Reducing Drilling Costs
A High Pressure Small Bore Drilling Riser System

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Introduction

The need to reduce the cost of drilling offshore wells has never been greater. This is particularly true in deep water where the high cost of drilling may limit the deepwater industry such that it will not realise its full potential.

There are many ongoing initiatives aimed at reducing drilling costs. However, they do not generally consider the drilling process as a whole and rather focus on a particular aspect, often in isolation. Little effort has been given to the riser system and yet this is an area that can have a large impact on drilling costs both directly and indirectly.

This paper, whilst focused on the riser system, attempts to take a more system based view and challenge some of the design features and interfaces that result in current drilling riser solutions.

In principle, offshore drilling methods have changed little in 20 years. Proven techniques have simply been extrapolated and the commercial constraints imposed by rig contracting methods have led to a universal 'sledgehammer' solution to riser, wellhead and BOP design. However, this 'sledge hammer' approach is increasingly costly to apply in deepwater.

It is important that we now investigate whether there are more efficient deepwater drilling solutions and take advantage of some new downhole technologies that are fast maturing such as slimhole drilling, expandable casing and surface BOP drilling.

Whilst alternative drilling solutions have the potential to offer significant cost reductions the commercial challenges may be as difficult as the technical. If these solutions are to be brought to market they may need to be heavily Operator led.

Background

The deepwater oil and gas industry is considered 'hamstrung' by the limitation on the number of wells it can afford to drill in the process of finding, appraising and developing reserves. If drilling costs could be reduced, more exploration wells can be afforded and this would lead to the discovery of more reserves and enable better definition of the reservoirs that are found.

The ability to drill more appraisal wells leads to lower risk development since development solutions can be based on known data rather than assumptions. Fewer contingencies need to be included in the development plan and this reduces the overall development cost and allows solutions with optimum recovery to be defined. Consequently, reducing drilling costs has a far greater benefit to the industry than simply the drilling cost saving.

The main reason for the high cost of offshore drilling is the day rate of the specialist drilling vessels. The typical day rate of a high specification MODU, varies widely between $150k and $250k per day depending on market and vessel specification. At these rates a typical 40day well costs in excess of $8million and this is before hardware, consumables, downhole services and personnel costs are added.

One of the main reasons for the high day rate is the need for high specification drilling equipment including derrick, subsea BOP, riser and tensioning equipment. Consequently, if the specification of this equipment could be relaxed then lower cost vessels could be possible.

A review of deepwater drilling equipment concludes that BOP, wellhead and riser hardware has not really been optimised for deepwater. Rather, shallow water equipment has been incrementally extended such that today's deepwater vessels use the same technology as 20 years ago with the difference that it is necessarily bigger, heavier and more costly.

The high cost of drilling deepwater wells has led to an approach whereby wellbore size is maximised to allow a large completion to be installed. This maximises the potential production flow rate per well helping to offset the initial high drilling costs. However, in deepwater this approach puts increasing demands on riser and vessel specification resulting in spiralling costs. Whilst the preference in the conservative drilling industry is to extrapolate proven technology a point comes when this approach is not cost effective and must be reconsidered.

Current Status

After a brief flirtation with the two stack (21-1/4inch by 13-5/8inch) system the drilling industry has largely standardised on the 18-3/4inch wellhead and BOP system rated at 10,000 or 15,000psi. Some vessels use the lighter 16-3/4inch system but this puts constraints on casing programs. All current vessels rated for depths greater than 7600ft utilise the 18-3/4inch wellhead system. The typical deepwater riser system used in conjunction with the 18-3/4 inch wellhead is summarised in Table 1. Of note is the high steel weight and large buoyancy diameter.

In deepwater, despite the use of large levels of buoyancy high top tensions are required to keep lower flex joint angles less than 2 degrees for the connected drilling condition. Specific requirements are dependent on prevalent current conditions and mud weights as shown in Figure 1.

The need to apply such high tensions is often the limiting factor that prevents a lower cost vessel from drilling in deepwater and the number of vessels that can apply this level of tension is very limited as shown in Figure 2. It may be concluded that 70% of the deepwater fleet have a limit less than or equal to 7500ft.

The 18-3/4inch wellhead system can accommodate large applied loads that result from the attached drilling riser and BOP stack. It allows a flexible casing program including an intermediate 16inch casing string. The casing program is typically one that uses a 9-5/8inch surface casing with a 7inch liner, Figure 3. This provides a good size completion to be installed, capable of offering high production flow rates. The 18-3/4inch wellhead also provides adequate space to set a production tubing hanger with large diameter production bore and annulus access, complete with a host of electrical, chemical injection and hydraulic ports for downhole equipment.

