Oil well blowout contingency plug and method for stopping a subsea oil gusher

Introduction

On April 20, 2010 the Deepwater Horizon offshore oil drilling rig, positioned about 40 miles off the coast of Louisiana in the Gulf of Mexico, became the site of the worst oil disaster in U.S. history. A deep-sea oil well, located 5,000 feet beneath the rig on the ocean floor, blew out creating an oil gusher of unprecedented force, expelling oil and gas up the one mile high riser to the rig and continued upward another 250 feet over the rig, before exploding and consuming Deepwater Horizon in flames.

Eleven crew members were killed. Firefighters were unable to extinguish the flames. On April 22, 2010 Deepwater Horizon capsized and sank to the bottom of the Gulf of Mexico. Oil continued to gush out of the well at the seafloor – about 60,000 barrels per day. All attempts to plug the well were unsuccessful.

Until the well is plugged, support ships above the well will continue to capture as much of the oil as possible. Those ships are exposed to the possibility of hurricane weather conditions. If the ships are forced to evacuate, then all of the oil gushing out of the well will be left to spill into the Gulf waters until the ships return.

It was determined that a relief well would be the only hope for permanently plugging the damaged well. A relief well would drill into the bottom of the damaged well where mud and cement will pour through the relief well into the damaged well, blocking the flow of oil to the wellhead. A second relief well will provide backup in case the first relief well fails. If both relief wells fail, options are uncertain. Explosives have been proposed.

At this time, no option exists for plugging an uncontrolled deep-water well quickly and completely. Current discussions appear to be focused on prevention for future wells. There is no doubt that better technology will be developed to ensure prevention, including strict safety standards and enforced inspections. But if prevention fails again, in spite of all measures taken, what can be done quickly to stop an out-of-control deep-sea oil gusher? Drilling a relief well requires three months or longer.

The invention described herein could be used to plug the existing BP well quickly and completely, and also be employed in advance on all future deep subsea wells, installed at the seafloor, positioned at the well site in standby mode during drilling.

U.S. Patent law requires that a new invention be useful, novel and non-obvious. The subsea oil well plug and method that I have invented is clearly needed, therefore useful. Novel means that the invention has not already been invented or known. If similar technology does already exist, then BP engineers, along with government scientists, will need to explain to journalists why the technology was not used. If my invention is considered obvious, but was dismissed, then it is not really obvious: it has been said, "Discovery consists of seeing what everybody has seen and thinking what nobody has thought."

Ron Bengtson, inventor, and founder of www.AmericanEnergyIndependence.com
July 4, 2010

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Description

The goal is to plug or cap, and stop the uncontrolled flow of oil and gas from a gushing subsea well.

The problem is the immense water pressure at the deep ocean floor. The surrounding pressure at a wellhead 5,000 feet below the surface of the water is about 2,000 pounds per square inch (psi). To put that in perspective, if you mark an area on your floor that is three feet square, or one square yard, and if you could somehow apply 2,000 psi over the entire surface of that area without destroying the foundation underneath, the square yard area would weigh 2,592,000 pounds or 1, 296 tons. Designing equipment to withstand such pressure, and performing work under such conditions is an engineering challenge that perhaps is greater than what NASA has faced in developing space technology and performing space operations.

In addition to the surrounding water pressure, the pressure of the oil reservoir deep beneath the ocean floor can be huge, due to the great depth of the reservoir and because of the immense water pressure on the ocean floor pressing down on the geological formation housing the reservoir. The initial oil pressure at a deep subsea wellhead can exceed 10,000 psi, and at greater subsea depths, say two miles from the ocean surface to the seafloor, oil pressure at the wellhead, stemming from the reservoir, could conceivably exceed 20,000 psi.

This paper discloses an apparatus and method [invention] that, when built and operated by someone skilled in the art, will plug (or cap) and stop the flow of oil and gas gushing from an out-of-control subsea well, at any seafloor depth where remotely operated vehicles (ROVs) can operate and a well can be drilled, including wells with a wellhead oil pressure exceeding 20,000 psi.

Before the well plugging process begins, the blowout preventer (BOP) will be removed from the subsea wellhead or stack connector, allowing the full gusher of oil to flow into the water above the well. When the BOP is removed, time will be critical. In order to minimize the volume of oil released from the well, after the BOP is removed, the process for plugging the well must be performed quickly. For this reason, the support structure for the plug (described below) should be in place before the BOP is removed.

The plug support structure is designed to enable the plug to resist the full pressure within the well when the plug valve is closed and the oil flow is stopped. This will be accomplished without transferring force or stress to the wellhead or casing. In other words, the plug will not need to be secured or fastened to the wellhead or casing in order to resist the force of the oil pressure from the reservoir. The invention provides a means to secure the plug, and stop the oil spill, by way of external force pushing against the plug opposite to the direction of the oil pressure within the well; thus protecting the wellhead and casing from additional stress.

The Deepwater Horizon blowout has raised concerns about the condition of the wellhead and casing. Although it appears that the blowout did not create a leak at the wellhead or casing beneath the BOP, there is good reason to be concerned. It is unknown whether the wellhead has been weakened or hairline cracks exist in the stack connector or casing. The weight of the BOP may be preventing a leak. Removal of the BOP could expose a risk of cracking the wellhead.

The fact that the BOP was not torn off of the wellhead (stack connector) by the force of the bending riser as the Deepwater Horizon drilling rig sank to the bottom of the Gulf is evidence of the extraordinary engineering accomplishments of the subsea drilling industry.

