Next Generation Drill Pipe for Extended Reach, Deepwater and Ultra-deep Drilling

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Introduction

A new drill pipe size, 5-7/8 in. OD, represents enabling technology for Extended Reach Drilling (ERD), deepwater and other deep well applications. Most world-class ERD and deepwater wells have traditionally been drilled with 5-1/2 in. drill pipe or a combination of 6-5/8 in. and 5-1/2 in. drill pipe. The hydraulic performance of 5-1/2 in. drill pipe can be a major limitation in substantial ERD and deepwater wells resulting in poor cuttings removal, slower penetration rates, diminished control over well trajectory and more tendency for drill pipe sticking.

Hydraulic pressure losses are minimized with 6-5/8 in. drill pipe, but 6-5/8 in. drill pipe is an "over-design" solution in many cases. The 6-5/8 in. drill pipe is difficult to handle, requires excessive physical space on the rig, can limit setback capacity and generally requires significant rig handling equipment modifications. In addition, 6-5/8 in. drill pipe cannot be used to drill inside of 9-5/8 in. casing and 8-1/2 in. hole sections.

The 5-7/8 in. drill pipe provides a significant improvement in hydraulic efficiency compared to 5-1/2 in. drill pipe and does not suffer from the disadvantages associated with use of 6-5/8 in. drill pipe. It represents a drill pipe assembly that is optimized dimensionally and on a performance basis for casing and bit programs that are commonly used for ERD, deepwater and ultra-deep wells.

Realizing the full potential of 5-7/8 in. drill pipe requires a high performance tool joint connection. A second-generation double-shoulder tool joint connection, optimized for 5-7/8 in. drill pipe, provides exceptional torsional strength combined with a streamline configuration. Configured with a 7 in. OD tool joint the connection permits fishing inside of 9-5/8 in. casing or 8-1/2 in. open hole sections.

The first string of 5-7/8 in. drill pipe went to work on a Gulf of Mexico project in July 1999. Since that time more than 830,000 ft of 5-7/8 in. drill pipe comprising over 40 drill strings has been manufactured and put into the field. The drill pipe has been successfully used to drill ERD, deepwater and ultra deep HPHT wells in the South China Sea, Gulf of Mexico, Offshore Trinidad, Onshore Wyoming and Onshore Colombia.

The 5-7/8 in. drill pipe has improved penetration rates with large diameter bits and significantly shortened drilling curves to total depth in established fields. Drilling engineers are currently evaluating 5-7/8 in. drill pipe for use on major ERD, deep directional and deepwater projects in various parts of the world.

The paper discusses the engineering philosophy behind 5-7/8 in. eXtreme Reach (XR) drill pipe, the design challenges associated with development of the product and reviews the features and capabilities of the second-generation double-shoulder connection. The paper provides drilling case history information on significant projects where the pipe has been used and details results achieved with the pipe.

Limitations of 5-1/2 in. and 6-5/8 in. Drill Pipe

ERD wells typically require long, 9-5/8 in. and larger diameter intermediate casing strings to reach their total depth objectives. Efficient drilling of the large diameter (12-1/4 in. and larger) hole sections necessary for these casing strings mandates a drill string design that minimizes pressures losses through the pipe. Deepwater wells drilled to true vertical depths approaching 20,000 ft and deeper are becoming common.[1] Many of these deepwater wells encounter sections with reduced margins between pore pressure and fracture pressure gradients. As a result, these wells often require several intermediate casing points and long, 9-5/8 in. or larger intermediate casing strings. Just as in ERD wells improved hydraulic performance of the drill string can enhance drilling efficiency in deepwater applications.

As stated above, substantial ERD and deepwater projects are generally drilled with 5-1/2 in. drill pipe or a combination string of 6-5/8 in. and 5-1/2 in. pipe. Use of a full string of 5-1/2 in. drill pipe introduces hydraulic limitations in long 12-1/4 in. and larger hole sections. With 5-1/2 in. pipe the pressure losses through the drill string are too great to efficiently remove cuttings from the well resulting in slower penetration rates, diminished control over well trajectory and more tendency for drill pipe sticking.

Hydraulic pressure losses are minimized with 6-5/8 in. drill pipe, but 6-5/8 in. drill pipe, again, is an "over-design" solution in most cases. The 6-5/8 in. drill pipe is difficult to handle, requires excessive physical space on the rig, can limit setback capacity and generally requires significant rig handling equipment modifications. In addition, 6-5/8 in. drill pipe cannot be used to drill inside of 9-5/8 in. casing and 8-1/2 in. open hole sections. Consequently, once 9-5/8 in. casing is set, the 6-5/8 in. drill pipe simply adds to the rig setback weight and occupies valuable rig space. This is a major disadvantage on offshore projects where rig space and setback capacity are at a premium.

Due to the shortcomings of 5-1/2 in. and 6-5/8 in. drill pipe, an intermediate size between these drill pipe sizes is required.[2] Based on engineering analysis and discussions with potential end users, 5-7/8 in. was determined to be an optimum size.

Hydraulic Performance

Figure 1 shows a hydraulic performance comparison of 5-7/8 in. 23.40 lb/ft and 5-1/2 in. 21.90 lb/ft (most common 5-1/2 in. product for ERD applications) drill pipe. The graph shows the pressure loss in psi/1,000 ft while drilling inside of 12-1/4 in. hole with 12-ppg mud. The benefit of the new drill pipe size is clearly illustrated in this comparison.

The 5-7/8 in. 23.40 lb/ft pipe provides 16% more ID flow area than 5-1/2 in. 21.90 lb/ft pipe. Pressure losses are reduced by approximately 28% with the 5-7/8 in. XR drill pipe.

