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Real World Examples of Solid Expandable Casing Applications

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Abstract

When most operators think of solid expandable casing they focus primarily on how its application relates to curing hole problems, while minimizing any loss of hole size incurred by running a casing string. However, many new uses for solid expandable casing are quickly growing in popularity. Some of the applications are remedial in nature, but more and more the technology is being planned in as part of the well design. Many of the normal drawbacks to conventional well designs can be mitigated with the application of solid expandable casing technology.

From deepwater wells where solid expandable casing is being used to slim the well design to sidetracking in existing wells, the technology allows operators to preserve hole size, downsize their rigs and save on consumable items. Other applications have involved shutting off water-producing fractures by expanding against the formation and repairing casing by cladding the solid expandable system across the damaged section. One advantage realized by using solid expandable casing includes the ability to drill the next hole section beyond the expandable casing with larger drillpipe and bottomhole assemblies (BHAs), including measurements-while-drilling (MWD) and logging-while-drilling (LWD) tools, which may have been impossible in the conventional casing plan. Larger production tubulars and related completion equipment also add to the value generated by using solid expandable casing.

This paper will look at a number of specific examples of installations performed to date or in the planning stages. These examples will cover a wide spectrum of applications.

Introduction

The desire to change well design and construction proved to be a primary driver behind the development of solid expandable tubulars. This goal initially required addressing the following challenges:

- drilling in high pressure zones
- drilling in deepwater environments
- drilling in troublesome sub-salt plays
- repairing and mechanically enhancing casing strings already in place
- enhancing existing wells

As an enabling technology, solid expandable tubulars allow operators to access reserves that cannot be reached economically with conventional technology.[1] Expandable technology helps facilitate far-reaching, untapped applications to solve present and future drilling and development problems that cannot be resolved with conventional measures. The evolution of this technology is due in part to the documented success of using expandable tubulars to save wells in danger of not reaching their planned objective.

Comparing the relative merits of preplanning expandables versus using them as a contingency produces legitimate issues worth considering. Using an expandable as a contingency to solve a well problem, although proven reliable, fails to reap the full benefits of the technology. Choice of size, length, time and location of the installation is dictated by the situation after the problem occurs. These situations are difficult to plan for and lead to running the expandables in or around hole sections with the greatest risks.[2] The operator is now forced to address problem conditions with a smaller expandable system that can result in

- hole sizes that are difficult to drill
- intervals that cannot be logged with tools that provide adequate evaluation information
- limited completion options due to the remaining inside diameter (ID)

Taking full advantage of the technology requires incorporating it into the original well design. Preplanning gives the operator more options to address conditions that can result in

- Using shorter lengths of expandables to enhance savings.
- Reducing the hole size diameter, which leads to hole cleaning and rate-of-penetration (ROP) improvements.
- Using lower expansion pressures during installation.

Since these systems can be planned behind regular pipe, any issues surrounding corrosion, size of completion tools, and pressure rating are eliminated when conventional pipe covers the expandable tubulars.

Instead of being used as just a remedial solution to problems encountered during drilling or production, solid expandable tubulars are an important construction element to drilling “better” wells. “Better” wells reduce costs, minimize environmental impact, and/or address challenges proactively. An example of “better” drilling in deepwater wells slims the wellbore, which results in reduced capital outlay for rig costs and drilling consumables. This reduction garners a superior rate of return (ROR) over conventional development scenarios. An example of “better” drilling for low cost shallow onshore wells uses an ultra-slim design also made possible by planning expandable tubulars as part of the well construction (**Figure 1**). This approach results in a well drilled with fewer consumables and increased ROP for each hole section involved in the construction of the casing plan.

