Storms, M. A., Natland, J. H., et al., 1991
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7. DIAMOND CORING SYSTEM—SEAFLOOR COMPONENT HARDWARE[1]

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EXECUTIVE SUMMARY

Engineering Leg 132 was used to test and further refine the Diamond Coring System (DCS) seafloor spudding equipment and drilling hardware. Information learned from Leg 124E with the prototype DCS revealed that it was imperative to establish a seabed platform from which to begin coring operations. Therefore, a complete and separate set of equipment was designed for the seafloor to complement the vessel-mounted drilling hardware. Two types of seafloor templates or structures were designed for operations on both hard rock and soft sediments. Experience from past legs where hard rock spudding was performed was combined with DCS requirements to develop a new Hard Rock Guide Base (HRB). This new mini-HRB was much smaller than those used in the past, primarily due to a different design philosophy used in establishing the hole. Previous attempts used the more conventional oilfield approach of drilling a larger hole and setting surface casing strings, whereas, a drill-in type Bottom Hole Assembly (BHA) was used on Leg 132. The drill-in BHA was implanted into the formation and then left through the use of a back-off sub especially developed for hard rock and DCS operations. This required only one trip for the BHA to be drilled in and backed off, whereas conventional practice required possibly several trips before establishing the hole. This concept eliminated any redrilling or reaming of the hole that might be necessary due to instability of the formation or due to the size of the hole drilled.

The other type of seafloor template deployed with the DCS was a modified reentry cone. Modifications to the standard ODP reentry cone included the addition of discharge tubes to divert the cuttings and a specially designed casing hanger compatible with the drill-in BHA. This reentry cone concept was designed for locations where a considerable amount of soft sediments overlay the formation of interest. Components of each type seafloor structure were fabricated using as much existing ODP hardware as possible.

The concept of using the conventional ODP drill string as a mini-riser also was incorporated in designing the DCS seafloor hardware. The drill string was held in tension throughout the drilling process. This was accomplished with a specially designed tensioning tool fashioned after the double-jay running tool. The tensioning tool utilized the same jay-slots that were used to lower the mini-HRB and reentry cone to the seafloor. Connected to the tensioning tool was a Tapered Stress Joint (TSJ) which provided a smooth transition from the mini-riser to the seafloor structure.

A considerable amount was learned pertaining to the strengths and weaknesses of both systems along with the individual hardware components deployed with them. It was further demonstrated that the HRB could be redeployed and repositioned on the seafloor for performing multiple holes. The back-off sub concept was validated, but additional testing of the mating receptacle tapers is felt needed. The retractable lugs on the tensioning tool were also felt to be underdesigned for the torsional loading conditions to which it was subjected. The majority of the engineering objectives were accomplished, though not without some redesign of equipment which failed. It was demonstrated, however, that all the concepts tested for establishing and maintaining holes in bare fractured rock or soft sediment were valid and suitable for continued refinement.

Much of the whole deployment scheme required/depended upon progressive success of each seafloor component in order for coring to be initiated with the DCS. Many of the problems encountered on Leg 132 were a direct result of either inadequate floatation for the cone on the HRB or poor welding practices. Inadequate welding on the casing hanger used in the reentry cone resulted in shearing both restraints used for holding the landing seat from turning when attempting to unscrew the back-off sub. These failures led to additional setbacks and consequent delays caused by repairing other hardware components placed in situations they were never intended or designed to be used.

This report provides some general background information pertaining to the design of the equipment along with technical and operational information gathered during the leg. Included where pertinent are both field performance and suggested improvements for future designs.

INTRODUCTION

Engineering Leg 132 was used to further refine the DCS's ability to both drill and core in sedimentary and crystalline rock formations and to test out new seafloor hardware to complement Phase II of the vessel-mounted drilling equipment. Three different locations were initially chosen to evaluate different coring conditions and seafloor hardware in water depths ranging from 1350 to 2634 m. These locations were Bonin Back-arc, Shatsky Rise, and M.I.T. Guyot. Specific formations expected at each were: (1) young fractured basalt, (2) interbedded chalk/chert sequences, and (3) reefal limestones. However, because of some initial start-up and operational problems with both the seafloor components and the DCS hardware, only two sites were actually investigated. These were the Bonin Back-arc and Shatsky Rise locations.

The previous attempt at drilling with the prototype DCS (Phase I) on Leg 124E met with limited success. This was mainly due to seafloor instabilities caused by some rubble zones and further disturbed by the large drill pipe being allowing to float in the borehole when the heave compensator was locked out. Several times the drill pipe became stuck and the borehole was abandoned. Therefore, in an attempt to alleviate problems associated with seafloor instabilities and to allow the DCS concept a chance to be fully proven as a viable drilling system, a complete seafloor hardware package was developed.

There were several major goals set forth in the Engineering Prospectus for Leg 132 that pertained specifically to the seafloor hardware. These goals were:

1. Deploy and test the new mini-HRB for DCS operations,
2. Deploy and test a modified reentry cone assembly for use with the DCS,

[1] Storms, M. A., Natland, J. H., et al., 1991. *Proc. ODP, Init. Repts.*, 132: College Station, TX (Ocean Drilling Program).

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3. Evaluate techniques and hardware for establishing and maintaining upper hole stability to allow successful deployment of the DCS in unstable formations, and
4. Evaluate the drill string tensioning system for use as a mini-riser.

The above goals can further be broken down into the specific engineering and operational objectives/tasks for the above concepts and hardware. These include:

1. Test the gimbal concept for greater rotational freedom on seafloor slopes up to 20°,
2. Evaluate the use of ballasting the mini-HRB with placement of weighted cement/barite before deployment,
3. Evaluate using the ODP API drill pipe as a mini-riser held in tension,
4. Install and evaluate the performance of the tapered stress joint,
5. Evaluate the use of the mechanical tensioning tool for pulling tension on the seafloor template (mini-HRB or reentry cone),
6. Test a modified casing hanger to accept a mechanical tensioning tool and a landing seat concept for unscrewing a back-off sub,
7. Evaluate the drill-in/back-off release mechanism allowing use of the BHA for spudding in bare fractured rock and upper hole stabilization, and
8. Evaluate adaption of mini-riser tensioning system to a standard reentry cone design.

All the above engineering goals and objectives were met during Leg 132 with the exception of item 8. However, this was felt to be achievable, but time ran out in the leg before it could be attempted. The successful deployment of the equipment proved that the concepts investigated were valid and suitable for future use with the DCS. The majority of the equipment worked as designed, though some failures did occur. Much of the whole program required/depended upon progressive success of every component in order for coring to be initiated with the DCS. Many of the problems which were encountered on Leg 132 were the direct result of the failure of a single item. This lead to some setbacks by not allowing other components or hardware to work as designed by placing them in a situation never intended.

The following report provides some background information pertaining to the design of seafloor equipment along with technical and operational information gathered during the leg. Included where pertinent are both field performance information and suggested improvements for future designs for the drill-in BHA, seafloor hardware, and techniques adapted for their deployment. A complete and detailed discussion on the DCS hardware is presented in a separate report (see "Operations Report" chapter, this volume).

COMPONENTS OF THE DCS SEAFLOOR HARDWARE

Seafloor Hardware

A considerable amount of time was devoted to developing a seafloor template system that would work with the DCS and be compatible with as much of ODP's conventional drilling equipment as possible. The seafloor system components were designed to be versatile so that they could be deployed on a variety of sediment and formation types. These included both bare rock and soft surficial sediments.

The following components make up the majority of the hardware developed for complementing the DCS drilling equipment. These components include:

1. Mini-hard rock guide base,
2. Modified reentry cone,
3. Landing seat,
4. Modified casing hanger,
5. Tensioning tool, and
6. Tapered stress joint.

How these components fit into the overall seafloor system is best illustrated on the composite drawing in Figure 1. It should also be noted that much of the equipment is interchangeable, thus allowing for less-specialized components. The hardware was also designed to be operated with two different sizes of BHA. This would allow a smaller size BHA to be run should hole or formations problems dictate. Additional details comparing the two types of seafloor templates are given in Figure 2.

Bottom Hole Assembly Hardware

The entire bottom hole assembly was looked at in the same fashion as the seafloor hardware. The problem statement required flexibility to be designed into the drilling assembly so that it could also be used for many different formations while providing a stable cased hole to begin diamond coring in. In addition, it not only had to be compatible with the seafloor components but also to be an integral part of the whole DCS.

It was felt that a drill-in type of BHA was needed particularly for fractured rock. This was demonstrated on bare rock drilling during Legs 106 and 109 where the formation would fall back in the hole as soon as the drill string was removed to run/set surface casing. Also because of the rugged and abrasive nature of the material at some locations, drilling-in surface casing was not an acceptable alternative to begin a hole. Furthermore, it had been learned that the best method to begin a hole on bare rock was with a Positive Displacement Coring Motor (PDCM). Therefore, the whole BHA was required to be compatible not only with the top drive on the *JOIDES Resolution* but also with a PDCM since it would be the primary means with which to begin the boreholes.

The following list includes not only new BHA equipment developed for use with the DCS but also existing equipment that was modified to be compatible with the seafloor hardware. This equipment includes:

1. Drill-in back-off sub,
2. Removable center bit,
3. Redesigned rotary core bit,
4. Modified XCB latch (center bit),
5. Spiral-bladed stabilizers,
6. Pony drill collars, and
7. PDCM with lock-out device.

As illustrated in Figure 3, two different sizes of BHA were developed. These were centered around an 11-5/8 in. and a smaller 9-7/8 in. bit size. Besides the two bit sizes, several different cutting structures employing Tungsten Carbide Inserts (TCI) were manufactured. Previous experience with roller cone bits in fractured rock indicated that the larger the bearings on the bit, the more likely it was to survive. However, it has also been shown that less borehole disturbance will be caused by the use of a smaller diameter bit. Therefore, both sizes were designed so that if specific drilling conditions dictated, a different size BHA and alternative bit type would be available.

A whole different design philosophy was adopted for the hard rock spud in for Leg 132. Previous attempts with drilling into hard rock on the surface tried to establish surface-set casing as a means to stabilize the borehole and get through the rubble zone. This involved multiple trips with large size bits and casing in order to

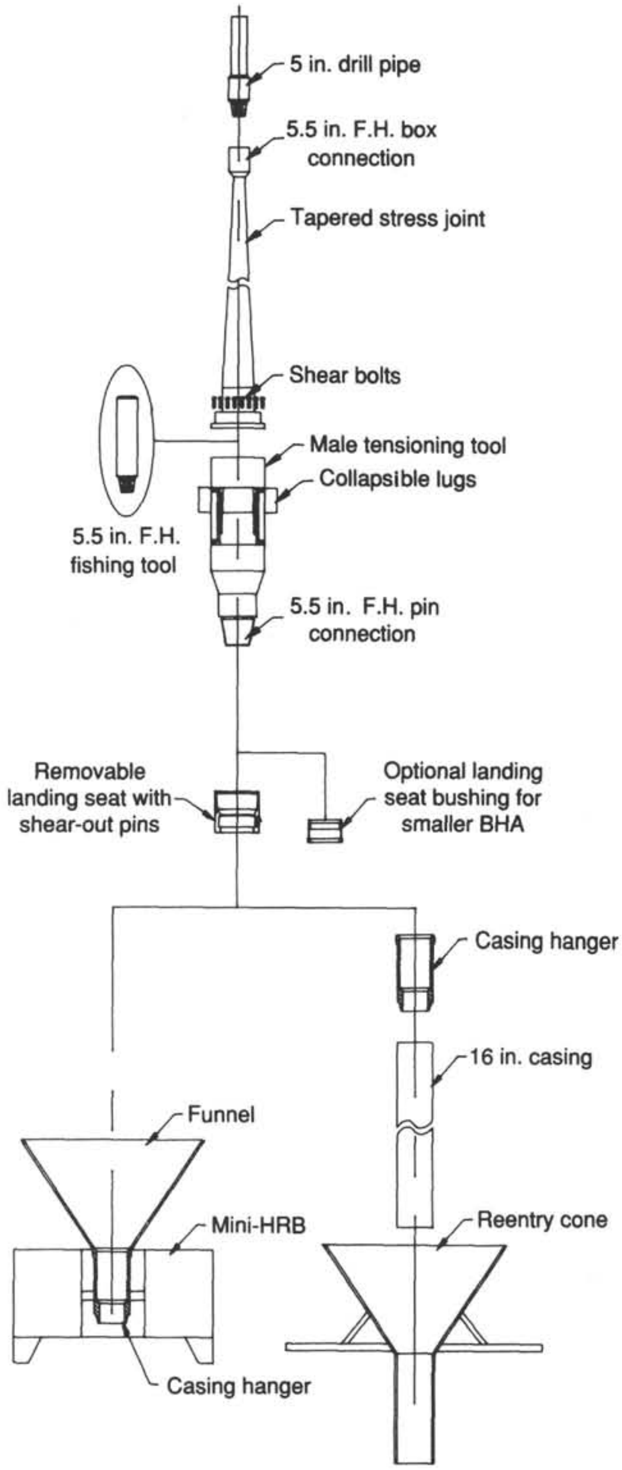


Figure 1. Seafloor hardware options.

establish a platform from which to use conventional coring techniques. The method deployed on Leg 132 allowed a single BHA string to be drilled in, backed off, and left as the reentry casing from which to begin DCS coring. The smaller DCS bit/core barrel and tubing was then run through the drilled-in BHA prior to beginning the coring operations.

MINI-HARD ROCK GUIDE BASE

General Description of Hardware

The mini HRB was designed to be deployed through the moonpool of the *JOIDES Resolution* on the same plane as it was run to the seafloor. The original version of the HRB had to be lowered below the vessel's hull sideways before being inverted into the lowering position. This operation not only required considerable time but was a labor-intensive maneuver during the inverting process and somewhat controlled by favorable weather conditions. The new mini-HRB is 10 ft square and approximately 5-1/2 ft tall with the legs collapsed. Part of the uniqueness of the mini-HRB is its ability to use existing ODP reentry cone hardware. The reentry cone funnel and 16 in. casing hanger are part of its design. With the addition of these two components the mini-HRB stands over 17 ft tall and almost 18 ft in diameter with sonar reflectors attached to the cone funnel. A space-out schematic is presented in Figure 4.

Other major differences between the old and new design of the HRB include:

1. The mini-HRB is pre-weighted prior to running to the seafloor whereas the earlier version required cement pumped into it once it was on the seafloor,
2. The new version allows a much heavier guide base to be run in order to develop the necessary reaction,
3. The new version has a fully gimbaled reentry cone to allow placement on seafloor slopes up to 20°,
4. Syntactic foam is used on the cone panels to provide a righting moment of the funnel,
5. Modular design allows easy shipping and assembly, and
6. The new version is constantly pulled against in tension with the main drill string whereas the earlier version was not connected to the vessel.

Ballasting the mini-HRB is accomplished with steel or lead shot, metal punchings, or cast iron ingots coupled with cement or barite to fill the voids. The mini-HRB is assembled from four identical tank sections with each tank holding 117 ft^3 (Fig. 5). If additional ballast is required for deeper water sites, steel plate can be added prior to running to the seafloor.

The mini-HRB proved to be simpler to assemble and transport than its predecessor version. Due to the smaller size, it could be positioned in the moonpool area without removing any existing equipment or fixtures from the *JOIDES Resolution*. Also unlike the earlier version, the mini-HRB could be brought into the moonpool area from underneath the rig floor instead of through it. This was extremely important since the DCS platform, guide dolly tracks, and other support equipment were already positioned on the rig floor. This assembly option allowed for other sites to be drilled without rigging down the DCS on the rig floor. Partial assembly of the HRB was also allowable during transit to the location in question. Total time to assemble and deploy the mini-HRB in 1800 m of water is broken down as follows:

Task description	Time (hr)
1. Tank section assembly	17.66
2. Cone/gusset/flotation panel assembly	4.00
3. Hanger installation	0.58
4. Cone attachment/weld-out	2.33
5. Ballasting operations	4.00
6. Final preparation/reflector attachment	7.00
7. Lower through hull/run to seafloor (1800 m)	4.17
Total	39.74

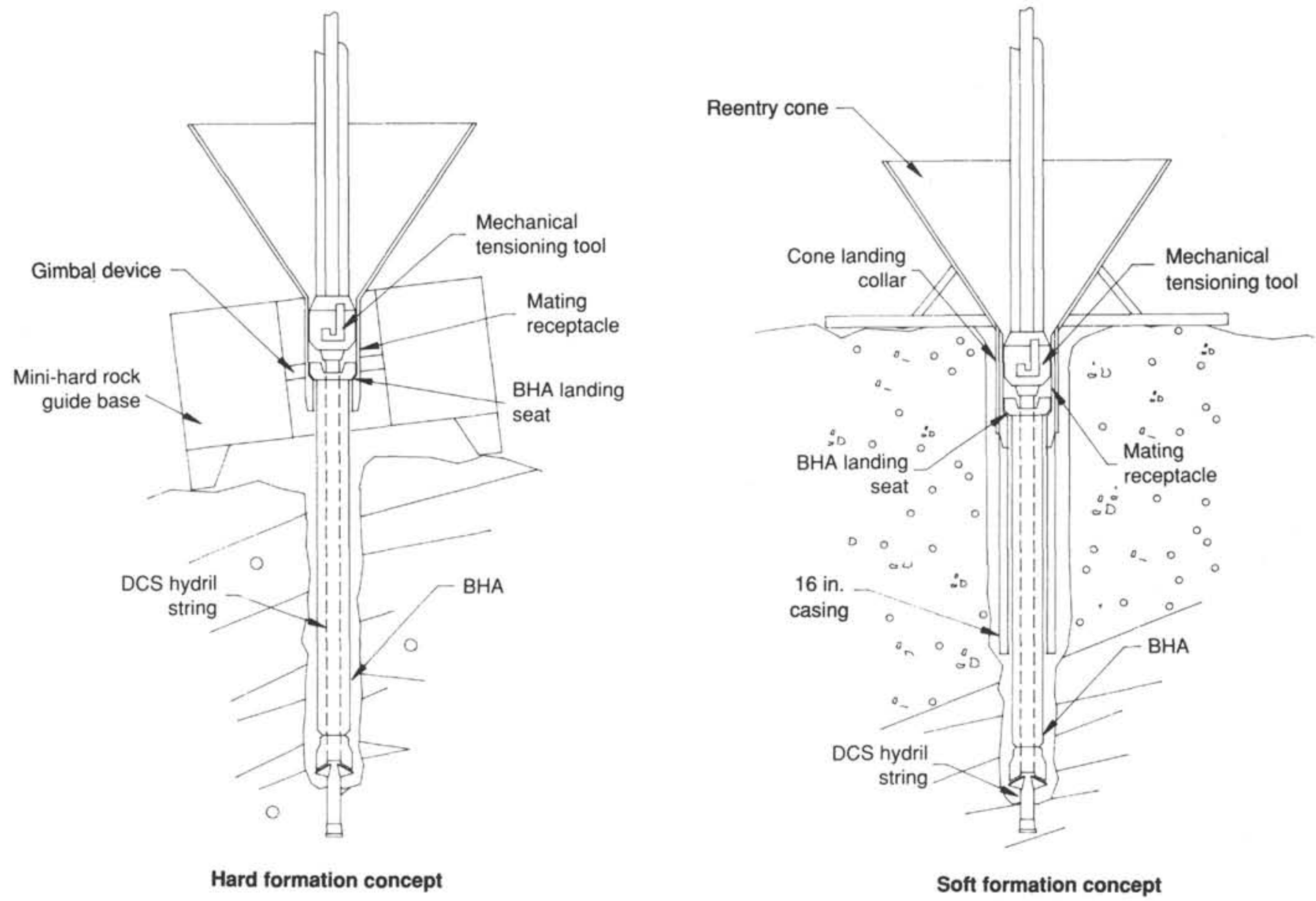


Figure 2. Comparison of seafloor deployment systems.

The majority of the components on the mini-HRB were designed to be bolted together. However, the crew aboard the *JOIDES Resolution* elected to weld everything together even after pre-assembling with the bolts. The total time reflected in the assembly process from welding by only one welder per shift amounted to 15.25 hr out of the total 39.74 hr. It should also be mentioned that full attention was not being devoted to the guide base assembly. The crews were split, in that other activities were being pursued simultaneously. It is felt that if the assembly process was performed from start to finish in a continuous effort that possibly another 6 hr could be saved.

Tank Section Assembly

The actual process of fitting together the four box sections on the moonpool doors could be improved. Some minor difficulty was experienced in positioning the box sections with the air tuggers on hand. However, the main annoyance was the critical alignment required with the 1 in. assembly bolts on the unlevel moonpool doors. While this was not a problem in the fabrication shop, the unlevel moonpool doors did require some additional effort in making up these sections. Larger bolts were recommended so that the alignment would not have to be so exact. It was also felt that the existing 1 in. holes would better serve as alignment holes through which pins could be driven to bring the sections together. Larger bolts (2 in.) were obtained in Pusan, Republic of Korea, before the vessel left port so the second guide base and the remainder of the first would have the benefit of using these larger bolts, if desired.

The area underneath the rig floor and the moonpool area in general were somewhat restrictive due to other equipment positioned in this area. It was originally thought that both bases could be made up in port and stored in the moonpool area. However, as it turned out only two parts of one four-box section were assembled prior to sailing. This could partly be blamed on the fact that work remaining from the previous leg (Leg 131) was scheduled to be done prior to the first DCS site. Since a cone reentry was required for this location, it couldn't be precluded that the VIT frame might not be required. Therefore, the mini-HRB had to be kept in halves since the moonpool doors may have needed to be opened.

Once the halves of the guide base were ready for assembly, they were positioned onto I-beams which spanned the moonpool doors. Slings were then lowered through the rotary table and the box sections lifted while the beams were skidded underneath. As the tank sections came together, alignment pins were driven into the respective slots. The 1 in. bolts did not present any problems this time for mating the two sections as in the initial case since the I-beams provided a more level surface from which to work. After tightening all the bolts between tank sections, the boxes were welded. This was not called out for in the design, however, the rig crew preferred this method of attachment in preference to the bolts.

Two of the four HRB legs were pulled off the corners and out of their respective tracks as they were unbolted to be lowered. The legs were originally bolted on for shipping and were to be unbolted and dropped into place before being permanently attached

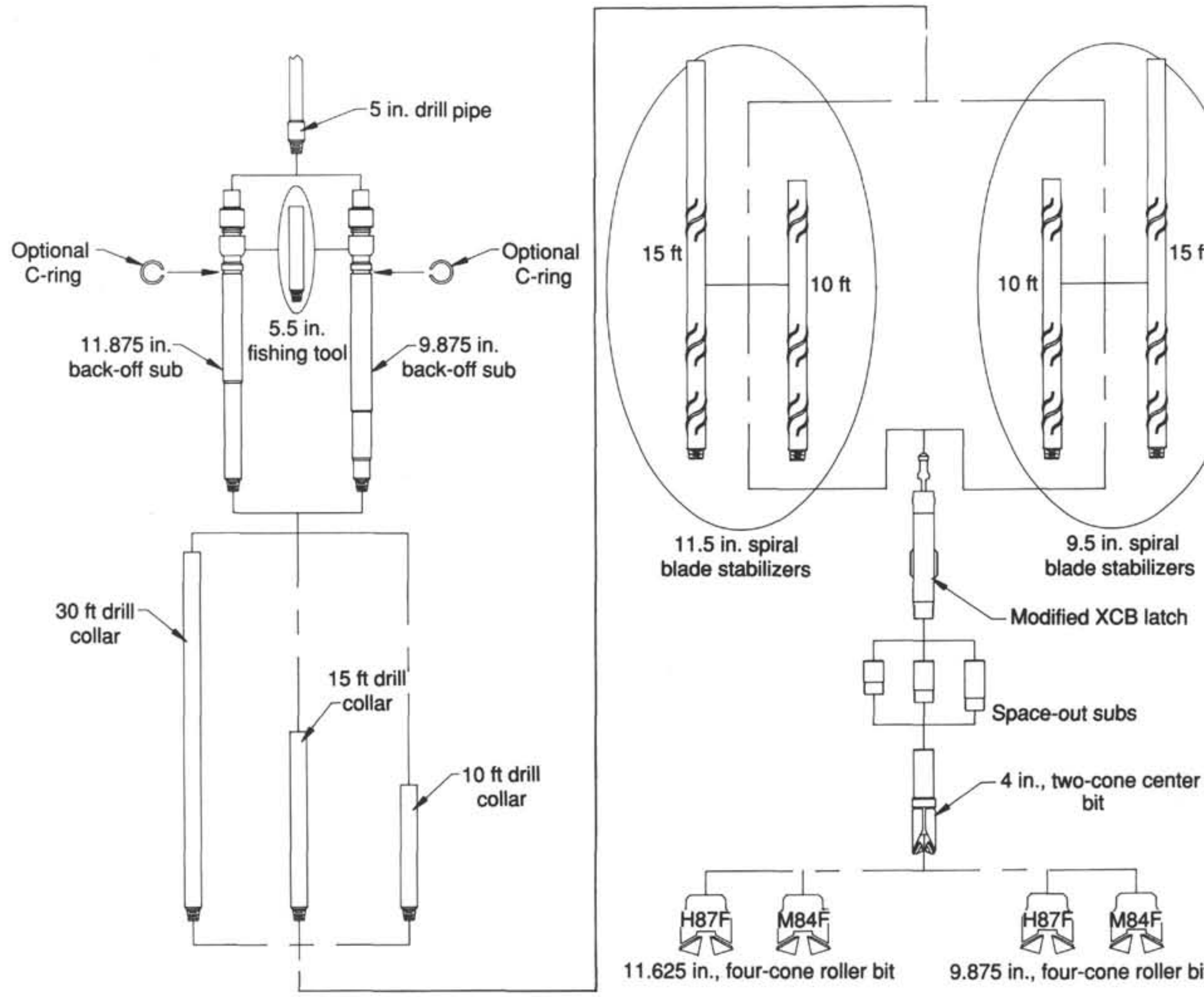


Figure 3. Comparisons of BHA deployment systems.

to the tank sections. The problem probably would not have occurred if the legs had been unbolted before raising the HRB. However, the reverse occurred. The legs were slightly pulled away from the corners when they were being lowered, thus resulting in the legs jumping out of the tracks. Even though the legs were adequate to support the distributed loads, the tracks should be redesigned so that there would be no way they could foul while being lowered. This should be a simple matter of incorporating wider-angle sections into the tracks so that a larger overlap is achieved.

Reentry Cone Assembly

A standard reentry cone was used on the mini-HRB. There were no problems during its assembly with the template normally used on board the *JOIDES Resolution* for this operation. However, the cone had to be inverted for the syntactic foam panels to be installed. This operation is illustrated in Figure 6. While this was not a major problem, the tightness and constraints of the moonpool area did make the process inconvenient. The triangular foam panels were designed so that they would fit into a small lip at the top of the cone panels and then be laid back onto the cone panels. Attachment of the eight panels was made with three sets of steel straps. These attachment straps or brackets used common bolts and nuts to hold the cone funnel together. While this required three set of bolts to be removed, this was not considered a hindrance when using an impact wrench. The straps could have just as easily been welded on but would probably have taken slightly longer. While the assembly went quite smoothly, the installation technique of inverting the cone was an extra step that the crew was not familiar with. Another improvement that can be made is in the number of lift points on the floatation panels themselves. A single through-hole was incorporated into each panel as a lift point. The addition of some screw-in-type lifting eyes attached for handling and then removed would greatly have assisted the crew in initially picking the panels out of the shipping crates.

A casing hanger adapter (Fig. 7) was used to attach the reentry cone to the casing hanger. This device was installed onto the base of the reentry cone. The assembly called for the cone to be inverted so that this adapter ring could be lifted on before being bolted. However the crew found it more convenient to set the cone on top of it. Two bolts per cone panel were used to hold the adapter onto the reentry cone.