Improved hydraulic efficiency of the 5-7/8 in. XR pipe permits higher achievable flow rates resulting in better hole cleaning and faster penetration rates. In addition, drill pipe sticking tendencies are reduced due to better cuttings removal, and the directional control of the well path is improved. Working pressure requirements for the mud circulating system are also reduced.

Only minor modifications are needed with regard to pipe handling equipment to use the 5-7/8 in. XR drill pipe.[3] These considerations are fully addressed in reference 3.

Drill Pipe Designs and Performance Capabilities

Two weights of 5-7/8 in. drill pipe have been developed and manufactured: 23.40 lb/ft with a nominal wall thickness of 0.361 in. and 26.30 lb/ft with a nominal wall thickness of 0.415 in. Performance specifications for these designs in the most common material grade, API S-135, are displayed in Table 1. In addition, 5-7/8 in. drill strings have been manufactured in material grades: XD-105, a sour service NACE tested material grade, Z-140 and V-150. Two 5-7/8 in. high capacity landing strings with a nominal wall thickness of 0.750 have also been manufactured.

eXtreme Torque Connection

An advanced, high-performance tool joint design was required to achieve the dimensional and performance objectives for the 5-7/8 in. XR drill pipe. The eXtreme Torque (XT) is a second-generation double-shoulder connection (see Figure 2).[4] XT57 is the eXtreme Torque connection configuration optimized for the 5-7/8 in. pipe.

The eXtreme Torque connection design evolved from the design of the HIGH TORQUE (HT) connection. Figure 3 depicts the make-up characteristics of XT and HT. Both connections spin up freely from the stab-in to hand-tight position. In the hand-tight position the primary external shoulder makes contact. As the connection is made-up from the hand-tight to power-tight position the secondary torque stop engages.

The secondary torque shoulder provides the increased torsional capacity compared to a standard API rotary shoulder connection.

Figure 4 shows a comparison of XT and HT. The thread taper of the XT connection was flattened to increase the area of the secondary torque stop resulting in increased torsional capacity. HT provides an approximate 40% improvement in working torque compared to an API connection of the same OD and ID dimensions. XT provides approximately 30% more working torque capacity than HT or an improvement in working torque of approximately 70% compared to a standard API connection of the same dimensions.

The shallow thread taper of the XT connection results in reduced clearance between the pin nose and box face during stabbing. Consequently, use of a stabbing guide is required to prevent damage to the box face or shoulder that acts as the pressure seal for the connection. With the exception of the stabbing guide requirement, eXtreme Torque handles and makes-up like a standard API connection. The double-shoulder configuration permits streamlined configurations with reduced OD's and larger ID's while still maintaining the desired torsional strength.

Most 5-7/8 in. drill pipe has been configured with an XT57 tool joint that has a 7.000 in. OD and a 4-1/4 in. ID to maintain the ability to fish the tool joint with an overshot inside 9-5/8 in. casing or 8-1/2 in. open hole sections and to minimize pressure losses through the connection.

Advantages of Utilizing a Single OD Drill String Versus a Dual OD Drill String

As mentioned previously, world-class ERD and deepwater water wells have traditionally been drilled with a mixed drill string of 6-5/8 in. and 5-1/2 in. drill pipe. For projects of this nature, hydraulics often drives the drill string design rather than torque or drag, especially with the use of high torsional capacity connections. In some cases, a full string of 5-7/8 in. will provide lower surface pump pressures than a mixed string of 6-5/8 in. and 5-1/2 in. Achieving equivalent pump pressures with a mixed string in 12-1/4 in. or larger hole sections requires a long section of 6-5/8 in. drill pipe. Once 9-5/8 in. casing is run, 5-1/2 in. must replace the equivalent length of 6-5/8 in., requiring the operator to have a longer drill string than that required when using a full string of 5-7/8 in. The combination of these two advantages allows the well to be drilled with lower surface pump pressures, promoting increased ROP and less maintenance and downtime, and reduces the amount of drill pipe required for the project.

A number of both tangible and intangible value advantages are realized with a single OD drill string compared to using a mixed OD drill string:

Tangible Value

- Reduced time picking up and laying down drill pipe.
- Reduced time tripping - No requirement to change elevators, slips and tongs.
- No time lost re-configuring the top drive from 6-5/8 FH to 5-1/2 HT55 or XT57 tool joints.
- No requirement for variable bore rams; VBR wear approximately 5 times faster than fixed bore rams. Therefore there is less rig downtime and less capital expense.
- Reduced inventory of fishing tools and specialty tools such as chemical cutters.
- Fewer sizes of drill pipe will reduce the number of handling tools and BOP rams. The result will be a reduction in the overhead expense of transportation, storage, maintenance and inventory management.
- 5-7/8 in. drill pipe is 15.6% stiffer than 5-1/2 in. pipe. This will result in less time spent orienting the bent housing motor during directional drilling operations.
- The additional stiffness will reduce the stress and wear caused by drill string vibration and dynamics. Pipe inspection frequency may also be decreased as a result.
- Other things constant, putting larger pipe in smaller hole sections increases the string's resistance to buckling, promoting fatigue resistance of the string. Since fatigue is the number one drill string failure mechanism, this property reduces the probability of a drill string failure.

Intangible Value

- Improved safety as reduced racked volume of drill pipe may improve V-door and rig floor visibility. As mentioned above, when using a mixed string, the entire length of 6-5/8 in. pipe used requires

an equivalent length of 5-1/2 in. to drill the 8-1/2 in. hole. This is especially important while running casing.
- Improved safety, as fixed rams are more reliable than variable bore rams.
- Improved safety, as cross over subs will not be required to install drill pipe safety valves (ball valve or IBOP) while tripping the alternate pipe size.
- Improved safety, as cross over subs will not be required to connect the top drive while tripping the alternate pipe size.
- Fewer problems during operations done on the inside of the drill pipe, such as dropping balls and darts for operation of downhole tools or cement isolation, or wireline fishing work.
- Mechanical back offs are more accurately done with a single size drill string using the same make up torque.
- Calculating pressures to kill a kick is easier with a single OD string than a mixed OD string.

