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Buoyancy Assist Extends Casing Reach in Horizontal Wells

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Abstract

This paper describes a case history of how a major operator operating offshore Louisiana, in the Gulf of Mexico, extended the casing-setting depth of a well by creating buoyancy in the leading section of the casing. The buoyancy was created when an air pocket was trapped between the float shoe on the end of the casing and drillable buoyancy-assisted casing equipment (BACE™) assembly located in the casing at a calculated distance from the float shoe.

Problems encountered when casing is run in a horizontal or highly-deviated well are compounded by the drag of the casing on the lower side of the wellbore. Adding buoyancy to the lower end of the casing string reduces friction between the casing and the wellbore, thus enabling the casing weight in the vertical section of the well to push the casing deeper into the horizontal section.

BACE assembly used to enhance buoyancy can present the following operational advantages:

- full casing inside diameter (ID) after release
- large annular clearance between BACE assembly internal components outside diameter (OD) and casing ID
- thread-type anchoring system (no shear pins, holes in the case, etc.)

This paper presents calculations, equipment design, operational detail, and results of BACE assembly used on the operator's platform.

Introduction

Attempts to run casing in extended-reach horizontal wells (wells with a measured-to-true vertical depth ratio greater than 2:1)¹ can fail because friction between the wellbore and the casing often results in a substantial amount of drag. This drag often

exceeds the available weight in the vertical section of the wellbore. In shallow, highly-deviated or horizontal wells, there can be insufficient casing weight in the vertical hole section to overcome the drag in the extended highly-deviated section.

Wellbore geometries that include severe doglegs, excessive turns, bends, or large amounts of formation cuttings can also adversely affect the casing/formation drag forces. A poorly cleaned wellbore may result in formation cuttings settling on the lower side of the bore hole, causing excessive debris to build up in front of the casing as it is being run in the hole. This buildup may prevent casing from reaching the desired setting depth. Differential sticking is another problem in extended-reach wells.

The incentives of extended reach drilling are purely economic. The need to reach additional reserves from existing surface facilities is apparent given the capital cost of additional surface facilities. In some cases, the additional reserves cannot be economically justified by any other means than drilling extended-reach wells from existing facilities.

Previous Solution Attempts

Drilling fluids and wellbore geometries have been altered in various attempts by researchers and operators to deal with the friction or drag problems associated with extended-reach drilling. Previous attempts include a catenary/modified catenary^{2,3} drilling method and the use of low-friction coefficient drilling fluids.

The catenary and modified catenary methods create a wellbore path in which the build angle is continuous and angle changes are minimal, all in an effort to reduce drag forces. In some cases, the wellbore geometry or trajectory was modified so that the maximum available weight would be present in the near-vertical section of the well. Drilling fluids with high lubricity are also used during casing operations to reduce the coefficient of friction or drag between the casing being run and previous casing/wellbore.

In other attempts, casing running procedures were modified to either overcome or decrease the coefficient of friction between casing and wellbore. One method involved the use of an inverted casing string in which heavy casing was run in the vertical section to provide additional weight. This method attempts to overcome the drag forces rather than reduce them. If drag forces are high enough, the lower end of the casing can buckle.

When casing is rotated, the friction coefficient is changed from the static friction coefficient to the dynamic friction coefficient. Because the dynamic coefficient is the lesser of the two values, any pipe movement (either by rotation or reciprocation) allows the available weight to maximize casing penetration in the horizontal section. The need for casing that could be rotated led to the development of torque-shouldered connections (**Fig. 1**) that allow rotation. Such connections allow torque to be transferred through the casing without compromising the integrity of the individual connections. To date, torque-shouldered casing connections have been widely accepted and used by the industry.

Casing Flotation Concept

In the 1980s, UNOCAL devised a method^{4,5} by which casing was “floated” in the wellbore. Casing flotation uses an “air chamber” that is created near the lower end of the casing string. The air chamber creates a buoyant effect that reduces the casing weight, resulting in less drag between the casing and the formation. UNOCAL has successfully implemented buoyancy-assisted casing programs^{4,6} on the platform Irene West, northwest of Santa Barbara, Calif.

In early casing flotation development, retrievable packers were successfully used to seal the casing above the air chamber. However, the retrieval of the packer, after total casing depth was reached and before cementing operations could be performed, was undesirable for two reasons:

1. The time required for retrieval of downhole packers increased on-site job costs.
2. The static time required to retrieve downhole packers allowed drilling fluid to develop gel strength making it more difficult to remove the drilling fluid during conditioning and cementing operations.