This invention can plug a well with a cracked wellhead, even if part, or all, of the connector flange is missing and (or) the casing is cracked and leaking. The invention describes two types of plugs: one type of plug is for plugging a well where only the BOP has failed, but the wellhead remains in good condition after the BOP is removed; the other type of plug is for plugging a well where the BOP has been removed but the top of the well is damaged and cannot be repaired before plugging.

The figures referenced herein can be found at the end of this paper.

Figure 1 is a view of the plug support structure as it might appear to an observer looking down from above the well. The well (w) is located at the center of figure 1. Each of the four spoke-like-arms extending out from the well at right angles to each other will be called a Subsea *Lever Anchor (SLA)*. The entire plug support structure, illustrated by fig 1, will be called the SLA structure or also an SLA. The SLA structure represents the means to secure the plug to the well. The choice of four SLA "spokes" is for illustration only; the illustration is not meant to limit the number of SLAs for an SLA structure. The number of SLAs could be two or more. The actual number of SLAs will be decided by the engineer responsible for adapting the invention to a specific well.

The SLA structure will enable a plug to seal the well without adding stress to the wellhead or casing. The SLA also makes it possible to secure the plug, and seal the well, with minimal obstruction near the wellhead, thereby facilitating access to the area during and after the process of applying the plug. The SLA also makes it possible to secure the plug without driving piles, or other anchor means, into the seabed near the well, which might compromise or otherwise weaken the area supporting the wellbore and casing near the top of the well.

The SLA located on the right-hand side of figure 1 is labeled to help identify the parts of each SLA. Each letter and number represent a part of the SLA that is common to all of the SLAs shown in figure 1. In other words, the description of the labeled SLA applies to all four SLAs. The 'A' represents the entire length of the SLA. The '1' represents the end of each SLA that is closest to the well, and where the well plug will be connected to the SLA. The '2' represents the end of each SLA that is farthest away from the well. The '3' represents the location on the SLA where the weight or resistance of the SLA is positioned. Labels A1 and A2 identify the length of the section of the SLA on each side of '3'. For example, the length of A1 might be 10 feet or 20 feet, or longer, or shorter. A2 can be equal to A1 or longer, but not shorter. The entire length of the SLA between '1' and '2', identified as 'A', is one continuous rigid structure, shaped to accommodate the area identified as '3', and strong enough to support the weight or resistance that will be located at '3'. The SLA may be assembled from several pieces, but the end result must be a rigid and strong structure.

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Figures #2, #3 and #4 illustrate the concepts of a lever. These concepts will be used in describing how the SLA will provide the resistance required for pulling the plug down onto the wellhead, and ultimately securing the plug, without adding stress to the wellhead.

Figure 2 can be recognized as similar to a playground seesaw or teeter-totter. The downward pointing arrows located at each end of the lever could represent the weight of two children sitting opposite each other. If the children weigh about the same, then they can easily cause the lever to move up and down, supported by the pivot located at the center under the lever. The pivot supports the combined weight of both children. Each child takes a turn at being lifted up by the force of the weight of the other child. However, if one child weighs much more than the other child, then the game is more difficult, because the weight of the small child cannot lift the heavier child.

Figure 3 illustrates a lever, or seesaw, that will help the small child lift the heavier child. The length of one end of the lever is longer than the other end, relative to the pivot supporting the lever. The small child will sit on the long end, and thereby have “leverage” over the heavier child because the longer end of the lever will move a greater distance.

Figure 4 shows the lever upside down, with the lever laying on the ground and the pivot inverted on top of the lever. The force of the upward pointing arrow (1) on the left-side of the lever is attempting to lift the lever. If the force of the weight of the inverted pivot (3), pressing down on the lever, is greater than the upward force represented by the arrow (1), what will happen? Because the length of the lever extends an equal distance on either side of the inverted pivot, the lifting force, represented by the arrow (1), will have a 2:1 mechanical advantage, or “leverage” over the weight of the inverted pivot (3). So, if the weight of the inverted pivot produces a downward force that is less than twice the upward force represented by the arrow (1), then arrow (1) will lift the end of the lever, raising the inverted pivot upward. And, at the same time, the opposite end of the lever will be forced down against the ground; the dashed downward arrow (2a) represents that force. The upward arrow (2b) beneath the dashed downward arrow represents the counter-force of the ground effectively “pushing” back up against the lever opposing the downward force of the dashed arrow (2a). The combined forces of arrow (1) and arrow (2b) press upward against the inverted pivot (3) similar but in opposite direction to how the combined weights of the two children press down against the pivot in figures 2 & 3.

Figure 5 illustrates a side-view of one SLA of the SLA structure described in figure 1. The side-view cut exposes a slice of the seabed under the SLA. The SLA is resting on the seafloor, similar to the lever in figure 4 that is resting on the ground. The weight (3) in fig 5 will function conceptually like the weight of the inverted pivot described in fig 4. The cable (1) in fig 5 is connected to a plug (figures 6 & 7 below) suspended above the well. The plug can be suspended above the well by buoyancy or by hanging from another cable connected to a surface ship above the well. Cable (1) will produce an upward force on the SLA similar to the upward arrow (1) that was described in fig 4. The force of cable (1) acting on the SLA in an upward direction will produce an equal and opposite downward force on the plug above, pulling the plug down toward the well (figures 8 & 9).

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If the length of sections A1 and A2, of the SLA in figure 5, are equal, then the weight (3) will need to produce a downward force against the SLA that is at least twice the upward force applied against the SLA by the cable (1).

If the length of section A2 in figure 5 is longer than section A1, then the weight (3) can be proportionately less, conceptually similar to how the longer end of the lever in fig 3 enabled the smaller child to lift the heavier child. In that case, the combined weight of the two children was less than twice the weight of the heavy child, and it is their combined weight that is supported by the pivot. In a similar way, in fig 5, a longer A2 will enable a lighter weight (3) to resist the upward force of cable (1). The design engineer responsible for adapting the SLA to a specific well can decide the best use of this concept: longer SLA section A2, or heavier weight (3).