In summary, there is considerable value in reducing the time from spud to completion when selecting a single OD string over a mixed OD string. The use of a single size OD drill string, in combination with a high pressure rated pumping system, will improve safety while optimizing drilling efficiency parameters, such as pipe handling, hole cleaning, and pump maintenance.

Field History Overview

Since October 1999, over 835,000 ft of 5-7/8 in. XR XT57 drill pipe has been manufactured and put into service. The mix of 5-7/8 in. manufactured has been in three wall thicknesses; 73% (613,00 ft) has been the standard 23.40 lb/ft (0.361 in. wall) product, 26% (214,000 ft) has been the thicker walled 26.30 lb/ft (0.415 in. wall) product that was designed to provide the same tensile capacity as 6-5/8 in. 27.70 lb/ft S-135 drill pipe and 1% (10,000 ft) has been thick walled (0.750 in. wall) landing strings used to run deepwater casing strings.

The customer base for the 5-7/8 in. drill pipe has evolved with time. Initially, the product was marketed and sold to rental tool companies predominantly in the Gulf of Mexico (GOM) region. Realizing the performance benefits of the 5-7/8 in. then yielded a number of operator direct and indirect purchases mostly for international project-specific drill strings. The most recent addition to the customer base is the purchase of 5-7/8 in. by drilling contractors, without any direction from operators, as a means to improve the performance and marketability of their rigs. Figure 5 depicts the customer base mix in each of these three categories.

Figure 6 illustrates the regional location of 5-7/8 in. strings. The majority of the pipe is located in the GOM region, but an ever-increasing amount is being used on international project-specific strings. Additionally, contractors are beginning to equip rigs with 5-7/8 in. prior to determining the regional area of operation.

Gulf of Mexico Field History Overview

The 5-7/8 in. drill pipe has been used on approximately 37 wells in the GOM. Figure 7 illustrates the location of these wells in the GOM region. All four major operators have used 5-7/8 in. extensively and make up approximately 70% of the total use in the GOM. Eight large independent operators account for the remaining 30% of use. Regarding well types, because 5-7/8 in. is dimensionally optimized for increased performance in typical deepwater casing strings, deepwater use of the 5-7/8 in. is dominant. Approximately 62% (23 wells) of GOM 5-7/8 in. wells have been deepwater type wells (water depth approximately 1,000 ft and deeper), 30% (11 wells) have been on the shelf and 8% (3 wells) have been inland barge projects. General performance reports from some of these wells include an estimated 60 hour large hole drilling time reduction due to improved Rate of Penetration (ROP) when compared to previous use of 5-1/2 in. pipe, improved ROP enabling three directional wells to be drilled over an eight month rental, successful high torque ERD completions operations (discussed in detail below) and successful use within small 8-1/2 in. hole sections on several projects. One major operator in deepwater reported a 14-3/4 in. hole size penetration record of 3,600 ft/day on one project and the fasted spud to completion well drilled in the ten-year history of the platform on another project. Use of 5-7/8 in. within the GOM region continues to grow as drilling contractors and rental companies acquire additional drill strings.

International Field History Overview

More recently, the most accelerated use of the 5-7/8 in. XR drill pipe has been in the international market. Several project-specific 5-7/8 in. strings have been manufactured and are in use on projects around the globe. ERD projects where 5-7/8 in. pipe has been successfully employed or is targeted for use include the BP Yacheng project in the South China Sea (discussed in the next section), offshore Trinidad and Tobago, offshore Norway, offshore West Malaysia and two projects in the Sakhalin Islands. Additional international projects include sour service applications in the Middle East, replacement of mixed OD 6-5/8 in. x 5 in. strings on projects in Colombia, and the strategic placement of two rental strings in the North Sea via a major rental company. In addition, deepwater use in the growing Brazilian market is currently under evaluation.

Extended Reach Drilling Case History

BP China Inc. purchased a string of 5-7/8 in. XR drill pipe for their Yacheng ERD project in the South China Sea. Phase 2 of this project began drilling in the first quarter of 2000. Five ERD development wells were drilled and completed from a single platform. The 22 in. and 17-1/2 in. hole sections on three wells were batch drilled with seawater and a 30 in. riser and diverter. Next the wellheads were installed and the first three wells were drilled and completed. The other two wells were drilled from top to bottom to accommodate geological evaluation efforts.

A typical casing program for the Yacheng field is depicted in Figure 8. The wells had horizontal departures approaching 20,000 ft and Measured Depths up to 25,000 ft (approximately 13,500 ft True Vertical Depth). A high-speed pipe handling system was rented to improve efficiency and safety of pipe make-up and break-out operations.

The improved hydraulic performance of the 5-7/8 in. drill pipe relative to 5-1/2 in. pipe was extremely beneficial in drilling the long 12-1/4 in. hole sections to measured depths in excess of 21,000 ft. Although, the 5-7/8 in. pipe was not required to drill the 17-1/2 in. hole sections it also improved drilling efficiency in these intervals.

Efficient hole cleaning was accomplished through a combination of controlled drilling, high drill string rotational speeds, heavy weight sweeps and backreaming connections as required by the hole conditions based on torque and drag monitoring. The 12-1/4 in. hole sections were drilled with pump rates of approximately 1,000 gpm in the upper hole portions, reducing to 800 gpm in the lower hole sections due to pressure limitations. The higher annular velocities achieved in the 8-1/2 in. hole sections resulted in good hole cleaning. Drill string rotational speed had a major impact on hole cleaning. In high gear the top drive maintained a rotary speed of 170 rpm resulting in good although still less than optimum hole cleaning. When low gear was engaged to overcome higher downhole torsional drag, drill string rotational speed dropped to 120 rpm and hole cleaning degraded significantly.