Casing Hanger Attachment

The casing hanger was a modified version of ODP's standard 16 in. casing hanger. The upper portion was identical with the normal jay-slot for typical running operations. However, before

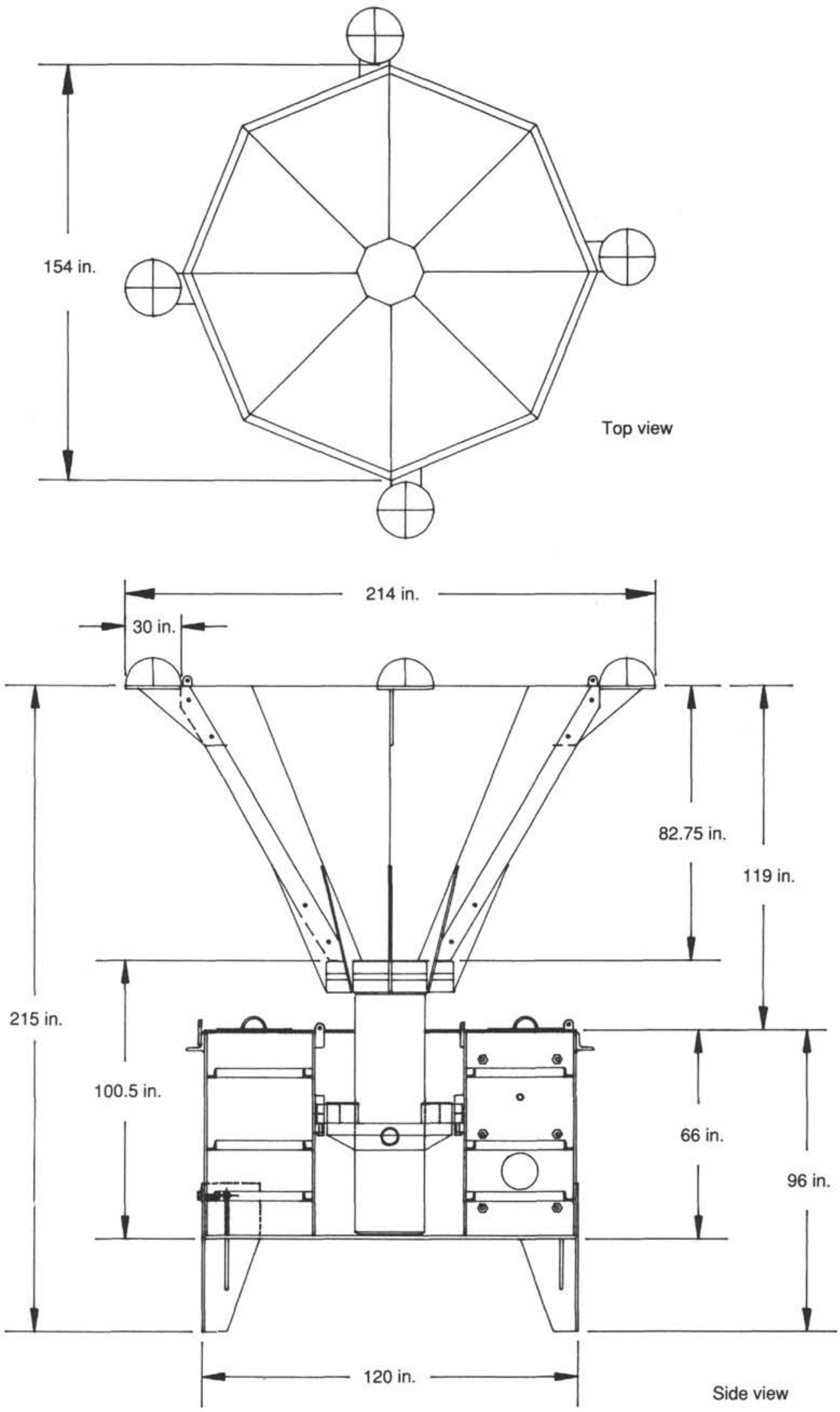


Figure 4. Mini-HRB space-out schematic.

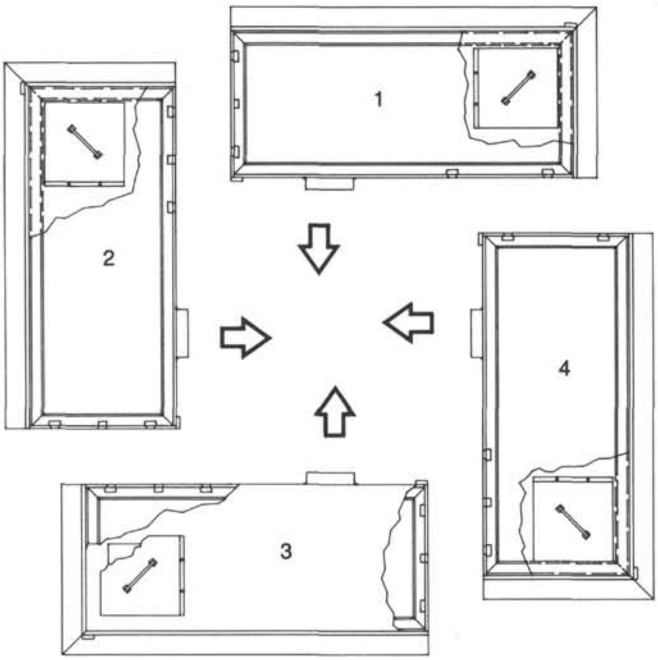


Figure 5. HRB tank section assembly.

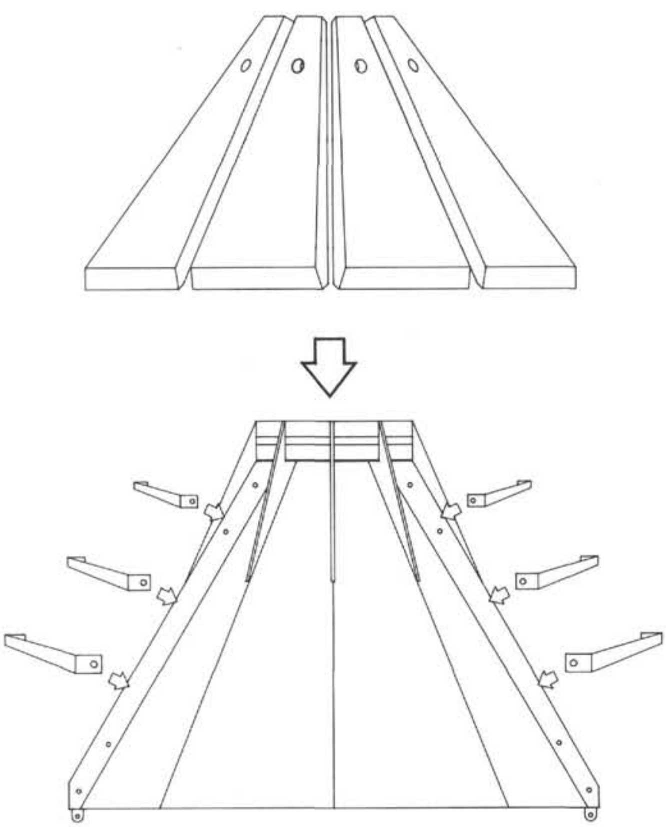


Figure 6. Installation of syntactic foam panels onto inverted reentry cone.

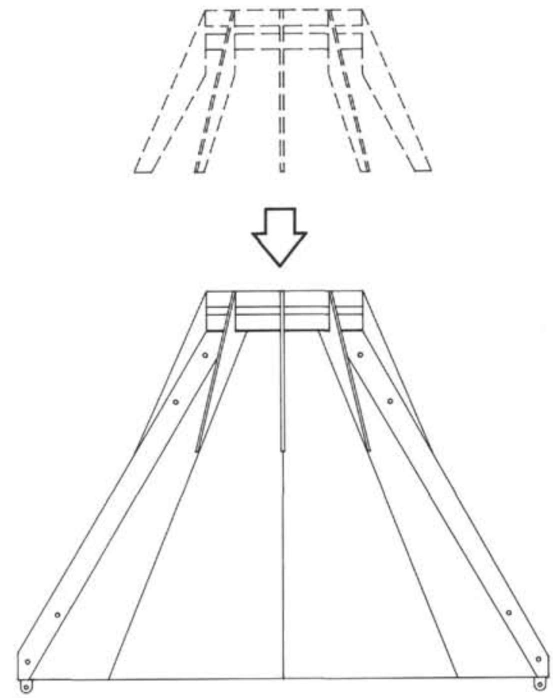


Figure 7. Installation of cone attachment gusset.

being deployed it was discovered that the jay-slots were manufactured backward. While this didn't present any installation problems, it did limit how roughly the double jay-running tool could be handled. This has been a common occurrence on a number of the last few casing hangers purchased. Upon reviewing the drawing, it is understandable how this fabrication mistake could have been made.

All the modifications were made to the lower portion of the casing hanger. These modifications included:

1. Introduction of exit ports for the cuttings,
2. Shearable landing seat assembly,
3. Thicker body diameter,
4. Reduced length,
5. Keyways to prevent the landing seat from rotating during back-off operations, and
6. External trunnions for attachment of the gimbaled assembly.

A schematic of the modified hanger is shown in Figure 8.

Due to its size and limited space on board for handling the hanger, it was shipped with the gimbal pre-assembled. This allowed it to be directly lowered into the mini-HRB in the moonpool area after installing the landing seat on the rig floor. The hanger with gimbal attached fit exactly as designed into the HRB sections. A schematic of this operation is illustrated in Figure 9. Again because of the space restrictions in the moonpool area, the rigging of the hardware proved to be the key in efficient and safe installation of the hanger.

Mini-HRB Assembly

The mini-HRB was basically assembled from three major component groups. These included:

1. The four tank sections,
2. The casing hanger/gimbal assembly, and
3. The reentry cone and flotation panels.

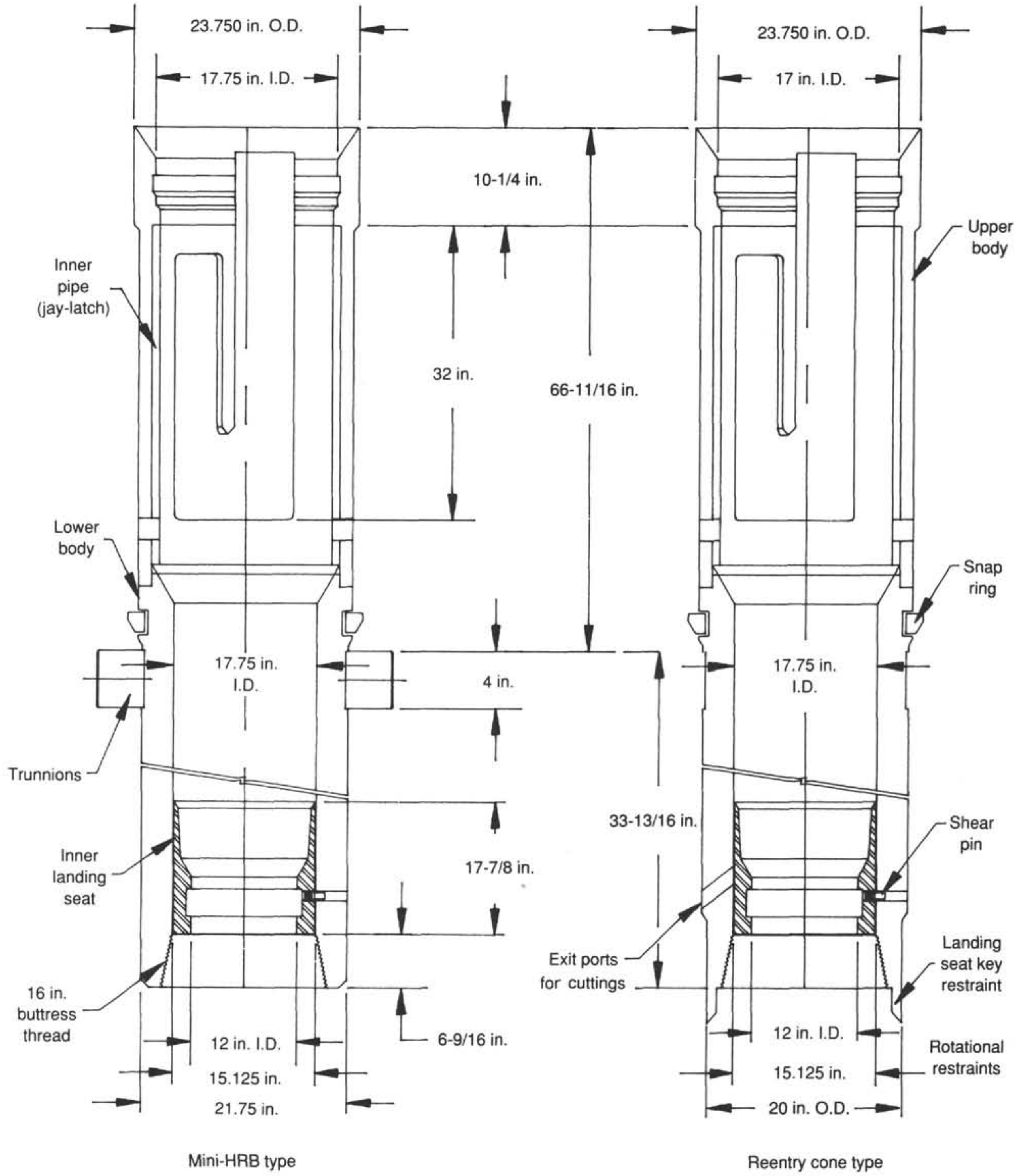


Figure 8. Modified casing hanger.

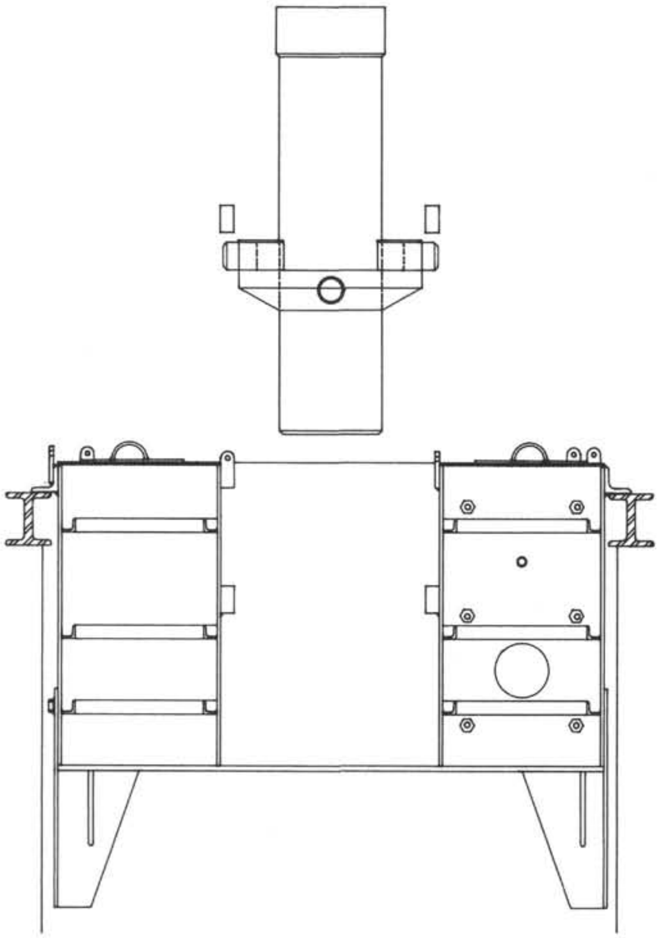


Figure 9. Casing hanger installation.

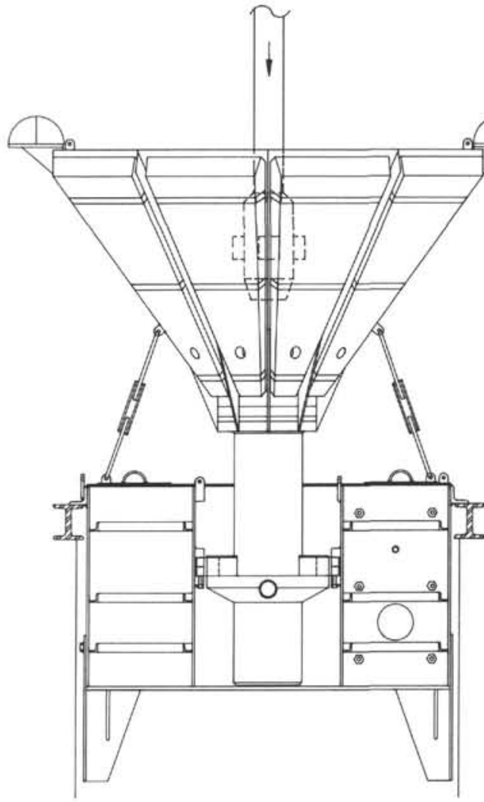


Figure 11. Running tool entering HRB. Lowering jay running tool into HRB and jay-in.

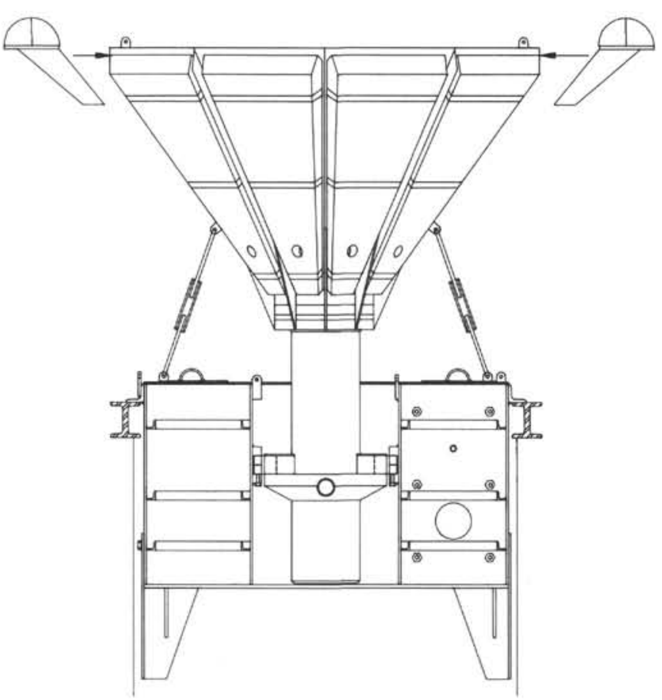


Figure 10. Temporary HRB setup prior to running; welding cone to casing hanger and installation of sonar reflectors.

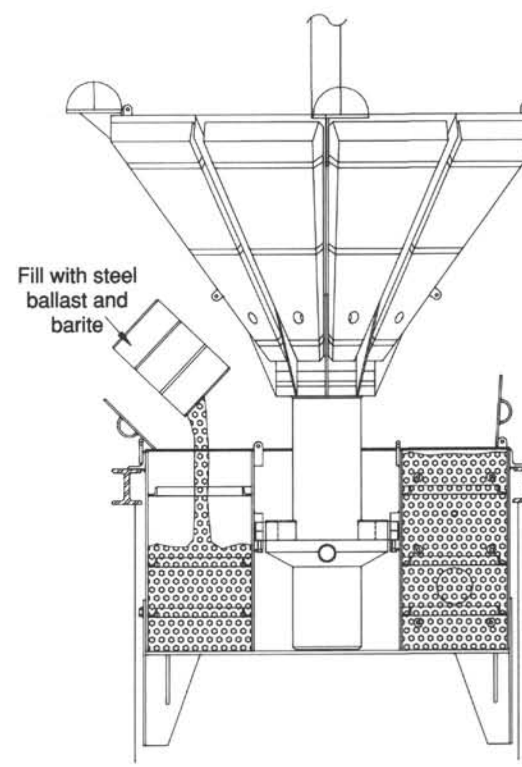


Figure 12. Ballasting assembled mini-HRB for deployment.

The tank sections and reentry cone/floatation panels were assembled at dock in Pusan for the Bonin location. The remainder of the assembly process was performed on the moonpool doors. The tank sections were first centered over the lower guide horn before adding the casing hanger. The hanger was added next and bolted into place. The gimbal blocks themselves were welded as an added measure of safety against the bolts backing off due to vibrations that might be experienced from currents during the lowering process (Fig. 9). The entire base was then picked up with the running tool so that the legs could be dropped into position. With this task completed the moonpool doors were opened and the HRB was lowered onto its holding brackets and set down on I-beams which spanned the opened doors. This operation was necessary so that there would be enough height clearance for the cone to be attached. The cone was then brought over and the hanger tilted in line with the lower section of the cone and attachment ring. The cone was then slowly lowered onto the hanger and brought into the vertical position. Temporary turnbuckles were then attached to hold the cone rigidly to the base while the attachment gusset was welded onto the casing hanger (Fig. 10). With the cone attached, the HRB was held with the running tool (Fig. 11) while the final task of ballasting was performed before deploying the mini-HRB. Discussions of the ballasting operations and deployment of the mini-HRB are presented in the following sections of this report.

Ballasting Operations

The ballasting operations of the mini-HRB was originally thought to be an area where a lot of problems could occur. However, this proved to be one of the more efficient and timely operations of the whole assembly process. The original design of the tanks called for steel or lead shot to be used as the ballast material. Procurement of this material would have allowed the shot to be either rained or pumped into the tanks with minimal handling required (Fig. 12). However the only product that could be located in Korea were steel ingots about the size of a common house brick. Due to the sheer volume (120 55-gal drums) and weight (90 metric tons) the drums could not all be placed around the moonpool area.

Special mechanical barrel handlers were used to move the barrels into position while a team of workers loaded the tank sections one brick at a time. While this was indeed a labor-intensive exercise, the hand loading progressed faster than moving the barrels into the moonpool area. Each tank section required approximately 15 drums. The total time required to load the complete base was around 4 hr. Barite was then used to supplement the ingots by filling voids so the desired weight could be obtained. Packing ratio of the ingots were estimated at around 45%. Upon final weighing after submerging beneath the hull the weight of the HRB was only 2000 lb less than the desired 131,000 lb for the 1800 m water depth in question. The recommended submerged weight of the guide base for varying water depths is presented in Figure 13.

Sonar Reflectors

Sonar reflectors and the associated mounting brackets were initially installed on the cone made up for the Bonin location. However, after the first deployment and failure of the cone to upright itself, they were taken off and not used again the entire leg. This was primarily due to the extra weight added and the negative effect they had on the uprighting moment. Also since the MESTECH was inoperable and all reentries required the VIT, the reflectors were also a hindrance by being damaged or hanging up while going through the moonpool doors.

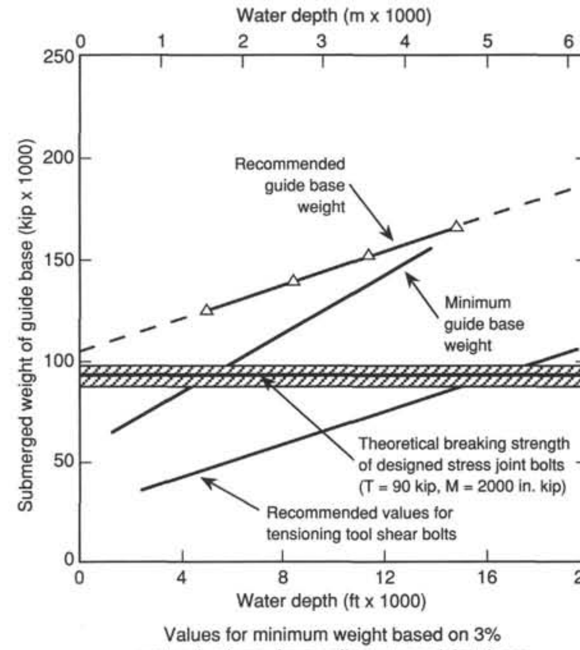


Figure 13. Submerged weight of HRB vs. water depth.

Deployment

Deployment of the HRB's did not present any difficulty in clearing the vessel's hull or while running to the seafloor. Sea conditions throughout the leg were such that response amplitude of the HRB and dynamic stresses of the drill string stayed well within acceptable design limits suggested by studies investigating the vertical motion of a weighted HRB being lowered to the seafloor. It was reported by the drillers that there was no noticeable difference in lowering the HRB after modifications to the cone and the addition of the extra syntactic foam other than the increased weight loss after total submersion. There were numerous reentries and redeployments of the HRB with both the conventional double jay-running tool and the tensioning tool. Neither tool had any trouble latching into and out of the casing hanger even though the jay-slots were cut backward. A complete schematic of the mini-HRB deployment is given in Figure 14.

Reentry

Reentry into the cone normally took only a few minutes once the HRB was located on the seafloor. There were a few problems associated with current at certain times of the day but nothing that created difficulty in actually reentering. An optical bull's-eye was painted on the panels of the cone to aid in reentry. This greatly assisted the dynamic positioning operators as well as the drillers in judging distance and in depth perception. It was noted on several occasions that orientation of the guide base would have been greatly improved with identifying marks on each corner.

Field Performance

Borehole 809C

Borehole 809C was the first location where the HRB was deployed. The procedure was without incident, and the HRB was placed on what was thought to be a relatively flat seafloor. Immediately after unlatching from the running tool, the cone laid over onto one side. This either indicated that the seafloor slope was greater than the 20° design slope or that the buoyancy of the foam panels was not enough to upright the cone. Further observation with the vibration-isolated televiewer (VIT) indicated that the foam supposed to right the cone was not sufficient and that it indeed was laying on its side. Inclination of the cone was recorded as 27° since it was completely into the corner of the gimbal. Seafloor slope was later recorded at between 7° and 12°, thus making the hanger's effective angle from vertical on the order of 34°–39°.

Several reentries were made with the cone in this position. This was accomplished by placing the bit into the throat and "walking" the drill pipe around by offsetting the vessel. The drill pipe would then slide further into the throat of the cone and thus upright the whole assembly. While this procedure was not ideal, it did allow operations to continue. This reentry technique worked for a while, but it was not long before the cone was damaged by this procedure. The repeated loadings of weight from the bit/BHA onto the cone panels resulted in generating bending moments greater than the attachment gusset could withstand. This caused progressive shearing of the bolts which attached the cone panels to the attachment gusset (Fig. 7). Two gussets initially sheared away from the panels resulting in a hole between the cone and casing hanger. Further reentry was deemed impossible until the cone could be pushed further, creating a larger open hole or completely breaking off the cone. It was decided to use the drill string by attempting to set it down on the cone or to drag it across the cone panels to further dislodge it from the casing hanger. This operation proved successful, clearing the cone away from the casing hanger completely. The attachment ring with the gussets remained on the casing hanger after all the cone bolts had sheared off. Attempts were made to reenter the casing hanger and proceed with the program, but strong currents prevented this operation from being easy.

The operation of reentering the casing hanger without the reentery cone involved placing an 11-5/8 in. bit into a 23.75 in. diameter hole almost 1800 m away. This operation with the drilling assembly was finally aborted when attempts to upright the hanger, even with a smaller BHA, were unsuccessful. It was then decided to fabricate a fishing tool and retrieve the cone so that the floatation at least could be redeployed on the other mini-HRB. This fishing operation was successful with complete retrieval of the cone and foam panels. Once in the moonpool, it was obvious that the A72 bolts holding the gussets to the cone panel had failed. There were a few bits and pieces of the foam broken from being struck with the bit but other than that, everything was in good shape.

Since the recovery of the cone went so well with the flexible fishing assembly used, it was decided to try recovering the mini-HRB itself with a similar type of flexible BHA but with the jay-tool attached. This operation also proved successful with attachment to the guide base taking less than an hour. Upon recovery in the moonpool, the HRB was in good shape with only the gussets bent. These were all cut off the ring support and new gussets fabricated. The new gussets were made from 3/8 in. metal plate instead of the 1/2 in. plate originally used. This was primarily intended as a weight-reduction measure.

Eight additional panels of floatation material were then attached to the HRB. These panels were originally dedicated for the MIT Guyot site and were not rated for the water depth at Bonin. However, by attaching them all (total of 16 panels), enough floatation could then be realized for a positive uprighting moment. It was felt that the sonar reflectors were not needed since the VIT was being used for all reentries. Therefore, the sonar reflectors were removed to rid the cone of unnecessary weight. Original calculations for the amount of foam required did not take into account the sonar reflectors being attached or the correct position of the gimbal. Nothing could be done about the position of the gimbal onboard the *JOIDES Resolution* due to limited machining capabilities. However, additional weight was cut off the cone panels to produce the same effect. Roughly 22% of the metal was removed from the top of the cone panels. The 22% represents slightly over 850 lb removed from the cone. The 3/8 in. sheets were 3 × 2.5 ft. and were as close to the top of the cone as structurally feasible.

