

# New BHA connection enhances fatigue performance for difficult drilling applications

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## ADVANCEMENTS IN DRILLING

tubulars are rapidly evolving to meet the energy industry's desire to drill deeper, longer-reach and more cost-effective wells. A great deal of new technology for drillpipe connections has increased torsional capacity and improved fatigue life for critical applications. There has been a serious lack of new developments in BHA connection technology since the introduction of stress relief features (SRF) and cold rolling of thread roots.

The predominant use of American Petroleum Institute (API) NC and Regular connections within the BHA serves to maximize the compatibility of the industry's inventory of BHA tools but does not necessarily optimally address the cyclic loading conditions that exist within every BHA. Fatigue continues to be the most common failure mode in the BHA and represents one of the most costly drilling problems, often requiring lengthy trips, open hole fishing and sidetrack operations.

In order to address this industry need, a comprehensive two-year program to design, develop and test a highly fatigue-resistant drill collar connection was pursued. As a result, a new connection was developed with test results that indicate at least a nine-fold improvement in fatigue performance when compared with standard API connections.

This new connection, which was developed for the drill collar section of the BHA in an intelligent drill string network, incorporates a secondary internal shoulder that houses inductive coils to permit telemetry transmission across the drill collar connection.

Although originally pursued to enable data transmission through the BHA, during the course of the development project, it was discovered that this new connection provides a dramatic increase in fatigue resistance to cyclic loads. Additional benefits from the optimized design are gained in handling and repair performance.

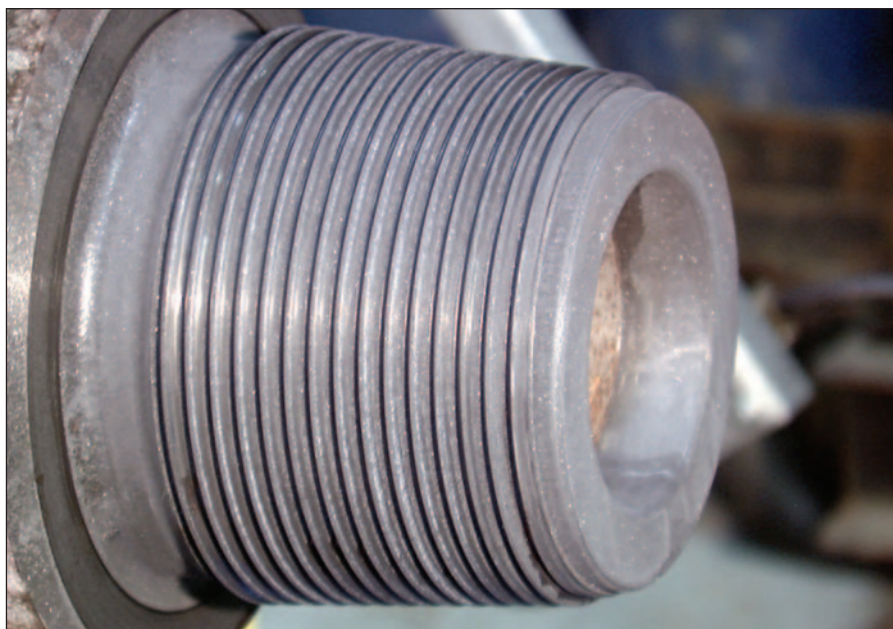


Figure 2: The 3-in./ft taper of the enhanced connection (bottom) is visually evident when compared with the 2-in./ft taper of the API 6 5/8 Reg (top). The enhanced connection's course 3 TPI thread form is also visual compared with the 4 TPI thread form of the API 6 5/8 Reg.

## CONNECTION DESIGN

As mentioned above, a primary design requirement for the new drill collar connection was a secondary (internal) make-up shoulder to permit data transmission through the BHA in the intelligent drillpipe network. Double-shoulder, rotary shoulder connections (RSCs) have been available for about two decades and provide increased make-up torque (MUT) and torsional strength when compared with API single-shoulder connections.