However, in many instances the 18-3/4inch wellhead may be considered a sledgehammer used to crack a nut. Often the wells being drilled are lower pressure, lower temperature and can manage with a smaller bore since the intermediate casing string is not required or the well being drilled is only for exploration and hence a large diameter bottom hole may not be required. Even on production wells an 18-3/4 bore wellhead may not be required if the well is completed with a horizontal tree where the hanger is located in the tree body eliminating some of the design constraints within the wellhead.

However, even in these instances the 18-3/4 inch system is used since this is the standard system that deepwater drilling rigs are equipped with. Such equipment is selected by the drilling contractors by necessity to ensure maximum commercial scope for their vessel. To change out this standard equipment for a small number of wells is not cost effective due to the down time to fit the new equipment and remove it on completion.

In shallow water there is only a small penalty for standardising on the 18-3/4 inch system, simply because there are few riser joints to install and support. In deepwater the cost impact is more significant with important knock-on effects.

- Increased cost of the riser and BOP system that requires increasingly heavy joints and need for buoyancy
- Increased installation and retrieval durations (typically 3 off 90ft joints per hour)
- Increased vessel day rate due to higher specification vessels capable of handling a large BOP and riser system and ability to provide adequate tension

Cost Reduction

To achieve a significant drilling cost reduction is a difficult challenge due to the many interrelated technical and commercial interfaces that exist between the disciplines involved. This means that only small changes can be made in isolation such that they do not impact the scope of other parties:

- Drilling contractors
- Drilling and downhole engineers
- Completion engineers and suppliers
- Riser engineers/suppliers
- Wellhead and BOP suppliers

It should be noted that the drilling contractors in particular have significant capital investment in existing systems and have an adversity to changes that could reduce day rate and which may require further investment. Similarly, but to a lesser extent, suppliers have an adversity to new solutions that upset the ‘status quo’ of the market ie. a new technology that could bring in new competitors or a solution that reduces the volume of consumables required to drill and complete a well, as this may lead to reduced profits. Therefore an appreciation of the inertia in the market is important and the need to align the various parties both technically and commercially is fundamental to achieving the overall goal of cost reduction.

Individual groups have already instigated and achieved certain levels of cost reduction within their own areas by designs that reduce manufacturing costs or more efficient installation procedures. However, significant reductions require a step change to occur and generally this can only be achieved by a cross discipline approach. New technologies are emerging that with appropriate application may offer sufficient potential for cost reduction that they will overcome the market inertia.

It is notable that there has been little effort to change the design or reduce the cost of drilling riser systems. The design requirements for these systems are so constrained by wellhead requirements that there is little scope for design change. Consequently, for many years riser systems have been simply extended in length without significant design change. To combat the increasing weight, higher tensions are specified increasing vessel specification and day rate. This has been offset to some extent by adding buoyancy to the riser, reducing its in-water weight. However buoyancy is expensive, makes the riser difficult to handle, requires large deck storage, is susceptible to damage and increases the hydrodynamic loading on the riser. Some companies have investigated the application of titanium and carbon fibre but apart from a few isolated instances this has not be adopted largely due to high capital cost and issues such as wear and handling resistance.

With almost any deepwater riser system weight is 'king'. Any reduction in riser weight leads to both direct and indirect cost savings and conversely an increase in weight leads to a negative design spiral where the final cost is far greater than initially expected.

Adopting riser weight reduction as the key driver the following strategies should be considered:

- Reduction in riser diameter
- Increase in material strength
- Reduction in mechanical complexity

Riser Diameter and Material Strength

Drilling risers are generally designed with a minimum 19-1/2inch bore to allow passage of drill bits and casing hangers. Despite being designed with a relatively low internal pressure capacity they often require a thick wall to accommodate axial loads and collapse pressures at high depth and provide an adequate wear allowance during drilling. A welded flange construction using high cost pipe manufactured by Pilger or pieced and drawn processes is typical.

If the riser diameter can be reduced to 16inches or less by reducing the diameter of downhole equipment, then other riser design and manufacturing processes can be considered. At this reduced diameter low cost seamless pipe is available and this also allows the use of non-welded threaded and coupled connections and high strength steel. The conclusion would be a riser that is lighter, cheaper and also quicker to install.

However, whilst the size of downhole components can be reduced by careful optimisation of manufacturing and drilling requirements the diametrical reduction that is achievable is relatively small and does not typically allow a 16 inch riser to be considered. Furthermore the use of a subsea BOP requires piggy back kill and choke lines that make threading riser joints together impractical and hence the 21inch flanged arrangement has prevailed.

