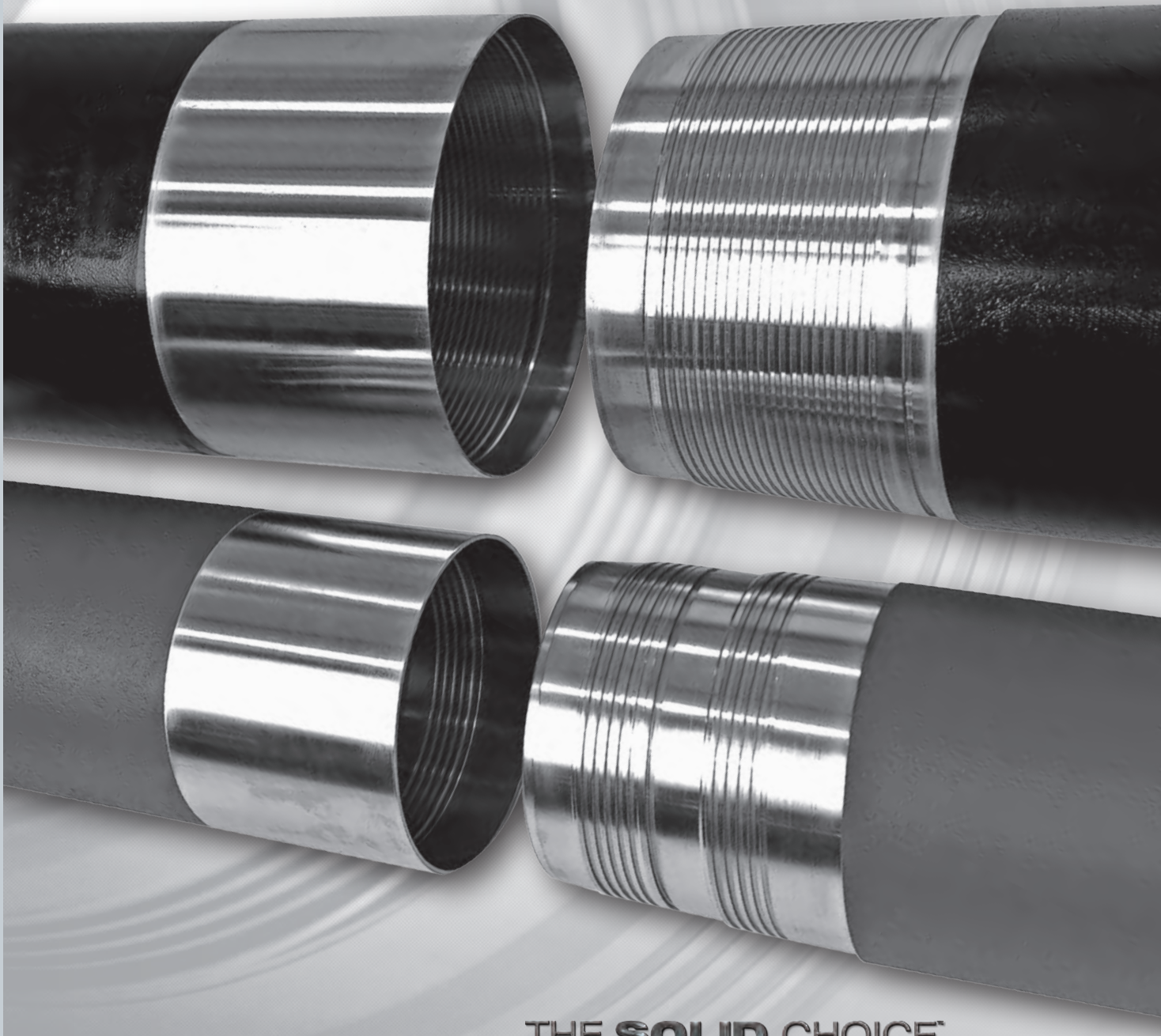
Weatherford®

MetalSkin® Threaded Connections



THE SOLID CHOICE™

Enhancing well construction with a premium threaded connection built for maximum reliability—before, during and after expansion, even in the harshest operating environments