The design team initially focused on drill collar sizes for long intermediate 12 1/4-in. hole sections. For the 12 1/4-in. hole size, the most common collar configuration pairs 8-in. outside diameter (OD) with 2

13/16 in. inside diameter (ID) and API 6 5/8 Reg. connections. To maintain the typical drift ID for this size collar and allow for the 3/16-in. diameter data cable that runs along the collar ID, the telemetry drill collar design for 12 1/4-in. hole sections needed to combine an 8-in. OD with a 3-in. ID.

Double-shoulder connections are generally designed for streamlined drillpipe tool joints with reduced OD and increased ID. Requirements to provide bit weight dictate larger ODs and smaller IDs for drill collars, also dictating higher MUTs for the double-shoulder connection. Development of the 8-in. OD X 3-in. ID drill collar double-shoulder connection required a new design that would have near equivalent MUT requirements

Connection Type	Taper (in./ft)	Threads per inch (TPI)	Thread root geometry (in.)	Torsional strength (ft-lbs) <sup>3</sup>	Tensile strength (lbf) <sup>3</sup>	Min MUT (ft-lbs) <sup>3</sup>	Revolutions from stab to hand tight make-up	Axial recut loss (Pin) (in.)	Axial recut loss (Box) (in.)
API 6-5/8 Regular <sup>1</sup>	2	4	0.025	81,120	1,601,955	50,700	6.22	3.169	1.776
DC58 <sup>2</sup>	3	3	0.060 and 0.065	99,793	1,653,446	62,371	2.757	2.043	1.208
<b>Difference</b>	<b>1</b>	<b>-1</b>	<b>0.035 and 0.040</b>	<b>18,673</b>	<b>51,491</b>	<b>11,671</b>	<b>-3.463</b>	<b>-1.126</b>	<b>-0.568</b>

Notes:  
 1. 8 in. OD X 3 in. ID API 6-5/8 Reg. connection with API pin SRG and API BBB  
 2. 8 in. OD X 3 in. ID DC58 with pin SRG.  
 3. Based on 100,000 psi material yield strength

Table 1 – Changes to the taper and TPI reduce revolutions to make-up by over three turns. Axial loss of material upon recut is also noted. The enhanced connection requires about 23% more make-up torque due to its double-shouldered design, still within rig make-up equipment capabilities.

as that of an API 6 5/8 Reg. drill collar connection.

The solution to this problem was found in an increased thread taper, which made the pin nose cross-sectional area adequate for the inductive coil yet small enough to limit the make-up torque. Throughout the development program, various connection designs were evaluated with different pitch diameters, stress relief features and various thread profiles. The final design resulted in a 3 in./ft taper (steeper than the API 6 5/8 Reg. connection taper of 2 in./ft).

Since fatigue failures in drill collars occur in the connection, another requirement for the enhanced connection design was improved fatigue performance over the API 6 5/8 Reg. connection. Designing a generous root radius by combining two design features, detailed below, reduced stress concentration in the thread roots:

- First, the number of threads per inch (TPI) is reduced to 3, fewer than on any standard API drill collar connection, making it a very coarse thread form.
- Second, a thread root feature including dual radii (see Figure 1 above) is installed that further enlarges the thread root radius and reduces the stress concentration at this critical location.

The design also incorporates well-known and widely used fatigue life enhancing features, such as a pin stress-relief groove and superficial cold rolling of thread roots. Table 1 compares the general characteristics of the enhanced connection with the API 6 5/8 Reg. connection, and photos of the enhanced connection next to the API 6 5/8 Reg. connection are presented in Figure 2.

In addition to the superior fatigue resistance, the connection design provides other improvements:

- Fewer revolutions from stab to final make-up.

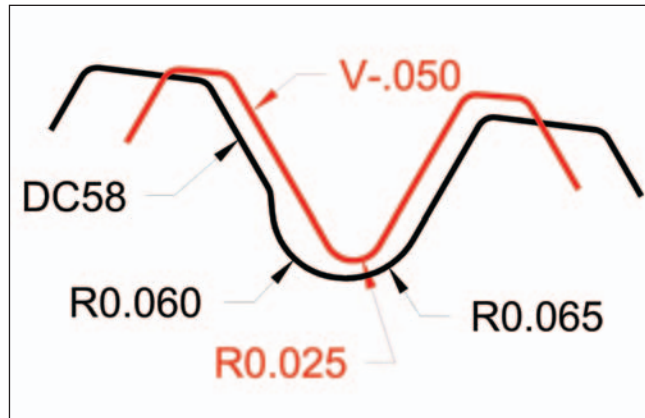


Figure 1: The enhanced connection has a double root radius that is larger than the V-0.050 thread root radius of the API 6-5/8 Reg. connection. Increasing the root radius 140 percent reduces stress concentration in the thread root.

