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Work Item	3081—Guidelines for Evaluating Connection Performance in Multi-Fractured Horizontal Wells
Distribution-type (Ballot, Comment-only Ballot, Recirculation (comment resolution), Re-ballot, etc.)	Re-ballot (ballot-2 voting and commenting)
API Standard	TR 5SF [proposed identifier]
Impacted Documents	RP 5C5
Revision Key	Current/unchanged content in BLACK; Track Changes as: 1) Additions in underlined-<u>BLUE</u> 2) Deletions in stricken-~~RED~~

Work Item Charge: Develop a testing protocol to evaluate premium connections for use in non-standard applications. This includes both shale gas wells and scenarios like casing drilling where low-cycle fatigue effects on premium connections need to be considered.

Ballot Rationale: Premium and semi-premium connections used in non-standard applications such as shale wells are subjected to unique fatigue load combinations during installation and well completion that are not addressed in the current industry premium connection evaluation protocol (API 5C5). These unique loads include:

- Low-cycle fatigue as a result of rotating while bending;
- Pressure cycling during frac operations; and,
- Thermal shocking as cold frac fluids are injected downhole.

Many users and manufacturers support a distinct protocol required for non-standard applications separate from API 5C5 because the load conditions are considerably different. Premium connections evaluated for shale application may not require the rigor of an API 5C5 CAL IV test program; however, they still need to be evaluated against a prescriptive and severe test matrix to ensure sealability and structural integrity.

This protocol will strive to create a representative and efficient and effective evaluation methodology (testing, and potentially analysis) that manufacturers and users can refer to when designing connections for non-standard applications.

NOTE See the ballot email notification for additional information regarding this ballot.

Guidelines for Evaluating Connection Performance in Multi-Fractured Horizontal Wells

API TECHNICAL REPORT 5SF
FIRST EDITION, XXXX 20XX

The *Special Notes*, *Foreword*, and *Contents* will be generated by API during the page proofing stage before publication.

Introduction

The well designs and completion strategies associated with hydraulic fracturing have a unique set of challenges. During well construction, the long lateral sections of extended-reach wells may require the production or intermediate casing to be rotated and pushed through build sections of relatively high curvature (i.e., greater than 10°/100 feet). Furthermore, some operators rotate the casing during cementing to improve cement placement quality. This rotation can subject the connections in the build section to a high number of rotating/bending load cycles, and the high stresses associated with these cycles could lead to localized yielding of the material, loss of sealability, or potential structural failure. The hydraulic fracturing process itself subjects the tubular to rapid increases in pressure (and potentially significant changes in temperature); consequently, wells with multiple stimulation stages will be subjected to cyclic pressure-loading. Given these considerations, connections used in hydraulically fractured wells can be subjected to significant and varied loads, and this loading may have an impact on the overall connection sealing integrity and structural capacity later in the service life of the well when the combined pressure, temperature and axial loads during production are acting on these connections.

API 5C5 outlines a process for experimentally validating a connection performance envelope. While this standard addresses galling resistance, sealability and structural integrity, the primary focus is validating the sealability performance of a connection under various combinations of pressure, axial force, and temperature. Although API 5C5 is applicable to a wide range of operating environments, the primary driver for the enhancements under its 4th Edition was the increasing severity of loading present in offshore applications.

The primary focus of this standard is to evaluate connection performance under the structural loads that typically occur in multi-fractured horizontal wells (MFHW). This standard may be used separately from API 5C5, if structural integrity is the sole concern, or in conjunction with API 5C5 to subject the connection to structural loading before subsequent sealability evaluation.

This standard will provide a means to evaluate connection performance under a consistent method of discrete test program elements developed to replicate the cyclic, rotating/bending loads of well construction and the pressure cycling of multi-stage hydraulic fracturing. This standard will not follow a prescriptive approach but rather allow the evaluator to customize a test program from the test program elements that are most representative of the well application. While evaluators following the guidelines of this standard should employ sound engineering judgment when devising test programs, it is ultimately the responsibility of the end-user to determine the level of applicability of a given test program to the design loads of interest.

Guidelines for Evaluating Connection Performance in Multi-Fractured Horizontal Wells

1 Scope

This standard defines tests that may be used to determine the performance of threaded casing and tubing connections for use in multi-fractured horizontal wells (MFHW). This standard defines experimental loading conditions intended to simulate the various stages of MFHW construction and use—installation of tubulars, stimulation of surrounding formation, and production of hydrocarbons. Dynamic effects from such factors as thermal shock, vibration during running/rotating, and hydraulics are beyond the scope of this standard.

This standard does not address erosion or metallurgical impacts such as corrosion or hydrogen embrittlement. This standard also does not establish a singular testing program or acceptability criteria. Not all the test program elements (TPEs) presented in this standard may apply to all MFHWs; consequently, this standard provides flexibility in tailoring a testing program for the specific, anticipated field loads of a given well (or group of wells). End-users are ultimately responsible for determining whether an evaluation program assembled from the TPEs presented in this standard is appropriate for a given set of field conditions. This determination will likely be based on historical practice, local regulatory requirements, and specific well conditions.

2 Normative References

API Recommended Practice 5C5, *Procedures for Testing Casing and Tubing Connections*, Fourth Edition is indispensable for the application of this standard. For a list of other documents associated with this standard, see the Bibliography. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

3 Terms, Definitions, Symbols, and Abbreviations

3.1 Terms and Definitions

For the purposes of this standard, the following terms and definitions apply.

3.1.1 connection

A tubular product, either threaded and coupled (T&C) or integral, that is tested according to this standard.

3.1.2 dogleg severity (DLS)

The amount of curvature built up in a casing string over a length interval, typically measured in degrees per one hundred feet or degrees per thirty meters.

3.1.3 end-user

The party who expects the connection to perform; typically an end-user operator that has operations where the connection will be used in the field.

3.1.4 evaluator

The party creating and executing a test program following the guidelines of this standard. In some instances, the evaluator will be one entity (e.g., a connection supplier selecting the TPEs and executing tests in an internal lab); in other instances, the evaluator may be multiple entities (e.g., an end-user and/or supplier selecting the TPEs and executing tests in a third-party lab).

3.1.5 multi-fractured horizontal wells (MFHW)
The target application of this standard wherein the target producing reservoir is drilled with an extended reach or long horizontal section and fractured over the length of that horizontal section in multiple zones.

3.1.6 S-N curve
An S-N curve is a plot that defines the number of cycles to failure (N) of a material when it is repeatedly cycled through a stress range (S).

3.1.7 specimen
A representative sample of the candidate connection design prepared for testing consisting of two casing pups, each with a pin connection and a shared coupling forming a coupled assembly, or two pups, one with a pin connection and one with a box connection forming an integral assembly. For threaded-and-coupled connection designs, a specimen consists of one coupling (centrally positioned) with connection boxes machined on both ends made-up on either side to casing pups machined with connection pins. For integral connection designs, a specimen consists of one box-end connection made-up to one pin-end connection.

3.1.8 supplier
The party that designs and/or manufactures the candidate connection tested according to this standard.

3.1.9 test program element (TPE)
A base component of the overall test program an evaluator can choose from this standard. Each TPE is designed to simulate a unique aspect of loading of the connection's service life in MFHW operation.

3.2 Abbreviations

CAL connection application level

CEPL capped end pressure load

MBG make-up/break-out galling test

MIYP minimum internal yield pressure

MFHW multi-fractured horizontal wells

PBYS pipe body yield strength

T&C threaded-and-coupled

TD total depth

TPE test program element

TS-A API 5C5 sealability test series A

TS-B API 5C5 sealability test series B

TS-C API 5C5 sealability test series C

3.3 Symbols

D_{pin} nominal diameter of the pin end of the connection on the pipe body

r_{pin} nominal radius of the pin end of the connection on the pipe body

$\Delta\sigma$ stress range of an S-N curve

4 Creating a Representative Test Program

4.1 General Philosophy

This standard describes test procedures that can be used to evaluate the performance of connections used in MFHW. The well conditions for MFHW can vary widely. The various procedures for each of the TPEs herein can be used to design an evaluation program for a specific application or a broad spectrum of MFHW applications. Not all TPEs in this standard may be necessary for a particular application. The evaluator following the guidelines of this standard is encouraged to use good engineering judgement in determining what TPEs are necessary to determine the performance properties for a particular service scenario. If uncertainty arises regarding the applicability of TPEs to a particular scenario, the evaluator should consult with an end-user(s) to ensure that the test program is as representative of field conditions as practical.

Because of the wide range of variables involved in MFHW design, the Connection Application Level (CAL) system established in API 5C5 is not used in this standard. This philosophy encourages the evaluator to consult with an end-user(s) to determine whether an appropriate combination of TPEs has been chosen to address anticipated service scenarios and include considerations of loads (internal/external pressure, bending, temperature, and test media). End-users should be familiar with the testing rigor inherent to the various TPEs in this standard to determine how a given evaluation program applies to field performance.

Section 5 describes the various TPEs representative of the loading common to unconventional wells with horizontal or highly deviated production strings.

4.2 Failure Modes

The primary foci of TPEs in 5.2, 5.3, 5.4, and 5.6 are structural integrity and liquid-tight sealability, not gas-tight sealability; the focus of TPES in 5.5 is gas-tight sealability. Consequently, the following three failure modes are relevant to this standard.

a) *Loss of structural integrity*—This failure mode could include excessive deformation of the pin or box, thread jumping or shearing, or excessive deformation of the tube body. Loss of structural integrity is often (but not always) preceded by loss of sealability. It is the responsibility of the evaluator to monitor the deformation of the specimen through strain gauges or other means and, in potential consultation with an end-user(s), to determine a threshold for loss of structural integrity. This monitoring should encompass the behavior of not only the test specimen(s) itself but also all associated test equipment (e.g., end-caps); see section 5.6 for further discussion. This monitoring is especially relevant if the selected TPEs and associated loads induce near-yield cycling in the test specimen(s).

b) *Loss of liquid sealability*—For the purposes of MFHW design, liquid sealability is most relevant to the containment of fluid during stimulation and some production operations. There is rarely dispute over whether a loss of liquid sealability has occurred; it is typically not a subtle event. While this standard does not discourage the use of leak detection systems for this failure mode, it does not specify a threshold over which liquid sealability loss has occurred. If such a threshold is desired, the evaluator should consult with an end-user(s) to determine what threshold is most appropriate for a given application.

c) *Loss of gas sealability*—For the purposes of MFHW design, gas sealability is most relevant to the containment of gas-laden hydrocarbons during production; as such, it is typically the purview of production loads in 5.5. Since loss of gas sealability can be a subtler event than loss of liquid sealability, the definition of threshold leak rates is recommended. The acceptance criteria presented in API 5C5 may be referenced for acceptable leak rates..