Identifying Avenues for Optimization

Several avenues can be considered to optimize well design with expandable casing. An obvious opportunity for realizing savings in expenditures and resources comes by reducing the casing size itself and by drilling in the most efficient size ranges. Savings are realized in the following topside costs:

- Location or platform costs
- Tubular costs
- Mud products costs

Current costs from operators in the Middle East indicate that savings on the order of 20 to 40% are realized by eliminating one full casing size. As technology for placing wells in the optimum spot in a pay zone and as the length of producible sections continues to improve, accepting deliverability with a small hole at total depth (TD) is an antiquated compromise. A conventionally drilled slim hole design also lacks some flexibility to cope with unexpected well problems. If a lost circulation or overpressured zone is encountered, there may not be enough diameter left in the existing hole to drill to TD or enough room left to effectively deal with corrosion or cement isolation problems.

Hole sizes exist that are more cost effective to drill. It is generally accepted that hole sizes below 7-7/8 in. are more difficult to drill than larger sizes due to the following:

- Less durability of smaller bit and other BHA parts because of their smaller mass.
- Flexibility of the assemblies which can lead to drag and buckling problems.
- Lack of space available to design engineers that prevents the removal of stress concentrations.

It is difficult to scale down items with moving parts, like roller cone bits, roller reamers and other downhole tools, due to size strength and heat dissipation issues. Scaling down can lead to problems dissipating heat that reduces bearing and cutting structure life.

On the opposite end, hole sizes above 12-1/4 in. tend to be slow to drill. Providing the energy to break the rock at the bit face becomes more difficult. Drilling a larger hole requires

- more drilling mud
- bigger volumetric flow rate
- bigger pumps
- more solids control equipment
- more waste disposal
- more expensive BHA parts
- more steel for casing
- more cement for zonal isolation.[3]

Optimizing Extended-reach Drilling

Solid expandable technology also allows for optimization of extended-reach drilling (ERD). Typically the ERD limit is reached when one of the following occurs:

- The hole becomes unstable due either to time exposure, geo-mechanical interaction, adverse pressure differential, or drilling fluid interaction (or incompatibility).
- The drillstring no longer travels to the bottom of the hole due to excess drag. This situation is not related to the friction factor which remains unchanged. When rotation is used to overcome friction and advance the drillstring, as in a rotary steerable application, the limit is reached when tubulars hit torque capacity.

The current ERD limit is the standard design criteria for casing-setting depths. Where engineering analysis or previous experience indicates a potential problem with pressure differential, hole stability, pressure gradient, or geo-mechanical interaction, the standard solution is to set casing. The more lateral distance to be drilled in an extended reach well results in longer casing sections to run and increases the chance that additional strings will be needed. This condition can lead to the use of far greater initial hole and casing sizes which results in the need for larger rigs, longer drilling times, and more costly well construction. By using a solid expandable casing section to cover a swelling shale or lost circulation zone, drilling can continue with minimum loss of hole size. The expandable solution results in a smaller casing size at the surface, reduced drilling times, and lower completion costs.

Addressing Helical Buckling

Performing a detailed engineering analysis of torque and drag on well design illustrates more effects on ERD limits. The drillstring/casing and drillstring/openhole geometry significantly influence the geometric limitation of torque and drag. A stationary drillstring conducts the directional correction or steering portion of the drilling in standard directional drilling (not rotary steerable). A mud motor with a bent sub provides the rotational motion to the bit and the direction of the build.

In many cases, the onset of helical buckling impedes and eventually stops the ability to control drilling direction. This phenomenon occurs when friction increases and then exceeds the downward force of gravity on the drillstring. The drillstring bends into a spiral, making constant contact on the hole or casing wall. Any additional force applied merely increases the normal force of the drillstring on the hole or casing wall and correspondingly increases the frictional force. The closer the tolerance between the drillstring and the casing or hole, the greater the ability of the system to resist helical buckling.[4]

The use of liners exacerbates the problem of helical buckling with adverse well geometries. The situation just above the liner top creates a third drillstring/hole size combination in the well that makes it exceedingly difficult to optimize the overall system. In conventional combinations, 5 in. drill pipe is usually optimum for drilling in 8-1/2 in. hole and inside 9-5/8 in. casing. When a 7 in. liner is used, the drillstring in the transition just above the liner top must be sized to fit inside the liner top as the well is drilled ahead. Typically drill pipe or drill collars must be used to try to prevent buckling in the 9 5/8-in. casing while still fitting into the 7-inch liner.

