QC-FIT EVALUATION OF WING VALVE FAILURES

Office of Offshore Regulatory Programs

QC-FIT Report #004
February 2017

Bureau of Safety and Environmental Enforcement

EXECUTIVE SUMMARY

On October 13, 2015, an initial blow out preventer (BOP) stump testing on the abandonment job of the well was conducted in the Gulf of Mexico (GOM) utilizing the Noble Paul Romano rig at Garden Banks block 216 Well Number 5 at a waterdepth of 1450 feet. After several attempts, HESS Corporation crew discovered that the failure to operate the actuator on the BOP blind shear ram (BSR) assembly was a result of failed actuator fasteners. The Original Equipment Manufacturer (OEM) reported the BSR fastener failure to the Bureau of Safety and Environmental Enforcement (BSEE) as a "near miss incident." Upon removal of the BOP stack on the surface five fasteners were found to have failed on the upper BSR of the Cam Block cylinder area and one on the lower BSR at the nut area. The BOP was in service April 28 – September 20, 2015, then went through the overhaul and was reinstated in service during September 21-28, 2015. The OEM also informed BSEE there was another impacted GOM active rig Amos Runner, with LLOG as the lease holder at Mississippi Canyon 794 Well number 001 at a water depth of 1462 feet.

In response, BSEE convened the Quality Control Failure Incident Team (QC-FIT) to conduct a technical evaluation of the equipment involved and determine if there were global quality assurance/quality control (QA/QC), technology, safety, or environment concerns that needed to be addressed by the BSEE and/or industry related to the design and use of subsea fastener equipment on the Outer Continental Shelf (OCS). This QC-FIT technical evaluation consisted of meetings with the operator, contractors, and OEMs and reviews of applicable reports, technical documents and industry standards. These activities provided significant information about the fasteners' design, material properties, manufacturing processes and protective coatings of the bolts to determine their fitness for service. A comprehensive list of recommendations is outlined at the end of this report.

The QC-FIT key concerns raised during the technical evaluation included the following:

- The Root Cause Analysis (RCA) conducted by the OEM showed BOP BSR fasteners with material hardness values greater than 35 HRC which increases the risk of failures due to hydrogen emberittlement. NORSOK M-001 Fifth Edition, September 2014 standard Section 6.1 states that "for submerged parts that may be exposed to cathodic protection (CP), for martensitic carbon, low-alloy and CRA, the hardness of any components shall not exceed 328 HB or 35 HRC."
- The specified post electroplating bake time was 3-5 hours in reference to an older version of ASTM B633 1998 Edition. The revised ASTM B633 2011 Edition for electroplated steel with hardness values greater than 31 HRC should be post baked to reduce the risk of hydrogen embrittlement. ASTM B633 2011 refers to ASTM B 850 2009 Table 1 which requires a post electroplating bake treatment time of a minimum of 8 hrs for material having a tensile strength $\geq$ 1000MPa (31 HRC).
- The maximum allowable tensile stress for closure bolting exceeded 83% of the minimum specified yield strength limit as per API 16A Third Edition December 2004, reaffirmed in August 2010 *"Specification for Drill Through Equipment."*
- Other possible causes of brittle fractures in fasteners (such as a crack at the root of a thread) should also be evaluated after fastener manufacturing. The possibility of pre-

existing cracks at the root of the threads due to inadequate heat treatment could continue into the threaded region and across the diameter resulting in premature failure of fasteners under normal load condition.

- Industry should perform a comprehensive review of industry standards related to fasteners and develop consistent guidance for ideal material property requirements for subsea fastener manufacturing. The review should also include a comprehensive analysis of manufacturing best practices and environmental service conditions for subsea fasteners.

As a result of these findings, in the interest of safety, BSEE recommends the following:

- The OEM should review the following for the fasteners: design, load, material specification, torque specification based on the lubricant used, installation, maintenance, fatigue and its impact on the functional performance for fasteners in other locations such as BOP shear blades, LMRP assemblies, etc.
- BSEE agrees with the OEM's recommendation to replace the fasteners with higher hardness values of 38-42 HRC with revised fasteners with lower hardness values of 31-34 HRC.
- The operators and inspectors should understand that the fasteners failures are not limited to BOP BSR fasteners, but failures may occur with fasteners with higher hardness values used in other locations such as BOP shear blades, LMRP assemblies, etc.
- The OEM should follow appropriate sections from the latest revision of API 20E *First Edition,* June 2013 "*Alloy and Carbon Steel Fastening for Use in the Petroleum and Natural Gas Industries,"* ASTM B633 2015 Edition, *"Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel,"* ASTM B849 2002 Edition (reapproved 2013), *"Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement"* & ASTM B850 1998 Edition (reapproved 2015), *"Standard for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement."* industry standards specifications for fastener manufacturing.
- Industry should perform a comprehensive review of relevant industry standards API, ASTM, ASME, NACE, NORSOK, ISO, etc. and develop consistent guidance for ideal material property requirements for subsea critical equipment fastener manufacturing. The review should also include a comprehensive analysis of manufacturing best practices and environmental service conditions for subsea fasteners.
- As noted in the previous H4 bolt and HC Connector QC-FIT reports, industry needs to develop a common database to ensure that the data for bolt failures of components used on safety critical equipment are collected, analyzed, and the recommended replacements are shared with industry and BSEE.
- Existing industry practices and BSEE regulations related to QA/QC and quality management systems may not be adequate to ensure that components were manufactured as "fit for service" at all levels of manufacturing supply chain. QA/QC practices should include controls for producing products and identifying non-conformities to industry standards and specifications.

- Industry should evaluate the latest edition of API Specification Q1, Ninth Edition, June 2013 including the addendums, *"Specification of Quality Management Systems Requirements for Manufacturing Organizations for the Petroleum and Gas Industry"* for the following:
    - This evaluation should also help develop and implement improvements to address the oversight and auditing of subcontracted second-tier, third-tier and lower tiered vendors who perform a manufacturing process in the manufacturing chain. This requirement would ensure proper manufacturing at the lowest levels.
    - Ensure that the API monogram program provides sufficient audit mechanism such that the OEMs are in full compliance with API Specification Q1 Ninth Edition.
- BSEE should review the latest edition of API Specification Q1 Ninth Edition for consideration to be incorporated into regulations. This specification defines the fundamental quality management system requirements for those claiming conformance to the requirements of this specification and help ensure that a piece of equipment is manufactured per the OEM's QMS specified requirements. API Spec. Q1 Ninth Edition also emphaizes for the following:
    - API may audit subcontracted second and third-tier vendors who perform manufacturing processes, to ensure their compliance with the requirements of the applicable standards.
    - Verification of the design, development and manufacturing processes at each stage of an OEM's supply chain. QA/QC practices should include controls for producing expected products, identifying non-conformities and their compliance with the requirements of applicable API product specifications and/or standards.
- BSEE and/or industry should consider conducting a joint industry research project on fasteners to determine the ideal material and coating properties, design, related torque specification based on the lubricant used, installation, maintenance, fatigue, fastener thread manufacture, load capacity, cathodic protection, and the impact of the stress load conditions on the fastener performance and reliability during subsea service.
- BSEE should closely monitor the industry's adoption of API Specification Q2, First Edition, June 2016, "*Specification for Quality Management System Requirement for Service Supply Organizations for the Petroleum and Gas Industries"* and consider whether this specification should be incorporated into regulations. This specification defines the process and risk based QMS requirements and provides guidance ensuring that a piece of equipment is manufactured per the OEM's requirements.
- API Standard 18LCM, First Edition, *"Standard for Product Lifecycle Management for the Petroleum and Natural Gas Industry"* will be published in the next few months. BSEE should review this specification for consideration to incorporate into regulations..
- BSEE should evaluate API Spec 20E First Edition, June 2013, *"Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industry"* for incorporation by reference into regulations for consistency in material property requirements, with the aim to improve offshore safety and environmental protection.

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BACKGROUND

On October 13, 2015, an initial blow out preventer (BOP) stump testing on the abandonment job of the well was conducted in the Gulf of Mexico (GOM) utilizing the Noble Paul Romano rig at Garden Banks block 216 Well Number 5 at a waterdepth of 1450 feet. After several attempts, HESS Corporation crew discovered that the failure to operate the actuator on the BOP blind shear ram (BSR) assembly was a result of failed actuator fasteners.The OEM reported the BSR fastener failure to BSEE as a “near miss incident.” Upon removal of the BOP stack on the surface five fasteners were found to have failed on the upper BSR of the Cam Block cylinder and one on the lower BSR at the nut area. The BOP was in service April 28 – September 20, 2015, then went through the overhaul and reinstated in service on September 20, 2015. The OEM also informed BSEE there was another impacted GOM active rig Amos Runner performing well work activity in Mississippi Canyon 794 Well number 001 at a water depth of 1462 feet. There were no reported personnel injuries related to the fasteners failures. The affected fastener failures located on BSR are shown in Figures 1 and 2.