This standard does not explicitly define acceptance criteria. The evaluator, in consultation with an end-user(s), may define acceptance criteria for loss of structural integrity. The evaluator may define acceptance criteria for loss of sealability, with API 5C5 as the recommended starting point.

4.3 Specimen Geometry

4.3.1 General

This standard does not specify geometric tolerance combinations for connections; it is the responsibility of the evaluator to understand the potential impact of thread, seal, and seal ring/groove (if present) geometry variations on structural integrity, liquid sealability, and gas sealability. Worst-case performance combinations should be identified by the evaluator or supplier using analytical, computational, and/or experimental techniques. If TPEs related to production loads are planned (see 5.5), then the geometry combinations presented in API 5C5 should serve as the starting point; any deviations from these combinations should be justified via analytical, computational and/or experimental techniques.

4.3.2 Grooved Torque Shoulder

Several premium and semi-premium connection designs involve a seal that is associated with the engagement of the connection torque shoulder or nose-to-nose contact. As this standard does not have sealability performance acceptance criteria, evaluators may choose to leave the torque shoulder seal intact to assess the entire connection assembly performance during a test program; however, if the evaluator is testing a premium connection design in their test program and subjecting test specimens to internal pressure loads as part of this, they should disable the connection shoulder seal prior to that test so that only the primary radial metal-to-metal seal of the premium connection is being evaluated for sealability. Disabling the connection shoulder may be done in the manner described in API 5C5.

4.4 Test Load Calculation

This standard is not intended to prescribe the magnitude or combination of loads that may be applied to a test specimen during its test program. The multiple load steps (as well as any necessary intermediate load points to get safely between load steps) that make-up a test matrix are the responsibility of the evaluator and should be generated with fundamental understanding of the connection performance, material properties, and limitations therein.

If an evaluator chooses to develop a test matrix based on pipe body geometry and material properties instead of connection load ratings, the evaluator may use nominal or actual values of these properties. The final report shall note what methodology was used to generate the test matrix.

4.5 Quality Control

Connection manufacturing quality control procedures should be consistent with those outlined in API 5C5, Fourth Edition, Section 4.4.

4.6 Test Facility Safety

Test facility safety requirements shall be consistent with API 5C5, Fourth Edition, Section 4.5.

4.7 Calibration and Accreditation Requirements

Test facility calibration and accreditation requirements shall be consistent with API 5C5, Fourth Edition, Section 5.4.

5 Test Program

5.1 Test Program Sequence and Test Program Elements

5.1.1 General

As stated in 4.1, test programs derived from this standard are composed of individual components referred to as test program elements (TPEs), each of which focuses on the loading representative of a specific process or stage in the well operation. Although this standard will allow evaluators to pick and choose what TPEs are employed, it is recommended that evaluators follow a connection test load path representative of field conditions as shown in the flow chart of Figure 1.

Test programs following the guidelines of this standard are application-driven, so there is no single way to perform a test with respect to the TPEs that are selected; however, it is recommended that the sequence of testing follows the load sequence of a typical operation: (1) connection make-up, (2) installation and running, (3) stimulation, and (4) production. Figure 1 shows the recommended load sequence.

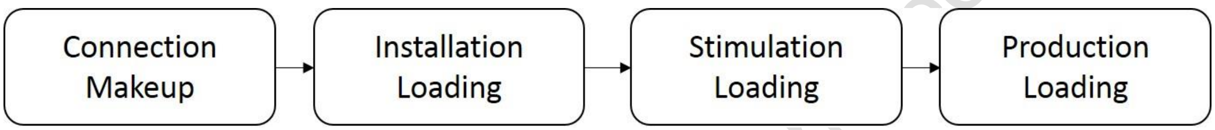


Figure 1—Recommended Test Sequence

The load sequence is significant in that much of the loading in MFHW applications may have a cumulative impact on structural (and possibly sealing) performance. Therefore, it is important to be as representative of field conditions during testing as possible, especially with respect to cyclic loading, since it can lead to localized material yielding in connections.

Within each stage of the load sequence there are two sub-categories:

— *Base TPEs*: the TPEs required as part of that stage; and,

— *Supplementary TPEs*: the TPEs that an evaluator can elect to include as part of the test program that would enable the test to be as representative of field conditions as possible.

Evaluators should perform the base TPEs on a minimum of one test specimen; however, the TPEs that an evaluator chooses to include in their test program are designed to be customized. Evaluators can skip supplementary TPEs if they do not feel that it is necessary to evaluate the connection performance under those loads (e.g., installation loading). Figure 2 shows the base and supplementary TPEs in the load sequence recommended by this standard. Annex A includes information and examples of using base and supplementary TPEs to construct a test program.

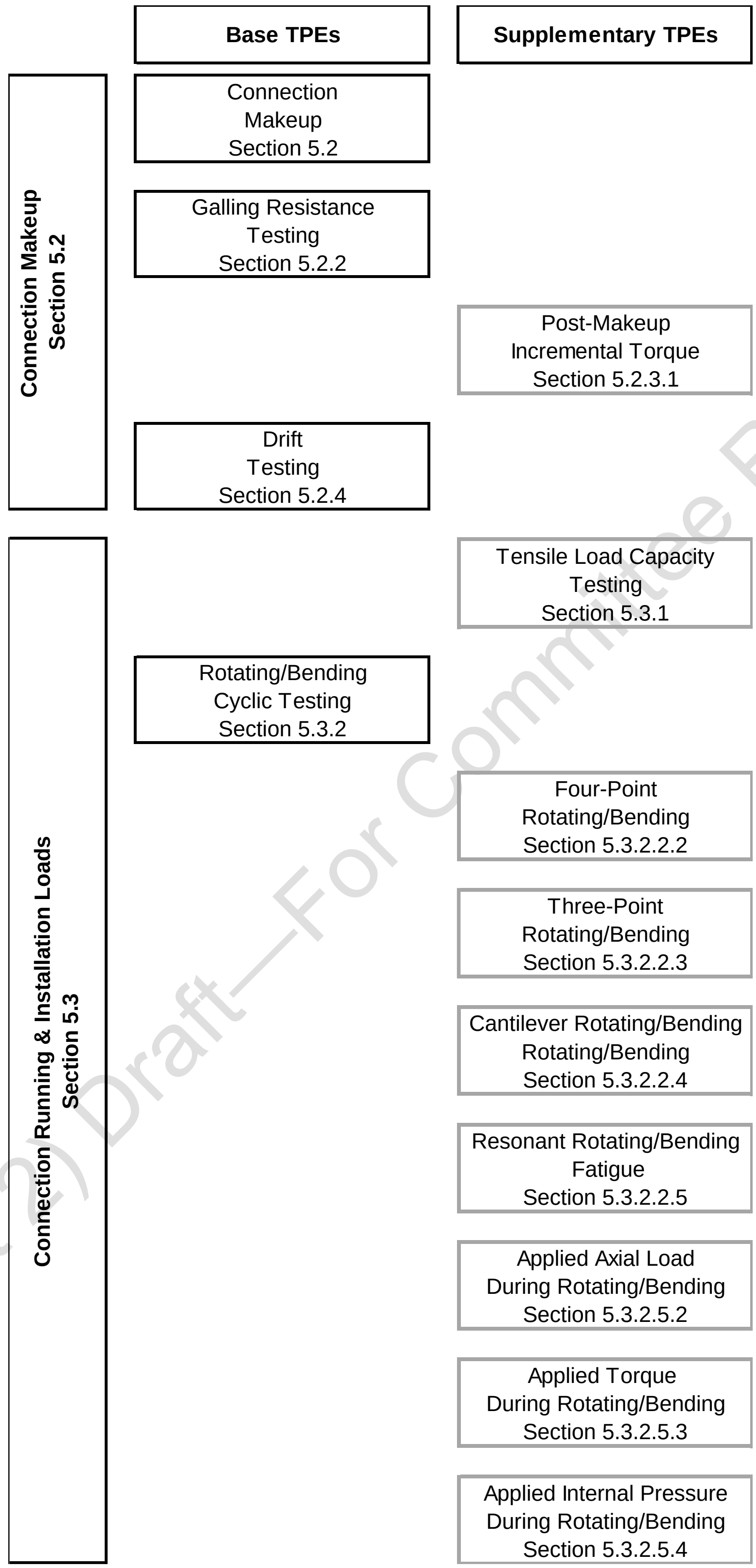


Figure 2—Base and Supplementary Test Program Elements in Sequence

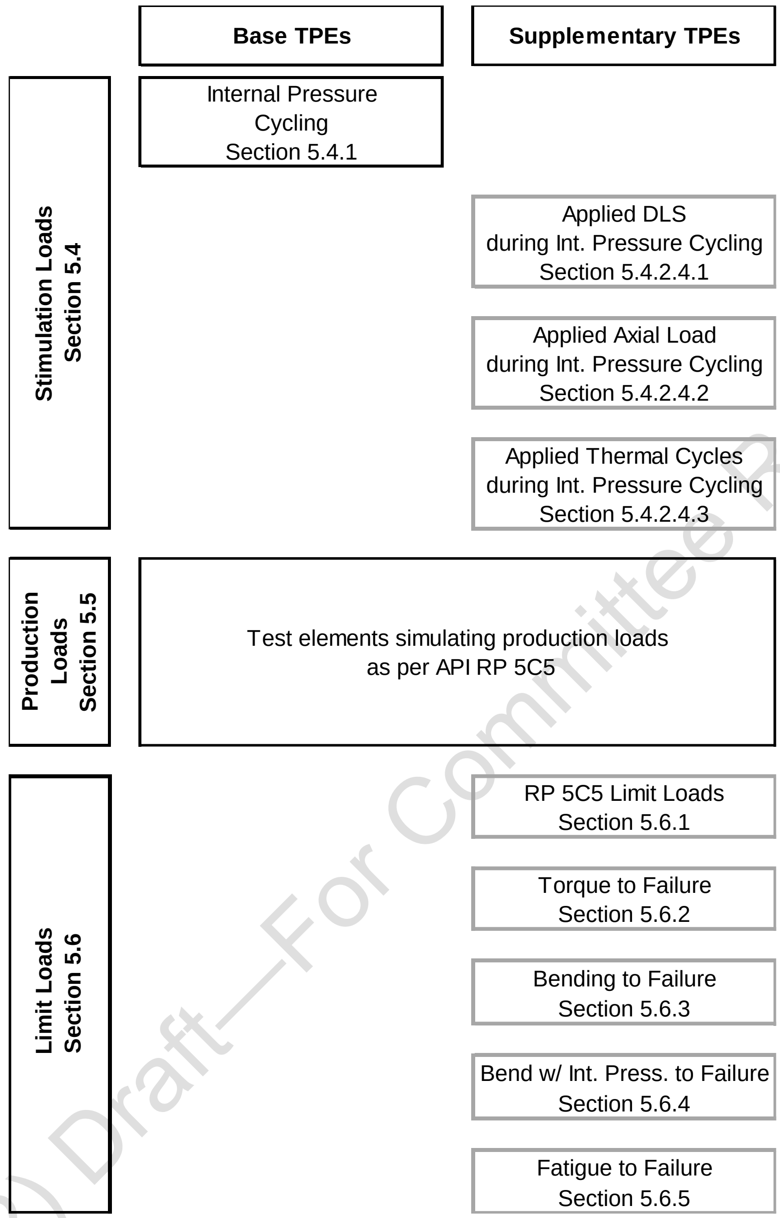


Figure 2—Base and Supplementary Test Program Elements in Sequence (Continued)

5.1.2 Specimen Preparation

Specimens should be provided with ends prepared for welding or threading onto end-caps that will attach the specimen to a load frame. The minimum specimen length should be consistent with of API 5C5, Fourth Edition, Section 6.3.1; however, any subsequent rotating/bending testing may require the specimens to be longer than the minimum length specified in API 5C5.