The hydraulics design was developed to maximize flow rate for optimal hole cleaning and was not geared toward achieving high hydraulic horsepower at the bit. Good penetration rates were maintained, even with hydraulic horsepower at the bit often below 2 HSI, by sustaining high flow rates across the bit face combined with the use of an oil base drilling mud to prevent bit balling.

The project was very successful considering that a small four pile platform was used to drill these demanding ERD wells. The five wells were drilled to total depth in an average of 68 days each with an average drilling performance time of 31.4 days/10,000 ft.

Deepwater Case History

A rental string of 5-7/8 in. XR drill pipe was used to drill the Green Canyon 743 well located in the Gulf of Mexico. This well was part of BP's Atlantis project. The well was drilled with the GlobalSantaFe Glomar Explorer deepwater drill ship. Water depth was 6,590 ft. The well consisted of 36 in. conductor pipe that was jetted in, 20 in. surface casing set at 9,323 ft MD inside a 26 in. hole size, 13-3/8 in. intermediate casing set in a 17 in. hole at 12,590 ft MD, an 11-3/4 in. drilling liner set at 16,239 ft MD in a 12-1/4 in.

hole and a 10-5/8 in. hole drilled to TD of 20,121 ft MD and 17,311 ft TVD. Maximum inclination angle was 48 deg. The drilling program included two sidetracks.

The Glomar Explorer rig was originally equipped with 5-1/2 in. drill pipe. Prior to drilling Green Canyon 743, the rig had been used to drill several other deepwater Gulf of Mexico prospects with similar bit programs. Consequently, this case history provides direct comparisons of results achieved with the 5-7/8 in. XR drill pipe relative to conventional 5-1/2 in. drill pipe. Comparisons between performance on Green Canyon 743 and three different wells drilled with 5-1/2 in. pipe were made for hole intervals drilled with 17 in., 12-1/4 in. and 10-5/8 in. bits.

A summary of the comparisons is included in Table 2. As shown in the table, penetration rates were 14% to 137% faster with the 5-7/8 in. drill pipe. In addition, these improvements in penetration rate were achieved with significantly lower mud pump pressures resulting in less wear and tear on the rig pumps.

Differences in formation type, bit characteristics, mud properties, etc. likely affected the relative results shown in Table 2. Nevertheless, use of 5-7/8 in. drill pipe for appropriate deepwater drilling applications is supported by the results achieved on Green Canyon 743 compared to previous wells drilled with conventional 5-1/2 in. drill pipe.

Ultra-Deep HPHT Well Case History

The Bighorn 8-35 is the eighth ultra-deep well drilled in the Wyoming Madden Deep Unit (MDU) of the Wind River basin and the fourth well drilled by Burlington Resources in this region. Burlington completely redesigned the casing/bit size program for the Bighorn wells after they assumed ownership of the MDU through a merger with Louisiana Land & Exploration in 1997 in an effort to significantly reduce the drilling time to TD and lower the overall cost to drill the well.[5] This redesign effort was highly successful. The current casing/bit size program requires that large diameter hole sizes be drilled over extended length intervals. Consequently, good hydraulic performance of the drill string is critical to efficiently drill the well.

The casing program for the Bighorn 8-35 is depicted in Figure 9. The first well operated by Burlington in the region, Bighorn 5-6, established the efficiency of this well design. Burlington successfully reduced the drilling curve on the Bighorn 5-6 by 155 days compared to the previous fastest Bighorn well resulting in a reduction in drilling time of 34% and a cost savings of $10 million over the prior well. Design parameters for the Bighorn 5-6 and 8-35 wells were nearly identical with one major exception:

- The Bighorn 5-6 was drilled with a combination of 6-5/8 in. drill pipe in the 17-1/2 in. hole section, 5 in. drill pipe in the 12-1/4 in. and 9-1/2 in. hole sections and a combination 5 in. x 3-1/2 in. drill string in the 6-1/2 in. hole section.
- The Bighorn (BH) 8-35 was drilled with 5-7/8 in. 26.30 lb/ft Z-140 XT57 (7-1/4 in. x 4-1/4 in.) drill pipe in the 17-1/2 in. x 16 in., 12-1/4 in. and 9-1/2 in. hole sections and a combination 5-7/8 in. x 3-1/2 in. drill string in the 6-1/2 in. hole section.

Use of the 5-7/8 in. drill pipe in the 17-1/2 in. x 16 in. hole section of the BH 8-35 well resulted in less desirable drill string hydraulics but did not reduce penetration rates compared to the BH 5-6 well. Significant operational efficiencies were realized on the BH 8-35 well by eliminating the requirement to lay down the drill string after drilling the 17-1/2 in. x 16 in. hole section. Use of the 5-7/8 in. drill pipe also eliminated transportation and inspection costs associated with laying down the 6-5/8 in. rental string on the previous well.

After the 17-1/2 in. x 16 in. hole section was completed and the 14 in. casing installed in the well, the 5-7/8 in. provided a significant improvement in hydraulics in the 12-1/4 in., 9-1/2 in. and 6-1/2 in. hole sections compared to the 5 in. drill pipe on the previous well. The 5-7/8 in. pipe permitted operation of the rig pumps at lower surface pressures versus 5 in. pipe resulting in less frequent pump maintenance. Slightly higher flow rates were also achieved with the 5-7/8 in. pipe. Shale impaction of the diamond impregnated bits was a problem in the 9-1/2 in. hole section. The 5-7/8 in. drill pipe facilitated running higher pump rates in an attempt to eliminate the impaction problems. In addition, the 5-7/8 in. provided sufficient tensile capacity to run and land the long, heavy 10-3/4 in. drilling liner without the use of a dedicated landing string as was required on the previous Bighorn wells.