Rig cost was reduced with improved designs, particularly the use of a displaceable assembly (**Fig. 2**) located in the casing string at the upper end of the buoyant chamber. However, currently available equipment has additional design limitations such as internal components with near-drift diameters and shear mechanism holes in the outer case that could require secondary squeeze operations.

Since its inception, flotation technology has allowed operators to extend wells in excess of 12,000 ft, and presently, 30,000-ft offsets are being considered.⁷ Other operators have successfully used such techniques in fields around the world. These proven applications help ensure the continued use of flotation technology to further extend wellbore reach and have led researchers to develop additional flotation tool designs.

Improved Tool Design Needs

The initial success of flotation technology challenged tool designers to develop additional flotation devices. Equipment to assist with buoyant casing programs should incorporate a few general parameters. Tool IDs should be increased to allow full casing ID after drillout. Seal configuration should allow for larger tolerances between flotation cases and internal components, thus helping to

eliminate problems with wedging or locking of internal components during displacement operations. In addition, tools should be capable of holding pressures from both above and below. After casing has been cemented, the internal components of the flotation equipment should be drillable with PDC bits.

Initial Design Criteria

Construction of the BACE assembly began with a list of criteria that included a full-bore case and a minimum pressure rating of 5,000 psi, from above, at 300°F. After rupturing, the tool should require a very low pressure (< 200 psi) to displace it to the float collar so standard cementing plugs could be used. To facilitate drillout operations, the equipment had to be PDC drillable and able to incorporate a non-rotation feature for use with non-rotating cementing plugs. With respect to application, the equipment needed to be suitable for liner or subsea applications as well as surface release type completions.

Test Schedule

The BACE assembly was first component-tested in the laboratory under controlled temperature and pressure conditions. Calculations were performed on a 9 5/8-in. assembly to confirm that components could be manufactured from PDC drillable materials. The assembly (**Fig. 3**) was built and successfully pressure-tested. A full-scale displacement test was successfully performed on the assembly, confirming that the tool could be released from its steel case.

After completing laboratory tests, researchers conducted on-site testing at an offshore platform in the Gulf of Mexico. An 11 3/4-in. flushline assembly was run in the well in early 1998. **Figs. 4 and 5** show the initial well path in which the equipment was run. The initial program was 11 3/4-in. flushline casing run to a 15,500-ft measured depth (MD) and 5,326-ft true vertical depth (TVD) with a 4,500-ft air chamber. Drilling problems required the 11 3/4-in. casing to be set at approximately an 11,500-ft MD and 5,124-ft TVD with a 2,500-ft air chamber. **Figs. 6 and 7** show the well path in which the equipment was run.

The casing in the openhole section was machined with Spiroline™ grooves to help reduce differential sticking and maximize fill area in the previous 13 3/8-in string set at 4,870 ft MD. No centralizers were used because of insufficient clearance between 13 3/8-in. and 11 3/4-in. casing. The casing was run successfully, and closely mirrored the calculated hook load (**Fig. 7**). Although the use of flotation was not absolutely required for the reduced hole depth of 11,563 ft vs. the planned 15,500 ft, the BACE assembly was used successfully.

Candidate Well Consideration and Selection

To determine the feasibility of using a BACE assembly on a casing operation, operators should consider the factors of wellbore geometry, casing size and weight, software aids, and rig equipment:

- *Wellbore geometry.* Does the well require special running procedures or equipment? Several software packages are available to aid the drilling engineer in this area.

- *Friction coefficient.* The friction coefficient of the drilling fluid can be obtained from most drilling fluid suppliers or cementing service companies.
- *Rig equipment.* Considerations should include top drive or available hook load to push casing into the wellbore in the event a negative weight situation occurs. Also, casing should be held in the well while the elevators are tripping to the next casing joint.
- *Fluid returns.* Will fluid returns be taken at the surface or lost to low pressure zones below the surface? Equipment problems related to the air chamber could result in a quick drop in annular fluid height, which could lead to a well control situation.
- *Casing collapse rating.* Does the casing collapse rating exceed the expected hydrostatic pressure at TD? Increases in collapse pressure as a result of running casing should be considered.

Application

Prejob Considerations. The need for buoyancy-assist casing can be based on the required safety factor (SF). Often, calculations show that measured depth can be reached with little SF, so buoyancy assist is used to increase the SF or meet the required SF at measured depth.