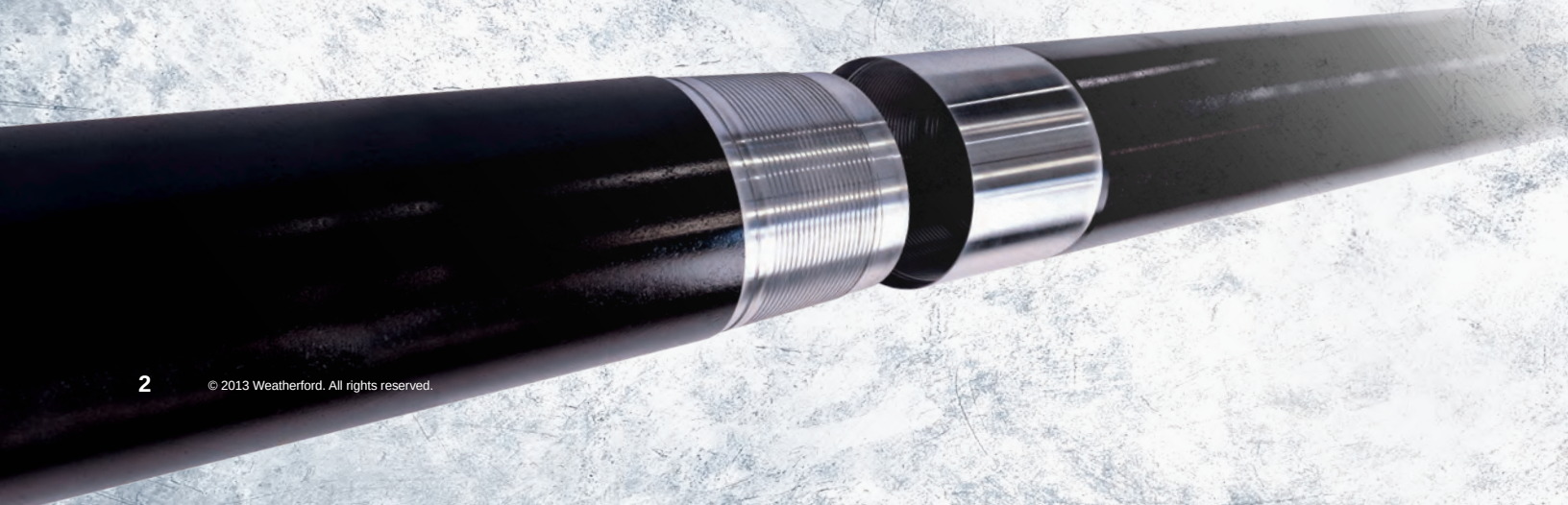
Ensuring Solid Qualifications

Repeatedly, Weatherford has pushed the technological envelope of solid expandable systems. With the advent of MetalSkin® FODC-OR and WTXC threaded connections, we've done it again.

Because radial expansion of threaded connections places severe combinations of bending, tension, compression and pressure on the liner, connections with special features are required. FODC-OR and WTXC threaded connections were developed to optimize *MetalSkin* solid expandable liner performance—before, during and after expansion, in the toughest environments.

Field results show that solid expandable liners improve well architecture, reduce operational costs, mitigate drilling hazards and, in some cases, make previously undrillable wells drillable. Designed, tested and qualified based on American Petroleum Institute (API) and International Organization for Standardization (ISO) guidelines at our dedicated facility, FODC-OR and WTXC threaded connections are built for maximum reliability to realize the full potential of solid tubular expandables.

Weatherford's Oil Country Tubular Goods (OCTG) Technology Center is a dedicated, state-of-the-art facility that tests threaded expandable connections to ensure dependable performance.



FODC-OR and WTXC connections are tested and qualified to rigorous ISO 13679 and API RP 5-EX guidelines at our OCTG Technology Center.

Qualification tests determine the performance envelopes based on variables that reflect realistic well conditions. These connection performance properties are published as a traditional table of uniaxial properties or as a von Mises-Hencky (VME) triaxial performance envelope.

In addition, we can perform customized tests for clients with special application requirements, such as using nickel-based alloy liners, to ensure that the FODC-OR or WTXC connection is the proper choice.