Riser Complexity

The subsea BOP is the standard approach for MODU drilling operations. This configuration has developed to allow the well to be safely closed-in in the event of vessel mooring, DP or riser failure and importantly prevents the need for the vessel to support the weight of the BOP stack. However it also locates the well control functions subsea and results in the need for high pressure kill and choke lines and a sophisticated control system.

As BOPs have become more complex this penalty has becomes greater. Stack heights have increased by the need for additional cavities and the control complexity increased due to the number of functions and the effect of depth. Furthermore, the requirement for large diameter kill and choke lines, booster lines, hydraulic supply lines and large control umbilical increase the riser weight, design complexity and installation duration.

A way to reduce the riser complexity is to locate the BOP at the surface eliminating the need for riser kill and choke lines and complex control requirements. It is noted that on dry tree platforms great improvements in drilling efficiency are claimed by the application of a surface BOP and high pressure riser. However, this approach is only practical when the vessel has a high quality, reliable mooring system that is designed to withstand extreme environmental events.

Small Bore High Pressure Riser with Split BOP

It is concluded from the above discussion that the optimum deepwater drilling riser configuration would incorporate the benefits of of both subsea and surface BOP systems and as the design is so weight sensitive should utilise a small diameter riser. An efficient deepwater drilling riser system would include:

- Small riser diameter (13-16 inches)
- High pressure (5m-10m)
- Surface well control BOP
- Subsea well isolation BOP

This arrangement uses a single lightweight BOP ram and disconnect package at the seabed to close-in and isolate the well in the event of a vessel mooring, DP or riser failure. The reliability of this item is critical but provides the same functionality as a conventional subsea BOP stack.

The riser would be a single bore system without the need for kill or choke lines and can be assembled from high strength (110 ksi) steel with threaded and coupled (T&C) connections. These joints are light, comparatively low cost and can be run ten times faster than a conventional 21inch riser joint.

The steel weight of this system is 107lb/ft compared to 210lb/ft for a typical 21inch system giving a 50% saving. In a water depth of 7500ft a top tension of only 1000kips is necessary assuming 250kips of buoyancy. With such an arrangement all deepwater rigs could upgrade to 10,000ft and many of the shallow water fleet would be able to operate in depths up to 7500ft.

At the surface a BOP is used to provide well control functions and typically includes 3 rams and an annular preventer. Kill and choke lines connect directly to the BOP via flexible jumpers and the control equipment will be located in a suitable topside location with direct hydraulic connections to the BOP.

This arrangement offers the following features

- Lightweight and compact subsea BOP
- Small diameter lightweight riser joints
- Reduced buoyancy volume
- Low cost riser joints using casing technology
- Improved riser joint availability
- Reduced riser mud volumes
- Faster installation/retrieval durations
- Reduced riser and BOP capital cost
- Improved well control (kick detection)
- Improved cuttings transport
- Lower deck space storage requirement
- Lower riser tension requirement
- Ease of riser joint rotation and replacement
- Weekly BOP test conducted at surface
- Ram changeout conducted at surface
- Reduced cost impact due to BOP maintenance
- Reduced joint weight offers improved safety
- Reduced vessel specification

The above benefits should allow a significant reduction in well costs particularly by reducing the vessel specification. Furthermore, such an arrangement does not appear to offer any significant reduction in safety when compared to conventional subsea and dry tree platform drilling methods. Rather, this approach combines the benefits of both surface and subsea drilling methods without the disadvantages. It is noted that a similar approach has already been adopted by one operator without the subsea isolation package with high cost savings claimed. However this application was unique in that it involved:

- Use of a prelaid mooring
- Shallow reservoirs with low pressure
- Exploration wells
- A large number of wells in the same geographic area
- A number of wells drilled from a single mooring location

Such a set of criteria is not typical and therefore it is unlikely that such an arrangement will be technically or commercially suitable for wide spread application. However it is an illustration of the benefits that can be realised by an optimised drilling system.

The disadvantage of the small bore HP riser with split BOP is that it does not allow standard casing programs to be used and until recently this has been unacceptable. However, it is possible that this configuration could receive wider application if considered in conjunction with recent developments in drilling and downhole, discussed below.

Casing Optimisation and Slender Well Technologies

The simplest approach to using a smaller diameter riser is to fully optimise the diameter of casing program and take maximum combined advantage of best practice and manufacturing capability. This approach reduces the maximum casing size whilst still maintaining a 9-5/8inch bottom hole and so does not impact the completion design. This is achieved by a combination of

- Reduced casing clearances
- Under-reamers and hole openers
- Non standard casing sizes
- Longer sections drilled open hole

It is noted that reducing a casing by a single size can reduce the drilling costs by 20% due to increased drilling rates, reduced cuttings and consumables.