In figure 5, a block (4) is located under the far end of the SLA between the forces represented by arrows 2a and 2b. The block (4) is a solid foundation for the purpose of keeping the end of the SLA from sinking into the seafloor in response to the force represented by 2a. Force 2b is represented through Block 4 as an immovable resistance to force 2a.

The SLA weight (3) in figure 5 can be provided by dead-weight, for example: solid iron, or other heavy material; or the weight can be resistance provided by securing the location on the SLA identified as (3) to the seabed; or, a combination of both dead-weight and seabed anchor. By increasing the length of section A1 of the SLA, the location of the weight (3) on the SLA can be positioned far enough away from the well to alleviate concerns about securing the SLA into the seabed near the well. But if concerns prohibit securing the SLA to the seabed, for any reason, then dead-weight distributed over several SLAs positioned around the well can provide sufficient resistance to enable the SLA structure to overcome the oil pressure at the wellhead as the plug is lowered and then held secure by the resistance of the SLA, thereby plugging the well and ending the oil spill.

Figure 6 illustrates the Type 1 Plug (T1), which would be used for plugging a well that has a good wellhead after a defective BOP is removed. The T1 plug is open at both ends to allow the gushing oil to flow through the plug as the plug is lowered over the well. The T1 plug will have one or more valves that can be closed after the plug is secured to the SLA and a tight seal is made over the wellhead. The bottom flange (F1) of the T1 plug can be bolted to the wellhead flange at that time, to ensure alignment, but the bolts are not needed for securing the plug against the oil pressure within the well; the SLA clamps (3 & 4) will hold the plug securely in place as well as bolts would, but without transferring stress to the wellhead flange. The plug is secured to the SLA by clamping or latching the plug arm to the SLA after the plug is lowered to its final position by the force of the cable (1). The item on the arm identified as 3 & 4 represents the clamp or fastener that will hold the plug arm to the SLA after the cable is removed (however, the cable could be used as the final fastener, as well).

The number of arms shown on fig 6 is for illustration only; the actual number of arms would match the number of SLAs that would secure the plug via the arms. Connection (2) on the arm in fig 6 shows where cable (1) is connected to the plug. All of the plug arms use a similar connection. The arms can be either above or below the valves, but must allow room to open and close the valves, and allow access to the flanges if bolts are used.

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The flange (F2) at the top of the T1 plug allows for the connection of a production tree, for use if the well is to be brought back into production after the gusher is stopped.

Figure 7 illustrates the Type 2 Plug (T2), which would be used for plugging a well that has a cracked or otherwise damaged wellhead and casing. The type 2 Plug is essentially the same as the T1 plug in fig 6, except for the addition of an insertion pipe that extends from the lower end of the T2 plug shown in fig 7. Because the T2 plug is essentially the same as the T1 plug (except for the insertion pipe), the detail of the T1 plug is not reproduced in figure 7 nor are the duplicate descriptions repeated here.

The insertion pipe in fig 7 must be long enough to extend into the casing below the cracks or leaks, therefore it will either be custom built for the specific well based on the conditions of the well and where the leak is located, or the insertion pipe will be threaded to enable extension lengths to be added on site, as needed.

Near the end of the insertion pipe in fig 7, an inflatable tube (1) is shown wrapped around the outside of the insertion pipe. The inflatable tube is shaped like a vehicle tire inner tube, held flat and tight to the outside wall of the insertion pipe until it is inflated. A hydraulic line (2) connects the inflatable tube with a means to pump hydraulic fluid through the line to inflate the tube after the insertion pipe is positioned in the well and the T2 plug is secured to the SLA. The tube will be inflated with a pressure greater than the pressure in the well, sufficient to block the oil flow between the outside wall of the insertion pipe and the inside wall of the wellbore casing, preventing oil from reaching any cracks above the tube. When that is done, the T2 plug valve can be closed and the well gusher will be plugged.

The engineering challenge will be in connecting the inflatable tube to the pipe in such a way that it will not be torn off by the force of the oil pressure. The tube would also need to be made of material strong enough to not be ripped or damaged during the lowering of the pipe into the well. Fortunately, this procedure can be simulated in an onshore test facility using the conditions and pressures found at a subsea well, which means the inflatable tube and insertion pipe do not need to be tested for the first time on a live subsea oil gusher.

Figure 8 illustrates one method of connecting the SLA to plug T1 or plug T2 and lowering the plug onto the wellhead. For purpose of illustration, two SLAs are shown in fig 8 positioned on either side of a subsea well (w), in a side-view cut showing the seabed and wellbore beneath the seafloor. Oil and gas under pressure is shown coming up through the well and gushing out into the seawater at the subsea wellhead, forming a rising column between the wellhead and the plug suspended above the wellhead. Cables (1) are connected to the arms on the plug at one end of the cables and to the SLAs at the other end where the vertical cable makes a 90 degree turn through an SLA connected ring or other mechanical means designed to facilitate the direction and movement of the cable along the horizontal length of the SLA, pulled by a subsea winch and motor assembly (5) mounted on or adjacent to the SLA.

The winch and subsea motor will cause a horizontal force pulling the cable toward the winch/motor, and an equal and opposite horizontal force tending to move the winch/motor toward the wellhead. A pile anchor (4) driven into the seabed at the far end of the SLA will provide resistance, via a separate cable connecting the winch/motor and or SLA to the pile anchor (4), to prevent horizontal movement toward the wellhead. An alternative to the pile anchor is represented by the square shape formed in dashed lines set around the wellhead and connecting the two SLAs. The square represents a brace joining the SLAs in such a way as not to obstruct or contact the wellhead, but would be strong and rigid enough to allow the two horizontal forces produced by the opposite winch/motors to counter each other, thus preventing horizontal movement.