Qualification Guidelines

for threaded connections expanded in the fixed-free condition

API RP 5-EX (DRAFT)

Sample Number		1	2	3	4
Pre-Expansion	Manufacture samples	LS/HT	HS/LT	LS/HT	HS/LT
	M&B		2		2
	FMU	1	1	1	1
	Quadrant 1 and 2	Amb			Amb
	Quadrant 3 and 4		Amb	Amb	
Expansion	Straight fixed-free	Amb	Amb	Amb	Amb
	Straight fixed-fixed				
Post-Expansion	Installation cycles	Hot	Amb	Amb	Hot
	Quadrant 1 and 2	Hot			Hot
	Quadrant 3 and 4		Amb	Amb	
	ISO Series A				
Failure Test	Failure 1 = Ten + Pi to fail	Amb			
	Failure 2 = Comp + Pi to fail				Amb
	Failure 3 = Comp + Pe to fail		Amb		
	Failure 4 = Ten + Pe to fail			Amb	

LS/HT = Low seal/high thread tolerances

HS/LT = High seal/low thread tolerances

M&B = Makeup and breakout tests

FMU = Final makeup

Amb = Ambient temperature

Fixed-free = Liner not constrained on both ends during expansion

Hot = Elevated temperature

Installation cycles = Expansion load-cycle simulation

Quadrant 1 and 2 = VME testing of internal pressure + tension / compression

Quadrant 3 and 4 = VME testing of external pressure + tension / compression

Pi = Internal pressure

Pe = External pressure

Ten = Tension

Comp = Compression

The API RP 5-EX draft uses a test matrix to define which tests will be done on the threaded test samples before and after expansion. RP 5-EX also defines the conditions that must exist when the test sample is expanded.

Solid Connections

MetalSkin® FODC-OR threaded connections

incorporate numerous unique, patented features that combine for enhanced mechanical and pressure-sealing dependability and performance before, during and after expansion downhole. This combination of design features translates to the most dependable threaded connection for smaller-diameter solid expandable liner systems.

For liner sizes 5-1/2 in. and larger, a tapered, radial-interference, **internal metal seal** is generated during makeup to provide exceptional internal pressure integrity during running and expansion.

Hooked-thread tension flank improves resistance to connection jump-out during running and expansion, especially in deviated sections and doglegs.

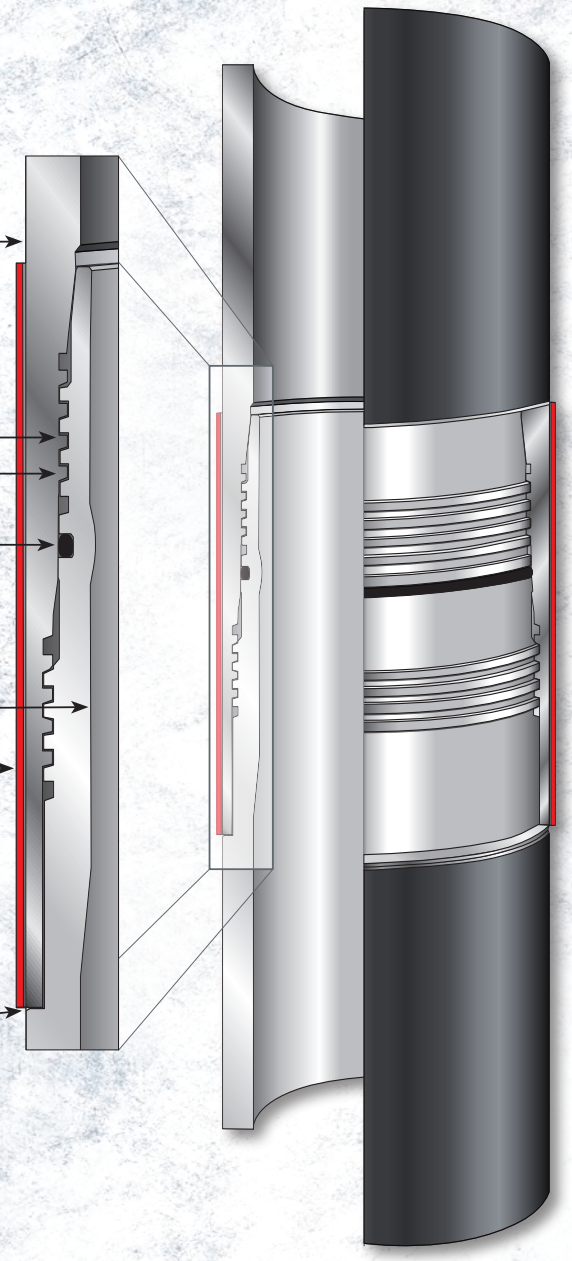
Two-step thread design facilitates stabbing and makeup of connections and enables the use of a single O-ring seal, as opposed to one at each end. The design generates high tension strength, up to 60% of pipe body strength.