- Reduced material loss from recut when compared with standard API connections.

Nonlinear finite element analysis (FEA) was performed to qualify the design and verify stress distributions in the connection.

### CONNECTION TESTING

The laboratory test program was focused to gauge and substantiate the new connection's fatigue life. Harmonic fatigue testing of the enhanced connection was conducted against API 6 5/8 Reg. connection with both pin stress-relief groove and box boreback as the industry benchmark. Both connections were 8-in. OD x 3-in. ID and had cold rolled thread roots. Three enhanced connection samples and five API 6 5/8 Reg. samples were tested under equivalent bending stress.

The bending stress level was chosen based on experience and in an attempt to fail the samples within a reasonable number of cycles. Strain gauges were installed on the connection samples and monitored throughout the test. Each sample was tested until the connection failed or until a target fatigue life of 10 million to 15 million cycles was reached.

Resonant bending fatigue machines were used for the tests due to their cyclic rate capabilities, which are typically 25 to 30

Hz. This results in fatigue cycles accumulating at a rate of about 100,000 cycles per hour or 2.5 million cycles per 24-hour day. The resonant bending fatigue machine consists of two supports, a variable speed electric motor, a drive housing and a dead weight housing (see Figure 3). The motor rotates an eccentric mass in the drive housing clamped to one end of the sample and loads the sample. The revolutions per minute (RPM) of the motor are adjusted to load the sample near its natural frequency.

The fatigue test results are presented in Table 2. Three of the five API 6 5/8 Reg. samples cracked in the root of the last engaged thread of the pin, while the remaining two samples failed in the root of the last engaged thread of the box. On average, the API 6 5/8 Reg. connections failed at 1,288,717 cycles. The maximum cycles to failure for the API 6 5/8 Reg. connection was 1,845,040 and the minimum cycles to failure was 927,919.

None of the enhanced connection samples failed during the fatigue testing program. All enhanced connection fatigue tests were voluntarily stopped after reaching either 10 million or 15 million cycles. The test results indicate that on average, the enhanced connection is at least nine times more fatigue resistant than its API counterpart of equivalent dimensions with pin stress-

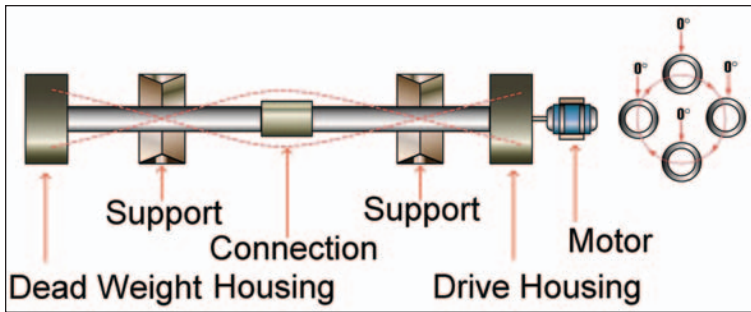


Figure 3 – Resonant bending fatigue machine schematic (left) and photograph (right).

relief groove, box boreback and cold rolled thread roots.

FIELD TRIAL CASE HISTORY

A field trial program was initiated with BP America Inc. in the Tuscaloosa development to determine the effectiveness and rig robustness of the new connection under actual severe drilling operations. The Tuscaloosa Trend is a prolific natural gas field that extends from the Louisiana-Mississippi border through Baton Rouge to the Texas border. Initial drilling within the Tuscaloosa formation was driven by a Chevron discovery in 1975. Formation pressures and temperatures exceed 15,000 psi and 400 degrees F respectively.\*