Liner top buckling can be eliminated using a 7-5/8 x 9-5/8 in. solid expandable liner and 5 in. drillpipe above and below the liner top. This configuration extends drilling reaches 30% before nearing the helical buckling limit. Because the drillstring has the largest available torque capacity, this solution offers the greatest potential for rotary steerable reach. The enhanced resistance to helical buckling illustrates the potential of offering the largest available conventional directional drilling reach.

Deepwater Applications

Drilling margins (the difference between pore pressure gradient and fracture pressure gradient) narrow as operations move into deeper water. These narrow drilling margins require more casing strings to drill to an equivalent depth below the mudline compared to a well drilled in a shallower water depth. In some cases, using conventional casing programs with an 18-3/4 in. blowout preventer (BOP) stack and a 21 in. outside diameter (OD) drilling riser, well objectives cannot be reached with sufficient hole size for evaluation and production operations. An ultra-deepwater well, in water depths over 5,000 ft, reached it's objectives by using a 13 3/8 x 16 in. solid expandable tubular system (**Figure 2**). This enabling technology can also provide contingency casing deeper in the well.

Traditionally, as water depth increases, the size of the drilling vessel and equipment capacities increases. Water depth, ocean conditions, BOP, and riser size affect the size of the rig. The well objectives and casing program determine the minimum BOP stack and riser size. The riser size affects the following systems on a drilling rig:

- Deck load
- Deck space
- Riser tension capacity
- Hoisting system capacity
- Mud system volumes
- Bulk volumes

Case History: Ultra-Deepwater

The objective of these ultra-deepwater installations in the same well was to overcome low drilling margins without sacrificing hole size. These installations were in water ~ 8,000 ft (**Figure 3**).

The initial solid expandable openhole liner was installed below the 16 in. 84.0 lb/ft casing string set at 11,760 ft. The 13-3/8 x 16 in. solid expandable liner was set at 12,684 ft.

The learnings from the first installation were applied while running the second system, improving the running time of the second liner. The second application installed a 1,521 ft, 9-5/8 x 11-3/4 in. system below the 11-3/4 in. drilling liner. System expansion took ~5 hours at propagation pressures of 2,000 psi. With the second installation this well became the world's first to have multiple solid expandable tubular installations. More importantly, the successful installations allowed the operator to explore deeper objectives. The well ultimately reached TD with 8-5/8 in. casing.

Sidetracking With Solid Expandable Tubulars

Presently, two relevant cases exist for recompleting and revitalizing wells using solid expandable tubular technology. The first case involves recompleting wells that are no longer meeting productivity expectations or that require a wellbore in another reservoir location to achieve optimal drainage. Using solid expandable tubulars in a window exit process allows for a larger completion through a casing sidetrack (**Figure 4**).

The second case deals with planning the field development using solid expandable tubulars. In this circumstance, the operator would include solid expandable tubulars in the original well plan to explore and produce a well. The drilling plan runs tubulars in each interval that would facilitate an easy sidetrack operation if needed later. The primary benefit is manifested in hole size retention that enables the use of conventional diameter completion equipment or corrosion-resistant alloy (CRA) beyond the expandable section.

Incorporating the technology initially allows the operator to slim the wellbore construction by starting with a smaller base casing and still reaching sidetrack TD with the required size. Compared with conventional development scenarios, slimming the well design results in the following:

- Reduced capital outlay
- Minimized environmental impact
- Maximized reservoir potential
- Superior ROR

Two significant benefits become apparent when deepwater operators use solid expandable tubulars in conjunction with sidetracking technology. The first benefit pertains to older platforms with no remaining template slots. In this case, the only economically feasible method to reactivate a field may require re-entering existing wells using solid expandable tubulars to preserve a larger ID. The costs of drilling a new well may not meet the operator's economic parameters.

The second benefit is evident in deepwater recompletions on a tension-leg platform through a riser. In this scenario, solid expandable tubulars can be run through a milled casing window using the smaller production riser. This application saves cost and effort required in a complete slot recovery operation, such as having to pull the production riser, install a larger drilling riser to perform the recompletion, and then rerun the production riser. By eliminating extra steps in the process, solid expandable tubular technology saves expensive rig time and reduces non-productive time (NPT).