Center O-ring seal provides excellent internal and external pressure. The O-ring seal is rated for temperatures up to 300°F (149°C).

Box and pin are swaged and stress-relieved before threading to ensure perfect concentricity at the ends of the connection, maximizing resistance to expansion stresses.

Protective metal sleeve* is fastened to the box OD and minimizes damage caused by wellbore debris and other running hazards.

90° external torque shoulder positions the box and pin during makeup and provides visual verification of proper makeup. Coupled with the threads, it delivers a high maximum compression strength.



*Other protective, hardfacing options may be available.

***MetalSkin* WTXC threaded connections** are designed for solid expandable liner installations of 7 5/8-in. OD and larger. Larger expandable liner sizes have a heavier wall thickness than smaller-diameter liners to increase pressure and mechanical post-expansion capabilities. Other sizes require a very thin wall thickness to create the drift clearance required after expansion. Both of these OD to wall-thickness ratios present significant post-expansion performance challenges to a large-diameter connection design. The WTXC is specially designed with unique, patent-pending features that withstand the applied loads and pressures larger-diameter liners experience before, during and after expansion.

For liner sizes 7-5/8 in. and larger, a radial-interference, **internal metal seal** is generated during makeup to provide exceptional internal pressure integrity during running and expansion.

O-ring seal at both ends of the connection are specially designed to prevent applied pressure from penetrating the threads, giving these larger expandable liners more dependable pressure integrity. The standard seals are rated to 300°F (149°C), with higher-temperature seals available.

Hooked-thread tension flank improves resistance to connection jump-out during running and expansion on larger pipe sizes, especially in deviated sections and doglegs.

Tapered, noninterference thread design maximizes the number of engaged threads to enhance tension, compression and bending strengths, which large-diameter liners require.

Pin and box are swaged, stress-relieved and then machined to a defined ID and OD to ensure excellent concentricity at the connection ends.

Protective metal sleeve* is fastened to the box OD and minimizes damage during running operations.

O-ring seal

90° external torque shoulder positions the box and pin during makeup and provides visual verification of proper makeup. The torque shoulder and engaged threads provide the connection's compression strength.

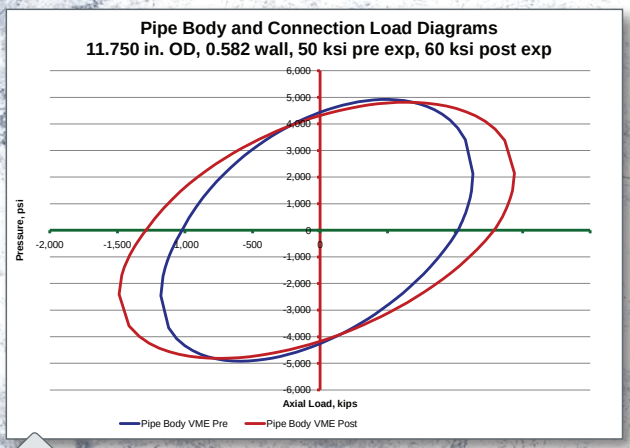
*Other protective, hardfacing options may be available.