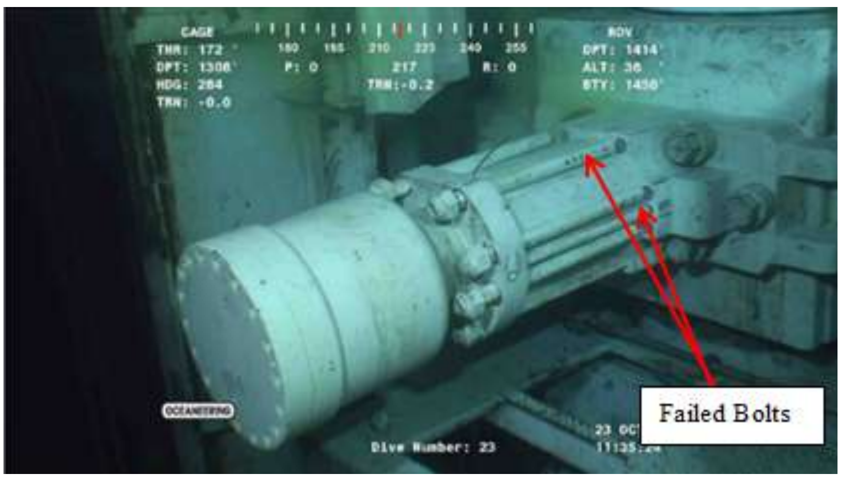

FIGURE 1: UPPER BOP BSR ASSEMBLY (OEM RCA)

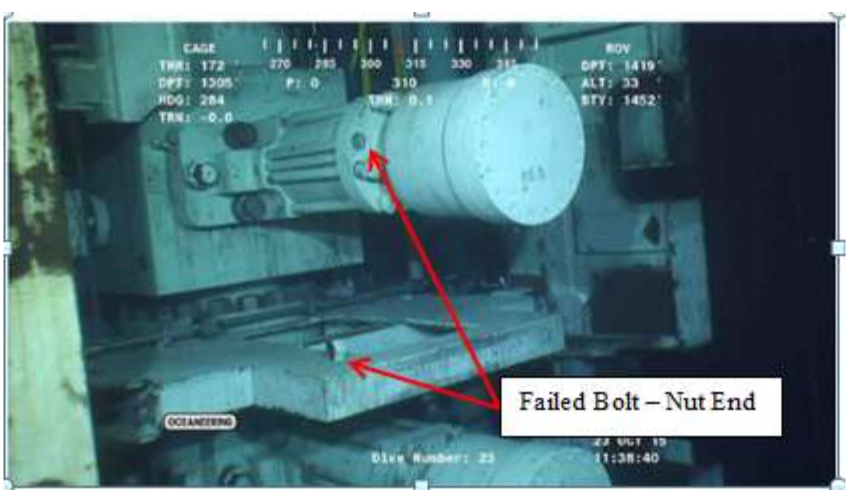

FIGURE 2: LOWER BOP BSR ASSEMBLY (OEM RCA)

The BSR assembly's cylinder head is located on the side of the BOP and is secured by eight fasteners. Five of the eight fasteners fasteners were found to have failed on the upper BSR of the Cam Block cylinder and one on the lower BSR at the nut area.
The BSR fasteners assembly schematic is shown in Figure 3.

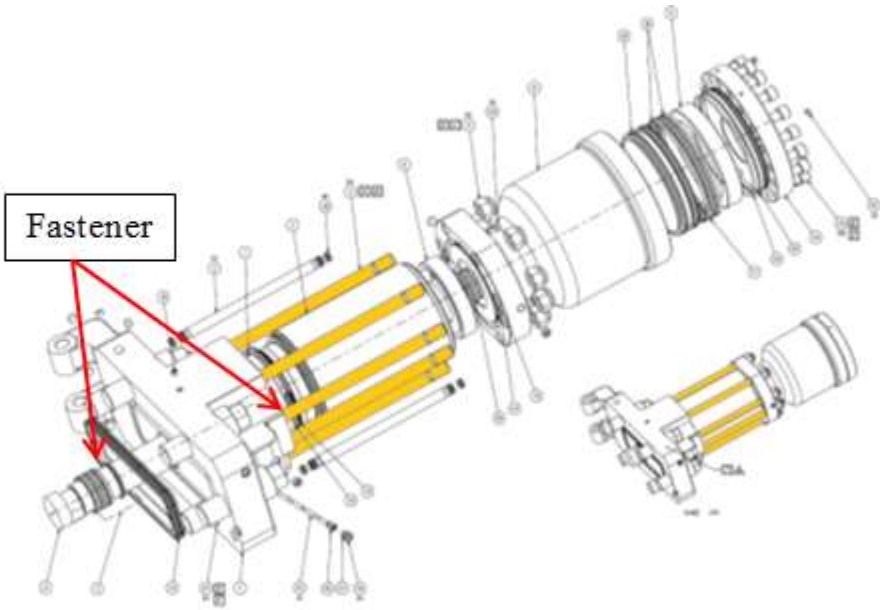

FIGURE 3: BLIND SHEAR RAM ASSEMBLY WITH FASTENERS HIGHLIGHTED (OEM RCA)