Such an approach is not applicable to all wells but has reasonable scope of application. Typically this approach allows a 13-5/8inch wellhead and 16inch riser to be considered. This casing approach has been used extensively by Petrobras and is claimed to offer an average saving of 17% on drilling time not accounting for other savings such as consumables. In this application drilling was conducted using a conventional 16-3/4inch subsea BOP and riser and therefore the benefit of using a lower cost vessel was not realised. It is noted that such slender well drilling does require a good knowledge of the geology and pore pressures to allow full optimisation to be achieved with acceptable risk.

Slimhole

The definition of slimhole is a well that is completed in 4-3/4inches or less at TD. Slim hole wells allow smaller casing dimensions to be used through out the well such that a 16inch riser or even 13-5/8inch riser can be utilised. However the smaller bottom hole dimension puts significant constraints on the completion design and its maximum productivity.

Slimhole drilling benefits include:

- Reduced cuttings (50%)
- Reduced drilling consumables
- Improved wellbore stability
- Faster drilling rates
- Lower environmental impact

However there are some disadvantages and added risks to consider.

- Better planning and well engineering required
- More complex well control
- Higher risk of stuck casing
- No contingency hole sizes

The slim hole approach allows the riser diameter to be reduced to 13-3/8inches with clear weight and cost benefits to the riser.

The ability to accept a smaller bottom hole must be evaluated within the context of the whole project. If wells can be drilled much quicker and at lower cost then the cost of drilling two 4 inch wells may be lower than one 7 inch. This may be possible if the rig rate is 40% lower, riser installation time 50% less and the volume of cuttings and consumables also 50% less. The combined cost reductions may make the slimhole approach more cost effective even for production wells. For exploration and appraisal wells it is probable that smaller holes can be accepted anyway.

Also, recent developments in downhole technology offer a diversity of options to improving productivity. Multiple completions and multilateral technology allow production rates to be improved and potentially allow increased production rates from smaller completions. This technology when combined with slim hole drilling may allow highly cost effective but small bore completions.

It is accepted that complex small bore completions may require additional workover compared to conventional large bore systems however this should be cheaper as smaller lower specification rigs can be used and intervention durations shorter. Further, concepts such as the 2H **storm**™ deepwater production system are specifically designed for efficient well intervention.

Expandable Casing and Liners (Figure 4)

The most important technology to facilitate reduced riser dimensions for both production and exploration wells is expandable casing technology that has been widely documented in recent months. This has the capacity to offer a true monobore completion with 9-5/8inches from seabed to TD.

The effect of this technology is to facilitate the use of a 13-3/8inch drilling riser but without the constraints and risk associated with the slender well or slim well given above. The disadvantage however is that it is not yet fully mature and further development work is required. However the potential to deliver is high with over 50 field applications of expandable liners and casing to date. The impact of this technology will be significant and provide the impetus for the industry to redesign and re-equip the deepwater fleet to facilitate the step change the deepwater industry needs.

Small Bore Drilling Riser Configuration

Figure 5 shows the general arrangement of the small bore HP drilling riser system to be used in conjunction with the reduced casing diameter drilling system. The riser is assembled using threaded and coupled connections machined onto 13-3/8 and 13-5/8inch standard casing in 110ksi steel. The riser is rated for up to 10,000psi burst.

At the seabed a 16-3/4inch wellhead, machined to accept a 13-3/8inch casing hanger, is used. This is set in a 30inch conductor and provides the structural capacity to accommodate riser loads.

A subsea isolation BOP is run on the bottom of the riser sting that allows the well to be closed in the event of a mooring or riser failure. The BOP will be connected to the wellhead using a conventional collet connector and controlled via small diameter electrical control umbilical strapped to the outside diameter of the riser. A back-up acoustic system will also be used along with an ROV interface to provide triple redundancy.

Local hydraulic accumulators, charged at the surface before installation will be used to provide the closure of the BOP and function the emergency disconnect. The volume of fluid is quite considerable however this is greatly reduced for a 13-5/8inch BOP compared to the 18-3/4inch.

The strength capacity of the BOP needs to be selected to match the riser loads. This may require a 13-5/8inch 15m system even if the pressure rating of the well is lower. For high pressure wells the body and the connecting flanges of the BOP may need to be uprated to 16-3/4 for increased load capacity.

Immediately above the BOP will be located an upward facing 16-3/4inch hydraulic collet connector that provides the emergency disconnect facility. The connector is controlled through the BOP control function and will allow release in a short period of time and at high angles.