Strain gauges may be used to verify the pipe body or connection stresses during testing. It is recommended to prepare specimens with the appropriate number and type of strain gauges as specified in API 5C5.

5.2 Connection Make-up

5.2.1 Connection Make-up Guidelines

Connection make-up and break-outs should follow the procedures outlined in API 5C5,; however, connections may be made-up to any torque within the range of final make-up torque specified by the connection supplier. The following aspects of connection make-up should be in accordance with the connection supplier's requirements:

a) make-up speed,

b) make-up position,

c) thread compound type, volume, and application distribution (pin, box, or combination thereof),

d) shoulder torque range (for shouldered connections), and

e) Final torque.

Connection make-up should be monitored with a torque-turn monitoring system and, if included, the evaluator should provide record of the following: make-up speed, mass and type of thread compound, shoulder torque (if applicable), and final make-up torque for each connection.

5.2.2 Galling Resistance Testing

If galling resistance testing is to be included in the test program, the relevant test procedures for galling resistance testing as described in API 5C5 should be referenced. The evaluator may select any combination of galling resistance tests for any connection specimen. Results from galling resistance testing shall be documented.

5.2.3 Connection Final Make-up

If there is only one connection specimen being tested, then at least one end should be made up to minimum specified make-up torque. If connection torque shoulder disabling is selected by the evaluator, it should be performed just prior to final make-up.

5.2.3.1 Post-Make-up Incremental Torque

Connections may be subjected to incremental torque in the field beyond initial make-up due to casing running or cementing activities. If incremental make-up torque is to be applied to a connection after final make-up, it should occur separately from the original connection make-up. At a minimum, the tong or bucking-unit backups gripping the other end should be released for 15 minutes before being re-applied to the connection. Evaluators may scribe or otherwise mark the relative circumferential position of the pin and box of each connection before incremental torque is applied as shown in Figure 3.

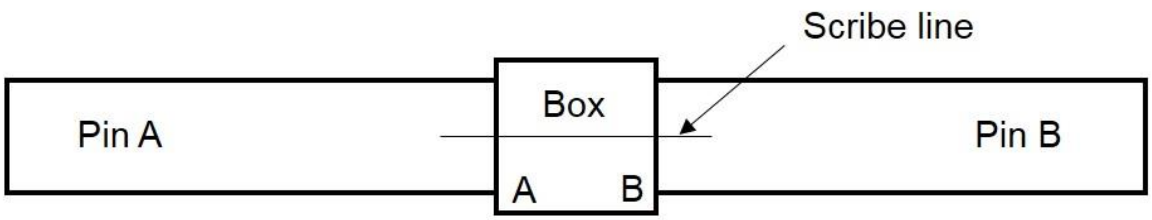


Figure 3—Connection Scribing Example

The evaluator may assign any maximum torque value at their discretion; however, the target maximum incremental make-up torque should be defined by the connection supplier as the highest torque to which a connection can be subjected without significant structural damage, such as:

a) ovalization of the pin and/or box,

b) evidence of pin nose yielding or deformation,

c) thread jump or shearing, and

d) loss of fluid sealability.

Incremental make-up torque should be applied to individual connections; however, if the evaluator decides to float the two connections of a threaded and coupled specimen, this should be documented as part of the test results. It is not a requirement of this TPE to be able to break-out a connection that has been subjected to incremental make-up torque. If only one specimen is to be evaluated, apply post make-up incremental torque to only one side while keeping the other side at the specified torque value.

The incremental torque applied to a given connection should be recorded. If the relative position of pin and box was recorded prior to incremental make-up, record any change in rotational position of the pin and box in degrees using Equation 1 as shown in Figure 4.

$$\Delta Rotation_{Pin-a} = \frac{360 \times \Delta C_{Pin-a}}{\pi D_{Pin-a}} \quad (1)$$

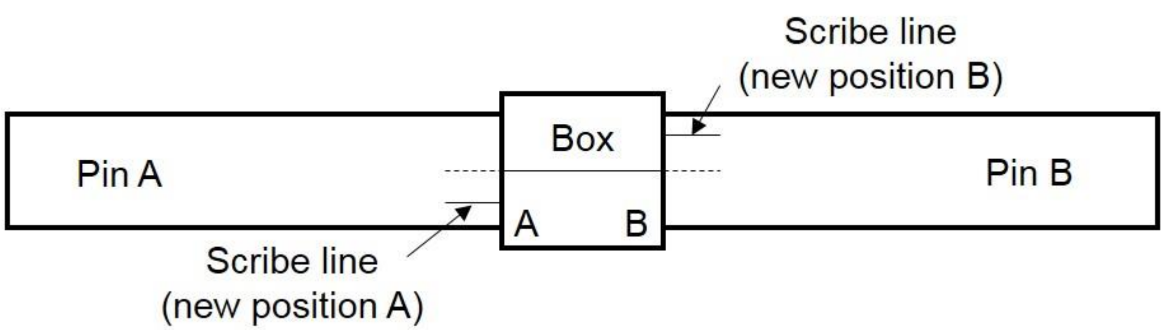
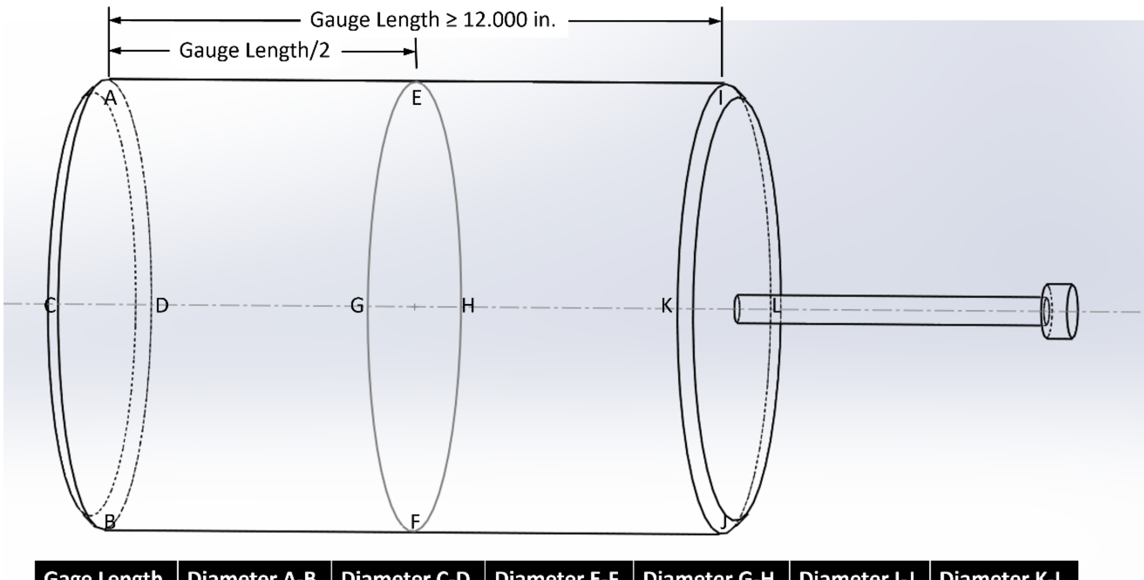


Figure 4—Example Connection Scribe Relative Position After Incremental Make-up Torque

5.2.4 Drift Testing

Drift testing shall be performed with a drift mandrel containing a rigid cylindrical portion conforming to the drift diameter specifications of the base pipe or the connection. The drift mandrel shall pass freely through the connection using a manual or power drift procedure. In case of dispute, the manual drift procedure shall be used. Drift test shall be performed in both directions.

Drift gauge length shall be a minimum of 12 inches (30.4 cm). Document the drift mandrel dimensions; one gauge length measurement and six diametrical measurements (at the top, middle and bottom of the drift and at two positions 90° apart). The ends of the drift mandrel extending beyond the specified cylindrical portion should be shaped to permit easy entry into the pipe. Pipe should be free of all foreign matter and properly supported to prevent sagging. Figure 5 shows a schematic of the drift gauge as described herein.



Gage Length	Diameter A-B	Diameter C-D	Diameter E-F	Diameter G-H	Diameter I-J	Diameter K-L

Figure 5—Drift Gauge Schematic

5.2.5 Connection Make-up Reporting

A brief report should be written summarizing overall specimen performance. Any torque-turn curves that were generated as part of this TPE should be included as an appendix to the report, as well as any relevant photos showing the condition of the connection components before initial make-up and between any subsequent make-ups in a galling resistance test.

5.2.6 Connection Bakeout

If the connection will be subjected to elevated temperature testing in subsequent TPEs the evaluator may subject the connection to a bakeout. Bakeout procedures in API 5C5 are the recommended starting point; however, the bakeout temperature and duration are at the evaluator's discretion.

The bakeout does not necessarily need to immediately follow final make-up of the connection. The evaluator may choose to perform the connection bakeout at any point before a TPE involving elevated temperature.

5.3 Casing Running and Installation Loading

5.3.1 Tensile Load Capacity

5.3.1.1 General

Given that many MFHWs incorporate extended-reach horizontal sections, evaluators may want to confirm the maximum tensile load capacity of the connection. Connections near surface may see high tensile loads during such operations as reciprocation during running, stimulation, or casing recovery.

This TPE consists of subjecting specimens to high axial load to simulate near-surface hanging load. If the test program includes production load TPEs in 5.5 testing of tensile load capacity may be incorporated there.