Another concern is the unlikely but possible “swivel” movement of the SLA from left to right if the oil gusher pressure hits the plug as it is being lowered to the well in such a way as to cause a powerful horizontal tending pull on the cable connecting the plug arm and SLA. Although the huge weight (3) should prevent a swivel movement, it is possible. An SLA configuration using four SLAs positioned around the well 90 degrees from each other, as in figure 1, with the above mentioned brace joining the four SLAs, represented by the dashed line square in fig 8, would provide resistance to a swivel force. In addition, pile anchors could be driven into the seabed on either side of section A2 of each SLA to counter a swivel movement. An alternative to driving piles into the seabed would be to use heavy dead-weight positioned on either side of section A2 of each SLA.

Figure 9 illustrates an alternate method of connecting the SLA to plug T1 or plug T2 and lowering the plug onto the wellhead. Fig 9 is similar to fig 8, except the winch/motor assembly is positioned at the plug rather than on the SLA. For this configuration, the plug arms would be designed with means to mount a removable structure to the arms that would house the winch/motor assembly, supported by a buoyancy means. The removable winch/motor assembly structure would be much larger in diameter than the plug arms. The horizontal forces of the winch/motors would counter each other as the arms would be positioned opposite each other, and therefore the winch/motors would be opposite each other. After the plug is secured to the SLA at the wellhead and the plug valves are closed, stopping the oil gusher, the winch/motor assembly would be removed and made available for another project.

Figure 10 illustrates the final position of the plug at the wellhead, fastened to the SLA. Adjustable clamps are bolted onto the plug arms and again at the SLA, securing the plug and sealing the well by the pressure of the downward force caused by the weight or resistance of the SLA. If the plug is a Type 2, then the inflatable tube (fig 7) is inflated by hydraulic fluid before the plug valves are closed. The plug valves are then closed.

The well is plugged. The oil spill has been stopped.

It is important to emphasize that the process of plugging an out-of-control subsea oil and gas well, using this invention, could be completed in less than 24 hours if the support structure (SLA) and plugs were already in place, positioned in standby mode at the well before a blowout occurs. For that reason, this invention should be installed at all future subsea well sites, before drilling begins.

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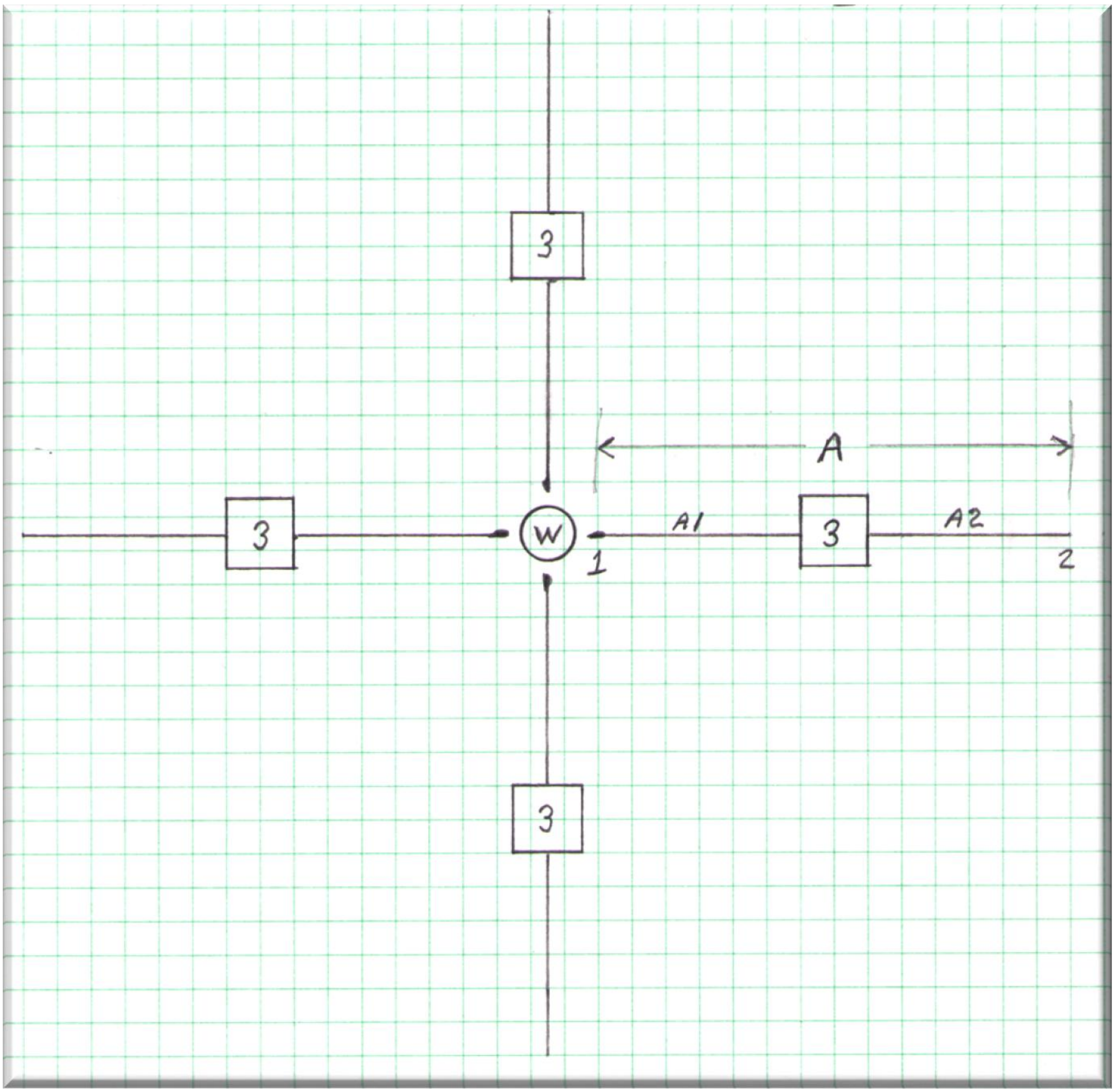
Figure 1