The riser is connected to the BOP via a taper joint. The base of the taper joint is machined with a hub profile to suit the collect connector or a saver sub can be flanged onto the bottom of the taper joint.

The taper joint interface also includes an electrical control line connection that is initially mated at the surface but can be remotely disconnected during a riser disconnect procedure.

The taper joint is a single piece forging manufactured in a 110ksi yield material. Typically this will be 8-10m long and be machined with a tapered profile to suit the rig and environment conditions. The top end of the taper joint is machined directly with a T&C connection and fitted with a short saver sub typically 2m long.

The first 3 joints in the riser string will be heavy wall joints manufactured from 13-5/8inch pipe to ensure a common drift through the riser. Above these will be standard 13-3/8inch joints all machined with T&C connections. The riser joints will be manufactured from seamless pipe with a 110ksi yield. Some of the joints will be fitted with buoyancy half shells and thrust collars. Typically the diameter will be 36inches.

At the top of the riser a standard joint connects to pup joints and then to thick walled 13-5/8inch joints. These then interface with the downward facing taper joint via another saver sub. The upper taper joint will be shorter than the lower taper joint, typically 4-5m long.

The upper taper joint is connected to the surface BOP via a manual hub connection such as a Fastlock.

The upper BOP is a conventional 13-3/8inch system comprising 3 rams and 1 annular preventor. The BOP is housed in a handling frame but designed for maximum compactness so as to minimise the potential for clashing with the moonpool. This may include designing the unit as a triple rather than flanging 3 singles.

The riser is tensioned from above the BOP using the conventional riser tensioners. These attach to a tensioning ring flanged to the upper face of the annular preventor.

A conventional slip joint is connected between the flanged tensioner ring and the divertor housing as normal.

It is noted that in the proposed arrangement the BOP is unconstrained laterally. This allows it to move in sympathy with the riser loads and vessel motions and thus reduce bending loads generated at the BOP/Taper joint interface.

Riser/BOP clearance with the moonpool and splash zone is a key issue to be resolved and is the reason for minimising the BOP size. The space out of the BOP is dictated by the vessel maximum heave during the connected condition and depending on the geographic location will result in the BOP being located in the splash zone. Consequently, design for wave impact and submergence of the BOP and the additional loading that this produces must be considered in the riser structural arrangement.

However, the use of such a system with a drill ship where the BOP is sheltered within the moonpool may enable this approach to be adopted in harsh environments.

Cost Comparison

The cost of a 21inch riser and 18-3/4inch BOP system for 8,000ft is in the region of $49m whilst the like for like cost of the small bore split BOP riser system is $12m.

Further savings are realised in

- Lower specification vessel at lower day rate
- Shorter well duration due to faster drilling
- Faster installation and retrieval of riser

- Lower cost wellhead assembly
- Reduced consumables

Therefore it is probable that the total cost reduction per well may be in excess of 50% compared to the conventional approach.

Conclusion

Drilling riser technology has not changed much in 20 years and yet the impact of riser systems on drilling cost and feasibility is significant.

A small bore drilling riser has the potential to significantly reduce drilling costs and the application of such a system may be facilitated by recent downhole developments such as slim, slender and monobore wells.

The current level of investment by drilling contractors in existing drilling riser systems and the existing contracting arrangements means that it will be difficult to change the market away from the current approach. Any changes will need to be Operator led.

In the short term it is likely that the Operator will need to design and procure the small bore drilling riser system and supply this to the drilling contractor in order to overcome a 'chicken and egg' market situation.

Whilst the 18-3/4inch subsea BOP will never be completely replaced, it is anticipated that the small bore split BOP riser system has the potential for a significant market share. It is probable that some rigs will ultimately offer both large bore subsea BOP and small bore split BOP systems whilst others may specialise in only one. Whilst this increase in options may appear to fragment the market it is concluded that the Operators will be able to use the 'right tool for the job' resulting in improved efficiency and increased potential for the deepwater market.