In response to the incident, the OEM conducted a RCA investigation into this failure. The material analysis for the fasteners' chemical and mechanical properties were confirmed to the OEM specified material specification to ASTM A540 Grade B23 2011 Edition, "*Standard Specification for Alloy-Steel Bolting for Special Applications."* The OEM specified the zinc coating and post electroplating bake treatment to be performed at 190°C for 3-5 hours in accordance with ASTM B633 1998 Edition, "*Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel."* After the BOP was retrieved and the treaceablitiy for the heat code, the fastener material hardness values were reported to be 38-39 HRC. The measured hardness values of the failed fasteners were in the range between 38-42 HRC (Table 1).

The OEM reviewed BSEE QC-FIT Report #2014-01 and decided to lower the yield strength value requirements for the fasteners. The OEM also specified a longer post electroplating bake treatment time of 10 hours minimum for fasteners per ASTM B850 2009 Edition (reapproved 2015): "*Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement,"* with a required fastener material hardness of less than 35 HRC.

ASSESSMENT

Following the discovery of the fasteners failure on the Noble Paul Romano, BSEE convened the Quality Control Failure Incident Team (QC-FIT) to conduct a technical evaluation of the equipment involved. The QC-FIT was tasked to determine if there were global quality assurance/quality control (QA/QC), technology, safety, and/or environmental concerns that needed further action by the BSEE or industry related to the design, manufacture and use of these fasteners on the Outer Continental Shelf (OCS) or globally. The QC-FIT technical evaluation consisted of the following: meetings with the operator, contractors, and OEMs; review of applicable reports, technical documents and industry standards. These activities provided relevant information about the fasteners' design, material properties, and manufacturing processes to ensure that the fasteners' design was fit for service. The OEM initiated a RCA evaluation to determine the root cause for the fasteners' failure.

OEM AND THIRD PARTY ENGINEERING RCA INVESTIGATION

The OEM initiated a RCA investigation using an independent third party test laboratory to determine the root cause of failure for the six of the eight fasteners (Figures 1 and 2). The RCA report by the independent third party test laboratory was provided to the OEM. BSEE contracted NASA as an independent third party test laboratory to analyze the failed fasteners. NASA provided their testing results with analyses to BSEE. The RCA investigation conducted by the OEM and the third party included a review of the fasteners' design, load conditions, and manufacturing and maintenance procedures, fasteners' chemical composition, material properties, microstructure, and an evaluation of the material specifications. In summary, the QC-FIT concluded the following:

- The chemical composition of the failed BSR fastener material met ASTM A540 B23, 2011Edition as specified by the OEM.
- The fasteners were zinc plated in accordance to ASTM B633 1998 publication. The OEM specified improper post electroplating bake treatment with temperature of 190^{o}C and for 3 hours. The measured hardness values range of the bolt shank material was as high as 42 HRC (Table 1). In response to this failure, the OEM revised their design specification to material with lower hardness values of 31-34 HRC which meets the requirements of API 20E, First Edition, June 2013, *"Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industry."*
- The original fasteners had higher material yield strength value to contain the force of the 18" booster and the 14" Poslock. A finite element analysis (FEA) was conducted on the door assembly, which revealed that the maximum allowable tensile stress exceeded 83% of the minimum yield strength limit allowable per API 16A Third Edition, reaffirmed in 2010. The OEM lowered the fastener's material yield strength and the maximum allowable tensile stress values to within the limits of 83% of minimum yield strength limit.
- Metallographic evaluation included macroscopic and microscopic methods for identification of the failure mechanism for the bolt failure. The microstructures of the failed surface, multiple threaded areas, and thread root were examined by optical microscopy.

- Macroscopic evaluation show tear lines indicating two primary fracture initiation locations, identified by the black and yellow arrows (Figure 4) of the failure at the nut end of the fastener and the direction of the propagation of the crack indicated by the yellow arrows (Figures 5). These primary fracture location could be at the location where pre-existing cracks, as shown in Figure 8, that may be present due to higher strength material properties and inadequate heat treatment. Cracks were also observed in multiple threads below the fracture surface. Figure 6 shows fluorescent dye penetrant test identifying the crack and its propagation across multiple threads of the bolt. These cracks could have been generated during the fracture of the bolt.

