ATTAINING SIGNIFICANT VALUE WITH SOLID EXPANDABLE TUBULAR TECHNOLOGY

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ABSTRACT
With over 1,000 installations, solid expandable tubulars have established a legacy as an enabling technology that mitigates a variety of unfavorable wellbore conditions. From preserving hole size in drilling operations, to providing the ability to re-complete an existing wellbore in production operations, solid expandable tubulars put a new and valuable tool in operator's toolbox. In addition to technical solutions, operators have realized significant savings in the consumption of equipment, days on the well, attaining optimal rate of penetration (ROP), reduction of non-productive time (NPT), and HSSE exposure. Incorporating these systems into the initial wellbore plan reduced overall costs of some wells by up to 30%. Projects previously deemed cost prohibitive gained economic feasibility.

This paper describes the operational process of how solid expandable tubulars have been used in varied environments and conditions to solve a broad range of downhole problems. Actual case histories are used to illustrate how this technology was advantageous to projects, be it economic, technical, or environmental. This paper explains the planning and implementation process to ensure that maximum value of the solid expandable system is attained.

INTRODUCTION
The wealth of history that exists regarding solid expandable tubulars is a testament to its enabling and practical capabilities since first field tested in 1999. Actually expanding pipe in-situ opened a realm of mitigation possibilities that continues to provide dynamic options to drilling and production challenges. Solid expandable systems were initially used as last-resort contingencies that enabled operators to:

- Fight fluid losses and other borehole instabilities.
- Isolate unwanted perforations by cladding against existing casing.
- Remediate and strengthen corroded and worn casing while increasing the mechanical properties of the well.
- Increase the probability of reaching the planned total depth (TD) with the desired casing size.
- Extend economic field-life of mature fields.
- Optimize completions for maximum well flow and better reservoir drainage.

The technology quickly became a viable option, seriously considered by operators to address a myriad of drilling challenges and conditions. Installation demands and conditions prompted tool enhancements that made the expandable systems more robust, versatile, and applicable.[1,2] As the technology evolved, operators found that the most advantageous approach is to incorporate the expandable system into the drilling plan as part of the wellbore design.[3] Solid expandable solutions provide drilling engineers with another tool to optimize well construction and minimize the loss of hole size while dealing with drilling challenges.[4] Expandables mitigate difficult drilling conditions and preclude problems associated with challenging formations including the following:

- Sloughing shales
- Loss circulation/depleted zones
- Abnormally pressured zones

SOLID EXPANDABLE TUBULAR TECHNOLOGY
Over the last decade, the technology has evolved to include a suite of systems capable of addressing varied challenges even in extreme environments and dynamic formations (**Figure 1**).

Openhole Liner System
Openhole expandable tubulars have successfully mitigated downhole conditions such as equivalent circulating density (ECD) -related drilling problems, borehole instabilities, and narrow pore pressure/fracture gradient windows.[4] Opposed to a conventional casing run, the SET liner is “pulled” into the wellbore. During the installation

process, a bottom-up expansion procedure utilizes regulated hydraulic pressure, with some liner weight, to expand the liner while keeping the expandable liner at its lowest depth, thus effectively isolating the troubled zone.

Cased-hole Liner System

Cased-hole expandable systems have been used to isolate old perforated intervals, reinforce casing with substantial wall loss due to corrosion, and cover defective or leaking tools. This expandable solution has quickly begun to replace less reliable conventional operations, such as cement squeezes and "ID costly" scab liners. Field rejuvenation projects developed with solid expandable tubulars have proven critical in helping mitigate the adverse effects of corrosion and re-completing additional zones.

Openhole Cladding System

Water-bearing fractures and depleted zones have been successfully isolated and controlled with expandable openhole cladding systems. As opposed to a conventional tie-back liner or full casing string, the openhole cladding system incorporates special expandable anchor joints with elastomeric bands that clad into the formation above and below the problematic zone to provide an annular seal. Because of the diameter of the borehole dictates system size and elastomer thickness, the openhole cladding system can be customized for a variety of borehole sizes.