Many fields are not being drained optimally because the original wells drilled are no longer or never were in the best location of the reservoir. Wells exist that, even if located correctly, are incapable of producing at peak performance for various reasons, such as tubing constraint. In high permeability reservoirs, large-bore completions deliver high well rates above and beyond that of conventional completions. A well's outflow performance increases because of decreased pressure drop in the larger diameter tubing. A problem occurs when the original production casing limits the size of tubing that can be used to improve productivity. The size of any casing string set in a well limits the size of the next string and ultimately limits the size of the completion string. This situation constrains the ID available for production or injection.

Solid expandable tubulars, however, can turn a tubing-constrained completion into a large-bore producer, whether by incorporating systems into the original well plan or using them to address drilling hazards. One operator developed a performance model built around a well with 7 in. tubing in 9-5/8 in. production casing. This model showed only a 10% increase in well deliverability from a tubing change-out completion to 7-5/8 in., the largest size tubing that can be run. Comparatively, a recompletion using 7-5/8 in. solid expandable tubulars showed a 40 to 50% increase in well deliverability and a 50 to 100% increase in production. A successful field pilot test of a solid expandable tubular workover proved the viability of the application.[3]

Recompletion technology is regularly used to reverse less-than-optimal performance or to expand the drainage reach of individual wells. Operators recognize the many benefits the technology offers, which have been driven by slot availability on aging platforms, better reliability and feasibility of casing whipstock and milling systems, and increased reservoir knowledge.[4]

When used together, solid expandable tubulars and new recompletion technology present the revolutionary potential application of larger multi-lateral sidetracks. The combined benefits of these technologies include the following:

- Increased productivity
- Use of wells and facilities already in place
- Availability of a larger ID for recompletion and stimulation[5]

Water Production Management

As oil fields mature, production wells experience co-production of oil and water because of aquifer encroachment and/or water injection. Controlling the water production is one of the major challenges in reservoir management. Diagnosis of the zone of water influx in horizontal well bores, however, is not always straightforward and must certainly precede any remedial water shut off treatments.

Openhole Clad Design and Operation

The development of an openhole clad system was driven by the necessity to shut off water in barefoot completed sections of a reservoir. This cladding system is made up of a pre-expanded pipe section called the launcher assembly that houses the expansion cone, which is closed off with a float shoe. Expandable pipe, for the length of the open hole to be isolated, is connected to the launcher assembly. Seal elements can be placed on the exterior of this expandable pipe. A running string is connected to the cone and the openhole clad is run to the required setting depth. Once at depth, a dart is pumped and latched into the float shoe. This action creates a pressure chamber below the cone to initiate the expansion. Pressure is applied to the running string and the cone starts expanding the pipe. Upon expanding the first joint, the seal elements grip the formation and anchor the system. Towards the end of the expansion process, before the cone exits the pipe, a pull test can be performed to confirm the anchoring and placement of the openhole clad.

Case History: Open Hole Clad

The field in this case history started production in May 1970 and initially used vertical wells to produce the hydrocarbons. As drilling technology progressed, the operator began to use horizontal wells in 1990 to optimize drainage area per individual well and improve field economics. The 70 producing horizontal wells in this field average 8,200 ft measured depth (MD).

The horizontal wells were successful in achieving drainage objectives except for the issue of water production. The field is a heterogeneous fractured carbonate reservoir, drained by a series of horizontal production wells via depletion drive with a strong aquifer support. Completions are mainly cemented and perforated liners, but, historically, some wells have been completed barefoot without noticeably different production behavior.

One of the barefoot wells, originally drilled and completed in 1973 as a vertical oil producer, was found to be producing water through a dense fracture system. The well was subsequently sidetracked through a milled window in the 9-5/8 in. casing and drilled to 6,620 ft TD It was completed with a 6.125 in. openhole, plugged back to 6,470 ft MD, and produced by gas lift through 4-1/2 in. tubing.