Solid Validation

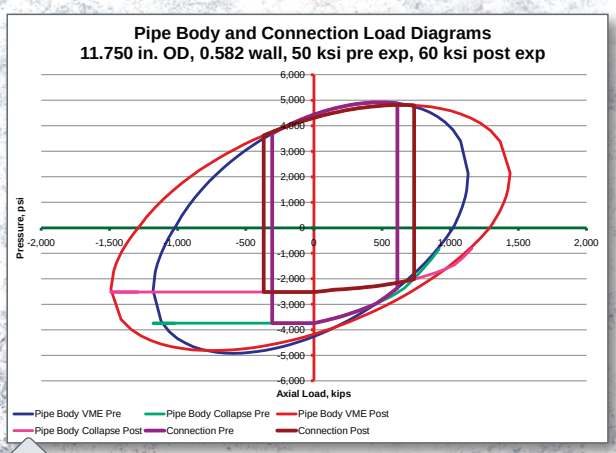
Performance Envelopes

Weatherford produces triaxial performance envelopes for all connection types before and after expansion and verifies them with qualification tests. Because expansion changes the liner and connection performance properties, two different triaxial performance plots are produced—one for the pre-expanded liner and connection and the other for the post-expanded liner and connection. With this performance information, you can design the application with full confidence that the liner will perform as required before and after expansion.

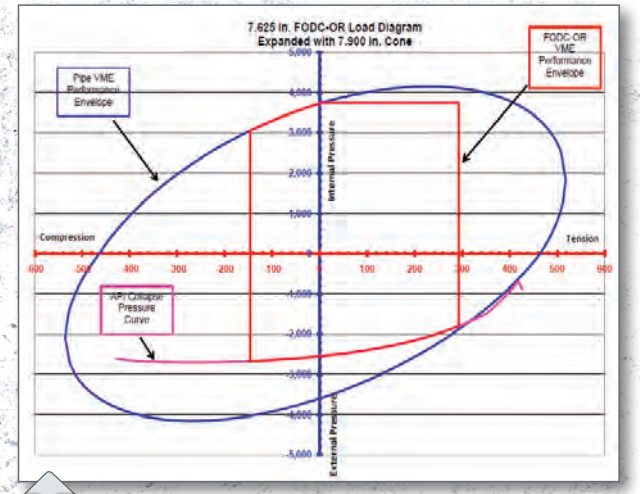
Accurately simulating the test-sample expansion process is critical as it affects the properties of a post-expanded product. The ability to maintain compression and tension loads during expansion in the testing phase makes Weatherford the only connection provider that can reproduce all conditions experienced downhole—meeting the RP 5-EX testing requirement by API.



Depiction of the pipe's theoretical performance envelope before and after expansion. The connection's performance properties can be published as a traditional table of uniaxial properties or as a VME triaxial performance envelope.



When the API collapse criteria are added, the pipe's external pressure capacity is reduced from the VME ellipse capacities. Following those collapse limit lines, the connection tension and compression limits also change with expansion.



Weatherford's FODC-OR and WTXC VME performance envelopes are verified by testing. We produce performance envelopes for all of our connection types in a variety of downhole conditions.

To accompany performance envelopes for all tested connections, Weatherford produces datasheets that summarize the properties of a pipe and connection before and after expansion. The datasheets provide the operational parameters that a particular connection is capable of withstanding downhole, so the client can choose a connection suitable for the well environment.

Weatherford — **FODC-OR™ Connection Performance Properties**

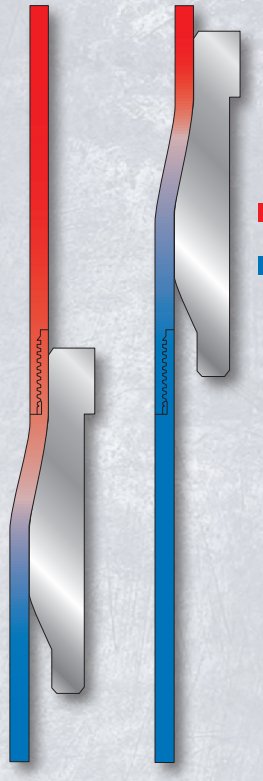
Form Number	Form Rev	Written By	Approval	Date
PP1055-50	0	S. Osburn	R. DeLange	April 24, 2012