5.3.1.2 Test Set-up

This TPE will require specimens to be installed into a load frame capable of applying axial load to the specimen. The specimens should have endcaps attached to both ends; however, the end-caps do not need to have pressure sealing capability as internal fluid pressure is not part of this TPE.

The specimen should be instrumented with strain gauges to monitor strain. Information on the location and orientation of the strain gauges is provided in API 5C5 Section 5.8.5.4.1.

5.3.1.3 Test Matrix

The test matrix for tensile load capacity should incorporate a number of intermediate load steps to evaluate connection behavior under increasing axial load. The number of steps between zero load and maximum axial tensile load is at the discretion of the evaluator; however, it is recommended that at least one intermediate step be incorporated in this TPE to demonstrate connection stability at various loads. Table 1 shows an example of the tensile load capacity test matrix for an arbitrary T&C connection on 5-1/2 in., 17 ppf, P110 casing; for reference, the PBYS of the tube body for this example is 546,000 lb.

Table 1—Tensile Load Capacity Test Matrix Example for 5-1/2 in., 17 ppf, P110 T&C Connection

Load Step	Axial Load	Hold Time
	lb	minutes
1	130,000	5
2	275,000	5
3	490,000	5
4	275,000	5
5	130,000	5

5.3.1.4 Reporting

Reporting of the tensile load capacity TPE will consist of a time-history plot and a table showing the recorded loads at each load step. Supplementary observations of the test and specimen as a result of the test can be included in the report as well as any relevant photos taken during the TPE.

5.3.2 Rotating/Bending Cyclic Testing

5.3.2.1 General

Connections that are run through a build section can be subjected to multiple rotating/bending cycles if the string is rotated during either installation or well cementing activities. This cyclic loading can lead to crack initiation and propagation at areas of high stress concentration (e.g., thread roots). In addition to creating stress changes inside the connection, rotating/bending cycles may impact connection sealability later in the service life due to seal contact stress variation or connection make-up torque changes.

The purpose of this section is to define fatigue testing to evaluate structural behaviour of the connection under rotating/bending cyclic loading. For testing the performance of rotating/bending cyclic fatigue there are two approaches: evaluating specific well conditions or defining the fatigue resistance of the connection design.

The first approach is to test the connection under specific well conditions, which requires the following two inputs: estimated number of rotating/bending cycles for the well operations of interest, and estimated DLS experienced by the pipe during installation. The primary objective of this approach is to apply fatigue loading representative of field conditions before proceeding to other TPEs in the test program. The expectation is that the specified number of rotating/bending cycles will be applied without loss of structural integrity or fluid sealability. The second approach is to perform fatigue testing on a limited number of samples to failure or target cycles, to generate an S-N curve for the connection, which can then be compared with the material S-N curve. All rotating/bending cyclic loading tests rely on material properties (among other things) and will therefore have a statistical nature in their results. Consequently, the number of tested specimens should be carefully chosen to achieve reliable results. As demonstrated in Figure 5, the purpose of this approach is to obtain an S-N curve that represents the minimum number of cycles needed to produce failure in the connection within a certain level of statistical confidence (typically 97.5 %). This approach can be used to define a conservative combination of number of cycles and DLS for the first approach that may exceed expected well conditions. As the two approaches are different in nature, a proper definition of the purpose of the test program shall be performed by the evaluator beforehand. For instance, if the program is intended to simulate the well conditions, the worst DLS expected in the well should be selected and checked for the intended number of cycles for a selected connection geometry. On the other hand, if the S-N curve approach is followed, then at least three DLS representative of the application should be selected, typically using nominal connection geometry. Both approaches should account for the additional mean, tensile stress anticipated in the string during the running operation through the bent sections of the well.

The evaluator should acknowledge that the tests presented in this section are simplified representations of the conditions observed in the field. None of the testing devices mentioned in this section replicate the exact field conditions of MFHW, where bending, axial loads and torsion are performed simultaneously. Also, the following effects are not included in the scope of this testing procedure:

- vibrations and interactions between the string and wellbore wall,
- alternating applied torque while rotating,
- temperature changes,
- potential casing wear on pipe and connections, and
- corrosive and/or sour environments.

Fatigue tests parameters are defined in terms of applied maximum and minimum stresses observed in cyclic loading, which are represented in Figure 6.

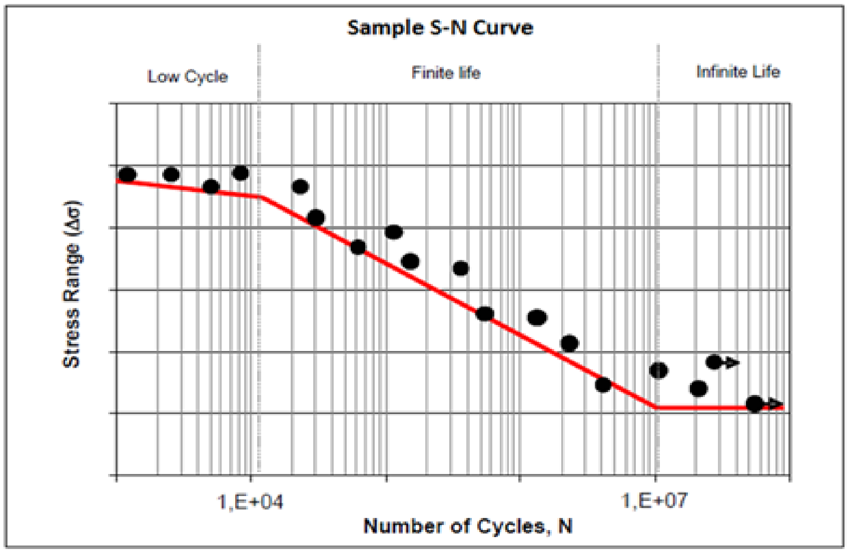


Figure 6—Example of an S-N Curve

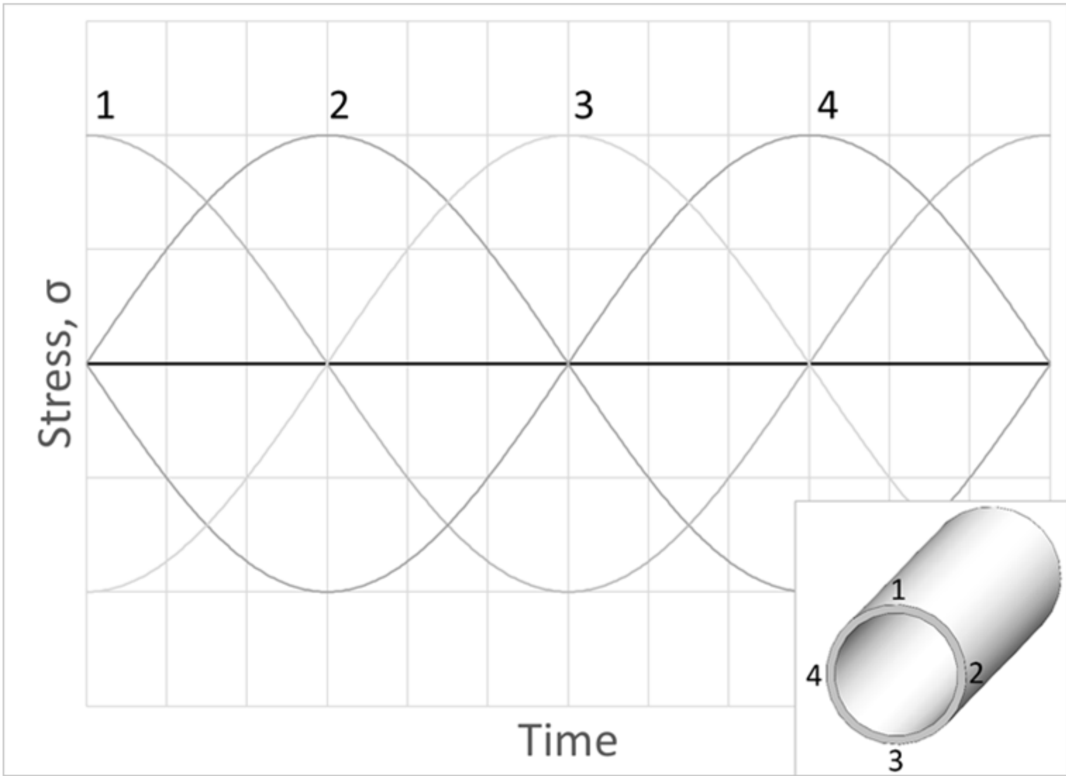


Figure 7—Schematic of Cyclic Loading

5.3.2.2 Test Set-up

5.3.2.2.1 General

Two typical set-ups for rotating/bending testing are briefly described below. Bending fatigue testing can be applied by rotating the sample (e.g., four-point bending) or exciting the sample to the first natural frequency without rotation (e.g., resonant rotating/bending fatigue). Both methods have advantages and limitations and should be selected based on the bending test requirements, and each can apply low and high dogleg and cycles/minute; however, the evaluator should select the method that best fits the application.

This section is not an all-inclusive list of acceptable test setups. Other methods are acceptable if they can be demonstrated that the required loading (e.g., number of cycles, DLS, and cycles/minute) can be applied in a controlled and measurable fashion.

5.3.2.2.2 Four-Point Rotating/Bending

Some well trajectories may motivate an evaluator to consider DLS beyond the capabilities of set-ups typically used for high-cycle rotating/bending testing. In such instances, use of an experimental set-up tailored for four-point bending may be necessary to achieve the desired DLS.

Performing four-point bending testing will require a dedicated test frame capable of applying a prescribed DLS to the specimen while simultaneously rotating the specimen. This section will focus on the four-point bending test apparatus to achieve the desired curvature.

For the four-point bending configuration, curvature is typically applied through contact points to the specimen incorporating bearings or bushings to allow the specimen to rotate without significant friction or wear. Note that the pipe body in contact with the four-point bend system may work harden over the span of the test program if the two adjacent contact points of applying and reacting the bending load are narrow.

Specimen rotation is typically achieved using a motor connected to the specimen through a universal joint or other flexible junction to allow the connection specimen to properly flex under curvature loading. Figure 7 shows a schematic of a typical low-cycle rotating/bending test system.