Flexible Cladding System

For challenging conditions in small casing sizes such as 4-1/2 and 5in., the flexible cladding system can provide a permanent fix to casing repair. This system is also widely used in wells with special requirements, such as a gas-tight seal rating, high frac pressures, or high pressure/high temperature (HPHT) applications, This expandable solution can also provide isolation of existing perforated sections in smaller casing sizes that would typically not have remediation options available in that specific size. This system consists of expanding upper and lower "anchor hanger" sections, spaced accordingly with conventional or specialty API tubulars, and cladding into the existing casing. This clad creates the sealing mechanism that isolates the unwanted area from the rest of the wellbore.

Single-diameter System

A successful field application trial of single-diameter solid expandable tubulars authenticated new systems as another valid solution to downhole problems.[5] Planning successive expandable liners with uniform ID would allow the operator to eliminate any telescoping of the wellbore or some portion of it. This advantage allows the entire well design and related drilling equipment, such as BOPs, risers, and rig size to be slimmed down. Standardizing the drilling program, including drillpipe, bits, mud/cement volumes, and rig sizing, helping to lower drilling cost-per-foot and increase drilling efficiency (**Figure 2**).

Successive single-diameter liners are also expected to enable significantly extended lateral reach. These extended-reach drilling applications would be capable of boosting the recovery factor, enhancing the productivity index, and increasing reservoir contact. Extended-reach lateral would be cased with successive liners that preserve ID. Using shorter lengths of casing that maintain a constant ID prevents friction and drag increases and could extend drilling reach up to 50%.[6]

In dynamic formations, the single-diameter system could be used in an open hole to clad over just the problematic formations. Wellbore diameter is maintained and the need and cost to cover an entire zone is eliminated. Multiple casing points can be made up or initially attained without losing hole size. The single-diameter system would be used as a drilling liner or production liner in low pressure, non-gas applications just as conventional expandable liners are presently used.

FUNDAMENTAL OPERATIONAL PROCESS

Expandable casing is nominally sized API L-80 jointed casing manufactured to more exacting specifications. The use of electric resistance weld pipe results in a uniform wall thickness. Additional steps in the manufacturing process provide the material properties necessary to allow successful expansion of the pipe. The underlying concept of solid expandable tubular technology consists of cold-working the steel downhole to a desired size.

The installation of solid expandable casing starts with drilling the openhole section in which the casing is to be deployed. The launcher assembly, which is the bottom section of the expandable liner containing the expansion cone, is made up and run through the rotary table. Expandable casing is screwed together in approximately 37-ft joints until the required amount of liner is hanging in the slips. An anchoring joint with multiple elastomer sections bonded to the pipe is placed at the top. The drillstring is then run as an inner-string inside the liner, made up to the expansion cone through the use of a safety-thread connection and run to bottom.

Once on bottom, the cement is pumped as in an inner-string cement job. Immediately after the cement is pumped, a latch-down plug is pumped. When the plug reaches the launcher, it lands and is locked into a seat. This action creates a pressure chamber below the expansion cone. Expansion is initiated by applying hydraulic pressure (through the top drive or high-pressure hose) down the drillstring while simultaneously applying sustained pulled (mechanical) force on the drillstring at surface. The liner expands at approximately 20 to 30 feet per minute. As each stand is removed from the hole, the pressure is bled off and the stand is broken out and racked back. This process is repeated until the entire liner has been expanded and sealed back into the overlap with the existing casing. The expansion cone is then recovered to surface, and the float shoe is drilled during the next trip in the hole (**Figure 3**).

Expansion Sequence (for openhole systems)

1. Drill the hole section to facilitate the expandable liner installation.
2. Make a dummy run with a drift tool to ensure passage of the liner assembly.
3. Run in the hole with the launcher, expansion assembly, and expandable liner.
4. Circulate and cement the expandable liner.
5. Pump and seat the latch-down plug to facilitate liner expansion.
6. Expand the expandable openhole liner.
7. Expand the expandable liner's hanger joint.
8. Circulate and conduct pressure test of the liner and the seal at the hanger joint.
9. Pull out and lay down the expansion assembly.
10. Drill out the expandable liner float shoe.

