S-N Fatigue Design and Test Data for Low-Alloy Steel Bolts

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue NW, Suite 1100, Washington, DC 20001, standards@api.org.

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Introduction

The requirements for bolting fatigue assessment were a charge of the API CSOEM Multi-Segment Task Group on Bolting Failures. Due to documented subsea bolting failures defined in the BSEE QC-FIT Evaluation of Connector and Bolt Failures, the charge of the sub-task group TGR-13 was the following:

"*Guidance should be issued by API on when and how to perform fatigue sensitivity analysis on bolting*."

API CSOEM Bolting Report for TGR-13 and TGR-14 was issued. It defined the design guidelines and provided recommendations for performing a full-scale fatigue testing on bolting. Upon further approval, full-scale fatigue testing was performed.

The scope of work was conducted in two phases; Phase I: Evaluation of bolting under cyclic loading which meets the requirements of API 17D:2011, 2nd Edition [1] standard and Phase II: Evaluation of bolting which meets the requirements of API 6A/16A [2, 3] standards. The following guidelines are provided for both design verification fatigue analysis and corresponding full-scale fatigue testing that was performed.

Design verification analysis for fatigue assessment of bolting requires an evaluation for S-N (stress number of cycles to failure) or fatigue crack growth rate. The S-N fatigue evaluation can be based on either the stress concentrations of the thread profile, which will need stress concentration factor (SCF) and smooth tensile bar S-N testing, or the axial stress due to the load divided by the minimum root diameter area and full-scale bolt fatigue tests [4]. The basis of this document is the S-N approach using full-scale fatigue testing. The full-scale fatigue testing was conducted for bolts manufactured to meet API 20E [4] BSL-3. The testing was performed in two phases; Phase I was conducted to obtain S-N fatigue curve with API 17D:2011 loading conditions, Phase II was conducted with API 6A/16A loading conditions.

The fatigue testing was based on alternating axial stresses in the bolt with a defined preload. The preload was applied with the load frame to a value of 2/3*SMYS for Phase I testing and 0.5*SMYS for Phase II testing, based on the cross section at the root radius of the thread. The defined bolt lengths represent API flange by flange connection conservative bolt lengths for a given bolt size. The bolt-to-nut thread engagement met the requirements of API 6A for all tests. Each bolt tested had two bolt/nut connections where the failure of the first connection was defined as the fatigue life.

The objective of the Phase I test program was to provide S-N fatigue curves for bolts that are preloaded per API Series 17 standards and are subjected to a range of alternating axial stresses. The objective of the Phase II test program was to provide S-N fatigue curves for bolts that are preloaded per API 6A/16A standards. The preload and alternating stress ranges were defined based on the cross-sectional area at the root radius of the threads. The test program evaluated bolt size effects and environments of air and saltwater (SW) with cathodic protection (CP).

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1 Scope

The scope of the test program was to obtain bolting material fatigue data required to perform design verification analysis of bolting subjected to fatigue loading to assure accurate design life estimation. The bolting fatigue testing program provided S-N fatigue curves for three alternating stress ranges in air and in SW+CP environments and for bolt sizes of 1 in., 2 in. (Grade L7), and 3 in. (Grade L43) in Phase I and for bolt sizes 1 in. (Grade L7) and 3 in. (Grade L43) in Phase II.

The results of these S-N fatigue tests allow the bolting design to be assessed for S-N fatigue through structural analysis using the nominal root area stresses in the bolt, avoiding the need to define stress and load concentrations in the bolt root radius of engaged threads.

The design guidelines and the fatigue data provided in the document are intended to be used for bolting with unified national thread with root radius (UNR) specifications of ASME B1.1 [5] Class 2A/2B.

2 Normative References

There are no normative references for this document.

3 Terms, Definitions, Abbreviations, and Symbols

3.1 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1.1
ambient air (dry)
Room temperature and ambient pressure.

3.1.2
high-stress range fatigue cycles
HFC
Tested fatigue cycles to failure for a high-stress range or high-force condition applied.

3.1.3
low-stress range fatigue cycles
LFC
Tested fatigue cycles to failure for a low-stress range or low-force condition applied.

3.1.4
mean stress
Maximum axial stress plus minimum axial stress divided by two.

3.1.5
medium-stress range fatigue cycles
MFC
Tested fatigue cycles to failure for a medium-stress range or medium-force condition applied.

3.1.6
S-N fatigue
Stress range (S) versus number of cycles to failure (N).