The sidetracked well was put on production in May 2001. The initial sidetracked production in May 2001 included an oil rate of 1,260 bbls/day and a gross fluid rate of 2,700 bbls/day, representing a 53% water cut. The oil rate steadily declined in the following nine months to ~314 bbls/day because of a water breakthrough, representing a water cut of 91%. A stiff-wire electric line production log run in September 2001 showed that only the last 557 ft of the 1,060 ft of openhole interval were contributing to fluid production. Of this interval, a 130 ft central section was producing both oil and water, and the remainder was producing only water. The log also incorporated a four-arm caliper to determine the wellbore profile. The exceptionally high water cut of this well, coupled with a too-close-to-gauge hole profile, made it an ideal candidate for the solid expandable tubular system. The objective would be to shut off the water inflow from the toe to the first clad, then cure the water inflow further up the hole with the second clad (**Figure 5**).

Prior to and during clad deployment, static losses were 94 bbl/hr. Losses immediately dropped to 57 bbl/hr after setting the first clad, and dropped further to 31 bbl/hr after setting the second. The final loss rate was 50 bbl/hr once the shoe of the upper clad was drilled out to re-expose the section between the two cladding systems. After recompletion, the well was put on production and the produced oil rate was found to have more than doubled to 705 bbls/day, with a reduced water cut of 84%.

Conclusions

Solid expandable tubular technology is no longer just an interesting theory but provides viable solutions to drilling and recompletion challenges in both conventional and deepwater wells. Recompletion of previously lost or shut-in wells are less cost prohibitive with this technology. Drilling in formations and at depths once thought too expensive is now operationally and technically feasible. With over 300,000 ft. of solid expandable tubulars installed to date, this enabling technology is becoming the first choice rather than a last resort. Feasible applications continue to be defined and implemented. One operator plans to set production packer(s) inside the solid expandable liner(s). Plans are also in progress to mill windows in future expandable liners and use intelligent completion technology. These future applications and the move to plan the use of the technology demonstrate another evolutionary step in solid expandable casing and highlight the role that associated technologies play in facilitating this growth.

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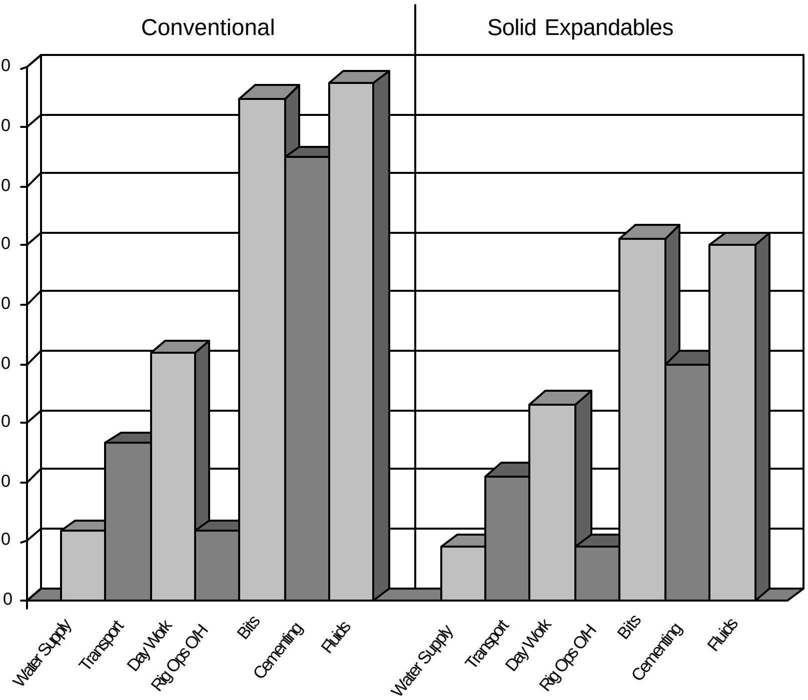

Figure 1 – Conventional consumable costs compared to solid expandable tubular technology consumable costs.