Product: 7.625 in. OD, 0.375 in. Wall, 50 KSI, FODC-OR

Pre-Expansion	Property	Post Expansion			
Base Casing					
NA	OD (in)	9.625	9.625	9.625	9.625
NA	Weight (lb/ft)	40.0	43.5	47.0	53.5
NA	ID (in.)	8.835	8.755	8.681	8.535
NA	API Drift (in.)	8.679	8.599	8.525	8.379
Pipe Information					
7.625	OD (in.)	8.632	8.555	8.489	8.348
0.375	Wall (in.)	0.343	0.345	0.347	0.352
6.875	ID (in.)	7.946	7.865	7.795	7.644
6.750	Drift (in.)	7.821	7.742	7.673	7.524
50,000	Yield Strength (psi)	60,000	60,000	60,000	60,000
4,430	Internal Pressure (psi)	4,290	4,360	4,410	4,550
3,640	External Pressure (psi)	2,480	2,550	2,620	2,790
Connection Information					
7.931	Connection OD (in.)	8.852	8.778	8.713	8.577
6.800	Connection ID (in.)	7.900	7.820	7.750	7.600
293,000	Tension Load (lb)	293,000	293,000	293,000	293,000
293,000	Compression Load (lb) (without Pressure)	293,000	293,000	293,000	293,000
146,500	Compression Load (lb) (with Pressure)	146,500	146,500	146,500	146,500
4,430	Internal Pressure Resistance (psi)	4,290	4,360	4,410	4,550
3,640	External Pressure Resistance (psi)	2,480	2,550	2,620	2,790
4000 5000	Make Up Torque (ft-lb)	NA	NA	NA	NA

Notes:
1. Maximum temperature is 300°F.
2. Post-expansion pipe OD and pipe wall thickness are based on test and FEA data.
3. Post-expansion pipe ID is calculated from post-expansion OD and wall.
4. Post-expansion connection OD is based on test data and includes the presence of a metal protective sleeve.
5. Post-expansion connection ID is based on test and FEA data.
6. Pre- and post-expansion connection tension and compression loads have been verified by testing.
7. Pre- and post-expansion connection internal and external pressure resistances have been verified by testing.
8. These performance properties are for a fixed-free expansion.

Weatherford-produced data sheets display performance properties before and after expansion.



Accurately simulating downhole conditions must be done when making qualification samples.

For example, vertical liners have a pre-expansion compressive load on the connection that changes along the cone face during expansion to a post-expansion tension load. The differences in these loads at the bottom of the liner compared to the top of the liner produce connections with varying dimensions at those locations. Therefore, it is important to test samples from both locations.

Generating Solid Designs

Recognizing the shortcomings of traditional techniques used to test threaded connections, we built our **Oil Country Tubular Goods (OCTG) Technology Center** in Huntsville, Texas, USA.

With a core staff of engineers and lab technicians, it houses highly specialized equipment that can test threaded connections for expandable liners under realistic conditions. The center includes a custom-built dynamic-load expansion simulator, which expands sample connections before testing, and a unique bending frame that enables researchers to study the effects of wellbore deviation on connections.

The OCTG Technology Center has a unique work environment, tailored to implement safety standards and practices at all workstations with a combination of specialized trained personnel, routine safety meetings and posted workstation safety reminders.

Prep Lab

The center's prep lab performs the following makeup test samples prior to testing.

3D coordinate measuring machine (CMM) measures connections before and after testing to compare theoretical results from finite element analysis with actual results

Computerized power tongs perform the sample makeup work

Pipe mapping measures the OD and wall thickness required for testing

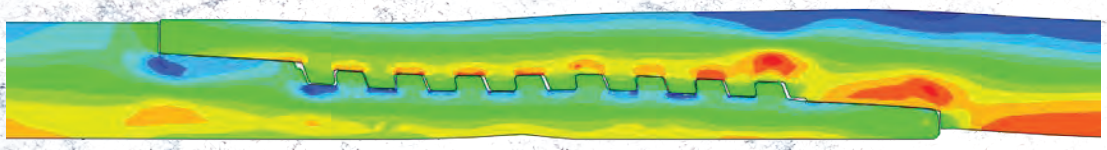
Engineering Design

Weatherford engineers use the latest technical tools to generate advanced connection designs.