INSTALLATION CONDITIONS AND CHALLENGES

The key advantage of solid expandable tubular technology is that it enables an operator to reach TD with a larger wellbore size than could be achieved using conventional casing. The openhole liner system overcomes operational problems associated with borehole instabilities, small pore pressure/fracture gradient windows, and the effects of salt or subsalt formations (rubble zones). The expanded openhole liner effectively creates an intermediate size of casing compared to conventional casing sizes. Expandable casing reduces the tapering effect of telescoping casing strings by reclaiming the clearances required between conventional casing strings.

Pressure applied underneath the cone pushes the liner to bottom. The openhole liner system is then expanded from the bottom up. During this process, the wall thickness of the expandable liner does not thin per say; on the contrary, the liner will axially shrink from the top-down. A bottom-up expansion process that pumps through and pulls on the inner-string generates greater forces than by adding weight to it. Because the inner-string is already being pulled out of the hole as a part of the bottom-up expansion operation, additional tensional forces, up to the weight of the liner, can be added as a secondary force to supplement the hydraulic expansion. The size of the tubular, its mechanical properties and expansion percentage determine the expansion forces required.

PLANNING IN VS. CONTINGENCY

The preemptive approach of incorporating solid expandable systems into the well plan has enabled operators to effectively combat the negative influence of problems they may have on the drilling plan. Most importantly, it has created the ability for operators to drill the well with a smaller rig, slim down the original casing profile, and push the drilling envelope while ensuring the necessary casing size at TD is attained. Incorporating and planning expandable systems as a wellbore design element has averted numerous problems identified from offset data or real-time challenges. In this capacity, the expandable systems have become the catalyst for successfully completing and producing from previously undrillable or shut-in wells. These systems have proven their relevance in wells without offset data and in hot exploratory profile wells where the operator has been able to drill deeper than previously thought possible.

When unknown conditions necessitate setting casing higher than planned, expandable technology has successfully extended the shoe and prevented losing casing points. Because solid expandable tubular systems reduce the well-tapering effect and help maximize wellbore ID at TD, additional casing strings can be deployed to drill deeper and evaluate the resulting wellbore with sufficient hole size. Larger evaluation and completion tools are more reliable, efficient, and reasonably priced.

Operators conducting well restoration and rejuvenation projects have realized significant economic results by incorporating solid expandable tubulars especially with field-wide applications. Developing workover plans around expandable technology has helped facilitate more economical operations by optimizing rig time, streamlining processes, and reducing consumables.

Engineering support for using expandables can be provided throughout the life of the well. If the well is in the planning stages, the first step is to evaluate the well. It is imperative to know the TD of the well, the number of casing points required, and the production casing required.

Once these questions are answered, potential casing scenarios can be evaluated. Each hole section can be analyzed to determine the best interval for an expandable. When performing this analysis, items to consider include the following:

- Length of hole section.
- Burst and collapse requirements.
- Bore-hole hydraulics.
- Drilling challenges such as lost circulation, rubble zones, HPHT conditions, etc.

It is important to note that there are advantages to setting the expandable systems higher in the wellbore. For example, the upper wellbore is a more stable and reliable because the pore pressure/fracture gradient window is usually wider. Also, in the larger expandable systems, more annular clearance exists between the expandable tubular outside diameter and the ID of the existing casing. Due to the larger cross-sectional areas of the bigger sizes, the expansion pressures are lower. Running an expandable in the upper section of the wellbore still allows for additional expandables being run deeper in the wellbore, if needed.

By evaluating the placement of the solid expandable liner proactively, the most appropriate section for system installation is decided in the design stage rather than in the operational stage. Using solid expandable tubulars as a fundamental wellbore design element enables the operator to select the placement of the system rather than the conditions dictating the system's use, thereby optimizing the benefits of an expandable solution. If the solid expandable tubular is only considered as a last resort to solving drilling problems, then the choice of size, length, and depth of the installation are dictated by the situation after a problem occurs. These problems can be difficult to manage and lead to running the expandable system in or around hole sections with the greatest risks.