FIGURE 4: FRACTURE INITIATION AT NUT END (BSEE RCA)

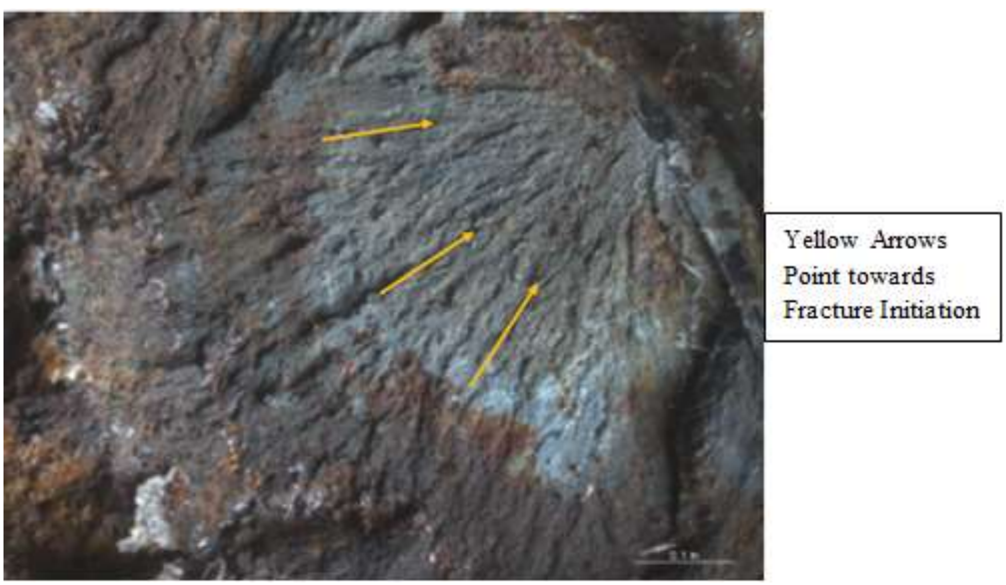

FIGURE 5: CRACKS THAT EXTEND INTO THE THREADS BELOW THE FRACTURE FACE (BSEE RCA)

FIGURE 6: CRACKS PROPOGATION THAT EXTEND INTO THE THREADS BELOW THE FRACTURE FACE INTO THE THREADS (OEM RCA)

- Microscopic evaluation was conducted in the areas of the threads. Cracks were observed in the thread root areas identified by yellow arrows as stress cracks as seen in Figure 7. Cross-section of the thread shows crack initiation at the thread root and propagating towards the center of the fastener as seen in Figure 8. The fracture surface of Figure 7 was further evaluated at a higher magnification. Figure 9 shows intergranular fracture typical of hydrogen embrittlement. This metallograph indicates that the material is susceptible to hydrogen embrittlement or hydrogen induced stress cracking (HISC) in the presence of hydrogen ions. Hydrogen remains trapped in the material if improper post electroplating bake treatment is performed. When stresses are applied to the fasteners during installation, i.e. bolt torqueing, or the system load condition, this entrapped hydrogen could lead to HISC.