Sophisticated computer-aided design capabilities enable the creation of new and novel connection concepts

Engineering analyses gathered using the finite element method refine design concepts

Physical testing completes the development of state-of-the-art designs



Testing Lab

The OCTG Center's testing lab houses four test cells—including two covered cellars for enhanced safety to personnel and the environment—which accurately replicate downhole conditions.

Dynamic-load expansion (DLX) simulator accurately replicates any mechanical and pressure variable load conditions that can exist downhole during a liner expansion

Load frames subject connections to real-well conditions, including combinations of pressure and loads with high temperatures

Bending beam simulates liner expansion in a deviated wellbore when the liner is stuck or in a fixed position, a particularly taxing scenario for threaded connections

Our new testing lab features two underground bunkers, measuring 50 ft long × 20 ft wide × 15 ft deep with steel deck plates, to provide safe testing parameters for our accommodated test load frames.

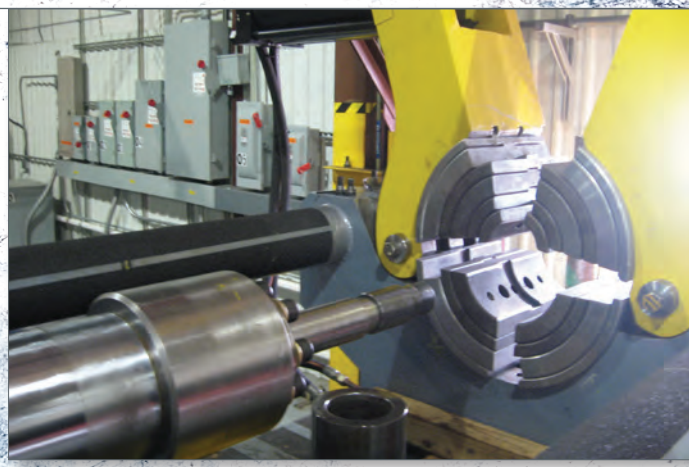
Our 3.1 million-lb test frame is housed in one of the bunkers.

Prototype Threading

The center's prototype threading station provides the accuracy needed to meet ISO and API guidelines, and can accommodate liners ranging from 3 1/2- to 14 1/2-in. OD.

Sample threading stations

▪ Handling tables ▪ Horizontal swage ▪ Stress relief ▪ Threading ▪ Inspection ▪ Magnetic particle inspection ▪ Surface treatment



Solid Simulations

Weatherford's state-of-the-art, DLX bench accurately simulates all downhole variables during the expansion of test samples. The one-of-a-kind, downhole expansion simulator is designed and built to meet the API RP 5-EX requirement that states, "The expansion test shall reproduce the conditions experienced downhole."

The DLX simulator can expand test samples using fixed-free or fixed-fixed conditions, cone movement using mechanical- or pressure-driven force, and tension or compression constraint with any combination of pre-load and post-load while maintaining these conditions during expansion.

Tested Variables that affect threaded-connection performance

- Bending
- Cone design
- Constraint variant (compression, fixed-fixed, fixed-free, tension)
- Downhole pressure
- Downhole temperature
- Drilling fluid
- Expansion speed
- Expansion system (mechanical, pressure)
- Hole configuration
- Liner length
- Load changes during expansion (pre- and post-load)

The DLX simulator is the world's most unique and capable expansion bench, which accurately produces all downhole conditions for expandable liners.

The F1 load frame (shown above) can replicate downhole tension loads up to 650,000 lb and pressures up to 30,000 psi for qualifying samples in the pre- and post-expanded conditions.

The F2 load frame qualifies test samples by replicating tension loads up to approximately 3 million lb.

Our load frames comply with ISO 13679 testing requirements and are capable of performing any combination of tension or compression loads using internal or external pressures within the frame capacity limits.

Our custom-built constant-radius bending beam is designed for expanding and testing threaded connections in a bent condition to accurately simulate conditions in a deviated wellbore section. The beam can systematically bend the sample to any deviation, expand the sample in the fixed-free or fixed-fixed condition, and then complete the qualification testing, all while maintaining the required deviation.

MetalSkin® Threaded Connections

THE SOLID CHOICE™

To learn more about optimizing well construction with our *MetalSkin* FODC-OR and WTXC threaded connections, contact an authorized Weatherford representative or visit **weatherford.com/metalskin.**

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