel and nickel alloys and the like. Examples of hydrogen damage and ways to avoid it include the following.

- ***Problem:*** Internal cracking or blistering.
  Solutions: Use of steel with low levels of impurities (i.e., sulfur and phosphorus); modifying the environment to reduce hydrogen charging; use of surface coatings and effective inhibitors.
- ***Problem:*** Loss of ductility.
  Solutions: Use of lower strength (hardness) or high resistance alloys; careful selection of materials of construction and plating systems; heat treatment (bakeout) to remove absorbed hydrogen.
- ***Problem:*** High temperature hydrogen attack.
  Solutions: Selection of material (for steels, use of low and high alloy Cr-Mo steels, selected Cu alloys, nonferrous alloys); limit temperature and partial pressure H_2.

Since a metallurgical interaction occurs between atomic hydrogen and the crystallographic structure, the ability of the material to deform or stretch under load is inhibited. Therefore, it becomes "brittle" under stress or load. As a result, the metal will break or fracture at a much lower load or stress than anticipated. It is this lower breaking strength that makes hydrogen embrittlement so detrimental.

In general, as the strength of the steel goes up, so does its susceptibility to hydrogen embrittlement. High-strength steel, such as quenched and tempered steels or precipitation-hardened steels, is particularly susceptible. Hydrogen embrittlement is considered the Achilles heel of high strength ferrous steels and alloys.

Fig. 3 — Hydrogen embrittlement and failure of a hard chromium-plated chain conveyor bolt.

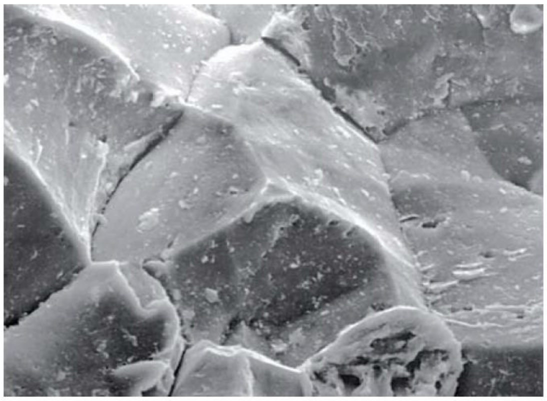


Fig. 4 — Intergranular fracture due to hydrogen embrittlement (photo courtesy of Aston Metallurgical Services Co., Inc.).

And nonferrous materials are not immune to attack. Tough-pitch coppers and even oxygen-free coppers are subject to a loss of (tensile) ductility when exposed to reducing atmospheres. Bright annealing in hydrogen bearing furnace atmospheres, oxy-acetylene torch brazing and furnace brazing are typical processes that can create hydrogen embrittlement of these materials.

The attack in these copper alloys involves the diffusion of atomic hydrogen into the copper and subsequent reduction of cuprous oxide (Cu_2O) to produce water vapor and pure copper. An embrittled copper often can be identified by a characteristic surface blistering resulting from expansion of water vapor in voids near the surface. Purchasing oxygen-free copper is no guarantee against the occurrence of hydrogen embrittlement, but the degree of embrittlement will depend on the amount of oxygen present.

For example, CDA 101 (oxygen-free electronic) allows up to 5 ppm oxygen while CDA 102 (OFHC) permits up to 10 ppm. A simple bend test is often used to detect the presence of hydrogen embrittlement. Metallographic techniques (**Figure 4**) can also be used to look at the near surface and for the presence of voids at grain boundaries.

How Hydrogen Gets Out?

Hydrogen absorption need not be a permanent condition. If cracking does not occur and the environmental conditions are changed so that no hydrogen is generated on the surface of the metal, the hydrogen can re-diffuse out of the steel, and ductility is restored. Performing an embrittlement relief, or hydrogen bake out cycle (the term "bake-out" involves both diffusion within the metal and outgassing) is a powerful method in eliminating hydrogen before damage can occur.

Some of the key variables include temperature, time at temperature, and concentration gradient (atom movement).

For example, electroplating provides a source of hydrogen during the cleaning and pickling cycles, but by far the most significant source is cathodic inefficiency. A simple hydrogen bake out cycle can be performed to reduce the risk of hydrogen damage (**Table 1**).