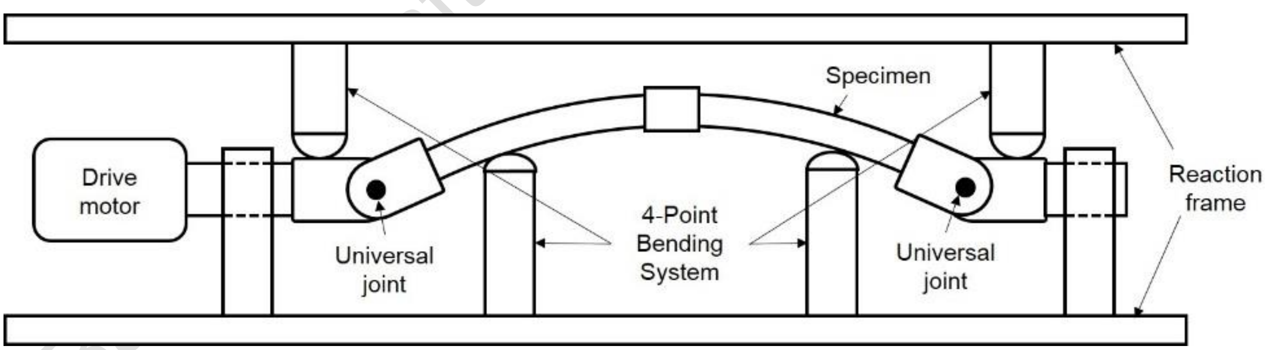


Figure 8—Example Four-Point Bending Test Apparatus Schematic

Figure 7 displays only one option of implementing a four-point bending test. Other options are permissible if the set-up can apply the desired magnitude of DLS while simultaneously rotating the specimen.

Specimens tested in four-point bending frames shall be sufficiently long to allow for the specimen to fit inside the test frame and have the contact points for the four-point bending system sufficiently far from the evaluated connections in the middle of the specimen. Specimens that are later subjected to combined load testing may be shortened to fit in the load frame. Furthermore, if there are concerns about localized material hardening on specimens because of the rotating/bending test set-up, the hardened sections may be removed if the remaining length of the specimen exceeds the minimum length specified in API 5C5, Fourth Edition, Section 6 (part 6.3.1). Figure 8 shows a schematic of specimen preparation for low-cycle rotating/bending testing and potential locations of localized material hardening.

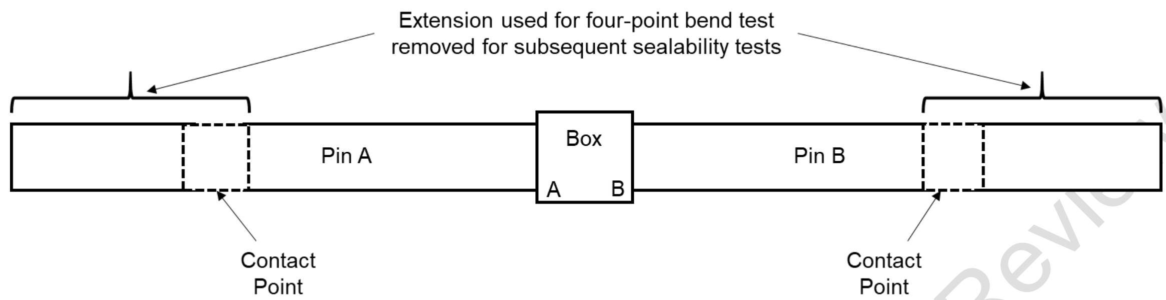


Figure 9—Four-Point Bending Specimen Contact Point Locations

Strain gauges are recommended to verify the pipe body stress and induced DLS during testing. It is recommended to prepare specimens with uniaxial strain gauges on both casing pups at locations specified in API 5C5, Fourth Edition, Section 5.9.3.4.

5.3.2.2.3 Three-Point Rotating/Bending

The three-point rotating bending configuration is like that of the four-point bending configuration, except that the bending is applied in a three-point configuration. A transverse force is applied to the axial midpoint of sample to achieve the desired bending strain, bending moment, or DLS. Each location around the pipe circumference undergoes a sinusoidal alternating bending stress with a maximum at the axial midpoint transverse force and zero at the outer transverse force locations. The distribution of the bending moment is ideally symmetric about the axial midpoint transverse force location. The connection being evaluated is typically placed at the axial midpoint location.

5.3.2.2.4 Cantilever Rotating/Bending

The cantilever rotating bending configuration is similar to the three-point bending configuration, except that the bending is applied in a three-point configuration. A transverse force is applied to the sample at a known distance from the point of interest to achieve the desired bending strain, bending moment, or DLS. Each location around the pipe circumference undergoes a sinusoidal alternating bending stress with a maximum at the gripped location and zero at the transverse force location, with the connection being evaluated placed close to the gripped location.

5.3.2.2.5 Resonant Rotating/Bending Fatigue

This machine uses a high-rate sinusoidal input to induce bending in the specimen. Since the resulting bending frequency can be applied near the natural resonant frequency of the specimen, many cycles can be applied in a relatively short time-frame. Although this method facilitates the execution of many cycles in a reasonable period, the system is sensitive to small variations in the set-up of the machine.

A typical test set-up includes a specimen supported at two locations away from the connection. These locations serve as the mode shape nodes where specimen deflection is near zero in any direction. The connection to be tested is usually at or very near the midpoint between two node points, where the maximum bending deflection occurs. One end of the specimen is attached to the apparatus applying the sinusoidal input. The alternating bending strain on both sides of the specimen connection should be monitored continuously during testing as well as used for control. The sampling frequency of the data acquisition system should be high enough to record the complete sinusoidal sample response. An example resonant high-cycle rotating/bending test set-up is shown in Figure 10.

Specimen length plays an important role in the determination of the natural resonant frequency, and therefore this length is defined by the laboratory based on their available test equipment. Specimens that are later subjected to combined load testing may be shortened to fit in the load frame as required by API 5C5, Fourth Edition, Section 6 (part 6.3.1).

Strain gauges are recommended to verify the pipe body stress and induced DLS during testing. It is recommended to prepare specimens with a ring of four biaxial strain gauges on both casing pups as specified in API 5C5, Fourth Edition, Section 5 (part 5.9.3.4). Note that the hoop strain gauges do not need to be connected for resonant rotating/bending fatigue testing.

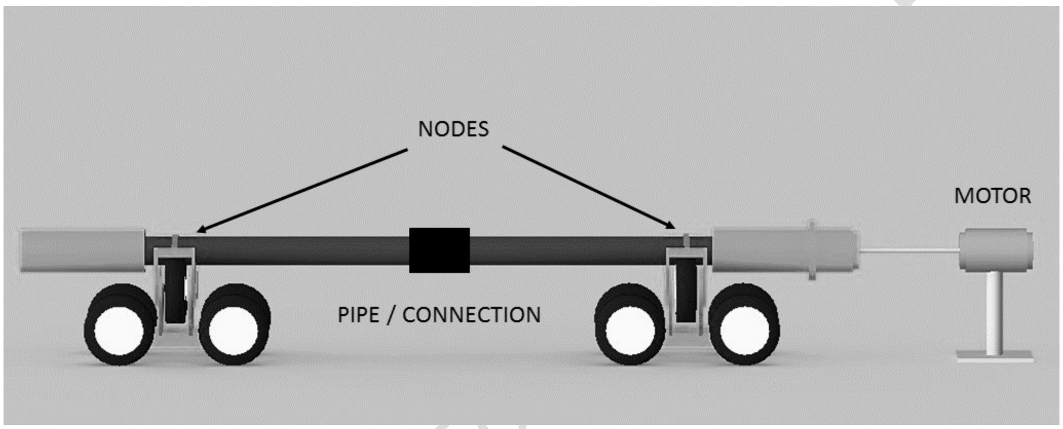


Figure 10—Example of Resonant Rotating/Bending Fatigue Test Apparatus Schematic

5.3.2.3 Test Matrix—Rotating/Bending Cycling Test

Choice of rotating speed requires a balance between: (1) replicating field conditions as accurately as practical and (2) achieving a reasonable test duration. Rotating speed may be increased relative to field conditions to reduce the overall test duration; however, care should be taken to not exceed a safe rotating speed above which excessive vibrations or other dynamic loads may occur. It is worth noting that the types of rotational operations envisioned by this standard encompass rotating while cementing or incidental rotations required to run casing to its intended depth; rotations incurred during drilling with casing are not covered by this standard.

The evaluator should establish both the curvature magnitude and number of rotations to which the specimen will be tested. Several rotating/bending cycle test sequences can be performed at multiple DLS (i.e., X number of rotations at one DLS in Sequence 1, Y number of rotations at another DLS in Sequence 2); however, a typical test under this TPE would consist of one test sequence with a single DLS. Table 2 shows an example test matrix for rotating/bending testing.

Table 2—Well Condition Test Matrix (Example)

Test Sequence	DLS	Number of Cycles
	deg/100 ft	
1	10	20,000
2	20	20,000

If the connection is to be tested under well conditions, it is expected to continue with sealability tests. In cases where no data (previous testing or S-N curve) exists to confirm that the required number of cycles can be safely achieved at the required dog-leg, some tests to failure at the required dog-leg (typically three specimens) are recommended to generate confidence on the results.

If the program is intended to define an S-N curve, the specimens should be tested at high, medium, and low stress ranges, and the evaluator should document the magnitude of these ranges. Due to the stochastic nature of the fatigue evaluation, a minimum of two different specimens are recommended at each level of stress range, for a minimum total of six specimens; however, the number of specimens is up to the evaluator. A reduced number of specimens affects the construction of the S-N design curve, as the same has to be built considering the standard deviation and could penalize the curve.

The alternating bending stress range and mean stress should be tested at stresses that are representative of the stresses connections would experience in the field. To maximize the value of each specimen, stress ranges should be chosen such that all specimens can be tested to failure. Table 3 shows an example of a program with three specimens (instead of the minimum of two) aiming to obtain an S-N curve either by reaching failure or a significant number of cycles far larger than the number of cycles expected in the field.

Table 3—S-N Approach Test Matrix (Example)

Test Specimens	DLS degrees/100 ft	Number of Cycles
1–3	8	To failure or 10 million cycles
4–6	15	To failure
7–9	20	To failure

5.3.2.4 Test Termination

Depending on the approach decided at the beginning of the program, the test terminates when either the target number of cycles is reached or a loss of structural integrity or fluid sealability occurs.

If a loss of structural integrity or fluid sealability occurs, the specimen and especially the specific area around the connection should be investigated for cracks and other anomolies. Cracks can be detected by means of non-destructive evaluations (e.g., magnetic particle inspection); if necessary, the connection may be broken out for further inspections. If the specimen has fractured, the nature of the fractured cross section should be documented in the report.

If the number of cycles was achieved without loss of structural integrity or fluid sealability, the specimen may continue with subsequent TPEs. Review and record the position of the scribed line to check if the connection position changed during the test program (i.e., did the connection make-up further or back-out). In the event of incremental make-up, proceed with the remainder of the test program. However, if a connection has changed position because of a rotating/bending test, the change in connection position shall be documented in the report, the party(ies) involved in the test program should decide the next steps, as the conditions at the beginning of the test have changed.