New tilt indicators were fabricated and attached to all sides of the mini-HRB. These were similar to the first version deployed but with longer pendulums and restraints so that they would not fall away from the HRB. Though crude, they would allow viewing at angles up to 20° in increments of 5°. In addition, a Datasonics electronic positioning beacon was converted into a tilt beacon. Even though it would not give qualitative angles, it did send back a signal if the base was either over or under 20°. The time required to refit and repair the cone was 27.25 hr. This can be broken down in the following time categories:

Description	Time (hr)
Attach extra floatation panels/repair cone	11.75
Repair hanger for reattachment of cone	1.25
Spread cone around drill pipe	2.25
Weld out gussets	7.00
Remove plate from cone	5.00
Total	27.25

Borehole 809D

With repairs completed on the cone and the mini-HRB, the cone was rerun to the seafloor and placed in a location near where Hole 809C was spudded. The tilt beacon worked as designed and indicated that the seafloor slope was less than 20°. Observation of the running tool before unlatching appeared that it was free to float up and down in the hanger throat and not in any bind. With this as a positive indication that the cone was positioned upright, the running tool was released. The cone did not tilt upon removal of the running tool from the throat of the casing hanger. The vessel was then offset to see if the tilt indicators could be seen and what their readings might indicate. In one plane the angle appeared very near to zero slope, whereas in the other direction inclination was recorded around 15°. Further viewing of the cone with the VIT and from seafloor inclinations led to the conclusion that the cone was upright and working as originally designed. As a final check, the cone was again reentered to see if it could be determined if it was indeed upright. This test also proved successful with the running tool barely touching the walls as it made its way down the vertical casing hanger. With this test completed, the HRB was left at this location for further deployment with the DCS drilling assembly.

Borehole 809E

Failure of the tensioning tool on Hole 809D resulted in a jay-lug being left in the throat of the drilled-in BHA. Therefore, the guide base was required to be moved since fishing the lug was not possible. The guide base was not latched to the drill-in BHA, thus allowing it to be stripped over and repositioned. It was reentered and lifted off the seafloor in seas that caused heave of 2–2.5 m. It was moved approximately 10 m away from Hole 809D. Seafloor slope at this new location (809E) appeared to be less than at the previous location (809D). This operation proved that the mini-HRB could be moved and reused without being brought back to the vessel. It also demonstrated that the HRB could endure the additional shock loading when being repositioned on the seafloor in a heavier sea state.

After partially drilling-in the BHA on Hole 809E, it was feared that the bit may have come apart due to the hours on the bit and

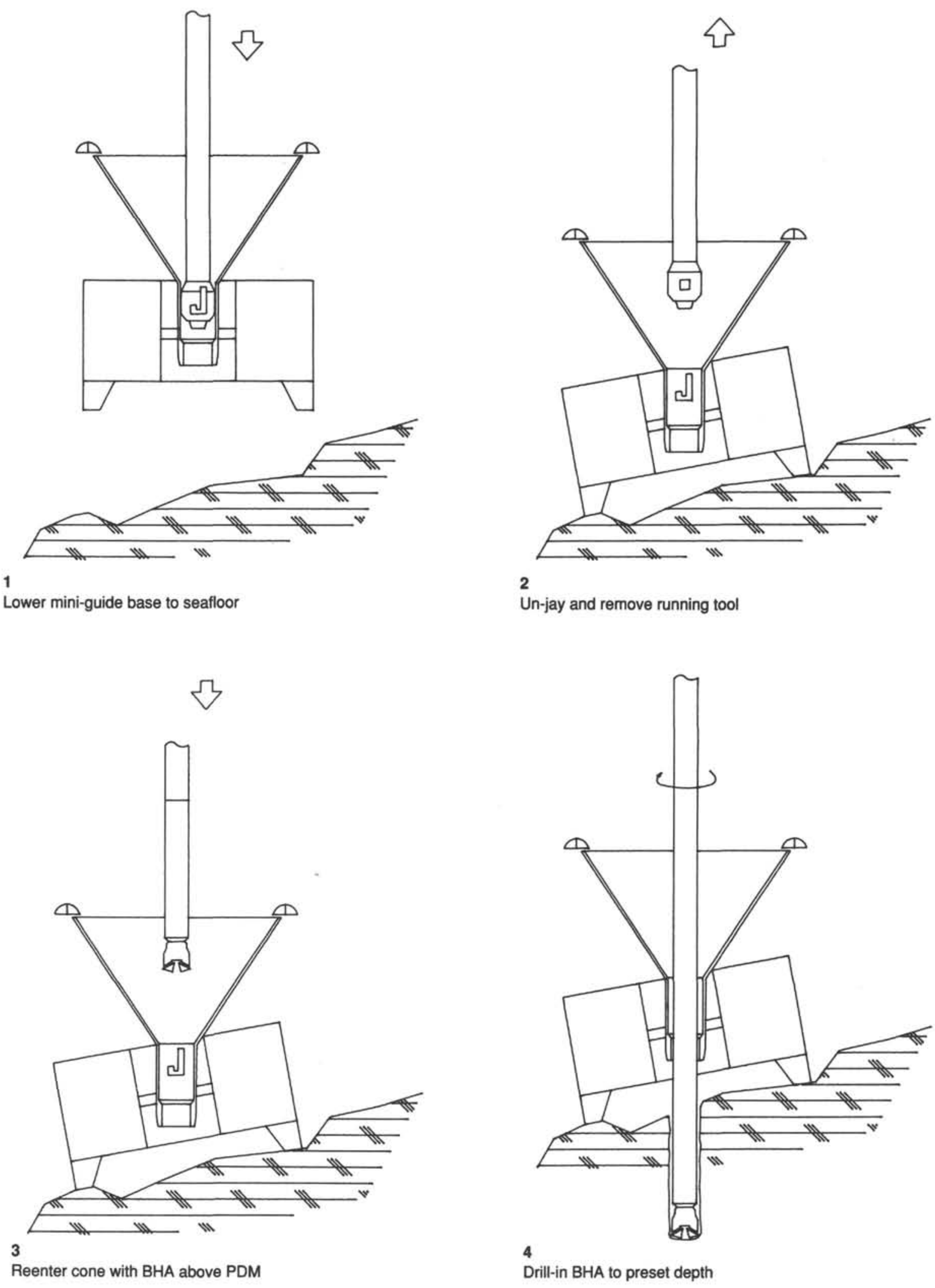
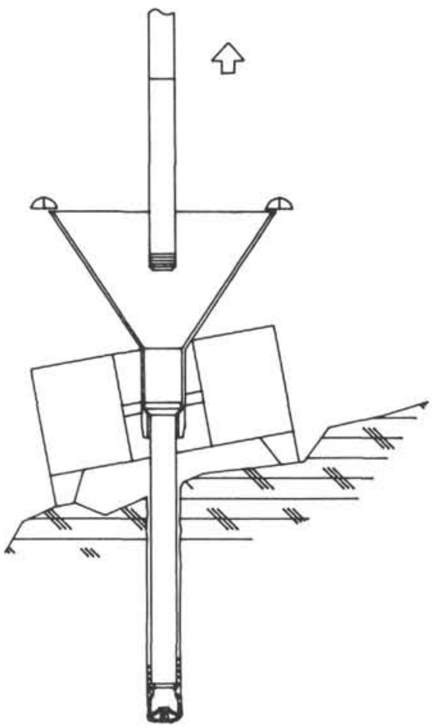
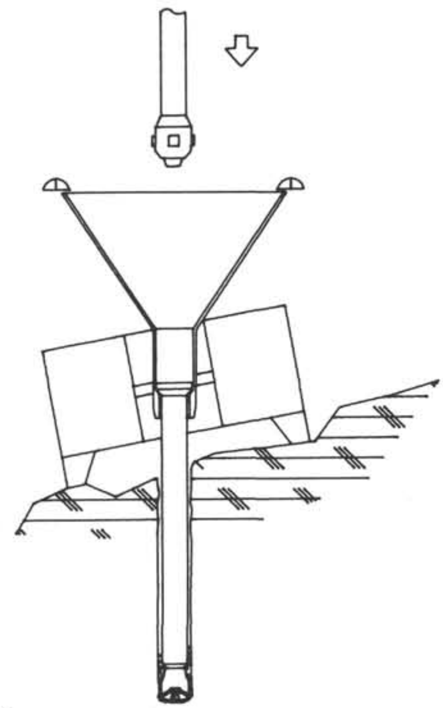


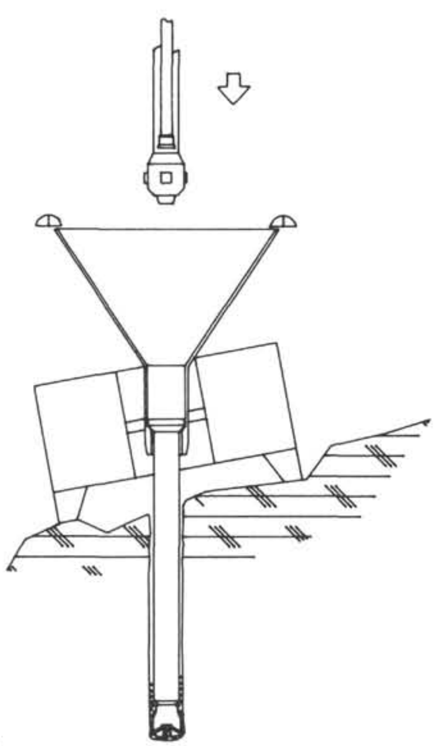
Figure 14. Deployment sequence for DCS with mini-HRB.



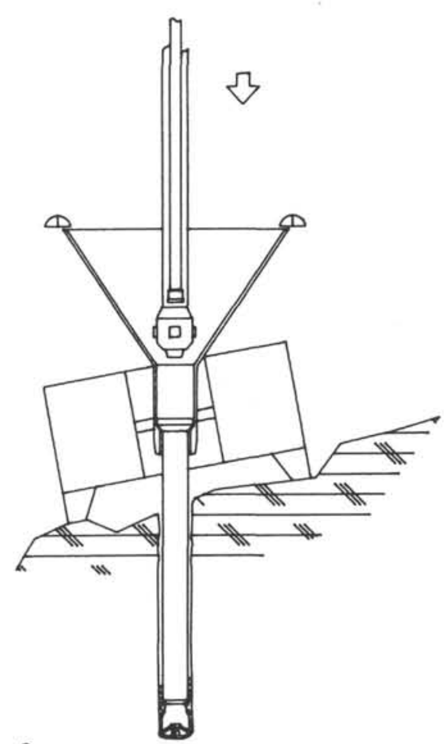
5
Spot with cement and back off BHA below PDM and retrieve string



6
Lower mechanical tensioning device above reentry casing

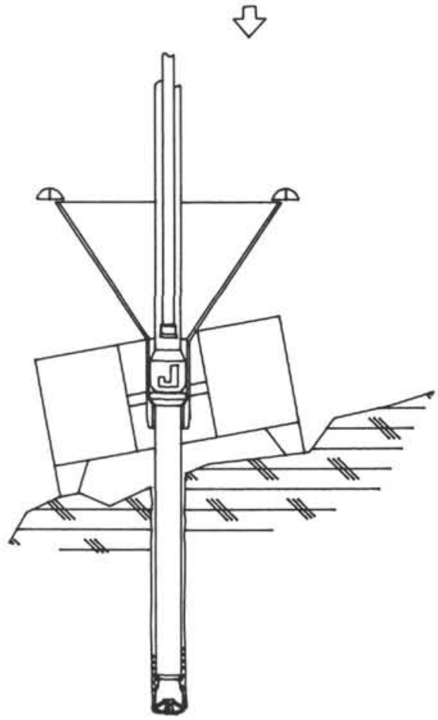


7
Trip in hydril tubing to just above mechanical tensioning device

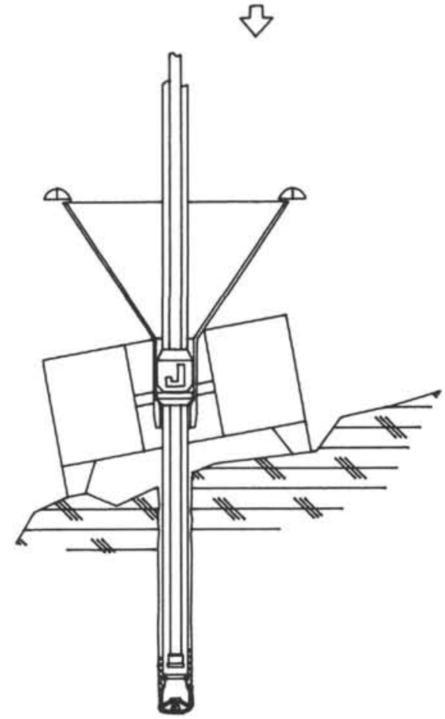


8
Reenter HRB and run in with mechanical tensioning device

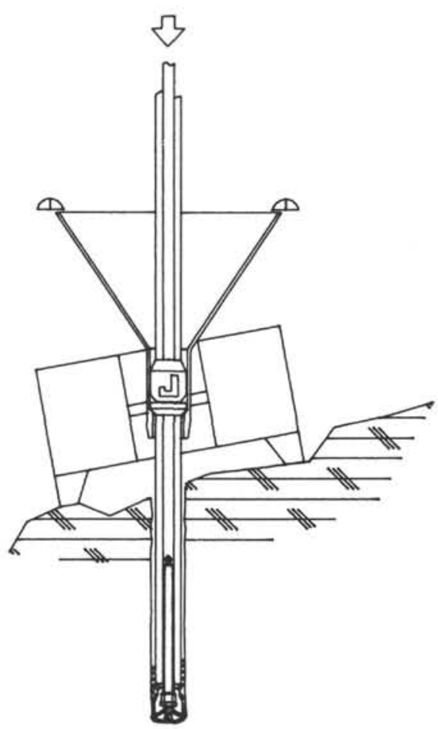
Figure 14 (continued).



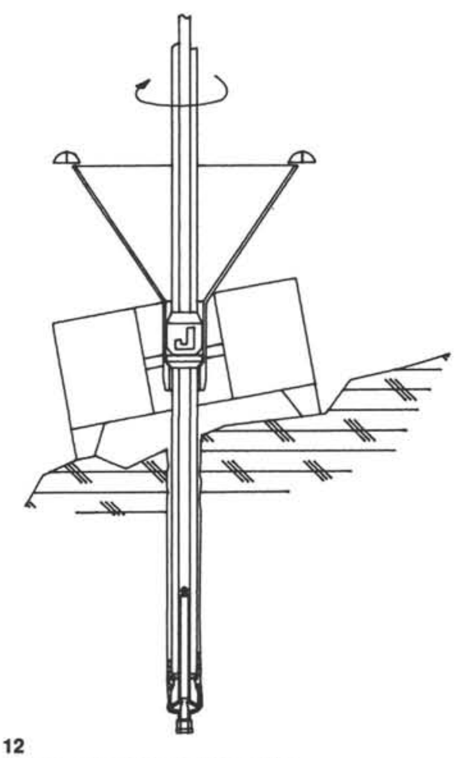
9
Latch in and "tension up" mini-HRB



10
Lower hydril tubing to just above BHA bit



11
Pump down inner barrel and latch in



12
Activate secondary compensator and begin drilling with DCS string

Figure 14 (continued).

the difficulty in getting it to the termination depth. Therefore, in an attempt to avoid potential problems later, the BHA was pulled. Upon recovery it was learned that the BHA assembly was rubbing against the side of the hanger creating most of the drilling problems. This was an indication that the base was at a greater angle than the gimbal of the cone could compensate for. This additional inclination may have occurred due to base shifting during drilling, wash out, or penetration of one or more of the legs from vibration. Therefore, it was necessary to move the HRB a third time.

This became evident from looking at both tilt devices mounted on the sides of the HRB with the VIT. It was clear that material had fractured or washed out on at least one corner of the HRB.

Borehole 809F

Seafloor topography was proved to be quite irregular at the Bonin location, thus demonstrating the importance of selecting the most level location possible. This reduces the chances of HRB movement and/or irregular washout beneath the base. From all indications, the guide base at this fourth location was within 10° of level in one plane of inclination and less than 4°–5° in the other. This was further demonstrated in that the drill-in BHA went in without any drilling problems and in less than 30 min for the 6 m of penetration.

Recommended Design Modifications And Improvements

For a prototype concept, the mini-HRB worked reasonably well. Though there were some problems initially with uprighting the cone on the first deployment, it soon proved to be a viable hard rock reentry system. Several things were learned on the first deployment that enabled its further performance on the leg to be more than satisfactory. Also, because of the failures experienced with the floatation, quite a lot of other information was gathered about its strengths as well as its weaknesses.

The most obvious shortcoming was that not enough floatation material was attached as a means to upright the cone. The original computations made to determine the amount of floatation required had been made with the gimbal at a higher position. Thus, what was purchased was not based on the as-built or final design but on an earlier version before these changes had been made. Even though the problem was corrected in the field by adding additional foam, the solution is not just to add more syntactic foam for future versions. Syntactic foam rated for deep-water applications is rather expensive. Therefore, amounts used must be kept to a minimum or eliminated altogether. Large overages of foam for an added safety factor are not practical.

There are several other ways to reduce the amount of foam required or eliminate it altogether. However, it all revolves around reducing the overturning moment that the cone and casing hanger produce. While the prototype model attempted to use existing ODP hardware in order to keep design and fabrication costs down, it is obvious that some changes should be instituted. This could be done by initiating several or all of the following design changes. These include:

1. A smaller size cone,
2. Reduced weight of cone,
3. Counterweight on the casing hanger, and
4. Moving the trunnions higher on the casing hanger to provide a more natural counterbalance.

One of the other problems was the failure of the bolts in the cone adapter gussets. While the cone was not designed for the type of freak loading condition it encountered, the problem can be easily remedied by welding the gusset in place or increasing the number of bolts themselves. Bolting is, however, the preferred manner in which to make the attachment. Use of this technique does have its merits in that the cone can simply be removed in the moonpool instead of having to be cut off if the base should be used for more than one location. The head space in the moonpool area does not permit the fully assembled mini-HRB with the existing cone to be stored without setting it down between the moonpool doors. Transit between locations is not permissible with the doors open, therefore, disassembly of the cone to HRB is required.

There has also been considerable discussion concerning whether to use a three-legged or four-legged base. It was felt that the base moved or slid on several occasions due to vibrations caused from drilling. Three-legged structures tend to be more stable than any other leg design. Fabrication and transportation must also be considered when building a base with more or less than four sides. The four-sided base may be much easier to assemble than a three-sided one mainly due to its symmetrical nature. Limited working space and equipment in the moonpool area also presents a host of other problems. The idea of possibly deploying three legs on a six-sided box has been considered and should be studied further.

Leg design has also been commented on as another possible area where some improvement could be made. Though no structural damage occurred in four deployments, some general strengthening of the legs is recommended. This is to ensure that landing an HRB with a large surface-induced heave would not overstress one of the legs. Puncture into the seafloor or collapse of the leg or legs altogether could result in lost time due to a round trip for repair. Since different seafloor topography may be encountered and if the idea of a reusable HRB is adopted, it may be prudent to have a couple of different types of legs/footings that can be attached. The prototype HRB had legs which, when unbolted, dropped into position. These could be replaced with interchangeable legs that weld on or that have different footing imprints. Thus, the idea of custom-fitting the type of leg for each location depending upon seafloor conditions could be adopted.

Mentioned above, but under a different heading, the idea of reducing the cone size not only presents a feasible option for weight reduction but also would allow a completely assembled mini-HRB to be stored and transported to different sites. This gives rise to the concept of a reusable guide base for locations where returning at a later date are not anticipated. Several other minor modifications mainly pertaining to the assembly of the mini-HRB were discussed in the earlier section and will not be repeated here.

MODIFIED REENTRY CONE

General Description

The standard ODP reentry cone was modified in order to be adapted for use with the DCS for locations where soft surficial sediments overlie harder, more competent formations. Several significant changes were made that allowed the reentry cone to be used. These included:

1. Introduction of discharge ports through the walls of the transition section,
2. Adding anti-rotation receptacles to prevent the casing hanger from moving during back-off operations,
3. Introduction of the shear-out type landing seat, and
4. Adding an exterior collector manifold with discharge pipes for cuttings removal.

The reentry cone derives its seafloor support from both the mud skirts at the surface and from 16 in. casing washed to depth. The large mud skirts provide extra surface area for distributing the weight of the cone. These skirts typically are necessary so that the available bearing capacity of the seafloor sediments are not exceeded. However, the available capacity is site- and material-dependent. Should general failure occur, the reentry cone would sink until enough capacity could be developed to support it.

The major difference between the two types of seafloor templates (mini-HRB and reentry cone) is in the way they develop reaction against the applied overpull when in tension. The mini-HRB is ballasted at the surface with dead weight, whereas the reentry cone relies primarily on skin friction developed between the 16 in. casing washed into the seafloor in order to produce the same amount of reaction.

A common component of the both the mini-HRB and the reentry cone is a 16 in. casing hanger. The casing hanger is snapped into the transition section of the reentry cone after a predetermined length of casing has been added. The entire weight of the reentry cone, casing hanger, and casing is supported by the snap ring while being lowered to the seafloor with the running tool.

Another shared component of the two types of seafloor templates is the cone funnel and sonar reflectors/mounting brackets. In the case for the reentry cone, the funnel is bolted onto the base/mud skirts with long gusset-type plates. Since all the components of the cone are submerged below the mud-line except the cone funnel, cuttings removal is accomplished through the discharge manifold and pipes attached along the transition section. A schematic of the reentry cone is presented in Figure 15.

Skin Friction Requirements

The modified reentry cone was originally designed for providing a reentry structure on soft, unconsolidated sediments. The casing was used primarily to provide a vehicle for sampling deeper depths where hole stability threatened borehole advancement. The secondary requirement of the casing was to provide additional support to complement the mud skirts so that the reentry cone would not sink beneath the surface of the seafloor on extremely soft bottoms. The axial compressive capacity of the casing is made up of two components: (1) end bearing and (2) skin friction. However, in the case for the modified version used for the DCS deployment, the reentry cone was no longer in compression on the seafloor but was being pulled against in tension. Therefore, without the contribution of the end bearing component altogether and coupled with reduced skin friction of the casing/BHA in tension, some knowledge of the physical properties of the material was required so that the depth of penetration could be better estimated for an adequate safety factor.

Some preliminary estimates were made using a conservative limiting skin friction value of 200 psf for the expected calcareous oozes known to exist in the general area and confirmed from seismic records on earlier legs. These estimates are presented in Figure 16 for different amounts of overpull vs. depth of penetration for various safety factors against pull-out. It should be pointed out that the entire tensile reaction is made up not only of the skin friction developed along the exterior casing shaft but also the weight of the reentry cone, BHA, casing hanger, and casing itself. Therefore, the deeper the casing is set, the more skin friction is developed along with added reaction weight of the casing and washed-in BHA string. Weight of the reentry cone, casing assembly, and BHA alone are more than the required overpull for tension at the Shatsky Rise location. Therefore, the skin friction on the casing/BHA serves only as additional reaction force and provides the factor of safety against pull-out. An added benefit is that it also serves as a lateral restraint should a drive-off situation occur. A suggested reaction of 140,000 lb was needed for the Shatsky Rise location to provide a safety factor of 3.0.

A wash-in test along with some limited Advanced Piston Corer (APC) tests was performed prior to deploying the reentry cone. Vane shear tests confirmed that *in-situ* strength exceeded earlier estimates and that not as much casing as earlier thought would be required. Strengths reported on the material were fairly consistent at 50 kPa (1,000 psf) to 127.1 mbsf (417 ft below seafloor). The wash test with the drill pipe revealed that 60 mbsf was about all that would be practical to expect physically for the casing to be washed-in. With a limited strength profile and data from the wash test, it was decided to try to install the casing to approximately 50 mbsf. This not only would give an adequate reaction to pull against but would ensure that more competent material would be present in which to began coring with the DCS.

Assembly

The reentry cone is composed basically of six large components which required assembly prior to deployment. These consisted of the following items:

1. Cone funnel,
2. Base,
3. Four discharge tubes,
4. Extension beams/mud skirts,
5. Modified casing hanger/landing seat, and
6. 16 in. casing.

The reentry cone base was first brought into the moonpool area and lowered between the opened moonpool doors so that the base sat on top of the doors. The extension beams and mud skirts were added before attaching the cone funnel. The cone funnel was assembled as previously using the template fabricated for this purpose. The cone was then bolted to the base with long gussets and welded as an added measure against possible failure by the bolts shearing. The next step was to add the discharge tubes to the base and cone funnel. With these steps completed in the moonpool area, the rotary bushing was removed on the rig floor so the 16 in. casing could be run through the reentry cone. The casing hanger had been fitted with the landing seat and external snap ring prior to bringing it onto the rig floor.

The casing hanger was attached to the final section of 16 in. casing before lowering through the rig floor with the running tool. The make-up/attachment of the casing went well with the complete process taking less than 2.5 hr. All the casing joints including the hanger were tightened to 7500 ft-lb of torque.

The casing hanger was positioned as it was lowered through the rig floor so that it would latch into the proper rotational restraints situated in the bottom of the conductor base. These restraints were provided to eliminate the possibility of the casing hanger itself rotating when the back-off nut was deployed on the landing seat. The snap ring situated on the hanger mid-body provided a means to lock the casing hanger into the conductor pipe of the reentry cone.

There was some difficulty in aligning the hanger's rotational restraints with the mating receptacle in the bottom of the reentry cone conductor pipe. The problem was later discovered to be that the cone itself was not over the well center thus, pinching the hanger and not allowing it to drop in all the way. While attempting to correct this misalignment in the moonpool, the casing which was made up and welded to the hanger somehow separated from the hanger and fell to the seafloor. Upon pulling the hanger back to the rig floor, it was observed that the threads were not damaged and that they had been made up over 4 in. The only explanation offered as to why the casing was lost could be that the box connection was slightly larger than the casing itself and that not as many threads were engaged as thought. Thus, the weight of the casing alone when jolted by a sudden shift of the base while being

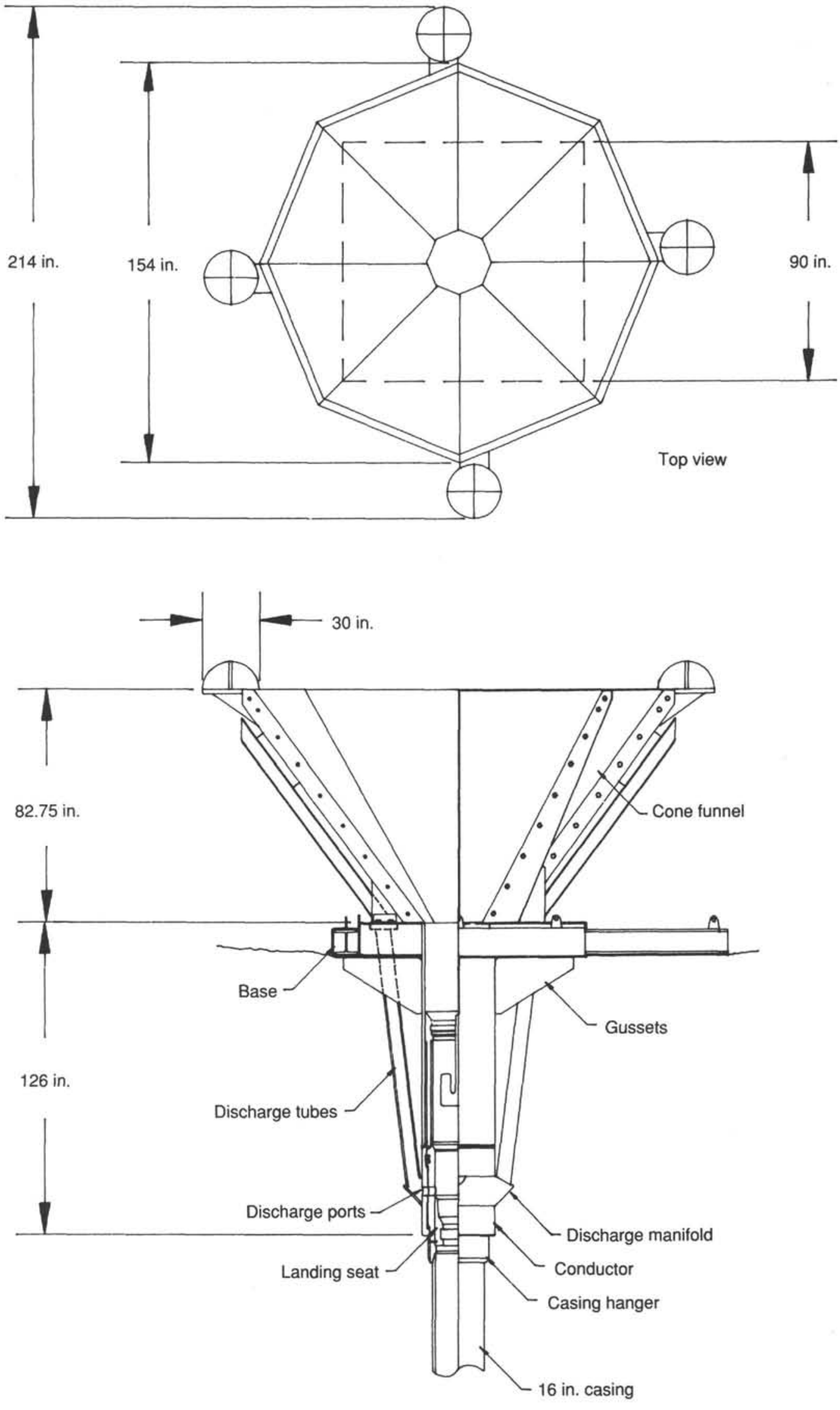


Figure 15. Reentry cone schematic.