Caution: over-tempering or softening of the steel can occur, especially on a carburized, or induction hardened part.

Table 1. Hydrogen Bake-Out Requirements for High Strength Parts.

Tensile Strength		Hardness (HRC)	Time (hrs) Post Plate Bake Out at 375°- 430°F (190° - 220°C)
MPa	ksi		
1700 – 1800	247 – 261	49 – 51	22+
1600 – 1700	232 – 247	47 - 49	20+
1500 – 1600	218 – 232	45 - 47	18+
1400 – 1500	203 – 218	43 - 45	16+
1300 – 1400	189 – 203	39 – 43	14+
1200 – 1300	174 – 189	36 – 39	12+
1100 – 1200	160 – 174	33 – 36	10+
1000 – 1100	145 -160	31 – 33	8+

Note: Per *ASTM B 850-98 (2009)*, Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement.

Factors that Influence Hydrogen Embrittlement on Parts

The severity and mode of the hydrogen damage depends on:

- Source of hydrogen—external (gaseous)/internal (dissolved).
- Exposure time.
- Temperature and pressure.
- Presence of solutions or solvents that may undergo some reaction with metals (e.g., acidic solutions).
- Type of alloy and its production method.
- Amount of discontinuities in the metal.
- Treatment of exposed surfaces (barrier layers, e.g., oxide layers as hydrogen permeation barriers on metals).
- Final treatment of the metal surface (e.g., galvanic nickel plating).
- Method of heat treatment.
- Level of residual and applied stresses.

Low Hydrogen Concentrations Can Also Be Problematic

Of concern today is embrittlement from very small quantities of hydrogen where traditional loss-of-ductility bend tests cannot detect the condition. This atomic level embrittlement manifests itself at levels as low as 10 ppm of hydrogen (in certain plating applications it has been reported that 1 ppm of hydrogen is problematic).

Although difficult to comprehend, numerous documented cases of embrittlement failures with hydrogen levels this low are known. This type of embrittlement occurs when hydrogen is concentrated or absorbed in certain areas of metallurgical instability.

This type of concentrating action occurs as a result of either residual or applied stress, which tends to "sweep" through the atomic structure, moving the infiltrated hydrogen atoms along with it. These concentrated areas of atomic hydrogen can then coalesce into molecular-type hydrogen, resulting in the formation of highly localized partial pressures of the actual gas.

What Type of Parts Are Susceptible?

Although almost any type of part is subject to hydrogen embrittlement, certain components such as fasteners and nuclear components are most susceptible.

Ways to Avoid Hydrogen Embrittlement

Steps that can be taken to avoid hydrogen embrittlement include reducing hydrogen exposure and susceptibility, baking after plating (mandatory and as soon as practical) and using test methods to determine if a material is suspect.

Other options that could help in avoiding hydrogen embrittlement include the use of lower strength steels (not always viable), the avoidance of acid cleaning, the utilization of low hydrogen plating techniques and the reduction of residual and applied stress.

Where to Go For Help?

A good, but relatively unknown source for information about the effects of hydrogen, is the **NACE International**, **The Corrosion Society** (*www.nace.org*). Also, various **ASTM** specifications (*www.astm.org*) can also help, including *ASTM B850-98, 2009* (Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement); *ASTM F1113-97* (The Barnacle Electrode Method to Determine Diffusible Hydrogen in Steels); *ASTM F519-08* (Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments); and *ASTM F1624-09* (Standard Test Method for Measurement of Hydrogen Embrittlement Threshold by the Incremental Step Loading Technique).

The Bottom Line

Although many of the most severe problems associated with hydrogen embrittlement have occurred with aircraft/aerospace parts, a simple motto to remember is that the part doesn't have to "fly" in order to "die".

The insidious nature of hydrogen embrittlement continues to cause product failures during processing and during service. These failures are often catastrophic, leading to injury or damage to adjacent structures, and are difficult to detect after the fact. For this reason, hydrogen damage can and must be avoided.

For additional information on dealing with hydrogen embrittlement, visit the website listed below.
www.heat-treat-doctor.com **WFTI**

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