Before casing is run, prejob considerations should include the length of the air chamber (which will depend on the casing weight and size), well depth, wellbore geometry, completion fluid density, and estimated friction coefficients. Float equipment (i.e., float shoe and collar) should be backpressure-rated to exceed hydrostatic pressure and temperature at TD, because the floats will be subjected to true hydrostatic pressure at TD. The BACE assembly should be matched in terms of casing size, weight, grade, and thread type; the equipment must also be rated to the expected pressures and temperatures encountered in the well. Special drift requirements should be noted.

A suggested prejob checklist includes the following items:

1. Check the BACE assembly to help ensure that it meets the following actual well conditions and requirements.
 - casing size and weight
 - thread type
 - burst, collapse, and tensile ratings
 - special drift requirements
2. Rupture disk pressure rating compared to actual pressure requirements (based on the actual bottomhole temperature), is calculated as

$$P_1 \leq (80\% \times P_2) \dots\dots\dots (1)$$

where P_1 is hydrostatic pressure in pounds per square inch; and P_2 is the pressure, also in pounds per square inch, required to rupture the rupture disk.

3. Check float collar, BACE assembly, and cementing plugs to ensure that plug landing surfaces are all compatible (i.e., all standard or non-rotating plugs).
4. Determine BACE assembly releasing method [i.e., surface release or subsea release (SSR)]. Are proper releasing plugs available?
5. Confirm required buoyant chamber length and location of BACE assembly in casing string.
6. Confirm that casing used for the buoyant section can withstand the collapse pressure that it will be subjected to during running conditions.
7. Perform calculations to determine whether buoyed casing will float before installing the BACE assembly. Identify safe running procedure in the event the air-filled section of the casing must be pushed into the well from the surface.

The hydrostatic pressure exerted on the BACE assembly rupture disk by the column of mud above the BACE assembly is calculated as

$$P_1 = P_2 \times D_1 \dots\dots\dots (2)$$

where P_1 is the hydrostatic pressure in pounds per square inch; P_2 is the hydrostatic pressure gradient of a column of mud in pounds per square inch per foot; and D_1 is the total vertical depth, in feet, of the BACE assembly. The fluid above the BACE assembly may contain more than a single weighted fluid. If multiple fluids are used above the BACE assembly, each fluid is considered separately with all fluids totaled to determine the total P_2 .

Job Procedure. Once prejob considerations are taken into account, installation can begin. Surface pressure-control equipment should be placed to ensure well control while the casing is run. The use of centralizers is recommended to give the casing maximum standoff. In highly-deviated holes, rigid centralizers that allow free rotation can decrease formation drag on the casing, thereby reducing the casing’s overall contact area with the formation.

A float shoe and collar should be installed on the casing’s lower joints. The float shoe will help guide the casing in the hole past ledges or bridges that might be encountered. The float shoe will also help guide the casing through the bend radius. Both the float shoe and collar should prevent wellbore fluid from entering the casing while it is being run downhole.

The predetermined length of casing, equivalent to the length of the desired buoyant chamber, should be run in the well. If air is used to buoy the casing, then the casing will not be filled while the air chamber is run. However, if a lighter-density fluid than the wellbore fluid will be used, then the casing must be filled from the surface. When enough casing string has been run to equal the desired buoyant chamber length, the BACE assembly collar should be made up in the casing string (**Fig. 8**). Additional casing run to reach the desired total depth (TD) should be filled with wellbore fluid from the surface through a fill hose or fill-up tool. The volume of fluid used to fill the casing above the BACE assembly should be closely recorded with either tank measure-

ments or a flowmeter on the surface fill line. If some type of casing fill device is available, the rig pump barrel or stroke counter can be used.

Operators should remember that wellbore circulation is not possible while casing is being run because the action will compromise the buoyant chamber. Circulation equipment can be installed only after TD is reached. If the buoyant fluid is allowed to percolate to the surface, returns should pass through some type of degasser. The casing should then be pressurized to rupture the BACE assembly rupture disk (**Fig. 9**). The surface pressure required to rupture the disk is calculated as

$$P_1 = P_2 - P_3 \quad (3)$$

where P_1 is the surface pressure; P_2 is the pressure required to rupture the rupture disk; and P_3 is the hydrostatic pressure. All pressures are measured in pounds per square inch.

The volume of pumped fluid required to rupture the BACE assembly disk should be calculated with the following items taken into account: casing volume above the BACE assembly compared to volume used to fill above the BACE assembly, casing expansion/elongation as a result of internal pressure, air entrapment in the drilling fluid, and drilling fluid compressibility.