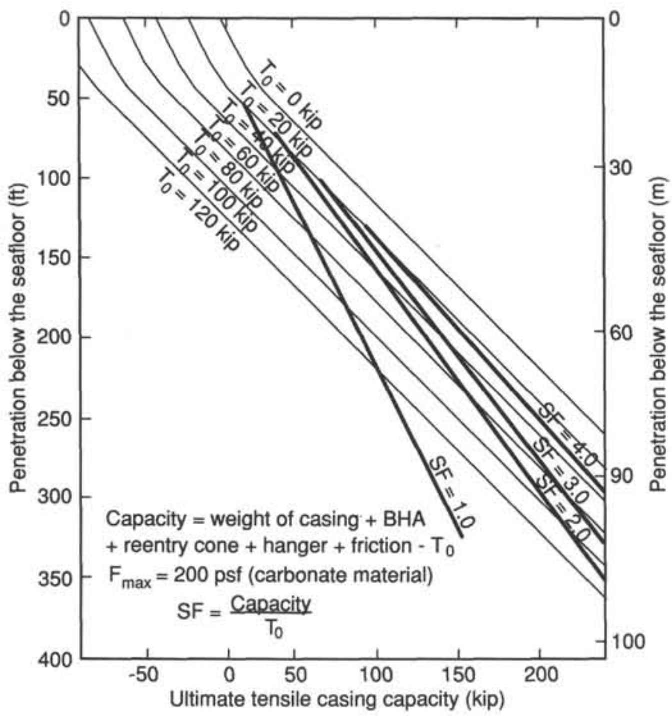


Figure 16. Ultimate tensile capacity for 16 in. casing vs. penetration below seafloor.

aligned in the moonpool may have been enough to allow the casing to fall out. Before lowering the hanger back into the conductor pipe to check for obstructions the snap ring and rotational restraints were removed. This was to ensure that these two items were not themselves causing the problem. Upon reentering the conductor, the hanger appeared to be in the proper position. This was confirmed with the snap ring groove being observed through snap ring suppression holes. Upon attempting to remove the hanger so that casing could be reattached it would not come free. Repeated jarring with the compensator and attempts to rotate the hanger were unsuccessful. It appeared that the hanger was wedged in below the snap ring groove. The only plausible explanation was that some possible weld beads attaching the hanger sections together were not ground flush with the hanger body.

The decision was then made to run the reentry cone without casing and not waste any additional time attempting to free the hanger. So not to reduce the amount of dead weight that the casing provided, 14 drums of iron ingots were placed onto the mud skirts and secured. This was over twice the dead weight that the casing provided. However, without the casing, the required skin friction to provide the majority of the factor of safety would have to rely solely on the amount developed from the smaller BHA.

With the reentry cone outfitted with the drums of ingots and the casing hanger welded into the conductor, it was picked up with the running tool and rotated to align it with the moonpool doors. The nose of the running tool was within 0.5 m of the bottom of the conductor so it was felt that no additional washing pipe was required. The complete assembly was then picked up and lowered through the *JOIDES Resolution* moonpool and run to the seafloor.

The majority of the reentry cone assembly (items 1–5) were performed while underway to the Shatsky Rise location. The assembly process was not performed in a continuous manner but rather as a secondary task when the drilling crew was not busy with other rig maintenance projects during the transit. However, even with the problems encountered, only 16.25 hr of actual rig time was fully devoted to deploying the reentry cone. A detailed breakdown of the assembly process is provided below:

Description	Time (hr)
1. Assemble cone/gussets	4.0
2. Install I-beams/mud skirts	1.5
3. Attach cone to base	1.0
4. Attach discharge tubes	1.0
5. Weld out	4.0
6. Skid over well center	0.5
7. Rig up/run 50 m of 16 in. casing	2.5
8. Attempt to snap in casing hanger	2.25
9. Attempt to free hanger	5.5
10. Refit reentry with ingots/secure	3.0
11. Rig up jay-tool/pick up reentry cone	1.5

Deployment

The reentry cone was deployed at the Shatsky Rise location in 2634 m of water. Without operational problems, its deployment requires three round trips of the drill pipe before final placement of the drill-in BHA string is achieved. These trips included:

1. Lowering/washing in the reentry cone,
2. Washing/drilling in the BHA and backing off, and
3. Tensioning the mini-riser.

The idealized deployment scheme/sequence is probably best described with the illustrations presented in Figure 17. Even though the casing was not run and some other problems occurred with its deployment, the other schematics provide a step-by-step approach showing how the reentry cone and borehole were to be established for the DCS.

Two additional pipe trips were actually required in an attempt to unscrew the back-off sub. These trips (9 through 17) normally would not have been required, however, failure of the landing seat's rotational restraints prohibited the back-off nut from unscrewing on the first two deployments. The extra time spent making these trips was 34.5 hr. Total time spent to finally establish the BHA bit on the seafloor was 63 hr. Each step in the deployment sequence along with its description is shown below.

Description	Time (hr)
1. Run reentry cone assembly to the seafloor	5.25
2. Wash-in	0.50
3. Un-jay/recover running string	5.00
4. Make up BHA and PDCM	4.50
5. Run BHA	4.00
6. Locate cone/reenter	0.25
7. Drill down 110 m	2.50
Attempt to back off (landing seat failure)	2.50
8. Recover PDCM and drilling string	4.00
9. Repair landing seat/back-off nut	2.50
10. Run BHA into hole (second time)	3.50
11. Attempt to back off (flushed nut to landing seat)	3.50
12. Recover drill string/lay out T.D.	4.75
13. Break down back-off sub	3.00
14. Run BHA into hole (third time)	3.75
15. Drill down 15 m and back off	0.25
16. Attempt to pull center bit	8.75
17. Recover drill string	4.50

Field Performance

The reentry cone was deployed in 2634 m of water at the Shatsky Rise location. Tension requirements for this water depth with vessel offsets less than 3% were around 45,000 lb for a safety factor of 3.0. However, since operating conditions were favorable and vessel offsets were less than 1%, the amount of overpull that was to be applied was reduced to 35,000 lb. Exactly 48.79 m of casing were originally planned to be set. However, after losing the casing string once it had been made up, it was decided to continue without casing at all. This decision was based on the fact that the casing hanger could not be pulled free of the reentry cone conductor, therefore, no additional casing could be added. This decision and the events which lead up to it are described in the section on the reentry cone assembly.

The above figures were based on backing off drill collars as part of the BHA string inside the casing. However, since casing was not run, the majority of the skin friction would have to be supplied by the BHA set to a depth of 110 mbsf. This was also beneficial in that it allowed the BHA to get close to the first chert interface so as to limit the amount of DCS coring in the chalk before encountering the interbedded material. Also with the BHA drilled to 110 mbsf, it produce approximately 45,000 lb of additional weight that would be left in the casing hanger as reaction against the tensile overpull. The ballasted reentry cone provided 35,000 lb of dead weight. This amount coupled with the 45,000 lb of drill collars was felt sufficient to react against the 35,000 lb of overpull. Therefore, whatever additional skin friction that could be achieved with the drill collars added to the safety factor. It was expected that another 30,000–40,000 lb would be easily achieved from skin friction on the drill collars accumulating over time from the collapse of the formation.

The first two times the back-off sub was deployed it did not separate from the BHA. On the third attempt, the length of drill collars in the BHA was increased another 15 m after the first two deployments resulted in the BHA not latching in. The failure of the landing seat and steps taken to correct the problem are discussed below (see "Shatsky Rise" in "Performance" section, this chapter). This additional length (15 m) was added since it was suspected that a washout zone may have been created by the additional circulation which occurred during the repeated back-off attempts. Total depth of penetration with the addition of the 15 m would place the bit at slightly more than 126 mbsf. It was felt that this precaution should be taken since additional lateral stability of the tubing would be required in attempting to core through the chert expected at approximately 127.1 mbsf.

On the third attempt the BHA separated from the drill string as planned. An attempt to recover the center bit was then made through the back-off sub. This procedure was normally required after reentering the cone with the tension tool and stress joint made up in the string. However, since the PDCM was not used in/on the third deployment of the BHA, a through diameter of 4.125 in. was available. The overshot was run in but encountered an obstruction in the drill collar approximately 33 mbsf. After the overshot/sinker bar assembly was worked, it finally cleared the obstruction and made it all the way to the bottom of the hole. However, it returned to rig floor without the center bit. The body of the overshot was broken on one side immediately in line with a latch finger. This prohibited one of the fingers from latching onto the center bit, rendering the other two useless.

Several additional trips were made with the wireline using different overshot configurations to see if they might pass the obstruction. At this point it was speculated that one of the drill collar connections might have broken off or came unscrewed, thus separating and requiring the sinker bar to bridge a gap in order to pass. It was decided to suspend efforts in retrieving the center bit until the drill string could be retrieved to see if any tell-tale signs were apparent. Upon recovery of the drill string, the landing seat was still attached to the back-off nut. This immediately indicated that the reason for failure was the C-ring did not hold the weight of the drill collars but was pulled on through the bottom of the landing seat and out into the open borehole.

Reconstructing exactly what happened now reveals that this third attempt was doomed to fail. Two modifications in the field, one to the landing seat and the other to the C-ring to correct different problems compounded the problems when both pieces were run together. The I.D. of this particular landing seat had been opened up earlier in the leg for use with the mini-HRB to enlarge the annular clearance between it and the BHA. This had been done, since at the time it was felt that the landing seat may be causing a bind on the BHA with the borehole at a slight angle. Thus when the C-ring engaged the modified seat, it would effectively have 50% less area to make contact with. The effective lip diameter of the C-ring groove was turned down from 1/4 in. to 1/8 in.

The second modification was to the shoulder on the C-ring itself. A small bevel was put on the leading edge so that it would better centralize itself when entering its respective groove as the back-off sub was drilled down. There was some earlier concern that the C-ring was hanging up and not allowing the back-off nut to come into contact with the landing shoulder.

Neither modification to the equipment was intended to be operated in the particular application in which they were finally deployed. However, with the supply of back-off components limited, they were run together. It was not foreseen at the time of their deployment that the problem which occurred would happen. However, they were run together and failed together. Without being able to retrieve the center bit, the borehole had to be abandoned. A detailed account pertaining to the deployment of the back-off sub on Hole 810D is given below (see "Shatsky Rise" in "Performance" section, this chapter).

Recommended Design Modifications and Improvements

Due to the nature of the sediments for which the reentry cone was designed, it is still felt quite adequate for this purpose. While it has been suggested the size of the cone for the mini-HRB be made smaller, this modification should not be made for the reentry cone itself. This is because cuttings tend to mound around the cone itself. Thus by reducing the cone's height or diameter, it could possibly become buried and hard to locate for reentry purposes. Though not a problem encountered on this leg, the base could be outfitted with some vertical plate attached on either side to prohibit rotation of the entire reentry cone and to reduce the amount of washout from underneath.

The mating receptacle for the splines on the bottom of the casing hanger needs to be modified for a more positive engagement. Quite a bit of time was lost in attempting to latch the hanger into the conductor pipe on the reentry cone. Even though not actually tested, it is felt that some improvement should be made to the cuttings removal process. Exit holes should be enlarged from the landing seat outward including the conductor pipe. The concept of collector manifolds is still thought to be effective, though a constant diameter would be preferable in the discharge tubes. It is thought that they might eventually load up with sediment due to a decrease of annular velocity where an increase in tube diameter occurs.

Another improvement to be looked into is how to effectively flood the cone without creating potential problems of drill bits hanging up when reentering the cone. Even with ideal sea conditions, there is a time while lowering the cone that it tends to float momentarily. The sheer size of the cone coupled with the addition of sonar reflectors requires exact maneuvering through the moon-

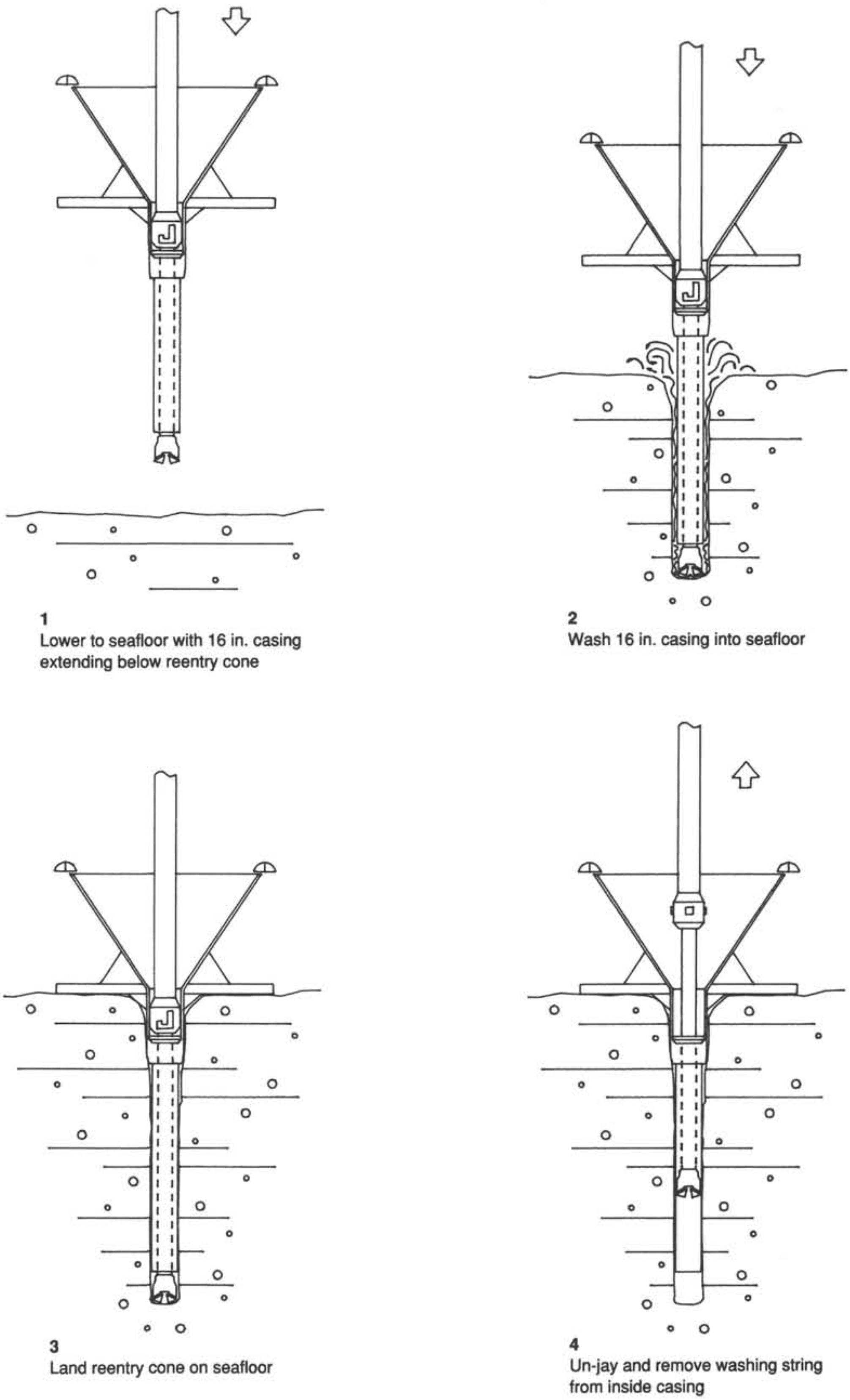
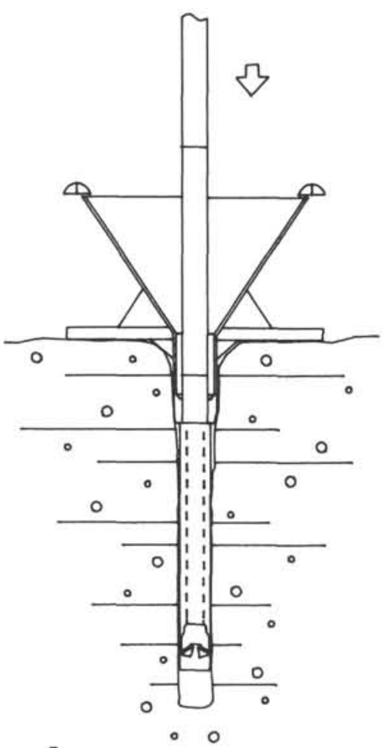
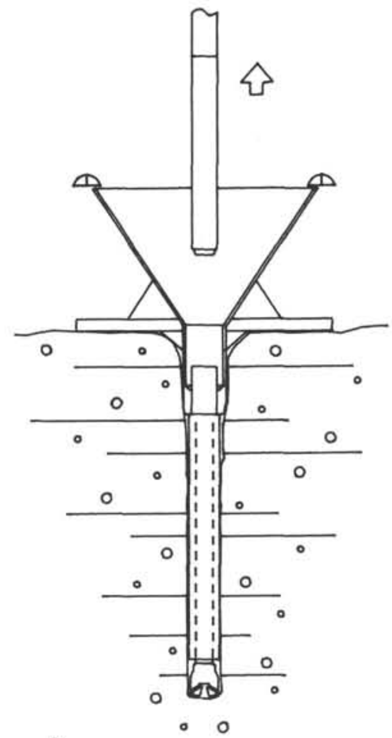


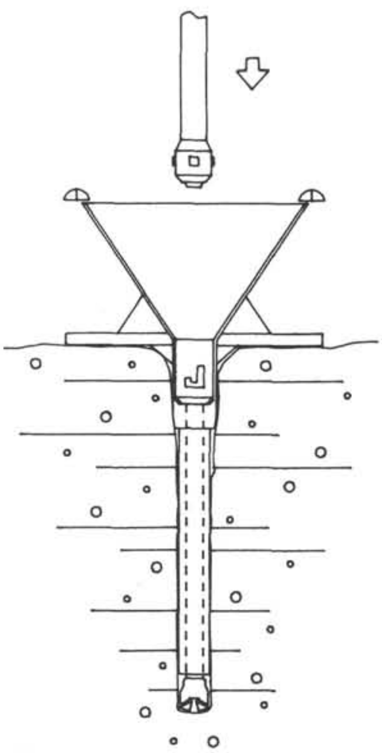
Figure 17. Deployment sequence for DCS with reentry cone (Shatsky Rise).



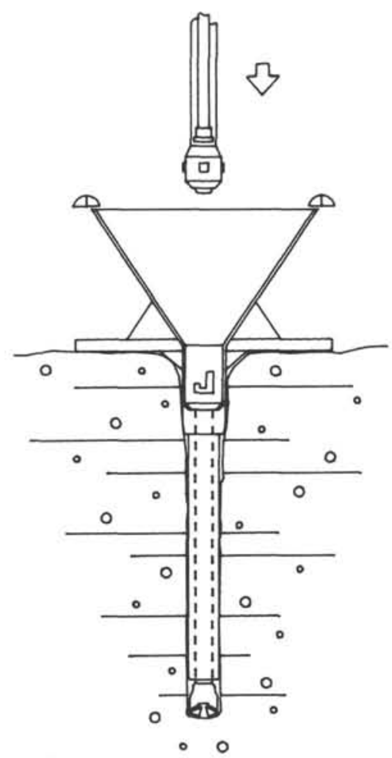
5
Reenter and lower BHA into casing



6
Drill-in and back off BHA to retrieve string

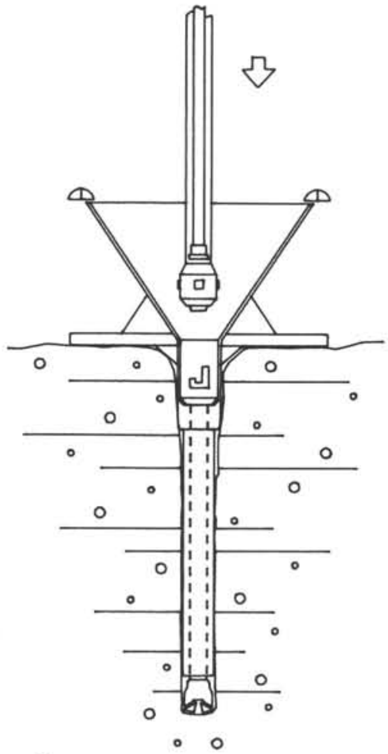


7
Lower mechanical tensioning device above reentry cone

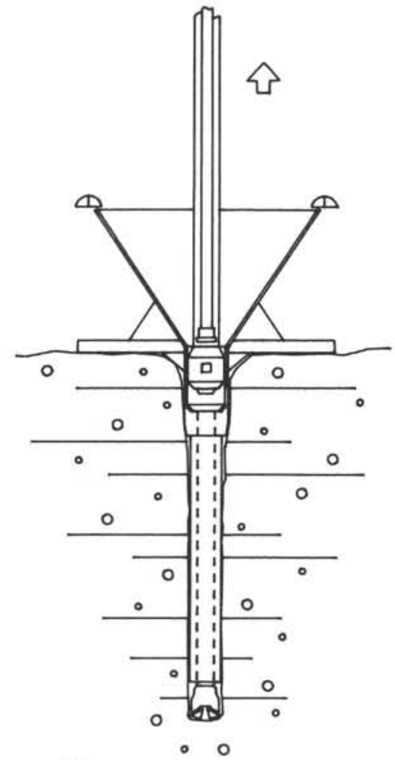


8
Trip hydril tubing to just above mechanical tensioning device

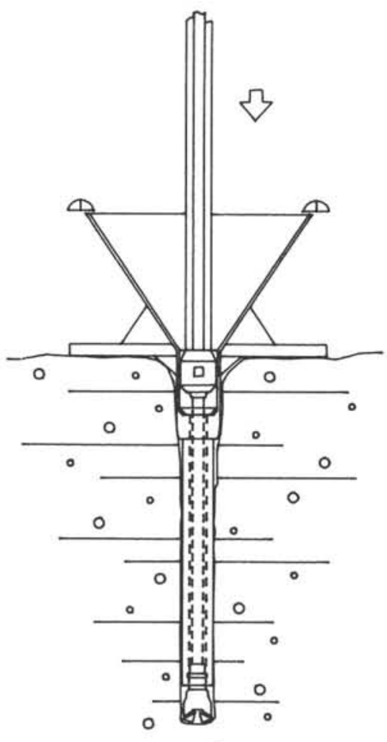
Figure 17 (continued).



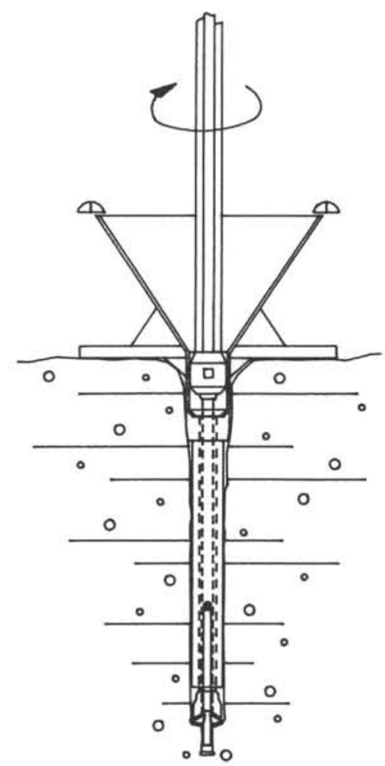
9
Reenter and run in with mechanical tensioning device



10
"Tension up" mini-riser



11
Lower hydril tubing to just above BHA bit



12
Pump down inner barrel and begin coring by activating secondary heave compensator and top drive

Figure 17 (continued).

pool. It has already been demonstrated on Leg 130 that a cone can be lost by hanging up on the lower guide horn while clearing the hull of the *JOIDES Resolution*.

CASING HANGER/LANDING SEAT

General Description

A modified version of the ODP casing hanger was developed for use with the DCS hardware. The upper portion of the casing hanger is identical to ODP's standard 16 in. casing hanger with only the lower section below the snap ring being different. A schematic of the 16 in. casing hanger used for both the mini-HRB and reentry cone is illustrated in Figure 8. The major differences for the hanger used with the DCS include:

1. A larger diameter and wall thickness of the lower section,
2. Vent ports drilled through the side of the hanger,
3. Shorter length,
4. Reduced O.D. at base for accommodating the 20 in. casing tongs (reentry type only),
5. Rotational restraints to prevent the hanger from rotating while being deployed with the reentry cone,
6. Adaptation of an internal landing seat, and
7. Attachment trunnions for the mini-HRB version.

Casing Hanger

Two versions of the casing hanger exist for deployment with either with a mini-HRB or reentry cone. Differences here pertain to only the number of vent ports (eight for the reentry cone as compared to four for the mini-HRB) and the way the hangers are attached. Weight of the two hangers is approximately the same at around 5200 lb. The version for the mini-HRB is held by the trunnions welded into the side of the hanger itself. This not only provides attachment to the gimbal but prevents the hanger from rotating when the back-off nut is engaged in the landing seat. The gimbal adds another 1200 lb to the hanger. The version used in the reentry cone does not use the trunnions since it must fit inside the reentry cone conductor. It is held into the conductor with a snap ring above the landing shoulder. Four splines which mate with matching grooves in the bottom of the conductor provide rotational restraint. Since the reentry cone version is run with 16 in. casing, it has a reduced diameter for the lower 12 in., allowing for make-up tongs to be used on it. The overall length of both the hangers was reduced to 100.5 in., with outside dimensions being similar to the standard ODP hanger. Both hangers were fabricated from four large diameter forgings before being machined and welded together.

Landing Seat

The uniqueness of the casing hanger developed for the DCS evolves around the introduction of the landing seat concept. The landing seat was designed as part of the back-off sub assembly as a convenient means to activate and thus separate the BHA from the drill string. This allows the DCS to begin in a more favorable environment than at the seafloor. The landing seat also has a snap ring receptacle so that the BHA can be captured, if desired. The landing seat is held in position with two key slots which prohibit the seat from rotating when the back-off sub has landed and begins to unscrew. Another feature of the landing seat is that it can be removed by shearing spring-loaded pins when recovering the BHA. This option allows for larger diameter casing to be run at a later date after the landing seat is removed. The snap ring would normally be run on the back-off sub in situations where the material encountered in the borehole would be too soft to support the weight of the BHA. For harder formations, the back-off sub could be run without the benefit of the snap ring, thus not linking the BHA to the seafloor system. This has some benefits in that if the HRB were required to be used at an adjacent location should another borehole be desired, it could be lifted over the BHA stub and repositioned, thus effectively making the guide base reusable. The landing seat is illustrated in Figure 18. Besides all the above options, a sleeve can be attached to the landing seat to allow a smaller size bit/BHA combination to be run. The unsleeved landing ring seat allows for a 11-5/8 in. bit to pass and a 9-7/8 in. bit to pass, being the largest when sleeved. A schematic of the sleeved version is presented in Figure 19.