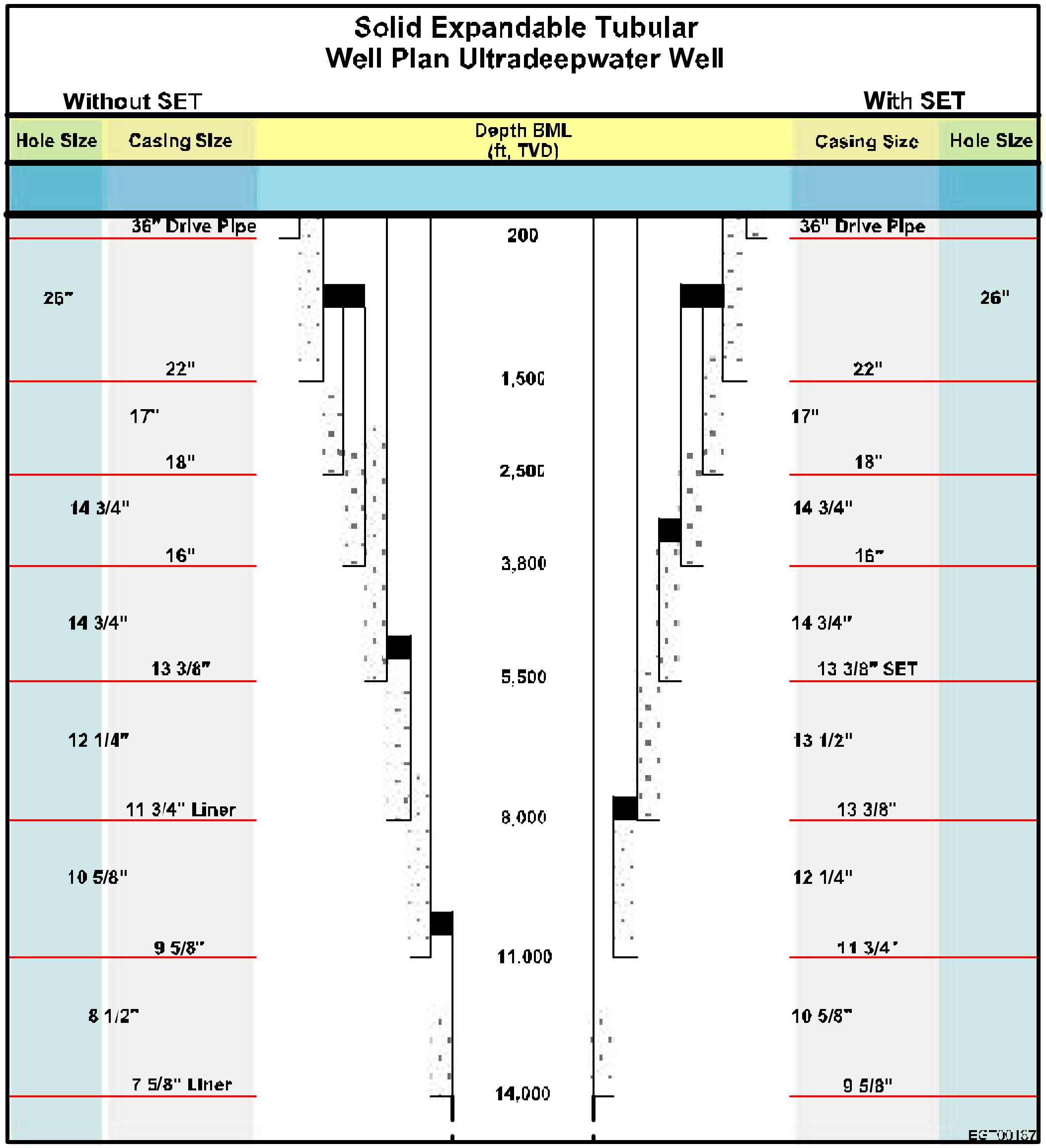

Figure 2 – Ultra-deepwater well using a 13-3/8 x 16 in. solid expandable tubular system.