In the event of connection back-out, the decision may be made by the party (parties) to restore the original make-up condition of the connection. In this case there are two options:

1.) Restore connection to original make-up torque or scribed-line position

2.) Break-out the connection, clean and inspect the connection for damage, and subsequently make it up with the same torque target or scribed-line position as the original assembly. If inspection of the connection reveals damage, the specimen shall be removed from the test program.

It should be noted that restoring the connection to its original make-up will alter the connection state to which all previous tests have been conducted, including stresses, thread compound distribution, and changes as a result of fatigue testing, etc.

5.3.2.5 Rotating/Bending Testing Combined Loading Options

5.3.2.5.1 General

Connections that are run into MFHWs may see combined loads beyond just rotating/bending loads because of factors such as casing string weight, hydrostatic pressure, borehole friction, and tortuosity. Evaluators may wish to include some or all the auxiliary loads in the following sections as part of the rotating/bending TPE; however, care should be taken to understand the combined loading effects and their impact on the overall stress condition in the pipe body and connections.

All of the following combined loading options—axial load, torque, and internal pressure—are optional test elements and may not be applicable to all field conditions or operations. When the applicability is uncertain, consultation between the evaluator and an end-user(s) is encouraged.

5.3.2.5.2 Applied Axial Load during Rotating/Bending Testing

Evaluators wanting to incorporate applied axial load during their rotating/bending TPE should ensure that the frame or testing apparatus used to perform the rotating/bending TPE has capability to both apply and react axial load. Example methods of applying axial load include a hydraulic cylinder or screw jack in line with the test specimen, or internal pressure by means of CEPL, but other means are also acceptable. Note that there may be limitations to the amount of axial load that can be applied depending on the rotating/bending test set-up.

Axial load will affect the overall stress profile in the pipe body and connection(s) of the specimen. It is the responsibility of the evaluator to understand the impact that the combined loading of axial load and rotating/bending will have on the specimen, especially in localized areas of stress concentration inside the connection(s). Axial load will also affect the overall specimen curvature so evaluators should measure the curvature in accordance with 5.3.2.3 after axial load is applied and make corrections to the curvature as needed prior to rotating the specimen.

5.3.2.5.3 Applied Torque during Rotating/Bending Testing

Evaluators wanting to incorporate applied torque during the rotating/bending TPE should ensure that the test frame has sufficient torsional rigidity to apply torsion loads on the specimen. For example, torque can be applied to the specimen by connecting a hydraulic motor to the opposite end of the specimen from the motor driving the rotation of the specimen. The opposing motor will create drag on the rotation and a resultant torque load through the specimen. Specimen torque can be calculated from the output power of the drag motor. Care should be taken to ensure that the combined effect of the driving and opposing hydraulic motor does not affect the intended stress state of the connection during the evaluation causing rotations either in the direction of make-up or break-out. To check the relative position of pin and box it is recommended to scribe a line between pin and box and check after the test if the relative position has changed.

If applied torque is incorporated with applied axial compression, care should be taken to prevent out of plane bending as this combination of loads can result in helical buckle formation.

5.3.2.5.4 Applied Internal Pressure during Rotating/Bending Testing

Evaluators wanting to incorporate applied internal pressure during their rotating/bending TPE should ensure that the specimen endcaps can maintain liquid sealability up to the target pressure of the TPE. The pressurizing medium should be liquid.

Once the target pressure is achieved it should be locked in place and monitored or checked after the test is completed. Note that concession for some pressure drop should be considered because of disconnecting and reconnecting the specimen to the pressure manifold.

Internal pressure will affect the overall stress profile in the pipe body and connection(s) of the specimen in both the hoop and axial (because of CEPL) directions. It is the responsibility of the evaluator to consider the impact that the combined loading of internal pressure and rotating/bending will have on the specimen, especially in localized areas of stress concentration inside the evaluated connection(s).

5.3.2.6 Reporting

The report for a rotating/bending TPE shall contain the following data related to the test program:

a) type of approach followed (field condition or S-N curve determination);

b) type of equipment used for the test (resonant, four-point bending, other);

c) number of specimens tested, and number of tests performed per DLS or stress range;

d) DLS or stress ranges evaluated;

e) mean stress level(s) used, if applicable;

f) number of cycles achieved during the test;

g) reason for finishing the test (failure, completion of number of cycles, etc.);

h) results of crack evaluation (magnetic particles, etc), if applicable, including pictures;

i) if cracks were found, position (pipe body, pin and/or box, etc.) and pictures of the crack(s);

j) material test certificates or mechanical properties of each of the specimens tested;

k) graph of stress range or DLS applied vs number of cycles; and

l) any changes in scribe line position.

5.4 Stimulation Loading

5.4.1 General

The hydraulic fracturing process can subject casing to very high internal pressure at a rapid rate, which may have a ballooning effect on the casing even when supported by cement. Modern MFHWs can repeat the hydraulic fracturing process hundreds of times during the stimulation process, and this cumulative pressure cycling may have an impact on the structural integrity of the casing and connections. As such, evaluators may choose to recreate this condition in the test program by subjecting specimens to several pressure cycles with very rapid pressure increases to simulate the hydraulic fracturing process.

5.4.2 Internal Pressure Cycling

5.4.2.1 Principle

This TPE is designed to simulate the effect that the hydraulic fracturing process has on connections. The specimen will be subjected to multiple pressure cycles at a frequency, magnitude, and duration established by the evaluator. Applying a DLS during stimulation loading is encouraged, and including an axial load is an optional aspect of this TPE.

5.4.2.2 Test Set Up

Performing internal pressure cycling requires a high-pressure liquid pumping system connected to the specimen by a high-pressure manifold. Evaluators should try to achieve pressurization rates as high as possible during the test and document these rates in the form of a pressure vs. time plot in the report. Although the pressurizing medium is liquid, it is recommended that filler bars are installed in the specimen to reduce the amount of pressurized fluid in the event of specimen catastrophic failure.

Test pressure-rated endcaps should be used for internal pressure cycling, either threaded or welded to the specimen. Evaluators that want to eliminate the axial load because of CEPL can install the test assembly into a load frame to counteract the pressure-induced load. The counteraction can be active in which the load frame is controlled to match the axial tension load build-up because of pressure increase with a corresponding axial compression load, or it can be passive in which the load frame is set to displacement control and the frame prevents elongation of the specimen.

5.4.2.3 Specimen Preparation

Specimens subjected to the internal pressure cycling TPE do not need much modification from previous TPEs. Strain gauges are not required for this TPE; however, it may be desired by the evaluator to monitor hoop strain over the course of the test to check for any pipe body yielding because of the multiple pressure cycles, and in this case strain gauges used in prior TPEs can be reconnected to monitor strain.

5.4.2.4 Test Matrix

The test matrix for the internal pressure cycling TPE is established by the evaluator. The target pressure should be consistent with pressures used in hydraulic fracturing applications but should also consider the material property limits of the test specimen; inducing stresses that approach the material yield strength of the test specimen should be avoided.

The rate at which pressure is increased before a hold at target pressure and the rate at which it is bled down after shall be established by the evaluator. Rates and pressures do not need to be consistent throughout the entire test matrix, evaluators can choose to have two or more sequences of pressure cycling in the test matrix at different pressure magnitudes, rates of increase and decrease, and duration. Minimum pressure does not need to be zero but should be less than 20% of test pressure. Evaluators should strive for a minimum number of pressure cycles for this TPE that is representative of field conditions.

Table 4 shows an example test matrix for internal pressure cycling TPE over four cycles for an arbitrary T&C connection on 5-1/2 in., 17 ppf, P110 casing. For reference, the MIYP of the tube body for this example is 10,640 psi.

The hold times in Table 4 are only suggestive but are representative of typical hold times when structural integrity is the primary concern. Lastly, the evaluator may wish to perform the test at elevated temperature representative of certain reservoir conditions in MFHW applications. Extra caution should be taken if testing at elevated temperature with water; the use of a heat-resistant oil is recommended. The evaluator can set the test temperature to meet their requirements but note that sufficiently elevated temperatures can affect material properties of the test specimen. Figure 11 shows the pressure profile over time of the example test matrix.

Table 4—Internal Pressure Cycling TPE Example Test Matrix

Cycle	Cycle Point	Pressure	Hold Time	Temperature
		psi	minutes	
1	1.1	1,600	5	Ambient
	1.2	9,000	5	Ambient
2	2.1	1,600	5	Ambient
	2.2	9,000	5	Ambient
3	3.1	1,600	5	Ambient
	3.2	9,000	5	Ambient
4	4.1	1,600	5	Ambient
	4.2	9,000	5	Ambient

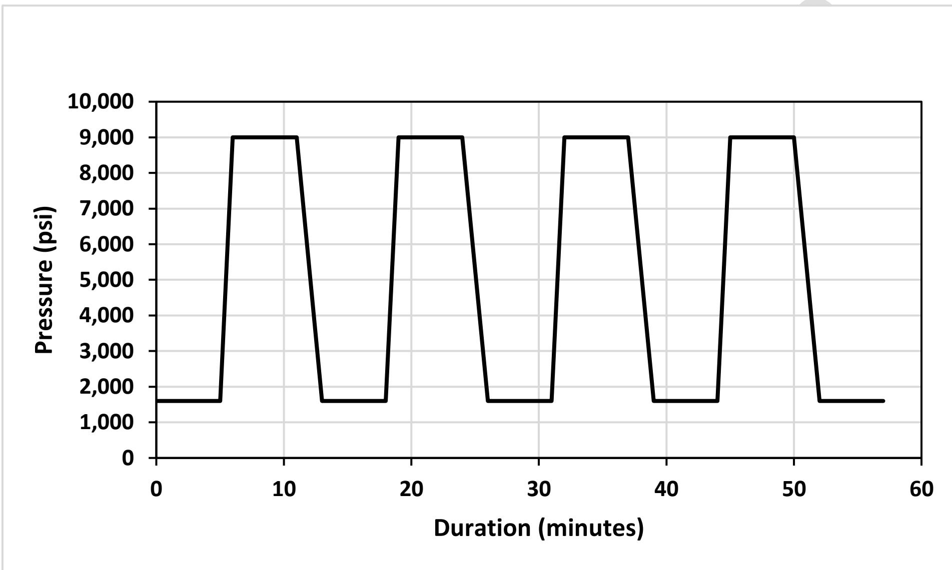


Figure 11—Pressure vs. Time Plot of Example Internal Pressure Cycling Test Matrix

5.4.2.4.1 Applied DLS During Internal Pressure Cycling

The most severe loading during stimulation often occurs in the build section, where the internal pressure of stimulation combines with bending stresses due to DLS. As such, the application of a constant DLS during stimulation loading is encouraged. In this circumstance, the evaluator can use a four-point or uniform bending system similar to the setup employed in API 5C5, Series B. The DLS can be locked in prior to testing by the evaluator. Care should be taken by the evaluator to pay attention to the cumulative stress of internal pressure cycling and curvature on the maximum tensile fiber on the outside curve of the specimen, as the combined load may approach or exceed the material yield strength for high DLS.