There are 16 threaded C-ring suppression bolt holes evenly spaced around the diameter of the landing seat. This allows the landing seat to be removed from the BHA when pulled from the casing hanger. Another 16 threaded C-ring suppression bolt holes are included on the sleeved insert if the smaller BHA is run. These bolt holes allow the C-ring to be captured in any orientation. It should be noted that if the smaller size bit/BHA combination is used, the sleeve must be installed in the casing hanger prior to deploying the mini-HRB or reentry cone.

Cuttings removal is accomplished with flow ports drilled through the casing hanger and annular ports between the landing seat and casing hanger for the mini-HRB style landing seat. This allows cuttings to exit from the sides and along the bottom of the casing hanger. A different style of landing seat is employed with the reentry cone operation. In this application the casing hanger is situated beneath the seafloor requiring cuttings to be moved upward instead of downward as in the case of the mini-HRB. Therefore, the annular ports are removed so that cuttings will not fill the cavity between the casing and the BHA. This is so the BHA can be removed once the boring is terminated. Four additional flow ports are drilled through the side of the casing hanger to increase the cuttings removal for the reentry cone option. These eight holes are captured by four manifolds and discharge tubes built as part of the reentry cone base.

Field Performance

This general type of casing hanger has been used since Texas A&M University became the science operator for ODP. It has performed remarkably well and been quite trouble-free. The modifications made to it for this leg have seemed to work with the DCS as intended. There were no indications from drilling that the cutting removal ports on the landing seat did not performed as designed for the hard rock site. The landing seat itself withstood repeated reentries from the BHA when deployed with the mini-HRB. Three back-off subs were landed without any problems in the same hanger. The rugged construction of the hanger has allowed it to be handled in a typical oilfield manner. The only fabrication flaw noted was that the jay-slots were manufactured in a reversed direction.

The hanger used with the reentry cone did present several problems. However, the problems encountered were the result of poor fabrication techniques and not the design itself. The first problem involved an improper fit between the hanger and the reentry cone conductor. This may have been caused by welds not being ground flush on the exterior of the hanger or an improper dimension of the conductor itself. This lead to the hanger becoming lodged in the conductor and not able to be relieved. A fit-test of the hanger inside the reentry cone conductor was supposed to have been conducted by the contractor fabricating the hangers but was not witnessed by an ODP technical representative. While the contractor most likely performed the fit-test, it is possible that the orientation was different in the field and not noticed by the fabricator. It should also be noted that the reentry cone and casing hanger were manufactured by two different firms.

The second problem centered around the threads cut into the bottom of the hanger for the 16 in. casing. While it is not con-

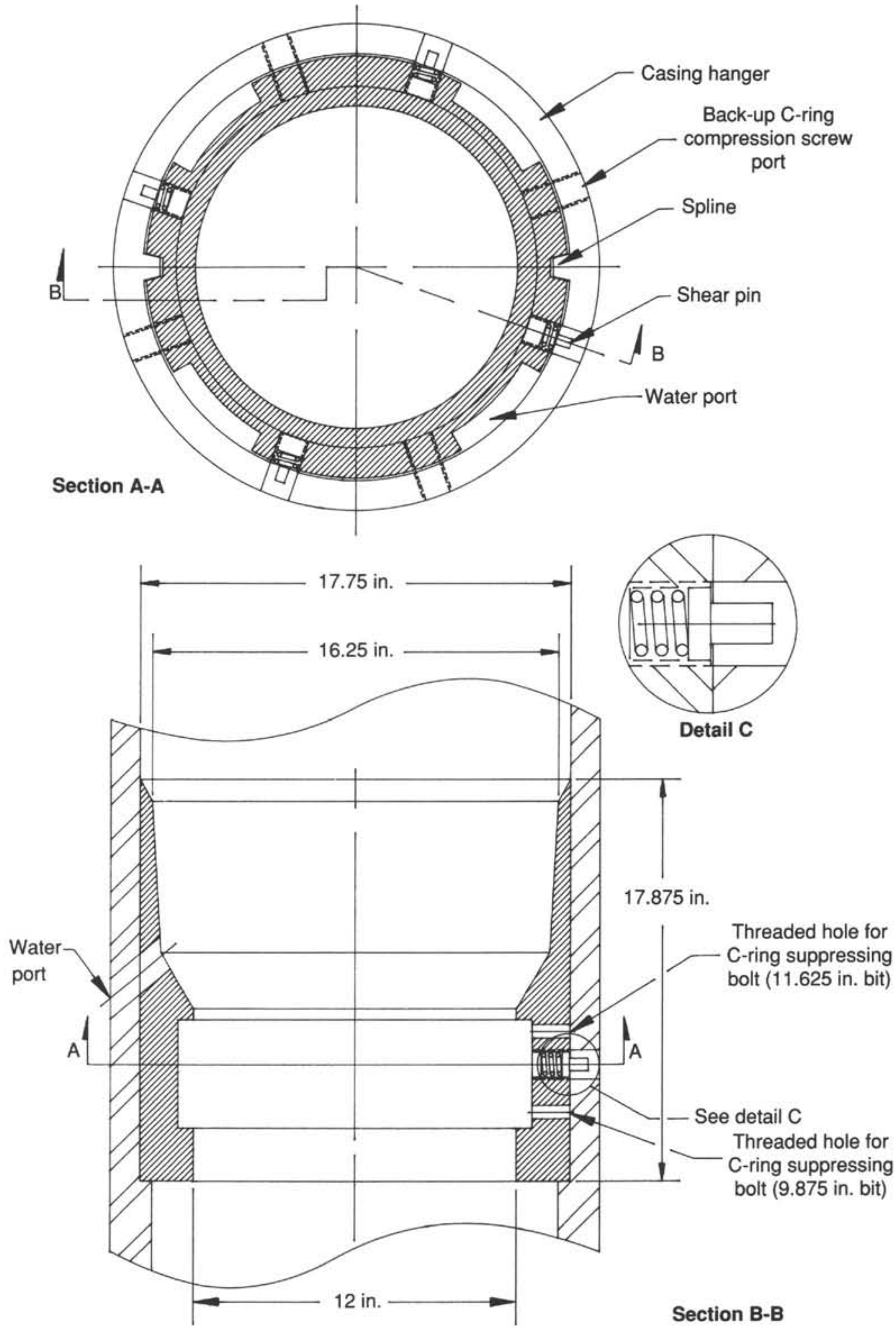


Figure 18. DCS landing seat, 11 5/8" OD bit.

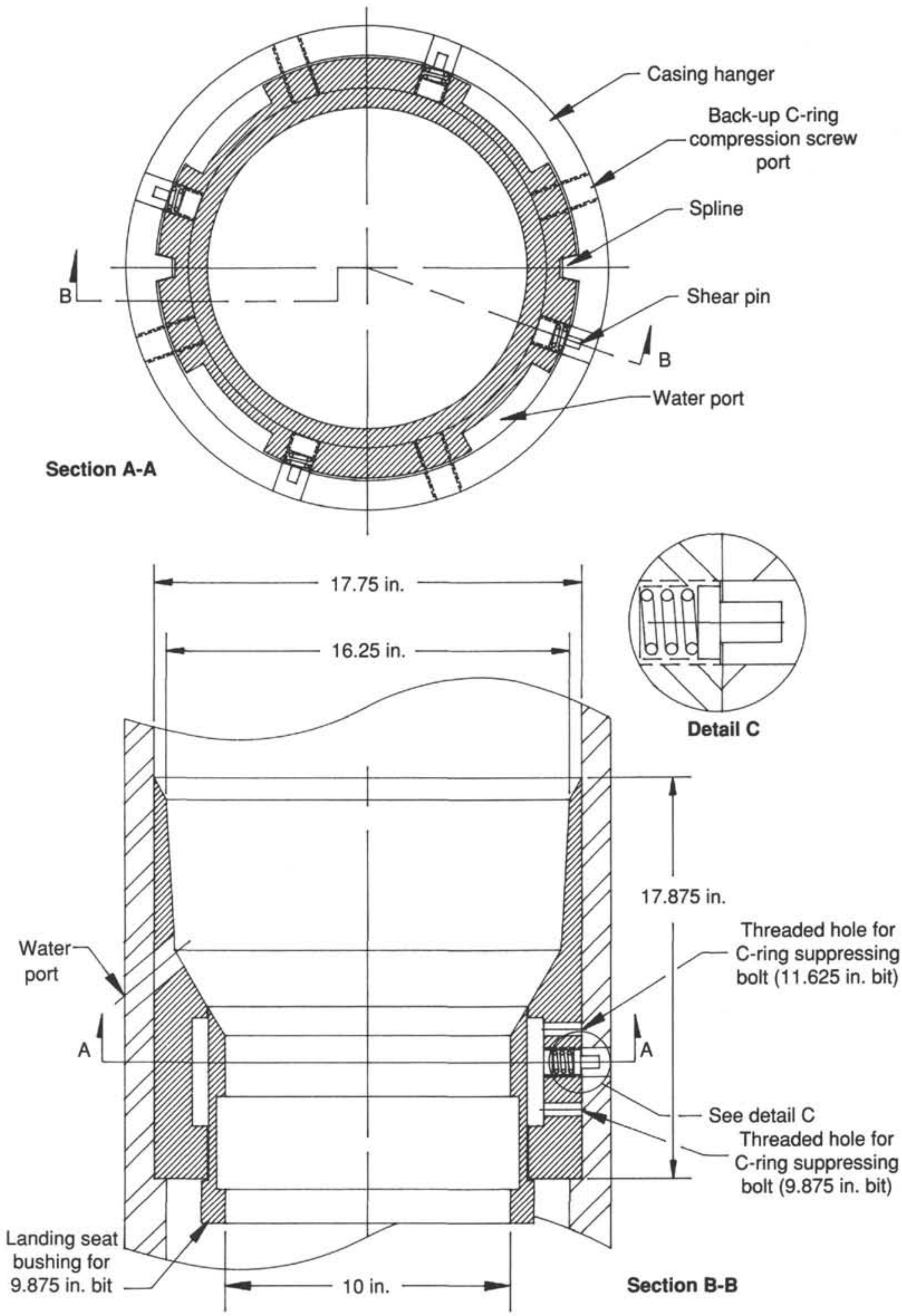


Figure 19. DCS landing seat, 9 7/8" OD bit.

firmed, it is suspected that the diameter of the threads were oversized in the box or they just were not made up tight enough. Almost 50 m of casing was lost when they mysteriously dropped out of the box connection. The threads appeared to have made up over 4 in. when the hanger was inspected after the incident. Furthermore the casing was tightened to 7500 ft-lb torque and even tack-welded to the hanger. No other explanation can be offered as to why the casing was lost.

A second attempt to attach the casing was impossible because the hanger was unable to be pulled free of the conductor. This precluded the casing from being run all together and consequently resulted in additional time, effort, and resources being used to fix something that should have been a routine procedure.

The third problem encountered with this particular casing hanger was the failure of the keys welded into the bottom of the hanger to prevent the landing seat from rotating. This then allowed the landing seat to rotate with the back-off sub and consequently it did not allow the back-off sub to unscrew as designed. This rotation of the seat also caused failure of the spring-loaded shear pins designed to hold the landing seat in when retrieving the back-off nut. Thus, without any resistance to separate the nut from the landing seat, it also was recovered when the drill string was pulled back to the surface. While the landing seat was designed to be recovered in certain applications, it was to be only in a controlled overpull situation. It is suspected that poor welding practices and insufficient welding contact lead to the failure of the keys. The keys were designed to withstand 2–3 times the amount of torque that the top drive was capable of delivering, but without sufficient welding contact, they were essentially useless.

In an attempt to back-off the BHA once the keys had failed, it was demonstrated that welding hard-facing material onto the exterior surface of the landing seat would provide enough reactive torque to effectively lock it into position so that the back-off sub could be unscrewed. This operation was tried twice on Hole 810D and each time was successful in allowing the back-off sub to unscrew. However, because there was no way to hold the landing seat down, separation between the two pieces did not occur, leading to the recovery of the entire landing seat/back-off nut on both occasions.

Recommended Improvements And Design Concerns

Several improvements in design and operational procedures could be made to the hanger/landing seat if its further use is planned with the DCS concept. These include:

1. Modify the drawings showing the jay-latch so that there will no be confusion as to which direction the jay should be rotated to latch in,
2. Eliminate extra machining as a cost-saving measure in the fabrication process for items that can not be used in this particular application (i.e., 11-3/4 in. casing hanger slots, exterior snap ring on HRB model, etc.),
3. Move the trunnions higher to allow for more righting moment in the case for the HRB,
4. Use thicker wall material or add counterweights to the lower end of the hanger as another means to help in self-righting for application with the HRB,
5. Insure that all dimensions are checked by an ODP technical representative along with fit-testing each component and witnessing by an ODP technical representative,
6. Weld-out the 16 in. casing completely when attaching to the hanger,
7. Install four rather than two keys of a larger size into the casing hanger to prevent the landing seat from shearing from torsional loading,
8. Insure that all welds on the exterior of the casing hanger are ground smooth for proper mating into the reentry cone conductor.
9. Modify lower landing seat key slots with tapered entryways so that the seat will realign and drop into position by rotating.
10. Shorten or modify the length of the snap ring groove so that the back-off nut becomes unscrewed before latching the lower sub into the landing seat.
11. Investigate a better method or stronger shear pins to hold the landing seat in place so that it requires a known amount of overpull to shear it from the casing hanger.

BACK-OFF SUB

General Description

A back-off sub was designed and built in collaboration with Houston Engineers. The major impetus behind the design of the tool was to provide a means to back-off the BHA in unstable, fractured hard rock formations, thus giving the DCS tubing a cased environment in which to begin coring. This sub would be placed in the BHA at a location where penetration resistance could easily be overcome because of the life expectancy of the bit for the formation in question.

The tool was designed with an internal threaded ring housed inside a larger nut assembly which held the upper and lower pieces of the tool together. The two pieces would separate only when the external nut made contact with a landing seat and its threshold make-up torque was exceeded. The external nut was not required to transmit any drilling torque. This was accomplished with four 3 in. splines housed above the internal threaded ring. These splines held the upper and lower assemblies together and would also allow 3 in. of overdrilling to disengage the lower assembly. An exploded view of the back-off sub is presented in Figure 20.

Two sizes of lower subs (11-7/8 in. and 9-7/8 in.) were manufactured to work with a common upper nut assembly. This allowed some flexibility in selecting the size of the drill bit and BHA to be run should formation problems dictate a smaller hole. To accommodate the smaller lower sub, a sleeve bushing was provided so that centralization would be constant even with the smaller, lower sub. This sleeve bushing, however, required installation in the landing seat prior to running the casing hanger.

Another option built into the lower sub was it could be run with or without a locking C-ring. The C-ring was designed to lock the lower assembly to the landing seat/casing hanger. This option was designed into the tool for the deployments with the reentry cone or where soft sediments might not support the weight of the BHA if not held by the C-ring. The back-off sub without the C-ring was originally developed for use with the mini-HRB to allow the base to be stripped over the backed-off BHA. This would enable mini-HRB to be recovered or moved without the BHA attached.

It had been demonstrated in the past that the most efficient means to spud-in on hard rock was with the aid of a mud motor. Therefore, the back-off sub was also designed to be operated with the low torque attainable with a mud motor. The frictional torque obtained with the Mach I motor ranged between 4,000 and 6,000 ft-lb. The nut could be made up to higher torque levels if the PDCM was locked out or not in the drilling assembly altogether. There was some initial concern about using such low make-up torque on the nut. Therefore, as a back-up in case premature separation occurred, the nut could be tightened up further on a following run and the top drive used exclusively to back it off while the PDCM was used to spud the hole and drill-in the BHA. The PDCM had been modified with a lock-out device inside the motor housing that could deployed anytime while drilling-in the BHA. This lock-out device would allow up to 25,000 ft-lb of torque to be transmitted through the PDCM.

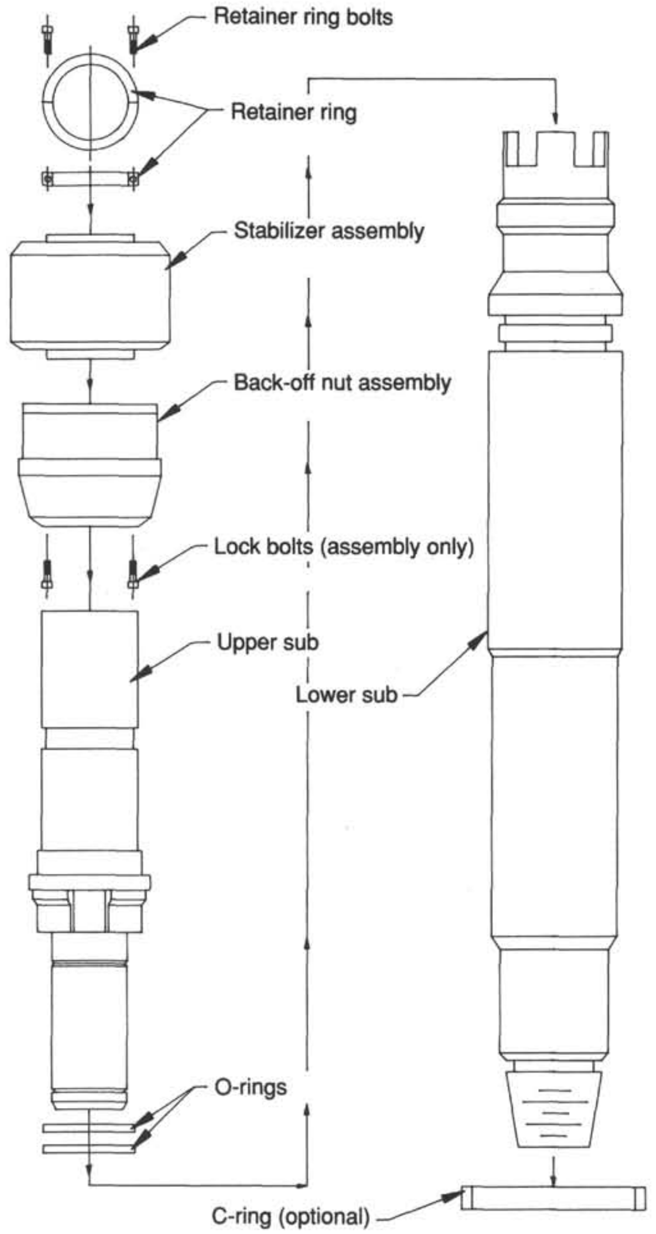


Figure 20. Exploded view of back-off sub.

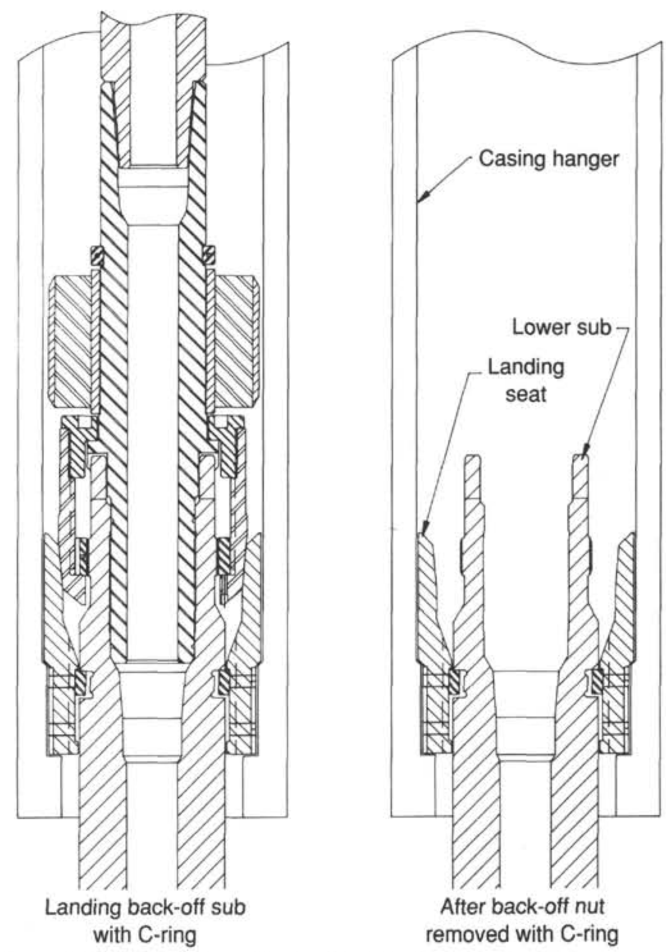


Figure 21. Cutaway view of back-off sub before and after deployment.

Deployment Sequence

In order for the nut to back off at the correct place, a mating receptacle (landing seat) was housed in the lower throat of the casing hanger (Fig. 8). This landing seat was also used as a lower centralizer for the BHA. It would help keep the upper nut from leaning over and touching the sides of the casing hanger while being drilled in, thus preventing premature back-off. An upper larger stabilizer was placed above the back-off nut to aid in centralization after the nut had passed the throat of the cone. The back-off sub is shown in Figure 21 as it would appear seated in the landing seat and what would remain as the nut assembly is removed. The complete back-off sequence is illustrated in Figure 22.

To help centralize the bit while it was passing through the casing hanger, the BHA was made up with a lower stabilizer assembly placed immediately behind the bit. These stabilizers were to keep the hole as straight as possible prior to the back-off sub entering the hanger. A schematic of the type of stabilizer used is shown in Figure 23 along with the two different sizes of back-off subs. The stabilizers themselves were also provided in two sizes to complement whichever back-off sub/bit combination was selected for the hole conditions encountered. The spudding technique described above illustrating the alignment characteristics of the stabilizers and lower sub are graphically presented in Figure 24.

Performance

Bonin Location

The back-off tool was deployed three times at the Bonin location. The first time in Hole 809C resulted in a premature back-off. However, the early separation of the tool was not due to any design flaws but rather to deploying it through the casing hanger which was pressing hard against the drill string. This allowed the nut to rub the hanger as it entered and generate enough torque to unscrew. The deployment in the second borehole (809D) performed just as designed. The casing hanger/reentry cone in this deployment was free to pivot about the gimbal. This allowed the back-off sub to seek centralization as it entered the hanger before seating in the landing seat. The third deployment for Hole 809F was a repeat of the previous hole (809D). This deployment was necessary since Hole 809D could not be reentered due to a jay-tool lug blocking the throat of the drill-in BHA. Another hole (809E)

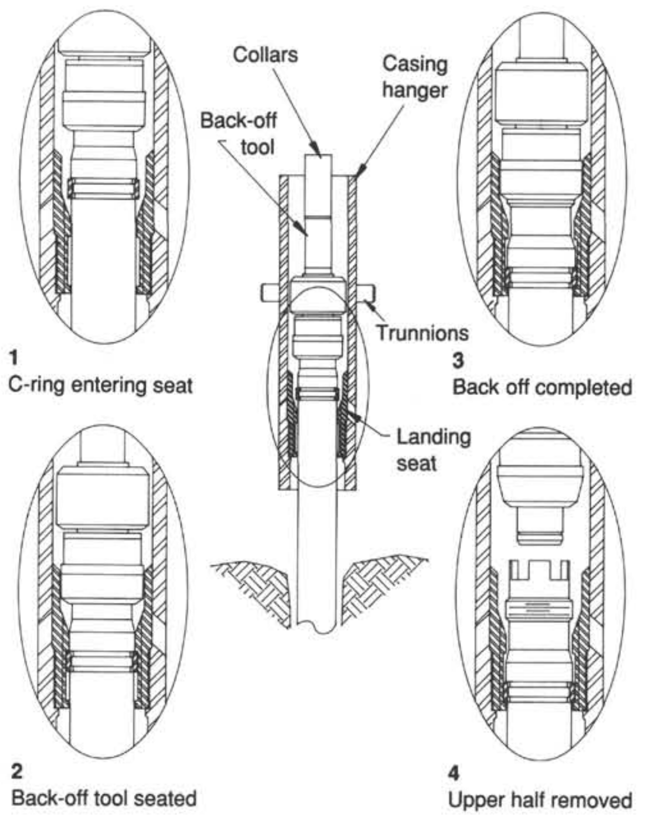


Figure 22. Deployment scheme for back-off sub (guide base not shown for clarity).

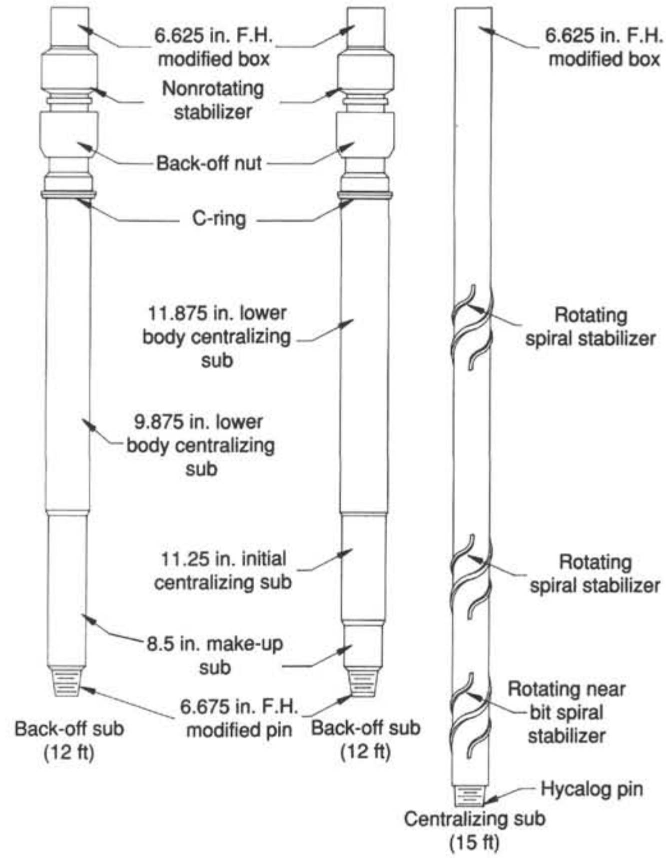


Figure 23. Major DCS BHA subs.

was attempted prior to the final deployment on Hole 809F but was aborted before the back-off nut entered the landing seat. The hole was terminated when it was discovered that the guide base had shifted during the drilling operation and was at an angle greater than the mini-HRB gimbal could compensate for. Detailed information pertaining to all four boreholes are presented in the following paragraphs.

In Hole 809C, it appears that the back-off sub manufactured by Houston Engineers worked as designed but apparently backed off prematurely at the reentry cone/casing hanger interface. This occurred on the first attempt at drilling in the BHA. Drilling depths marked on the pipe suggested that the transition section or upper centralizer may have hung up when the BHA had been drilled to only 4 m of the 6 m required. Drilling rates decreased at the 4 m mark indicating that back-off may have occurred, and that the pipe or water depth measurement may have been slightly off. At this point it was decided to run the VIT down and see if there were any obvious reasons why penetration had slowed. Upon visual inspection it appeared that the entire back-off sub assembly was inside the throat of the cone. The decision was made to pull out since it appeared that the termination depth was reached. Upon pulling back, the sub parted, giving the indication that it had landed and backed off. It was only after trying to reenter with the tensioning tool that it was discovered that back-off sub had not been drilled to the desired depth.

The separation of the nut most likely occurred due to the failure of the reentry cone to right itself when the back-off sub entered the casing hanger. Therefore, when the back-off nut came in contact with the casing hanger enough torque was developed so that it came unscrewed. Tight tolerances designed into the back-off sub and landing seat to insure centralization may have worked opposite the intention when the sub entered the hanger at a slight slope. This tight tolerance further prevented the BHA from being drilled to its correct position by pinching as it was going through the landing seat. It was also noted from the VIT that complete verticality was never obtained with the hanger as drilling proceeded.

The drill-in BHA below the PDCM consisted of the following:

1. 11-5/8 in bit. (1 ft.)
2. 11-1/2 in. stabilizer sub (15 ft),
3. 11-7/8 in. back-off sub (9.5 ft),
4. Crossover sub, and
5. PDCM.