Generally, the effects of temperature can be considered negligible. However, the bottomhole temperature should be used to determine the actual pressure required to rupture the rupture disk.

After the disk is ruptured, circulation should be stopped. Fluid from the buoyant chamber should either be allowed to percolate through the casing (**Fig. 9**) to vent lines at the surface and through a degasser or displaced out of the casing and circulated to the surface or into a thief zone. If the buoyant fluid is allowed to percolate to the surface, the buoyant section of casing should be filled with a volume of mud equal to the capacity of the buoyant section.

A BACE assembly releasing plug can then be pumped down the casing to disengage and displace the BACE assembly internal components to the float collar. The BACE assembly releasing plug can also be used as the bottom cementing plug (**Fig. 10**). The cementing plug is then displaced to the BACE assembly,

which is located at the float collar (**Fig. 11**). After the cementing is complete, drillout operations should be conducted.

Conclusion

The data received from laboratory and on-site testing indicates that BACE assembly is a viable, effective, and economically feasible method for operators to run casing successfully in extended-reach horizontal wells. Based on the use of current flotation technology, BACE assembly eases certain operational problems or concerns formerly associated with typical casing flotation programs.

Acknowledgements

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References

1. Ruddy, K.E. and Hill, D.: "Analysis of Buoyancy-Assisted Casings and Liners in Mega-Reach Wells," paper IADC/SPE 23878 presented at the 192 IADC/SPE Drilling Conference, New Orleans, La., Feb. 18-21.
2. McClendon, R.T. and Anders, E.O.: "Directional Drilling Using the Catenary Method," paper SPE/IADC 13478 presented at the SPE/IADC 1985 Drilling Conference, New Orleans, La., Mar. 6-8.
3. Sheppard, M.C., Wick, C., and Burgess, T.: "Designing Well Paths to Reduce Drag and Torque," paper SPE 15463 presented at the 61st Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, New Orleans, La., Oct. 5-8, 1986.
4. Mueller, M.D., Quintana, J.M., and Bunyak, M.J.: "Extended-Reach Drilling from Platform Irene," paper SPE 20094 presented at the 60th California Regional Meeting, Ventura, Calif., Apr. 4-6, 1990.
5. Hood, J.L., III, Mueller, M.D., and Mims, M.G.: "The Uses of Buoyancy in Completing High-Drag Horizontal Wellbores," paper SPE 23027 presented at the SPE Asia-Pacific Conference, Perth, Western Australia, Nov. 4-7, 1991.
6. Mueller, M.D., et al.: "Extended-Reach Drilling from Platform Irene," *SPEDE* (June 1991) 138.
7. Ryan, G., Reynolds, J., and Raitt, F.: "Advances in Extended Reach Drilling—An Eye to 10 km Stepout," paper SPE 30451 presented at the 1995 SPE Annual Technical Conference and Exhibition, Dallas, Oct. 22-25.

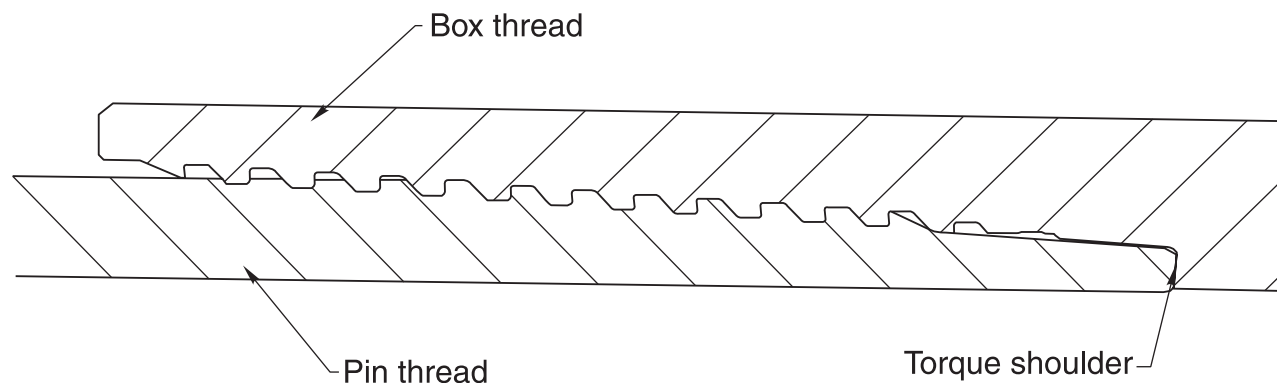


Fig. 1—The torque-shouldered connection between box thread and pin thread effectively transfers torque from joint to joint.