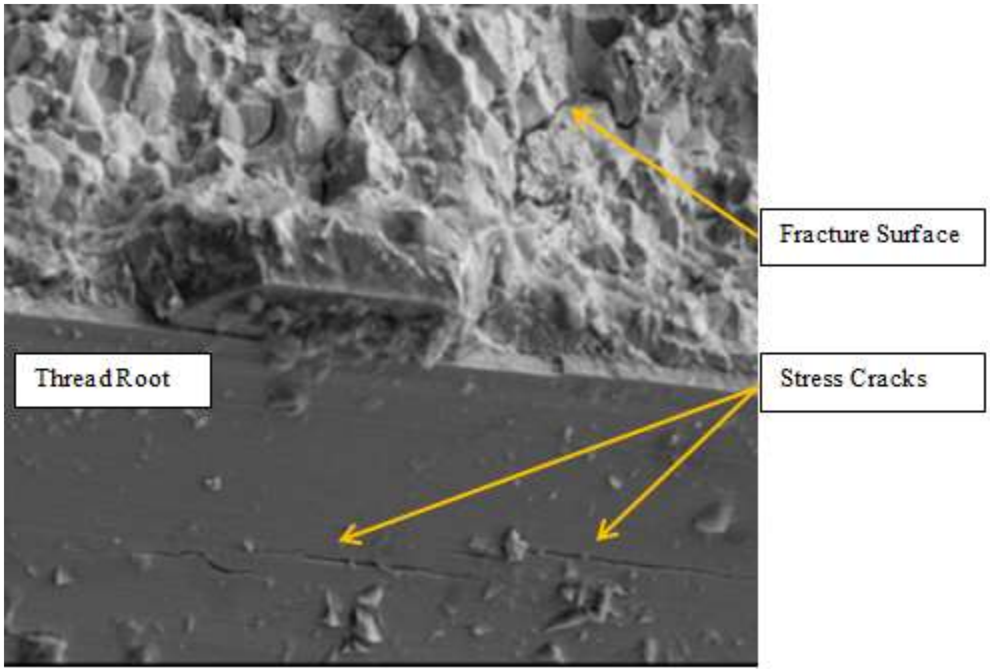

FIGURE **7**: CRACKS OBSERVED IN THREAD AND THREAD ROOT NEAR FRACTURE (BSEE RCA)

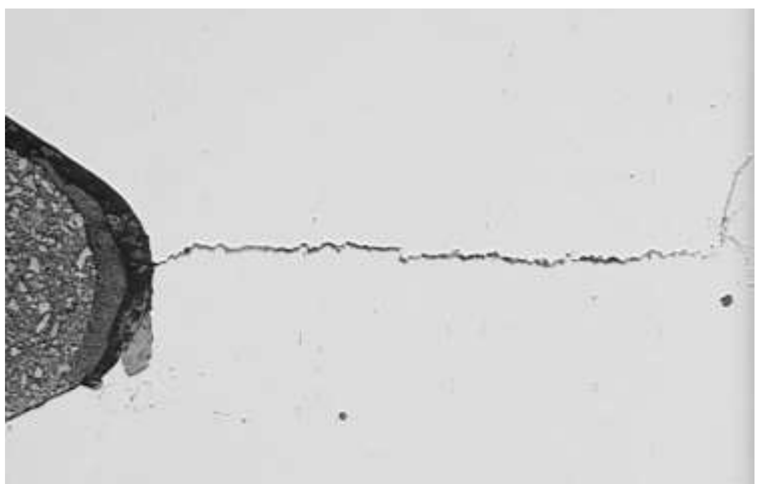
FIGURE 4: CRACK INITIATION AT THE THREAD ROOT (INTACT OTHER END OF THE FRACTURED FASTENER – BSEE RCA)

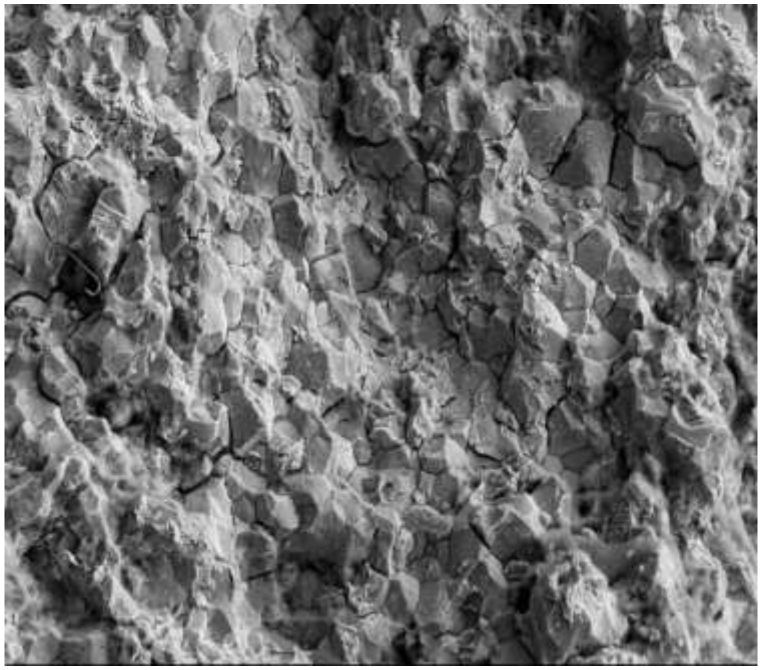

FIGURE 5: SEM MICROGRAPH OF THE INTERGRANULAR FRACTURE (BSEE RCA)

In response to the OEM's RCA analysis, BSEE recommends the following:

- The OEM should conduct a FEA on the design of the new fasteners to ensure that operational stress concentrations and load levels remain within the designed load limits.
- The OEM should verify the material test certificates for the fasteners that it meets the OEM's material design specification requirements (for e.g. alloy chemistry, coatings, and mechanical properties – yield strength, ultimate tensile strength, hardness, etc.) and are manufactured to the latest revision of specified industry standards specification.