The drilling rate for this supported spud was much better than the two previous boreholes (809A and 809B) in the same material. This supported spud-in produced a rate of almost 4 m of basalt being drilled in the first hour. After the 4 m mark was reached, the drilling rate fell to almost no penetration for the next hour of drilling. However, this is attributed to the pinching of the BHA as the widest section begin entering the landing seat. It is unknown if the earlier penetration rate (>4 m) can be totally attributed to the supported spud-in or partially to the fact that the center bit was recessed behind the larger roller cones by 1.5 in., though it is suspected that the later had more to do with penetration rate than the centralization.

Another scenario of the above events were also originally considered. However, it is now felt that this was not the case. It was surmised that the sub landed and backed off at the proper location but did not decouple immediately when the drill string was pulled back, thus adding some rationale as to why the painted mark on the BHA was at the throat of the casing hanger when viewed with the VIT. There was also some galling noted on the recovered mating receptacle indicating that it may have possibly stuck together with its counterpart before separating. The back-off nut only showed wear at the leading edge of the tapered nut. There was also some confusion as to what the actual water depth was when the hole was started. There had been a 2 m difference in water depth tagged between the side and the center of the HRB. Thus when no additional penetration was made after drilling 4 m, it was felt that maybe the tool was indeed landed. Videotaping of pulling out of the cone was not done, so replay was not possible to determine if indeed the back-off sub was landed properly at a mark placed on the drill pipe. This was only verified after the reentry with the tensioning tool was attempted. For whatever the reason, the sub was in the top of the casing hanger approximately 2 m short of the desired target depth.

A fishing sub supplied by Houston Engineers was modified to include a 16 in. muleshoe centralizer to aid in catching the drilled-in BHA. The fishing operation took less than 20 min to successfully screw into the BHA. Overpull to retrieve the BHA was approximately 5,000–10,000 lb. Upon retrieval of the sub, the hole was reentered with a similar assembly less the back-off sub. Problems again occurred when the bit and the 11-1/2 in. stabilizers would not pass through the upper portion of the casing hanger due to it lying at a 20°–27° slope. It appeared that they were hanging up on the jay-slots. Therefore, to expedite the operation, the 11-5/8 in. drilling assembly was changed to a smaller 9-7/8 in. assembly without any stabilizers. This was to help the BHA in getting through the upper portion of the hanger until it would right itself. This also proved ineffective in passing the bit to the seafloor. The difficulty appeared to be in the rigid drilling assembly and the fact that the hanger would not right itself long enough to allow the BHA to pass through the landing seat.

Several reentries were made, but all proved unsuccessful in getting the BHA through the throat of the casing hanger. Again, the reason was the severe tilt of the hanger. The maximum calculated angle at which the hanger could be seen while lying in the corner of the HRB was 27°. This angle, coupled with the estimated tilt of the seafloor, resulted in approximately 34°–39° that the hanger had to be righted before approaching vertical. It was finally decided that any further attempt at drilling through the hanger in its present orientation were futile. However, it was decided to try to recover both the reentry cone and mini-HRB with a flexible fishing assembly rather than abandoning it. This fishing attempt was successful and recovered both. Repairs were made to the HRB to insure that the floatation would be sufficient to upright the cone before redeploying it.

Borehole 809D proved that both the concept and equipment worked exactly as designed. The borehole was spudded through a vertical reentry cone/casing hanger on a 20° seafloor inclination after having moved the mini-HRB. Drilling rates were approximately the same for the first 4 m as those reported in Hole 809C and continued at the same rate until separation occurred.

The pressure generated by the PDCM was substantially less than the other runs. The operating pressure gradually increased from around 200 psi to about 450–500 psi as the BHA became more embedded. There was a momentary pressure spike of 600 psi approximately where the back-off nut was to land. Continued rotation gave a slight pressure drop indicating the lower sub was drilling off the upper assembly. After several more minutes of rotation the pressure had dropped to around 100–150 psi giving further indication that the lower assembly had completely drilled off the splines. No additional penetration was recorded after the initial pressure spike. At this point the pumps were shut off while the VIT was run down the drill string to verify the correct penetration at the guide base. It appeared the tool was drilled to the proper depth so the string was slowly lifted out of the casing hanger. Both the upper stabilizer and nut appeared as the drill string was pulled out. Final verification was made when the jay-tool was able to latch into the jay-slots. Sea conditions were relatively calm with vessel offsets averaging less than 0.2% water depth. Vertical motions were producing only 1–2 ft of motion at the drill floor. However, currents were causing some problems with reentry.

Borehole 809E was required to be drilled after Hole 809D was abandoned. This was due to a jay-lug breaking off the tensioning tool and leaving it in the throat of the BHA on Hole 809D. Penetration rate in the previous holes had been relatively fast, therefore it was decided to lengthen the drill in BHA to 9.2 m instead of the 6.3 m used on Hole 809D. The formation drilled as expected for the first 6 m in less than 45 min. However, the remaining 3 m presented some rather difficult drilling along with some hole stability problems. It took over 16 hr to advance the borehole to a depth of 9 mbsf. Penetration rate at this point had fallen to less than 0.25 m/hr. The hole had been drilled to 8.75 mbsf earlier in 5 hr, but stability problems required the bit to be pulled back to 3 m and the hole to be redrilled. After 9 hr more of rotation and very little penetration, there was some uncertainty as to the condition of the large roller cone bit and whether the center bit was still intact and capable of being pulled. Thus, if the BHA was drilled to termination depth and latched in, the hole might possibility have to be abandoned if either of the bits had come apart. Therefore, the BHA was pulled in an attempt to save the hole and to observe how the bits performed in the time they had accumulated.

It was later determined that the main reason for slow penetration was that the BHA was rubbing/pinching on the landing seat again, thus reducing the amount of torque reaching the bit. This further indicated that the hole was being drilled at an inclination exceeding what the gimbal could compensate for. Initial placement of the guide base revealed that is was on a relatively flat seafloor. However, after the BHA was pulled it was noted that the base had shifted and that one side was now definitely lower than the other. While the tight tolerances between the landing seat and the back-off nut prevented the hole from being drilled, it is now evident that this may be a built-in safety measure indicating excessive borehole or base inclination.

Several things were learned from this hole that pertained directly to the back-off tool. First, the back-off tool withstood over 16 hr of severe hard rock drilling and the associated drilling vibrations which accompanied rotational speeds of approximately 80 rpm. Second, the tool was drilled through the throat of the casing hanger two times without backing off. Third, it withstood repeated overpulls in excess of 25,000 lb each time the drill string became stuck. All of this information was extremely important in assessing the performance of the tool. Another interesting note was when drilling became extremely difficult or presented some different characteristics than previous test holes suggested, the inclination of the guide base may be more of a suspect than the formation.

In Hole 809F, the deployment of the back-off sub was almost an exact replica of what occurred in Hole 809D. Drilling time for the 6 m BHA was around 30 min. A noticeable pressure spike was not observed on this hole as the nut backed off. However, the operating pressure of the PDCM did fall significantly after drilling off the splines. Two explanations could be offered as to why this pressure spike was not observed. The first was that this back-off sub had been reassembled on board the *JOIDES Resolution* after being used on an earlier hole. Therefore, the make-up torque may not have been as high as initially set at Houston Engineers facilities, and some wear of the components may have also contributed to the internal nut moving easier than the first time it was deployed. The second reason was that the PDCM was

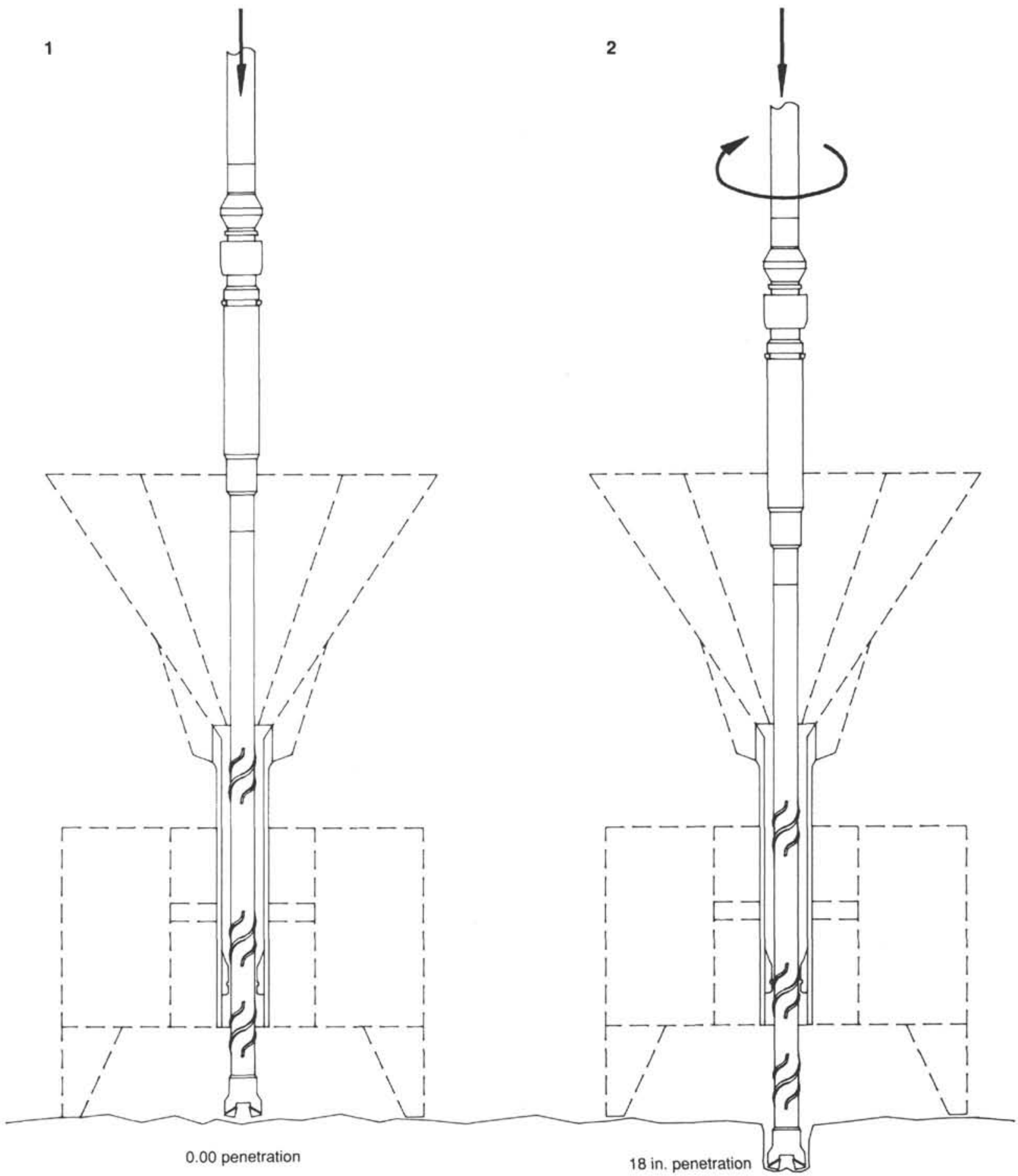


Figure 24. Spudding sequence of the BHA.

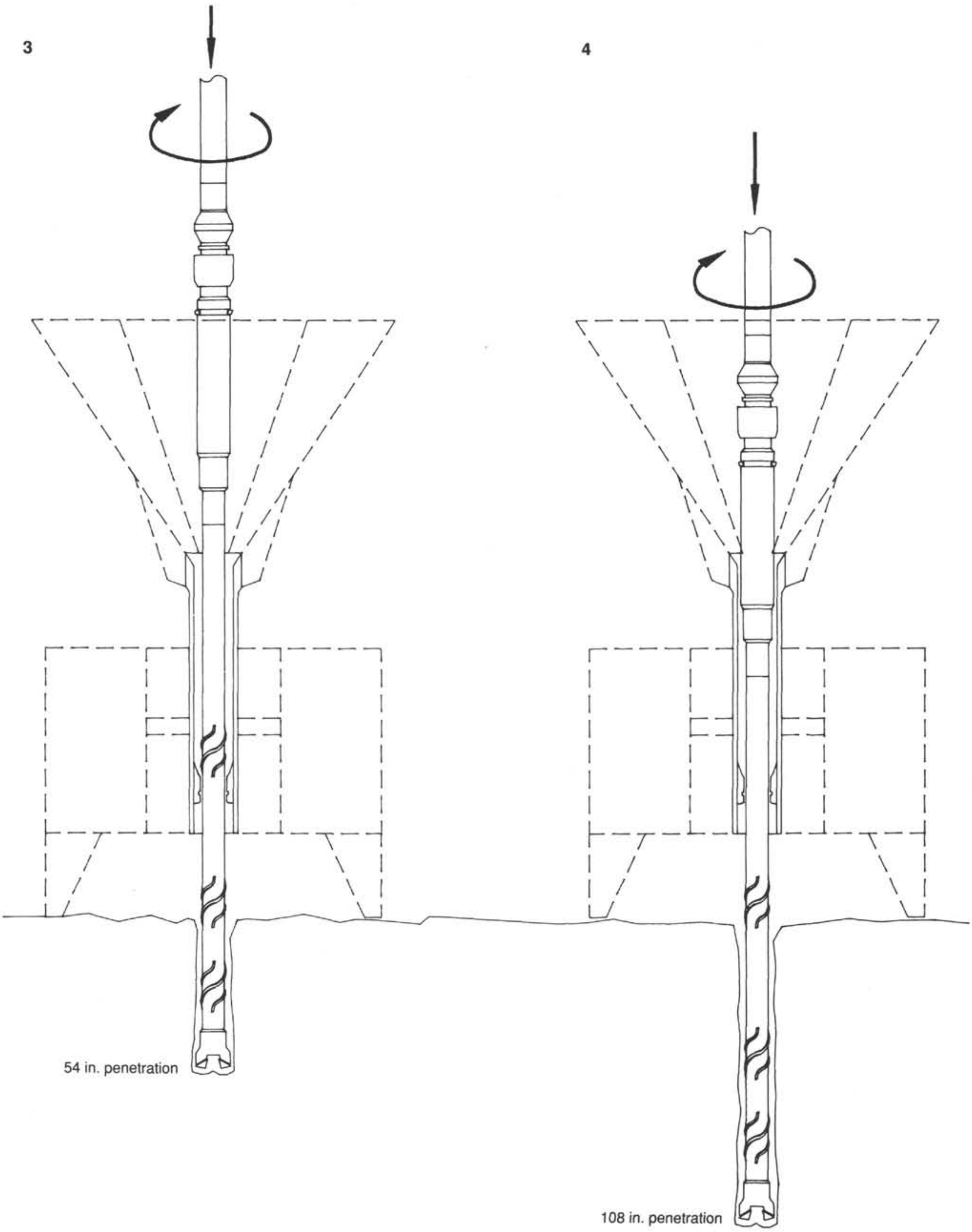
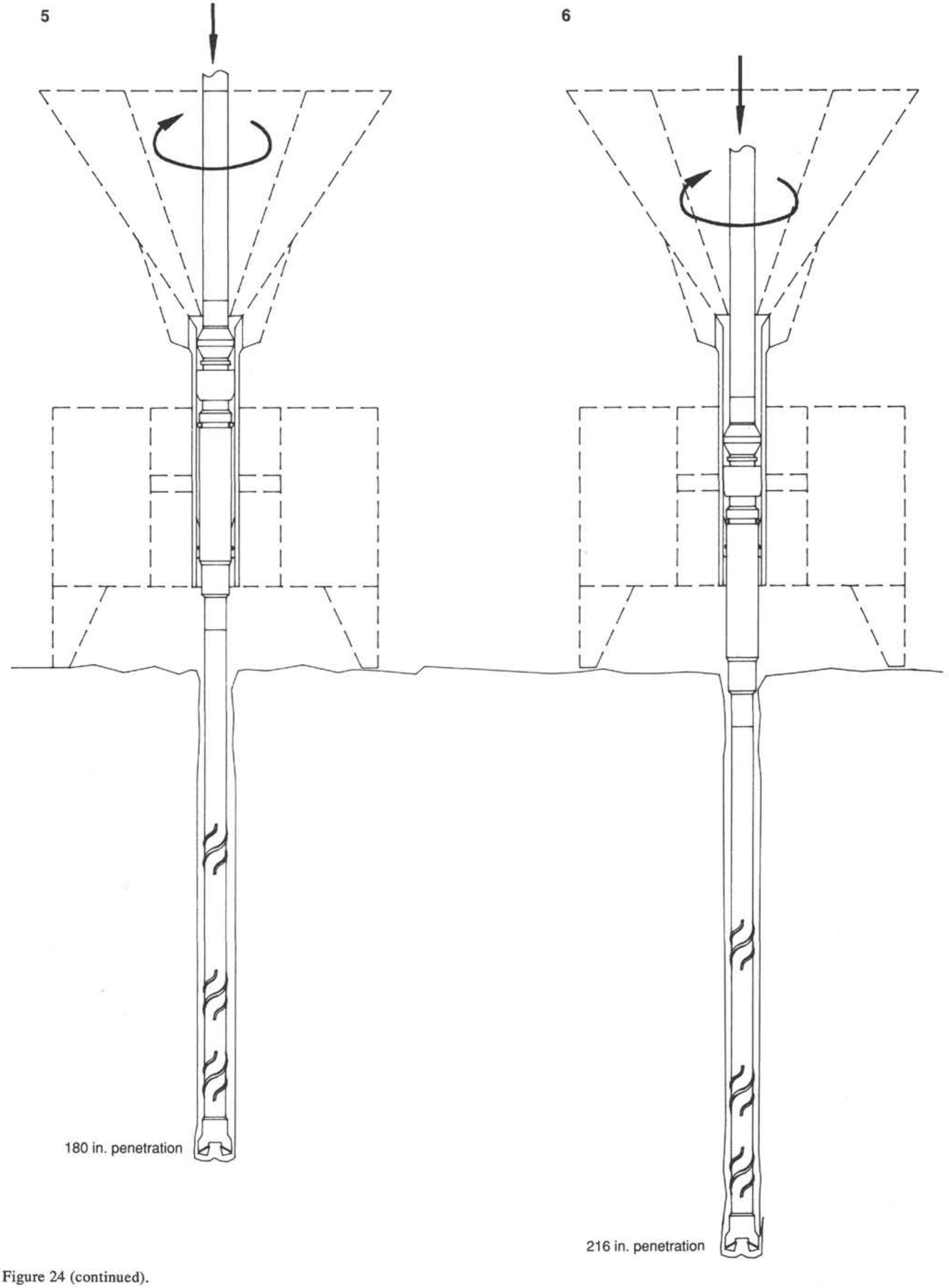


Figure 24 (continued).



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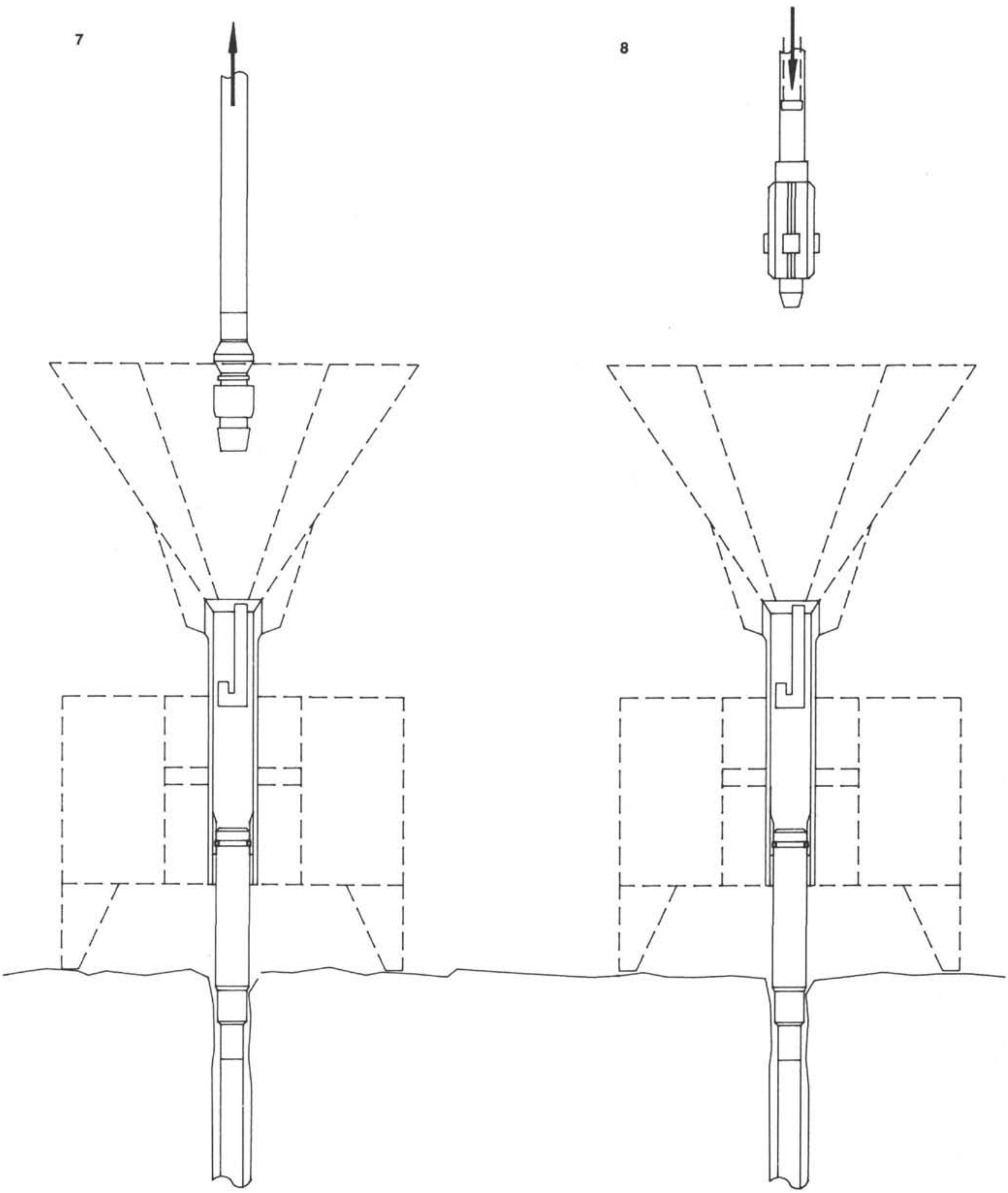

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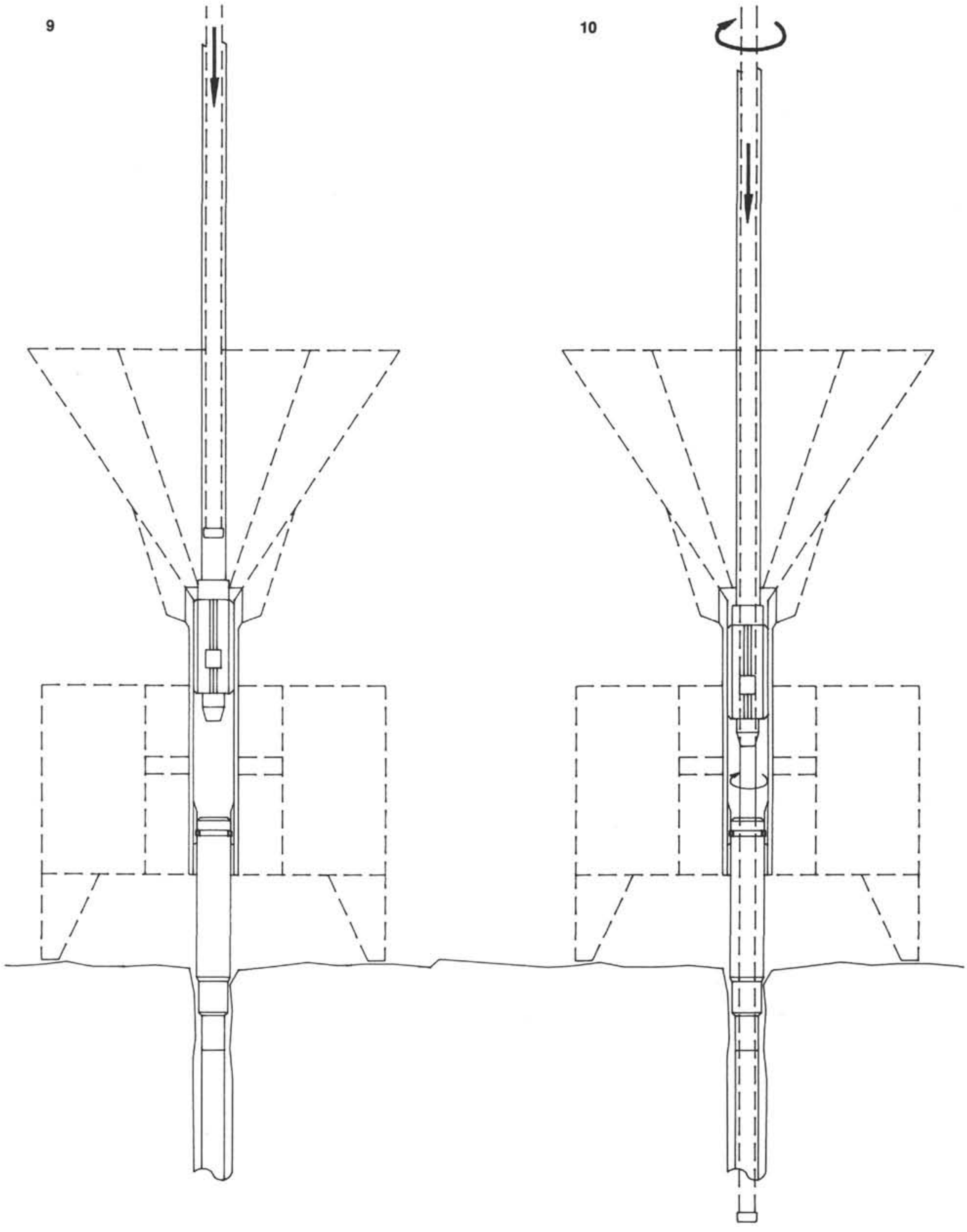


Figure 24 (continued).

operating at a higher pressure and rpm than when the pressure spike had been seen on the Hole 809D and thus not noticeable at all.

Shatsky Rise

The back-off sub was originally planned to be run as a tool for the Shatsky Rise location with limited drilling expected since it was to be inside the 16 in. casing. However, due to the unforeseen loss of the casing and the inability to retrieve the hanger to attach more, the complete BHA had to be drilled-in. Hole 810C confirmed the present of firm chalk to a penetration of 127.1 mbsf. The two other boreholes (810A and 810B) were drilled to establish a practical limitation as the depth that the 16 in. casing could be washed in and for some geriatric cores to be taken for an ongoing study at ODP. With these three holes drilled, we chose to set the BHA at a depth slightly less than the first chert layer. This would allow some DCS coring runs in the chalk to establish drilling parameters before encountering the interbedded sequences. Four stands of drill collars were chosen as a convenient length to drill-in. This represented a penetration depth of 111 mbsf for the tip of the BHA.

The reentry cone was entered and the BHA washed down with the PDCM at low flow rates. Marks on the pipe and visual observation with the VIT indicated that the nut on the back-off sub had landed in the proper location. The drill pipe was rotated to back-off the nut and then was picked up. However, upon lifting the string, no weight loss was seen, indicating that the back-off sub did not separate. Several more attempts were made at higher rotational speeds and with more weight on the landing seat, but the nut would still not separate. It was concluded there might be several reasons causing the back-off nut not to separate. These included: (1) the nut had been torqued too high (> 6,000 ft-lb) when rebuilt on the rig, (2) the landing seat had sheared from its key slots and was rotating with the nut, (3) the C-ring had somehow jammed in the groove and would not allow the nut to advance or make contact with the landing seat, and (4) the internal threaded ring had been damaged and would not disengage.