Following initial placement of the expandable, the design can be validated by calculating the casing design, torque and drag, and swab and surge simulations to ensure that the solid expandable system is fit for purpose. At this point, all parameters affecting the expandable can be considered. The ID and weight of the existing casing is fundamental information that governs the design because the solid tubular not only expands in the open hole but also expands in the overlap of the existing casing. Because ID is crucial to the expansion process, anything that has a restrictive ID should be evaluated. The following components, at a minimum, should be analyzed:

- Openhole conditions
- Inline centralizer ID
- Float equipment
- Landing collar ID
- Casing connection ID
- Shoe joint ID and length
- Dogleg severity in the overlap and openhole section
- Liner hangers
- Overlap casing ID

If the well is already in the operational stages when an expandable is being considered, the well drilled to date is reviewed and the remaining options for placement of the expandable are determined. The installation of the expandable is preceded by a thorough system design, and recommendations on well preparation are provided. Upon installation of the expandable, post-job reports are generated to ensure that learnings from previous jobs are implemented in the future.

CASE HISTORY 1

Challenge and Objective

An independent operator with a large gas field in Central Texas needed a technical solution to develop the field as economically as possible. With plans to drill 12 to 18 wells in this field over the next few years, the operator realized that any cost-per-well savings would extrapolate into huge savings for the field.[7] Field development challenges included the determination of the maximum number of wells that could be drilled while reducing the cost per well, despite the rising costs of services. As an example of the rising costs, in the first six months of field development rig rates had increased approximately 40%. To combat rising rig rates, the time spent drilling each well needed to be reduced. The major culprit of time consumption, an intermediate section of 12-1/4 in. hole, had proven to be problematic in the four wells drilled in the field. Eliminating the need for this size of hole section would greatly increase the efficiency of drilling operations. As a challenge, however, the operator required a minimum of 4-1/2 in. production casing to facilitate the high gas flow rates of this field.

Installation and Results

After drilling approximately four wells with a conventional big pipe design, the new slimhole well design was implemented. Incorporating a 6 x 7-5/8 in. solid expandable system into the base well design enabled the operator to drill a 14-3/4 in. surface hole instead of a 17-1/2 in. hole, allowing drillout of surface pipe one day earlier. Below the surface pipe, the operator drilled a 9-7/8 in. hole (drilled at 3.0 days/1,000 ft) versus a 12-1/4 in. hole (drilled at 4.8 days/1,000 ft). The solid expandable liner was then run below this section, allowing for 4-1/2 in. production casing at TD to facilitate planned production rates.

Value Added

Overall results showed that the operator reduced total drilling time to target depth by 19%, from 89 to 72 days. In addition to cost savings from reduced drilling time, the operator could cut costs even further by using water-based mud, due to the improved hole cleaning dynamics. Using water-based mud saved money in both environmental and disposal costs.

Evaluation of total savings per well showed that the solid expandable system reduced total drilling costs by $79 per foot, approximately $1MM per well. From a field development perspective, these savings translate into every fifth well being drilled at no cost and four free wells per year. Additionally, reserves could be brought online faster accelerating production.

Increasing the Value Added

Two years into this multi-well campaign drilling HPHT formations, the operator decided to build on the success and expand the benefits. Previously, this installation required underreaming the 7-1/4 in. hole section. In this particular installation a 6-3/4 in. section was drilled without underreaming. An expandable joint with swellable elastomers was installed above the launcher to provide zonal isolation, thus eliminating the need for cementing. Zonal isolation was achieved by setting the elastomers at the shoe of the expandable liner.

Formation characteristics and solid expandable tubular efficiency enabled employing swellable elastomers in the hard rock and eliminating the need for underreaming and cementing. Although underreaming or hole enlargement is usually a requirement when running expandable systems, this liner did not require a cement job, therefore the hole size required could be minimized (**Figure 4**).

In addition to the $1M per well savings realized by slimming the well with the 6 x 7-5/8 in. solid expandable systems, the elimination of underreaming requirements saved another four to six days of rig time, equating to an additional ~$300,000 (USD) in savings.