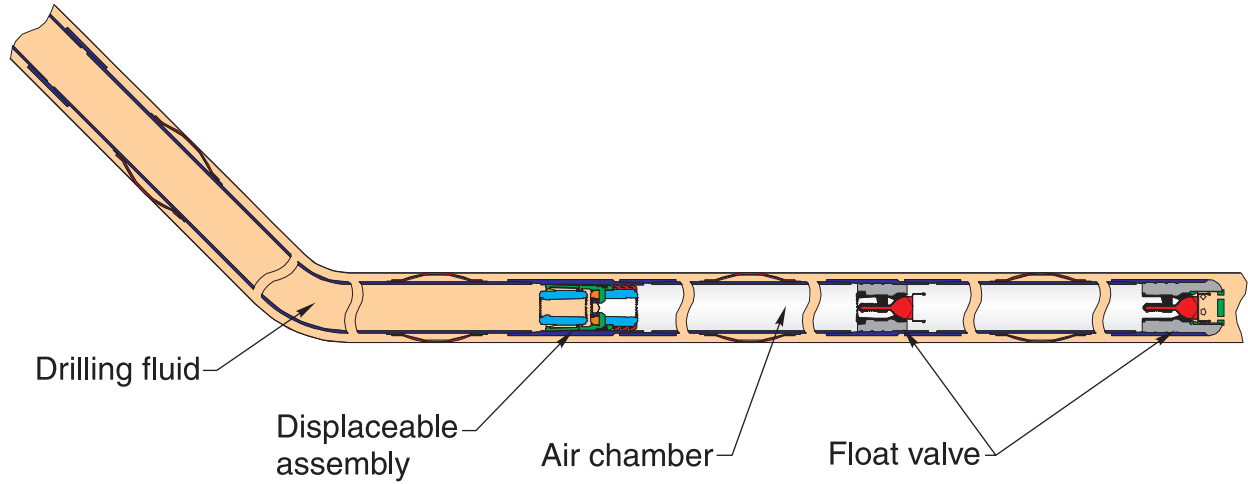


Fig. 2—Typical casing string with flotation equipment run into horizontal well.

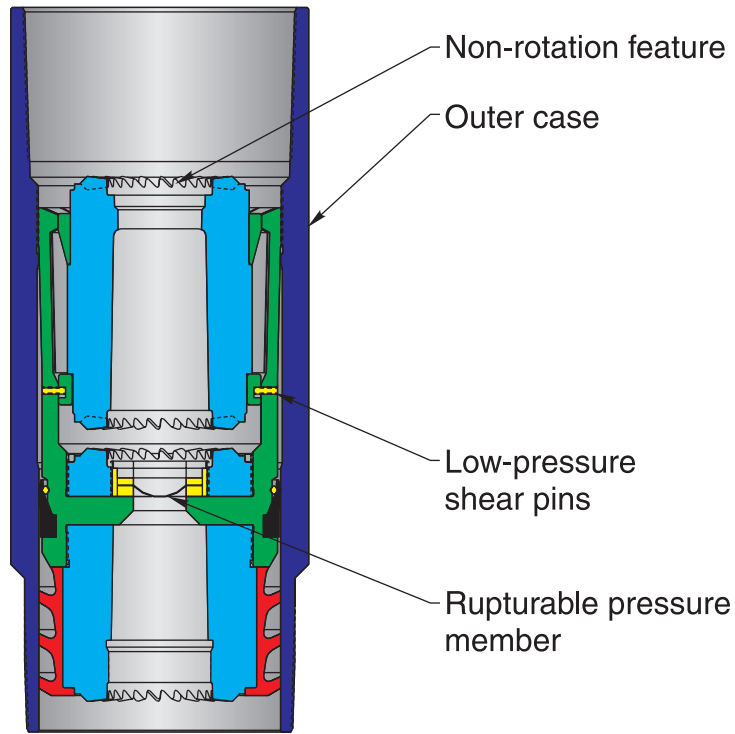


Fig. 3—Close schematic of buoyancy-assisted casing equipment assembly.