Since the PDCM could generate only 6,000 ft-lb of torque at peak operating conditions, it was thought that some additional torque might be need. Therefore, the PDCM was immobilized by locking it with steel balls dropped into a splined sub within the motor housing. Additional torque was gained from this procedure, but there was still no weight loss recorded to give an indication the sub had separated. At this point, the only alternative was to recover the assembly and see if there was any apparent reason the nut would not separate.

Upon recovery, the back-off sub was intact, including having the landing seat snapped onto the C-ring. This confirmed that the nut was rotating with the landing seat. Apparently the keys (rotational restraints) welded into the casing hanger to prevent this from happening had failed. The back-off sub's nut was then broken-out on deck to ensure that it was not made up too tight. Break-out torque was less than 6,000 ft-lb. It was rotated another three-quarter turn to ensure that it was not causing the problem. The landing seat was square on the nut also indicating that it was properly latched.

Since the key slots had sheared, some method had to be devised to hold the landing seat in the casing hanger so as to allow the nut to unscrew. The tolerances between the diameter of the landing seat and casing hanger were less than 1/4 in., making possible welding of hardfacing onto the O.D. of the landing seat. It was thought that this might allow enough friction to be developed between the landing seat and the casing hanger to let the back-off nut unscrew.

Vertical beads of hardfacing material were applied in a tapered fashioned around the landing seat and along the bottom in a radial outward pattern. The hardfacing, together with leaving the nut unscrewed about three-quarter turn, was felt to provide about as good a solution as any other, in lieu of recovering the reentry cone and welding the seat to the hanger. The time remaining in the leg at this point would probably only allow 1–2 days at most for the DCS, given no further operational problems in establishing a hole. It should be mentioned that the landing seat used at the Bonin location had been welded into the casing hanger and that to date no problems of this nature had been experienced with the back-off sub/landing seat.

The nut required 12 complete turns in order to separate. (This would require less than 12 s of elapsed time to back-off the nut with drill pipe rotating at 60 rpm.) The BHA was then tripped back into the hole with the PDCM removed from the string so that the full amount of torque from the top drive could be applied if required. The seat was again landed in the same location and rotated in attempts to back-off. Continued rotation, along with various other drilling techniques, did not produce the desired result of backing off the sub. Therefore, so not to waste any additional time, the effort was abandoned. However, in attempting the pull out of the casing hanger, the drill string became stuck. It appeared that the back-off sub/landing seat was hanging up on something inside the casing hanger or that repeated attempts in landing on the nut/landing seat may have flared the landing seat itself. After repeated attempts of jarring up, the back-off nut and landing seat finally worked free.

Once on the rig floor, the back-off sub was disassembled. It was revealed that it had properly backed off within the landing seat. However, it was being held by a mechanical wedge/heat fusing between the tapers on the nut and landing seat. Once broken-out with the rig tongs, the landing seat and C-ring were free to rotate about the lower sub. The internal threads used to back-off the nut were in good shape. The only damage reported was at the lip where the first thread started on the internal ring. It was slightly galled about one-quarter turn. However, this type of damage had also been seen on the other back-off subs as well after inspection.

It was surmised that the landing seat keys failed before the back-off sub had an opportunity to unscrew on the first attempt. Then, during the second attempt when locked together with the C-ring, the friction generated enough heat from continued rotation and repeated attempts to force the two pieces together (so that they could separate) that they actually wedged/fused together. The high torque and fact that the nut/landing seat were stuck when attempting to remove them from the casing hanger now appears to prove the above surmise. The repeated attempts of dropping/ramming the nut into the landing seat forced the seat to flare, causing the pipe to become temporarily stuck. This generated high torque in that the flared portion of the seat was being milled on the inside of the hanger until enough material was worn away so the landing seat was again able to rotate freely.

With this known, another back-off sub and landing seat were made up and rerun into the hole. It was felt that with all the pumping and rotation on the two previous attempts that the formation might be highly disturbed beneath the bit, so another 15 m of drill collars was added to the BHA. This would ensure that the DCS tubing would be laterally supported when encountering the chert. A new landing seat was again prepared with hardfacing to provide the wedging action/rotational restraint required so that the nut could be backed off.

Drilling down the additional 15 m began as soon as the bottom of the hole was tagged. The VIT frame had been pulled as the top drive was being used, so real-time viewing of the nut/landing seat entering the cone was not possible. However, as soon as the landing seat touched down, a sudden loss of weight (approximately 50,000 lb) occurred as the back-off sub unscrewed.

It was felt that the BHA was in the proper position; this was reconfirmed when the cone was again entered and the pipe tagged to check depth measurements. Since the PDCM was not in the string, the center bit could be retrieved through this assembly so another reentry would not be required until the DCS was ready to put into service.

The attempt at retrieving the center bit was not successful because the sinker bar was unable to pass an obstruction at 33 mbsf. Attempts to recover the center bit were finally aborted after several hours of inability to lower the sinker bar assembly below this depth. Upon recovery of the back-off sub, it was discovered that the landing seat was still attached and that the nut had again fused itself into the tapered seat. Then it was realized what had actually happened; modifications to the C-ring and landing seat used on this deployment, though not intended for this application, were run together. This rendered the C-ring ineffective and allowed the BHA to slip through the groove it was intended to snap into.

The modification to the landing seat consisted of enlarging the internal diameter. This effectively lead to decreasing the contact area for the C-ring. This modification was intended to allow more annular clearance for the BHA while drilling through the mini-HRB for hard rock applications where the C-ring was not required. The second modification entailed machining a small bevel on the face of the C-ring itself. At one time it was thought that the C-ring was causing part of the problem by not allowing the back-off nut to come into contact with the landing shoulder. Therefore, a small bevel was made on the leading face to help in centralizing the C-ring. While both modifications were intended to serve a specific purpose, their use together lead to the BHA slipping through the landing seat.

Observations

The following list gives some general observations learned from the field tests with the back-off sub:

1. The upper stabilizer may have worked as a bearing in a non-vertical hole (809C), thus allowing the sub to just spin as it hung up on the casing hanger lip,
2. The tool was built very ruggedly to withstand handling on the rig floor and hard rock drilling,
3. Drilling torque on the PDCM was higher than expected for the output suggested by the flow rates used,
4. The tool withstood hard rock drilling over 14 hr on a single bit run,
5. Little or no drilling penetration may indicate hole inclination or excessive tilt of the HRB (Holes 809C and 809E),
6. The PDCM produces more whiplike effect, thus flexing the drill string, than earlier thought,
7. Drilling vibrations do not seem to have an effect on decoupling the back-off nut,
8. The tool remained intact after repeated entries through the throat of the casing hanger on the same bit run (809E) and with overpulls of 25,000 lb,
9. The tool is easily reassembled in the field,
10. In order for the tool to work properly, the gimbal on the HRB had to be free to pivot so the casing hanger would not bind against the BHA when it was entering the casing hanger,
11. No problems were experienced with alignment of the BHA and the tensioning tool (both the center bit and the tubing passed without any weight indication recorded),
12. It would be helpful to have a spacer/centralizing ring on the snap ring,
13. The landing seat could be effectively anchored using a built-up surface of hardfacing without having the benefit of the key slots,
14. Continued rotation of the nut on the landing seat with the C-ring engaged most likely will cause a mechanical wedge/heat fusing between the two parts,
15. Reduction in contact area of the landing seat coupled with the addition of a small bevel on the C-ring allowed the BHA to pass through and not be held as designed.

Suggested Design Improvements

There were a few areas where the design of the back-off sub could be improved. These minor deficiencies could only have been discovered during field applications. While the tool was not successful on every deployment, it is probably correct to say that it was some other component or piece of equipment failure which prevented the back-off sub itself from working as designed. The following list gives areas where some improvements should be made.

1. Tight tolerances designed into the landing seat and lower body should be relaxed. Dimensions between these two parts should at a minimum of 0.375 in. annular clearance.
2. Additional protection to the back-off nut so that premature back-off will not occur should be further investigated.
3. The upper rotating stabilizer may need to be eliminated in favor of a rotating-type stabilizer with a longer taper on both sides for certain applications.
4. The short-stepped diameter increases of the lower sub should be increased to give a more tapered appearance.
5. Even though separation due to drilling vibrations has not been a problem, some additional testing is needed for the back-off nut assembly along with its mating receptacle and a PDCM. These tests should include measuring the force to break apart the nut and landing seat after they have mechanically fused together.
6. Thread protectors should be made for the square-shouldered threads on the lower sub.
7. Dimensional checks for quality control on all components should be made and signed for by the manufacturer.
8. The snap ring should be modified to include a centralization ring so it will maintain a positive alignment.
9. The position of the snap ring groove should be lowered so it will not engage until the nut has backed off.
10. The taper angle on the mating receptacles needs to be reexamined and some additional testing performed under different loading applications.

Conclusions

In general, the overall performance of the back-off sub proved reasonably successful on the first time in the field with only one shakedown test before being sent to the *JOIDES Resolution*. Its ruggedness in design proved to withstand hard rock drilling as well as working exceptionally well as a running tool. Three deployments were made at the Bonin location; the second and third were successful. The first test is questionable since the casing hanger came in contact with the back-off nut as it was drilled-in.

The deployment at Shatsky Rise, though not totally successful, did provide a considerable amount of information which will be helpful in modifying the tools for future service. It is felt that with some minor changes to the back-off sub it will be a viable tool to complement the DCS in providing a stable cased hole in which to begin coring.

It is not felt that 50–100 m of BHA could be deployed in this manner with the present tool for hard rock formations. However, it was demonstrated that it is quite feasible for sediment/reentry cone deployments. Not being able to drill the tool to the desired depth is not thought to be caused by the tool design or any deficiencies but rather in the other hardware that complement it; the most notable components being the roller cone core bits and center bits. However, it is not out of the question to expect that 10–20 m of penetration is feasible with the present bits now designed for hard rock spud-in.

The same back-off concept could possibly be adapted when deploying a longer BHA in hard rock using a nested string inside the primary BHA. This would allow the BHA to be drilled to the 10–20 m depth; then drill a tubing/casing string inside of it with a smaller version of the back-off sub. This would provide a cased hole much deeper than presently thought feasible for the life expectancy of the roller cone bits. The back-off tool as it is now designed would need slight enlargement so there would still be enough clearance for the intermediate string and DCS tubing to pass. It is recommended that this concept be studied for future use where there is a need to begin the DCS at a much deeper depth for a hard rock spud-in.

TAPERED STRESS JOINT

General Description And Design Formulation

The TSJ was designed to provide two primary functions for use with the DCS drill string riser. First, it provided a smooth transition in bending stiffness from the bottom of the riser to the seafloor template, and, second, it provided a mechanical fuse to release the riser from the seafloor template in a drive-off situation.

The TSJ is approximately 33 ft long with a 5-1/2 in. F.H. box connection on one end and a 16 hole flanged connection on the opposite end. The flanged connection is grooved for an API BX-156 stainless steel gasket. The high-pressure seal was included in the design so that returns could be directed through the annulus between the DCS tubing and the riser string if desired. The body of the TSJ was machined from a single piece of 4140 stock. The flange was welded on after initial machining of both the body and flange section. Final machining of the inlay groove and the flange were completed once the weld had passed all inspections. Taper of the body section is 0.104 in./ft. Since the flanged connection rode on the tensioning tool, it had to be the same diameter so both would pass the throat of the casing hanger while latching in. This required a special flange be cast since standard API flanges were several inches larger in diameter. The design of the tapered stress joint is illustrated in Figure 25.

The stress joint was designed to control the bending at the bottom of the riser so that a minimum bend radius would be maintained. This was to prevent excessive fatigue to the DCS tubing inside. The design bend radius maintained was 350 ft. The second design feature of the TSJ was to serve to release the riser from the guide base. This was accomplished with 16 shear bolts placed with a 12-3/4 in. diameter.

The shear bolts were 6-1/2 in. long, 1/8 in. × 8 unc. with a standard hex head design. Material used for the shear bolts was ASTM A193 grade B7 with a minimum yield of 105,000 psi. The shear bolts were necked down to a 1 in. radius 1/2 in. below the bolt head. The design breaking strength of each bolt was 76,000 lb. The machined stress joint bolt design is presented in Figure 26.

The parameters the mechanical fuse was designed for while maintaining a bending radius of greater than 350 ft were: (1) an axial load of 90,000 lb and (2) a 2,000 in.-kip bending moment. Parting loads were calculated at an axial load of 111,000 lb with a 2,480 in.-kip moment. A schematic of the loading conditions for the stress joint are presented in Figure 27.

Stress Joint Design

The actual stress joint dimensions were arrived at from a dynamic response analysis performed by Alan Bryant & Associates with the aid of several computer programs specially designed for deep water risers. This analysis investigated both the lateral and axial response of the mini-riser as it was envisioned to operate for the DCS. Results of these studies provided the reaction forces that would be seen at the seafloor under normal operating loads and for more severe conditions should the riser be unable to be unlatched. Nine different operating parameters and water depths were investigated. Water depths ranged from 1,500 to 4,500 m in 1,000 m increments. The riser make-up ratio was held constant for the various cases investigated. Results from the stress joint and lateral motion study are presented in Tables 1 and 2. Nomenclature used for the lateral study is presented in Figures 28–31.

Though not as critical as the lateral study in the physical design of the tapered stress joint, the axial study did provide results that were useful in checking parameters in its design. Two different axial studies were performed. The first analysis was made by Alan Bryant & Associates who performed the lateral analysis, and the other was done at ODP with a refined parameter input. Results from this study provided maximum and minimum dynamic stresses in the riser and axial stretch that the riser/stress joints might possibly be subjected to in different sea states. Input for the wave height/wave periods correlations used for class II type drill ships was taken from API publications. Results from the consultant's axial motion study are presented in Table 3 with parameter definitions illustrated in Figure 32. A more complete assessment of both the lateral and axial studies performed is presented in another report.

Evaluation And Performance

Field evaluation of the TSJ without use of any X-ray techniques is rather difficult since it has no moving or mechanical parts. However, it appears to have served its purpose even though it was subjected to only the minimal operating conditions for which it was designed. Vessel offsets during the entire leg were typically less than 1% of water depth. Therefore, the bending radius (350 ft) it was designed to maintain could not be fully tested. Due to the excellent dynamic-positioning system keeping the *JOIDES Resolution* on location the entire leg, the mechanical fusing between the stress joint and the seafloor template also never had to severed.

Connections on both ends mated properly without any handling problems by the drill crew. The shear bolts were changed after 329 hr of operation at the Bonin location. Though there was no indication of any problem, it was thought prudent to look at the shear bolts in case there were some visible signs of fatigue or other noticeable indications that the shear bolts/stress joint might be experiencing loads higher than suggested by the computer analysis. The stress bolts were saved for further examination by a materials consultant once they could be returned to Houston. It is also planned to make a thorough and complete pipe inspection of the TSJ with emphasis placed on the welded flange connection.

TENSIONING TOOL

Description Of Hardware

A breakaway tensioning tool (Fig. 33) was designed as part of the DCS seafloor component package. The tool is actually a modified jay-type running tool which is used to attach the riser (drill string) to the seafloor template (mini-HRB or reentry cone). Two levels of breakaway design have been incorporated into the tensioning tool. The first or primary level allows one 3/8 in. shear bolt in each of the four individual jay-lugs to shear and retract into the body of the tensioning tool. A bolt-in cage with a ramp design allows the individual lugs to slide down the ramp into the body of the jay-tool when the bolt is sheared. This is accomplished with an upward pull on the drill pipe exceeding the breaking

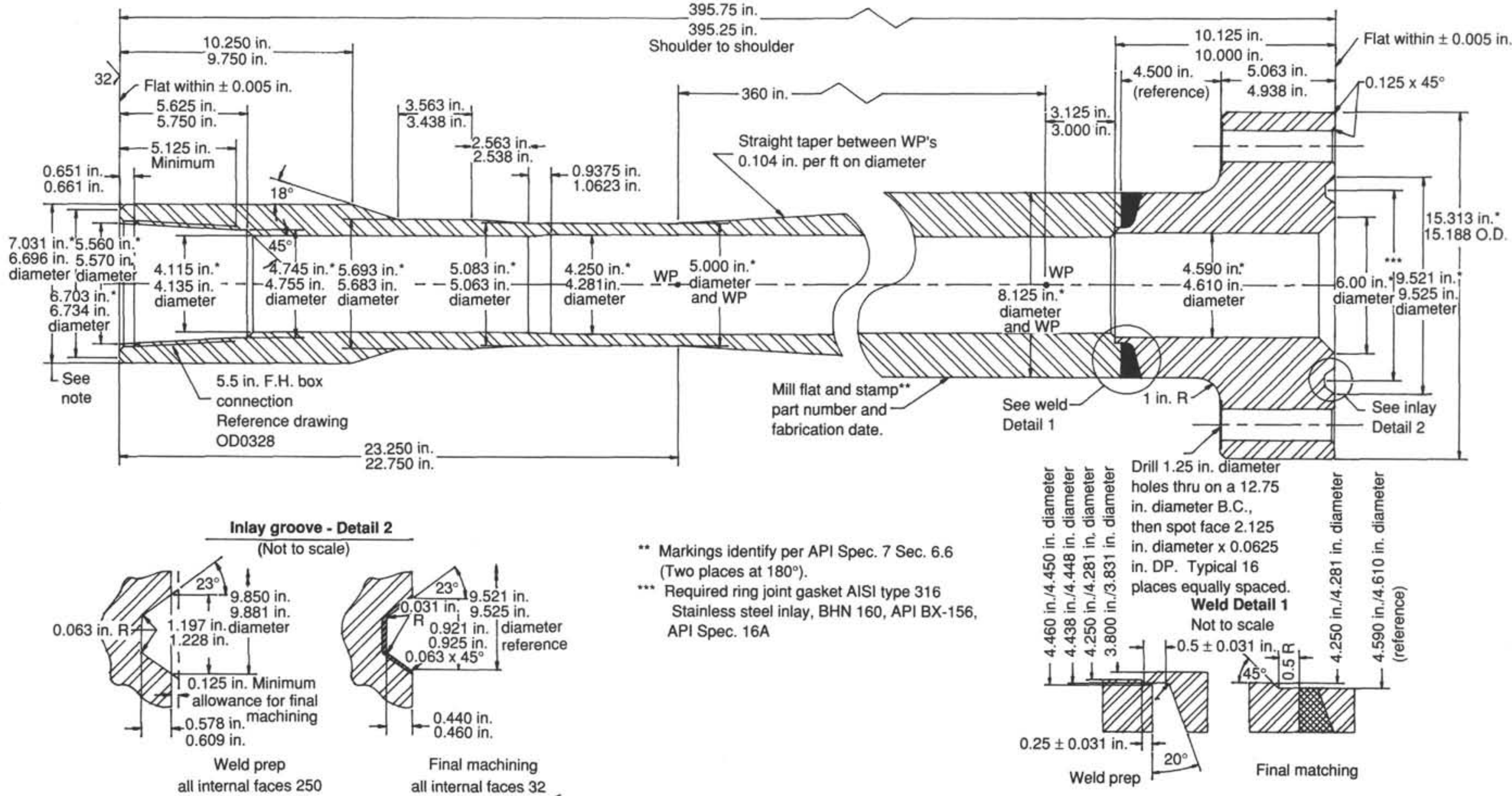
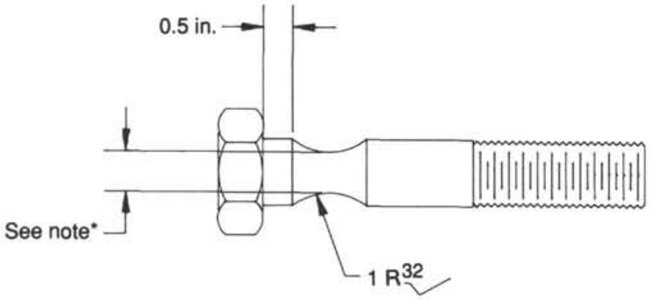


Figure 25. Tapered stress joint.



Bolt Description (OQ3757)

1.125 x 8 UNC x 6.5 large standard hex head ASTM A193 grade B7 (105,000 psi minimum yield)
Breaking strength of bolt to be established by use of machined neck as indicated
*Minimum diameter to be determined by mechanical testing of standard coupons machined from bolts of the same manufactured lot. Design breaking strength under pure axial tension to be 76,000 lb. Results from bolt material tests shall be provided.
Quantity required for tapered stress joint: 16
Reference drawing OQ3756

Figure 26. Tapered stress joint shear bolt (1-1/8 in. × 8 unc. × 6-1/2 in. large modified).

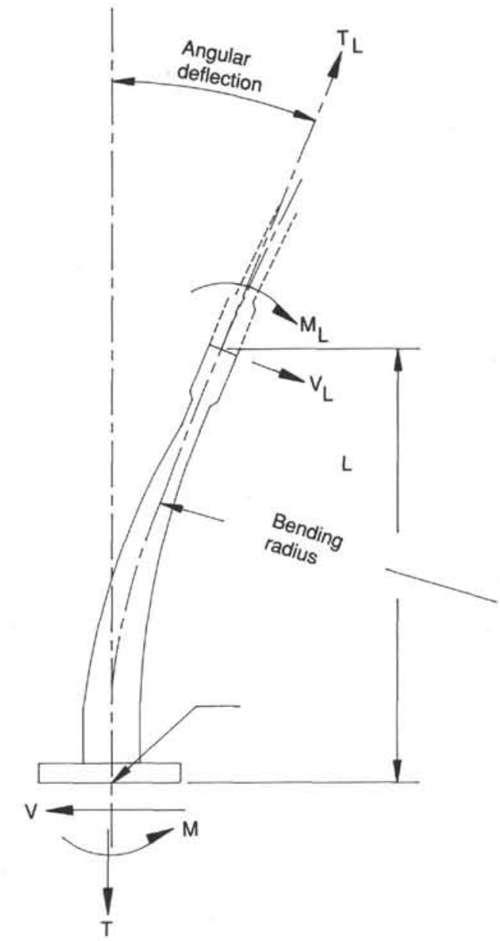
strength of the shear bolts. Four different strengths of bolts have been designed for different water depths; the shearing strengths range from 23,700 to 37,000 lb per bolt.

The secondary level in the breakaway design for the seafloor template, should an emergency situation arise, is through shearing of the flanged bolts at the top of the tensioning tool (Fig. 34). The flange connection which is part of the tapered stress joint is attached to the tensioning tool with 16 1-1/8 in. shear bolts. These bolts are necked down in varying diameters to allow different break-out strengths. This method was chosen as a back-up since shearing of these bolts is a more complex event should a drive-off situation occur. Also part of the flanged connection is a BX ring gasket groove cut into both mating receptacles. This high-pressure type gasket was incorporated into the design for sealing the drill string if drilling fluid and cuttings returns are desired to be brought back to the surface in the future.

If the tension tool lugs are sheared, the tool must be brought back to the surface for the jay-lugs to be repositioned and new shear bolts installed. Should the secondary method of releasing the seafloor template be used, then a fishing trip will be required to retrieve the tensioning tool left in the casing hanger. To aid in the fishing operation, a 5-1/2 in. F.H. box connection was installed into the body of the tool itself. The tensioning tool also has a 5-1/2 in. F.H. pin connection on the lower end. This was incorporated into the design for possible attachment of a seal sub at a later date so that returns to the surface would be possible if so desired.

Assembly Procedures

The tool was shipped from the manufacturer with the cages housing the shearable lugs and preset shear bolts already installed. These bolts were rated for 33,400 lb each. The attachment to the tapered stress joint was made with 16 1-1/8 in. shear bolts. The bolts were originally coated with a light film of lubricating oil before being tightened to 600 ft-lb of torque as suggested by the manufacturer. However, after the TSJ was returned from the first trip to the seafloor, several of the bolts had worked loose. This was after only a few hours in the water. It is unclear why these



Design values

Case	M(ink)	T(K)	Stress (psi)	Bending radius (ft)
Normal operating	2,000	90	72,000	350
Parting	2,480	111	120,000	-----

Figure 27. Stress joint loading conditions.

bolts came loose in the limited amount of operating time. Therefore, in order to safeguard against the bolts becoming loose on further subsequent deployments, a different assembly procedure was adopted. The assembly procedure included the following steps:

1. Clean both mating flanges, bolt holes, and tensioning bolts.
2. Coat bolt threads with blue "Lok Tight,"
3. Hand-tighten all bolts,
4. Tighten all bolts to 300 ft-lb torque using a star pattern sequence,
5. Retighten all bolts to 600 ft-lb torque,
6. Place a small tack weld on the flange next to the nut to prevent back-off, and
7. Wait 45–60 min for the "Lok Tight" to harden.

No problems were encountered either in handling or make-up of the tool.

Field Performance

The first time the tool was deployed on Hole 809C, it was didn't latch in. This was due to the BHA being backed off too high in the throat of the casing hanger preventing the tool from entering the jay-slot until the hanger could be cleared. Because of the other operational problems with this hole, it was aborted without further attempts at latching in with the tensioning tool.

The second time the tool was deployed was on Hole 809D. The tool entered the casing after taking several hard bumps during reentry operations. It appeared to jay-in and took 40,000 lb of overpull. This pull was held for approximately 20 min while attempts were made to retrieve the center bit with the wireline winch. After being released from tension, the tool was rotated and then pulled out of the hanger. As the tool cleared the hanger it appeared that one of the jay-lugs fell off and into the hole. With the tool on deck, the amount of damage revealed total failure of the four bolt primary shear-out device. One jay-lug was missing along with one side of the assembly cage. Further investigation revealed that poor workmanship and welding technique probably were the primary causes of failure. The tool may also have been underdesigned for the amount of torsional and dynamic loading it underwent when being unlatched.

The second tensioning tool was checked, and it also revealed poor quality workmanship. It was decided that one mechanical fuse was probably enough should a situation arise where the vessel had to pull off the location. Therefore, the retractable shear lugs were welded to make them inoperable, and additional gussets were added to strengthen the tool for torsional loading. The tool could now be run as a conventional running tool without the TSJ attached or as intended, but with only one way to shear off from the seafloor template.

The modified tensioning tool was redeployed on Hole 809D after welding the lugs. It was latched in and tension imposed to 40 kip while an attempt was made to retrieve the center bit. Three reentries were made during this process. A 2–2.5 m heave was being experienced while all of these reentries were being made. After several attempts at trying to latch onto the center bit it was concluded that the jay-lug lost from the previous tool was in the throat of the BHA and that further time spent trying to retrieve the center bit was futile. The tensioning tool was then put to another test by lifting the HRB (approximately 130 kip) over the BHA and moving it to another site. Once back on deck, the welded connections were magna-fluxed to see if any cracks had developed. Results indicated that no cracks were present after subjecting the tensioning tool to the higher loading conditions. Hole 809E was drilled after moving the guide base to another location several meters away. This hole also was aborted due to drilling difficulties in lowering the BHA to termination depth caused by a tight hole when the base shifted. The HRB was again moved with the tensioning tool being substituted as a running tool. The final testing point at the Bonin location was Hole 809F. The tool was then put into service reentering the cone with the TSJ attached. The center bit was retrieved without any noticeable overpull indication on the wireline winch. This indicated there was not any misalignment between the tensioning tool and the lower sub remaining after backing off in the landing seat. This was later reconfirmed with successful passage of the DCS tubing string and core barrel assembly.

The tensioning tool was deployed for two continuous periods throughout the leg while the DCS coring operations were underway. These consisted of:

1. Initial tensioning at Bonin—183.5 hr.
2. Retensioning after a bit change—145.5 hr.

The shear bolts were removed after this combined period of operation and new bolts installed for the Shatsky Rise location. However, due to some operational problems with the reentry cone, the tensioning tool was never deployed at this location.

Suggested Design Changes and Improvements

The primary improvement which should be incorporated into the tensioning tool design is elimination of the mechanical shear lugs. After the field experience gained on the leg, it is now felt that only one release mechanism is needed. The idea of two sets of releases provides an added degree of confidence, however, it also adds a greater degree of complexity to the hardware that may not be needed. The elimination of the shear dogs will not only make the tool less complicated and easier to manufacture, but remove any doubt associated with the breaking strength of the small shear bolts used to hold the lugs in position. This would also allow it to serve for more than one purpose or operation if the situation arises where it is needed as a running tool.

Overall strengthening for torsional loading should be easily incorporated into the tool with a single body construction. The length of the tool proved to work well within the constraints existing inside the casing hanger between the bottom of the jay-slots and the top of the drilled-in back-off sub. It is recommended that the compactness of the tool be retained in future designs.