There was some concern that the higher weight/foot of the 5-7/8 in. pipe compared to the 5 in. pipe used on the BH 5-6 might contribute to increased casing wear. The 5-7/8 in. pipe includes casing friendly hardband and only minor amounts of casing wear were observed in the 14 in. casing string. The higher string weight did complicate running lower bit weights in hole sections drilled with diamond impregnated bits. This problem has been eliminated by making adjustments to the rig braking system and increasing the number of string up lines.

Overall the 5-7/8 in. drill pipe reportedly performed well. At the time this paper was written, the BH 8-35 well was 11 days ahead of the drilling curve for the BH 5-6 and near TD. More experience will be required to determine whether the 5-7/8 in. drill pipe provides optimum drilling efficiency compared to use of 6-5/8 in. and 5 in. drill strings in the Madison Bighorn wells.

Completion Operations Case History

BP selected a tapered string of 5-7/8 in. 23.40 lb/ft V-150 XT57 x 4 in. 14.00# S-135 HT38 to perform completion operations on well A32-2 of the Amberjack Project in the Gulf of Mexico. The completion pipe included casing friendly hardband to minimize production casing wear during completion operations. The production casing for the well consisted of a 9-5/8 in. x 7in. tieback landed at 18,606 ft and a 7 in. production liner set at total depth of 25,740 ft. Water depth was 1,030 ft. The completion string was used for the following operations:

- Displace the drilling mud with completion fluid.
- Perforate the well with a tubing conveyed perforating gun.
- Perform a hydraulic fracture stimulation job.

Completion string design selection also considered the possibility that a section of cement in the lower portion of the 7 in. liner may need to be drilled out if the cement was not fully displaced during the liner cement job. The well had a reach of approximately 22,000 ft and an inclination angle of 72 deg. Consequently, high torques were expected to drill out any cement in the 7 in. liner and to rotate and reciprocate the string during the fluid displacement procedure. In addition, once the oil base drilling fluid was displaced by the brine completion fluid, torque and drag were anticipated to increase due to the lower lubricity provided by the brine.

Extensive torque and drag modeling was performed during the planning of the completion operations. The torque and drag model predicted that torque as high as 40,000 ft-lb may be required to rotate the completion string. Additional torque could be required if drilling of cement in the liner was necessary. The 5-7/8 in. XT57 and 4 in. HT38 pipe represented the only suitable completion string commercially available with the required torsional capacity.

The cement was fully displaced and the cement plug successfully bumped. As a result it was not necessary to drill cement. Actual torque during the fluid displacement operation reached 35,000 ft-lb. All the completion operations were accomplished successfully.

Conclusion

The effectiveness of 5-7/8 in. drill pipe for extended reach, deepwater and ultra-deep drilling has been demonstrated in numerous challenging wells in multiple regions of the world. This new drill pipe size does not replace 5-1/2 in. and 6-5/8 in. drill pipe sizes. Instead, 5-7/8 in. drill pipe represents a logical intermediate size between these conventional sizes that offers both tangible and intangible benefits in many applications. The case histories presented in this paper offer examples of the types of projects where 5-7/8 in. drill pipe can improve overall drilling efficiencies and economics.

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Table 1
5-7/8" 23.40 lb/ft (0.361 in. wall) and 26.3 lb/ft (0.415 in. wall) S-135 XT57
Performance Properties

XT57 7.000 in. OD x 4.250 in. ID
Tool Joint Torsional Strength – 94,300 ft-lb
Tool Joint Working Torque – 56,600 ft-lb
Pipe Body Performance Ratings:

	23.40 lb/ft		26.30 lb/ft	
	New	Premium	New	Premium
Torsion-ft-lb	105,500	83,000	117,900	92,500
Tension-lb	844,200	666,500	961,000	757,100
Int. Pres.-psi	14,520	13,610	16,690	15,700
Collapse-psi	10,830	6,200	14,890	9,370

Table 2
Comparison of Drilling Performance
5-7/8 in. vs. 5-1/2 in Drill Pipe

	Well A	GC 743	Well B	GC 743	Well C	GC 743
Drill Pipe (in.)	5-1/2	5-7/8	5-1/2	5-7/8	5-1/2	5-7/8
Bit Size (in.)	17	17	12-1/4	12-1/4	10-5/8	10-5/8
Penetration Rate (ft/hr)	44	50	56	94	19	45
ROP Improvement (%)	n/a	13.6	n/a	67.9	n/a	136.8
Mud Weight (ppg)	10.1	9.2	10.6	11.4	12.5	11.8
Number of Pumps	2	2	2	3	2	2
Strokes/Minute	100	100	80	80	60	90
Flow Rate (gal/min)	1,000	1,000	800	1200	600	900
Pump Pressure (psi)	4,500	2,459	3,600	2,800	5050	4300
Footage Drilled (ft)	1,320	4,504	1,125	1,933	3,836	1,522
Water Depth (ft)	7,086	6,590	7,086	6,590	5,505	6,590