5.4.2.4.2 Applied Axial Load During Internal Pressure Cycling

Evaluators may want to assess internal pressure cycling performance of connections where axial load may be present. Axial load can be applied by the load frame in one of two ways: actively by setting the target load in the frame and then programming the load frame controller to compensate for the CEPL in the specimen, or passively by targeting a displacement that results in the desired target load. In either case, the target axial load (in either tension or compression) is established by the evaluator.

If axial compression is selected by the evaluator, bracing or other means should be installed around the specimen to prevent the specimen from buckling during testing. Care should be taken by the evaluator to pay attention to increasing strains for higher axial loads, as the combined load may approach or exceed the material yield strength for higher axial loads.

5.4.2.4.3 Applied Thermal Cycles During Internal Pressure Cycling

Well stimulation can introduce temperature changes due to differences between the surface temperature of injected fluid and the in-situ temperature of the tubulars (usually assumed as geothermal). Replicating these temperature changes in a laboratory environment is extremely difficult due to the high injection rates during stimulation operations; such high rates of temperature change in the field are sometimes referred to as “thermal shock.” Thermal shock is beyond the scope of this standard. Evaluators are free to replicate temperature changes to the best of their ability as part of the stimulation load TPE, but it should be recognized that such thermal cycling may not be an accurate representation of field conditions.

5.4.2.5 Reporting

The report for the internal pressure cycling TPE shall include the number of pressure cycles the specimen was tested to, magnitude and rate of increase/decrease in pressure and duration at target pressure, and test temperature (if elevated). Supplementary observations of the test and specimen because of the test can be included in the report as well as any relevant photos taken during the TPE.

5.5 Production Loading

5.5.1 General

Production loads for MFHW cover a wide range of potential load combinations. API 5C5 has procedures to assess connection sealability and structural performance through a series of complex test programs over different CALs. This standard does not include separate test procedures from API 5C5 for the evaluator to use when assessing production loading performance for connections in MFHW; however, the test procedures are referenced as a guideline. This standard does not mandate sealing performance criteria of connections as API 5C5 does; consequently, the evaluator, with optional input from an end-user(s), should determine the appropriate combination of procedures to address anticipated production loads.

Some of the connections that may be subjected to test programs created from this standard may have already been tested to API 5C5. Regardless of past connection performance, it is recommended that production load TPEs are incorporated into an overall connection test program for MFHW as the cumulative effects of the previous tests (casing running/installation, anticipated torque, and stimulation loading) may have an impact on production loading performance.

5.5.2 Principle

Production loading TPEs assess the performance of connections under combined pressure, axial load, bending, and temperature in conditions representative of MFHW operations. As stated previously, it is up to the evaluator to create the TPEs from various test procedures from API 5C5, sealability tests (Series A, B, and C) using the following high-level suggestions as a starting point:

a) If evaluators want to perform tests to assess alternating external and internal pressure in combination with axial load and temperature performance of the connection, they can create a TPE using the procedures for API 5C5, TS-A tests.

b) If evaluators want to perform tests to assess internal pressure in combination with axial load, DLS, and temperature performance of the connection they can create a TPE using the procedures for API 5C5, TS-B tests.

c) If evaluators want to perform tests to assess thermal cycle performance of the connection in the presence of internal pressure and axial tension, they can create a TPE using the procedures for API 5C5, TS-C tests.

5.5.3 Test Set-up

The test set-up for production load TPEs will vary depending on what production loads are considered. Evaluators are advised to refer to API 5C5, Fourth Edition, Section 5 for the various test set-up requirements and guidelines for each of the production load tests.

5.5.4 Specimen Preparation

Evaluators are recommended to refer to API 5C5, Fourth Edition, Section 6 for the guidelines and requirements of specimen preparation for production load tests such as leak collection devices.

5.5.5 Test Matrix

Evaluators are recommended to refer to API 5C5, Fourth Edition, Section 7, for the guidelines and requirements of test matrix development and calculation for production load tests. This standard does not provide performance or acceptance criteria for production loads, nor pressure media; it is up to the evaluator to define these aspects of the test matrix, whether from API 5C5 or from fit-for-purpose criteria based on the production load TPE they have developed.

5.5.6 Reporting

Production load TPE reports shall include all relevant TPE information to explain the performance of the connection. The reporting requirements from API 5C5 Fourth Edition, Section 9 may serve as a guideline.

5.6 Limit Load Testing

5.6.1 General

Limit load testing is intended to apply loads to the connection up to failure. Failure is typically defined as the inability of connection to seal or to maintain structural integrity, as described in 4.2.

According to the information in 4.2, this document does not specify acceptance criteria for limit loads tests. In a typical scenario, loads are increased until a loss of sealability and/or structural integrity is obvious or until the limits of the testing apparatus have been reached. The geometry selection for limit load testing is in accordance with 4.3. For safety reasons, limit load pressure tests shall be conducted with a liquid pressure medium.

A good reference for threaded connection limit load testing can be found in API 5C5. The four recommended limit loads paths most relevant to this standard are:

— Limit Load Test Path 1 - High Internal Pressure with Tension Increasing to Failure

— Limit Load Test Path 2 - Compression with External Pressure Increasing to Failure

— Limit Load Test Path 3 - Tension Increasing to Failure

— Limit Load Test Path 4 - Tension with Internal Pressure Increasing to Failure

Beyond the scope of API 5C5, there are some (not all-inclusive) limit load tests that can be conducted to help evaluate a connection for MFHW service, such as torque-, bending- or fatigue-to-failure.

5.6.2 Torque to Failure

The limit load should be determined by the following procedure.

a) Apply torque to the test sample in accordance with 5.2. Consideration should be given to how the make-up condition (pin-and-box, floating, etc.) reflects the intended field conditions.

b) Increase torque beyond the rated maximum recommended torque for that connection type. The limit load can be evaluated as:

    1) change in the torque-turn relationship of the connection (e.g., non-linear torque-turn plot beyond shoulder torque), or

    2) loss of drift according to the applicable drift specification.

Regarding change in torque-turn relationship, conversations should be held with the manufacturer as to what constitutes a significant change in the torque-turn relationship. This definition could depend on the specimen geometry chosen in accordance with 4.3.

The torque beyond the rated maximum should be applied in increments determined by the evaluator. After each increment of torque is applied, the sample should be drift tested. Smaller increments will provide a more precise measure of the torque at which loss of drift occurs. As an additional option, multiple drift sizes could be used so that a relationship between applied torque and allowable drift can be developed. Such information could be useful to an end-user attempting to determine the maximum diameter of tools that can be run through an over-torqued connection.

5.6.3 Bending to Failure

The limit load should be determined by the following procedure.

a) Use a specimen geometry with the worst-case performance as defined in 4.3

b) Test set-up is similar to that in 5.3.2.2.2, apply low liquid internal pressure (e.g., 100 psi) and monitor leakage via the appropriate visual means as defined by API 5C5.

c) Apply increasing bending load to specimen failure. The test may be terminated when any of the following apply:

    1) loss of sealability in accordance with 4.2, or

    2) loss of structural integrity in accordance with 4.2.

Alternative termination criteria can be established in agreement between the evaluator and end user.

After the end of the tests the evaluator may check for loss of drift according to the applicable drift specification and report results for information only (i.e., not a test criterion).

Report the results of each test on a separate datasheet and include representative photos of the failure in the connection test report.

5.6.4 Bending with Internal Pressure to Failure

The limit load should be determined by the following procedure.

a) Use a specimen geometry with the worst-case performance as defined in 4.3.

b) Bend the pipe using similar set-up as that in 5.3.2.2.2. The amount of bending curvature shall be defined by agreement between the evaluator and end-user(s)

c) While maintaining a constant bending load, apply increasing internal pressure. The test may be terminated when any of the following apply:
   1) loss of sealability in accordance with 4.2, or

   2) loss of structural integrity in accordance with 4.2.

Alternative termination criteria can be established in agreement between the evaluator and end user.

Report the results of each test on a separate datasheet and include representative photos of the failure in the connection test report. The results of this limit load test could provide the end-user(s) with an estimate of the maximum stimulation pressure that could be applied to a connection in an extreme dog-leg.

5.6.5 Fatigue to Failure

The limit load should be determined by fatiguing the sample until it reaches one of the failure modes described in 4.2. The type of loading can be rotating/bending cyclic testing (see 5.3.2.2), or other means established in agreement between the evaluator and end user.

Details of the test set-up, loads applied, and the number of cycles until failure shall be reported in the connection test report.

Annex A
(informative)

Examples of Creating a Customized API 5SF Test Program

A.1 General

Evaluators using API 5SF are given the flexibility to create a test program that suits their specific needs. There are no minimum number of connection test specimens, nor are there a required series of TPEs that need to be included in any test program. Two example cases are included in this section to demonstrate how an API 5SF program can be configured to assess connection performance based on different objectives for the evaluation. The example programs constructed from the various TPEs of API 5SF address two different user needs:

a) an operator with an extended reach well, and

b) a connection manufacturer creating a new semi-flush connection.

A.2 Example 1—Operator with Extended Reach Well Design

An operator that has an extended reach well design involving significant DLS in the build section. The cementing program requires both rotation and reciprocation of the casing string to improve cement quality. The extended reach horizontal section of the well has 80 fracture stages, and the operator wants to use a monobore well design (i.e., same connection, casing, and casing weight run from surface to TD). The operator is running cement through the production zone; however, they are concerned with cement voids in the long horizontal section (if voids are present, fracture fluid may propagate along the production string, subjecting intervals of the casing to high external pressure). The formation temperature is 300 °F, so material property performance of the casing may be affected.

The evaluator creating a test program should consider a range of TPEs to address various aspects of the well design and the critical loads that, in succession, may impact the overall performance of the connection in service. The number of connection test specimens should be sufficient to give the evaluator confidence in connection performance in different locations in the well, or confidence in the repeatability of the test results.

The evaluator has decided to construct a test program for three connection test specimens. Each of the specimens is subjected to a sequence of TPEs that address connection performance in different sections of the well. Figure A.1 shows the sequence of testing for each connection test specimen.