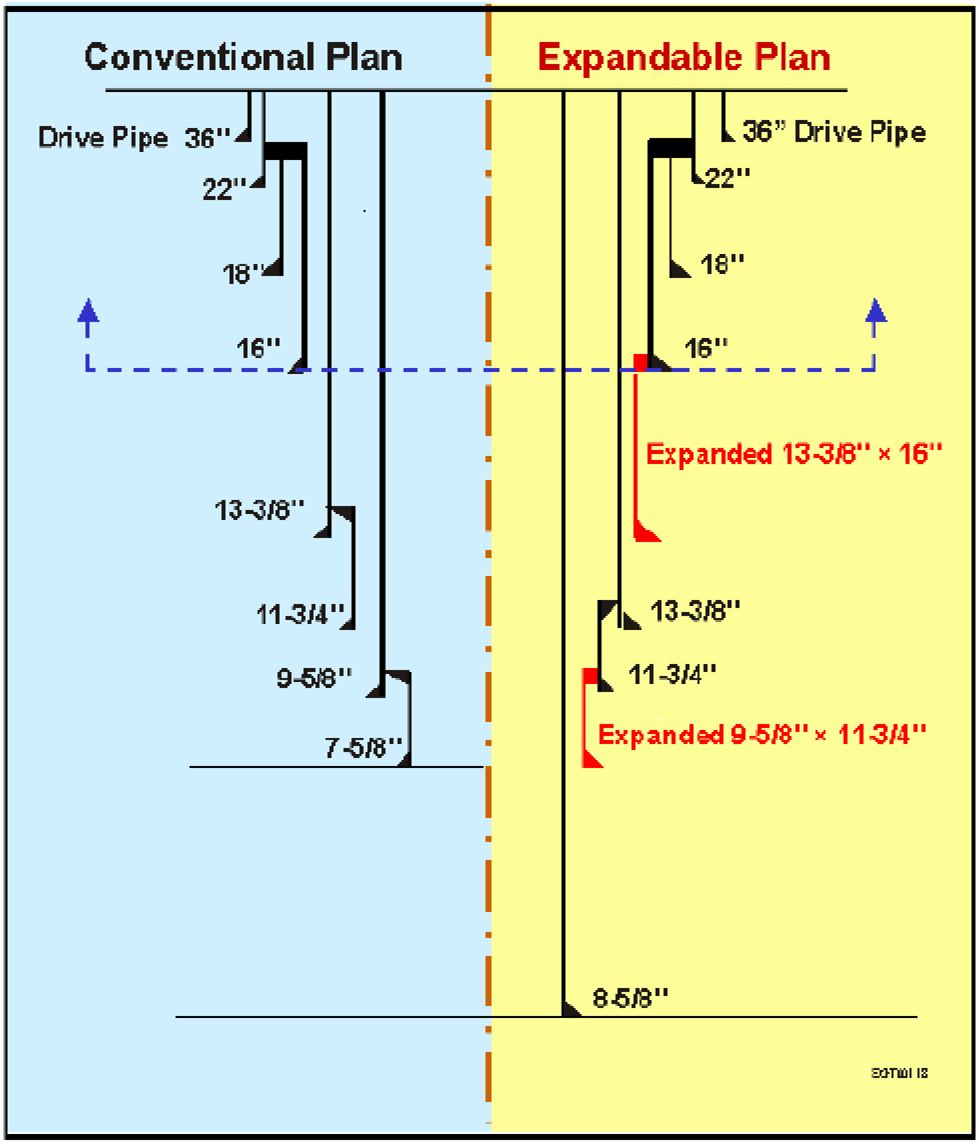

Figure 3 – Conventional vs. expandable solid expandable tubular installation for an ultra-deepwater well.