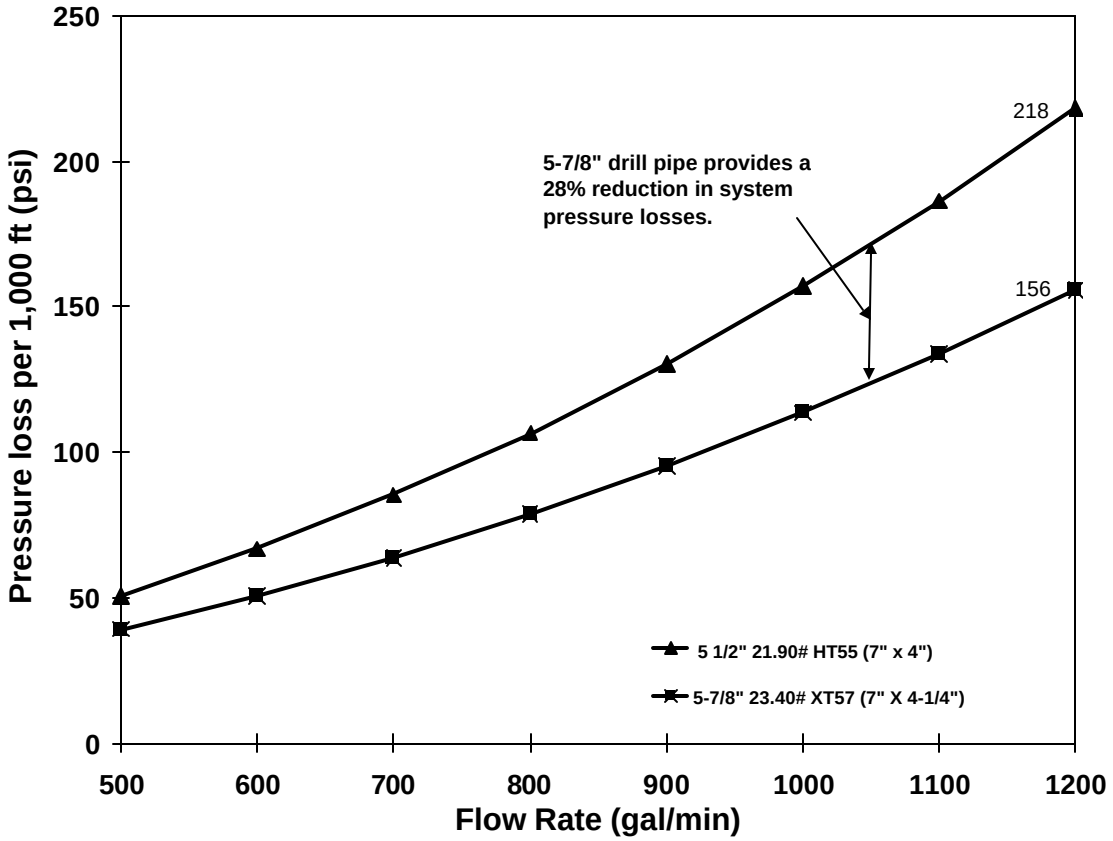

Figure 1 - 5-7/8" vs. 5-1/2" drill pipe hydraulic performance comparison. Pressure losses through and around the drill pipe are shown for a 12-1/4 in. hole with 12 ppg mud.

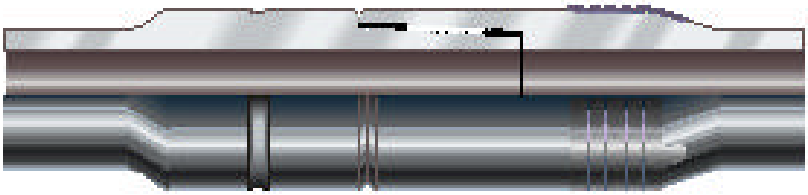

Figure 2 – eXtreme Torque is a second-generation double shoulder drill pipe connection. XT provides increased torsional capacity, promotes more streamline configurations and tolerates more tool joint wear than standard API rotary shoulder connections.

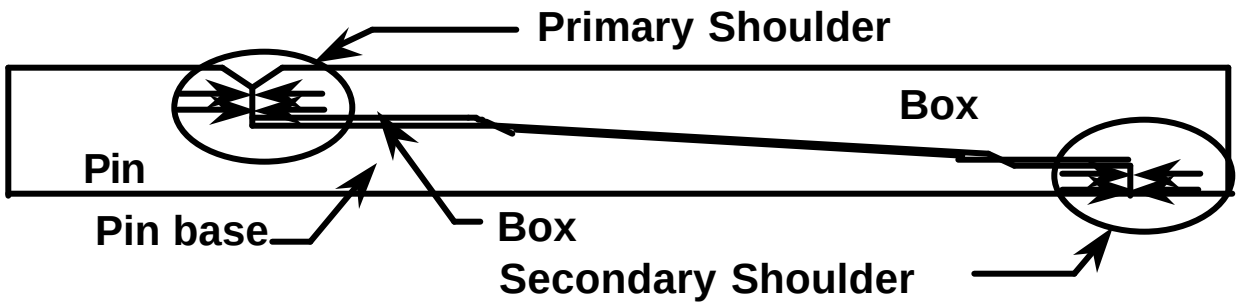

Figure 3 – eXtreme Torque (XT) in the power-tight make-up position. The secondary torque stop increases the torsional strength compared to a standard API tool joint connection.

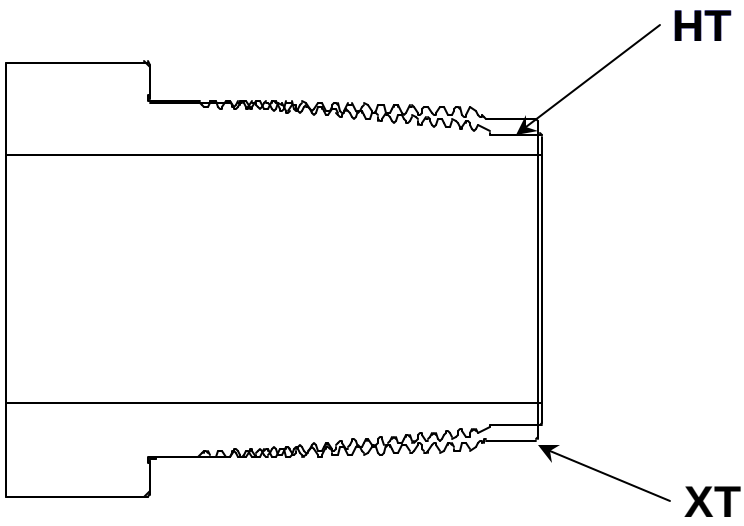

Figure 4 – Comparison of eXtreme Torque (XT) and HI TORQUE. The flatter taper of XT increases the secondary shoulder area resulting in more torsional capacity.