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Joint Type	Outer Diameter (in)	Wall Thickness (in)	Buoyancy Diameter (in)	Dry Weight (kg)	Wet Weight (kg)	Joint Length (ft, m)
Slick riser, bare, top & bottom	21.50	1.00	NA	16,700	14,500	80, 24.38
Riser with 9000' rating buoyancy	21.50	0.812	54	26,300	1,000	80, 24.38
Riser with 8000' rating buoyancy	21.50	0.812	54	26,500	900	80, 24.38
Riser with 6400' rating buoyancy	21.50	0.812	54	25,800	1,500	80, 24.38
Riser with 4500' rating buoyancy	21.50	0.812	54	27,800	-400	80, 24.38
Riser with 2500' rating buoyancy	21.50	1.00	54	29,400	-2,100	80, 24.38
Slick Riser Bare at Top	21.5	1.0	NA	17,500	15,200	80, 24.38

Table 1 – Typical Deep Water Drilling Riser Joint Configuration

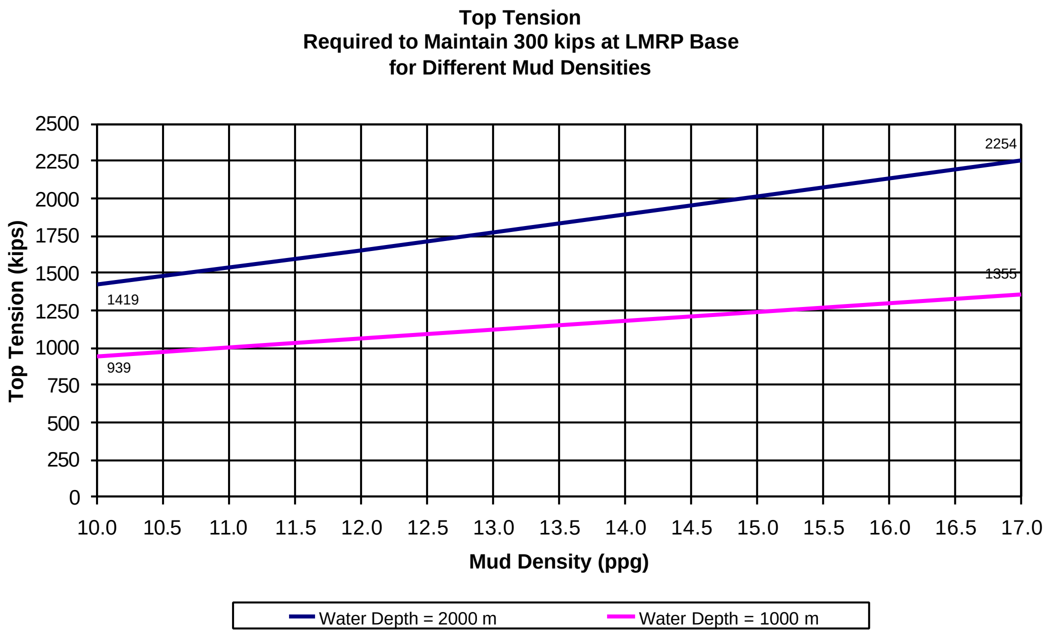

Figure 1 – Top Tension Requirement Verses Mud Weight