Subsea Lever Anchor (SLA)



Figures 2, 3 and 4

Concepts of a lever

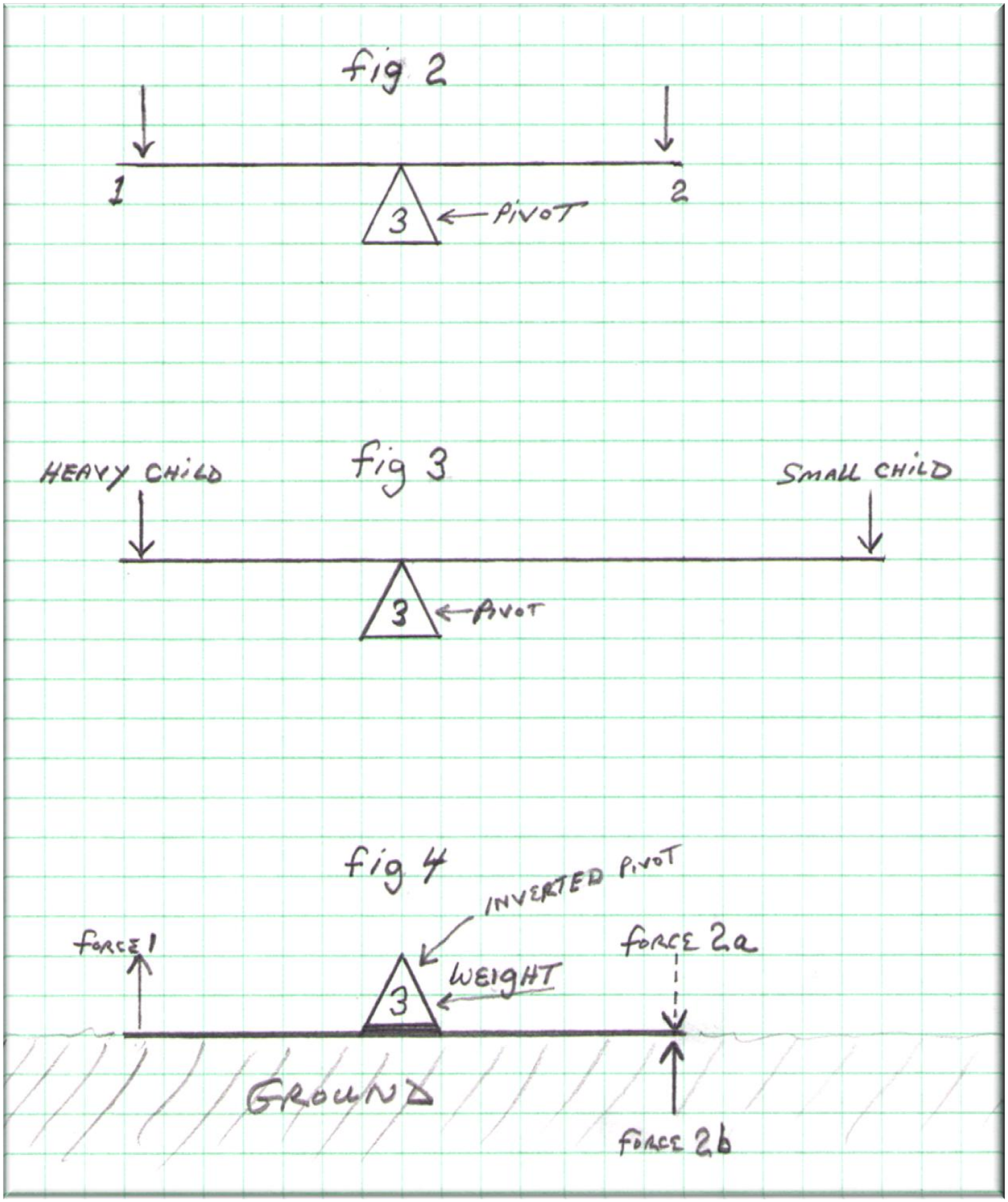


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Figure 5

Single Subsea Lever Anchor (SLA) on seafloor