The intermediate 12 1/4-in. hole section is typically drilled to approximately 8,000 ft with a mill tooth bit on a packed rotary assembly and from this depth to approximately 16,000 ft with extended gauge PDC bits. PDC extended gauge bits, stabilized motors, roller reamers instead of integral blade stabilizers and real-time monitoring and adjusting to downhole conditions have all been employed to reduce abrasive bit wear and drill string vibrations

Nevertheless, throughout the intermediate hole section from 5,150 ft to 16,000 ft, BHA mechanical damage, including twist-offs and bit damage, and well control issues remain a challenge. Consequently, the vertical intermediate 12 1/4 in. hole section of BP’s Tuscaloosa Trend presented a challenging environment to test the enhanced connection. Eight drill collars and primary and backup crossovers were manufactured with the enhanced connection and shipped to location.

The collars were added to the BHA at 7,807 ft measured depth (MD) after rotary assemblies were removed for a 12 1/4 in. PDC motor assembly. Six collars were placed in the lowermost part of the BHA to ensure maximum compression loading

	Bending Moment (in-lbs)	Micro Strain (ue)	6-5/8 Reg. <sup>1</sup> Cycles to Failure	Failure Location	DC58 <sup>3</sup> Cycles to Failure	Failure Location
Sample 1	739,000	500	1,845,040	Pin LET <sup>2</sup>	11,034,468	None <sup>4</sup>
Sample 2	739,000	500	1,275,531	Box LET <sup>2</sup>	15,441,140	None <sup>4</sup>
Sample 3	739,000	500	1,040,026	Box LET <sup>2</sup>	10,186,224	None <sup>4</sup>
Sample 4	739,000	500	1,355,070	Pin LET <sup>2</sup>	-	-
Sample 5	739,000	500	927,919	Pin LET <sup>2</sup>	-	-
Avg.	739,000	500	1,288,717		12,220,611	None <sup>4</sup>

Notes:  
 1. 8 in. OD X 3 in. ID API 6-5/8 Reg. connection with API pin SRG, API BBB and cold rolled thread roots.  
 2. LET = last engaged thread root  
 3. 8 in. OD X 3 in. ID DC58 with pin SRG and cold rolled thread roots.  
 4. No failure noted during test.

Table 2 – Resonant bending fatigue tests at equivalent bending moments indicate the enhanced connection performed at least nine times better than the API 6-5/8 Reg. connection. Throughout all fatigue testing of the enhanced connection, no failures were encountered. Resonant fatigue tests were concluded without failure.

for the PDC bit run from 7,807 ft to 15,450 ft MD. While drilling with the motor assembly, issues with the mud motor were noted and the BHA was pulled from the hole after reaching 13,106 ft MD. Following a BHA inspection, a rotary assembly was configured and the enhanced connection collars were placed back in the BHA. Drilling of the intermediate hole section resumed to its total depth of 15,450 ft prior to 9 5/8-in. casing installation.

Observations during this field trial of the enhanced connections included:

- Noticeably improved make-up time.
- No requirement for stabbing guide due to increased connection taper.
- MUT requirements within rig capability.
- No issues noted during breakout of the connections.
- If thread galling were to occur during make-up of the enhanced connection, it could go unnoticed due to the low number of revolutions from stab to full make-up (3 revolutions).

- The rig crew must be aware of the reduced clearance (less than 1 in.) between the primary shoulders while stabbing.

- During inspection following the field trial, all enhanced connection collars were accepted. Minor thread crest damage was noted on one pin and mating box of an enhanced connection. Thread crests damage was cleaned up. The primary seals were pristine.

The enhanced connection collars have accumulated 364.5 rotating hours and 1,372,410 rotating cycles during the drilling of 7,643 ft of 12 1/4-in. hole section.

Based on the FEA modeling, physical laboratory testing and favorable results during a severe environment field trial, it is clear that this new BHA connection with enhanced stress relief features can improve drilling performance in areas with the most challenging fatigue operating conditions.

\* Shaughnessy, J.M. and Locke, H.A., “20-Plus Years of Tuscaloosa Drilling: Continuously Optimizing Deep HTHP Wells,” paper IADC/SPE 59181 presented at the 2000 IADC/SPE Drilling Conference, New Orleans, Louisiana, United States of America, 23-25 February, 2000.