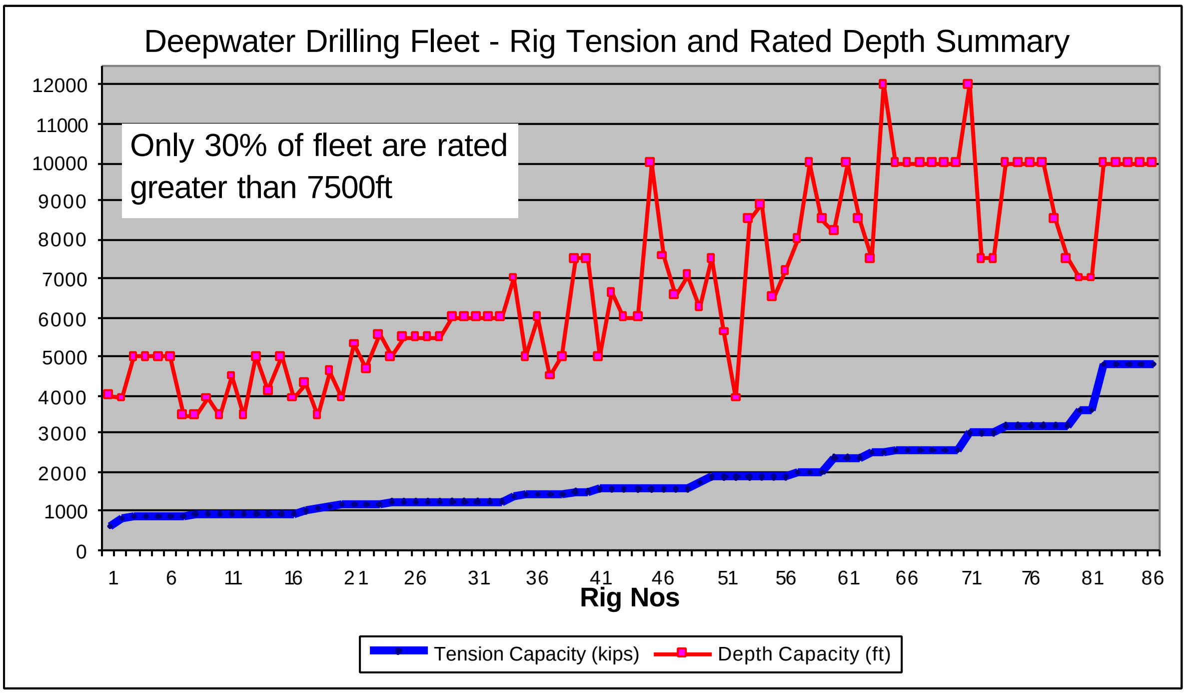

Figure 2 – Summary of Deep Water Fleet Tension and Depth Capacity

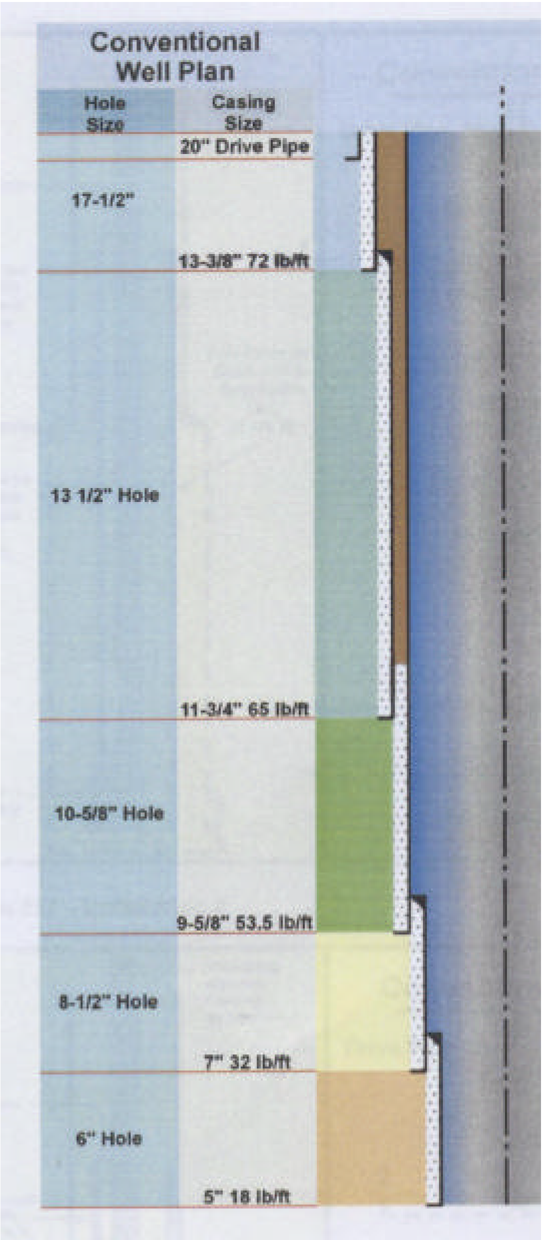

Figure 3 - Conventional Well Plan

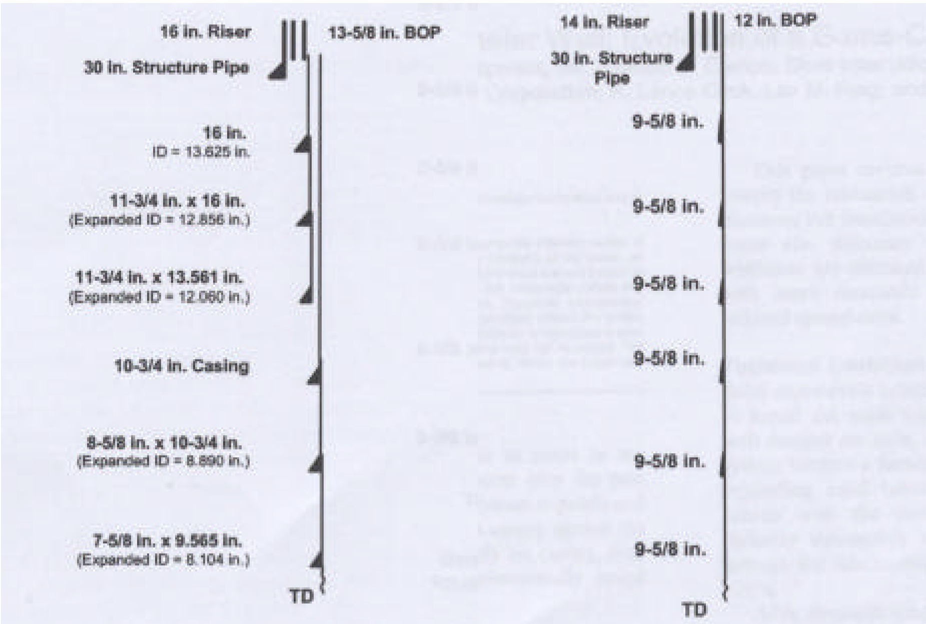

Figure 4 – Expandable Slim Well and Expandable Mono Diameter Liner

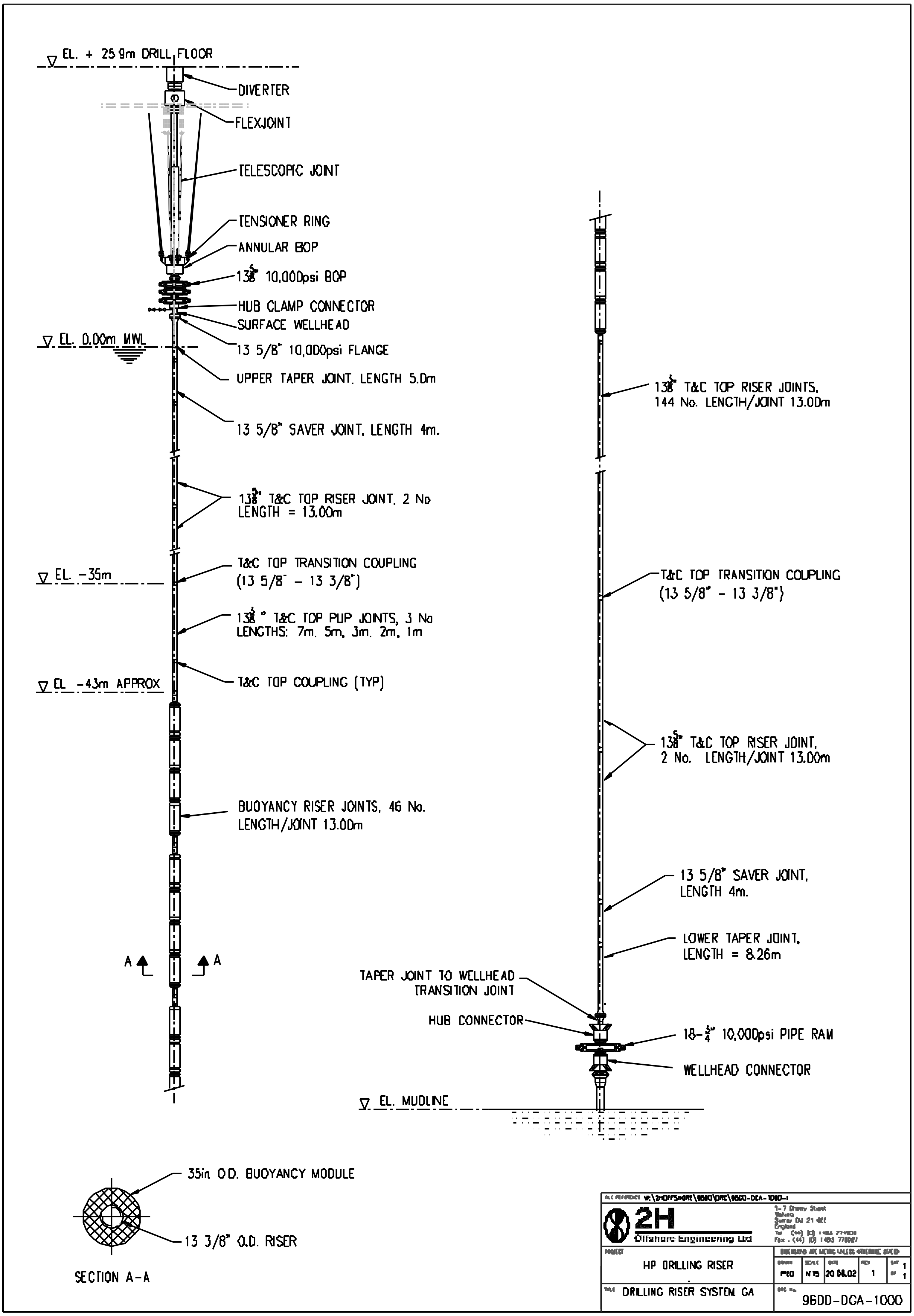

Figure 5 – Small Bore High Pressure Drilling Riser System