CASE HISTORY 2

Challenge and Objective

The vertical section of a 9,433 MD gas well in Central Texas was damaged prior to the initiation of the completion program. The vertical section needed to be repaired in order to perforate and frac the target zones. However, the repair process would reduce the wellbore ID and impact the plan to differentially frac five zones in the horizontal section. The operator needed to implement a solution that would enable targeted completion with packer seats while also repairing the damaged vertical section of casing.

Installation and Results

Five 4-1/4 x 5-1/2 in. solid expandable cased-hole systems were installed in the horizontal section of the well to serve as packer seats with a sixth system covering the damage in the vertical section. The liners were run in place and expanded over a four-day period. This approach enabled the operator to successfully complete the targeted production zones as planned. This was the first time six expandable liners have been installed in one well (**Figure 5**).

Value Added

By installing the solid expandable systems, the operator was able to utilize the existing wellbore, thereby avoiding the expenditures and time consumption of a redrill. The well was completed as planned and began producing 1.2 million cubic feet of natural gas per day.

FUTURE OF SOLID EXPANDABLE TECHNOLOGY

The increasing demand for energy has pushed the oil and gas industry to re-examine and re-evaluate processes and equipment. Methodology, procedures, and technology evolve to provide the tools for practical and profitable access of production zones. Extreme conditions, troublesome formations, and sensitive environments influence drilling programs and projects and can easily turn an already complicated process into a complex ordeal. Static wellbore designs, unreliable cement squeezes, and time-consuming lost-circulation materials too often fail to address drilling challenges with longevity and reliability. The problems that ensue require a solution economically feasible, logistically practical, and technically proficient.

Solid expandable tubular systems provide a dynamic approach to well construction by strategically applying expandables to push the drilling envelope in new territories and to develop mature assets. Further evolution of expandable technology has seen the development of more system sizes and more applicable options such as the 5-1/2 x 7 in., 8 x 9-5/8 in., and 9-5/8 x 11-3/4 in. single-diameter systems. The 9-5/8 x 11-3/4 in. single-diameter system provides borehole stabilization and extends the shoe in what is commonly a crucial casing string. With the same or nearly the same ID, depending on well constrictions, a subsequent 9-5/8 in. casing string can be run. The 8 x 9-5/8 in. system stabilizes the borehole without the need to cement or tie back into the existing casing with a metal-to-formation expansion. This system provides a means by which to isolate problem formations and still maintain an 8-1/2 in. pass through and use of a standard BHA to drill ahead.

Current and future environmental concerns and economic challenges for operators are forcing the industry to re-examine the drivers for exploring and producing hydrocarbons. Solid expandable tubular systems contribute value-added technology to drilling and workover operations to the extent that they maximize reservoir potential by reducing wellbore tapering and ensuring TD is reached in optimal hole size for evaluation and testing or production. In addition, solid expandable tubulars have helped maximize the rate of investment via leveraging capitalized assets and infrastructure.[8] As the potential application realm continues to be redefined, the installation history has proven that solid expandable systems are adaptable and robust enough to be tailored to help meet the growing worldwide energy demand.

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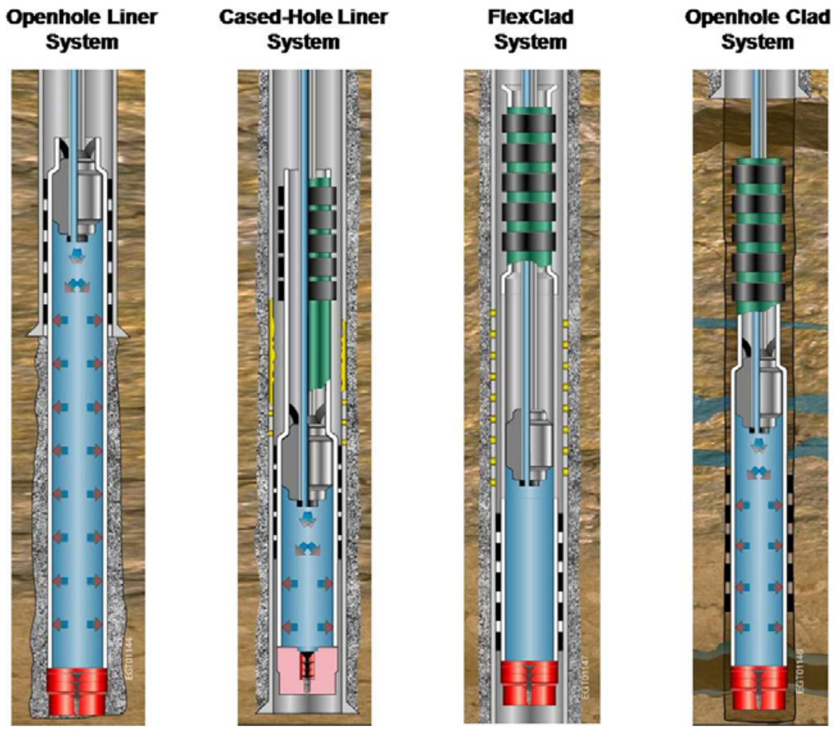