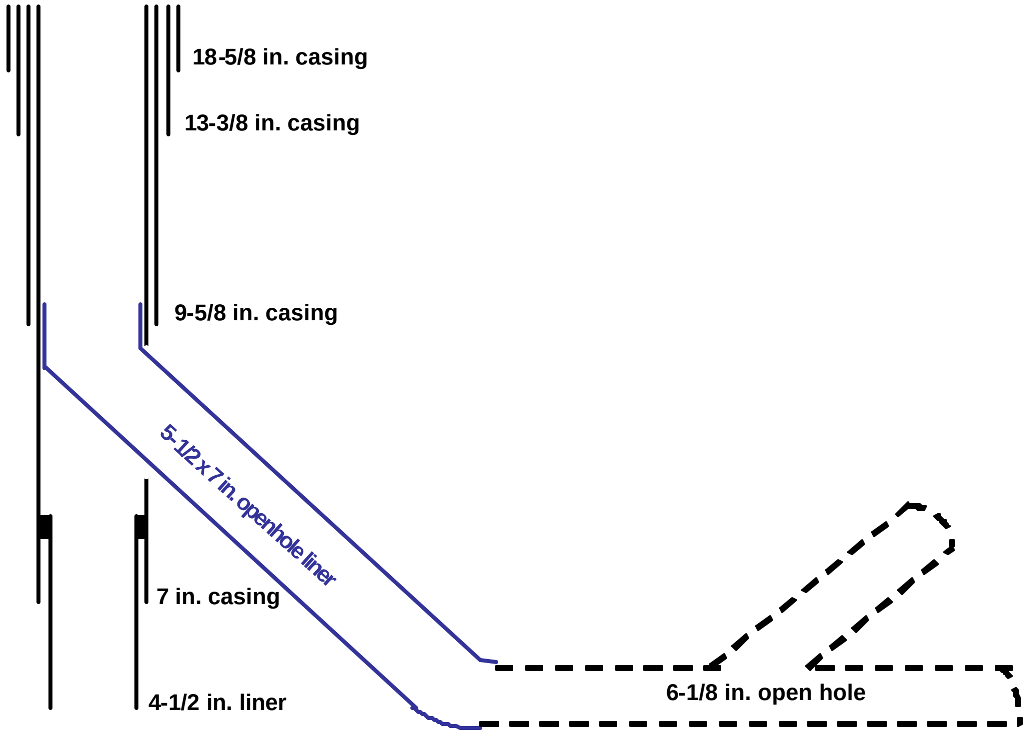

Figure 4 – Sidetrack and recompletion through a 7 in. window while retaining a 6-1/8 in. drain hole.

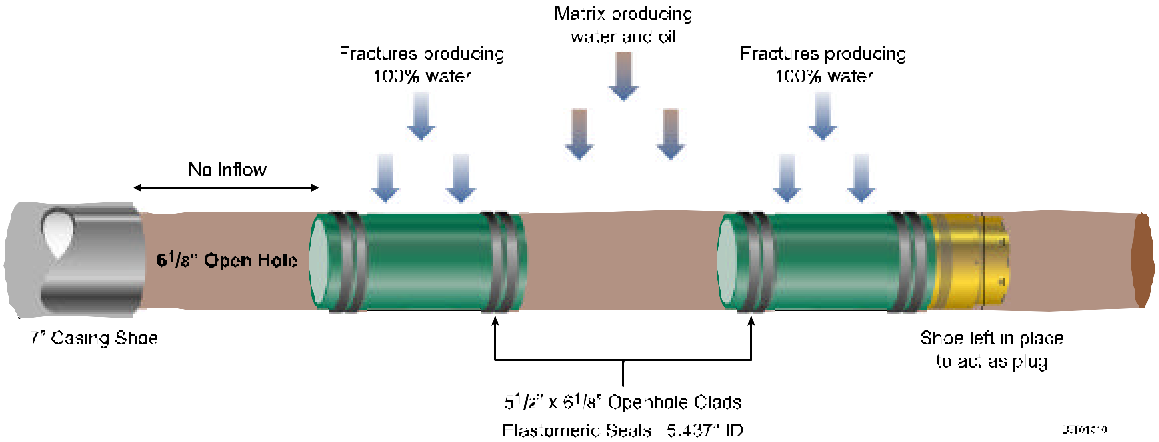

Figure 5 – Solid expandable tubulars used for fracture isolation.