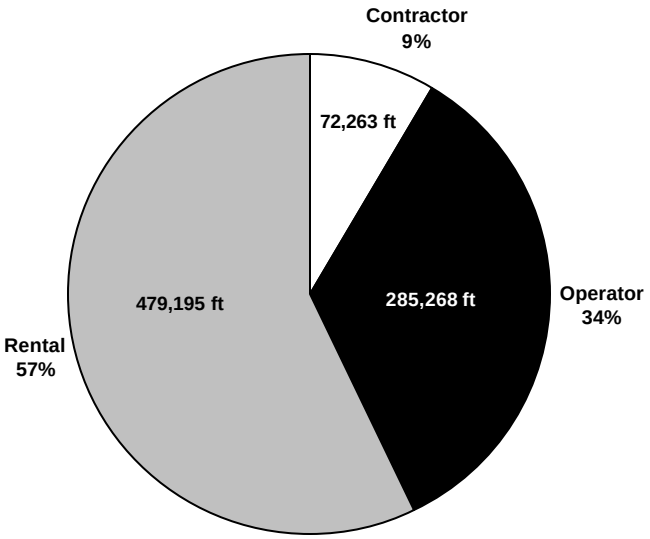

Figure 5 – Distribution of 5-7/8 in. drill pipe ownership by company type. Most of the 5-7/8 in. XR drill pipe is in the rental companies' fleets, but contractors are beginning to outfit more rigs with the pipe

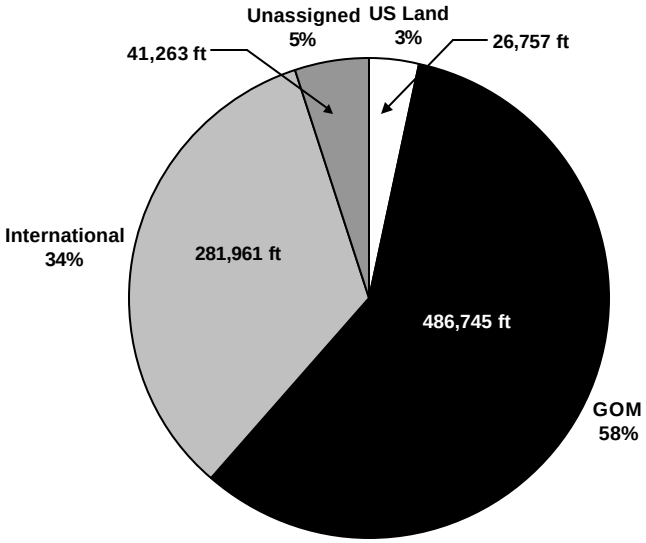

Figure 6 – Distribution of 5-7/8 in. drill pipe applications. The majority of the 5-7/8 in. drill pipe is located in the Gulf of Mexico. International use of the pipe is growing

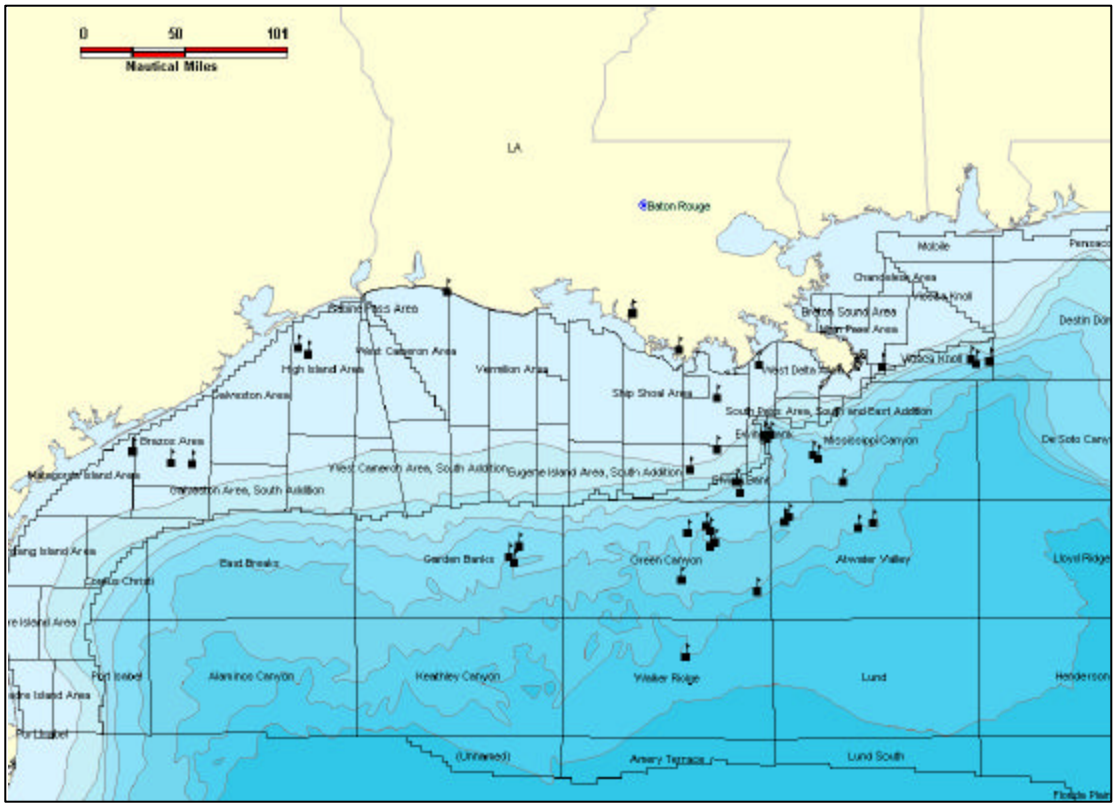

Figure 7 – Most of the 5-7/8 in. XR drill pipe in the GOM has been used on deepwater projects. Additional applications include wells located on the shelf and inland barge projects.