Side view cut showing slice of seabed and wellbore below seafloor

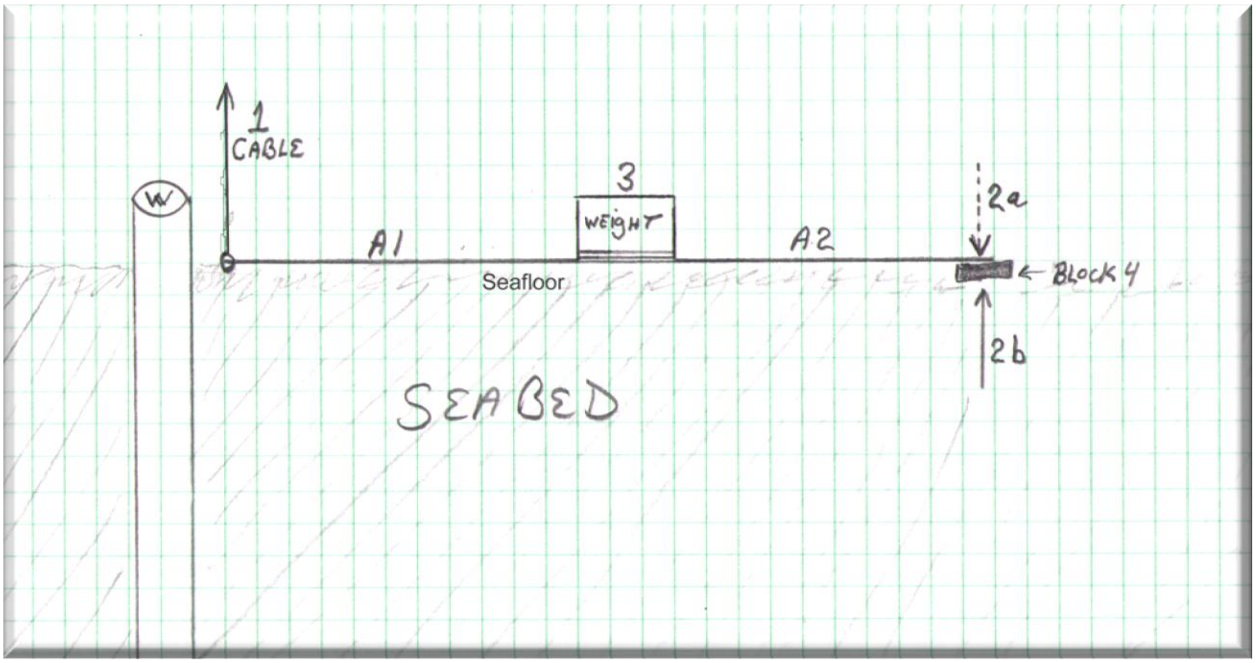

Figure 6 – Type 1 Plug

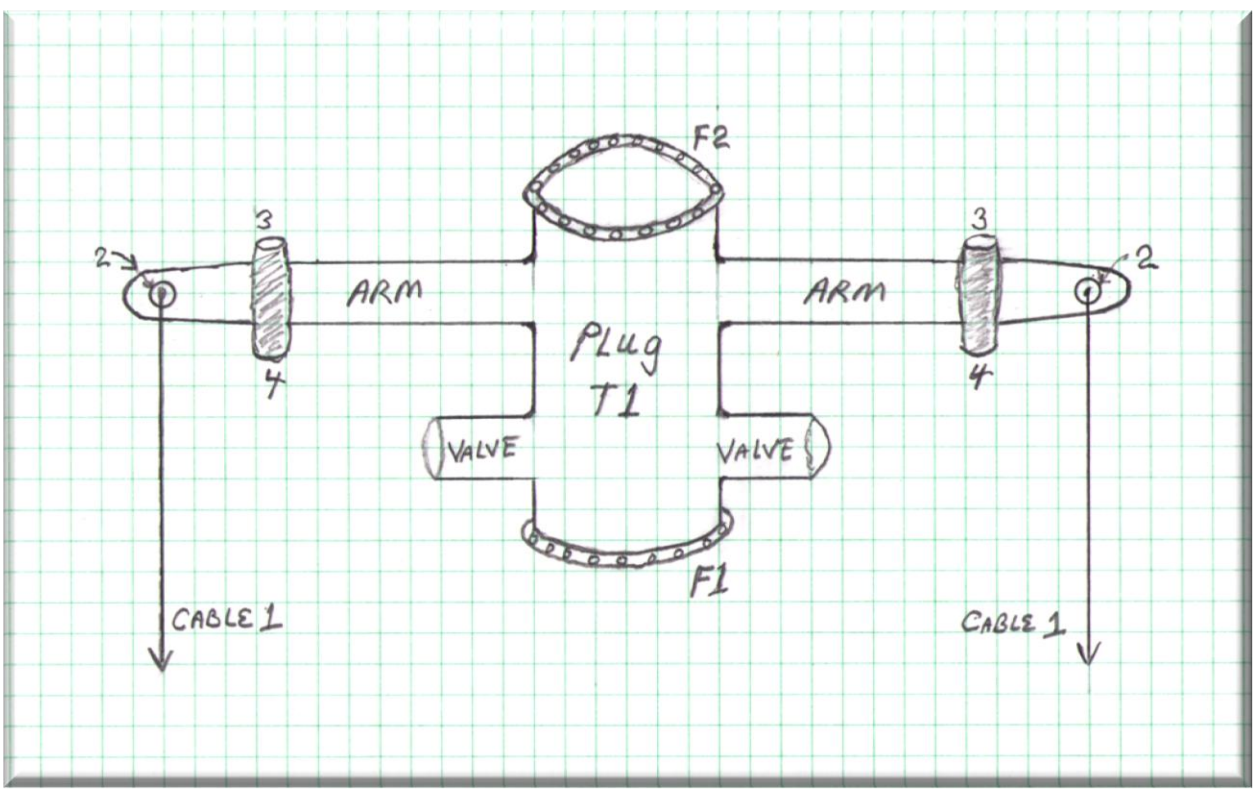

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Figure 7