POTENTIAL CONTRIBUTING FACTORS

The RCA investigations by the OEM contracted test laboratory identified the following potential contributing factors to fasteners' failure:

- An FEA conducted on the door assembly revealed that the maximum allowable tensile stress exceeded the 83% of the minimum yield strength limit of API 16A Third Edition, reaffirmed in 2010.
- The OEM specified ASTM B 633, 1998 Edition with improper post electroplating bake treatment of 190^{0}C for 3 hours which resulted in a measured hardness values range of 38-42 HRC and could lead to hydrogen embrittlement.

APPLICABLE INDUSTRY STANDARDS

MATERIAL PROPERTIES

The API Spec 20E *"Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industry"* First Edition was published in June of 2013 with Addendum 1 published in June 2016. API 20E specifies the requirements for the qualification, production, and documentation of alloy and carbon steel bolting used in oil and gas applications. This standard provides guidance for consistency in material property requirements for fasteners to be used for the required design load conditions, its manufacturing processes for the reproducibility and verification of the fasteners' function and that it is fit for service.

QUALITY ASSURANCE

API Spec. Q1 Ninth Edition, June 2013:*"Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry"*, API Spec. Q2, First Edition, June 2016: *"Specification for Quality Management System Requirements for Service Supply Organizations for the Petroleum and Natural Gas Industry"* and API Standard 18LCM First Edition, 2016: *"Standard for Product Lifecycle Management for the Petroleum and Natural Gas Industry"* to be published in the next few months addresses quality management, equipment tractability and service risk for manufacturing organizations and service supply organizations, covering both products and services used in the oil and gas industry. The goals of these standards are to improve the manufacturing processes, the overall quality and the reliability of the equipment being used throughout the functional lifecycle.

API Spec. Q1 Ninth Edition was developed to address quality management systems for organizations that manufacture products or provide manufacturing-related services under a product specification for use in the petroleum and natural gas industry. It defines the fundamental quality management system requirements for those claiming conformance to the requirements of this specification and also provides guidance for the following:

- API may audit subcontracted second and third-tier vendors who perform manufacturing processes, to ensure their compliance with the requirements of the applicable standards.
- Verification of the design and manufacturing processes at each stage of an OEM's supply chain. QA/QC practices should include controls for producing expected products, identifying non-conformities and their compliance with the requirements of applicable API product specifications and/or standards.

In the case of this evaluation, the fasteners failure falls under API Q1 Ninth Edition the "Control of Nonconforming Product" section. This specification outlines guidance for identifying product failures after delivery and the appropriate action to address the effects of nonconformance. If the design and risk assessment criteria were followed as per API Specification Q1 design and development guidelines, the associated risk of the fastener failure may have been identified.

API Specification Q2 First Edition June 2016 defines the process and risk based QMS requirements and service controls for the service supply organizations.

QMS is in reference to API Q1 & API Q2 specifications where these industry standards establish minimum requirements for organizations that manufacture products or provide services or service-related products for use in the petroleum and natural gas industry.

API Standard 18LCM *"Standard for Product Life Cycle Management,"* First Edition, will be published in the next few months . This new standard will address the lifecycle management of equipment used in the petroleum and natural gas industry. When complete, this standard will provide guidance for tracking a piece of equipment's compliance to its original and/or current manufacturing and design requirements, product standards, and industry/product-specific technical and regulatory requirements.

SUMMARY OF RECOMMENDATIONS

As a result of these findings from this QC-FIT evaluation, in the interest of safety, BSEE recommends the following:

- The OEM should review the following for the fasteners: design,load, material specification, torque specification based on the lubricant used, installation, maintenance, fatigue and its impact on the functional performance for fasteners in other locations such as BOP shear blades, LMRP assemblies, etc.
- BSEE agrees with the OEM's recommendation to replace the fasteners with higher hardness values of 38-42 HRC with revised fasteners with lower hardness values of 31-34 HRC.
- The operators and inspectors should understand that the fasteners failures are not limited to BOP BSR fasteners, but failures may occur with fasteners with higher hardness values used in other locations such as BOP shear blades, LMRP assemblies, etc.
- The OEM should follow appropriate sections from the latest revision of API 20E *First Edition, June 2013* "*Alloy and Carbon Steel Fastening for Use in the Petroleum and Natural Gas Industries,"* ASTM B633 2015 Edition, *"Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel,"* ASTM B849 2002 Edition (reapproved 2013), *"Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement"* & ASTM B850 1998 Edition (reapproved 2015), *"Standard for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement,"* industry standards specification for fastener manufacturing.
- Industry should perform a comprehensive review of relevant industry standards API, ASTM, ASME, NACE, NORSOK, ISO etc. and develop consistent guidance for ideal material property requirements for subsea critical equipment fastener manufacturing. The review should also include a comprehensive analysis of manufacturing best practices and environmental service conditions for subsea fasteners.
- As noted in the previous H4 bolt and HC Connector QC-FIT reports, industry needs to develop a common database to ensure that the data for bolt failures of components used on safety critical equipment are collected, analyzed, and the recommended replacements are shared with industry and BSEE.
- Existing industry practices and BSEE regulations related to QA/QC and quality management systems may not be adequate to ensure that components were manufactured as "fit for service" at all levels of manufacturing supply chain. QA/QC practices should include controls for producing products and identifying non-conformities to industry standards and specifications.
- Industry should evaluate the latest edition of API Specification Q1, Ninth Edition, June 2013 including the addendums, *"Specification of Quality Management Systems Requirements for Manufacturing Organizations for the Petroleum and Gas Industry"* for the following:
    - This evaluation should also help develop and implement improvements to address the oversight and auditing of subcontracted second-tier, third-tier and