The flanged connection also worked quite well. It was found that it can be made-up prior to being needed so that valuable rig time is not wasted in its assembly. It is also recommended that the conversion of the four shear bolts holes should be studied to possibly better serve as torsional restraints when the tool is rotated to jay-in. Some type of positive thread protector should also be designed to protect the pin connection when not attached to a lower BHA. Conventional protectors with open holes cut in the end for the DCS tubing to pass could be damaged or lost in reentry and tensioning. Depending upon the configuration and/or design of the next tensioning tool, a thorough analysis of both dynamic axial and torsional loading cases should be investigated.

FUTURE CONSIDERATIONS FOR SEAFLOOR HARDWARE

It has been demonstrated on several occasions that it is technically feasible to begin drilling operations on bare rock formations with the aid of a seafloor template and the PDCM. However, hole stability problems usually require casing to be set. Setting a casing string itself was time-consuming and sometimes gave rise to more formation problems as the hole became larger.

Drilling difficulties and hole stability problems will continue to play a big role in achieving the desired results when attempting to spud a borehole and core into young fractured basalts. However, some significant steps have been taken on this leg which may provide a basis for a new direction or methodology to eliminate many of the problems encountered in the past. While drill-in casings are not new, this concept has never been effective in hard rock. The techniques adopted here combined with a back-off type of drill-in BHA promises some possibility in the future in attempts to spud and core into young fractured basalts.

An effective solution to this problem will require continued research efforts and testing in order to provide a system that will be rugged and adaptable to difficulties encountered while attempting to drill and core in highly unstable formations. Several areas where research should be directed and continue include:

1. Development of a multistage or nested drill-in BHA apparatus,
2. Refinement of the mini-HRB to be more adaptable for steeper slopes, different seafloor topography, and more versatile applications,
3. Incorporate a return mud circulation system as part of providing better hole stability after the initial drill-in string is set,

Table 1. Results of lateral motion analysis; nomenclature given in Figures 28–31.[a]

	Case definition						Results					
Case number	WD (ft)	L_0 (ft)	T_1 (kip)	V	δ (%WD)	H (ft)	To (kip)	ϕM (°)	σ_1 (ksi)	σ_2 (ksi)	σ_3 (ksi)	σ_4 (ksi)
1	4920	235	130	1	3	0	37.8	3.20	16.6	23.7	19.1	21.0
2	4920	235	180	1	5	0	87.8	4.30	22.9	31.2	26.8	35.0
3	8194	1035	205	1	3	0	45.1	4.02	26.1	32.8	23.8	26.1
4	8194	1035	250	1	5	0	90.1	5.27	31.8	41.3	29.7	43.6
5	11472	3000	300	1	3	0	65.3	4.32	38.2	40.9	24.2	33.2
6	11472	3000	330	1	5	0	95.3	6.10	42.0	46.5	30.2	52.1
7	14752	4600	375	1	3	0	67.9	4.97	47.7	45.7	25.5	39.0
8	14752	4600	415	1	5	0	107.9	6.66	52.8	53.2	31.5	60.8
9	4920	235	130	1	3	19.0	37.8	3.43	16.6	23.9	22.0	20.3

[a] WD = water depth (ft). L_0 = Length of 5½ in. drill pipe. T_1 = Top tension, (kip). V = Current profile. δ = Horizontal offset, (ft). H = Wave height (ft). T_0 = Tension at stress joint derived from analysis. ϕM = Angle developed by offset and boundary conditions.

Table 2. Stress joint analysis results; nomenclature given in Figures 28–31.

Case number	Water depth (ft)	Offset δ (°)	Shear V (kip)	Tension T (kip)	Moment M (in.-K)	Angular deflection (°)	Stress σ (ksi)	Bending radius (ft)
1	4,920	3.0	2.95	33.6	797	3.20	21.0	433
2	4,920	5.0	7.57	83.6	1510	4.30	35.0	327
3	8,194	3.0	4.21	40.9	1070	4.02	26.1	381
4	8,194	5.0	9.45	85.9	1870	5.27	43.6	265
5	11,472	3.0	5.99	61.1	1330	4.32	33.2	353
6	11,472	5.0	11.47	91.1	2220	6.10	52.1	223
7	14,752	3.0	7.09	63.8	1560	4.97	39.0	305
8	14,752	5.0	13.92	103.8	2560	6.66	60.8	193
9	4,920	3.0	3.10	33.6	835	3.43	20.3	397

Notes. V, T, and M are defined in Figure 27. Angular deflection is at top of stress joint. Stress is stress intensity at bottom of stress joint (maximum value). Bending radius is minimum value over length of stress joint and adjacent drill pipe.

4. Pursue the concept of a reusable HRB to reduce both project costs and the amount of hardware needed for attempting multiple holes on a single leg,

5. Adapt different sampling and coring techniques to the diamond coring technology to provide a more versatile suite of sampling tools (i.e., mechanical piston sampler, sidewall corer, lateral stress probe/pressure meter, etc.),

6. Investigate and/or adapt equipment being developed by other companies or countries for taking seafloor cores with a self-contained coring system,

7. Pursue association/work with drilling mud and/or chemical companies in developing or trying new techniques or injections to stabilize formations,

8. Continue open dialogue with bit manufacturers to test and develop longer-life bit components and/or designs,

9. Develop drill bits which use a high-pressure water or mud source as the drilling medium (i.e., no mechanical parts to wear out).

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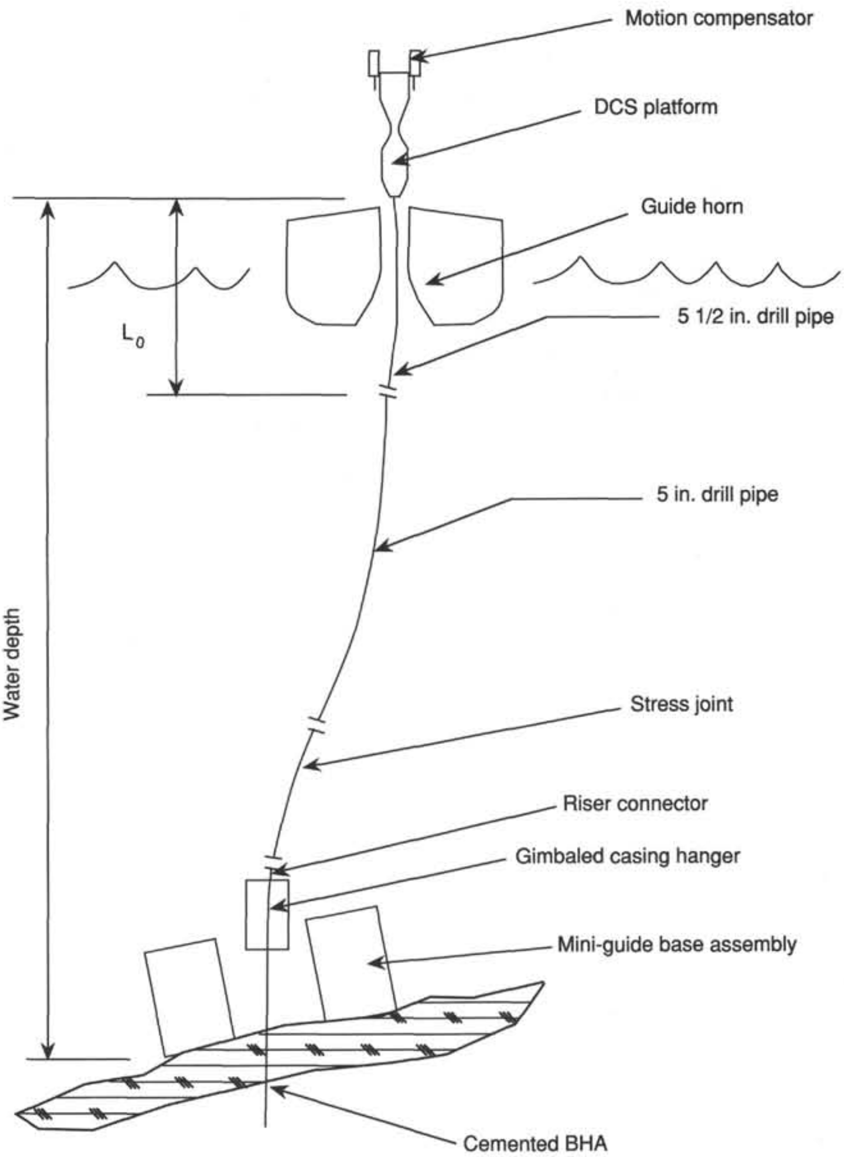

Figure 28. General riser arrangement.

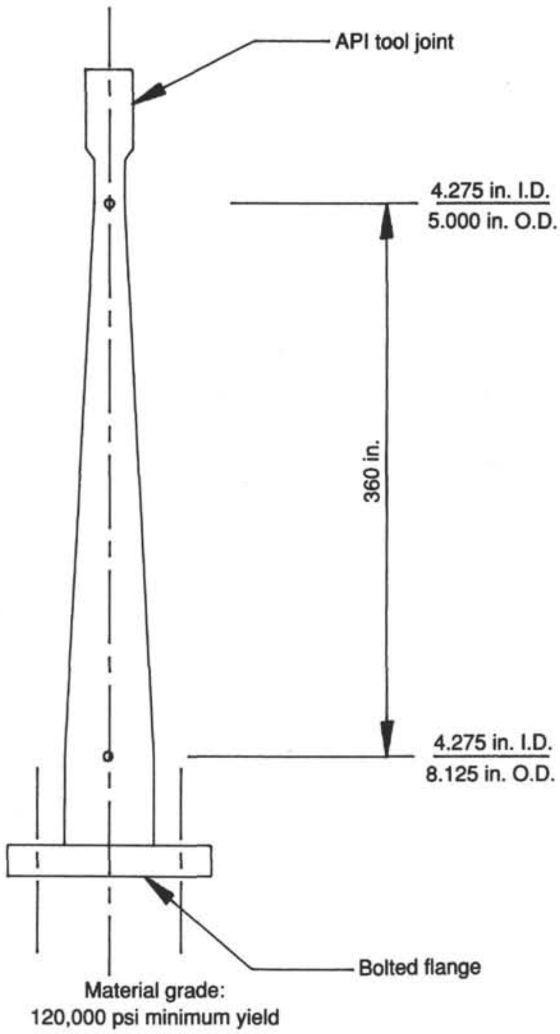

Figure 29. Stress joint configuration.

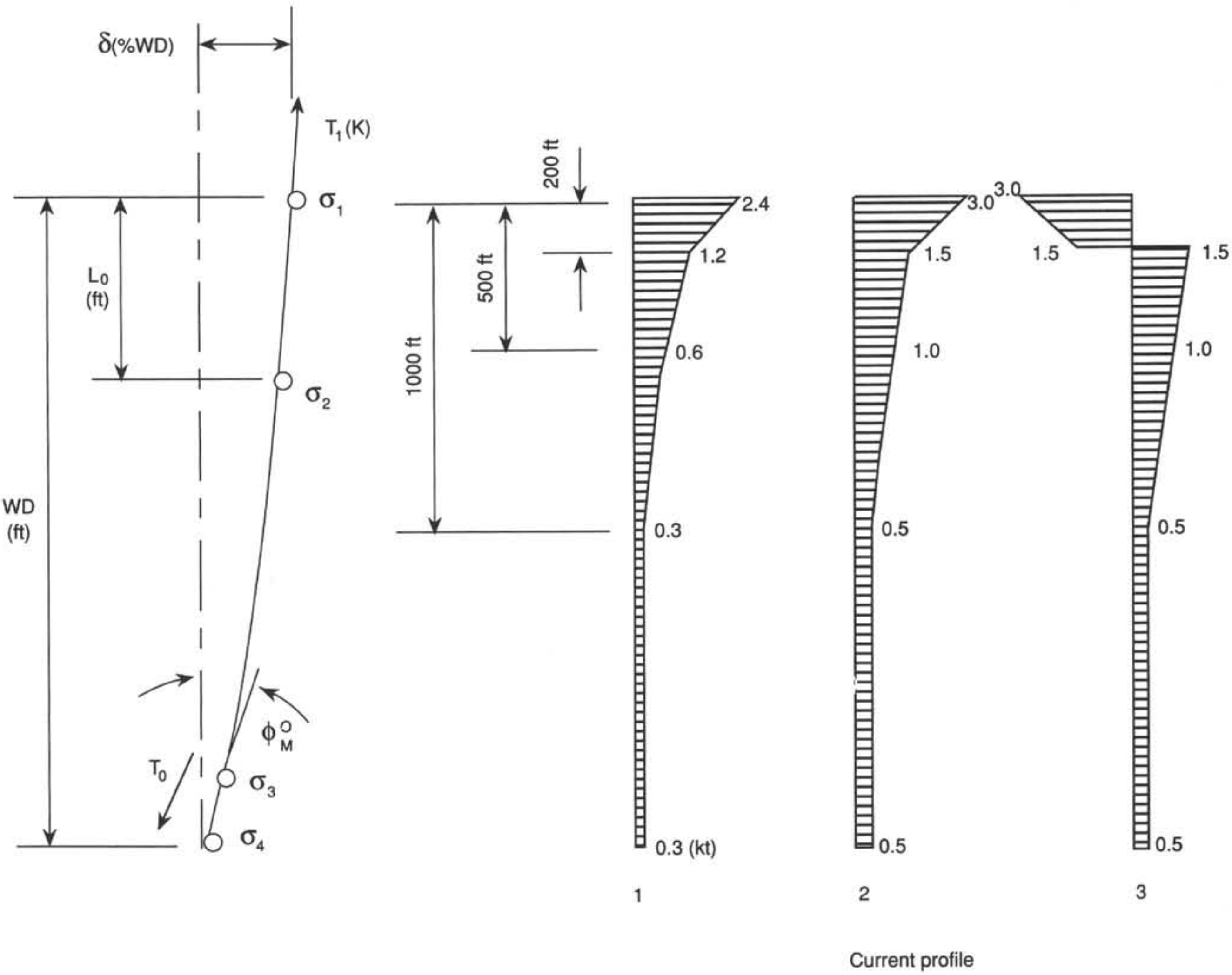

Figure 30. Definition of lateral parameters.

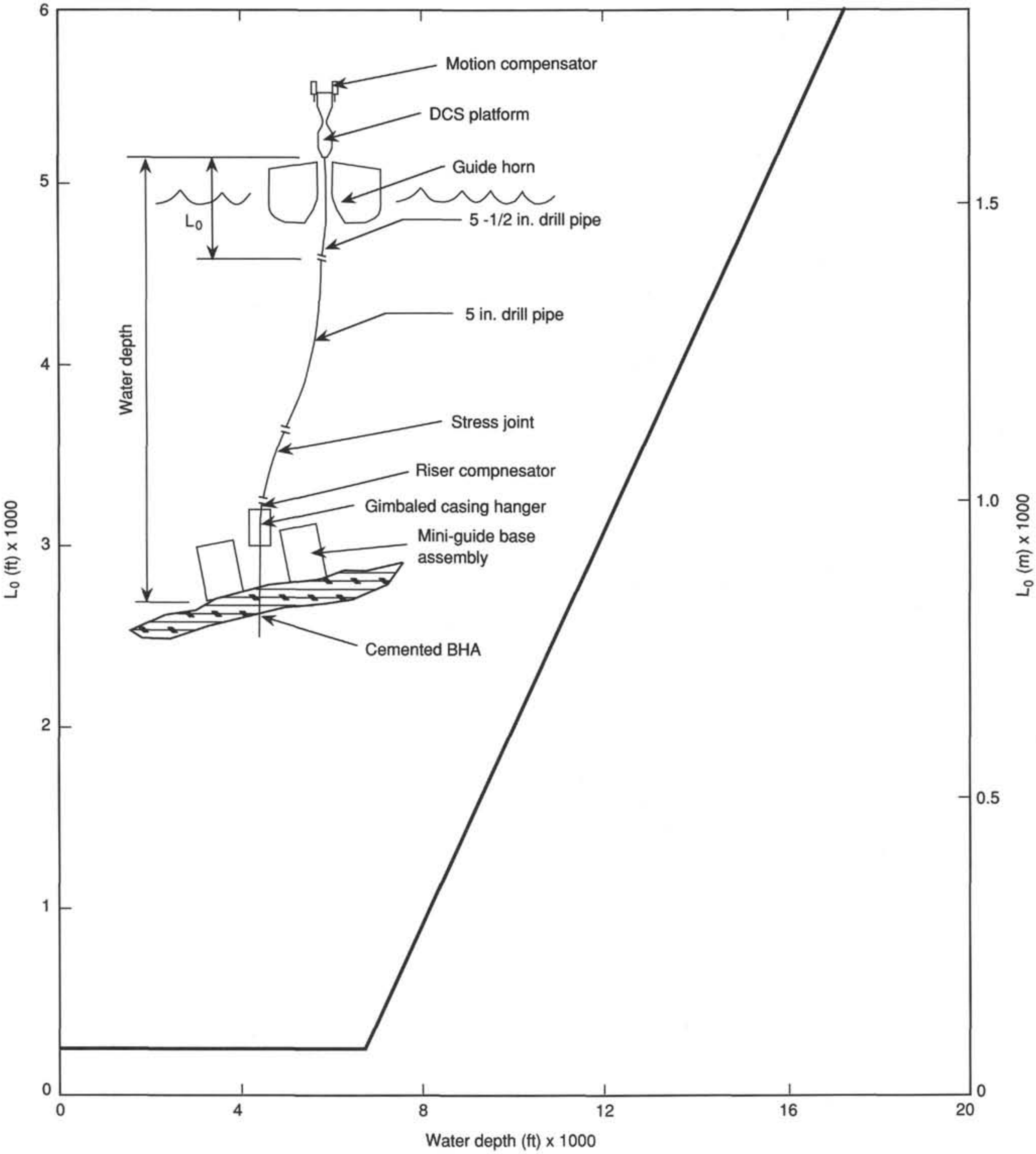

Figure 31. L_0 vs. water depth.

Table 3. Axial motion response results; parameters further defined in Figure 32.[a]

T (s)	H (ft)	Ω (1/s)	Z_o (ft)	P_{max} (kip)	P_{min} (kip)	Z_b (ft)	Z_b/Z_o
L = 8,200 ft							
4.0	3.0	1.571	0.20	338	225	2.03	10.15
6.0	5.0	1.047	0.90	313	280	1.55	1.72
8.0	11.0	0.785	2.00	314	279	2.63	1.32
10.0	15.0	0.628	4.30	319	274	5.08	1.18
L = 11,480 ft							
4.0	3.0	1.571	0.20	412	382	0.72	3.60
6.0	5.0	1.047	0.90	427	367	2.36	2.62
8.0	11.0	0.785	2.00	422	372	3.12	1.56
10.0	15.0	0.628	4.30	428	366	5.60	1.30
L = 14,760 ft							
4.0	3.0	1.571	0.20	491	482	0.28	1.40
6.0	5.0	1.047	0.90	587	386	7.42	8.24
8.0	11.0	0.785	2.00	524	448	4.12	2.09
10.0	15.0	0.628	4.30	528	445	6.52	1.52

[a] T = Heave period. H = Corresponding wave height. $\Omega = 2\pi/T$. P_{max} = Maximum dynamic tension. P_{min} = Minimum dynamic tension. Z_o = Single amplitude heave. Z_b = Single amplitude guide base motion.

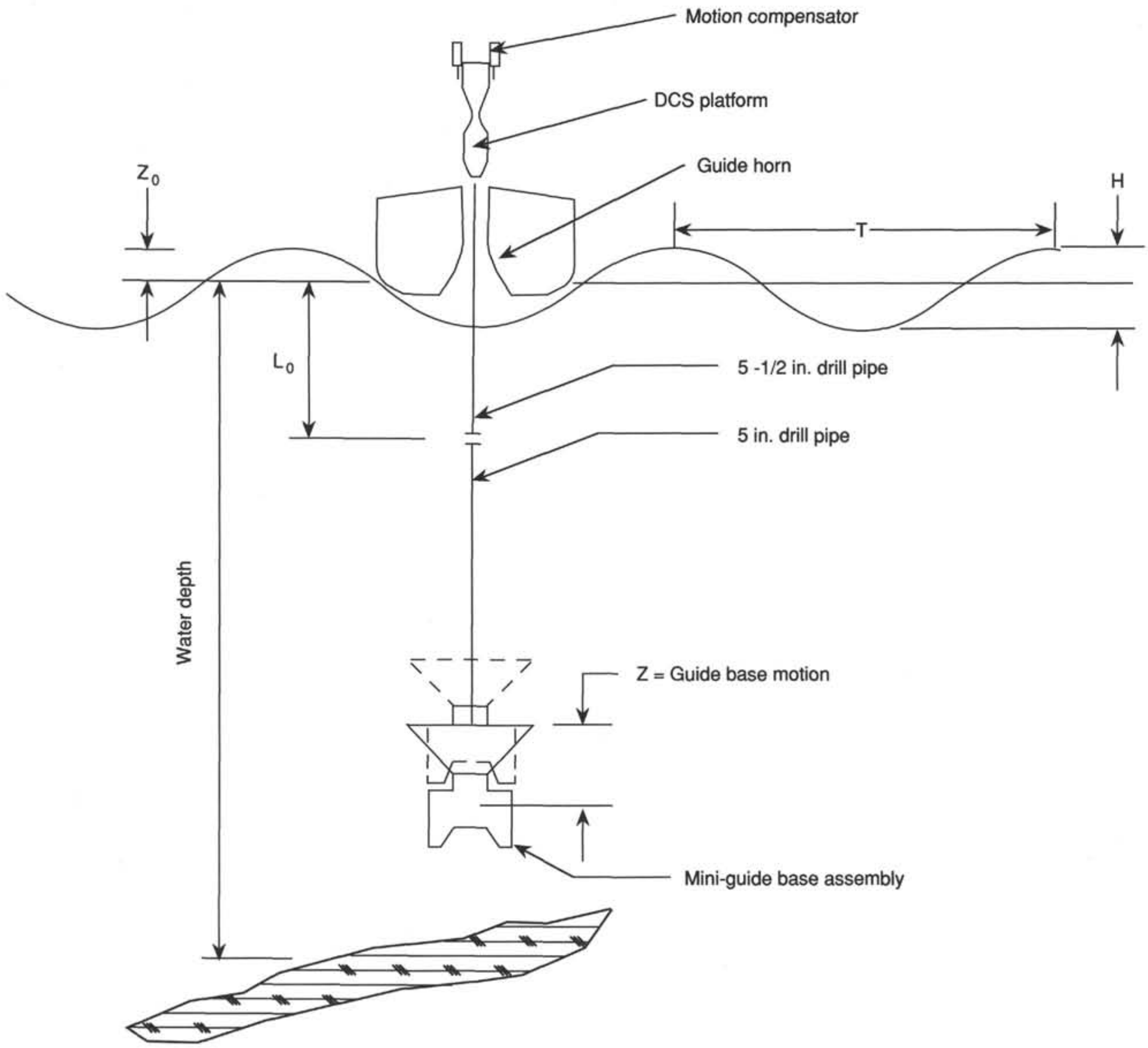

Figure 32. Definition of motion analysis parameters.

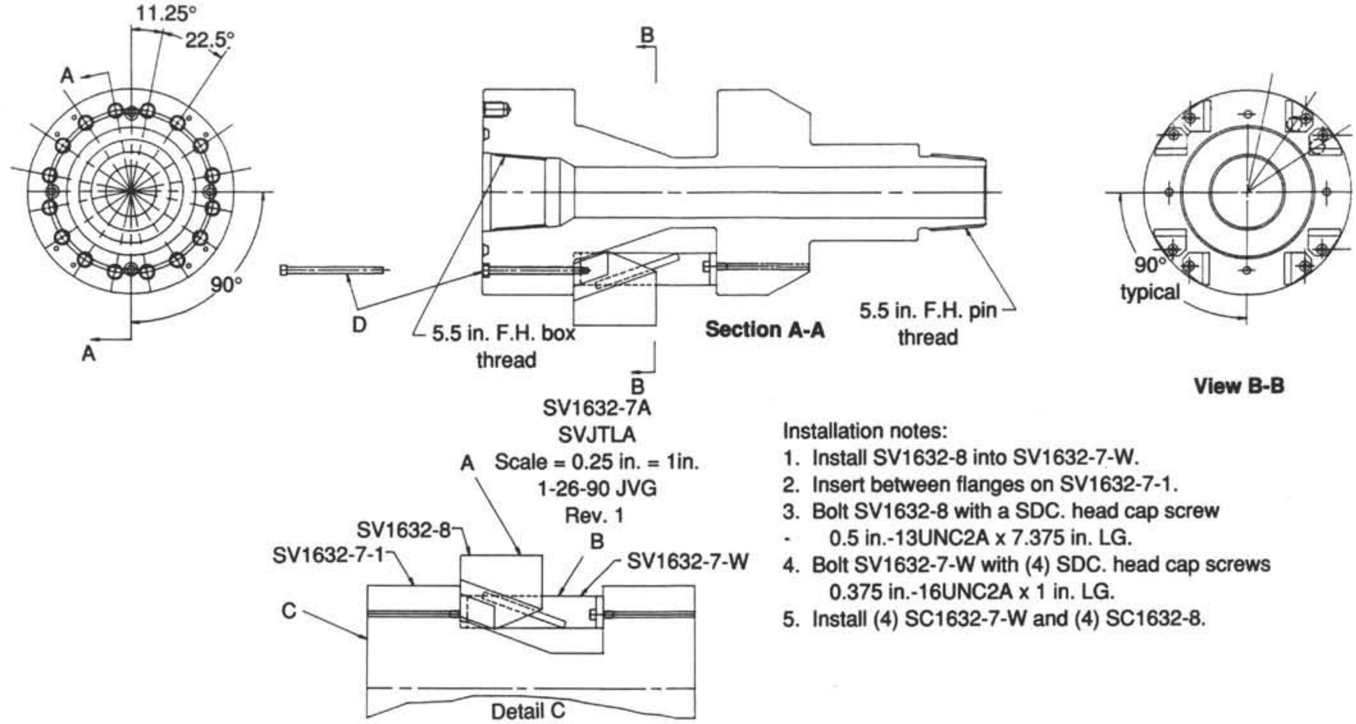

Figure 33. Tensioning tool assembly.

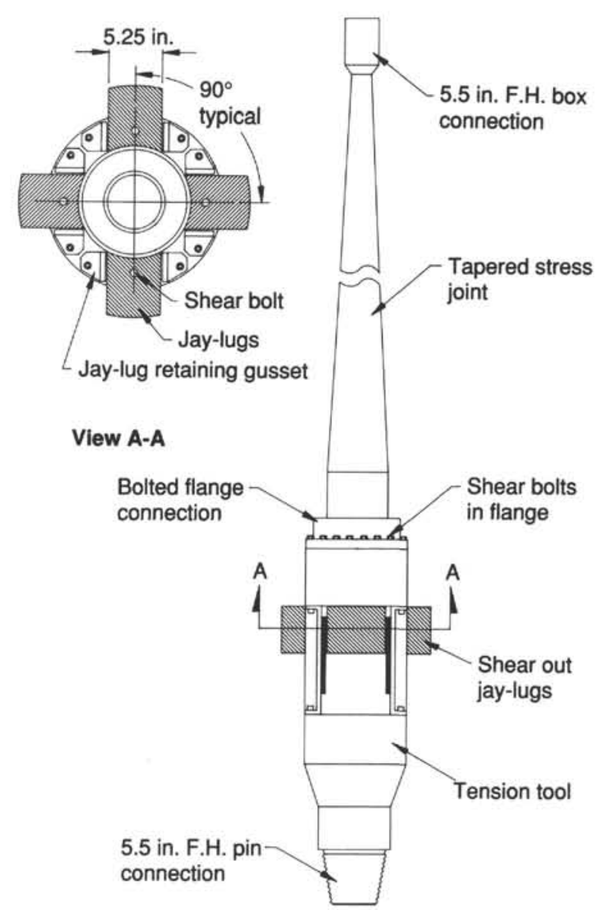

Figure 34. Tensioning tool with stress joint attached.