Figure 1 – Current commercial suite of solid expandable solutions.

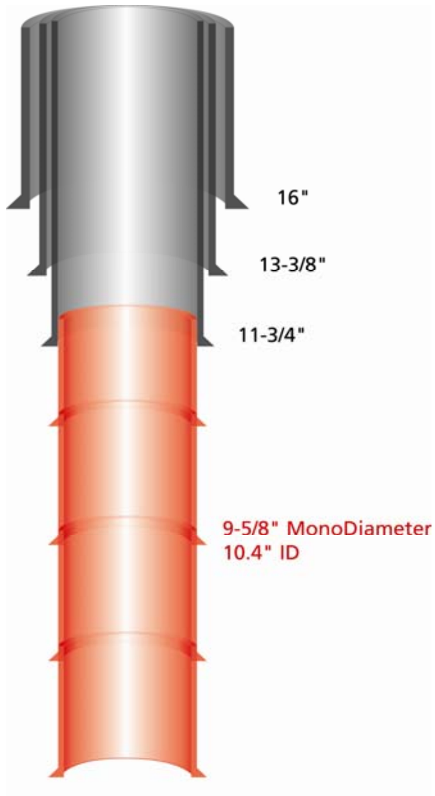

Figure 2 – Single-diameter system enables uniform or nearly uniform ID.

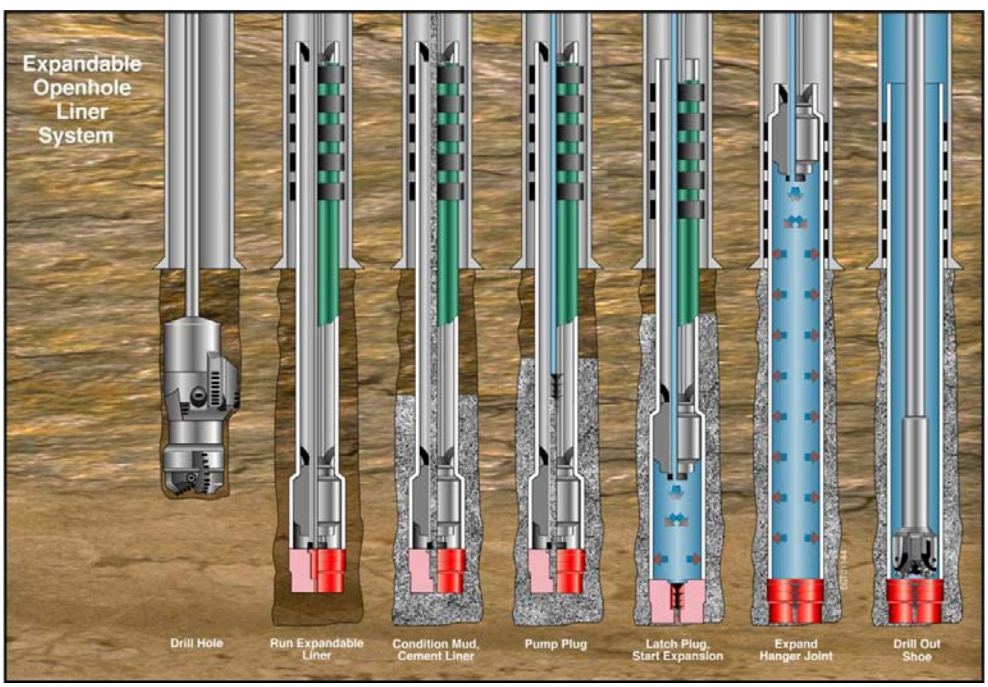

Figure 3 – Expansion sequence for a solid expandable openhole liner.