Specimen 1 is the connection test specimen representing a connection near the wellhead that is not run through the build section of the well and therefore does not require rotating bending testing; however, it does see the stimulation and eventual production loads. Note that the evaluator has elected not to apply a DLS to the production load TPE to be consistent with the well location of the targeted connection. After the production load test, the evaluator removes the connection specimen from the test frame and torques it to failure; first to a level to establish the torque threshold to maintain drift, and then further to structural failure of the connection and/or pipe body.

Specimen 2 is a connection that is along the build section of the well; this connection sees many rotating/bending cycles and remains in a bent configuration for its service life. After the rotating/bending test of 50,000 rotations at a DLS of 15°/100 ft, the connection specimen is subjected to a modified API 5C5, Series B test program at elevated temperature (target temperature 300 °F). After completing the production load test, the connection specimen is held in the bent configuration and internally pressurized to failure.

Specimen 3 represents the connection in the production zone, which implies that it has been run through the build section and is now in a deviated/horizontal configuration. It goes through essentially the same test matrix as Specimen 2 with the exception that during the production load TPE the connection specimen is straight. The evaluator chooses to not perform a limit load test on Specimen 3 having gathered enough supplementary failure information about the connection design from the previous two specimens.

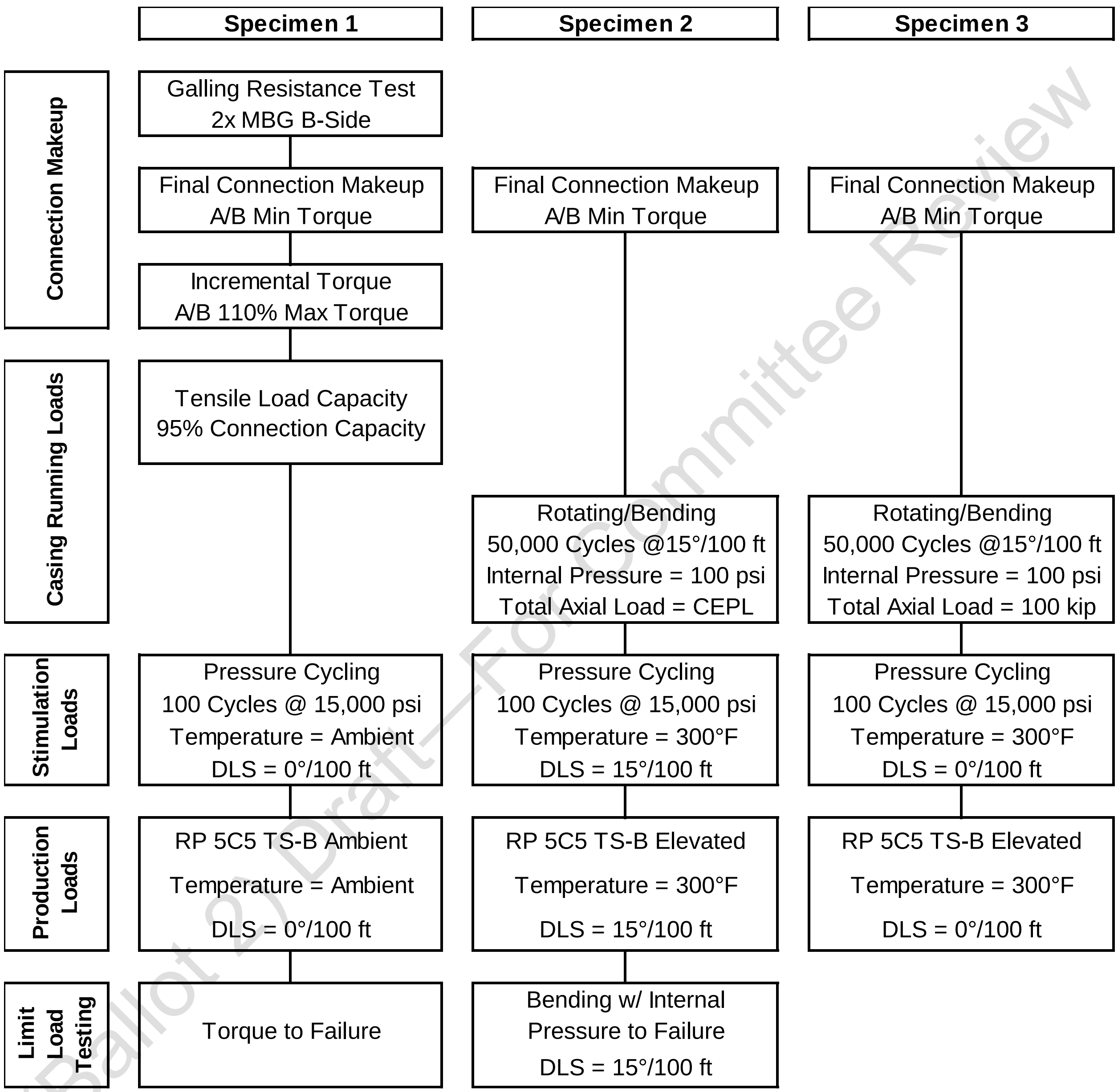


Figure A.1—Example Test Program 1 (Extended Reach Well Operator)

A.3 Example 2—Connection Manufacturer with a new Semi-Flush Connection Design

The second test matrix example represents a connection manufacturer that has developed a new semi-flush connection design and wants to assess the performance of this connection design in MFHW applications. In this case, the manufacturer wants to evaluate the effects of combined rotating and bending loading on connection performance, and they also want to know how many rotating/bending load cycles the connection design can withstand before failure. As it is a preliminary assessment of connection performance, the manufacturer does not want to invest too many specimens in the initial testing and has settled on a two-specimen test matrix, as the design may change based on the outcome of the first few tests. Figure A.2 shows the test matrix the evaluator developed to address the needs of the connection manufacturer.

In this example, the evaluator subjected Specimen 1 to a galling resistance test in alignment with the guidelines of API 5C5, followed by a final make-up. The connection specimen was installed in a fatigue bending frame to perform a rotating/bending test up to 40,000 cycles at a prescribed DLS of 20°/100ft. The connection specimen was then subjected to 100 pressure cycles using water from low pressure to 15,000 psi while maintaining the prescribed curvature. The specimen was then installed in a load frame where an API 5C5, TS-B (elevated) test followed by a TS-B (ambient) test were performed. After all load frame testing was completed, the connection specimen was removed from the frame and torqued to failure.

The test program for Specimen 2 was created to give the connection manufacturer information about the fatigue performance of the connection design. Consequently, it was subjected to the same low-cycle rotating/bending TPE as Specimen 1 and then, after 40,000 cycles, was subjected to a high-cycle rotating/bending test, where it was tested to the greater of 500,000 rotating/bending cycles or until failure. No stimulation or production load testing was done on this connection specimen.

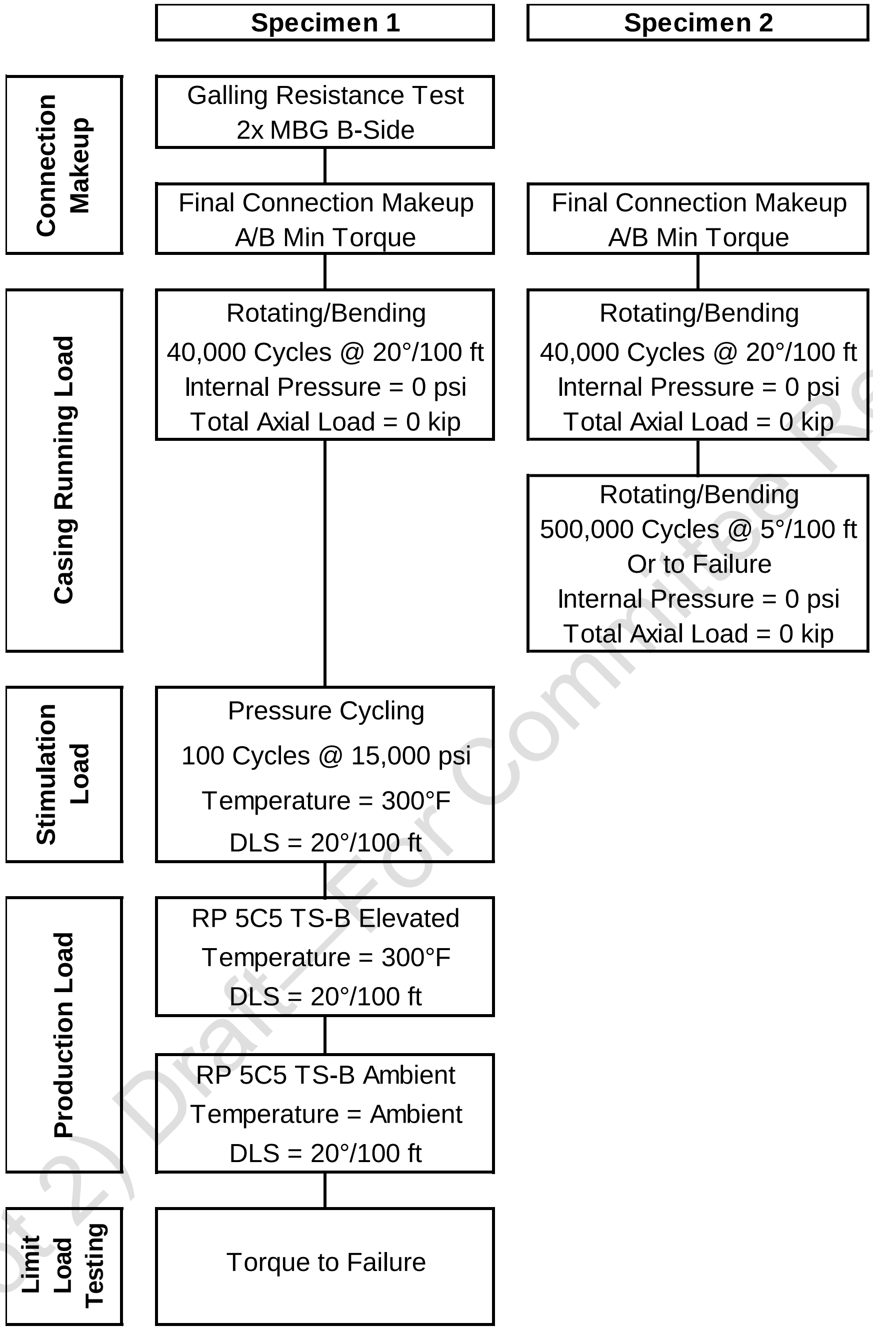


Figure A.2—Example Test Program 2 (Semi-Flush Connection Manufacturer)

Bibliography

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