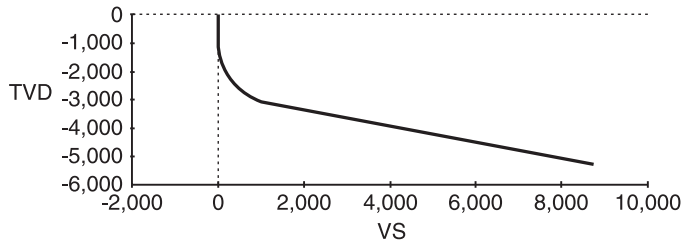


Fig. 4—Projected well path for BACE assembly run-in, measured in true vertical depth and vertical separation.

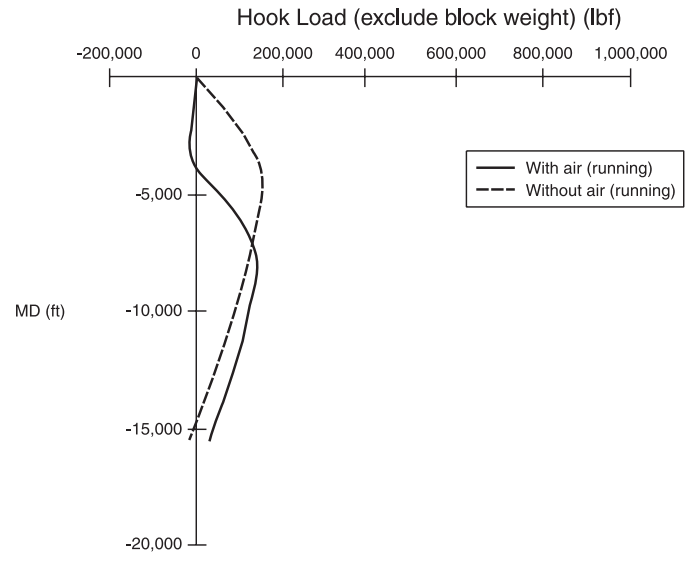


Fig. 5—Projected hook load for BACE assembly run-in with a 4,500-ft air chamber.

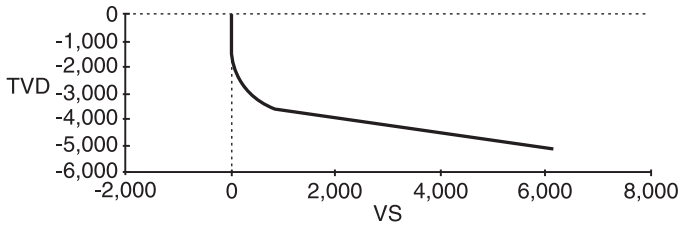


Fig. 6—Well path for BACE assembly run-in, measured in true vertical depth and vertical separation, at an actual measured depth of 11,563 ft.

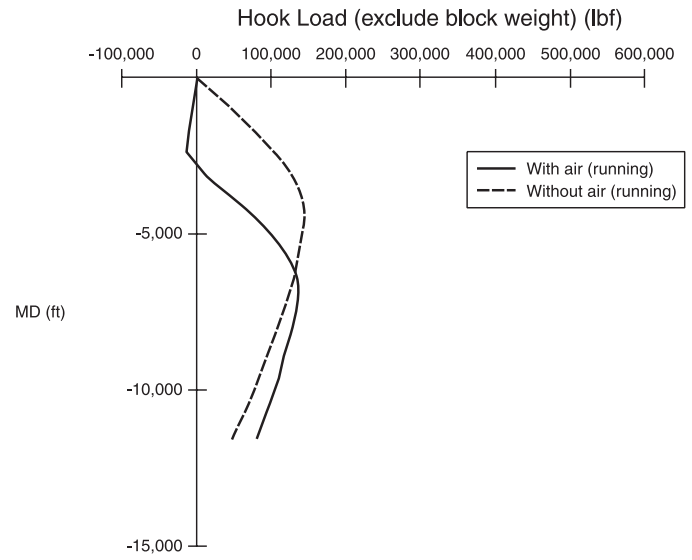


Fig. 7—Hook load comparison with and without BACE assembly.