lower tiered vendors who perform a manufacturing process in the manufacturing chain. This requirement would ensure proper manufacturing at the lowest levels.
    - Ensure that the API monogram program provides sufficient audit mechanism such that the OEMs are in full compliance with API Spec. Q1 Ninth Edition.
- BSEE should review the latest edition of API Specification Q1 Ninth Edition for consideration to be incorporated into regulations. This specification defines the fundamental quality management system requirements for those claiming conformance to the requirements of this specification and help ensure that a piece of equipment is manufactured per the OEM's QMS specified requirements. API Spec. Q1 Ninth Edition also emphasizes for the following:
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    b. Verification of the design, development and manufacturing processes at each stage of an OEM's supply chain. QA/QC practices should include controls for producing expected products, identifying non-conformities and their compliance with the requirements of applicable API product specifications and/or standards.
- BSEE and/or industry should consider conducting a joint industry research project on fasteners to determine the ideal material and coating properties, design, related torque specification based on the lubricant used, installation, maintenance, fatigue, fastener thread manufacture, load capacity, cathodic protection, and the impact of the stress load conditions on the fastener performance and reliability during subsea service.
- BSEE should closely monitor the industry's adoption of API Specification Q2, First Edition, June 2016, "*Specification for Quality Management System Requirement for Service Supply Organizations for the Petroleum and Gas Industries"* and consider whether this specification should be incorporated into regulations. This specification defines the process and risk based QMS requirements and provides guidance ensuring that a piece of equipment is manufactured per the OEM's requirements.
- API Standard 18LCM, First Edition, *"Standard for Product Lifecycle Management for the Petroleum and Natural Gas Industry"* will be published in the next few month. BSEE should review this specification for consideration to incorporate into regulations.
- BSEE should evaluate API Spec 20E First Edition, June 2013, "Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industry" for incorporation by reference into regulations for consistency in material property requirements, with the aim to improve offshore safety and environmental protection.

Table 1: Measured Hardness Values of Fasteners (BSEE RCA)

	Rockwell Hardness C (HRC)		
Fastener	Minimum	Maximum	Average
1	40	42	41
2	40	41	40.5
3	40	42	41
4	40	42	41
5	37	39	38
6	38	40	39
7	40	41	40.5
8	41	41	41

The above table indicates that

1) Improper post electroplating bake treatment time led to higher hardness of the fastener material which would lead which could lead to failure due to hydrogen embrittlement as compared to the proposed bake time refered in ASTM B 850 2009 Edition.
2) The OEM did not meet the NORSOK M-001 Fifth Edition, September 2014 standard Section 6.1 states that “for submerged parts that may be exposed to cathodic protection (CP), for martensitic carbon, low-alloy and CRA, the hardness of any components shall not exceed 328 HB or 35 HRC.

ACRONYMS

API	American Petroleum Institute
ASTM	American Society for Testing Materials
BOP	Blowout Preventer
BSEE	Bureau of Safety and Environmental Enforcement
BSR	Blind Shear Ram
FEA	Finite Element Analysis
GOM	Gulf of Mexico
HISC	Hydrogen Induced Stress Cracking
ISO	International Organization for Standardization
LMRP	Low Marine Riser Package
NACE	National Association for Corrosion Engineers
NASA	National Aeronautics and Space Administration
OCS	Outer Continental Shelf
OEM	Original Equipment Manufacturer
PN	Part Number
QA	Quality Assurance
QC	Quality Control
QC-FIT	Quality Control Failure Incident Team
QMS	Quality Management System
RCA	Root Cause Analysis
SEMS	Safety and Environmental Management Systems