Plug Type 2

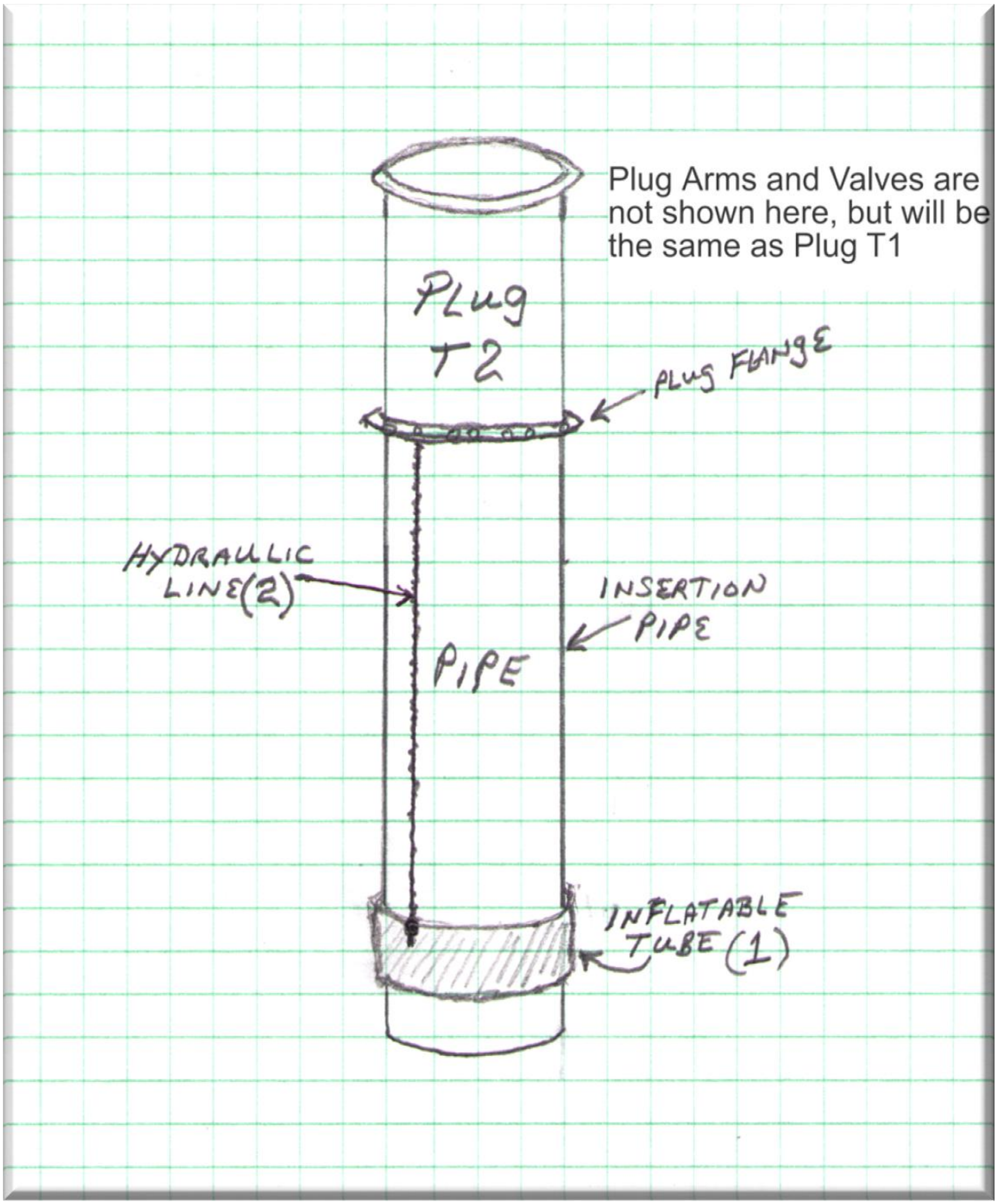

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Figure 8

Method for connecting the SLA to the plug and lowering the plug onto the wellhead