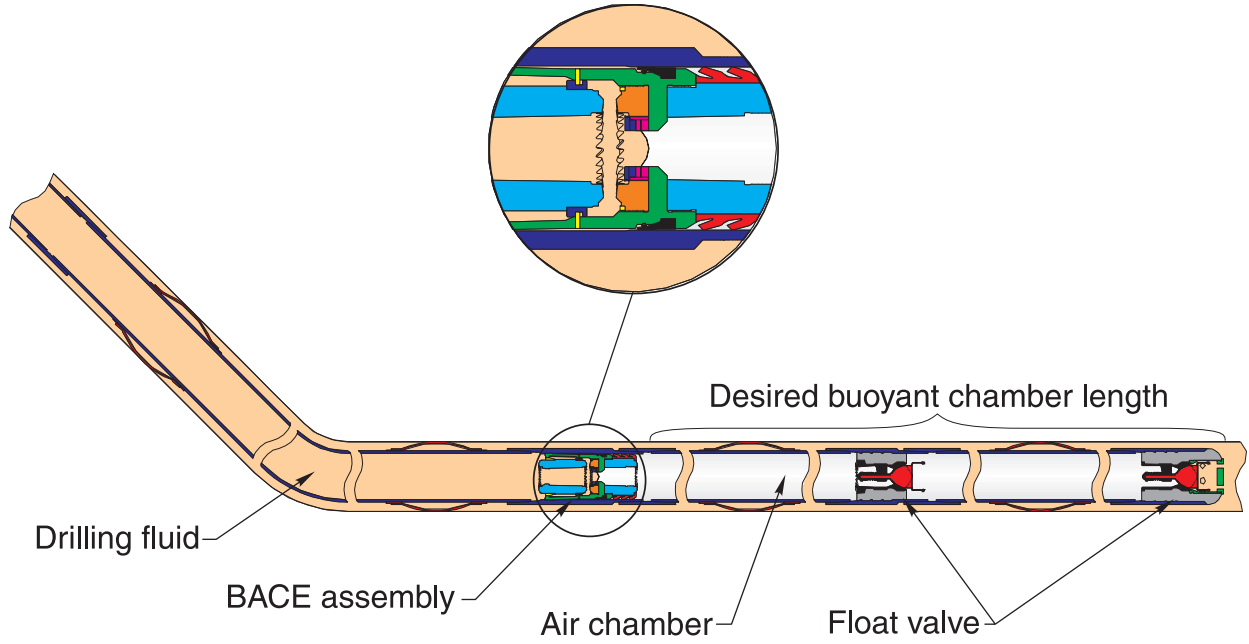


Fig. 8—Casing string with BACE assembly.

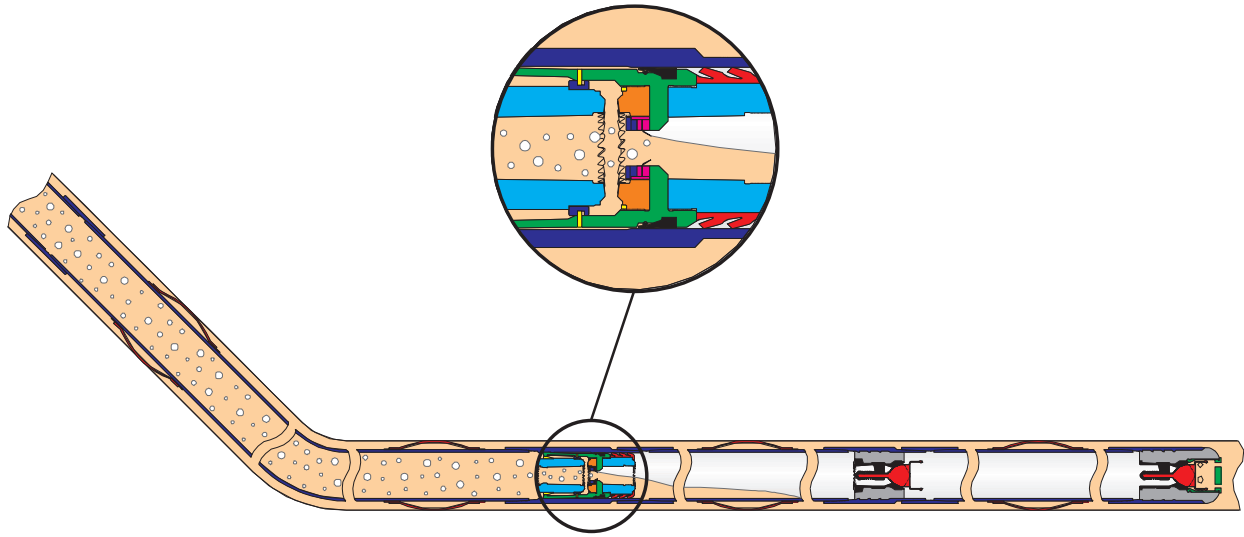


Fig. 9—When the BACE assembly rupture disk is ruptured, the buoyant gas or liquid percolates to the surface.