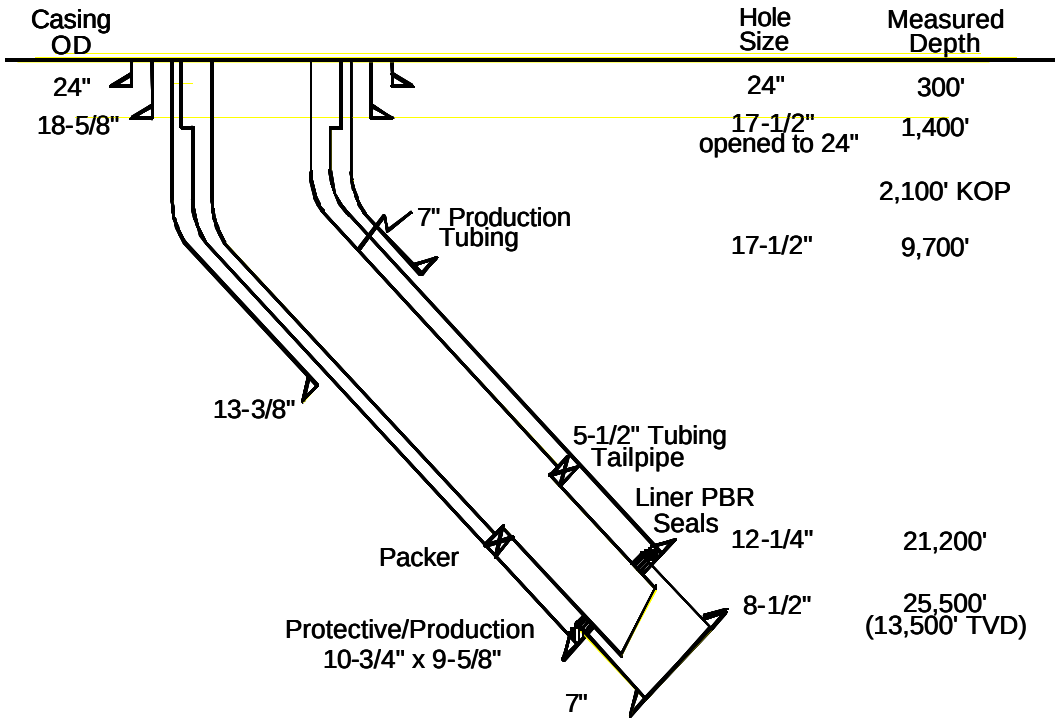

Figure 8 - Casing program for BP's Yacheng project in the South China Sea. The hydraulic performance of the 5-7/8" drill pipe enhanced drilling efficiency in the long 12-1/4" hole section.

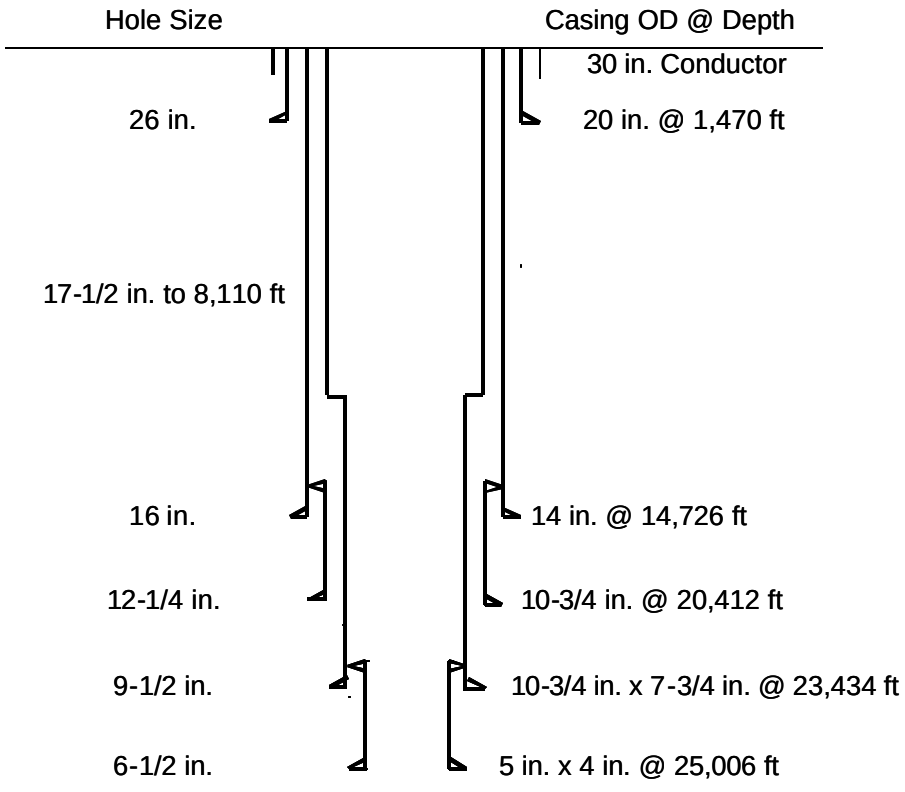

Figure 9 – Bighorn #8-35 wellbore schematic. The well is located in the Wyoming Madden Deep Unit (MDU) of the Wind River basin.