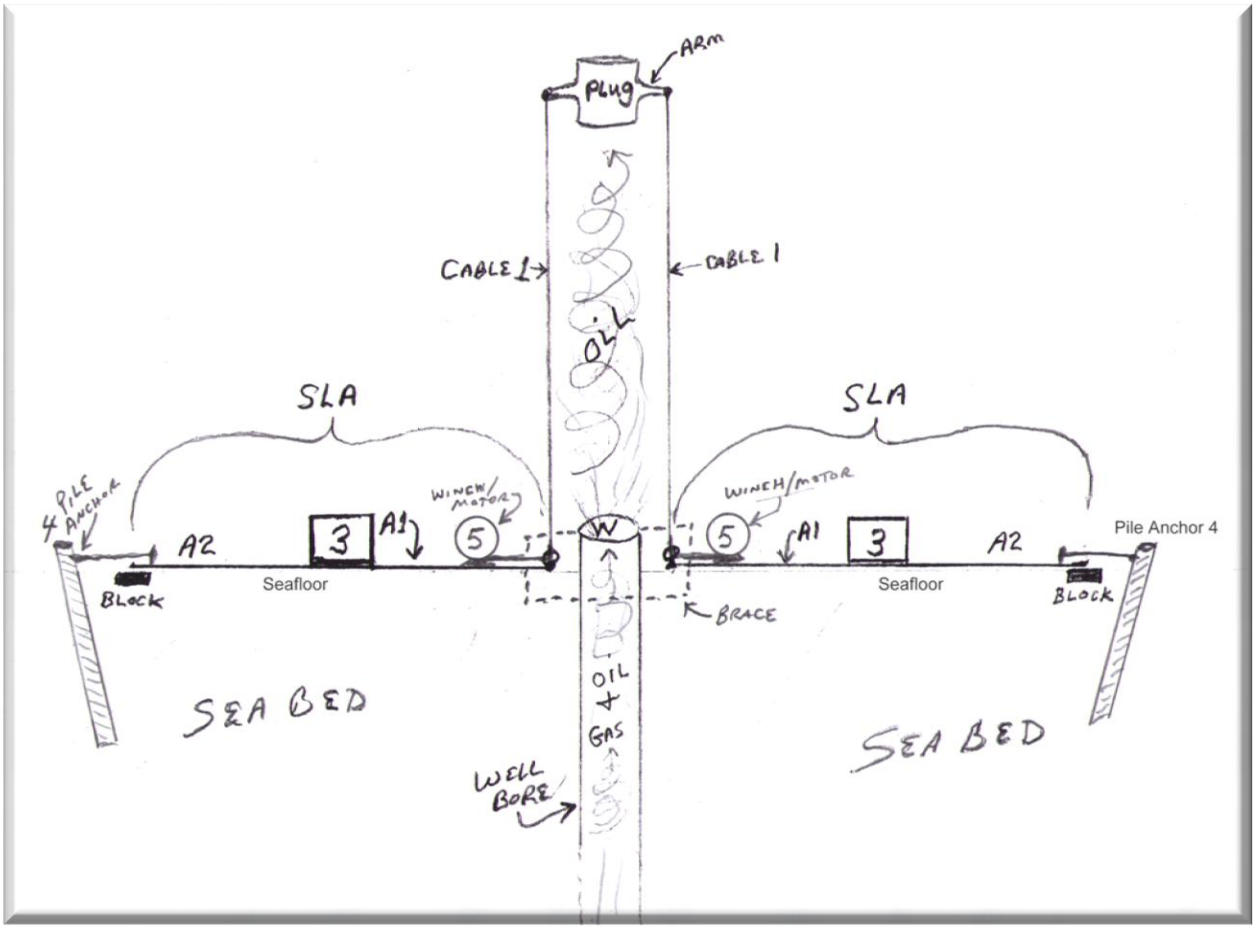

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Figure 9

Alternate method for connecting the SLA to the plug and lowering the plug onto the wellhead

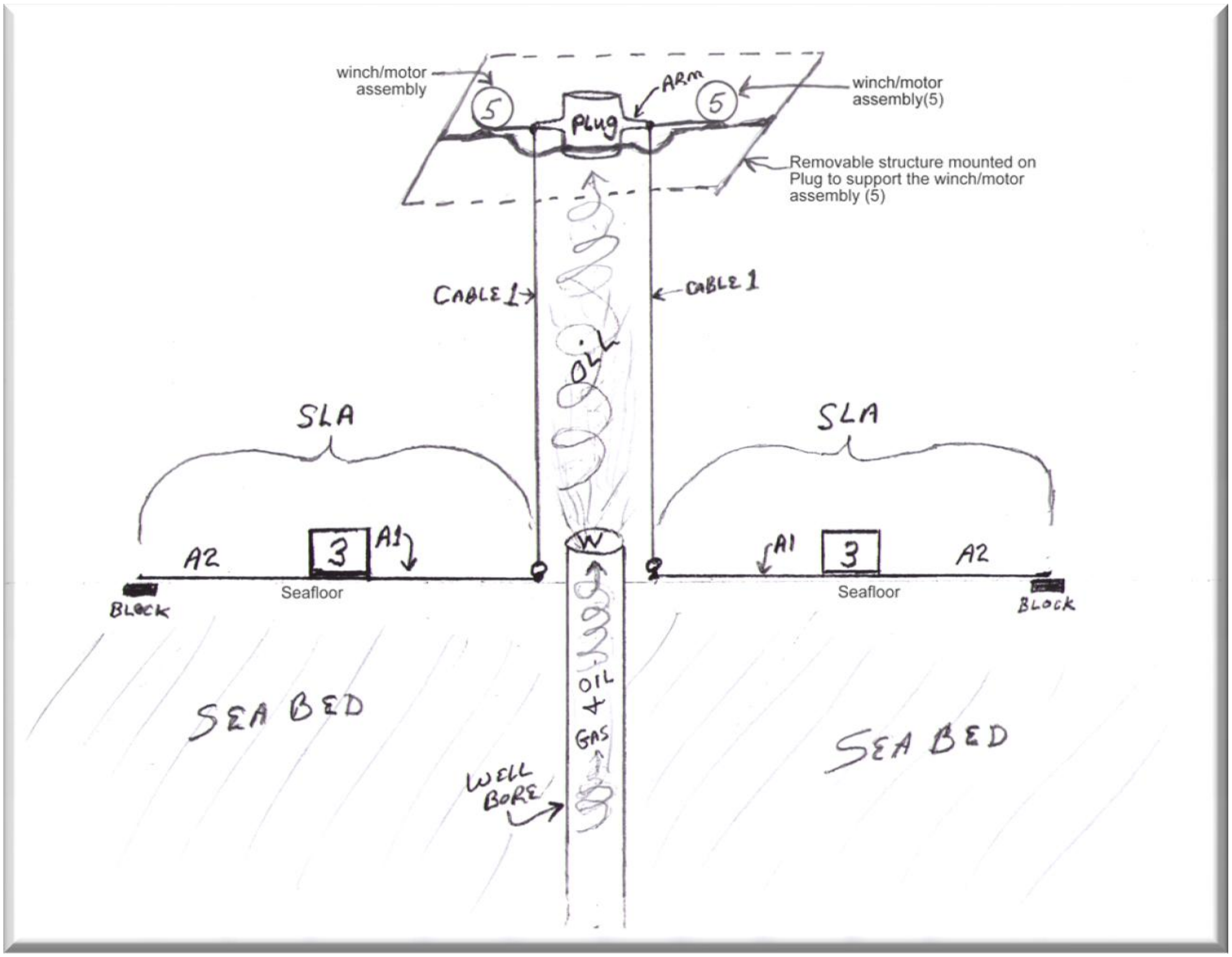

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Figure 10

Final position of plug at the wellhead, fastened to the SLA