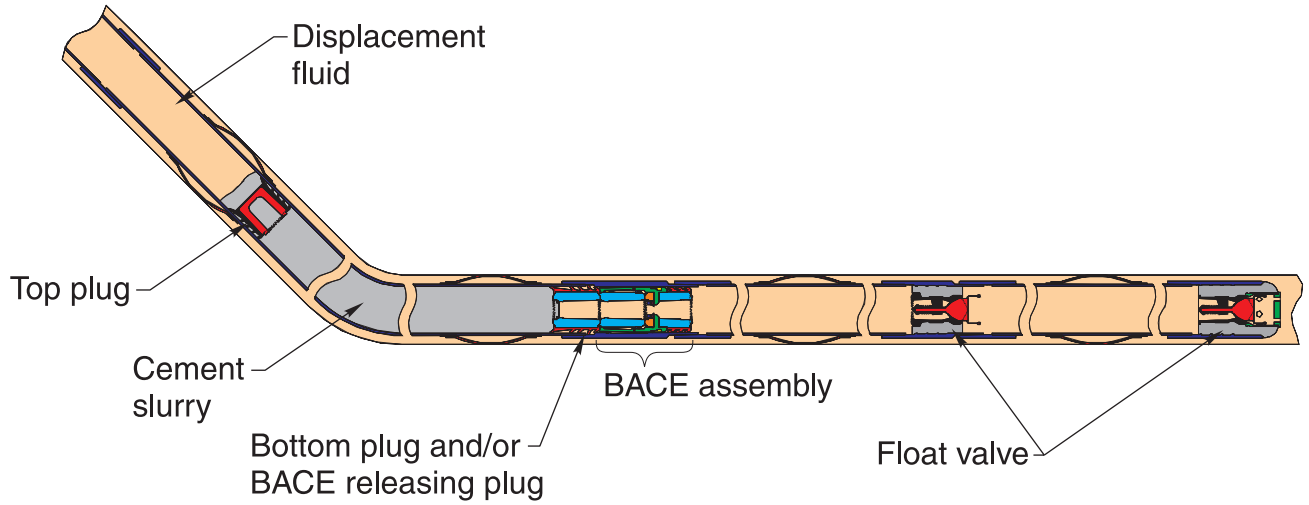


Fig. 10—After the disk is ruptured, the cement slurry is pumped, forcing the bottom plug or BACE assembly releasing plug to contact the BACE assembly.

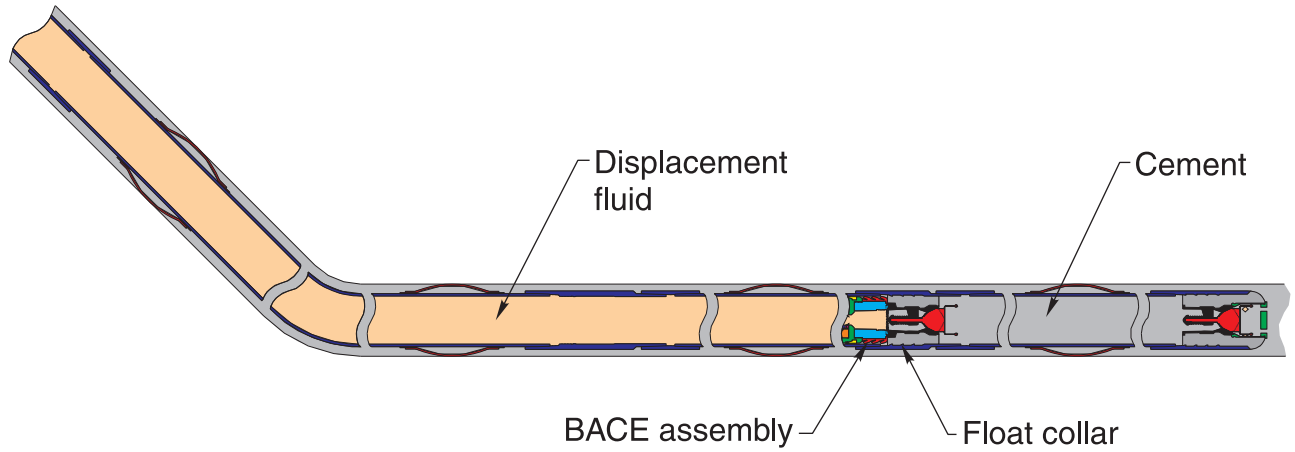


Fig. 11—Once the BACE assembly has been released, cement enters and fills the buoyant chamber.