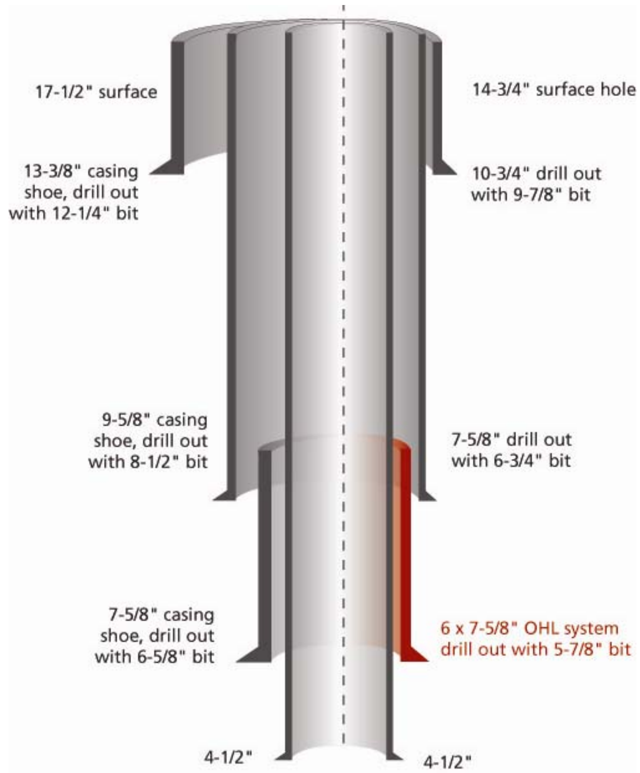

Figure 4 – Conventional wellbore profile (left) compared to the slim-well profile (right) that combined solid expandable tubulars and swellable elastomers.

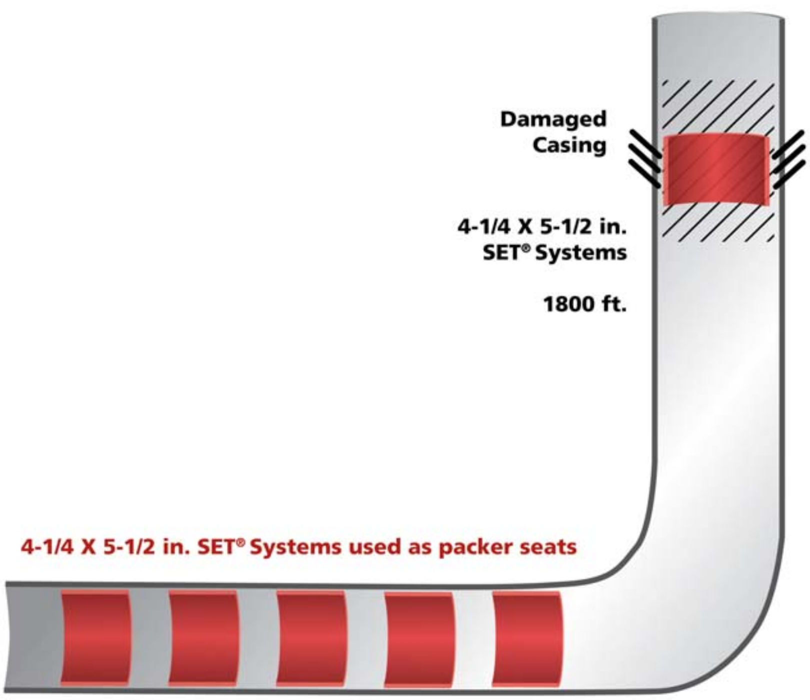

Figure 5 – Solid expandable tubulars used as packer seats while also repairing the damaged vertical section of casing.